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I, Dylan Holte B.S., hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture.

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An Experiment/ Blurring the Boundaries of Architecture & Nature

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An Experiment //
Blurring the Boundaries of Architecture & Nature

A thesis submitted to the
Graduate School
of the University of Cincinnati
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requirements for the degree of

Master of Architecture

in the School of Architecture and Interior Design
of the College of Design, Architecture, Art, and Planning
By

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At the heart of architecture lie the health, safety and welfare of the occupants. Much of the construction that occurs around the world, as a result of the availability of seemingly endless energy and efficient systems that allow for humans to create their own atmosphere inside, no longer responds to the ecosystem in which it is located. In looking at homes across the globe, in many different climatic zones, it is difficult to decipher which house is from which location, whether or not it is a hot and humid climate, or if the home could be buried under snow. The ecosystem is not something to shut out; in fact it can be utilized within the architecture and site to attempt homeostasis. The aim of this thesis is to move architecture away from the efficient linear design, to an effective complex relationship within its ecosystem by utilizing plants, sustainable principles, and surfaces on and within architecture that are underutilized.

Plants and the site have an array of benefits that can be effectively used with architecture. Initially, the context and the site must be interpreted to see what strategies are viable. The air can be polluted with particulate matter and VOCs (Volatile organic compound). Even in small quantities, over a long time these can have lasting health effects. Plants are able to take up many of these harmful chemicals and filter particulate matter produced by cars, trains, and industrial processes. Earth can be pulled into the architecture to be the growth medium for vegetation, as well as mitigating temperature swings. The architecture and the site have a mutually beneficial relationship. These strategies allow for a built environment to breath, evolve, and adapt, as Earth has for millennia.

This thesis will explore how to implement these elements and strategies within a skin system on three case studies; on a single family residence, a public co-working facility, and finally on a low rise residential complex. Plants and passive design principles can be used on a multitude of project typologies. Architecture can no longer continue down this linear destructive path focused on things that are aesthetically pleasing and ignoring the environment in which they are placed. Designers and architects could take principles from the natural world to push the built environment. Something different must be tested, and if it fails, we learn from our mistakes and try again until we succeed.
Dedicated to my brother,
he is a fairly okay brother.
Table of Contents

01. Introduction 8-9

02. Then/Now 10-17
   2.1 Vernacular Architecture 10-11
   2.2 The Industrial Revolution 11-13
   2.3 The Gilded Lily 13-14
   2.4 The Green Roof 14
   2.5 Sustainability & Resilience 16-17

03. Methods 18-26
   3.1 Plant Benefits 18
   3.2 Vegetation Integration 19
   3.3 Experiments With Algae 20
   3.4 Plant Selection 20-21
   3.5 The Cell System 22
   3.6 The Envelope System 22-23
   3.7 Passive Strategies 23
   3.8 Ventilation 23-24
   3.9 Solar Control 24
   3.10 Temperature and Thermal Mass 25
   3.11 Interpret the Site 25-26

04. Plants//Case Studies 27-36
   4.1 The Site//Case 1 & 2 27
   4.2 Case 1//The Home 28-30
   4.3 Case 2//The Co-Working Office 31
   4.4 Case 3//The Apartment Complex 32-36

05. The Evaluation 37-41
   5.1 Working with Plants 37
   5.2 Performance 38-39
   5.3 Conclusion 39-41

Appendix A 42-45

Bibliography 46-49
Illustration Credits 50-53
INTRODUCTION

I went to the woods because I wished to live deliberately, to front only essential facts of life, and see if I could not learn what it had to teach, and not, when I came to die, discover I had not lived.1 –Henry David Thoreau, Walden

Earth is humans primary home. Before anything was considered a built structure, the natural environment was depended upon to provide shelter and protect the health of living creatures. Too often are health, safety and welfare left in the background, while aesthetic values are brought to the focal point of design. With the plethora of advancements in house technology and mechanical systems, humans can produce their own atmosphere within buildings, regardless of what is occurring in the surrounding ecosystem.2 The sense of control that people have over their surroundings has procured the cookie-cutter homes and off-the-shelf box structures we live and work at in nearly every inhabited ecosystem (Figure 2).

The site should not be closed off from architecture; in most cases the ecosystem has many aspects that can be used to work together with the building. This type of thinking can begin to find a balance between nature and the built environment, homeostasis.3 The natural world is complex and chaotic, but naturally regulates itself. One system’s byproducts are other systems vital resources. Often, the linear assembly methodologies that are used to build, without flexibility, are used for a short time period, only to be torn down and replaced.4 Humans evolved on earth, we were meant to be here. Its atmosphere, its nutrients, its natural cycles and our biological systems evolved together and support us here, now.5 Architecture does not have to progress through thousands of years of natural selection; it can be designed and embody principles that have been proven to be productive within the field of architecture and biology. Architecture should acknowledge uncertainty, or room for evolution to occur. Aspects of natural processes and mechanisms can influence the design and

architectural elements (Figure 1). New ideas can be experimented with in order to produce architecture that works with nature. The aim of this thesis is to move architecture away from the efficient linear design, to an effective complex relationship within its ecosystem. According to Merriam-Webster6 Efficient most often describes what is capable of producing desired results without wasting materials, time or energy; the focus of the word is on how little is wasted or lost while the desired results are produced. Effective typically describes things — such as policies, treatments, arguments, and techniques — that do what they are intended to do. First, technologies should be effective before they can be designed to be efficient. By integrating plants and sustainable principles within building skins, what are normally considered waste products or unwanted environmental factors can be effectively used within architecture. Plants would clean the air for occupants and find a balance between the built environment and the natural environment. This reduces the requirement for efficient mechanical systems that commonly take the place of natural cycles. Experimental case studies will be looked at in order to test these methodologies. These case studies will start with the smaller scale of a single family residence, then a public co-working facility, and finally in a low rise residential complex.

