

2012

Biomimicry: Using Nature as a Model for Design

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BIOMIMICRY: USING NATURE AS A MODEL FOR DESIGN

A Thesis Presented

By

MICHAEL J. MAGLIC

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF ARCHITECTURE

May 2012

Architecture+Design Program

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ABSTRACT

BIOMIMICRY: USING NATURE AS A MODEL FOR DESIGN

MAY 2012

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The relationship and connection between architecture and nature is one that has brought forth many questions, criticisms, and solutions. Today there is a new form of design that was introduced several years ago which requires modern man to look at the natural processes found in nature for inspiration. These processes have been around for decades but only recently has their true potential begun to emerge. The question is, can we take the philosophy behind nature's living organisms and use them to aid in the development of mankind? We can and it is called Biomimicry.

This thesis will explore the natural processes found in two specific organisms, the Human Body and the Namaqua Chameleon. These processes will be used to influence the design and function of a medical research, manufacturing, and therapy facility that focuses on advanced robotic prosthetics. By mimicking a variety of elements from nature, the final composition will not only respond to the activities within the building, but also to the surrounding environment. It is intended for this building to relate to both Massachusetts General Hospital and the Spaulding Rehabilitation Hospital in Boston, Massachusetts. This project displays how Biomimicry can be used as an integrative architectural design component in order to achieve complete unity between the building, the users, and the environment.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the past, there used to be a common language amongst the built environment. Architects, engineers, designers, and society, understood that buildings were used to function as a form of shelter, creating a physical separation between people and the environment. As time went on the world was introduced to many different styles of architecture; and as this happened, the word architecture and the word building slowly began to split into two different meanings. When one thinks of a building we think of permanence. As architects began to become more sensitive to the idea of how important the impact that permanence (a building) had on the society as a whole, architecture began to break away from the typical cube and embarked on thinking outside the box.

It started to become more of an artistic expression and the relationship between art, architecture, and nature began to make its presence known. As the quality of materials continued to improve, the limitations from construction became less of a concern. Building forms had the ability to take on more dynamic, intricate shapes. Organic architecture started to appeal to the public and forms began to imitate elements from nature and the natural environment. Buildings such as the Disney Concert Hall by Frank Gehry, or the natural materials used by Frank Lloyd Wright in Falling Water. This was just the beginning of a new revolution that made strong gestures towards a connection to nature. Today there is a new type of ideology that combines biology and architecture in order to achieve complete unity between the building and nature.

This type of ideology is called Biomimicry. It is a method of looking at natural processes found in nature and uses these processes to aid in the development of mankind. This Thesis will focus on a deep exploration of how Biomimicry has been used in the past and how it can be used to generate a sustainable response to an architectural design problem. The final composition will display integrated sustainable and architectural design components in order to achieve a building that creates complete unity between the building, the users, and the environment.

1.2 Architectural Expression vs. Sustainability

"It may be true that one has to choose between ethics and aesthetics, but whichever one chooses, one will always find the other at the end of the road."¹ This is a neat summary of criticism toward modern architectural design. In her book, "Taking Shape: A new contract between Architecture and Nature", Susannah Hagan begins questioning an Architects understanding between the relationship of architecture and nature. It brings forth an opportunity to exemplify an importance to the profession of architecture, one that has been lost for several years. An importance that can justifiably influence the building industry as a whole.

Throughout the reading, she demonstrates how architectural expression and environmental sustainability have been incorporated separately, or one without the other, in most architectural solutions. She uses four examples of built work to illustrate that in most environmental architecture today there is an emphasis on either the buildings performance opposed to how it physically appears, or an emphasis on the buildings overall appearance opposed to how it performs. Architectural expression may be derived from nature, but this does not mean it functions cohesively with nature. "Such

manifestations can be seen in Frank Gehry's designs, also represented in the reading, with his use of "snakeskin-clad" as the skin of a building."² On the opposite end of the spectrum, many buildings incorporate sustainable features to increase energy efficiency, but the buildings form strongly lacks any architectural expression. Just about anyone can have PV panels, or water catchment systems installed in their homes or offices. But with a lack of artistic integration makes these components aesthetically displeasing.

The solution is unity between architecture and nature. According to Hagan, "What is clear from the work of those already inhabiting this 'both/and' domain of ethics and aesthetics is the groundedness of an architecture that holds both environmental design and architectural expression in tension, neither privileged over the other." She goes on to state that "this is vital if the term environmental architecture (as architectures in general) is to be anything but an oxymoron."³ This is the most significant ingredient in the entire passage, emphasizing on the current opportunity to demonstrate the importance of Architecture and the profession, before it is too late. What is inspiring about this piece, is that it is pertaining to the ethos of present day architecture and design. It exemplifies a profound opportunity for students, professors, and professionals in the architectural field, to have a detrimental contribution to the building industry and our society.

Society and culture have given us the opportunity to embellish architecture and nature as one; but has the economy? The problem with her argument is the reality. In most cases, a client wants an affordable solution that can be immediately implemented. Usually these solutions result in either one or the other phenomenon or neither to occur. The initial cost of some sustainable technologies are expensive, and undesirable to a client looking for quick, simple, cheap solutions. But at the same time, I see this as a

challenge to us as designers. The more we influence the building industry, the greater our chances are of influencing society.

An example of a building that has demonstrated a sensitive awareness to both nature and architecture is the Digiteo Labs designed by Stefan Behnisch (Figure 1). This building won the 2006 Digiteo Competition in France. The design elegantly showcases the sustainable features as well as conforming an artistic architectural composition. It was criticized as being a "well thought-out, creative solution to a complex problem" when presented to the community.

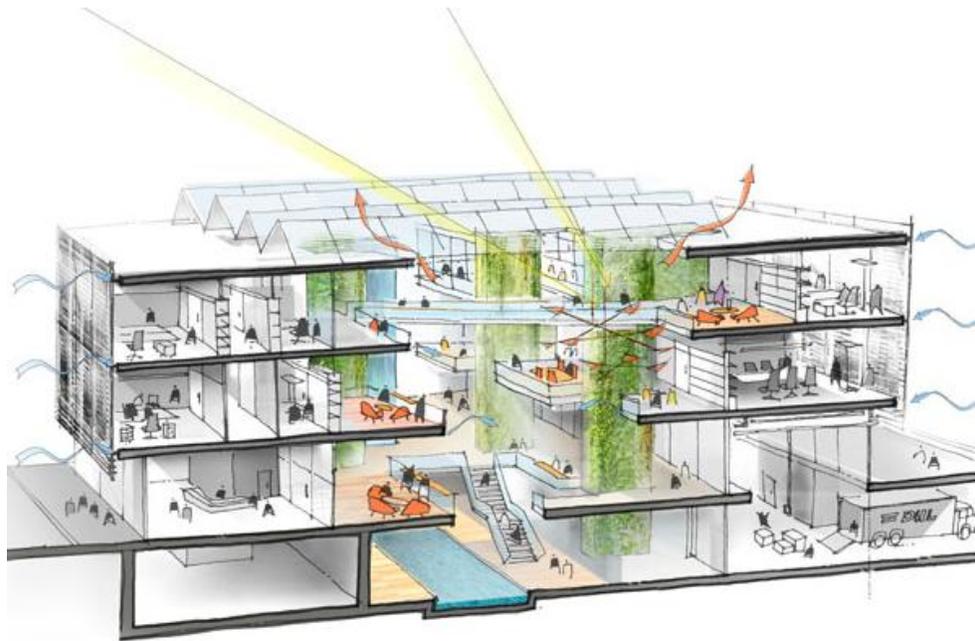


Image Source: <http://behnisch.com>

Figure 1: Digiteo Labs by Stefan Behnisch

Overall, the argument being made by Hagan is strong. And I do believe that this is the time for architecture to regain its purpose and once again be influential to our culture.

With architectural theories, technologies, and construction methods continuously progressing, the opportunities are endless.

1.3 Designing for permanence

The styles of architecture and the way in which one designs, (or should design), has drastically changed over the past few decades. This, in part, is due to the constant change of demands and technological advancements that have opened endless opportunities for progression. Today, society as a whole is accelerating rapidly; unconsciously adapting to change and persistently necessitating flexibility. This need for continual change has brought forth a new dilemma in the realm of architecture, an area that represents permanence. The interaction between buildings, humans, nature, society and culture, is a continuously criticized topic as well. American writer Stewart Brand states, “Architecture, we imagine, is permanent. And so our buildings thwart us. Because they discount time, they misuse time.”⁴ So how should Architects and designers respond to this statement? This is the argument that Brand makes in his book, “How buildings learn, what happens after they are built”.

Change is inevitable. In order for something to survive change, it must learn to adapt. Buildings are constantly faced with change, but these changes do not occur at the same time. Capitalizing on Frank Duffy's "four S's for commercial buildings", Brand himself revises the S's into six S's that can be designated to buildings in general. **Site**, geological setting, which is eternal; **Structure**, foundation and load-bearing elements, 30-300 year life expectancy; **Skin**, exterior surfaces, changes every 20 years; **Services**, mechanical systems, 7-15 years; **Space Plan**, interior layout, average 3 years; **Stuff**,

furniture, est., moved around daily. Each piece of the equation depends on the other, Site controls Structure, Structure controls Skin, and so forth down to Stuff. Brand goes on to state on page 20 that "A design imperative emerges: An adaptive building has to allow slippage between the differently-paced systems of Site, Structure, Skin, Services, Space Plan, and Stuff. Otherwise the slow systems block the flow of the quick ones, and the quick ones tear up the slow ones with their constant change. Embedding the systems together may look efficient at first, but over time it is the opposite, and destructive as well." The solution, scenario planning.

Scenario planning becomes a credible solution because it separates the difference between a plan and a strategy. A plan, as illustrated in the text, is a prediction. "The desired outcome of a plan is based on parameters, limiting the possibility of change. A strategy on the other hand, is designed to encompass unforeseeably changing conditions. A good strategy ensures that, no matter what happens, you always have maneuvering room."⁵ This is what makes scenario planning an adequate way to embrace change, rather than avoid it. Programming is a useful tool that Architects use to layout a detailed description of the users and space. Programming, though a useful tool, can sometimes cause limitations to the building which makes spaces less flexible. That is where scenario planning comes into play. "Scenario planning takes advantage of the information developed by programming, and offsets the major limitation of programming (overspecificity of immediate desires). The building is treated as a strategy rather than just a plan."⁶ Thus leaving the building open and welcoming to change if desired.

One example described in the text that showed the negative repercussions from the lack of scenario planning was IM Pei's MIT Media Lab Building. It was designed

without a program because the departments did not know who would be inhabiting the building, and for funding purposes, they wanted the design to begin early. By the time the building was finished, many of the rooms were not suitable for the occupants who eventually inhabited it. Even though the building is articulated nicely on the exterior, the interior spaces, according to Brand, works poorly.

I wonder what Brand would say about Frank Gehry's work? I know that Susannah Hagan speaks negatively about it because it does not function well with nature, all though the design is derived from nature. The way Gehry's buildings are designed creates awkward, unusable spaces; also forcing customary "Services" to be implemented. Thus, making it difficult to adapt to change which is what Brand argues as being essential for permanence. Take the Disney Concert Hall for example. It was not designed for flexibility, nor does it provide any maneuvering room for change or adaptation. It neglects the connection to the physical environment, and responds inefficiently with nature. So is this a poorly designed building? Is it not designed for permanence? What is permanence?

Brand thinks of permanence as the life, (age), of a building; flexibility increases its permanence. Hagan's form of permanence relies on architecture's cohesive response to nature. If only considering these two theories as the only way to establish permanence in architecture, then yes this is a poorly designed building. But I do not agree that this building does not demonstrate permanence. A third theory could be permanence by art. What makes the building iconic and highly appreciated is that nothing like this has ever been designed before. Originality also establishes permanence in architecture. But this is not the argument that neither Brand nor Hagan tries to illustrate.

The common argument in both is that architecture, to establish permanence, must design for the future. Designing for the future, is essentially creating a strategy for design. Gehry's building facilitates the user's needs accordingly, but is not built for flexibility or responds to the environment. Even though it excludes some of the S's depicted in Brands theory, and is not one with nature, it does not make the building a piece of "poor architecture". Permanence in both theories is relating to time. As designers, we must come to the realization that change is inevitable over time. In order to establish permanence, we must design in a way that allows for our buildings to change. According to Brand, *"Age plus adaptivity is what makes a building come to be loved. The building learns from its occupants, and they learn from it."* A good way to achieve both permanence and responsive design, is to look more thoroughly at architecture and nature..

1.4 Connection between Architecture and Nature

The relationship between architecture and nature, in most discussions, is closely referring or relating to sustainability and environmental design. Today, there are many supplementary solutions to make a building more energy efficient. And in most cases, many of these are not seen as an aesthetic, but as an "additive" element; thus, in turn, clashing with the buildings appearance. This is the core subject of Kieran's book. The relationship between architecture and nature in the form of beauty.

There are many points to his argument that I found inspiring, but two of them had the most impact on the way I perceive a connection between architecture, nature, and society. The comparison he makes between building skins and a coffee filter was captivating. "The filter is a smart membrane. It is designed to keep out what we do not

want (coffee grinds) and to let in what we desire (liquid coffee extracted from the grinds). The envelop, a term widely used today to describe building skins, is the antithesis of the filter. It completely segregates inside from outside--keeping inside in and outside out."⁷ A filter is an excellent metaphor to use. The Sidwell Friends Middle School, presented in the text, displays how the filter can be directly related to architecture and nature. The skin of the building is composed of two wooden layers. One acts as a solar shading device, and the other is a rain screen wall that also encourages adequate air movement. Both of these devices are filters in that they are filtering out what is not desired, for example direct solar gain, and allowing what is desired, indirect light, to penetrate the interior spaces.

Another inspiring statement Kieran makes is: "It is the aesthetic dimension, however, as much as the facts of unsustainable initiatives, that is likely to determine the long-term viability of environmental design. Aesthetic form can attract, and attraction is always more potent than force."⁸ This statement reiterates the importance of beauty opposed to additive solutions. If we truly want to encourage and have a substantial impact on sustainability in society, then we need to develop an aesthetic that is more accepting, more beautifying. A more prominent relationship between architecture and nature is exactly what Kieran is suggesting. The Loblolly House, clearly represents a building that was derived from nature. Every element, from the structural wood columns, to the deep green stained bamboo floors, represents a direct connection to the surrounding environment. This composition makes bold, literal statements, yet it is elegantly serene, and undistruptive to the site in which it lays.



Image Source: <http://kierantimberlake.com>

Figure 2: Loblolly House designed by Kieran Timberlake

The relationship and connection between architecture and nature is one that has brought forth many questions, many criticisms, and many solutions. Yet many of these solutions have not influenced society enough to make them universal. Buildings are created to shelter, to protect one from the outside environment. Kieran states, *"The separation of man from nature is the motivation for the existence of architecture in the first place."* Now, it almost seems unethical, to use architecture to separate man from nature. Today there is a new form of design that was introduced several years ago which requires modern man to look to nature as the solution to architectural and sustainable problems that exist today. These solutions have been around for decades but only recently has their true potential begun to emerge. The question is, can we take the philosophy behind nature's living organisms and use them to aid in the development of mankind? We can and it's called Biomimicry.

