ABSTRACT

Title of Document:	ECOLOGICAL ARCHITECTURE: A DIALECTICAL VISION
	Rachel Vaccaro Mihaly, M.Arch, 2014
Directed By:	Professor, Garth Rockcastle, Architecture

How do architects improve building design to increase harmony and reduce disassociation from our natural world and adapt beneficial natural systems that will result in better alignment with the environment? In order to improve experiential outcomes for re-association with the surrounding environment, this thesis is focused on two key areas: optimizing design to specific climatic factors through better integration into the natural ecosystem for improved building performance, and by using architecture as a catalyst to improve our understanding of our environment and the surrounding ecosystem. To provide a more rigorous testing of the proposed design process detailed in this thesis, I selected two extreme climates for placing environmental living and learning center on each site. The two sites with extreme climates provide useful comparisons that highlight key lessons learned by applying a consistent process to the design. My primary focus was to improve building performance by realigning the relationship between humans and nature for improved

environmental outcomes. By selecting two environmentally divergent sites, I developed a design process that can be applied for improved ecological design.

ECOLOGICAL ARCHITECTURE : A DIALECTICAL VISION

By

Rachel Vaccaro Mihaly

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
[Masters of Architecture]
[2014]

Advisory Committee:
Professor Garth Rockcastle, Chair
Assistant Professor Hooman Koliji
Professor Steven Hurtt

Preface

"Human industry has been in full swing for little over a century, yet it has brought about a decline in almost every ecosystem on the planet. Nature doesn't have a design problem. People do."(228)[1]

"It is clear that design and technology since the Industrial Revolution have been about disassembling organic nature. Now we need to heal, to make whole. The work before us is to recreate and regenerate natural systems through our designs. Designs which are integrally connected to nature can profoundly influence human consciousness and well-being" (909).[2]

The importance of this subject is elevated by the architecture profession's ethical imperative to design net zero buildings. The looming climate crisis and the promising catastrophic consequences requires that we change the way we think about architecture, and our relationship to the environment. This thesis focuses on designing two sustainable buildings in significantly different environments. By incorporating diverse forces at work in nature I hope to illustrate how designs can respond better to the environment. I will attempt to design to the goal and standard of net zero buildings, which in turn will lead to an enhanced relationship between humans and the surrounding environment. The performance of the building will be

[1] ***Cradle to Cradle: Remaking the Way We Make Things*** ***by William McDonough, Michael Braungart,228)***

[2] *(Culture, Architecture and Nature: An Ecological Design Retrospective by Sim Van der Ryn,909*

measured according to the Living Building Challenge. The purpose of selecting two sites with contrasting climate and geography is to highlight and compare various building techniques needed for effective design given different environments.

Foreword

Architecture can be a direct expression of our interaction with nature. My goal is to realign our relationship with nature through architecture by creating ecologically harmonious architecture.

Dedication

I would like to dedicate this thesis to my family for all their support throughout the years.

Acknowledgements

I would like to thank my committee: Professors Garth Rockcastle, Hooman Koliji, and Steven Hurtt for their unrelenting support, great insight and guidance throughout the year.

Table of Contents

List of Figures

Chapter 1: Site

The site choice was selected for two different climates to achieve a significant performance comparison and contrast. The desert climate is hot and dry and the temperate rainforest (not all, but specifically this site) climate is cold and wet. Beyond the climate differences, I was searching for towns populated with approximately 30,000 people surrounded by natural features. Larger communities tend to be more isolated from natural features in a formal sense (pure grid). The site requirement included the need for a cultural context, so that the buildings are not just connecting to the landscape but also to the existing culture. In particular I am looking at small towns because "Rural architecture is often characterized by a high degree of exposure-both physically and metaphorically. The architecture is more visible than in other situations and often from all sides… As an object placed in and impacting on the landscape, it also invites immediate comparison between the manmade and the natural."[3](63). My search included towns located adjacent to a national park, with a population that already has a heightened interest in the environment.

[3] Kemsley, Roderick, and Christopher Platt. *Dwelling with Architecture*. London: Routledge, 2012. Print.

My two sites are Yucca Valley, California and Squamish, British Columbia.

Figure 1: Sites, [Google Earth, Altered by Rachel Mihaly]

Both sites are built in a valley, which is why both sites experience high winds but Squamish has more articulation in the topography.

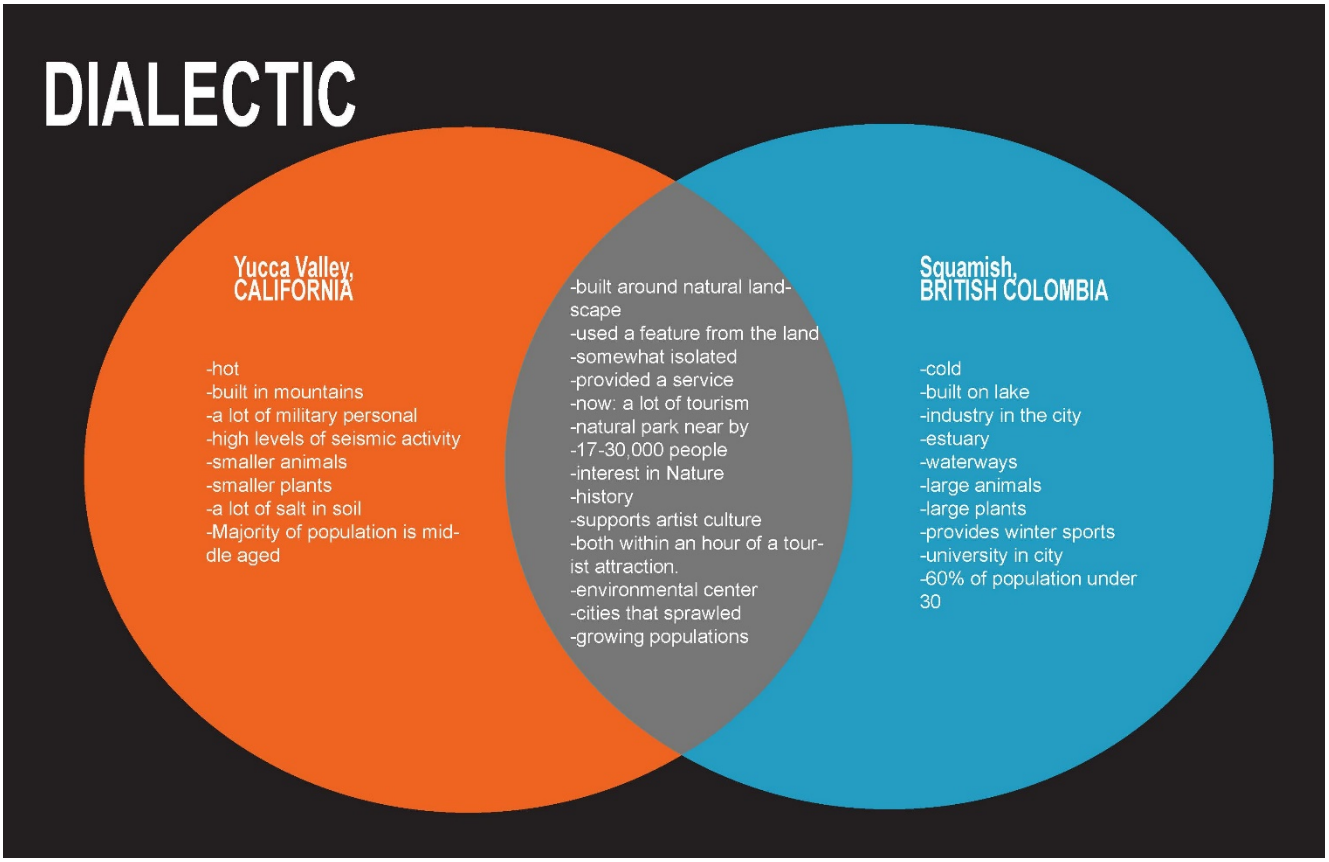


Figure 2: Dialectic [image created by Rachel Mihaly]

The important point is to understanding the similarities and differences about these two sites. For example, both communities are built around unique natural features, both experience significant tourism, and are on the way to major tourist destinations. In addition, both communities show an interest in sustainability, support an artist community and have growing populations. The differences in the sites extend beyond climate. There are differences in flora and fauna, adaptation to specific climates and significant demographic and cultural differences.

Yucca Valley was established around the 1880s, and today is a true desert small town. The town began with prospecting, but today the town has a growing and diverse population, including military families (due to the close military base). The town itself is located within a few hours of Los Angeles, and is right next to Joshua Tree National Park. Some people are attracted to Yucca Valley because of the desert environment. The town itself already has an existing initiative for sustainability, and the town is a huge supporter of the arts.

Figure 3: Yucca Valley California [Google Earth, altered by Rachel Mihaly]

Demographic statistics indicate a middle aged median population. However, the town has many families with children; consequently, the majority of housing is single family units. The population is projected to increase by 25% increase by 2030. Most of the buildings in this town are single family detached housing. The town is split into three parts: old town, midtown, and the east side. The old town is pedestrian friendly and dense. The midtown is the “heart” of the town, and is the civic and cultural center. The east side is the center of new commercial development. The plan for the future development of Yucca Valley is centered on sustainability initiatives. It is focused on the east side by mixing development ethically with the surrounding desert, with responsible design. The following environmental factors must be considered in this community: erosion, landslides, flooding, wildfires, earthquakes, and above 10 mph winds.

The site I chose is located off the main road, at the entrance of town. It has trails going through the site, and due to the larger nature of the site, it feels more connected to nature.

Figure 4: Squamish Site [Google Earth, Altered by Rachel Mihaly]

Squamish, British Columbia is my second site choice. Squamish is beautifully located on the Howard Sound, between protected forests and mountains. This site also began in the 1800s. and it still has a small indigenous population. Initially the town grew around the forestry industry. The town's population increased when a road was established from Vancouver to Squamish. Squamish is located within one hour drive of Vancouver and Whistler. It is increasingly becoming a tourist destination. The town itself has a very young population due to its proximity to Vancouver. The population supports the environment and the arts.

The local vernacular of Squamish is very diverse, ranging from modern buildings to small wooden sheds. Both Squamish and Yucca Valley celebrate their eclectic architectural styles. Like Yucca Valley, Squamish has an increasing population, due to its proximity to major cities, and its affordability. Unlike Yucca Valley, the population is younger, and has a more diverse population in terms of languages, and ethnicity. Although Squamish has a university much of the population does not have a university level education.

Figure 5: Squamish [Google Earth, Altered by Rachel Mihaly]

Squamish is strategically located on the Howard Sound, and is nestled between very steep mountains. It receives a lot of rain due to its location, and also the waterways the run into the Howard Sound.

The site I selected is within a five minute walk of the downtown. It is part of an estuary. There is a connection to the water. There are two ecosystems in the same site: the estuary and the highland. The site also has a popular trail running through the site.

Figure 6: The Sites [Google Earth, altered by Rachel Mihaly]

The image above shows the two locations of the sites.

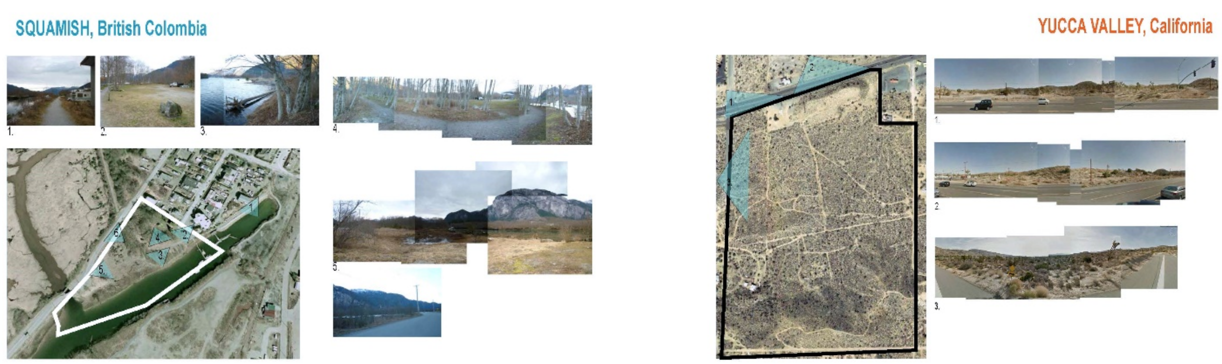


Figure 7: Views of the Sites [Google Earth, altered by Rachel Mihaly]

Figure 8: The Sites [Google Earth, altered by Rachel Mihaly]
The image above shows a size comparison of the two sites.

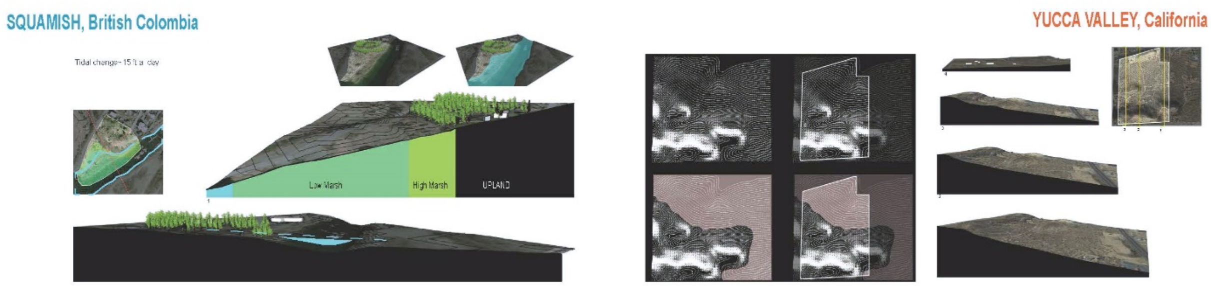


Figure 9: Topography of the Sites [images created by Rachel Mihaly]

The image above depicts the topography of the two sites. The Squamish site shows the ecosystem change, and the daily approximately 12 foot tidal change. The most important things about these two sites are as follows. In Squamish, one should always remember the Howe Sound, and the surrounding mountains. In Yucca Valley one should always keep in mind the sprawling landscape and the connection to the sky.