4 McDonough and Braungart, Cradle to Cradle, 2002. 87.

2. Vernacular Architecture

One of the basic necessities for human life: shelter. Before the built shelter existed, natural structures and features served the purpose of protecting life from the elements. The shade of a tree, a cave, a rock outcropping, offer a break from what can be harsh characteristics of nature. As humans began to evolve and learn, they employed different techniques to better survive in an environment. They were tailored to respond to their surroundings. Architecture and structures that were built were connected to the site, a part of its ecosystem. The mere fact of habitation inserts a new factor into the ecological balance of a locality. This balance was maintained on a local scale for some time. Not until villages and cities began to form were completely new ecosystems created which both the larger ecosystem and humans themselves would have to adapt to or face collapse.

Across the landscapes of the world are many plants, of what will be the primary focus of this thesis and how to incorporate them within architecture. Plants have been around for much longer than humans, adapted to many climatic zones, and have a plethora of benefits which work symbiotically with humans. They are vital to existence of the natural cycles of Earth. The use of plants in architecture goes back millennia, even into myth, i.e. The Hanging Gardens of Babylon. Both fruit trees and shade trees were planted within the gardens, of which served its users for sustenance and utilitarian purposes. These gardens developed over a long period of time and the climate and site of the Euphrates River Valley to support those in the city. Knowledge of an appropriate climatic response was implicit in many traditional ways of building. Architects should re-learn this knowledge and apply its principles to contemporary ways of design. This would perpetuate a new way of design and architecture, the natural re-evolution. Examples of vernacular architecture using both plants and site specific elements can be seen before the industrial revolution and the age of consumerism. Take for example the Viking long-house, which has been around for thousands of years. These homes utilize the grassy plains and cover nearly the entire structure with earth which protects and insulates them from the elements. Another example of a good application of plants was within the Crystal Palace. In 1851, a medical man wrote a letter pleading for part of it to be utilized as a winter garden, citing the polluted air of the city and mortality rates as compared to that of outside the city, which were lower. With such a large spectacle as the crystal palace, the poor air quality was mitigated for the many people who visited. The built environment also utilized the wind and passive ventilation to cool and exchange fresh air. These examples include architectural elements like wind catchers employed across the hot arid climates of the North Africa and Asia. It is important to note that all of these architectures utilized the natural environment around them; their conception was not that of exclusion, but symbiosis.

As the industrial revolution progressed, the way architecture was designed and built moved further away from being sustainable. New products that were available, mass produced and moved greater distances began to chip away at vernacular and regional responsive architecture. Climatic architecture opposes consumerism on many grounds: time, quality, and craft. After the turn of the 20th century, WWI and WWII there was the great push for modern architecture and a movement out of cities into the suburbs by many coming back from the war trying to find their own version of the American dream. Modern technologies allowed for mass production as well as mechanical means of producing a comfortable environment within their home, regardless of what was happening outside. Though the invisible air is apt to be forgotten amidst the more obvious attractions of architectural art, still practical point of view, the visible structure is only the shell or body of that interior atmosphere without which, existence could not be supported. The atmosphere and the architecture should attempt homeostasis. According to Merriam-Webster

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2.3 The Gilded Lily

surround them. Many of the homes showcase strikingly similar characteristics, while the ecosystems differ drastically.

In the contemporary age of architecture, some are realizing that built form is likely cause for environmental concerns. Some firms practice sustainable principles, which have even caught on within industries (Appendix A). Sustainability has become a twenty first century buzz word. This has developed into market practices and governmental programs like LEED, or the Leadership in Energy & Environmental Design. The ideas behind these principles are good, but are only a step in the right direction.

The LEED certification has moved clients to want energy efficient buildings, which pushes architects to design more responsive to the environment. Part of what has come out of the fad of LEED and Green design has

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19 McDonough and Braungart, Cradle to Cradle. 2002. 28.
One common trend that showed great potential is the green roof and green wall. What previously just shielded from the elements and separated inside and outside was being considered under a different light. The green roof offers benefits of storm water management, as well as reducing the solar radiation that a non-green roof would experience. Additionally, the green wall adds vegetation back to a space which was devoid of it. When inspected closely it is separated from the architecture. "To most of the world the green roof is: "a picture of idyllic nature." When it is broken down, "grassing the top of one’s architecture is the green equivalent of gilding a lily." Without forethought, or tacked on to a renovation, the green roof does not become part of the architecture, it is separate, a small picturesque part of nature added with hopes than it cannot fully provide.

Other examples of the way we are currently using plants are all too familiar, while not utilizing their benefits to the highest potential. The potted lobby plant, an afterthought, placed to liven up a drab space. Additionally, in the United States the average residential home has an obsession with the manicured lawn or the picturesque backyard garden. Huge swaths of land in a suburban neighborhood are fertilized and watered only to be continually cropped and trimmed into perfection. As of now, the way in which plants and nature are used is often detached, negating possible benefits, or highly controlled, at great energy costs. With linear construction methodologies and a push for efficient technologies, small steps are taken to combat high paced problems. If reimagined, plants and architecture can work together, and drive new ways of design.

2.4 The Green Roof

only been incremental, to attack large scale problems facing the world, like global warming and the exponential population growth, will take experimentation. Today the population is about 7.4 billion people, it is estimated by the United Nations that by the year 2100 that it will reach 11.2 billion. There is an enormous potential to change how we design in order to solve the housing shortage, while reducing energy requirements and pollution. In the United States, residential structures consume 21% of the total energy. This energy consumption along with CO₂ emissions can be mitigated by plants and sustainable principles discussed later in this paper.

Some of the post occupancy testing for LEED certified buildings is revealing that they are not reducing energy consumption as expected. For example, 7 World Trade, completed in 2006, received a LEED gold certificate, one rank below the highest a building can receive in this system. When Energy Star went back to rate the building after it was occupied for some time, it was given 74 points out of 100, which is not in the high efficiency category. To give some perspective, the Empire State Building, built 1931, received 80 points, and the Chrysler Building, built 1930, received 84 points, although some renovations have occurred. A building designed more than half a century later, to perform better and use less energy but does not. There is no such thing as a sustainable building, there can only be a sustainable system, being a part of a larger context. Real life example; the liver is a beautifully evolved organ, which humans have and need for survival. Once the liver is out of the body, it is nothing more than a mass of cells.