CHAPTER 2

BIOMIMICRY

2.1 What is Biomimicry

Biomimicry (from *bios*, meaning life, and *mimesis*, meaning to imitate) is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems.⁹ The way the design process is approached is that designers look at nature, specifically organisms or ecosystems, to solve a particular human need; and by doing so, converting these types of behavioral processes into man-made design solutions. Imagine it as the combination of biology, nature and architecture into one composition.

2.1.1 Framework to Biomimicry

Janine Benyus is known as the founder of the Biomimicry movement. She is a highly accredited biological sciences writer who has inspired and brought forth a new dimension to design by looking to nature as the key source of inspiration. Much of her research has been done by closely shadowing biologists, doctors, and inventors who dedicated many hours exploring new parameters which define her ideologies. Many people have studied Janine Benyus and Biomimicry closely. One of which in particular is Maibritt Pedersen Zari who is a professor at Victoria University in Wellington. From her research, she created a table that outlines the basic theories and ideologies of Biomimicry with the connection between biology, nature and architecture. By examining the biomimetic ideologies and implementations from other scientists, designers, and

writers, Maibritt Pedersen Zari was able to break down Biomimicry into three different categories or “levels”; Organism, Behavior, and Ecosystem.¹⁰

CHAPTER 3

EXAMPLES OF BIOMIMICRY

3.1 Organism Level

The first level is Organism- this refers to mimicking a specified organism. This could be the entire organism or a portion of the organism.

3.1.1 Namibian Beetle and Water Collection

One of the most interesting insects studied and mimicked in design is the Namibian beetle; also known as the African *Stenocara* beetle. The beetle lives in a desolate desert that rarely sees any rainfall. Since the area is dry for the majority of the year, many animals have to find alternative ways to survive and obtain an adequate water source, but not the *Stenocara* beetle. Even though there is less than one inch of rainfall per year, there is frequently fog in the morning; and the beetle instinctually knows how to take advantage of the situation. The intricate design of the beetle's shell provides the beetle with the essential nutrients and water necessary to survive in such a climate. There are bumps on the beetle's shell which are hydrophilic (water-attracting) along with alternate parts to its shell which are hydrophobic (water-repelling). The hydrophobic parts to the shell act like channels or groves for water and moisture. During the hot day the beetle is exposed to the radiating sun and its black shell absorbs a lot of the heat. When nightfall approaches, it comes out from below the ground and climbs to the top of a mound and waits for the morning to come. Because the beetle's temperature is a lot warmer than its surroundings, it is a beacon for moisture. When the morning fog rolls in,

water droplets from the fog are combined and collected on the beetle's shell. As the water droplets form, because of the shape of the bumps, the water droplets stay in tight spherical beads which make them more mobile and easier to channel towards the beetle's mouth.



Image Source: www.thecistern.com

Figure 3: Stenocara Beetle Collecting Water

When the water droplets have formed, the beetle tilts its back and the droplets run down the channels or hydrophobic groves and into its mouth.¹¹ After it has had its desired amount of water, it runs back underground and starts the process all over again. So how can this be applied in architectural design? Matthew Parkes' of KSS Architects has used the design of the Stenocara beetle to design a Hydrological Center for the University of Namibia.

The climate in Namibia is intense and is one of the driest places in the world with only approximately one percent of the land arable. Matthew Parkes found out about the Stenocara beetle by talking with some of the native Namibian people. He was impressed with the practicality of the beetle's innovative shell design and how it survives in such

harsh conditions. So he tried to mimic the same type of technology into a building design to turn water droplets collected from fog into usable water.

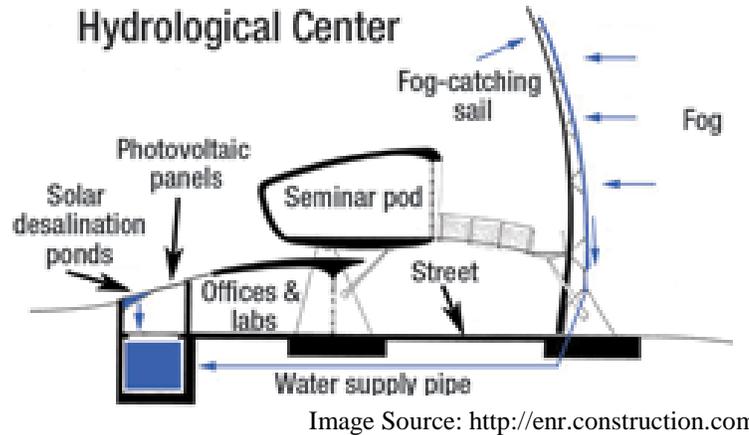


Figure 4: Section of Hydrological Center for the University of Namibia

His fog-catcher design won the architecture award for best first-time exhibitor at the Royal Academy of Art Summer Exhibition in 2001. The building is a series of pods that are positioned behind a tall, slightly-curved nylon mesh screen which is used to collect water. The nylon mesh wall is oriented towards the ocean so that it can adequately capture as much moisture as possible from the fogs that come easing in off the ocean front. According to Michael Killeen in *Metropolismag*, In Chile and Peru, mesh is similarly strung between trees to catch available moisture. The process that happens in Parkes' design follows the same principles as the beetle. The collects on the mesh screen and because of its shape and vertical orientation, the water naturally runs down the mesh into gutter system located at the bottom of the screens. The water is then transported through the gutters into large cisterns that keep the water at an appropriate cooler temperature so that the water does not evaporate.¹²

The need for designs such as Parkes' is essential for sustaining human life in areas that have similar climates such as Namibia's. Areas like Namibia are incredibly deprived of water, only receiving about three fifths of an inch of rainfall per year. That is an unbelievably low number when comparing it to Boston Massachusetts who had recorded forty-three inches of rainfall in 2010. *"People are currently dependent on receding groundwater. Fog water is sustainable, it's been there for millions of years, and collecting it is not taking anything away from the environment."* (Killeen, 2002).

This is not the only time that the technology of the Stenocara beetle has been used to solve human needs. Scientists have developed another way of capturing the moisture from fog. They experimented with placing small poppy seeds into a thin layer of wax. The small poppy seeds resembled the bumps on the beetles shell and were anticipated to respond to fog in the same manner. The experiment proved to be successful and the bumps were able to capture the majority of the water produced by the fog.¹³ The plan is to find a way to introduce such technology into arid, water deprived areas around the world.

This level of Biomimicry, the organism level, took the technology that was found in the organism itself and mimicked it to produce an innovative, simple, man-made sustainable solution to what was before seen as a difficult and complex problem.

3.1.2 Cactus and Temperature Regulation

Another organism that has adapted to arid, dry climates is the cactus, which has also been mimicked in design. What makes the cactus so unique is the technology it uses in order to survive. The signature characteristic of a cactus is the spines that encompass

the entire plant. But these spines serve more than just one purpose. The obvious purpose for the spines is for protection. It makes it very dangerous and difficult for herbivorous animals to eat the plant. They also serve to channel the rain water down to the base of the plant where it gets collected and stored. Being that most cacti live in areas that receive very little rainfall, it is crucial that it takes advantage of capturing water when the opportunity presents itself. But the most important function that the spines serve is to help shade the plant from the intense sun. By having so many spines throughout the exterior skin, it shades the plant enough to keep the internal temperature low enough to where the water that the plant stores does not evaporate. This is key for surviving in such an extreme climate.¹⁴ So how can these technologies influence the design of a building? Aesthetics Architects in Thailand designed a building in Qatar that uses these technologies to create a unique sustainable solution to a complex problem.

The new Minister of Municipal Affairs and Agriculture office (MMAA) in Qatar is going to be a first of its kind. Aesthetics Architects was looking for inspiration to design a building that would be situated in the hot, dry climate of Qatar, an area that only receives approximately 3.2 inches of rainfall annually. They decided to investigate the cactus for ideas on a building solution.

The new MMAA building was designed based on the shading properties of the cactus' spines. It achieves this by incorporating sunshades on the exterior of the building. Much like in Kieran's analysis on a buildings envelope and a filter, these shades act like filters with the sunlight that is penetrating the spaces. With the intensity of the sunlight that beats down onto the building and its occupants, a normal building would have to have a large cooling system in order to make that space comfortable for the user.



Image Source: <http://inhabitat.com>

Figure 5: Minister of Municipal Affairs and Agriculture office in Qatar

The sunshades on the MMAA building however have the ability to automatically fluctuate up and down, depending on the desired interior temperature, to regulate the amount of sunlight and heat that is transferred into the space. This innovative solution allows this building to lower the size and amount of artificial cooling necessary for the building to operate properly as well as providing a sustainable solution that is aesthetically pleasing. At the base of the building is a botanical garden which will hopefully be used as an edible garden and living machine.¹⁵ Overall the building is an example of a solution at the macro level, encompassing the building as a whole and how it functions within a specific environment. But Biomimicry also provides the opportunity to go even further and look at the micro level, such as looking at the design of the specific technologies that connect to the whole. An example of this type of discovery can be found in the research at WhalePower, a company dedicated to improving the technology behind wind energy and the design of wind turbines.

3.1.3 Humpback Whale and Wind Turbines

WhalePower is a Toronto based company that explores the technology found in a Humpback Whale's flippers and instituting this technology into the design of more efficient wind turbines. Their studies have provided scientists and researchers with essential information and advances on fluid dynamics which is the fundamental basis for many human technologies such as compressors, pumps, fans, and turbines.

The discovery of this technology came from Dr. Frank Fish, who runs the Liquid Life Lab at West Chester University and is also the president of WhalePower Inc. According to WhalePower Inc, through his research, his reputation has grown to be recognized as one of the world's leading experts on biomechanics of how animals such as minnows, beavers, and even whales swim. After noticing the bumps on the front of a Humpback Whale's flippers, he began to question what purpose they served because it seemed to go against the typical understanding of fluid dynamics and air flow. He collaborated his research with Dr. Phil Watts and Dr. Laurens E. Howle, who was a leading engineer in fluid dynamics for the Navy. Together, they made some incredible discoveries that changed the ideas behind turbine design.¹⁶



Image Source: <http://www.whalepower.com>

Figure 6: Humpback Whale Fin

Through their exploration they discovered significant differences in the efficiency of a typical turbine blade and a tubercle blade. Where smooth blades produce a sheet like flow of air, tubercles force the air into accelerated streams between the bumps. What happens in a conventional blade or fin is that when it spins, the air that passes over the surface begins to be pushed to the tip of the blade. This causes more turbulence and vibration to be generated on the end on the blade, which decreases the efficiency.

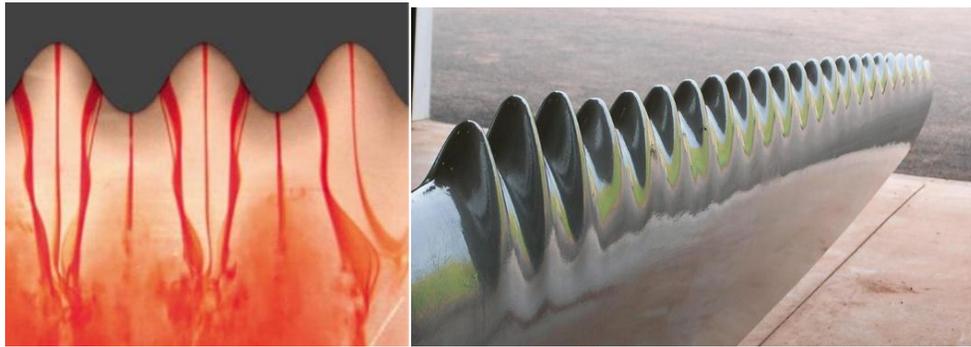


Image Source: <http://www.treehugger.com>

Figure 7: Tubercles Featured on Wind Turbine

By introducing tubercles to the front of the blade, the air that is pushed towards the tip is substantially decreased. In this instance, the fan is able to operate smoother, more efficient, and with less noise. What was incredible is that the same level of sustainable performance could be achieved at a pitch of 28° , unlike the conventional blade which usually has around a 16° stall angle. The overall design of a tubercle blade delivers a 20% gain in efficiency, and produces 1/5 of the noise and vibration.¹⁷ This incredible discovery was due to the intense research of a Humpback Whale, displaying another example of the impact Biomimicry can have on the development of mankind. But there is another way to look at nature for design solutions and that is to study the behavior of an organism.

3.2 Behavioral Level

The second level is Behavior- this refers to mimicking a specific type of behavior or act that the organism does to survive or replicates on a daily basis in relation to a larger context.

3.2.1 Termite Mound and Temperature Regulation

A great example of how the behavior of one organism can be studied to solve human design problems is the termite. The termite's home, a termite mound, was studied by architect Mick Pearce to solve the complex problem of heating and cooling a large structure.

Extreme termite mounds are formed when the aboveground nests grow past the capacity that was initially made. The nests are made to protect the nesting and royal areas as well as fungus combs (their primary food source). The fungus can only grow and be sufficient if it is kept at exactly 87 degrees F. The temperatures outside of the mound fluctuate greatly due to the location, Africa. At night, the temperature can drop to a chilling 35 degrees F and during the day can reach a scorching 104 degrees F! So how does the termite keep the fungus at exactly 87 degrees F? Simple, they open and close specific "vents" which are precisely placed in the mound to regulate the air within the mound itself.

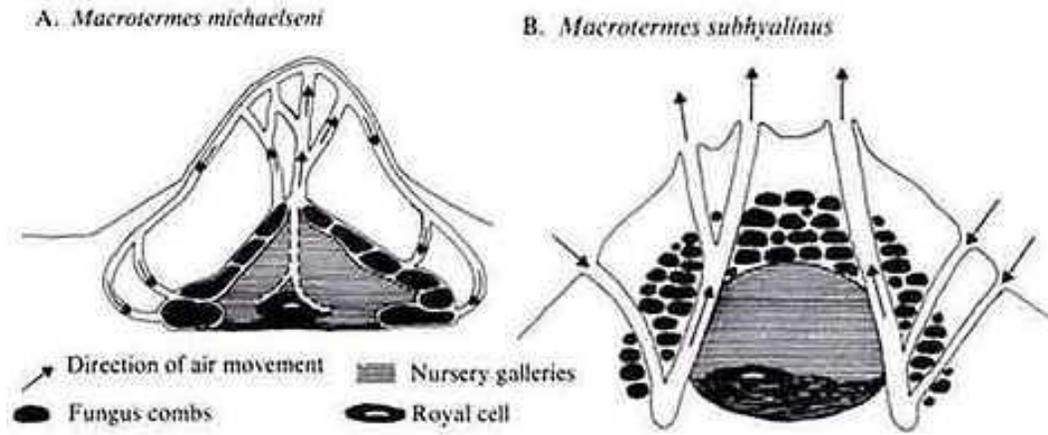


Image Source: <http://inhabitat.com>

Figure 8: Termite Mound Temperature Regulation

With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with the muddy walls, and up through a channel to the peak of the termite mound.¹⁸ What also makes this design so interesting is that the termites also plug some of the vents and create new ones if the old ones become inadequate and are not functioning to their full potential. It was precisely this type of instinctual behavior of termites that inspired Michael Pearce in his design of the Eastgate Center in Zimbabwe.