Chapter 2: Program

Institution

"when you plan a school, do you plan, do you say that you will have seven seminar rooms… or is it something that somehow has the quality of being a place, in which you are inspired?"(24)[4]

Because this thesis is to show a comparison of how to deal with different climates, the two buildings in these two different climates will have the same program. The program needs to be able to serve the two different communities, work in the different climates, cultures, and landscapes. The program is going to be education oriented, flexible, connected to the site and to the culture, and have indoor and outdoor program.

The program is an environmental living learning center. The main goal is to foster ecological awareness through a community. The two centers are to be part of national institution, that has the primary goal of fostering ecological awareness, with locations throughout the United States and abroad. They are designed to become a repository of information and knowledge of the immediately surrounding ecosystems. The building would act as a time capsule, and would constantly be recording data on the surrounding area. People would visit these centers to gain a heightened

[4] Louis Kahn, Conversations with Students,24

understanding of the surrounding ecosystem and to learn about ecological design. People would be able to visit for day trips or live at this center.

There would be two types of learning that would take place: active learning and passive learning. Active learning being that there would be technological and visual cues that would trigger participant's curiosity. The living room, kitchen, classroom, and laboratory spaces would be part of the active learning venue. Passive learning being the standard learning that occurs by just being in a given location. It would also be heightened through phonological changes, and purposefully isolated views. The bedrooms are designed as passive learning venues.

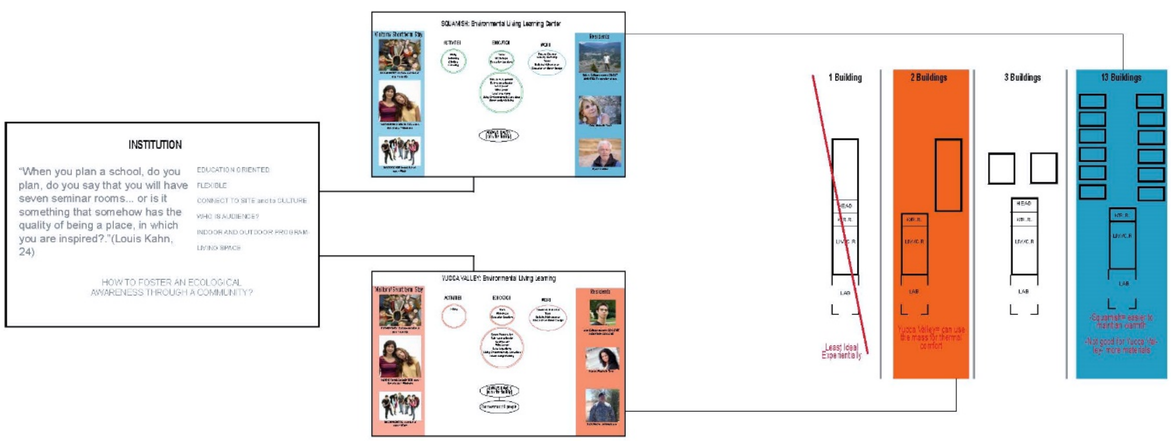


Figure 10: Program [image created by Rachel Mihaly]

In both sites the bedrooms will be separated from the classroom, living room, kitchen, laboratory, and restrooms. This is to ensure that the visitors interact with nature. In Yucca Valley the program is divided into 2 buildings, and in Squamish the bedrooms are each their own individual buildings, because smaller spaces are easier to heat.

Chapter 3: Humans and Nature

Section 1 Vernacular Architecture

One of the main goals of this thesis is to use architecture as a way to re-establish our relationship with nature. Our ancestors lived, in a large part, according to the laws of nature, in sync with seasonal changes. Their survival and well-being depended on natural events and they often worshiped the gods that "controlled" the weather, volcanos, earthquakes and predatory animals. To survive our ancestors learned how to adopt from nature and how to adapt to nature. As modern humans, we have lost our immediate connection with the natural world. Now we live in buildings that often disassociate us from nature to the detriment of our well-being and the environment. To move forward, we must remember the past by studying the old traditional building methods and incorporating beneficial features into contemporary designs. For this thesis I have chosen residential dwellings, because it is the most common building type and a strong reflection and manifestation of lifestyles and cultures.

Vernacular Architecture is broadly defined as:

> "an area of architectural theory that studies the structures made by empirical builders without the intervention of professional architects…synonymous for several different practices and theoretical stands on those practices. These include primitive or aboriginal architecture; indigenous architecture; ancestral

> or traditional architecture; folk, popular, or rural architecture; ethnic architecture or ethno-architecture, informal architecture…" [5].

Vernacular Architecture is categorized by classification of dwelling typologies, not necessarily by timeline or historical placement. Consequently, there are numerous examples of Vernacular Architecture in our contemporary world. For this thesis I have focused on the following type of dwellings: ephemeral or transient, episodical or irregular temporary, periodic or regular temporary, seasonal, semipermanent, and permanent housing types. These housing types show an evolution in design plans and social organization, as well as changes in environmental impact, sense of ownership or "property rights", and changes in the relationship between build time (how long it takes to build the dwelling) and stay time (occupancy time).

Societies

Ephemeral or Transient Dwellings belongs to nomadic families, of a band type society. These families survive by hunting and gathering.

Episodical or Irregular Temporary Dwellings: "the dwellings of nomadic band-type societies whose existence is based on either advanced hunting or advanced food-gathering practices; the former leads to pastoralism and the latter to primitive cultivation."(xv).[6]

Periodic or Regular Temporary Dwellings: "the dwellings of nomadic tribal societies with a pastoral existence"(xv).[7]

---

[5] www.vernaculararchitecture.com

[6] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

[7] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

Seasonal Dwellings: "the dwelling of tribal societies with a seminomadic way of life based on both pastoral and marginal cultivationional pursuits."(xv).

Semi permanent Dwellings: "the dwellings inhabited by members of sedentary folk societies or hoe peasants practicing subsistence cultivation."(xv.)[8]

Permanent Dwellings: "the dwellings of the sedentary agricultural societies that have a political social organization as a nation and a surplus agricultural economy"(xv).[9]

Environmental Impact

Ephemeral people for the most part lived in ecological balance, affecting the surrounding area no more than a large animal would.

Seasonal people with some dependency on land for substance, and the cultivation of animals and crops have marginal impact on the environment.

Semi-permanent people had considerable impact on the environment given dwelling development and significant exploitation of nature.

Permanent people with heavy reliance on agriculture have a large environmental impact given permanent clearing of the indigenous vegetation of large expanses of land and replacement with cultivated fields. This could be mitigated through more responsible treatment of the soil, and rotation of crops.

As the buildings become more permanent, the impact of the societies on the surrounding environment increases exponentially.

---

[8] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

[9] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

“Ownership”

Ownership and property rights change through changes in society and social organization. As ownership increases the impact of the society on the environment increases.

Ephemeral or transient: “at an elemental level man feels a sense of ownership over the wild plants and animals on his territory but his degree of control over them is small” (xv).[10]

Seasonal: the dependency on land and domestication of plants and animals creates a distinct notion of property that is not present before. This is still communal property and not individual ownership of the land.

Semi-permanent: “agricultural people who had direct control over domesticated plants and animals developed an explicit notion of property and its ownership”(xv).[11] Compared to hunter gather societies their land was very small.

Permanent: The notion of property evolves, and land becomes property that is privately owned.

This idea of ownership transforms as dwellings become more permanent which in turn creates greater environmental impact. At this stage of societal development, instead of working with nature, we now exploiting nature to provide us with more food, extraction of raw materials, more land, etc…

Build Time/ Stay Time

---

[10] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

[11] Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

The amount of time required to build a dwelling as well as the extent of occupancy varies with changes in society.

Ephemeral or transient: 1-2 hours to build, stayed for a few days

Episodical or Irregular Temporary: 1-2 hours to build, stayed for a few weeks

Periodic or Regular Temporary: Portable tent

Seasonal: stayed for a few months at a time

Semi-permanent: Stayed for a few years to 15 years (build time depended on length of stay)

Permanent: stayed for a lifetime to a few generations

The idea of permanence may be a factor in the building I design. The building itself may be deployable, and expand or contract based off seasonal, or diurnal changes. This could help with ventilation, heating, or cooling. Size of a building is a big factor in sustainability. The smaller the building, the less material and energy it uses. If the building can expand or contract to the amount of people using the space and be responsive to the climate, the building itself can be more sustainable.

Climate

I have selected two climates for my thesis, temperate rainforest and desert.

Desert Climate:

Low heat storage capacity = offering maximum shade and good ventilation.

Advantageous in winter when a quick heat response to the fire is

required and in summer when shade and ventilation are easily afforded during the long warm days.

-Have parts of the structure be able to open, to allow ventilation.

Temperate Rainforest:

Minimum exposed surface to the elements relative to volume and maximum stability of the structure

Low heat capacity, interior responds quickly to the warmth generated by the interior hearth.

-Thick walls to retain heat, use land around the dwelling to add to structure.

Ex/ snow around an igloo can increase the thermal mass.

Evolution of Plan

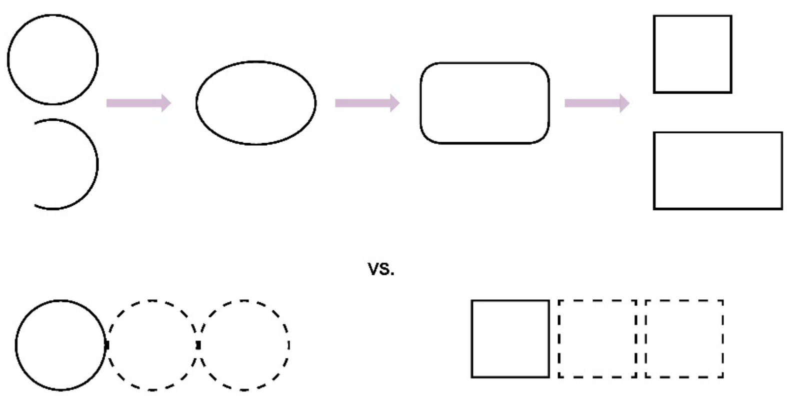


Figure 11: Plan Evolution [Image created by Rachel Mihaly]

As buildings techniques evolved, dwelling shapes evolved from the very simple circle or horse shoe to oval, rounded rectangle and eventually to square or rectangle shapes. This change was due to the need to make larger and more permanent structures. It is also easier to build additions to a square plan than it is to a circular plan.

So What?

By looking back upon traditional architecture, there are some helpful sustainable lessons to be learned. We can certainly identify dwellings that have been effectively integrated into the surrounding landscape and climate. It also provides a great perspective on how our relationship with nature has evolved, and how that relates to our sense of "ownership" and commitment to a place in time. It certainly raises some interesting questions about what changes we should make to our social organization to improve outcomes. Are there opportunities to change our customary idea of nature as property and can we maintain today's society, while still respecting the surrounding, and becoming more in tune with nature?

Section 2 Green Architecture

History

We have a long history of dealing with architecture and its relationship to nature. Although the idea of designing using proportions from nature originated in ancient Greece, in this thesis I am most interested to explore developments in the 20th century. I will draw from the experience of others to identify successful strategies.

Two modern innovators of green architecture were Frank Lloyd Wright and Antonio Gaudi. Both of these men were ahead of their time in this field. Antonio Gaudi studied the physiology of leaves, flower stems, and tree trunks as models for structural systems. Frank Lloyd Wright was focused on earth centric living, soil erosion, rock formations, and climatic influences. At the same time Modernism was taking form with the works of Le Corbusier, Mies van der Rohe, Theo van Doesburg and Gerrit Rietveld, who had a very different take on architecture. They focused on purity of shapes and the relationship between industrial production and its expression in form. “By insisting on a set of design standards divorced from ecological responsibility, architecture has forfeited its richest source of ideas, caused incalculable environmental damage, and failed to communicate with the very constituency it is obligated to serve.”(19).[12]

However, starting in the 1960s there has been a change away from purely Modernist concepts. People began to look towards nature in design again. By the 1990s, sustainable architecture and the green movement were well-established and became a common concept. L.E.E.D. and The Living Building Challenge are just two of the design standards accepted today by mainstream architecture.

Even though sustainable architecture has been accepted, there is still some confusion about what truly is an ecological design. The tendency is to address the architecture and nature issues in facets. I believe all facets need to be combined to truly design effective ecological architecture.

Since Ecology is “The science of the relationships between organisms and their environments”[13], if our buildings can respond and react to changing climatic conditions, if they can respond to human needs, if they can reflect how we feel, if

[12] Wines, James, and Philip Jodidio. *Green Architecture*. Köln: Taschen, 2000. Print.

[13] www.dictionary.com

they are connected to the landscape, then we will truly be making ecological architecture, that goes beyond the prescriptions of a sustainable measurement. Specifically I looked at how architecture could be integrated into the landscape, how technology could be translated into architecture and art, architecture that appeared to borrow from nature, art and ecology, green design research (1960’s till mid 1990’s), and architecture in its cultural context.

Architecture can not be detached from the site it is situated in. This is not only its natural site, but also the culture of the people on the site. One must understand the needs of the people using the architecture, and the traditions, and culture of the people.