Despite being a buzz word, the principles of sustainability are imperative to the constructed world. These principles have been around for some time, but have been pushed aside for inexpensive mass produced more efficient products. With the threat of global warming, the ideas are re-emerging, but in some cases of contemporary building, the practices are picked and chosen from in order to score points in the LEED system. As stated at the Passive Low Energy Conference, “Down to the most basic requirements for life: nutrients and shelter, both of which are the reasons we are destroying the planet around us.”

Architecture can begin to work with the site in which it will sit, responding to the climate and the context. Utilization of the natural cycles of materials, wind, water, and energy can be beneficial to building, which has a lesser impact to the site, (figure 3). Instead of blocking the natural cycles out and creating an artificial environment, sustainable principles can allow architecture and nature to work symbiotically. Many of the way buildings are constructed is not sustainable, although some materials are harvested in sustainable manners and from within a certain radius from the project. They are constructed in linear efficient construction methodologies. Parts and materials embody huge amounts of energy, input from research, manufacturing, and transportation, only to be built then torn down and replaced years later. With an extensive energy input, a building should not remain inert, but give something back. “90% of materials extracted to make durable goods in the USA become waste almost immediately.”

Many technologies and building strategies are tested and efficient, but only work within certain parameters. Resilient design asks for diversity and space to evolve, which works in conjunction with directly responding to a site. For instance the Fukushima nuclear reactor group in Japan, a centralized reliant nuclear reactor, when hit by a tsunami, resulted in catastrophe. It is challenging to design for the unpredictable, i.e. a tsunami, but had these reactors been spread out, or the source of energy diverse, the entire system would not have been incapacitated with one fell swoop. A push for resilient architecture would combat these linear methodologies. Designers and architects could move away from what is efficient and look at nature in order to extract more effective ways of design. Effective design would be mutually beneficial for the architecture as well as the site it is placed. “Can design have room for uncertainty; life results from the organization of novel relationships between inert things. A building can be designed to have previously evolved intelligences, instead of being determined by random mutations as in the evolution of different species.”

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28. McDonough and Braungart, Cradle to Cradle. 2002. 27.
3.2 Vegetation Integration

There are numerous benefits that plants do on their own, and the list continues with them applied to architecture. Foliage can act as screening, blocking or directing prevailing winds, while the vast root systems below prevent erosion. These screening lines of trees and shrubs along the edge of a road can reduce the particulate matter transferred into a building by >50%, reducing the need for mechanically filtrated air.

Closer to the building, larger plants will produce shade, which can reduce the cooling requirements in the summer, but also lose their leaves in the fall and allow for solar gains in the winter. Plants require soil or growth medium to exchange water and other nutrients, having significant mass, which adds to the thermal mass of a structure. Within the earth that roots grow, grey water could be utilized to water the plants and mitigate grey water being processed by a treatment plant. With excess water taken up by the plants in warmer temperatures plants will release water, evapotranspiration; which works like a similar process of a human sweating. This process cools the air directly around the plants, dropping the surrounding temperature and as well as humidifying it.

This research explores the possibility of there being a more incorporated way that architecture and plants can coexist. One ecosystem contains all of life we know; it houses humans, plants and nearly everything that has ever been built, homeostasis has been maintained, but humans continue to take advantage of that, tipping the scales.

The second basic necessity for human life: nutrients. The process of photosynthesis within plants and the natural cycles of Earth provide nearly every combination of elements that are required for human existence (with the help of the Sun). Not only is vegetation and algae the primary source of the oxygen that we breathe, but can be the sole nutrient intake for a person their entire life. Apart from the various benefits that plants provide nutritionally, they can be used within architecture for a vast array of effects. The health benefits are advantageous, they clean the oxygen (O$_2$), they uptake carbon dioxide (CO$_2$), Chlorofluorocarbons (CFCs; which are in aerosols, foams, solvents, and refrigerants), and volatile organic compounds (Formaldehyde, Xylene, Toluene, Benzene, Trichloroethylene, Ammonia; which come out of furniture, carpet, plywood, and cleaners). If a balance can be achieved with the use of vegetation (site dependent) and architecture, it can begin to reconnect with the natural sustainable cycles of the earth: Material Cycle, Wind Cycle, Water Cycle, and Energy Cycle (Figure 3). Pollutant removal, produced by transportation and industries (Ozone, PM10 matter, Nitrous Oxide, Sulfur Dioxide, and Carbon Monoxide) was varied among cities, but had total removal by US urban trees estimated at 711,000 metric tons ($3.8 Billion value).

Plants can be food or produce food. Potted plants are reported to improve productivity as well as reduce stress.

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When considering which type of plants to use with architecture, there are two major categories, water based plants and terrestrial based plants. While algae produce a large portion of the oxygen we breathe, they require a medium of water to function. In addition to this, they do not have the myriad of benefits, like toxin uptake, as terrestrial plants do. Structurally, dead load is a large portion of the calculations, and water is significantly heavy. Adding a substantial portion to the loads on a building seemed excessive, not to mention the fact that waterproofing can cause problems. Algae systems are often used as a medium to produce other things, like food and nutrients for a fish farm/vegetable garden, or biodiesel.46 For these reasons, this paper will focus on terrestrial plants and how they can be employed within architecture.