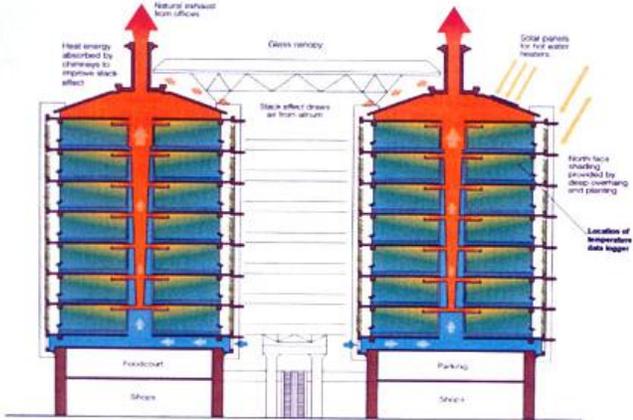


Image Source: <http://inhabitat.com>

Figure 9: Section Showing How Temperature is Regulated

The Eastgate Center is mostly made of concrete which is an excellent material to use as an insulator as well as absorbing heat from the sun. The outside air that is brought into the building is either warmed or cooled depending on the temperature of the buildings mass. If the buildings mass is cooler, than the air that enters the structure would also be cooled. The air is then directed upwards towards the chimney but on its way up to the top it passes into the building's floors and offices. As seen in figure 9, the building is actually made up of three parts; two exterior structures and a glass center that connects them together. The glass space in the center also participates in natural convection and is usually open to the local breezes.

3.3 Ecosystem Level

The third level is Ecosystem- this refers to mimicking a specific ecosystem and how it functions successfully as well as what elements and principles are required for it to function successfully.

3.3.1 Zira Island Master Plan

The Zira Island Master Plan, designed by Bjarke Ingels, founder of BIG Architects, is a perfect illustration of this form of biomimicry. I watched an interesting special on this project on TED, which stands for Technology Entertainment and Design. TED is a conference that hosts over 50 of the world's most innovative and influential people who speak about their new innovations and design proposals. TED searches the globe year-round to find presenters for this conference. According to Bjarke Ingels during his presentation on TED, *“Our presenters run the world's most admired companies and design its best-loved products; they invent world-changing devices, and*

create ground-breaking media. They're trusted voices and convention-breaking mavericks, icons and geniuses.” Bjarke Ingels is an architect who had the privilege to speak at this conference regarding some of his firm’s design proposals that may change the world. One of which was the Zira Island Master Plan, which is not yet built but under construction as of 2010.

The Zira Island is located within the crescent bay of Azerbaijan’s capital Baku, on the Caspian Sea. This project was designed to be a Zero Energy resort and entertainment city on the island. Creating a zero energy resort that consumes a 1,000,000m² island may seem impossible, but BIG has found a way to do it successfully and beautifully. The project was brought to BIG by a minister from Azerbaijan who was inspired from a previous project that BIG had proposed. The minister was inspired in the way that you can recreate “mountains” out of architecture because Azerbaijan is known as the Alps of Central Asia. With this in mind, the minister asked BIG if they could create a resort and entertainment city that would recreate the silhouette of the seven most significant mountains in Azerbaijan. This is how the building forms were derived. Each structure not only represents one of the seven most famous mountains in Azerbaijan, but they are all also inhabitable.¹⁹ What is unique about this site is that the Zira Island has absolutely no vegetation, no water or resources. Bjarke Ingels describes it as being a desert. Because of this, BIG’s overall master plan was designed to be its own independent ecosystem. They were able to do this by using a variety of new sustainable technologies to produce enough energy to power the entire island.



Image Source: <http://www.archdaily.com>

Figure 10: Overall Concept of Master Plan

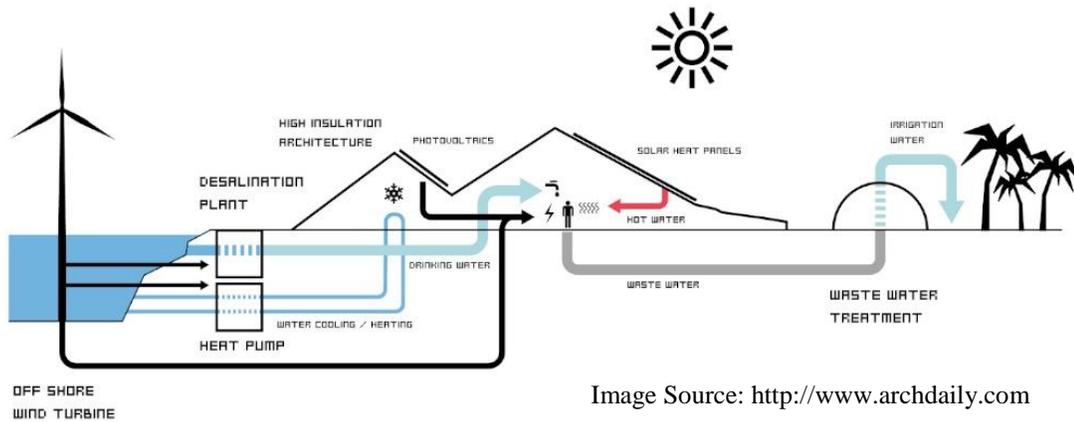


Image Source: <http://www.archdaily.com>

Figure 11: Section Displaying Sustainable Technologies

Wind energy from wind turbines which are seated in the Caspian Sea, are used to power desalination plants. The desalination plants are used to extract the salt from the sea water and convert it into fresh water which is suitable for humans. The water is then used for heating and cooling the buildings. All of the excess waste water is then dispersed into the landscape to provide nutrients to the new vegetation on the entire

island. In addition to the waste water, storm water is also collected and recycled for irrigating the plant life around the island. During the extraction process to make the water suitable for humans, there is a large amount of solid waste that is filtered and collected. The solid minerals that are gathered are also recycled by turning these solids into top soil and thus used to fertilize the vegetation. When describing the final design, Bjarke Ingels states “When in urban development normally happens at the expense of nature, in this case it actually creates nature”. I found this to be one of the most innovative solutions/designs I have ever seen. Evacuated tubes and photovoltaic panels were also placed on the exterior facades and at the top of the buildings to generate power as well. With all of these elements working together, the island becomes a self sustaining, independent ecological system; one that combines private resort villas with a gorgeous green valley that is easily accessible to all who inhabit the island. Not only does the composition become an iconic piece of architecture in the city’s skyline, but it also stands as an inspiration for future large scale sustainable development projects around the world. One in particular is the Coral Reef Project by Vincent Callebaut.

3.3.2 Coral Reef Project Haiti

Over the past few two years, Haiti has been victims to devastating earthquakes, ranging from 7.0 and up on the Richter scale, which had a substantial impact on the country as a whole. Families, friends, and neighbors were forced to watch as their homes and community were destroyed by these tremendous natural disasters. After the earthquake it was quite apparent the large amount of destruction it had caused. Haiti was in dire need of help and for a drastic redevelopment to occur. One architect in particular,

Vincent Callebaut, saw this as an opportunity to design a new, innovative way to create disaster housing; housing that is not only permanent but also affordable.

Vincent Callebaut, who is the founder of Vincent Callebaut Architecte, looked to nature as the basis for his design proposal. Callebaut explored the principals behind coral reefs. Coral is basically underwater structural formations that consist of calcium carbonate. They are home to many marine animals and also help to balance the underwater ecosystem. What is interesting about coral is the dynamic shape at which it grows. Each piece of coral is unlike the other. It is almost like the ocean has thousands of tiny fingerprints. Callebaut was fascinated by the non-uniform shape and formation of coral reefs and used this as the basis of his design principles.

The carbon neutral utopian village for Haiti is called the Coral Reef Project. Inspired by the coral reef with fluid organic shapes, the overall project is presented as a living structure that has the ability to grow and house over a thousand Haitian families.²⁰ The housing development appears as though it is two waves that undulate throughout the artificially built pier, which was constructed on seismic piles in order to withstand seismic impacts from earthquakes. In between the two waves, a valley of gorgeous green terraces and organic gardens lace the interior walls to form a space that embraces the community and culture of the Haitian society.

What makes this design so unique is that it is actually constructed from only using one standardized and prefabricated module. It is the placement and orientation of each module that give the overall scheme a non-uniform design aesthetic.



Image Source: <http://vincent.callebaut.org>

Figure 12: Proposed Arrangement of Passive Houses

The module consists of two passive houses, with metallic structure and tropical wood facades, which interlock in duplex around the horizontal circulation which links every unit. When these houses, or modules, are assembled together, they form the organic shape of the two waves of “coral”. Because they were designed in this way, the modules have the ability to cantilever out over one another which gives the opportunity for an organic garden to be present on every module, using the roof of the unit below as the garden. The roof gardens then serve as a way for each family to cultivate and grow their own food, making them self sufficient.²¹

Like coral, the design of the structure is undetermined because each piece, each module, can be integrated in a different way. This makes the design very flexible and provides the ability for the design to change with time. This notion is similar to Brands idea that buildings change and we must design in a way that is flexible to the users and occupants. The Coral Reef Project provides opportunities such as this. Rather than the rooms becoming flexible, the overall complex as a whole becomes flexible.

Callebaut describes the development as a true tropical ecosystem for the local fauna and flora. He states: “*Between the waves of these ecological housing, the sinuous*

lines of the anti-seismic basement (absorbing the vibrations in case of earthquake) integrate the public functions of the social life. Aquicultural farms welcome pisciculture pools whereas the purification plant lagoons recycle the used waters before rejecting them in the sea.”

The project also features hydro-turbines which are located underneath the pier. The hydro-turbines use the kinetic energy from the sea and convert it into electrical energy. To capture solar energy, arrays of photovoltaic panels are also placed on the top of the roofs. In the center of the two coral waves, there is spiraling wind turbines which generate power from the tropical wind that passes through the valley. With all of these systems working as one, the design becomes a self sufficient, carbon neutral village for the people of Haiti. But not all projects can just take any element of nature and transform it into solving human needs directly as is. This is a common criticism against Biomimicry and how it is used to solve human demands.

3.4 Criticism Against Biomimicry

Steven Vogels' book, *Cats' Paws and Catapults*, is a piece of literature that brings to reality some of the negative arguments towards Biomimicry. He refers to this as “*naïve Biomimicry*”. What he refers to as naïve is scientists and inventors that were using the exact same technology found in nature and without any adjustments, turning it into something at human scale. By implementing designs in this way, the majority of the designs were unsuccessful. In his book he uses several good examples that showcase this argument. These examples mostly focus on locomotion by both air and water.

One of his best examples is regarding air travel and the design of the airplane. Designers such as the Wright brothers spent much of their time observing birds and their ability to glide through the air. Although this is a good place to start, it actually led them in the wrong direction. The size to weight ratio of birds is much different than that required of an aircraft. Also birds are much smaller than people, and so the characteristics of their flight technology are different than that required for humans. In order for something that is heavier and larger in size to stay in the air, it must be moving at a faster rate, hence the introduction of jet engines and high powered propellers. Birds on the other hand don't need this type of propulsion because they are so much smaller. This was one of the reasons why there were so many failed attempts. But finally after many revisions, the airplane grew from just a one seated aircraft, to a vehicle that transports hundreds of people at a time across the world.²²

Along with these examples he does discuss successful projects as well which makes his book a viable source to uncovering both the positive and negative arguments directed towards the understanding of Biomimicry.

CHAPTER 4

BUILDING TYPE

4.1 Medical Implementations

Biomimicry is not limited to just aiding in the push for discovering new sustainable solutions in architecture, but it also can be implemented in other ways to help human needs. Scientists have used the technology found in the Bombardier Beetle to aid in the development of drug delivery devices such as inhalers, or even fuel injectors for engines. The beetle is found in Africa, Asia, and parts of the US and was studied thoroughly by scientists Andy McIntosh and Novid Beheshti at Leeds University in the UK.

The Bombardier Beetle has a unique defense mechanism to ward off its predators. It creates a chemical fluid that consists of hydroquinone and hydrogen peroxide and stores the two chemicals in two separate chambers. When the beetle becomes threatened in any way, it opens the chambers and mixes the two chemicals. The mixing of these chemicals creates a highly toxic mixture which heats up to a point that is hotter than boiling water. When the chemical is completely mixed, it then ejects the toxic liquid like a weapon toward its predator. The beetle can shoot the toxin with pinpoint accuracy and a variety of droplet sizes in any direction up to 20 cm in distance.

McIntosh and Beheshti began experimenting; trying to replicate the same process the beetle uses to fend off its enemies. As they continued with exploring new ways to get the propulsion to work as accurately as the beetles, it led to new advancements in other

technologies used by mankind. Devices such things as inhalers, injectors, and even nozzles for fire extinguishers.²³ This is just one example of how Biomimicry can influence technological advancements in fields other than architecture to solve human problems.

4.2 Building Research

This research led to the exploration of designing a building related to the medical field. When comparing different fields of study, there was a strong connection with the relationship between Biomimicry and prosthetics. The process in which prosthetics are designed today mimic the same methodology behind Biomimicry. Researchers are analyzing different parts of the human body and how they function in order to mimic them in the form of robotic limbs. In current studies, researchers are digging even deeper into this process and developing ways to connect to the nerves so that the prosthetic reacts to signals sent from the brain and will function like a regular part of the body.



Image collage by Michael Maglic

Figure 13: Examples of Prosthetics

4.3 Amputees

The number of amputees in the United States is continuously growing. Based on a population of 250 million in the US, the number of amputees is around 1.7 million.

53% Below the knee

33% Above the knee

8% Below the elbow

6% Above the elbow

In February 2008, 730 individuals suffered major limb amputations during Operation Iraqi Freedom and Operation Enduring Freedom in Afghanistan. Since then the number has more than double. But this is not the only cause of amputations. There is an increasing number of people who have diabetes. Over 25.8 million people in the US have diabetes. Diabetes can cause ulcers and a lack of circulation to the extremities.²⁴ If the ulcers or circulation is not treated soon enough, then one could lose their limb. This is actually the cause of the majority of amputations.

70% Circulatory disease

23% Trauma

4% Tumor

3% Congenital conditions

4.4 Prosthetics

Prosthetics are not the same as they used to be. When inventors came out with the first prosthetic leg, it was a shaved piece of wood with a belt that held it to the limb. The apparatus was very unattractive and caused a lot of negative attention. Some of the later designs which are still in production today, consist of a plastic apparatus that either pins or suction to the limb. The mobility and versatility of these prosthetics though is not ideal to all situations. But advancements in technology have allowed for huge leaps forward in developing a new way to design prosthetics that better fits everyday needs.