So What?

Many professionals are focused on different facets of “green” architecture, but truly ecological architecture needs to incorporate all of these facets. There are new theories and facets that have emerged since the 1990s including bio mimicry, biophilia, geo morphism, and others which will be discussed later. The following are some examples of leading exponents in this area.

“Environmental thinking means that walls, facades, interior spaces, and the general materiality of a building, outside of their obvious contributions to architectural function- and be seen as much more than physical components in the manipulation of form and space. They become vehicles for the absorption and communication of contextual information. ... is as much a social and psychological condition as it is part of an ecological initiative"(215).[14]

"walls and floor planes in a building should be seen as fluid and contextually responsive elements, converting the measure of aesthetic quality in architecture from formal design to how well a structure reflects and engages various aspects of landscape, regional identity, topography , and cultural references." [15] (224)

"developing an visionary "eco-digital" iconography in architecture. By incorporating ideas from both informational and ecological sources, architects provide an opportunity to develop an imagery that echoes the mutable and evolutionary changes found in nature and the fluid and interactive flow of data through electronic communications" [16] (236)

Human vs. Natural Building Techniques

The way we modern humans build is very different than how nature builds or evolves. Since the advent of the industrial revolution we have been able to mass produce products based on standard sizes. Although this has created material "progress", by driving costs down and improving efficiencies, this process is not in line with how the rest of the natural world creates or evolves over time. The natural

[14] Wines, James, and Philip Jodidio. *Green Architecture*. Köln: Taschen, 2000. Print.

[15] Wines, James, and Philip Jodidio. *Green Architecture*. Köln: Taschen, 2000. Print.

[16] Wines, James, and Philip Jodidio. *Green Architecture*. Köln: Taschen, 2000. Print.

world mass customizes in response to stresses from the environment. However, with the more recent advent of new technologies, we now have the ability to cost-effectively mass customize building materials; this is an exciting opening in architectural design customization. Mass customization can easily mimic how Nature designs. We should be able to harness mass customization and create processes that are responsive to the surrounding environment; at that juncture, we will begin to build in better harmony with nature. Nature also creates systems that perform multiple functions. We as humans create systems that perform one function. Nature creates a process for the generation of form it is a process that can evolve and serve on multiple levels. We do not create a process, we design an object. Nature builds through the repetition of fibres/building blocks. Nature's organizational process is done from least complex to the most complex. For example: From the molecular level, to the cellular level, to the tissue level, to the organ level, to the system level, to the body as a whole. Where as we as humans, create one object, one form, that has one purpose, it is not interconnected, all the pieces are separate entities.

Figure 12: Human Design Vs. Natural Design [image create by Rachel Mihaly]

Animal Architecture

In addition to the study of traditional building methods in our cultures, we should also study carefully building methods employed by animals. Animal shelters exist in a very holistic way within their surroundings, elements of which may translate well into architecture. The techniques are simple, and very similar to traditional building methods of humans, and traditional pattern making of humans. There is a very low impact on the environment mainly due to the use of local materials.

Living Building Challenge

The momentum to create sustainable architecture is widely based in the developed world. The Living Building Challenge is a building standard based on proven performance instead of anticipated performance. The certification requires a net-zero energy and net-zero water benchmark, as well as avoiding the "red list" of materials. The certification is based on 20 imperatives that must be met and 7 performance areas. This thesis is going to try to adhere to the living building challenge.

Organization

Site, Water, Energy, Health, Materials, Equity, Beauty

On top of the existing petals, I have added two more petals: the first one being an adaptability petal and the second petal being a connection to nature petal.

Figure 33: Living Building Challenge Petals [image created by Rachel Mihaly]

The image above shows the new petals. What is in grey is outside the scope of this thesis, what is in purple is what I have added to the Living Building Challenge. I specifically looking at Earthships and the Omega Center for Sustainable Living.

Chapter 4: Theories

Biomimicry

History

Biomimicry is a new field of science. One of the earliest examples of biomimicry is the study of birds in flight to help in the development of the airplane. More recently, in 1960 Jack Steele created the term bionics "a science concerned with the application of data about the functioning of biological systems to the solution of engineering problems"[17]. Eventually the meaning changed and took on the implication of super human strength. The term biomimicry first appeared in 1982. It was made popular by Janine Benyus, a scientist, in her book *Biomimicry: Innovation Inspired by Nature*. She suggests looking towards nature as "Model, Measure, and Mentor", and emphasizes its application towards sustainability. This field of science is very promising, it is pushing us to look towards the processes and traits of animals

[17] www.dictionary.com

and nature to design. The weakness of this field, is that most of the time designers are literally mimicking the form of nature instead of trying to adapt a process to a human design problem.

Biomorphism

History

The biophilia hypothesis was created by Edward O. Wilson in his 1984 book *Biophilia.* He defines biophilia as "the urge to affiliate with other forms of life"(416).[18] This hypothesis suggests that we are happier when connected to nature, and subconsciously we have a love for living things (one's that do not harm us).

So What?

Often our buildings are disassociated from our environment. Studies have shown that connection with our environment and natural sunlight makes us happier and more productive. So improved connectivity with nature in our architectural design should enhance our daily experience. This is vital to transforming humans' relationship with how we treat nature.

Systems Thinking

"Is the process of understanding how things, regarded as systems, influence one another within a whole. In nature, systems thinking examples include ecosystems in which various elements such as air, water, movement, plants, and animals work together to survive or perish. In organizations, systems consist of people, structures,

[18] Kellert & Wilson 1995, p. 416

and processes that work together to make an organization "healthy" or "unhealthy"." [19]

System

-composed of parts

-all the parts are related

-a system can be inside of another system (like the human body)

-complex whole

So What?

Nature works as a system by building from least complex to most complex elements. Therefore, applying systems thinking is a key element for designing ecological architecture. This is very important because everything is connected. A buildings effect on the environment doesn't stop when the property line stops.

<u>Evolution</u>

History

Charles Darwin was the first person to make a scientific argument for the theory of evolution through natural selection. Evolution is defined as "a theory that the differences between modern plants and animals are because of changes that happened by a natural process over a very long time."[20]

---

[19] **http://www.ask.com/wiki/Systems_thinking**

[20] www.dictionary.com

So What?

If one studies the change in traits in a given area, one can understand what physiological traits work, and what traits don't. These are the traits that can inform the architecture in the area.

"The relationship between biology and building is now in need of clarification due to real and practical exigencies. The problem of environment has never before been such a threat to existence. In effect it is a biological problem … Not only has biology become indispensable for building but building for biology. "[21]

Morphology/Morphogenesis

Morphology is defined as "the study of the form and structure of animals and plants." In architecture it is "research which is based on theories of two dimensional and three dimensional symmetries and then uses these geometries for planning buildings and structures."

Morphogenesis is defined as "Formation of the structure of an organism or part."

"It is the growth under stress that produces this material organization, as the forces that the living form experiences while it is growing encourage the selective deposition of new material where it is needed and in the direction in which it is needed."[22]

Design Thinking

---

[21] Emergent Technologies and Design: Towards a Biological Paradigm for Architecture by Michael Hensel, Achim Menges, Michael Weinstock Otto 1971: 7)

[22] Emergent Technologies and Design: Towards a Biological Paradigm for Architecture by Michael Hensel, Achim Menges, Michael Weinstock, 212

Design thinking is a methodology for practical, creative resolution of problems or issues that looks for an improved future result. In this regard it is a form of solution-based or solution-focused thinking that starts with the goal or what is meant to be achieved instead of starting with a certain problem. Then, by focusing on the present and the future, the parameters of the problem and the resolutions are explored, simultaneously. This type of thinking most often happens in the built environment, also referred to as the artificial environment (as in artifacts). [23](221-27).

This differs from the scientific method, which starts with defining all the parameters of the problem in order to find the solution. Rather, the design way of problem solving starts with a solution in order to start to define enough of the parameters of the problem to optimize the path to the goal. Projected solutions then, can actually be the starting point of both problem definition and problem solving.

Digital Conception

How does technology change how we think about design? How does it affect the way we think about a sequence of forms and spaces?

"Our software tools and the geometries and processes with which we design should not merely be more efficient ways of organizing and building the forms of yesteryear. Instead they should empower a new generation of conceptual thought, theoretical speculation, sustainable responsibility, and formal production."[24] (117)

"As extraordinary as these new tools are, they come with an entirely new challenge. Eliminating the need for two-by-fours requires replacing them with something… or

[23] Cross, Nigel. "Designerly Ways of Knowing." Design Studies 3.4 (1982): 221-27

[24] Lynn, Greg, and Mark Gage. *Composites, Surfaces, and Software: High Performance Architecture*. New Haven, CT: Yale School of Architecture, 2010. Print.

perhaps it requires an entirely new and bolder system of monologue structures with no internal frame at all."[25](38)

Technology also has changed the role of time in the design process. Through the animation, one can see the effects of seasonal and daily changes on a building. One can also show the experience of a space through an animation.

So What?

This ability to mass customize, and make shapes and forms that before were impractical, changes how we can think about form, and opens the doors to mass customization and trying to create ecological architecture. By this thought, our architecture can begin to have a new formal dialogue. Digital tools will be very critical to my thesis. Now with technology and performance data, I will be able to speculate about the efficiency of materials, energy use, solar gain, and wind forces of the building I design. This will be an integral part of the design process. This information will inform the design of the systems and the forms of the buildings, to enhance the performance of the buildings.

Geomorphology

Is defined as "The study of the evolution and configuration of landforms"

So What?

[25] Lynn, Greg, and Mark Gage. *Composites, Surfaces, and Software: High Performance Architecture*. New Haven, CT: Yale School of Architecture, 2010. Print.

Architecture needs to be responsive to the landscape and the environment it is in. To study how the land evolved gives insight into how the building can integrate with the land.

Combine all these Theories

All these different ideas, theories, hypothesis, provide valuable knowledge and insight. By utilizing all these different strains of thought, one can be better equipped to design ecological architecture.

Chapter 5: Materials

Timeline: transforming relationship to exterior

With the evolution and change of our building techniques our materials have also evolved and changed. Our relationship with the exterior has also changed from protection, to connection, and eventually exploitation. We need to realign our relationship and significantly improve our connection to achieve ecological outcomes. "What if we reconceived not the shape of the object but the materials of which it is made, in the context of its relationship to the natural world? How could it be a boon to both people and the environment?" [26](935) when choosing materials, I will not use materials that are on the Living Building Challenge's red list of materials. Furthermore, one needs to think about the lifecycle of materials. The materials need to be able to decompose, or be used for other purposes, so when the lifecycle of the

[26] McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point, 2002. Print.

building ends, the remains will not contribute to more waste. The materials should be local, and not be made from any toxic materials. **“**To eliminate the concept of waste means to design things—products, packaging, and systems—from the very beginning on the understanding that waste does not exist. It means that the valuable nutrients contained in the materials shape and determine the design: form follows evolution, not just function.”(1376)[27]

“The environment must be organized so that its own regeneration and reconstruction does not constantly disrupt its performance” (3).[28]

Traditional Materials

There have been exciting new applications with traditional materials. With improved understanding of material properties, we have started using traditional materials in new ways. For example wood, a traditional material, is at times used in novel applications such as for breathable façades, because the material curls and uncurls with changes in humidity.

New Materials

There has been significant and exciting research and development of new materials such as carbon fibers, polymers, composites, high tech ceramics, smart

---

[27] McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point, 2002. Print.

[28] Christopher Alexander, Notes on the Synthesis of Form, Harvard University Press (Cambridge, MA), 1964, p 3

materials, and others. In particular this thesis was looking at: (will cover in depth when further along in the study).

"In biological material systems there are four known solutions: [i] pre-stress the fibres in tension so that they hardly ever experience compressive loads; [ii] introduce high-modulus mineral phases intimately connected to the fibres to help carry compression; [iii] heavily cross-link the fibre network to increase lateral stability; [iv] and change the fibre orientation so that compressive loads do not act along the fibres."(249)[29]

Chapter 6: Structures

Deployable

"Is a structure that can change shape so as to significantly change its size".[30]

Ex/ umbrellas, some tensegrity structures, bistable structures, some origami shapes, scissor-like structures

This can be helpful in thinking about how architecture can respond and adapt to its environment. Perhaps buildings don't need to be static, maybe they can change size and shape in response to the users and the environment.

---

[29] ."Emergent Technologies and Design: Towards a Biological Paradigm for Architecture by Michael Hensel, Achim Menges, Michael Weinstock,249

[30] Pellegrino (Ed.), Deployable Structures, CISM International Center for Mechanical Sciences, Springer, 2002

Branching

Nature designs structures, to distribute the most weight with the least amount of material. By studying branching structures, one can easily see the direct correlation with building structures. The growth of branching is a response to the form, natural forces, and sunlight. What if the building structure can grow over time?

Bio-Structural

Looking towards nature, and the structures in nature to derive better structures in architecture.

Chapter 7: Patterns

Human

Weaving, Stitching, folding

Natural

Fractals, Layering, Stacking, Branching, Modular, Geometry

Technology

How can technology change our generation of patterns? Through the use of parametric and digital technology, our ability to create patterns has skyrocketed. We now have growth algorithms, paneling algorithms, branching algorithms,etc… How can this create more responsive architecture?

So What?

How can we look towards patterns in nature, to help generate forms that are more efficient and responsive? Through the use of technology we can now abstract and generate these patterns.   This is very important because everything in life is based off geometries.   "From a single cell to the entire planet, much of nature can be explained in terms of geometry alone" (144)[31](Everything is based of simple geometry, and small changes that have responded to stressors and forces from the environment. By looking towards patterns, one can see how a large system, can be broken down to its parts. Pattern making and geometry will play a large role in the development of the systems of the buildings.