The general principles of what plants can do for architecture are discussed previously; it is now time to select specific plants for these functions. The site of the first two case studies is in Cincinnati, Ohio, in the temperate climate zone and much of the foliage was selected to be native to the area. The types include ivy, shrubs, trees, grasses, forbs, and support plants. The site of the third case study is in Beijing, China, also a temperate climate with similar plants, but a more in-depth study would need to occur in the future. In order to reduce maintenance perennials are preferable and plants that produce foods were excluded from consideration. In 1989, NASA conducted a study to see which plants could uptake common chemicals that are produced by goods and materials that are used, as well as produce a breathable atmosphere within a sealed chamber (space).47 Additionally, Kamal Meattle in New Delhi, India was told that the pollution was diminishing his lung capacity so much that he should leave the city(Appendix A). Instead of leaving, he utilized plants and other passive design strategies in order to create a drastically cleaner fresh air supply within his building; this list also utilizes the plants within that building.48 In combination with Ohio native plants, there is a vast range of plants that can function in many ways, further explained in Figure 4, to be advantageous for the Earth and architecture in which they are placed.49

<table>
<thead>
<tr>
<th>PLANT NAME (COMMON)</th>
<th>IMAGE</th>
<th>TYPE</th>
<th>DECIDUOUS//EVERGREEN</th>
<th>USE</th>
<th>DIMENSIONS</th>
<th>CHEMICAL UPTAKE</th>
<th>SPECIAL INFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Oak</td>
<td>Tree</td>
<td>Deciduous</td>
<td>Shade Urban/Pollutant remover, air filtering (smaller leaf)</td>
<td>60-70 ft</td>
<td>40 ft (dead)</td>
<td>CO₂</td>
<td>Used to mitigate radon gas issues</td>
</tr>
<tr>
<td>Scott’s Pine</td>
<td>Tree</td>
<td>Evergreen</td>
<td>Shade Winter (wet) tree, air filtering, rain forest</td>
<td>Up to 100 ft</td>
<td>45 ft</td>
<td>CO₂</td>
<td>Good choice for rural sites, extending visual height</td>
</tr>
<tr>
<td>Kentucky Coffee Tree</td>
<td>Tree</td>
<td>Deciduous</td>
<td>Shade Low growing, air filtering, nitrogen fixing</td>
<td>Up to 10 ft</td>
<td>45 ft</td>
<td>CO₂</td>
<td>Produces seed pods to attract wildlife</td>
</tr>
<tr>
<td>Eastern Red Cedar</td>
<td>Tree</td>
<td>Evergreen</td>
<td>Shade Northern (wet) tree, air filtering, rain forest</td>
<td>60 ft</td>
<td>15 ft</td>
<td>CO₂</td>
<td>Aeromorphically unique in areas that have been cleared, with root growth over decades</td>
</tr>
<tr>
<td>Allegheny Serviceberry</td>
<td>Tree/Hub</td>
<td>Deciduous</td>
<td>Shade Soil cleanser, air filtering, rain forest</td>
<td>15-25 ft</td>
<td>15-25 W</td>
<td>CO₂</td>
<td>Produces berries that are shiny and edible, attracts wildlife and pollinators</td>
</tr>
<tr>
<td>Rose-Cane</td>
<td>Grass</td>
<td>Evergreen</td>
<td>Shade Northern (wet) tree, air filtering, rain forest</td>
<td>30 ft</td>
<td>15-25 ft</td>
<td>CO₂</td>
<td>Even in hot deserts, will reproduce well springing</td>
</tr>
<tr>
<td>Wolf-Hydrogen</td>
<td>Shrub</td>
<td>Evergreen</td>
<td>Shade Air/particulate pollution remover</td>
<td>5-10 ft (large)</td>
<td>2-3 ft</td>
<td>CO₂</td>
<td>Loose rice (flowers remain. Enough water)</td>
</tr>
<tr>
<td>Jade Clover</td>
<td>Vine</td>
<td>Evergreen</td>
<td>Shade Northern (wet) tree, air filtering, rain forest</td>
<td>1-2 ft</td>
<td>1-2 W</td>
<td>CO₂</td>
<td>Loose rice (wheat)</td>
</tr>
<tr>
<td>Common Wood Sedge</td>
<td>Grass</td>
<td>Evergreen</td>
<td>Shade Northern (wet) tree, air filtering, rain forest</td>
<td>3 ft</td>
<td>2-3 ft</td>
<td>CO₂</td>
<td>Hardy, often found along meek paths</td>
</tr>
<tr>
<td>Arrow Plant</td>
<td>Small Tree</td>
<td>House plant</td>
<td>Shade Production Pollution control</td>
<td>2-4 ft</td>
<td>2-4 ft</td>
<td>CO₂</td>
<td>Excellent production during day/night level</td>
</tr>
<tr>
<td>English Ivy</td>
<td>Vining</td>
<td>House plant</td>
<td>Shade Production Pollution control</td>
<td>Creep, variable height, can grow up to 35 ft</td>
<td>2-4 ft</td>
<td>CO₂</td>
<td>Excellent Bees abode</td>
</tr>
<tr>
<td>Mother-In-Laws Tongue</td>
<td>Succulent</td>
<td>House plant</td>
<td>Shade Production Pollution control</td>
<td>30 ft</td>
<td>1-2 W</td>
<td>CO₂</td>
<td>Hormone replaces O₂, no air pollution</td>
</tr>
<tr>
<td>Goldenrod</td>
<td>Stalks</td>
<td>House plant</td>
<td>Shade Production Pollution control</td>
<td>Up to 10 ft (upwards)</td>
<td>2-4 ft</td>
<td>CO₂</td>
<td>Rustic, yellow flowers</td>
</tr>
<tr>
<td>Peace Lily</td>
<td>Flower</td>
<td>House plant</td>
<td>Shade Production Pollution control</td>
<td>18 ft</td>
<td>6 ft</td>
<td>CO₂</td>
<td>Will bloom in the shade</td>
</tr>
</tbody>
</table>

Figure 4: Selected Plants and their Benefits

3.7 Ventilation

Ventilation occurs due to temperature differentials. This draws air in and through the vegetation before it enters the house proper. On the exterior surface daylighting control is employed to reduce unwanted heat gains in the hot season. With the larger scale of the envelope, micro-climatic control is feasible, in addition to connecting to the site in a more sustainable matter. The envelope system, as conceived, offers more in terms of sustainability and working towards homeostasis with architecture and plants. By designing spaces that pull earth into the architecture, or allow for the building to breathe through a series of related surfaces with plants inside have both benefits to human health and environmental health.