Image Source: <http://www.yankodesign.com>

Figure 14: Nike Prosthetic Leg Concept

Now the industry is producing prosthetics that have motors in them to simulate the natural movement of an arm or leg. The designs are also much more appealing than ever before. For example the Nike concept leg shown in figure 14, is very sleek and aggressive. But not all designs however take on such a realistic shape to the human limb. One prosthetic shown in figure 15 actually replicates the hind leg of a cat.



Image Source: <http://www.futurity.org>

Figure 15: Example of Prosthetic Designed for Running

This is a common prosthetic seen on runners because of its flexibility and responsiveness to the motion of running. Children are also forced to live with amputations due to birth defects and disease. Because a child grows so fast, usually the prosthetic is a temporary apparatus and as the child grows out of one, he or she will be fitted for another.



Image Source: <http://myfitnessdepot.com>

Figure 16: Childs Growth Process with Prosthetic Legs

What is so inspiring about the research behind advanced prosthetics is the passion and dedication that is put into developing these amazing machines. The overall goal is to give people back the ability to live their lives like they would normally and what better way to find out information on how this is accomplished than to contact a facility who specializes in prosthetics.

4.5 Building Type

Live Every Day Prosthetics and Orthotics is a small medical office located in Suffield, Connecticut. Their areas of focus are custom bracing, diabetic footwear and amputee care. In order to uncover how facilities such as this are ran, Anthony Calendrillo, the Co-Owner/Business Manager, was contacted for a phone interview to get an in depth look at how this process works.

At this specific facility there is only 1 physician who, on average, only attends to 2-3 patients a day. Currently it is located within a larger office building, but Mr. Calendrillo says that their future plan is to move to a larger facility where they can incorporate more programs into their office such as therapy. As of now, they outsource all of the manufacturing and therapy and in regards to this topic, he went on to say that the industry is moving towards combining all of these into one facility for convenience. Some facilities have incorporated a portion of the program to therapy but there is no building that exists today that has all 3 integrated into 1 complex. Mr. Calendrillo was very enthusiastic and encouraging upon the idea of creating a building that would not only have examination rooms but would also integrate the research, manufacturing, and therapy all into one building. Since a building like this has never been created before, he

was very interested into how one might solve this unique design proposal. The first place to start was to explore buildings who have focused on prosthetics in these categories.

4.6 Precedents

Hugh Herr, who is the inventor of the PowerFoot BiOM, an advanced ankle prosthetic that actually has a mechanical Achilles tendon to give the apparatus the function like a real ankle, was where the exploration started. Mr. Herr himself lost both of his lower limbs due to a climbing accident when he was in his late teens. He is now the Director of Biomechanics Group at MIT. Their research is located in the MIT Media Lab building which was designed by Maki and Associates. The 163,000sqft building has 7 research labs ranging from 5,000-8,000sqft. This was a good building to investigate in order to see the kinds of equipment such as computers, tables, desks, and small simulation space required to operate a small research lab.



Image Source: <http://www.boston.com> & <http://arstechnica.com>

Figure 17: MIT Media Lab

The next building studied was the Walter Reed Medical Center located in Washington, DC. This facility is an advanced training center for the U.S. Army. Recently, a new therapy and rehabilitation unit was put into the Walter Reed Medical

Center. The unit included a 2 story rehabilitation area with a rock climbing wall and advanced computer aided therapy machines. This was a good example that demonstrated what types of equipment and space were required for a large therapy room to function properly.



Image Source: <http://www.army.mil>

Figure 18: Walter Reed Medical Center Therapy Areas

As for the manufacturing, it was found that there needs to be adequate space for large, stationary fabrication machines as well as a computer area to run the machines. Mr. Calendrillo also described how a customization area is crucial to offer the ability to make quick adjustments to all the prosthetics.

4.7 Program

The program requirements for the proposed building began to formulate through all the research gathered. The Research portion would consist of micro labs and molecular studies, large open labs, testing rooms, offices, conference room, computer area, and adequate storage space. The Manufacturing portion would consist of computer rooms, customization area, fabrication room, heavy machinery area, assembly room, and

storage space. The Therapy portion would consist of clinician offices, exam rooms, reception desk, waiting area, staff offices, gait analysis room, therapy room, free weight area, simulation room, and small locker rooms.

4.8 Design Approach

After the program was decided, the next step was to begin looking at nature for inspiration to design the building. One of the major considerations, which was mentioned earlier, is the idea of implementing a solution at a human scale. As shown in previous examples this strongly influences the success or failure of a proposal. When looking back at some of the precedents pertaining to Biomimicry, the question arose, can more than one organism be mimicked in a single design? All of the examples shown only display one type of organism that was mimicked each. It was concluded that if more than one organism was to be mimicked, it would have to be in a way that compliments one another and works cohesively together to successfully form the final composition.

CHAPTER 5

THE HUMAN BODY

5.1 Theory

Looking back at the ideology behind Biomimicry, (the method of looking at the processes found in nature to aid in the development of mankind), as well as a deeper understanding of advanced prosthetics, what better place to start looking for inspiration than analyzing the organism in which you are trying to connect with, humans. The design of the human body is quite fascinating, especially when looking at how efficient our bodies really are. Each bone, muscle, organ, and cell in the human body are completely optimized to function for a specific purpose. Utilizing the conclusions derived from the previous research and precedents, the next step was to investigate more thoroughly the human bone in relation to structure, and arteries in relation to the internal components such as mechanical systems which are integrated into a building.

5.2 Spongy bone and Structure

The human bone is quite complex when breaking it down to a molecular level. By taking a section cut through the bone, one can see the multiple layering found within figure 19. What was so intriguing was the porous Cancellous bone, also referred to as spongy bone, found in the Medullary cavity. The Compact bone, which surrounds the Cancellous bone, is a dense composite composed of organic substances and inorganic salts leaving only small openings that contain bone cells. The Compact bone is subject to the major mechanical stresses that we apply in our everyday lives.²⁵

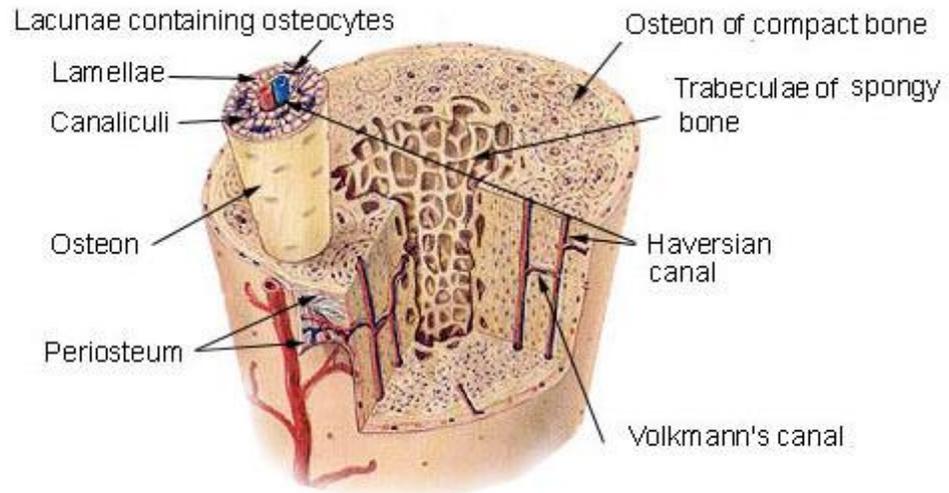


Image Source <http://training.seer.cancer.gov>

Figure 19: Section Cut of Human Bone

Therefore it is unnecessary for the Cancellous bone to be as dense as the Compact bone because it does not endure the same type of stresses and forces. What is so unique about this design is that the bone only has material where it is necessary to withstand the stresses and forces that are being applied to it; making the bone completely optimized. Because the Cancellous bone is very porous, it is not only lighter but it also allows for some flexibility. If our bones were completely solid and unable flex or bend slightly to absorb some of the stresses being applied, they would break much easier. The science behind this design was very inspiring and led to a variety of ideas on how this could be used to design an optimized structural system for a building.

Many of the same design principles discovered in the human bone directly relate to some of the structural systems used today, such as steel trusses. Steel trusses are also very porous and only have steel where it is necessary to support the loads being applied.

But steel trusses are just one component of a larger structural system which may not be as efficient as it could be.

5.2.1 Topological Optimization

The actual process in which the Cancellous bone is formed is referred to as Topological Optimization. This process is unique in that the solution is unknown until the analysis is complete. The only known factors in the problem are the applied loads, the possible supports, the size of the structure, and possible constraints on where some of the holes may be located.²⁶ This means that each solution will be different depending on the specified parameters. The process works just like the bone. Given the applied loads and supports (if applicable), the analysis begins to reshape and remove material that is unnecessary in order to formulate a completely optimized structural system.

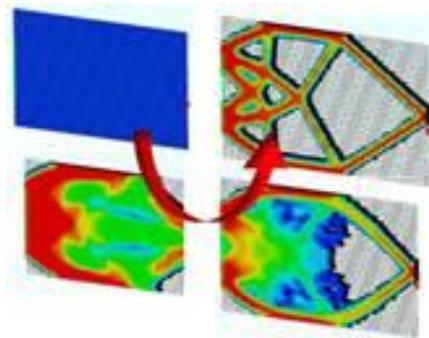


Image Source: <http://www.cosimtec.com>

Figure 20: Topological Optimization Process

Technology has provided us with the opportunity to integrate these functions into optimization software which uses the proper mathematical equations to calculate and generate results based on the specific parameters given. There are several examples of

how this methodology is used today. One of which is the design of the DaimlerChrysler Bionic Car.

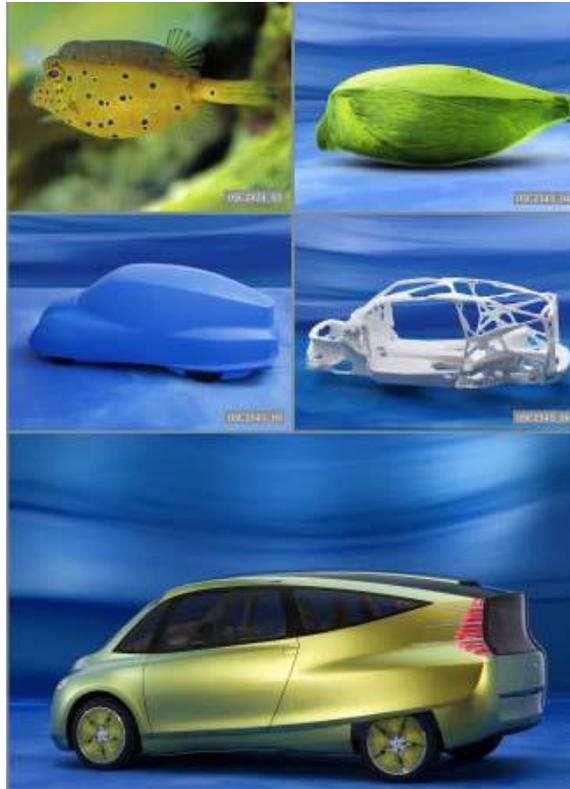


Image Source: <http://jalopnik.com>

Figure 21: DaimlerChrysler Bionic Car Development Process

The car's form was designed to mimic the Boxfish because of its aerodynamic shape. After achieving this form and slightly manipulating the "shell" so that it conformed to the desired shape of the actual car, topological optimization was implemented to generate an optimized, light weight structure. As mentioned earlier, having the ability to control some of the constraints in the process is crucial. This allowed DaimlerChrysler to have larger openings where the doors would be applied. As you can see from the image, the structure has more material by the engine and wheels.

This is due to the increase in applied loads and stresses that were set as the parameters before running the final analysis.

By evaluating the Cancellous bone and projects similar to the Bionic car, it provided enough information to formulate my own ideas on how this process could be mimicked to create a completely optimized structural skin composed of concrete for a building. But there was more to the human body than just bone structure that was found to be inspirational.

5.3 Arteries and Fluid Distribution

In order for humans to survive, nutrients, oxygen, and blood, needs to pass throughout the body. Oxygenated blood is carried to all the tissues in the body through arteries. This blood is being transported under high pressure from the pumping heart.²⁷ It is essential that this fluid has a clear and smooth path of travel otherwise it could cause heart failure. Both arteries and veins are specifically designed to be very efficient for fluid travel. Other things in nature such as leaves, when compared to human arteries are designed in a similar way.

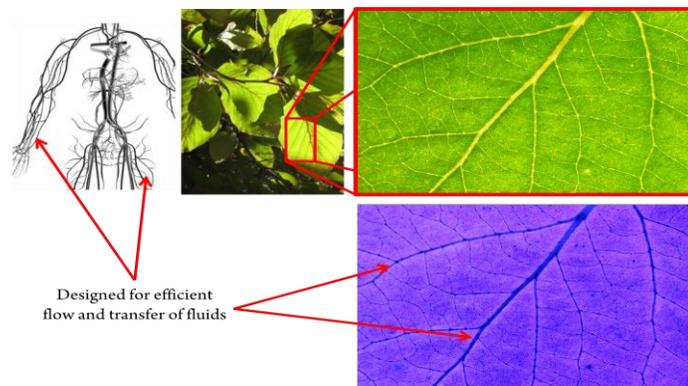


Image Collage by Michael Maglic

Figure 22: Comparison of Human Arteries and a Leaf

5.3.1 Fluid Dynamics and Efficient Mechanical Systems

Fascinated by how intricately articulated and efficient our circulatory system is it led to the detection of how inefficient our mechanical systems are in a building. Typical HVAC systems for example, usually have a primary duct located in the center of a double loaded corridor. The secondary ducts, which branch out into each room, run perpendicular to the primary duct. It is this transfer of air flow that is inefficient. By further investigating fluid dynamics, one can observe that air passing through a right angle causes eddies to form which cause resistance. The more resistance, the less air flow, which means the less efficient the system is. By increasing the angle of the duct or pipe, it reduces the formation of eddies creating a continuous flow throughout the entire system. This analysis also pertains to plumbing as well. It was this discovery that led to the decision to design the mechanical systems to be as efficient as possible by following the same processes found in arteries.