Chapter 8: Systems

Systems

A system is defined as "An assemblage or combination of things or parts forming a complex or unitary whole: a mountain system; a railroad system."[32] By studying systems we can understand how things are made, and their functions, and how they fit together as a whole.

Human

There are so many systems in the human body. The study of the human body can start at the lowest level, the molecular level, and the individual organs all the way to the body as a whole. No matter what level we focus on, the body consists of building blocks, a repetition of patterns, and is organization from the least complex element to the most complex form.

---

[31] The Shape of Green: Aesthetics, Ecology, and Design by Lance Hosey ,144
[32] www.dictionary.com

Animals

I am beginning to create a list of animals and plants located in each site, to understand the adaptations specific to each microclimate. This is critical to understanding how very different the sites are, and understanding the process for the adaptions will have a huge influence on the design of these two buildings.

Architectural

A lot of our systems of architecture work very similar to the systems in nature. The building has a skin that needs to let light and air in, it needs to protect us, and it needs to keep us warm. If we look to systems provided by nature we should be able to adapt them and adopt them to our architecture to make more ecologically holistic architecture. Specifically, the prevalent natural forces affecting the two sites are wind, sun, and water. The two very different sites have very different needs.

Chapter 9: Ecology/Climate

Proposal

I am proposing to have two sites in two different extreme climates. I am particularly interested in extreme climates because there are usually a few forces one has to deal with. There are also distinct traits that animals have adopted to deal with these harsh conditions. I am looking at two different extreme climates (desert, and temperate rainforest), to really show the difference in mass customization that needs to occur for the building to adapt and respond to its environment.

Ecology

Ecology is defined as "the branch of biology that deals with the relations of organisms to one another and to their physical surroundings."[33]

"Ecological systems have at least five features that make them interesting. First, they are comprised of many parts; most contain hundreds of billions of individual organisms and tens of millions of species. Second, ecological systems are open systems that maintain themselves far from thermodynamic equilibrium by the uptake and transformation of energy and by the exchange of organisms and matter across their arbitrary boundaries. Third, ecological systems are adaptive, responding to changing environments both by behavioral adjustments of individuals and by Darwinian genetic changes in the attributes of populations. Fourth, ecological systems have irreversible histories, in part because all organisms are related to each other genetically in a hierarchic pattern of descent from a common ancestor. Fifth, ecological systems exhibit a rich variety of complex, non-linear dynamics."(419)[34]

The site in Squamish is part of a fjord estuary, and estuaries are very important because they help filter our waterways. The site in Yucca Valley is part of a desert ecosystem.

---

[33] www.dictionary.com

[34] Emergent Technologies and Design: Towards a Biological Paradigm for Architecture by Michael Hensel, Achim Menges, Michael Weinstock Brown 1994: 419

Climate

Is defined as "the weather conditions prevailing in an area in general or over a long period." [35]

Desert: Hot and dry, receives less than 10 inches of rain a year. Usually has strong winds. Receives diurnal swings in temperature.

Temperate Rainforest: Cold and wet, receives very cold winters, and a lot of snow. It experiences seasonal swings in temperature.

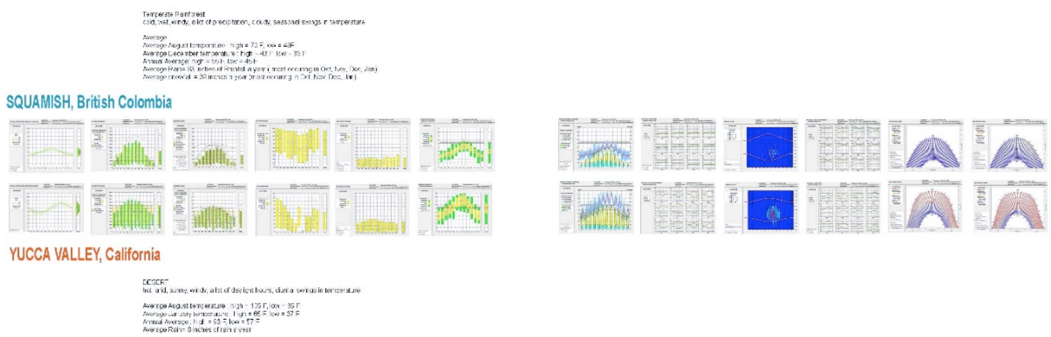


Figure 44: Climate Data [data gathered from Autodesk Ecotect, and the image created by Rachel Mihaly]

The above image shows the difference climatic data for the two sites.

Figure 15: Wind Data [data gathered from Autodesk Vasari, and compiled by Rachel Mihaly]

The above image shows the different wind conditions for both sites all year long. The important information to know is that at all times of the year, the wind in Squamish, will make the temperature feel below 70F, which is below the human comfort level.

---

[35] www.dictionary.com

The most predominant winds are North East and South East. In Yucca Valley, all winter, and at night the wind will make the temperature feel below 70F, and the rest of the time maximizing ventilation is a good thing. During winter and nighttime, the prevailing winds are predominantly west.

Chapter 10: Process

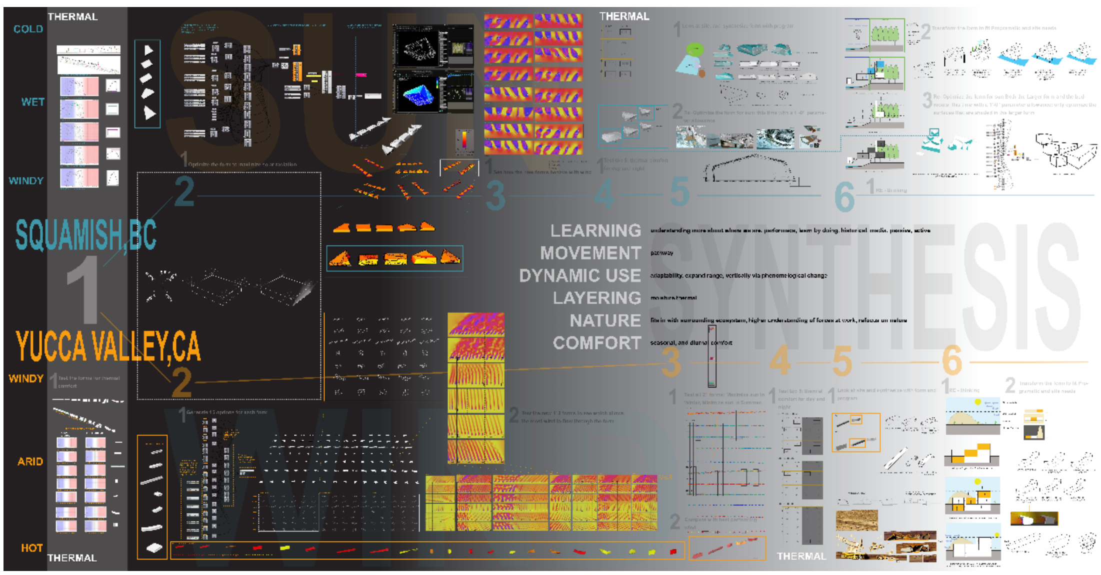


Figure 56: The process [image created by Rachel Mihaly]

All of the above research led to a process on how to design for ecological architecture.

1. Understand the climatic forces and start to optimize the form of the buildings to the specific sites.
2. Evaluate the sites, and the program and synthesize the design of the building with the optimized forms.
3. Re-optimize the forms

4. Evaluate skin of the building options to determine best choices for enhance building performance.
5. Use the Living Building Challenge as a guideline for performative design.

Step 1

Test multiple plan typologies for both sites. Make sure each plan has the same square footage, and test the different plans in EcoTect to see which plans allow for the most thermal comfort annually. Identify the forms that performed the best in the thermal test.

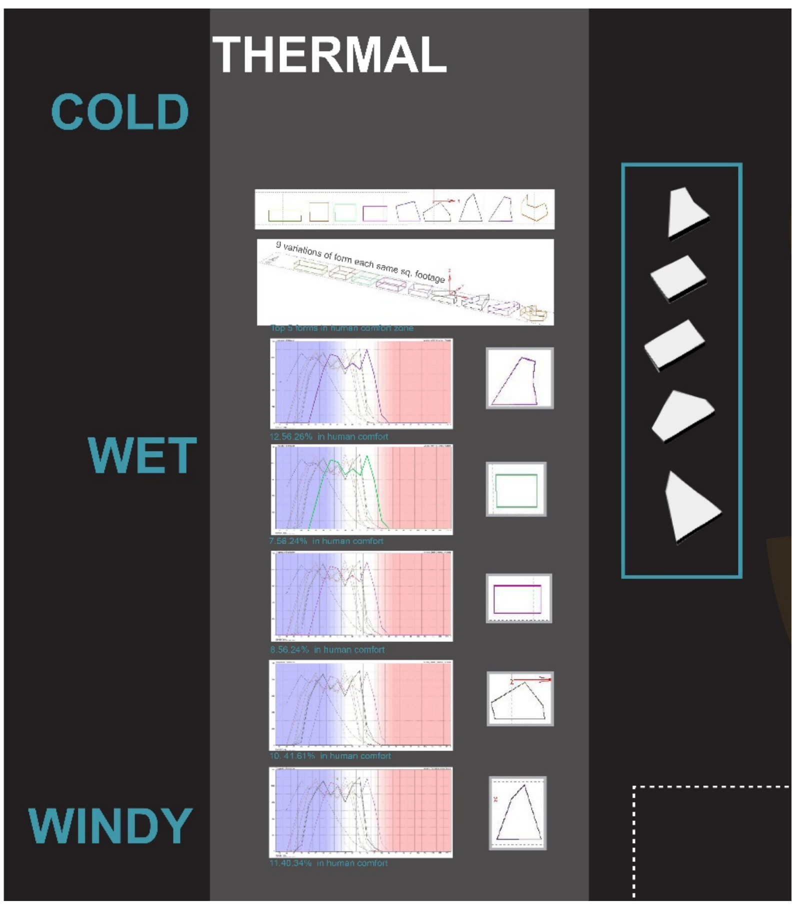


Figure 176: Thermal Testing for Squamish [image created by Rachel Mihaly]

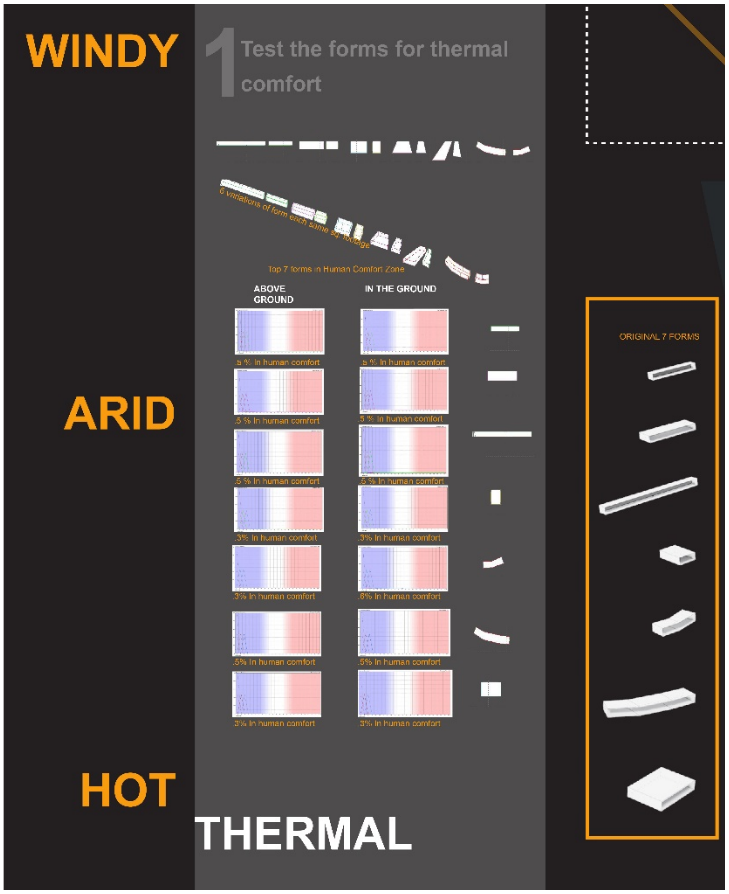


Figure 18: Thermal Testing for Yucca Valley [image created by Rachel Mihaly]

Step 2

Now look at the two sites. Since Squamish is colder than the human comfort zone 100% of the time, the next step is to maximize the amount of solar radiation that can hit the surface of the building. Since Yucca Valley is very hot most of the year, step 2 involves maximizing the amount of wind that can flow through the building.