The first aspect of passive design that this thesis will focus on is ventilation. Air exchange is required for buildings. A system that utilizes temperature gradients and prevailing winds, rather than a mechanical ventilation system lessens energy requirements. This provides a comfortable atmosphere within architecture. All of this can be done with much less input of various mechanical machines which require energy and toxic chemicals to manufacture and perform. The tolerance of variations becomes increased due to being exposed to the external environment.

3.5 The Cell System

Inspiration can be taken from nature, at many different scales (Figure 1). The first consideration was to use a cell system. Cells would make a skinning system on the exterior or inside as walls or floors, like living organisms. There is only a certain amount of space within a building, which priority is given to required programs. Between structure within walls and floors is an example of space that is underutilized and should be reconsidered (Figure 5). Cells are differentiated, having different types of plants within them, depending on their placement. Within the cells different functions are performed, leaving the outer shell a consistent shape, allowing for tessellation and modulation. Specific shapes have more or less surface area dependent on the types of stimuli the plants need, i.e. air, sun, water.

Plants are inside transparent walls, because they require light to grow, would act as a shading device and produce interesting daylighting effects. The scale of this type of system is closer to human scale, making it personal, and interactive. A cell system would be utilized on a small residential scale in addition to being a lower skinning system due to the ability to tessellate. While much of this is a benefit, the cell system tends to be separate from the site, most of what it does contained within the cell.

The second consideration for form comes from something even smaller than the cell, but also from passive design principles. An envelope system functions like a double skin façade. A section through a plant cell wall has organelles, stoma (Figure 1), which open and close allowing exchange of nutrients and chemicals that the plants need to survive. An operable expanded double skin functions just as a plant cell wall, but in built form (Figure 6). With plants inside, it opens a breadth of possibilities. The envelope is semipermeable to air, light, and earth. This system incorporates many layers giving room for vegetation, daylighting control, and operable windows. These aspects allow for a greater interaction between the architecture, site, and the occupants. It begins to blur the boundaries of inside and outside. Within the envelope system, passive

3.6 The Envelope System

Passive design principles have various effects that could be used along with plants and sustainable design to reduce energy requirements. This provides a comfortable atmosphere within architecture. All of this can be done with much less input of various mechanical machines which require energy and toxic chemicals to manufacture and perform. The tolerance of variations becomes increased due to being exposed to the external environment.


3.10 Temperature and Thermal Mass

Additionally using the site for thermal mass mitigates temperature swings by better insulating with earth. Depending on the site, a balance between insulating and insolating must be determined. By partially burying a building, a more consistent temperature can be maintained. At 3 to 5 feet below the ground the temperature is approximately 10°C (50°F), which reduces exposure and heat loss to the surfaces exposed to colder air (Figure 8). Earth berms are more frequently used to cool buildings, due to keeping a cooler surface than the outside air in warm months. Also, between depths of 6 to 12 feet, temperatures fluctuates 5-10°F compared to the mean average earth temperatures of the area. Thermal mass can be utilized in a vertical wall or mass flooring, which would release latent heat absorbed throughout the day. These mass walls or floors are known as a trombe wall (or floor).

The trombe wall works in conjunction with solar control, because they have to be coordinated with the proper sun angles to be able to absorb the radiation from the sun. Using the architecture to control the direct radiation, and thus, the temperature swings, reduces the burden on the mechanical systems which opens opportunities for interesting architectural moments that tie the inside and outside elements together.

These principles and adding earth does not only connect the building to the site, it has the possibility of bringing the site into the structure.

In order to make the most of the sustainable and passive principles work, along with plant selection, the site must be interpreted to conclude which aspects are viable. The orientation based on cardinal directions and latitude is important to take advantage of the Sun (Figure 9). Then decipher the prevailing wind directions because they can come from different directions in different seasons. After the wind directions are determined, sources of major pollution, particulate matter, and smog (Figure 10). Key things to locate are roads, highways, infrastructure, and pockets of industries or manufactures. After this, look on the site, plants or foliage can be utilized without having to

move or replace them (Figure 11). Look for grade changes, or places to use earth berms, without having to relocate soil. These methodologies will begin to synthesize passive, minimally active, climatic, solar responsive and sustainable practices with the natural world, plant benefits, biological principles and symbiotic ecosystems within architecture. Many of the methodologies could be engaged with a variety of project typologies at various scales. The following chapter will explore the scale of the home and a small office, to be evaluated and expanded upon in a final case study of a low rise residential complex.

The site that was chosen for the first set of case studies was 2826 West McMicken Ave. Cincinnati, Ohio 45225 (Figure 12) According to Climate Consultant 6.0 and the California Energy Code Comfort Model, the site is in the climate zone 4. This puts the site at an interesting location, being at the northern limit of the humid sub-tropical climate and the southern limit of the humid continental climate. Also known as the temperate climate zone, this area has varying temperatures throughout the year, but fairly cold harsh winters and hot humid summers. Due to this, the architecture must strike a balance of how it responds to the cold and the heat. Being adaptable by the inhabitants to adjust to the climatic changes will play an important role. For plant selection (Figure 4) the native plants should be hardy up to zone 6A. This hardiness zone allows plants, which are outside, to withstand freezing temperatures and still survive. As for the actual site, it is currently undeveloped. It sits at the edge of a residential neighborhood, as well as being adjacent to two businesses. This makes an ideal site to explore a residential home and a public co-working facility. Further West from the site, Central parkway and Interstate I-75 (which runs North/South) is a significant source of particulate matter and pollution. On the other side if I-75 is an industrial zone and then the Queensgate Rail Yard, adding to the pollution and smog. These are important, because the prevailing winds come from the Northwest and Southwest. The winter winds come from the Southwest, and need to be screened by vegetation. The warm summer winds come from the Southwest, so these need to be blocked, but cooler winds come from the Northwest and need to be utilized to ventilate through plants and cool the building with fresh air. The site has a slope, from East to West, of approximately 10 feet, which allows for use of an earth berm. Most of the site is covered in grass, with a few trees throughout. This vegetation remains in its current locations or is moved to serve as a wind break. Further breakdown of specific heating and cooling requirements must be determined for the next case study, but for the purposes of this study more general principles were employed.
As for the home, the placement on the site is significant. Once the pollution sources and wind directions are determined, placing tree lines to filter particulate matter is the first step to cleaner quality air. Secondly, the expanded double skin envelope, with the specified plants needs to be placed on the South side. This gives maximum sunlight to the plants, while allowing controlled solar gains in the winter. In choosing trees that are both deciduous and evergreen, screening is maintained throughout the cold months, while in the hot months, leaves would remain on trees and act as natural shading devices over fenestration (Figure 13). To break it down even further, some trees bloom or leaves fall off later or earlier to have a gradation between the seasons. The slope on the site allows for earth berms to be used with less energy requirements. The fact of inhabiting a space already affects the local ecosystem; the architecture should fold into the surroundings and allow for the re-evolution of the natural and the built to balance out. Grasses and other vegetation with extensive root structures would provide erosion control, reducing soil from being washed away from the building. The earth berm portion of the structure, at the depth of one floor, would reduce the temperature swings that would draw heat out of the building, reducing the energy required to heat the space (Figure 14).