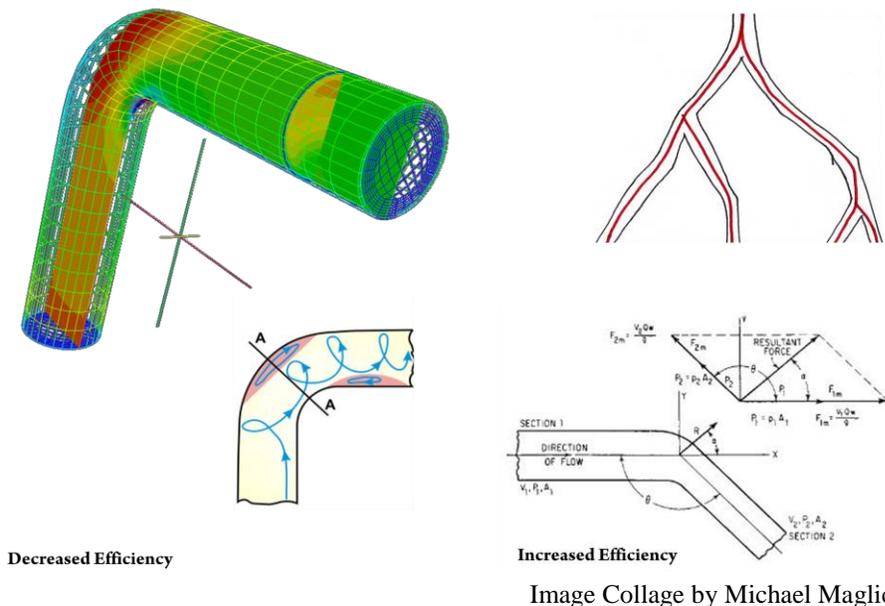


Figure 23: Fluid Dynamics Test Showing Efficient and Inefficient Design

CHAPTER 6

THE NAMAQUA CHAMELEON

6.1 Adaptive Skin and Regulating Temperature

The Namaqua Chameleon has a very unique adaptation that allows this reptile to survive in a very intense climate. The chameleon is found in the Namib Desert located just north of South Africa. The average temperature in Namibia during the months of November-March is roughly 90°F. At night however, the temperature can drop to as low as 45°F. The sun in this area is very extreme and many organisms have developed adaptations in order to cope with the sudden fluctuation in temperature change. In order to regulate its body temperature, the Namaqua Chameleon has the ability to change the color of its skin depending on where the sun is. Where ever the sun is shining, the chameleon changes that half of its skin to a darker color to absorb heat, while the other side turns to a lighter color to minimize the heat from escaping its body.



Image Source: <http://www.telegraph.co.uk>

Figure 24: Namaqua Chameleon

6.1.1 Adaptive Fritting and Solar Collection

The engineers at Hoberman Associates have developed a unique technology that functions in the same way as the Namaqua Chameleon's skin. The technology is called Adaptive Fritting. Standard fritted glass usually has a pattern or design that is typically displayed as a decorative feature or to control the transparency through the wall. Adaptive Fritting is an innovative way to apply operable thermal regulation and complete user control to a fritted glass system. In standard fritted glass the pattern is stationary. With Adaptive Fritting, the graphic pattern is used to not only control transparency and light that enters a space, but it also can control heat gain.²⁸

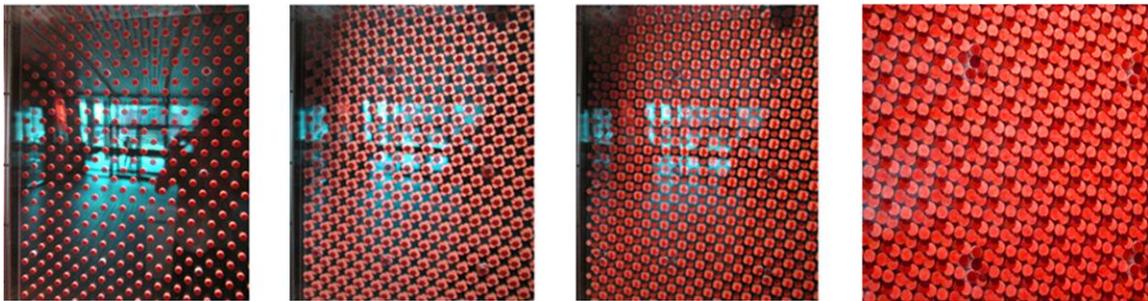
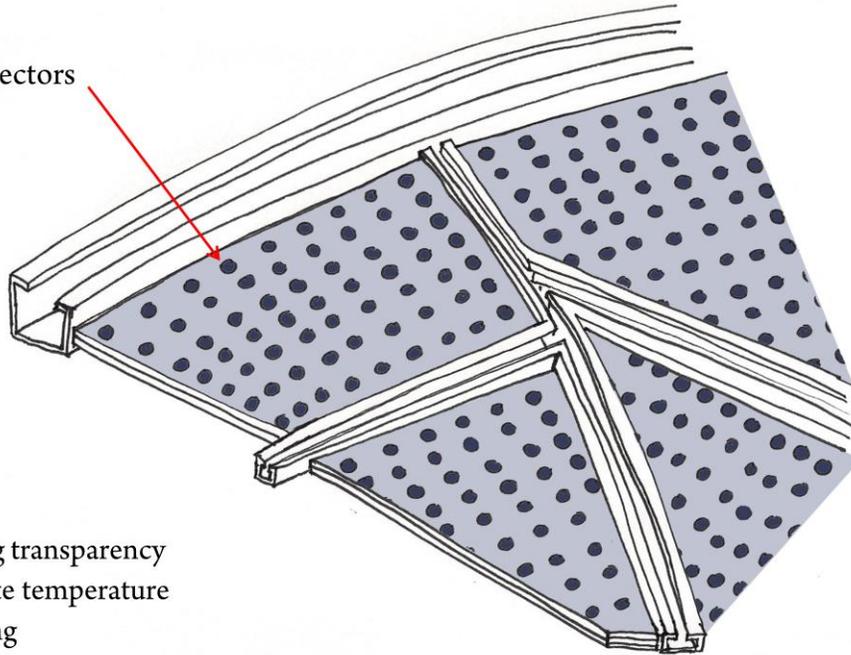


Image Source: <http://www.hoberman.com>

Figure 25: Adaptive Fritted Glass at Harvard GSD

But this fritting is usually used on interior walls and the question arose if this technology could be taken one step further and somehow be integrated into an exterior facade. If the glass can be used to regulate temperature within a building, why couldn't this glass also collect solar energy and be used as an exterior skin to a building? Instead of a fritted pattern on the glass, thin film solar panels would be integrated and used to regulate the temperature as well as collect solar energy. Therefore by using the same processes found in the chameleon, the building would have the ability to change its "skin" to regulate the interior temperature according to where the sun is.

PV Collectors



Adjusting transparency
to regulate temperature
in building

Image Source: Michael Maglic

Figure 26: Possible Integration of Thin Film Solar Collectors

CHAPTER 7

THE DESIGN

7.1 Moving Forward

With all the essential research gathered it was time to move onto designing the building. But before the building could be designed, an appropriate site must be selected for this project in order for it to be successful.

7.2 The Site

The site was a critical piece to the overall design. Since the program consisted of components such as research, manufacturing, and therapy pertaining to advanced prosthetics, an appropriate location for such a facility would be next to a building that also pertained to the medical field. With this in mind, the site chosen was on the Boston Inner Harbor just north of the Charlestown Navy Yard. Located on Parcel 5 at the corner of Sixteenth Street and First Avenue (Figure 27), the site provided a perfect connection to some of Massachusetts General Hospital's research facilities as well as a direct connection to the new Spaulding Rehabilitation Hospital designed by Perkins + Will.

The Spaulding Rehabilitation Hospital is located on Parcel 6 which is on the northwest end of the proposed site Parcel 5. This particular hospital has programs such as Amputee and Vascular Disease Rehab, Brain Injury Rehab, Child and Adolescent Rehab, Disorder of Consciousness, Musculoskeletal Rehab, Spinal Cord Injury Rehab, and Stroke/ Neurology Rehab.

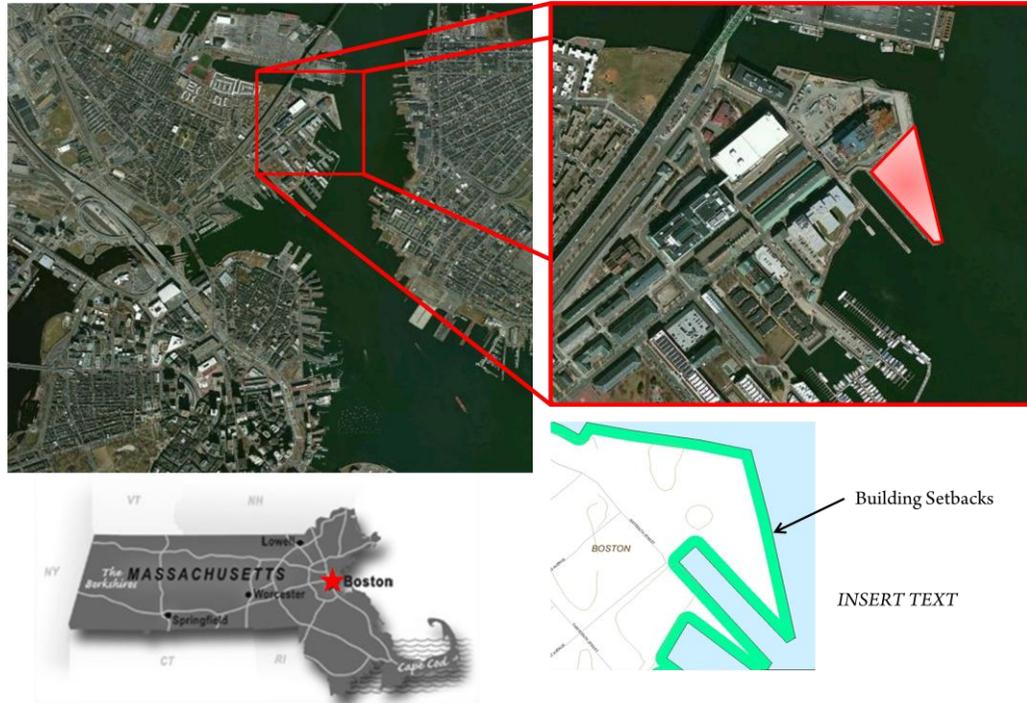


Image Source: Google Earth & <http://www.bostonredevelopmentauthority.org>

Figure 27: Site Location

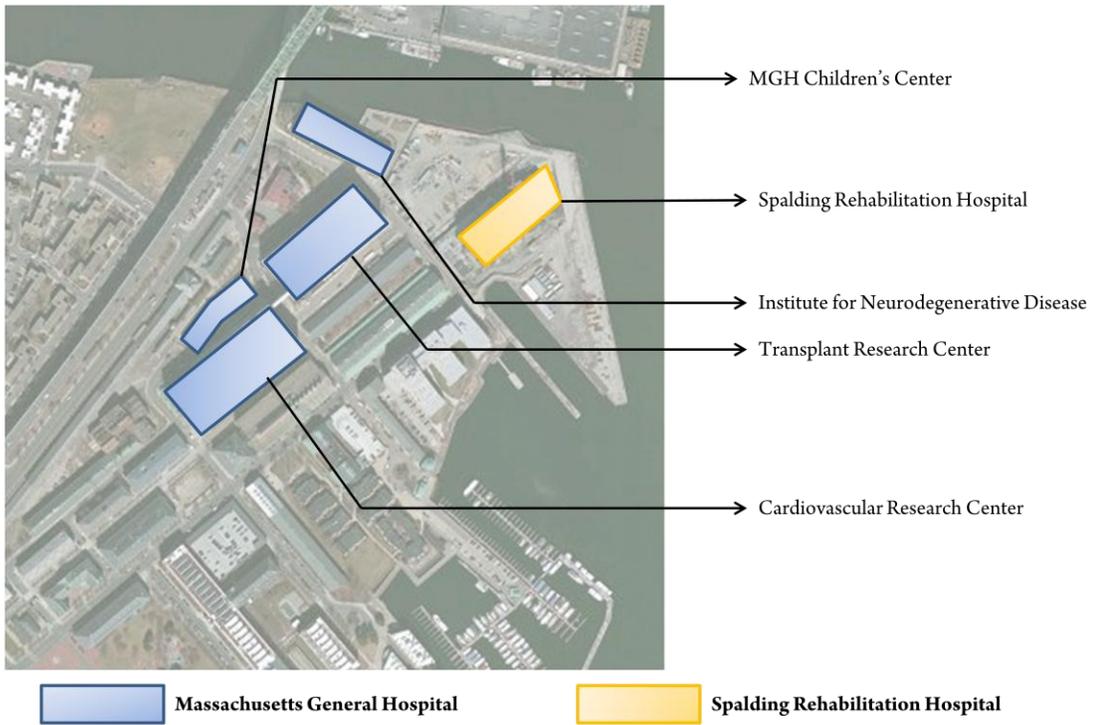


Image Source: Google Earth

Figure 28: Existing Medical Facilities Around Site



View A



View B



View C

Image Source: Google Earth

Image Source: Michael Maglic

Figure 29: Existing Conditions



Image Source: <http://www.perkinswill.com>

Figure 30: Proposed Spaulding Rehabilitation Hospital

It is intended that the Amputee and Vascular Disease Rehab program at Spaulding would connect and relate to the newly proposed Research, Manufacturing, and Therapy Facility for Advanced Prosthetics.

The proposed site has many interesting characteristics that strongly affect the design response. First is the overall triangular shape of the site which unintentionally opens up towards the Spaulding Rehab Hospital and in this case is also the only way to access the site by foot. The site is also surrounded by water on 3 sides. This makes the site completely exposed to all of the harsh climatic changes that occur throughout the year. There is an extremely high amount of exposure to the sun because there are no trees or buildings to shade any part of the site, which also means that the building will endure the intense seasonal wind loads as well. All of these site conditions combined create an incredibly dynamic situation that requires a very specific design response.



Image Source: www.bing.com



Image Source: Michael Maglic

Figure 31: Aerial & Panoramic View of Site with Spaulding Rehab Hospital

7.3 Building Form and Structural Skin

After referring back to the methodology behind the human bone and how it is designed in response to specific stress conditions, there was further investigation on how the building's form and structural skin could also be designed in such a way. If the building's form was derived from specific site conditions such as the wind/snow loads and was articulated in such a way to reduce the amount of stress being applied from the wind loads, then the amount of material and structure could be optimized in response to that.

There were several case studies explored pertaining to this idea of a site generated form and one in particular was found to be quite inspiring. Fraser Island in Australia was in a situation where the flood plain was too high for that particular area, so engineers built an island just off of the coast to reduce the flood plain.



Image Source: ArchitecturalDesign

Figure 32: Man-made Island

What was so interesting is that when they came back 5 years later to see how the condition of the island was, there was a whole new unexpected landscape. Because of the wind, rain, and other environmental changes that acted on the site, dunes and other mound formations began to emerge. This evoked another idea. What would happen if 5 feet of sand was placed on the proposed site, Parcel 5? What would it look like in 1,2, or 5 years from now after enduring many seasons of harsh climatic change and intense winds?

From this exploration it was decided that the wind loads would be the primary focus of investigation to discover the overall form of the building, the process began with gathering data on the monthly wind roses. The data gathered is shown in the image below. The wind rose graph is measured in knots, 1 knot = 0.869 mile per hour. Not only does the graph display the velocity of the wind, but it also measures which direction the wind is coming from as well as the amount of time in a month that the wind is coming from that direction. This is measured in hours and is represented in different shades of blue. With this data acquired, the next step was to begin generating a variety of forms.

The data for each month was taken into an advanced computer software program where it could be analyzed and extruded into a three dimensional form. By taking the monthly wind rose and generating a three dimensional height-field for each one, it was decided that the most appropriate form was generated for the month of December. The velocity and duration of wind acting on the site was the highest in this month and designing for the worst case scenario is a proper design response.