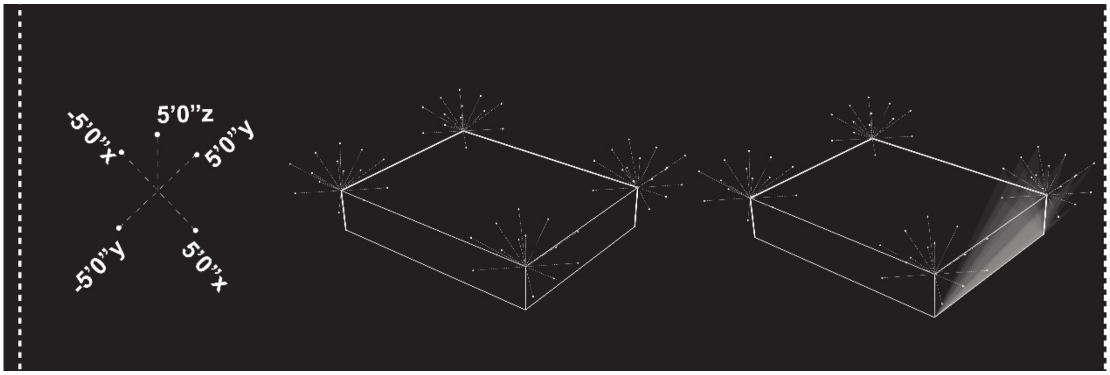


Figure 19: Optimizing form Diagram [image created by Rachel Mihaly]

This image shows how moving the points of a surface can allow for many different opportunities and outcomes. By setting the movement of the points of a surface, to 5'-00" parameters, one can see how surfaces transform and provide a number of potential outcomes. By using Grasshopper to allow the points of the surface of a form to be the parameters and by connecting it to Ecotect, and Galapagos to maximize the amount of solar radiation to hit the surface, I emerged with a new top 5 forms for Squamish.

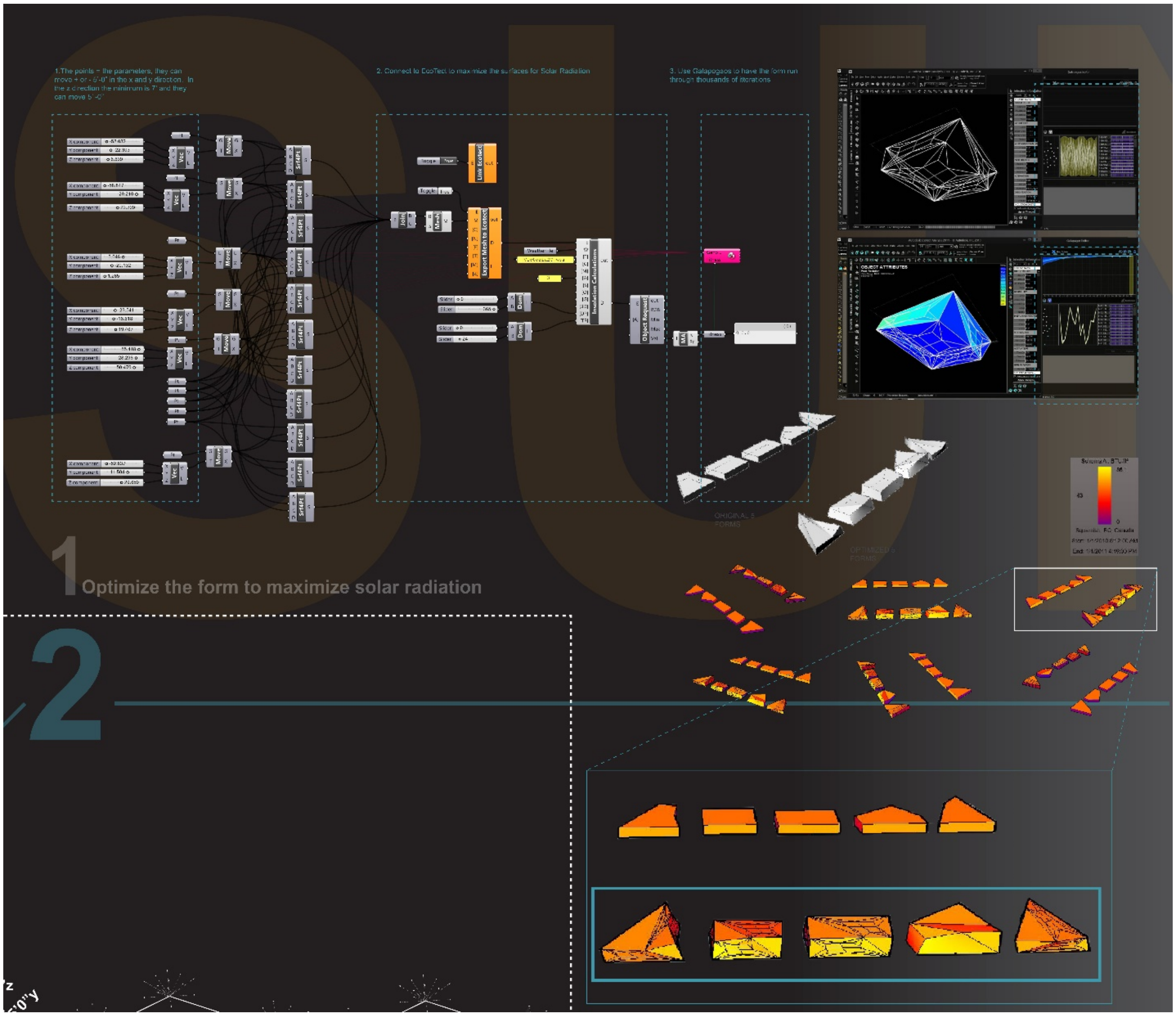


Figure 70: Solar Radiation optimization for Squamish [image created by Rachel Mihaly]

The above image shows the Grasshopper definition, the connection to Ecotect, and the maximizing of the solar radiation hitting the surface with Galapagos. Galapagos runs the parameters through many iterations/generations of the form, with each new generation of the form achieving a more optimized form. The 5 forms outlined in blue are the new top 5 forms.

In Yucca Valley, I used the same parameters of moving the points of the surface to create an array of new forms. I again used Grasshopper and Genoform to create an array of forms. I transformed the forms on a scale from 0 to unreasonable. I then took all the forms and brought them into Vasari and saw which forms allowed the most amount of wind to flow through, during conditions when maximizing wind is a desired outcome. The result was new top 21 forms.

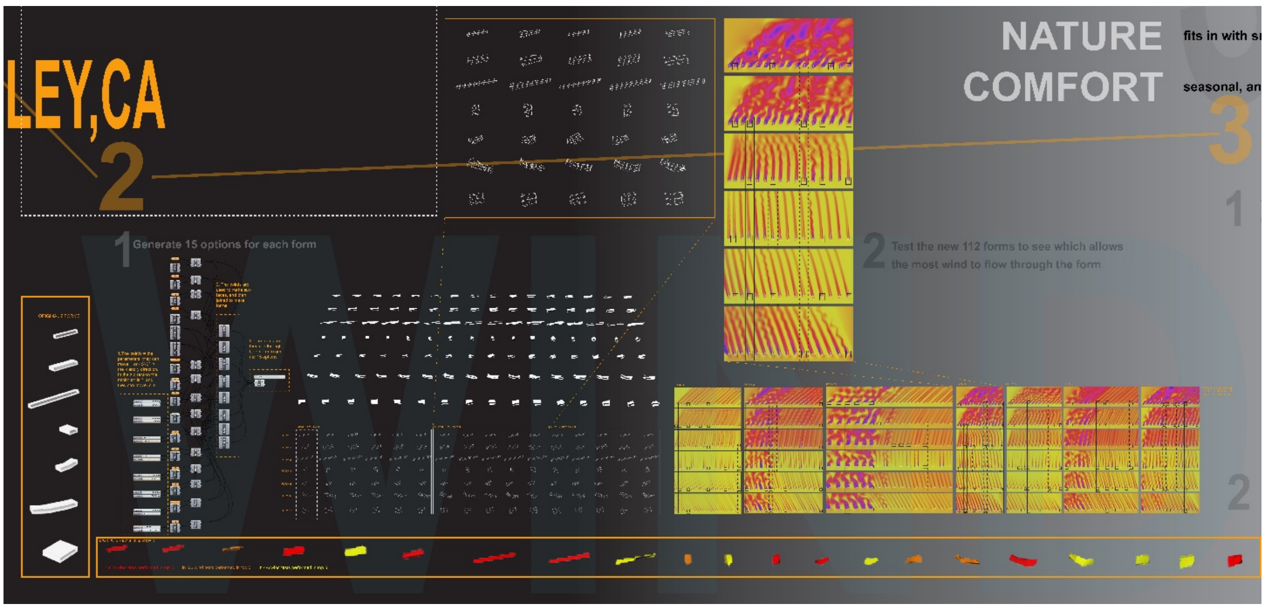


Figure 81: Wind Optimization : Yucca Valley [image created by Rachel Mihaly]

The above image shows the original top 7 forms, the Grasshopper definition, the new array of 121 forms, the 121 forms testing the wind , and then lastly at the bottom of the image the new top 21 forms.

<u>Step 3</u>

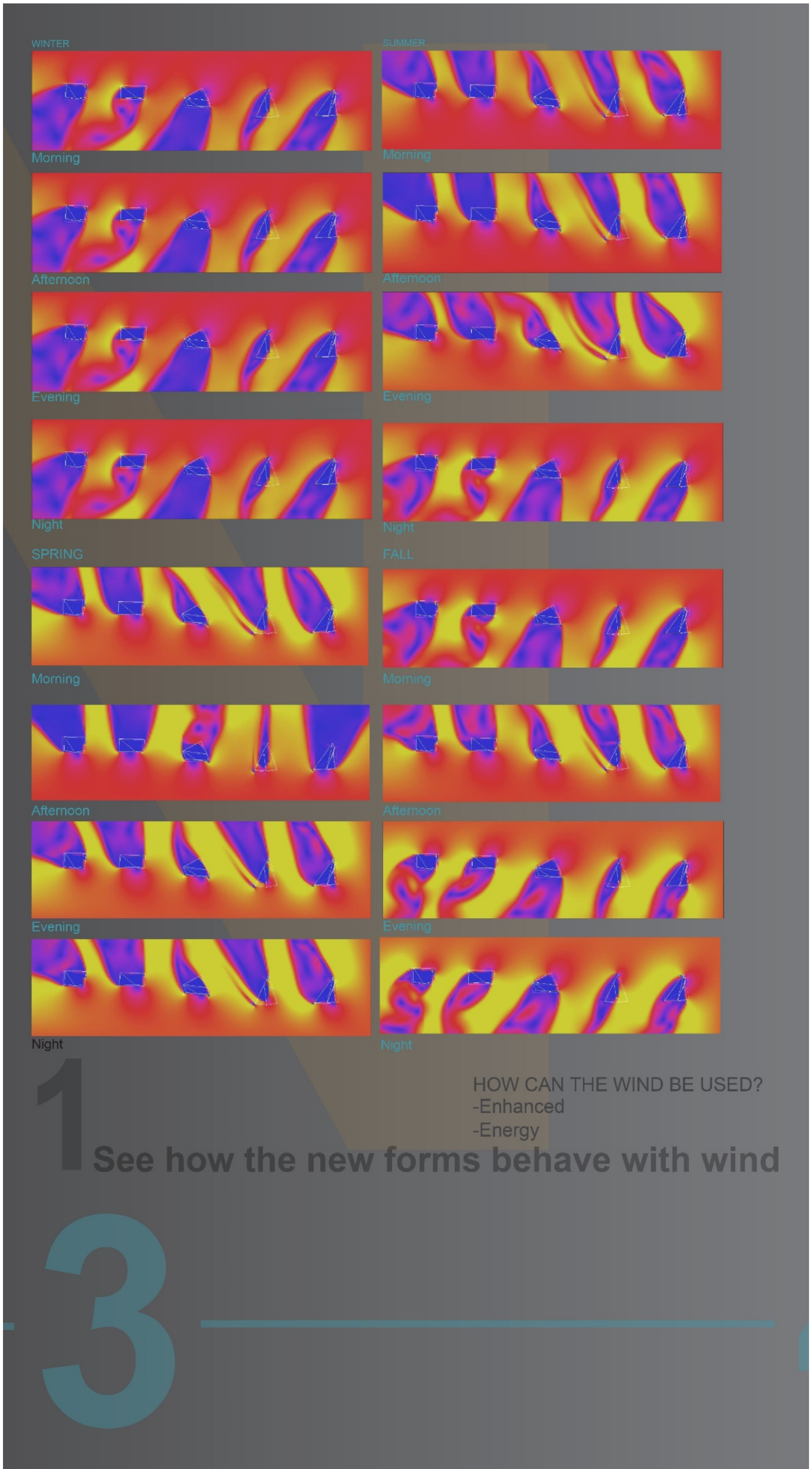
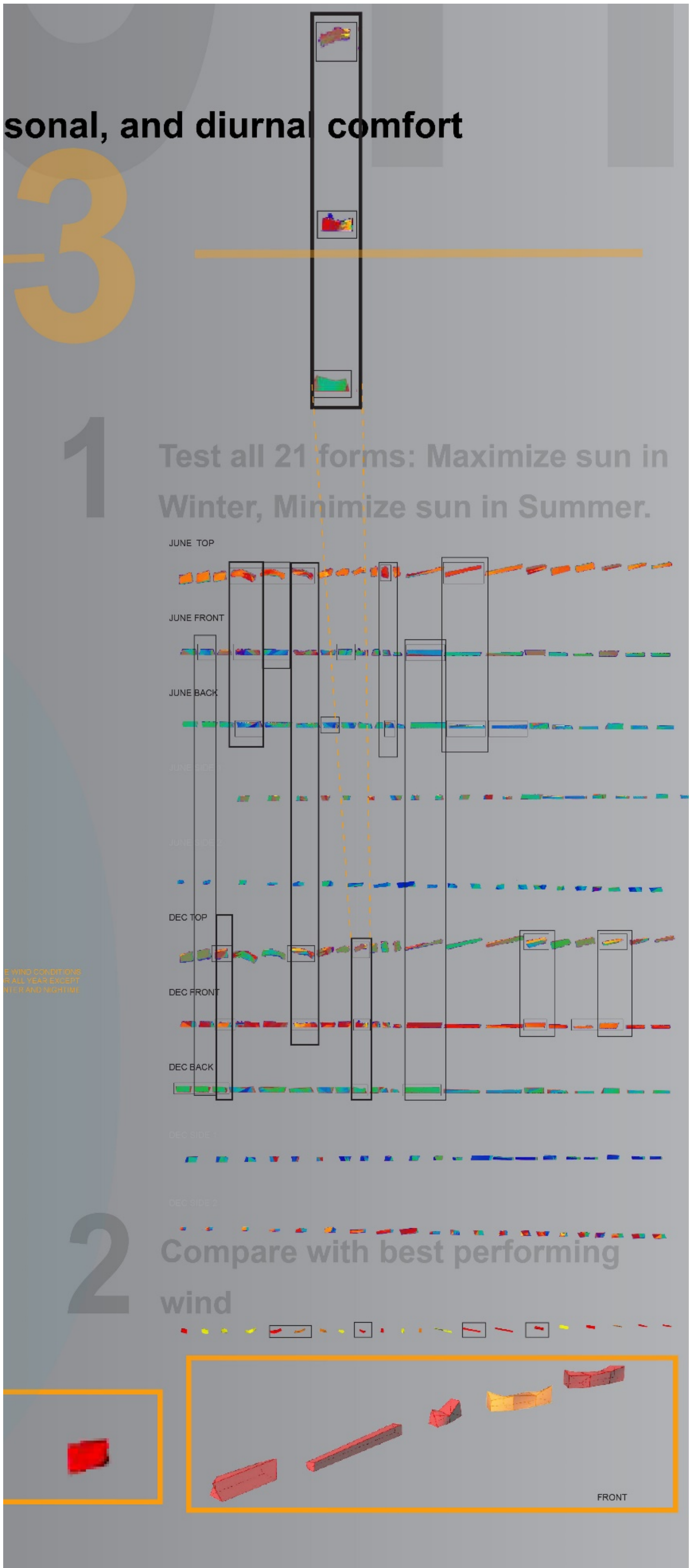