These principles would be also applicable to any plants that are placed within the double skin, although differences in temperatures allows for diverse species of foliage. If one tree reached maturity inside this system it able to produce a day’s worth of oxygen for four people. In addition to a tree, other plants for specific toxin uptake are utilized (Figure 4). Comprehensive diverse systems of beneficial plants that are chosen produce more air, while cleaning it. The plants inside, during the hot months, exhibit evapotranspiration, cooling the space between the layers and the air before it enters the house proper. The space between the double façade also has earth as the floor, connecting indoor and outdoor, blurring the boundaries (Figure 15). The double skin envelope has to be operable, to adjust for winds and weather, allowing for the inhabitants to connect to the site and the architecture. This space needs to be a thermal buffer as well as a zone to clean and produce more air. Towards the center of the home, a courtyard adds to the system. This space needs be taller, which acts as the end portion of the ventilation stack started with the double skin as well as bringing daylight and solar gains deeper into the building. Like the envelope, this portion needs to be operable to dissipate the air from within. If the system is properly used, cleaner air is produced as compared to the air that enters the building. The courtyard has similar effects as the double skin, but not as drastic, being open to the interior of the home. Both the double skin envelope and the courtyard, if incorporating daylight control, are the places to utilize the trombe wall and thermal mass. This lessens the temperature swings that the adjacent spaces experience. The heightened space allows for larger plants, i.e. a tree. Over one year a mature tree will take up 22 kg

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63 Meatie, TED, 2009.
of CO₂ and release O₂ instead. 1.3 million trees are estimated to remove 2500 tonnes of pollutants from the air. If every house had one tree inside, the additional reductions to CO₂ emissions across the globe would be significant. In using these various techniques along with a selection of plants (Figure 16) architecture requires less energy to operate, as well as producing cleaner air than is being taken in. Examples of how these spaces may look: Figure 17-20.

The second typology explored as a study is a public space. In this case it is a co-working office. This type of space is becoming more and more popular as small and independent workers need a place that is not their home to work out of. It allows for networking and amenities that usually come at a high price for a small business run by one person. While similar principles from the home case study could be employed on this typology, especially in regards to the site treatment outside the structure, but has some variations that allow for different opportunities. In this case, a larger double height atrium faces the south side entrance of the building to act as a thermal buffer and shading system. With more people and a public building comes a need for a parking lot. The parking on the south side, any pollutants that are procured would have to go through the atrium space before entering the building. Taller spaces take advantage of temperature and pressure differences to passively ventilate spaces. The double height allows for multiple trees to mature, due to the higher volume of people that would be in the building. In combination with the trees, many house plants and native plants grow in the atrium (Figure 21), acting as a large thermal buffer winter garden which produces vast amounts of clean air for the workers inside, and the neighborhood outside. A larger space for plants requires more water to maintain, but a larger building uses more water, producing more grey water that the system could survive off of, along with rain water collection. The atrium works within the natural cycles of material and water. By using these strategies with plants in a building for networking and innovation, it is an ideal place to experiment with plants within architecture. Examples of how these spaces may look: Figure 22-23.

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Instead of single family homes, as the case of Cincinnati, many people reside in apartment complexes. The final experiment employs a double façade skin system that goes over parts of apartment buildings. A series of layers is composed of bamboo and timber grid shells, which spans from the ground to the top of the apartments, or between the buildings (Figure 25). The exterior layer consists of the plant cell units. The skin acts as both the exterior layer of protection from the elements, while creating a courtyard underneath for the occupants of the apartments or people in the area to gather, as well as a new ecosystem for plants to grow and mature. The form of the skin has to respond to both solar requirements as well as the wind.

The site for the third case study will move to Beijing, China (Figure 24). While this site is on the other side of the globe from Cincinnati, they share the same latitude. This means the two sites have similar solar requirements being at the northern limit of the humid sub-tropical climate and the southern limit of the humid continental climate, according to Climate Consultant 6.0. The prevailing wind in the summer months comes from the South, while the winter wind comes from the North. In addition to this, Beijing also has a much higher pollution and smog problem as compared to Cincinnati. Pollution and Particulate matter in the air is given a value from 0 to 300 on the Air Quality Index scale. According to the World Air Quality Index, Cincinnati has AQI from 20-50 while Beijing is from 60-150, dependent on seasons and current weather. The specific site is located in the 798 Art District, just to the South of the intersection of S50 and S12 (the fifth highway ring and the highway to the airport respectively). These highways are significant pollutant producers for the site. Commonly going over 150 AQI, which is the threshold determined to be a general health risk for the entire population, new ways of purifying the air are tested here.
Many apartments, like the ones used for this test, have balconies, offering a private piece of the outside. Often, these balconies are built out, adding windows to seal off from the smog ridden air without destroying the view, but done so by the individuals who own the apartment. This results in miss-matched facades that are common to some of the apartment complexes. This raises a new design opportunity; the balconies need to be on the south façade of the building, and underneath the first layer of skin. This is the second layer of the skin before the air would enter the apartments. The balcony layer is operable, so depending on the occupants, the system can be toned for individual comfort within the home. No longer would the occupants want to shut out the exterior air because it would have less toxins and particulate matter.