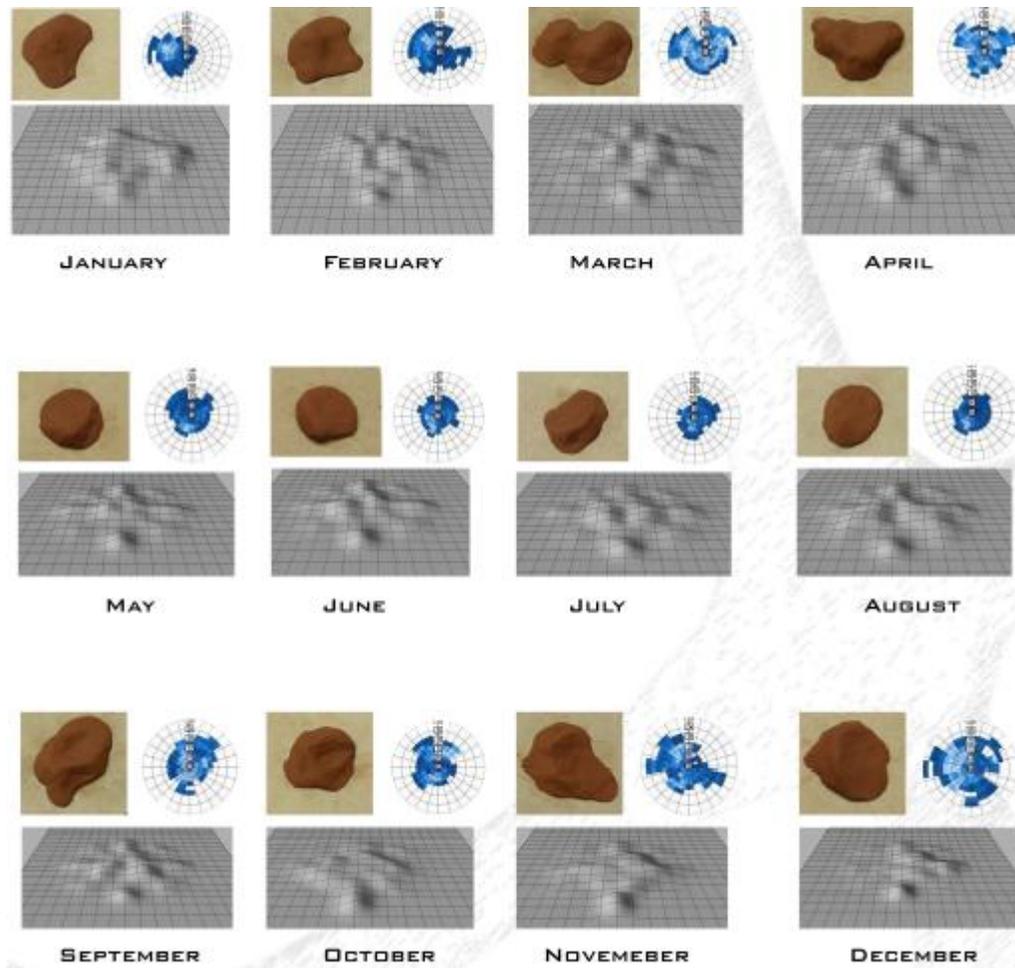


Figure 33: Wind Rose Height-field and Clay Model

Once again referring back to the human bone and the light weight structural integrity of the Cancellous bone, the design intention is to create a completely optimized structural skin. Since the form has been generated the next step is to run the topological optimization analysis on the form with set parameters and constraints. With a desire to have more operable glazing on the north façade, constraints were placed so that the holes created after running the analysis would be slightly smaller on this face. After successfully running the analysis, the final product is a completely optimized structural system that is ready to be integrated into the site.

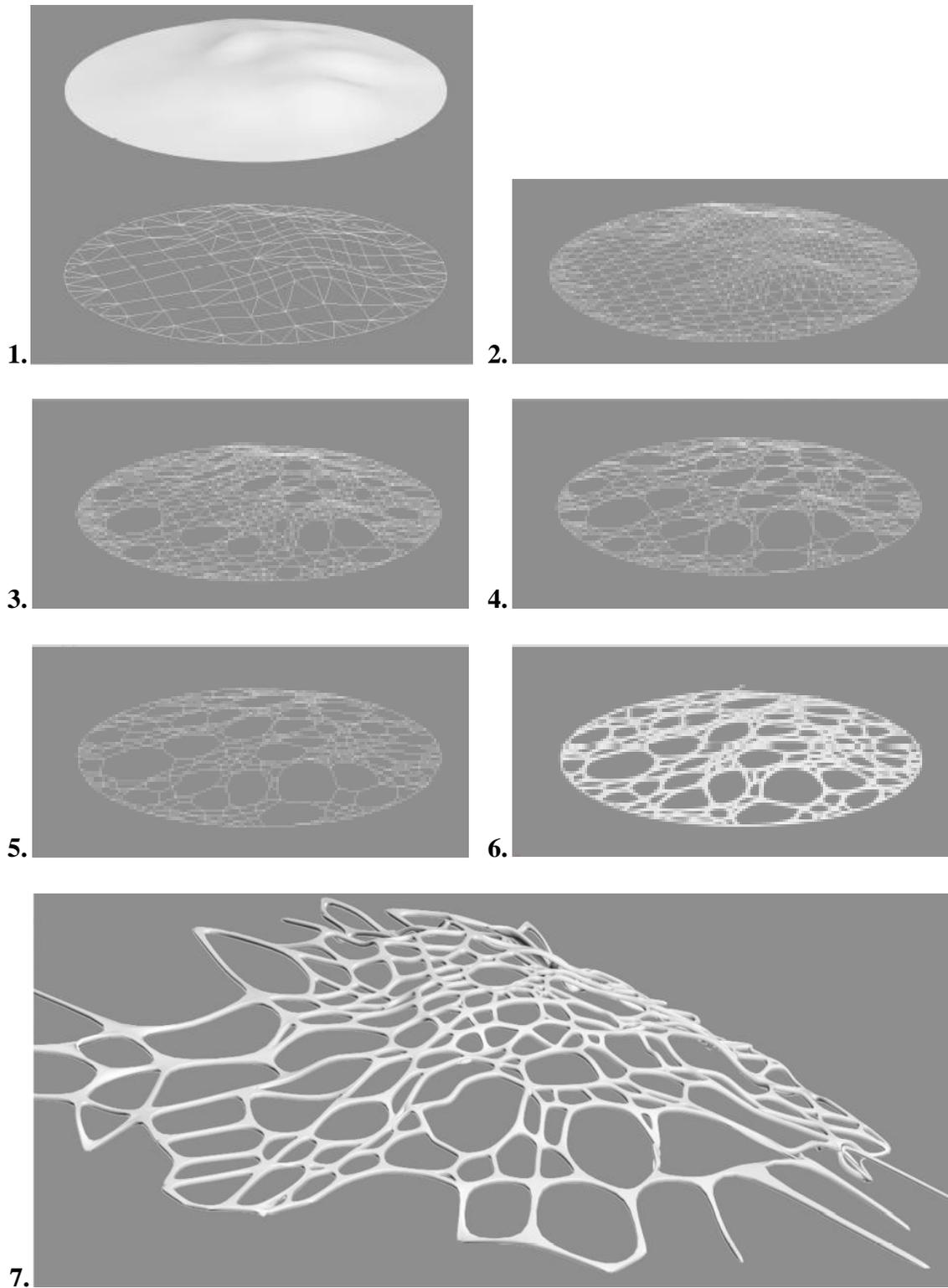


Figure 34: Topological Optimization Process to Create Structural Skin

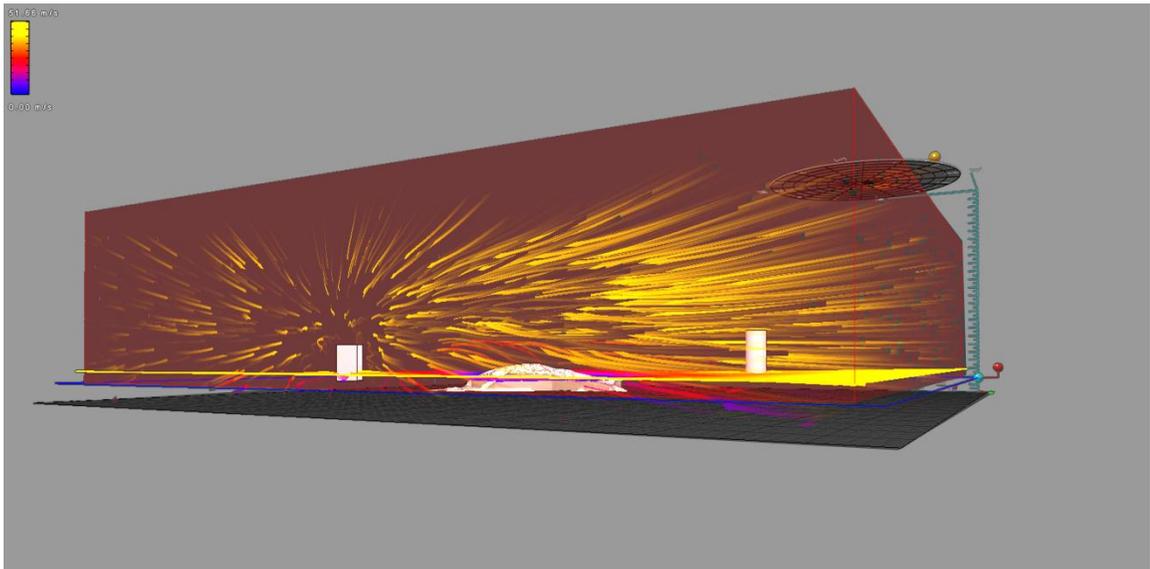
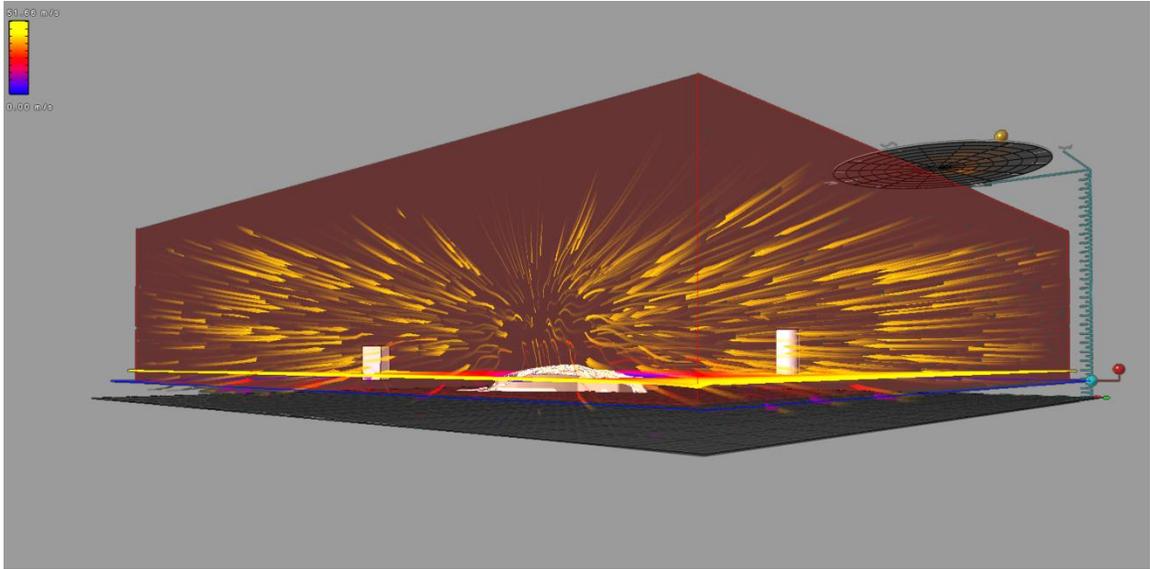


Figure 35: Wind Flow Analysis for Optimized Form

7.4 Site Development and Program Layout

The development of the site and the layout of the programmatic spaces were designed in parallel. During our phone conversation, Anthony Calendrillo had mentioned that many patients ask about how the prosthetics are made and designed. Since this building is a pioneer of its kind and taking into consideration what the patient's desire, it

was intended to have all of the programmatic spaces visible to the users. The idea behind this was to craft a space that would create an interaction between the patients and the researchers and because of the light weight structural skin, it provided an opportunity to achieve this. Aside from the exam rooms and private offices, the overall floor plan was able to remain open.

The production from research up until it is given to an amputee is a process and it is this process that shaped the program layout. The central circulation path takes you on a journey through the entire process of production. It begins with the micro labs and molecular studies then takes you through the larger research labs and then finally past the manufacturing. Next to the manufacturing is the large therapy room. The reason for placing the therapy room next to the manufacturing is to better serve the patients. There is a customization area that ties both spaces together. This space is designed to serve as a station that can make quick adjustments to the prosthetic for user comfort. For example if one of the patients is climbing a stair and feels some discomfort in the prosthetic, the customization area is right there to make adjustments and fix the problem. If the problem is more significant and parts need replaced, there is direct access to the manufacturing area so those parts can be replaced quickly. Placing the therapy room on the south side of the building along the port also provided the opportunity to engage the water. This allowed the therapy program to integrate some aquatic exercises such as swimming and kayaking. These types of activities would also be open to the public as well.