WINTER
Morning
Afternoon
Evening
Night
SUMMER
Morning
Afternoon
Evening
Night
SPRING
Morning
Afternoon
Evening
Night
FALL
Morning
Afternoon
Evening
Night
HOW CAN THE WIND BE USED?
-Enhanced
-Energy
1
See how the new forms behave with wind
3

Figure 92: Squamish Wind test [image created by Rachel Mihaly]

The next step was testing how wind behaved on the new top five forms from Squamish. This was not to change the form, but more to see how wind could be enhanced, or to see how this strong force is going to behave around the building.



sonal, and diurnal comfort
3
1
Test all 21 forms: Maximize sun in Winter, Minimize sun in Summer.
JUNE TOP
JUNE FRONT
JUNE BACK
DEC TOP
DEC FRONT
DEC BACK
2
Compare with best performing wind
FRONT

Figure 103: Yucca Valley Solar Optimization [image created by Rachel Mihaly]

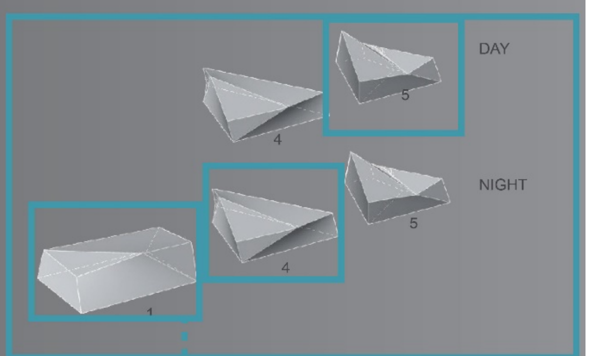
The step 3 for Yucca Valley involved taking the new top 21 forms from wind, and seeing which forms maximized the solar radiation in winter, and minimized the solar radiation in summer (I used DIVA for Rhino to gather the solar radiation data) . Overlaying the best performing shapes for solar, with the best performing for wind, I arrived at a new top 5 performing forms for Yucca Valley. In the image above the new top five forms are circled in orange.

Step 4

The next step was to test these new top forms for thermal comfort again through Ecotect. Now knowing that programmatically the living/classroom space will mainly be used during the day, and the bedrooms mainly at night, I tested the forms to determine which forms allow the most thermal comfort for day and night.

THERMAL

	DAY	NIGHT
1	899	914
2	894	860
3	903	871
4	1040	1045
5	947	910



1

Test top 5: thermal comfort for day and night

4

Figure 24: Thermal Testing Squamish [image created by Rachel Mihaly]

The above image shows the top 2 forms for the day in Squamish, and the top three forms for night in Squamish.

4

1 Test top 5: thermal comfort for day and night

ABOVE THE GROUND

	DAY	NIGHT	DAY	NIGHT
1	17	40	17	40
2	23	39	23	39
3	16	33	16	33
4	19	39	19	39
5	22	33	22	33

ON THE GROUND

	DAY	NIGHT	DAY	NIGHT
1	19	30	19	30
2	23	26	23	26
3	16	33	16	20
4	19	29	19	29
5	21	29	21	20

IN THE GROUND

	DAY	NIGHT	DAY	NIGHT
1	12	10	12	10
2	19	10	19	10
3	11	10	11	10
4	18	10	18	10
5	5	10	22	10

THERMAL

Figure 25: Thermal Testing Yucca Valley [image created by Rachel Mihaly]

The above image shows not only the thermal testing for day and night, but also how that affects the building if it is above the ground, on the ground, or submerged in the ground for Yucca Valley.

Step 5

Step 5 then says all these forms are performing at a high level, and it's a matter of looking at the site and the program, and starting to synthesize the forms with design.

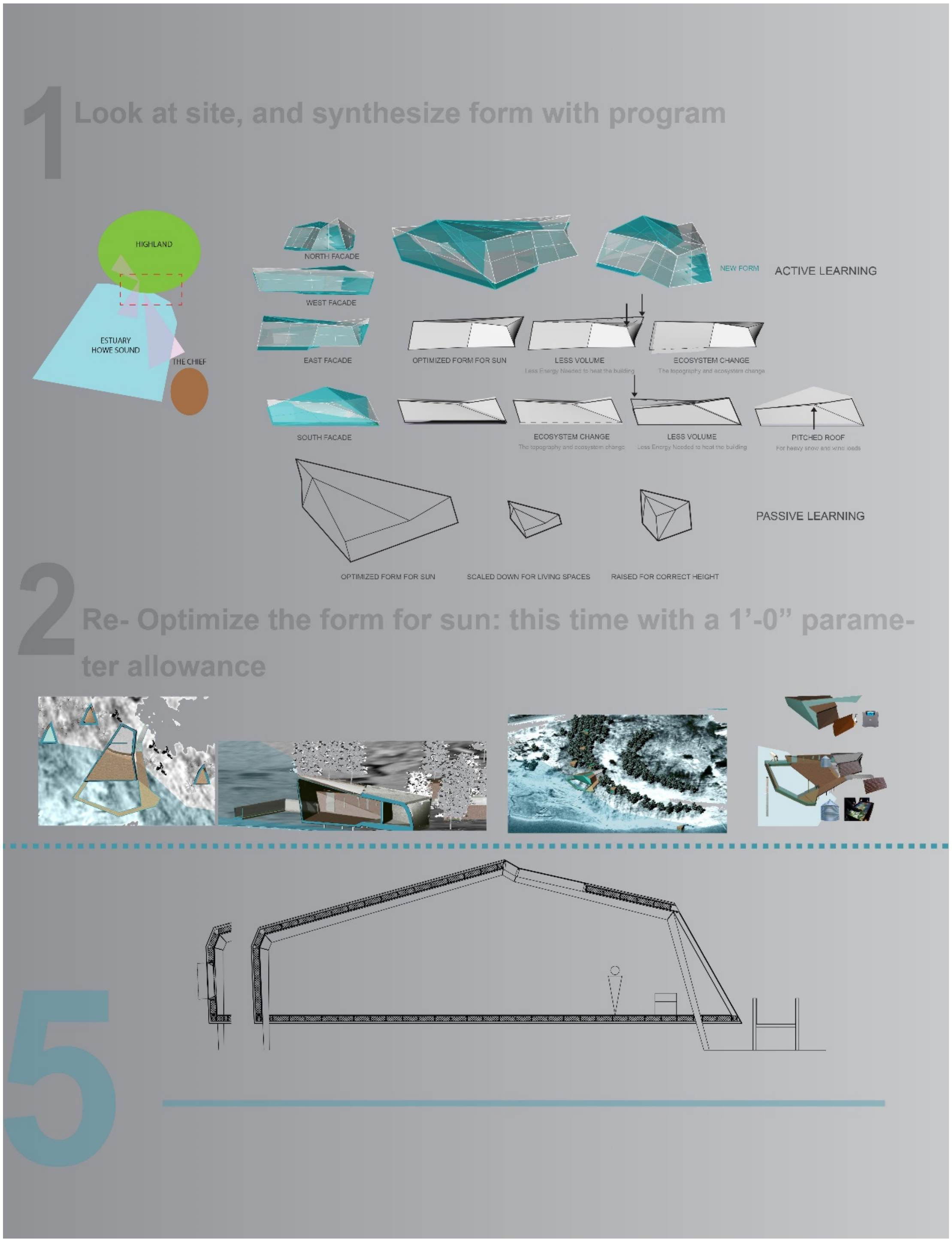


Figure 26: Step 5 Squamish [image created by Rachel Mihaly]

The above image shows the synthesizing of the form with design changes. It also shows that after all the design changes to the form occur, that there is a re-optimization process, but this time the parameters are smaller. Instead of the points on the surface being able to move 5’-0”, they can only move 1’-0”.

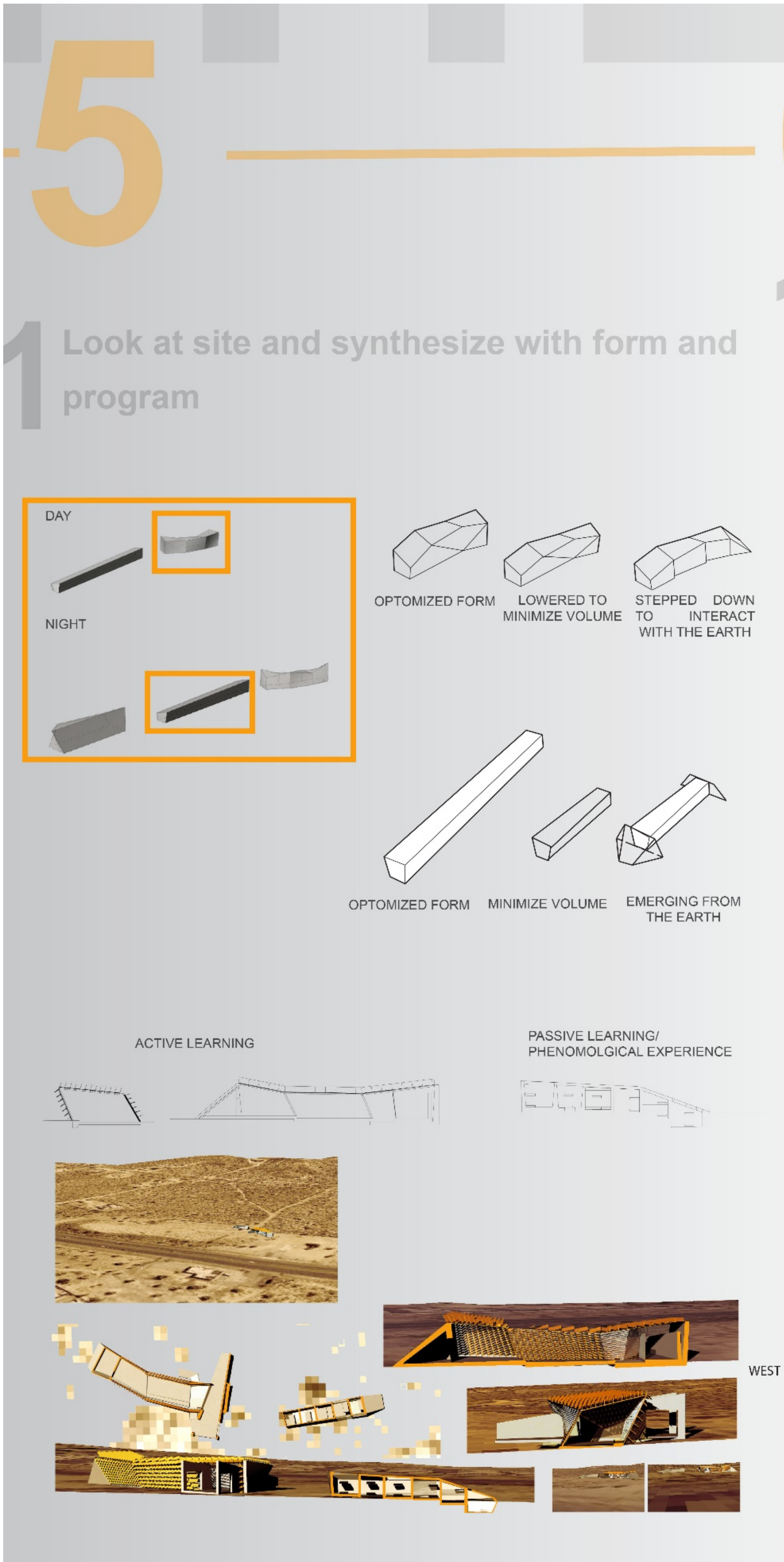

5
1
Look at site and synthesize with form and program
DAY
NIGHT
OPTOMIZED FORM
LOWERED TO MINIMIZE VOLUME
STEPPED DOWN TO INTERACT WITH THE EARTH
OPTOMIZED FORM
MINIMIZE VOLUME
EMERGING FROM THE EARTH
ACTIVE LEARNING
PASSIVE LEARNING/ PHENOMOLGICAL EXPERIENCE
WEST

Figure 27: Step 5 Yucca Valley [image created by Rachel Mihaly]

The above image shows the synthesizing of the optimized form for Yucca Valley with the programmatic and site needs.