This series of layers and interventions to an apartment complex offer a new take on how to respond to the environment and adapt to it. By utilizing principles found within nature and employing them in architecture, a space that can respond to the environment is possible. While functioning as an effective air filtration for the

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Incorporating plants within architecture has its benefits. Looking at the site and designing a skin that responds to the context and weather makes this system viable on different building typologies. The three case studies of various scales illustrated this principle. These differences in scale allow for variables to influence the design of the skin. A façade filled with plants as a passive ventilation system would create cleaner air and reduce energy costs by reducing dependence on mechanical air conditioning systems. Additionally, using a timber and bamboo grid shell system in conjunction with the light weight ETFE panels allows for plants and additional support systems to maintain the plants to be added without excessive weight increases.

Plants within a skin system also introduce some difficulties that should be addressed. By adding a new skin layer to the building, there will be increased costs. Furthermore, the cost increases due to the plants and the required maintenance that come with the plants. Vegetation also grows both above the ground and below it, often with vast networks of roots. There is some uncertainty built in, where the growth of the foliage may begin to compromise the architecture itself. Roots can push and shift structural members, or branches grow through walls. Another downfall of this system is that it is site specific. In order to get the skin to function properly wind, pollution, directionality, and plant species must be determined for every site. The system must be carefully designed for the place it will reside; utilizing technologies and sustainable principles of its climate. Additionally, working with plants in an attempt to blur the boundaries of inside and outside creates issues. Not completely separating spaces allows room for adaptation and evolution occur, but leaving too much open lacks spatial definition that occupants are used to or desire. A balance will only come out of experimenting with similar ideas and testing new skinning systems.
Much of the form that the skin has taken on is in response to the prevailing winds, pollution sources, and the site. While the prevailing winds are the most impactful to the design, there are winds that come from all directions, in both Cincinnati and Beijing. These minor winds, climate change, and possible new sources of pollution are something that could impact the performance. Furthermore, this is only one apartment complex, in all of Beijing. Under the skin the effects of pollution control would be significant, but to get a lasting effect and an effect that truly helps the neighborhood, city, and world this type of design will need to be more widespread.

The building envelope and exterior courtyard space will create different temperatures underneath. While shading mitigates overheating and the partially transparent plant cells allow solar gains in the winter, they will likely not produce comfortable temperatures on their own. With the skin being breathable, this will cause the space to still be cold in the winter. The skin reduces direct winds and allows radiation transmittance to heat the space more than just being exposed to the elements. On the other hand, if the envelope does not ventilate enough in the summer, the space may overheat. Observing these case studies would shed light on some of these questions, allowing the system to become more effective in later trials.

As theoretical case studies, these are a different direction in learning what architecture has done right and wrong up until now. Designers cannot continue the discourse down the path of aesthetics. If form is a concern for the architect, a way of making it useful should also be at the front of the design. The longer building practices and technologies advance the way they have since the industrial revolution, the more difficult it will be to re-balance the scales, preventing homeostasis on a global scale. Resilient principles must be employed. "The division between inside and out, nature and artifice, us and them, has served as a reassuring balm that is slowly cracking and revealing itself." 67

5.2 Performance

This next section will attempt to look at the performance of the plant skin system without it ever being constructed. The plants will clean the air, reducing particulate matter and taking up common toxins present in the air. Plants are alive, they grow and reproduce, dependent on the maturity when planted i.e. seeds or partially grown. It may take years before some develop into fully functioning organisms (within the architecture). The particulate matter that the leaves will be filtering may also have an effect on the plants themselves. Essentially dust and particles land on the plants which may in turn block their stoma and reduce their ability to respire and photosynthesize. Just as filters need to be changed, the plants may need to be rinsed off if there is not enough rain to maintain clean leaves. Despite selecting both evergreen and deciduous plants, the seasons will change the performance of the entire system. Due to the loss of the leaves on certain plants, there will indeed be less production of oxygen during the winter months.

With the proposed skin system, there will also be an increased requirement for maintenance. In ideal circumstances, when the system has been tested and improved, it would function just as the forest, with no outside maintenance. The system adapts and balances on its own as the cycles of materials and energy do. Foliage will need to be monitored and cared for, to make sure it does not grow to destroy the architecture. In addition, since the architectural skin envelope was designed to operate like a natural skin with cells, the plant units can be replaced if damaged. Simply detaching it from the structural layer underneath, a new unit would fit exactly where the old one was. Plants also require specific amounts of nutrients, water, and sunlight. This can be studied in a computer and weather patterns considered, but this can only be a prediction. Until the experiment is built and observed the actual conditions may warrant adjustments to the system. Perhaps there is a shortage of rain, the grey water produced by the building can be utilized or more water may have to be purchased. In the end, the system would ideally be producing cleaner air and outweigh the extra maintenance.

5.3 Conclusion

As theoretical case studies, these are a different direction in learning what architecture has done right and wrong up until now. Designers cannot continue the discourse down the path of aesthetics. If form is a concern for the architect, a way of making it useful should also be at the front of the design. The longer building practices and technologies advance the way they have since the industrial revolution, the more difficult it will be to re-balance the scales, preventing homeostasis on a global scale. Resilient principles must be employed. "The division between inside and out, nature and artifice, us and them, has served as a reassuring balm that is slowly cracking and revealing itself." 67

conclusions. Architecture can no longer continue down this linear destructive path focused on things that are aesthetically pleasing and ignoring the environment in which they are placed. Something different must be explored, and if it fails, learn from the mistakes and try again until successful.