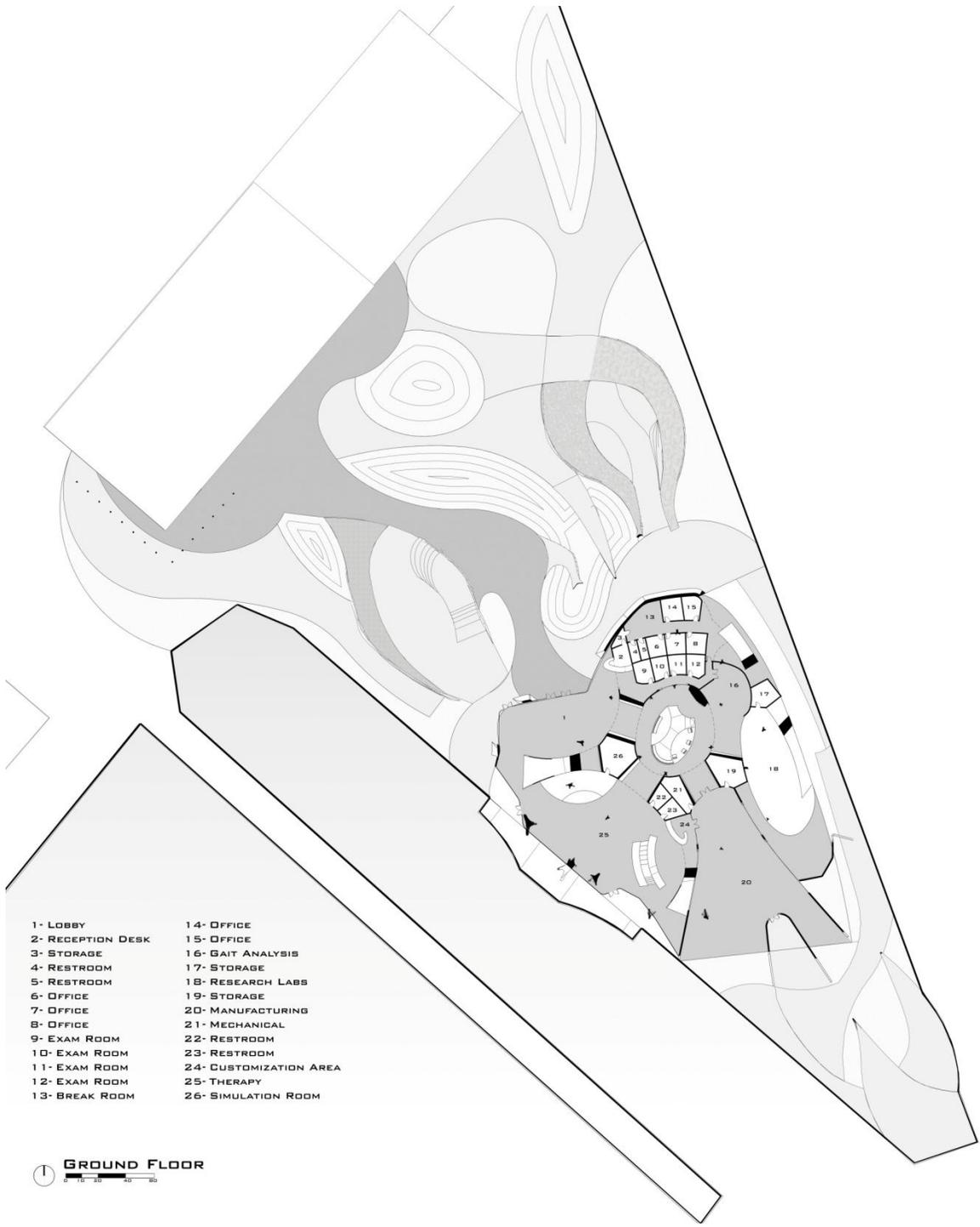


Figure 36: Floor Plan

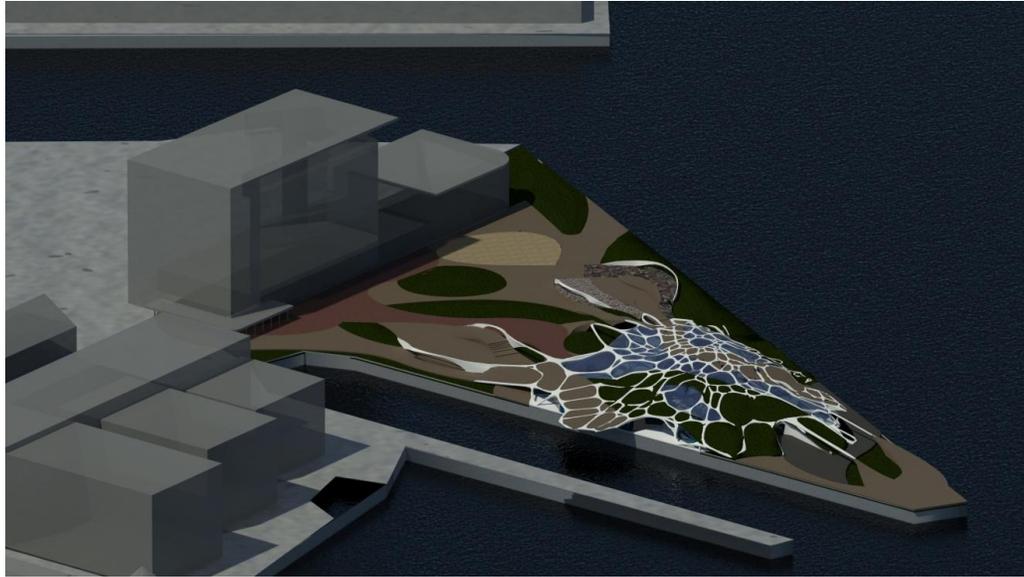


Figure 37: Aerial View of Site

The examination process is also articulated in a strategic way to encourage the patients. Upon leaving the gait analysis area, one is greeted with a large two and a half story rock climbing wall which is placed within the central lounge area. The idea behind this was to motivate the new patients and set an example that shows anything is possible.

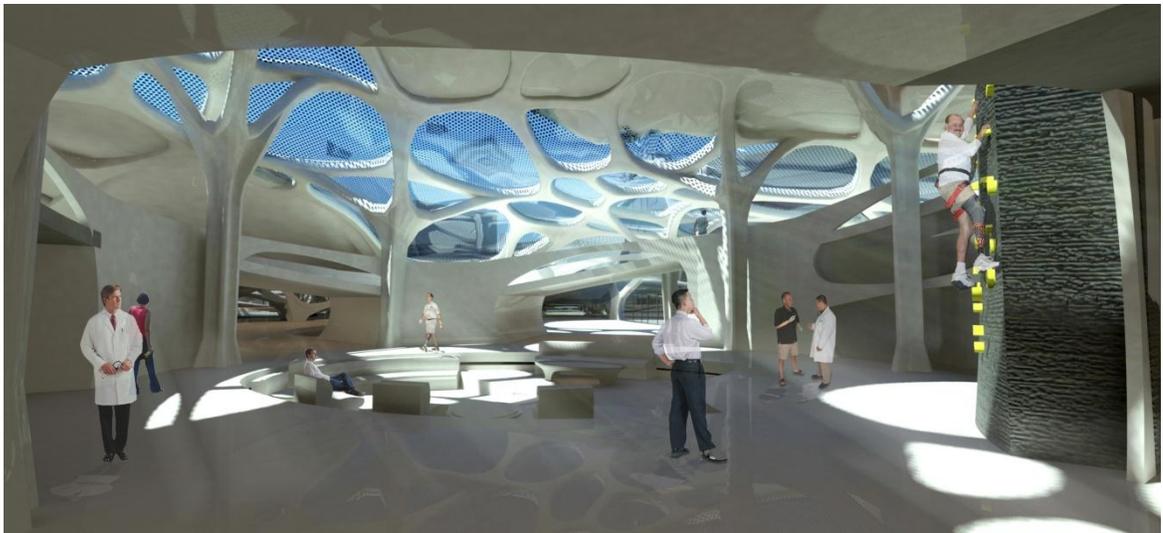


Figure 38: View Walking Out of Gait Analysis Room



Figure 39: View from Circulation Path



Figure 40: Therapy Room

Another way of doing this was to have the amputees interact with the public, which is where the design of the site came into play. The design of the landscape evolved from the notion of muscle and how it connects to the bone. It was intended to make it appear as though the building was growing from the site. This was achieved by using part of the hard-scape as therapeutic obstacles which could be used by both the public and amputees.



Figure 41: Outdoor Therapy Components

Each ramping obstacle would have a different degree of slope as well as a different type of material to increase the difficulty. The smaller sloped ramp, located just outside the therapy area, would be constructed with a smooth concrete, making this the easiest to walk on. The other ramps would have more difficult materials such as stone or thick aggregate. The way that the ramps are arranged, it creates intimate spaces in the middle where people can sit and interact with those around them.

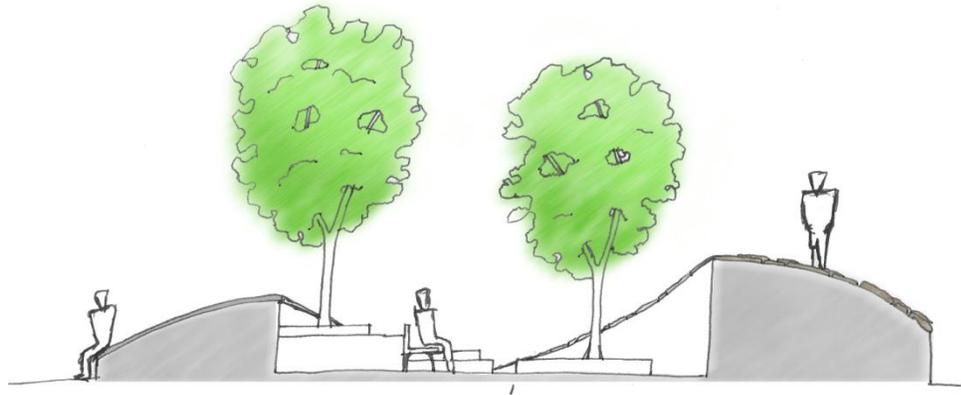


Figure 42: Intimate Spaces Created from Therapy Ramps

The children also have a place designated for them as well. Located just outside of the Spaulding Rehab Hospital is a small playground area where children from both Spaulding and the newly proposed facility can get together.

In an attempt to make a connection to the surrounding context, materials such as brick (Navy Yard) and a reddish brown concrete (Spaulding) were used to form the other pathways. Some of these pathways also continued onto the roof of the building itself. Not only did this allow full access to the site, but it also let the public experience some of the sustainable building technologies incorporated into the design.

7.5 Sustainable Building Technologies

The processes in nature which were mimicked and represented in the design are meant to engage the users. In the 3D exploded view shown on the next page, it shows a breakdown of how the sustainable technologies which were formulated from the research are incorporated into the overall design.

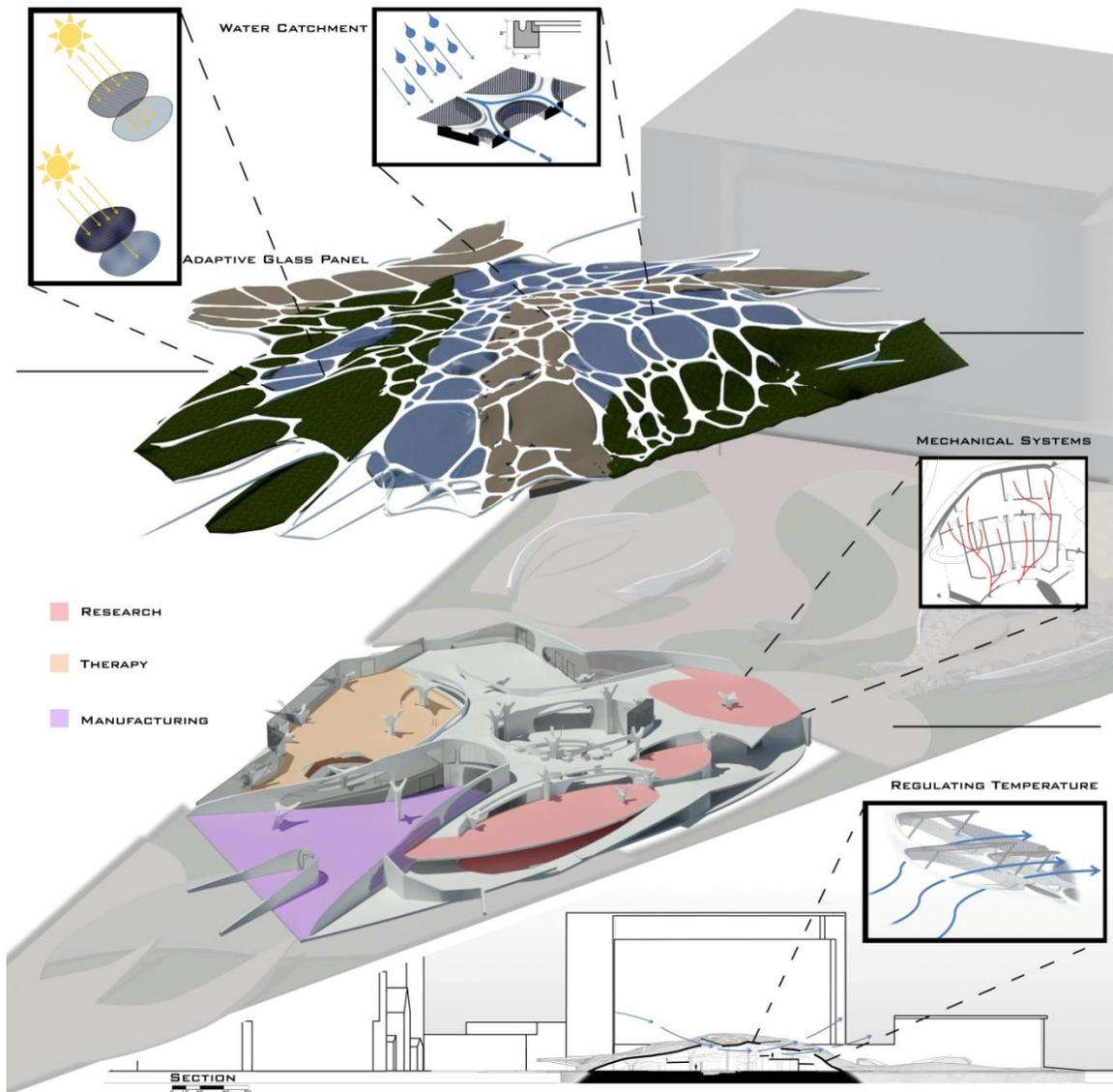


Figure 43: Exploded 3D View with Sustainable Technologies

Some additional technologies that were included are a unique water catchment system and passive ventilation system. The optimized structure provided the opportunity to cast channels into the concrete to create a network for collecting rainwater. This water would then be transferred into cisterns which could then be reused by both buildings.

Another featured is the operable adaptive glass. Not only is the glass able to change its transparency like the chameleon to regulate the building's temperature, but some of the panels can also open as well. Therefore the building can regulate its temperature through passive ventilation as well.