Step 6

Step 6 involves a critical look at the designs, and taking a step back to re-evaluate what the purpose of the program is and these buildings. To really think about how these buildings can teach people. There is a re-focus on these 6 programmatic goals:

1. Learning = understanding more about where we are, performance, learn by doing, historical, media, passive, active
2. Movement= pathway
3. Dynamic Use = adaptability, expand range vertically via phenomelogical change
4. Layering = moisture, thermal
5. Nature = fits in with the surrounding ecosystem, higher understanding of forces at work, refocus on nature
6. Comfort = seasonal, and diurnal comfort

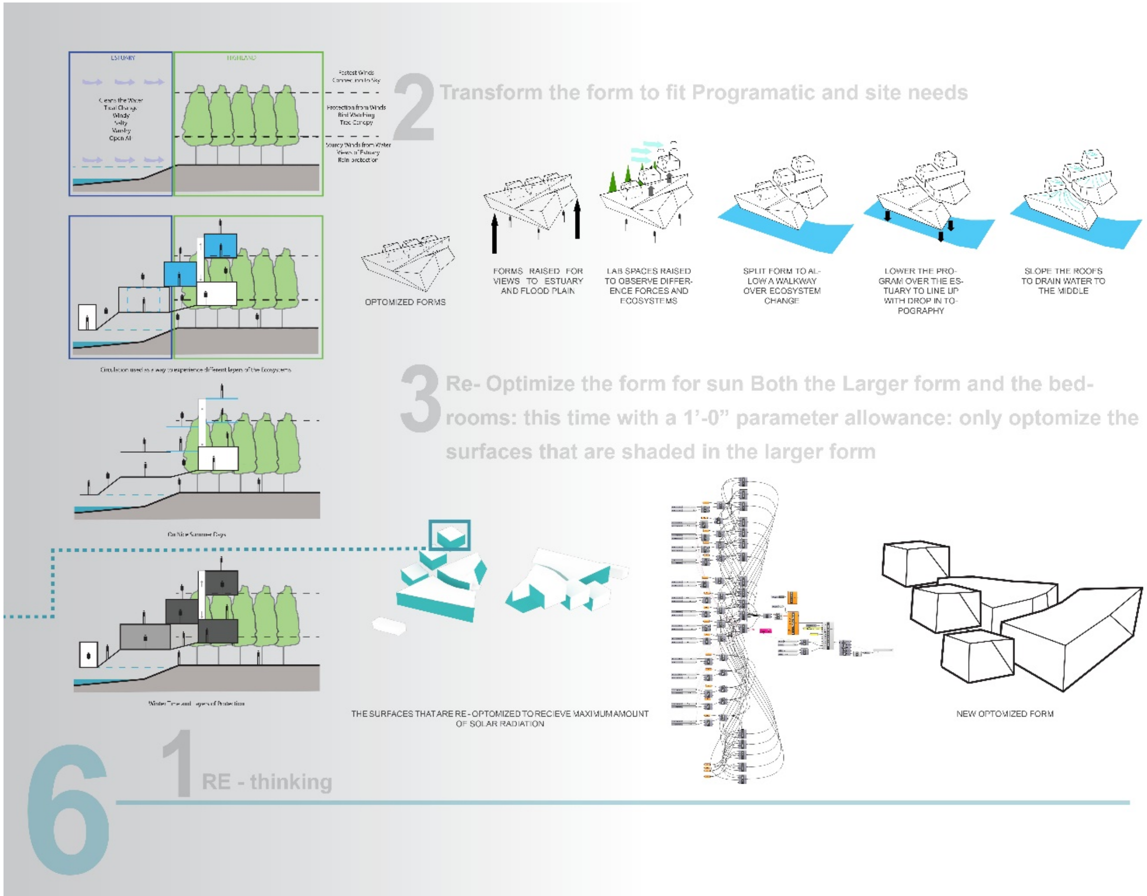


Figure 11: Step 6 Squamish [image created by Rachel Mihaly]

The above image shows step 6 for Squamish. The first step involved re-looking at the site, and the program. The next step was transforming the form to fit the programmatic needs, and the third step was re-optimizing the form for sun with smaller parameters.

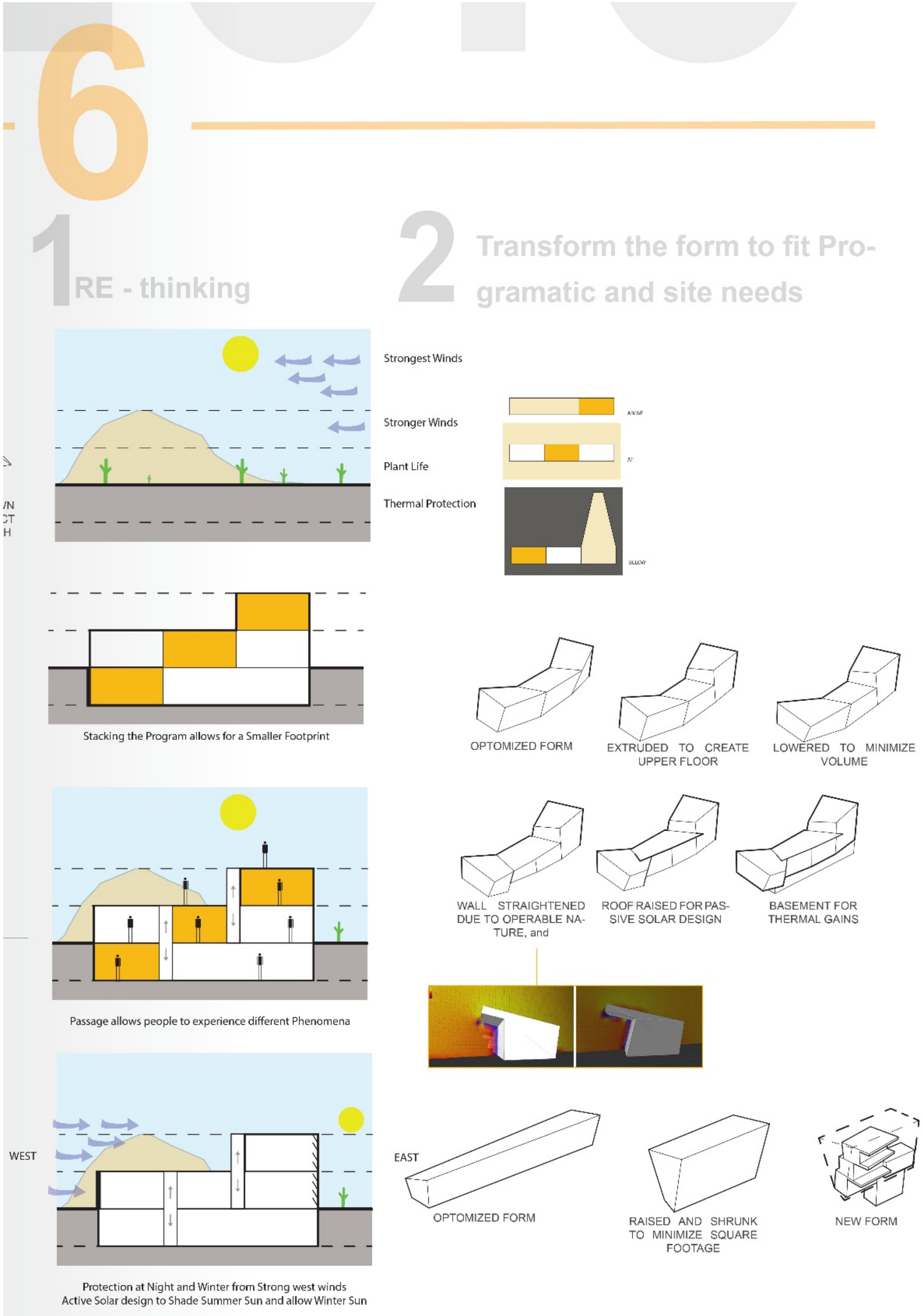


Figure 29: Step 6 Yucca Valley [image created by Rachel Mihaly]

The above image shows step 6 for Yucca Valley. It too re-looks at the site, and transforms the form for site and programmatic needs.

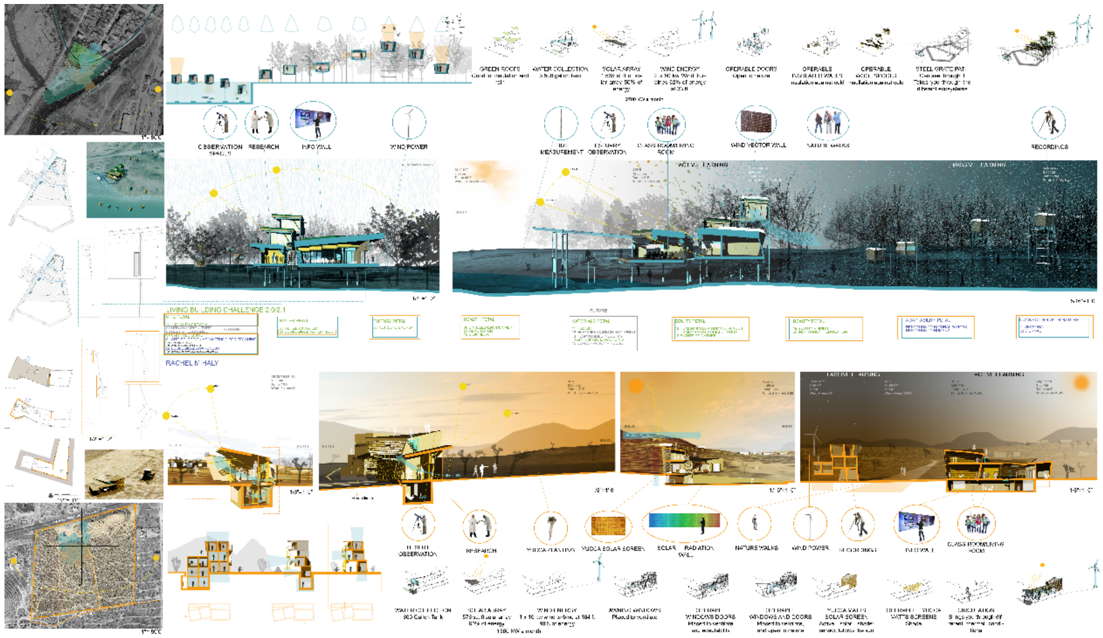
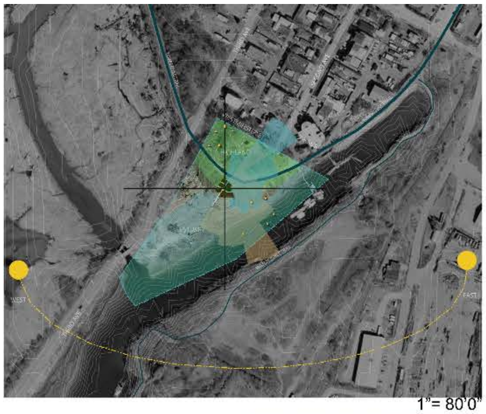


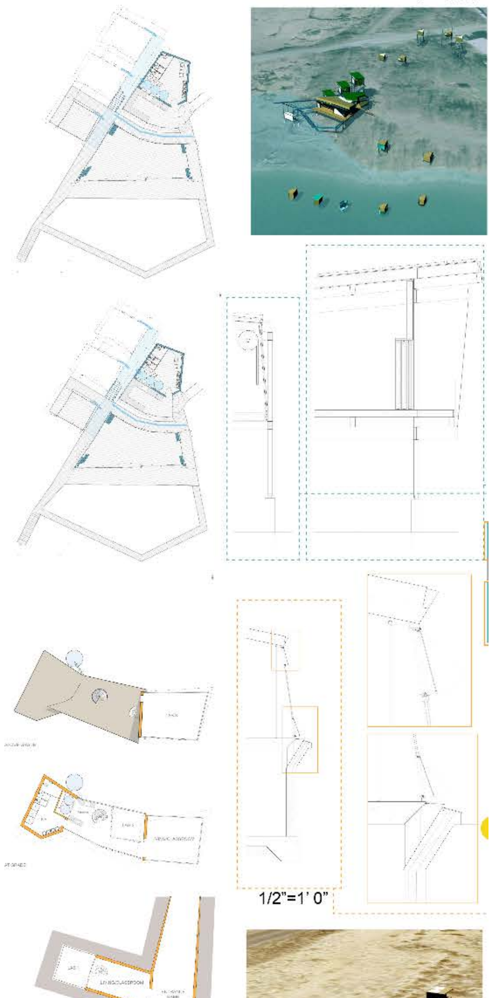
Figure 120: Step 6 Continued [image created by Rachel Mihaly]

The above image shows both designs.

The thesis really tried to examine how the skins of the building could function at a performative level, and how the building itself could be used as a teaching tool. The thesis was not able to achieve all the petals of the living building challenge, but was able to achieve a few with the goals that in the future all the petals would be met. If there was more time, the thesis would try to explore more at the detail level, and test the performance of the design through energy modelling. It would also re optimize the form of the building once more.