These tactics allow for a built environment to breathe, evolve, and adapt, as plants and animals have for hundreds of thousands of years. As a next step, a leap will need to be taken into the unknown, truly muddling what inside and outside are. Natural systems that have been tried for millennium and have succeeded inspire design. “We will look back at the last 70 to 90 years at what an amazing and sad time it was when we actually thought we could overcome nature. That we could hermetically seal buildings and air condition them, and heat them, weather it was needed or not.”

Finding a balance between nature and architecture will require more experimenting. Put plants at the foreground; test how architecture can respond to them. This type of architecture, if calibrated for environments across the world, begins to ease the destruction of the nature world. Re-think the traditional layout of a building; organize it like a plant cell. The built environment still must perform a function; too much uncertainty of growth may render the architecture unusable. Studies of how the systems will work as a whole must be comprehensive and variable, to avoid what happened with the green roof. Additionally, the very real effects of what is being proposed must be considered. There may be a higher initial cost to all of these methodologies, plus a maintenance requirement, but ideally worth it for the long term benefits of the buildings inhabitants and those who inhabit the world. With plants enters a larger complex water cycle to operate within and through the architecture, just because algae is not being considered here does not mean humidification and waterproofing will not cause an issue. Many of the principles discussed in this paper, as well as the plant selection, is extremely site specific. Often these principles are not viable in other climate zones and completely different plants would have to be understood to work symbiotically with the architecture.

It is important to remember that this is an experiment, and it needs to be tested and evaluated in reality to draw conclusions. Architecture can no longer continue down this linear destructive path focused on things that are aesthetically pleasing and ignoring the environment in which they are placed. Something different must be explored, and if it fails, learn from the mistakes and try again until successful.

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60 The Case For Hope, 2016.
APPENDIX A

Paharpur Business Center and Technology Incubator Park
2001 Kamal Meattle (CEO) | Delhi, India
- Health benefits of plants
- Produce clean breathable air in extremely smoggy condition
- Passive ventilation
- Water air filtration system removes particulate matter as well as cooling the air
(Image 1-2)

IBN – Institute for Forestry and Nature Research
1998 Behnisch Architekten | Wageningen, The Netherlands
- Novel integration with site
- Vegetative ecological systems in atrium
- Grey water reclamation for vegetation as well as cooling
- Daylighting and shading
- Standard budget: demonstrates sustainable building techniques with no additional costs
(Image 3)

Academy of Mont-Cenis Herne
1999 HHS Planer + Architekten | Herne, France
- Expanded double skin façade with separated buildings inside
- Microclimatic skin
- Passive ventilation studied to better control the internal structure temperatures

Naturaire Systems
1994 Dr. Alan Darlington
- System, works like a green wall with fan to pull air through and clean it for building

Andre Air Purifier
2007 Mathieu Lehanneur & David Edwards
- Small unit that cleans the air through minimally active system
- Could be extrapolated to be used as an architectural system, element, or feature
(Image 4)

Omega Center for Sustainable Design
2009 BNIM | Rhinebeck, New York
- ‘Eco Machine’ water reclamation system that cleans water by mimicking the processes of the natural world
- All water from campus (toilets, showers, sinks)
- Cleans with: algae, fungi, bacteria, plants, and snails
- Processes 52,000 gallons per day

Hundertwasser Vienna Apartments
1986 Friedensreich Hundertwasser & Joseph Krawina | Vienna, Austria
- Vegetation incorporated all over
- “They are a gift of the house to the outside world, for the people who pass by the house. Man gives voluntarily small territories of his dwelling space back to nature, from which we unlawfully appropriated and destroyed large areas.” Hundertwasser, 1985

Resort in House
2016 ALPES Green Design & Build | Dang Thai Mai, Vietnam
- Plants within window system, which air can ventilate through to inside
- Interesting daylighting with plants
- Tall space for proper ventilation stack
- Use of pool in lower level for cooling effect

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Green Edge House
2012 ma-Style Architects | Fujieda, Japan
- Screen and interstitial space with plants
- Interesting daylighting
- Solar control by reducing direct solar gains through glass with opaque exterior floating wall
(Image 5)

Stacking Green
2012 Vo Trong Architects | Saigon, Vietnam
- Façade covered by vegetation
- Operable windows on other side of exterior façade to allow for ventilation through the building

Botanical Garden Bordeaux
2003 Francoise-Helene Jourda | Bordeaux, France
- Douglas Pine columns, channel glass façade – interesting daylight, still allows plant growth
- Semitransparent and ventilated

Walloon Branch of Reproduction Forestry Material
1995 Philippe Samyn and Partners | Marche-en-Famenne, Belgium
- Double curve wood, steel, and glass structure (locally sourced)
- Utilized daylighting, skin with separate buildings underneath

Federal Environmental Agency
2005 Sauerbruch Hutton | Dessau, Germany
- Snaking atrium between 2 buildings, crossed by bridges, informal adaptable space
- Minimize external skin, maximize natural ventilation and daylight
- Landscaped space along the building edge

Lufthansa Aviation Center
2006 Ingenhoven Architects | Frankfurt, Germany
- 9 indoor glass roofed atriums, with gardens inside
- Naturally ventilated spaces, viewable from the offices
- Buffer zones insulating against air pollution emissions and noise
- Requires 1/3 of the energy compared to conventional office building

Frei Otto’s House
1969 Frei Otto & Rob Krier | Warmbronn, Germany
- Large scale greenhouse/winter garden attached to house
  - South facing, covers large portion of house, operable
  - Windows on house, inside the winter garden
  - German temperate climate

Eden Project
2001 Grimshaw Architects | Cornwall, England
- Garden, landscaping, indoor biome over an old clay mining pit
- Unique design based on natural structures (bubbles)
- Glazing system (ETFE) of biomes based on bubble structure as well as being 100X lighter than glass glazing system
(Image 6)

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BIBLIOGRAPHY