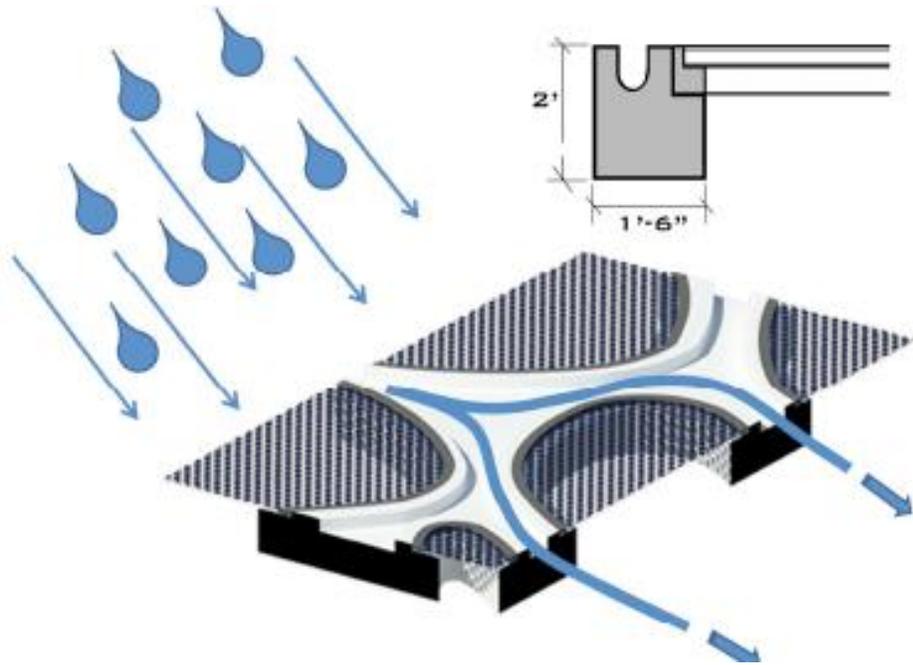


Figure 44: Water Catchment System



Figure 45: Operable Panels for Passive Ventilation

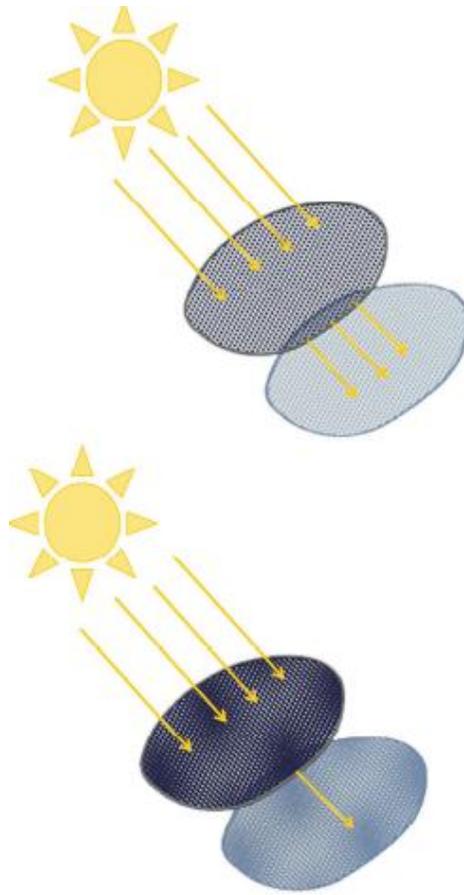


Figure 46: Adaptive Glass Mimicking Namaqua Chameleon

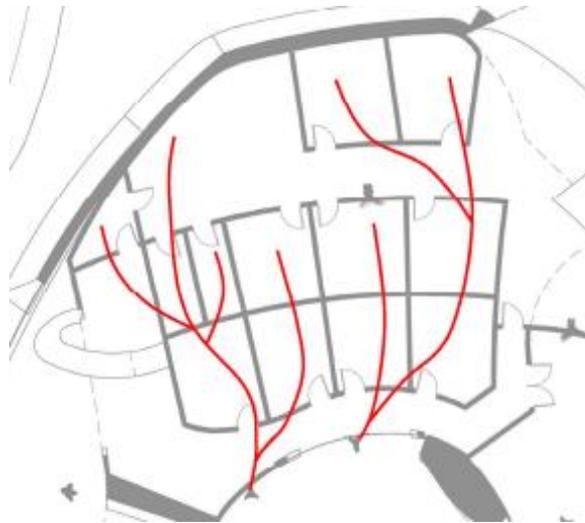


Figure 47: Proposed Mechanical Systems Layout Mimicking Arteries

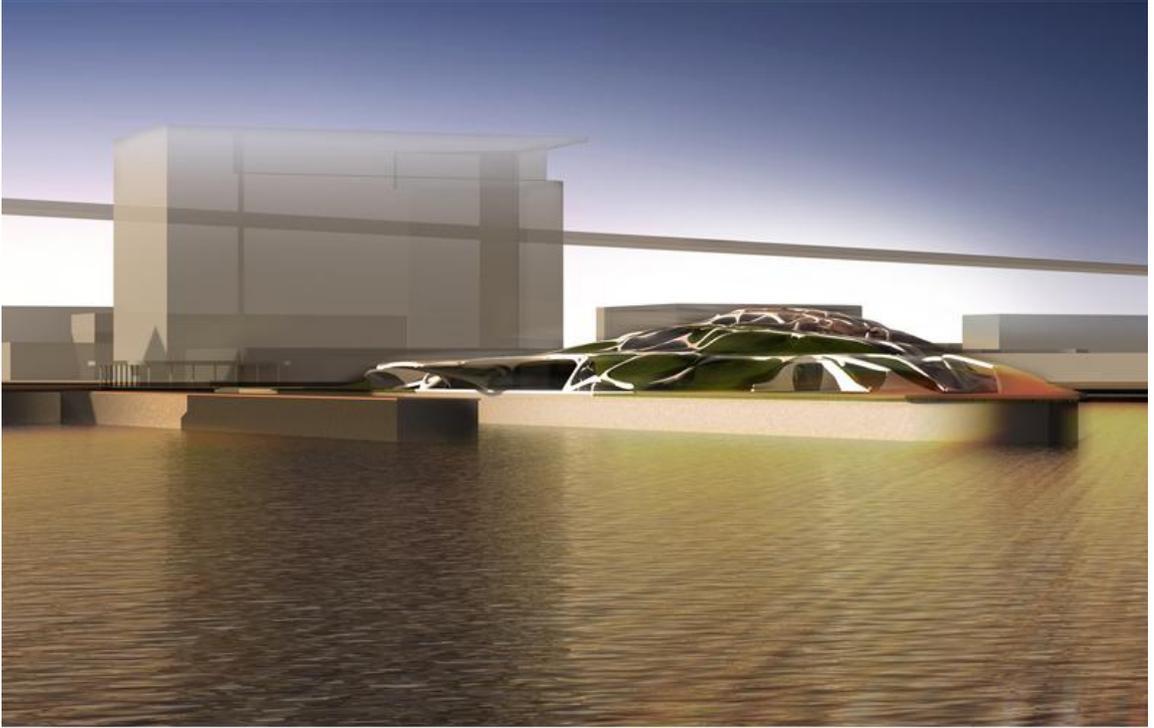


Figure 48: Final Building Composition

CHAPTER 8

CONCLUSION

8.1 Final Thoughts

Have scientists and inventors been looking too far and hard into man-made technological solutions to solve human needs? Is it impractical to derive their solutions from basic ideas and hypothetical assumptions on what works on a technology level but not on a social level? The answer is in front of us and the research has been done. Many biologists have dedicated their lives to finding out how different organisms in nature work and how they impact the environment. It is their research that can be utilized to solve the world's most complex problems.

Biomimicry may just be that solution. It is shocking that this type of analysis and design ethic is not more common in the built environment. Nature is always forced to adapt to new things much like humans are. For example, the climate that is always changing and now with global warming it is even more apparent that nature must find its own ways to adapt. Insects, mammals, reptiles, plants, trees, and other types of vegetation have evolved over centuries in order to survive in such a dynamic environment; and those that have not and were unable to adapt die off but still contribute to the equal balance of life. Those types of adaptations and evolving principals in nature should be studied and implemented into the built environment. Creating a sustainable built environment is not done by integrating just solar panels on every building. Humans need to be more in-tune with nature and look at nature for inspiration. Designs that

mimic nature's beauty and elegance should not just be on a material or form basis; it should be from a thorough understanding of the philosophy and principals that make those solutions from nature work successfully.

Now looking back at the question, can we take the philosophy behind nature's living organisms and use them to aid in the development of mankind? We definitely can and should to find a new way to survive that not only benefits humans, but the natural environment as well. Represented thoroughly in this project, Biomimicry can be used as an integrative architectural design component in order to achieve this, and create complete unity between the building, the users, and the environment.

APPENDIX A

FINAL BOARDS

BIOMIMICRY

USING NATURE AS A MODEL FOR DESIGN

MASTER'S THESIS PROJECT MIKE MAGLIC 4-12-2012

PRECEDENT

NAMIBIAN BEETLE & WATER COLLECTION



HUMPBACK WHALE & WIND TURBINE



CACTI & HEATING/COOLING



RESEARCH

IN FEBRUARY 2008, 730 INDIVIDUALS SUFFERED MAJOR LIMB AMPUTATIONS DURING OPERATION ENDURANCE AND OPERATION ENDURANCE FREEDOM IN AFGHANISTAN. SINCE THEN THE NUMBER HAS MORE THAN DOUBLED.

BASED ON A POPULATION OF 250 MILLION IN THE US - THE NUMBER OF AMPUTATED IS AROUND 1.7 MILLION:

- BELOW THE KNEE = 53%
- ABOVE THE KNEE = 33%
- BELOW ELBOW = 8%
- ABOVE ELBOW = 6%

CAUSES:

- CIRCULATORY DISEASE = 70%
- TRAUMA = 23%
- TUMOR = 4%
- CONGENITAL CONDITIONS = 3%



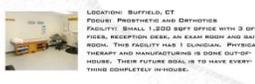
BUILDING TYPE



PROSTHETIC EXAMPLES

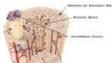


BUILDING PRECEDENTS



HUMAN BODY

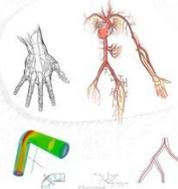
HUMAN BONE & STRUCTURE



MATERIAL IS PLACED ONLY WHERE IT IS NECESSARY TO SUPPORT THE STRESS AND LOADS THAT ARE PLACED ON THE OBJECT



VEINS / ARTERIES & FLUID FLOW



DECREASED EFFICIENCY INCREASED EFFICIENCY

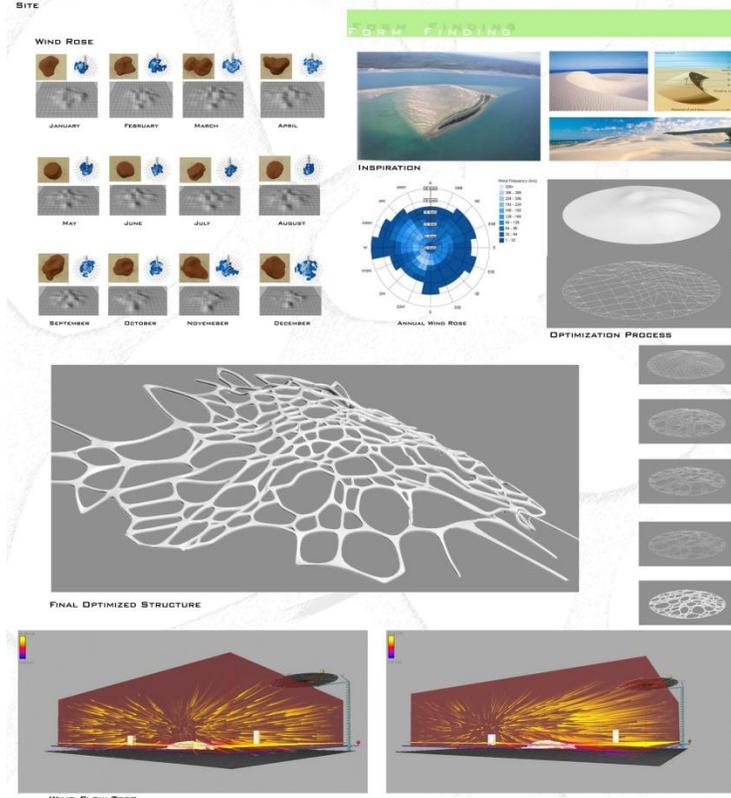
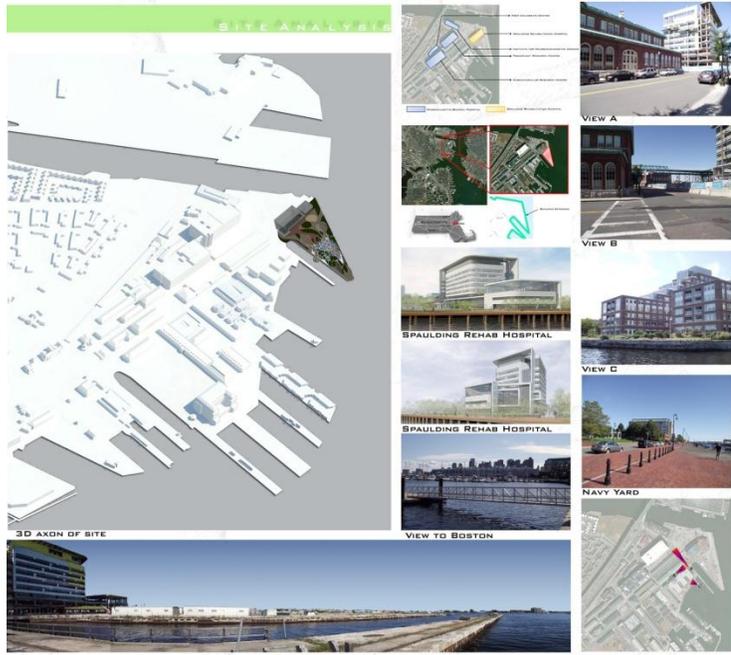
NAMAGUA CHAMELEON

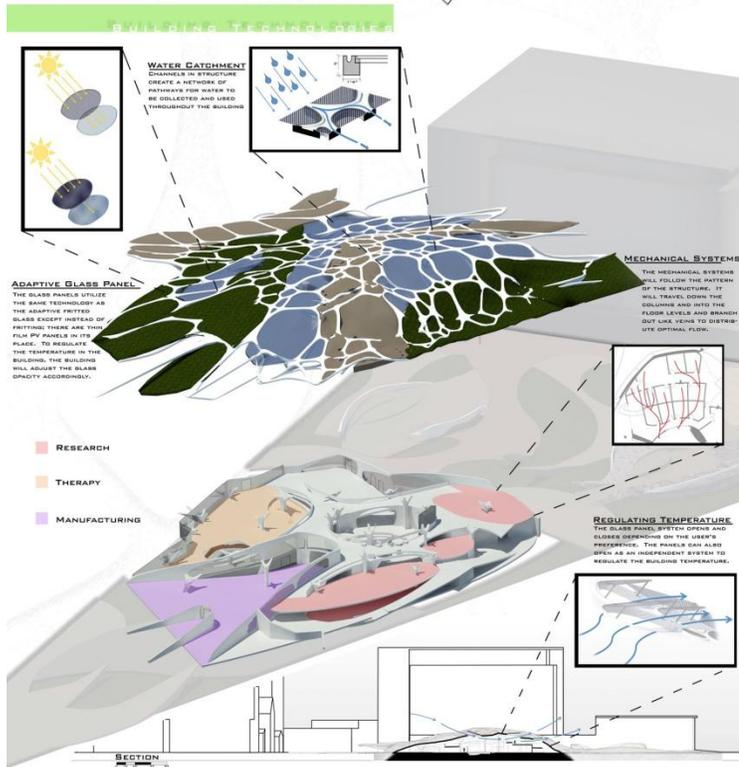
SKIN & REGULATING TEMPERATURE



ADAPTIVE GLASS SYSTEM









CONNECTION TO SPAULDING REHAB HOSPITAL



CENTRAL LOUNGE AREA



THERAPY ROOM



EXTERIOR EVENING VIEW

Notes

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