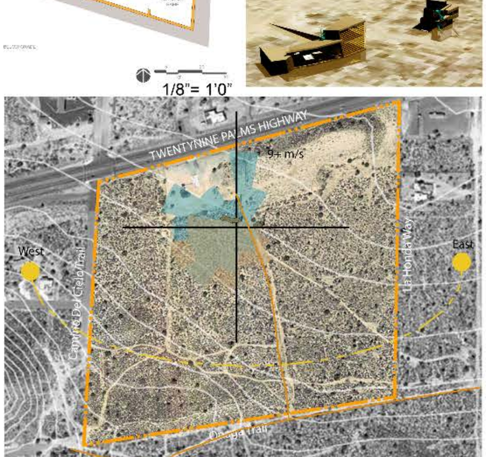


1"= 80'0"



1/2"=1' 0"

1/8"= 1'0"



1"= 80'0"

Figure 131: Orthographic drawings [images created by Rachel Mihaly]

The above image shows Squamish's Site plan, axon, plans, and the beginnings of detailed wall sections. The bottom half of the image shows Yucca Valley's plans, beginnings of detailed wall sections, axon, and a site plan.

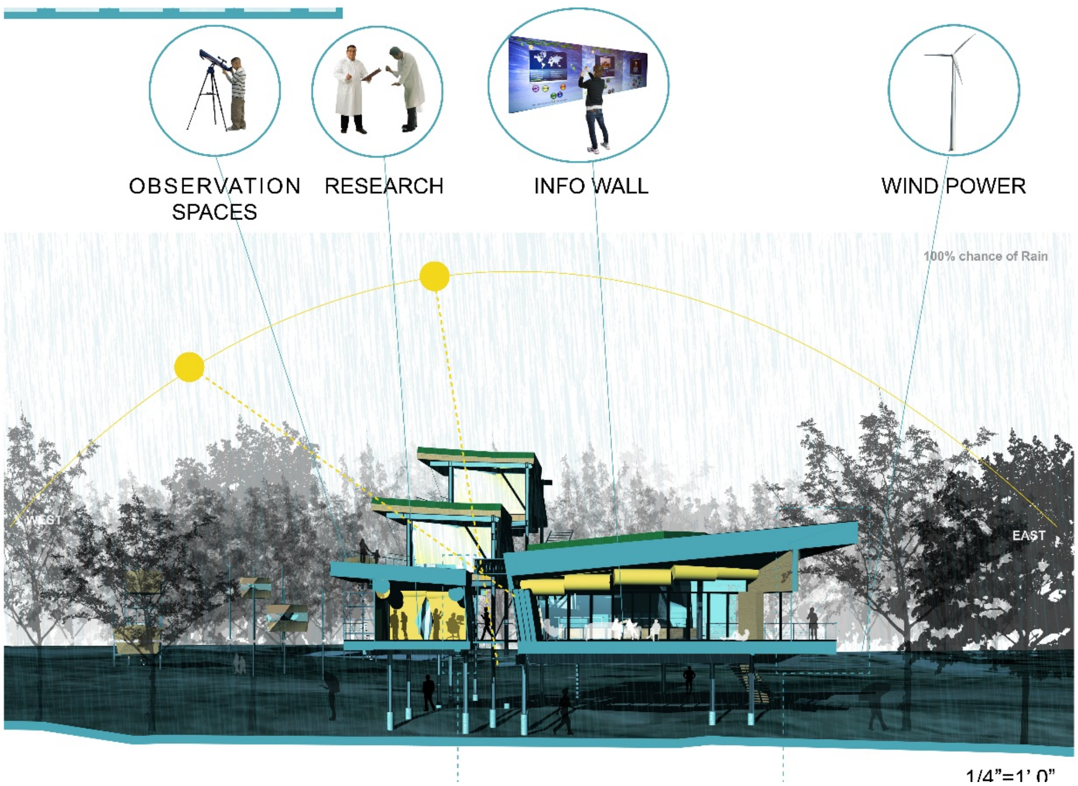


Figure 142: Section 1 Squamish [image created by Rachel Mihaly]

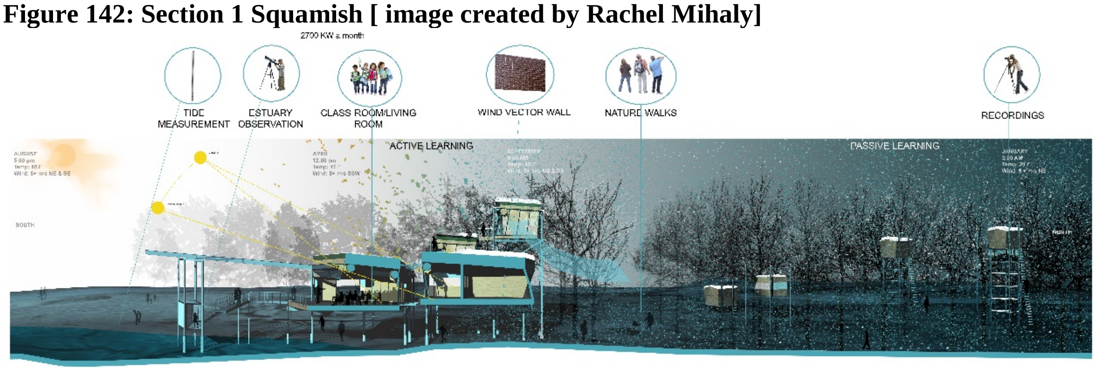


Figure 153: Section 2 Squamish [image created by Rachel Mihaly]

The above image shows two sections through the buildings in Squamish, and the callouts illustrate the interactive features of the design.

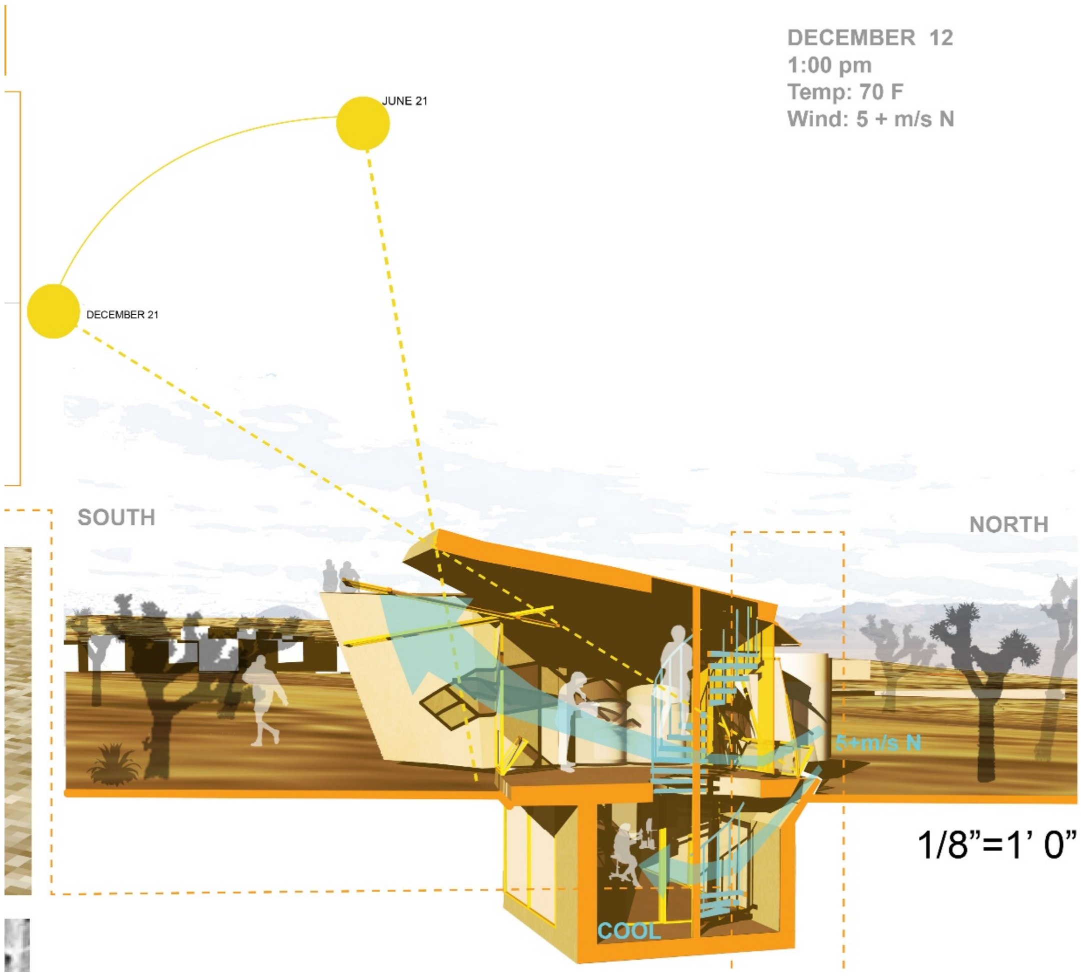


Figure 34: Section 1 Yucca Valley [image created by Rachel Mihaly]

Figure 165: Section 2 Yucca Valley [image created by Rachel Mihaly]

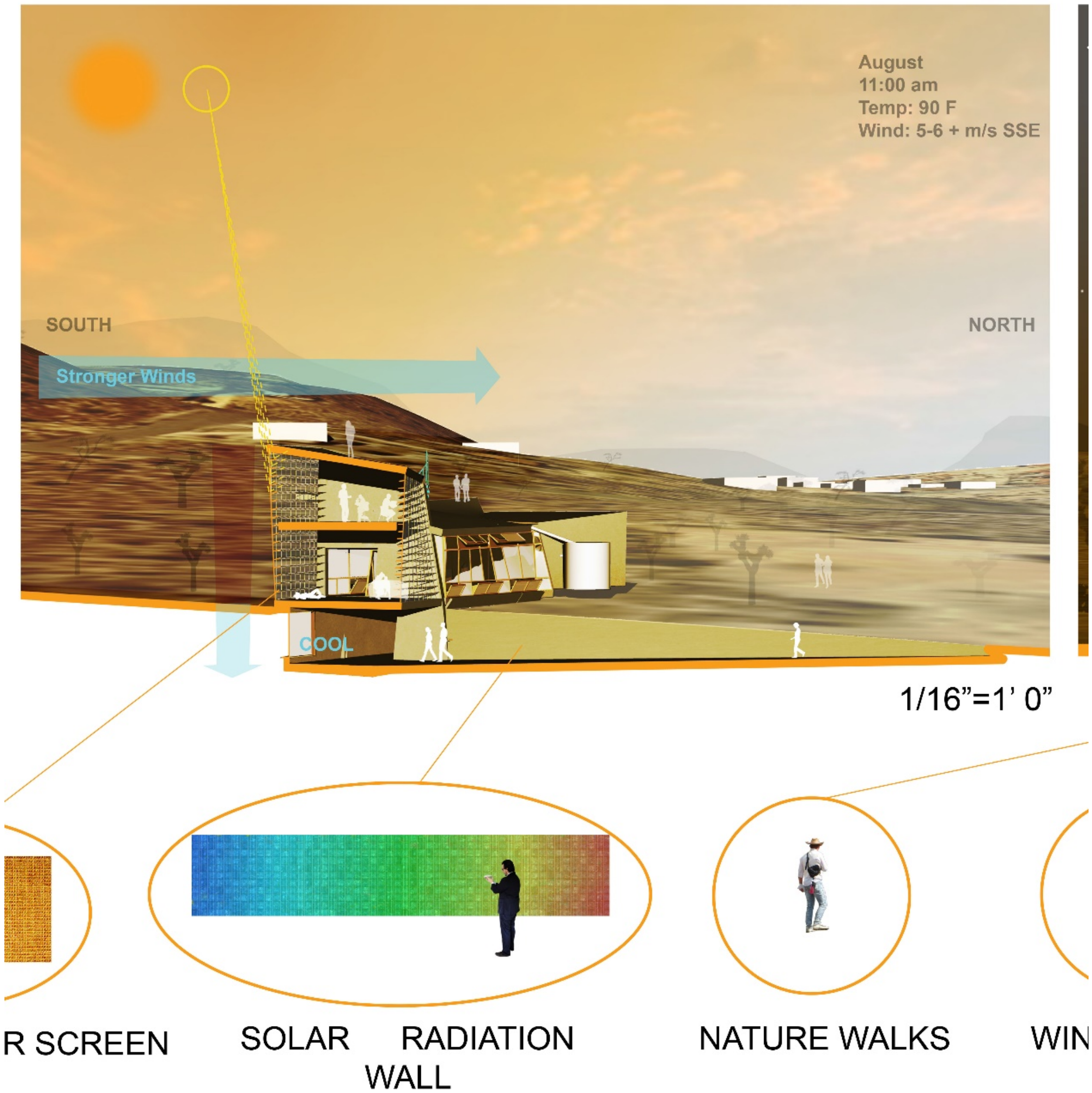


Figure 36: Section 3 Yucca Valley [image created by Rachel Mihaly]

Figure 37: Section 4 Yucca Valley [image created by Rachel Mihaly]

The above images shows four sections through the buildings in Yucca Valley, and the callouts illustrate the interactive features of the design.

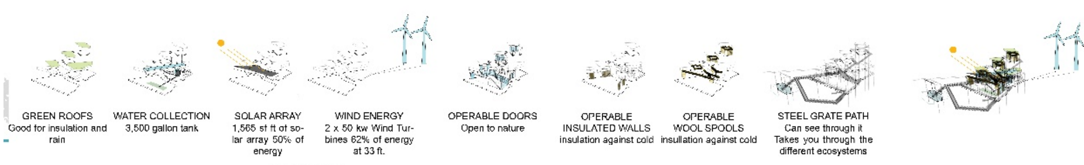


Figure 178: Interactive Diagrams Squamish [Image created by Rachel Mihaly]

The above image shows the performative and interactive features of the larger building Squamish.

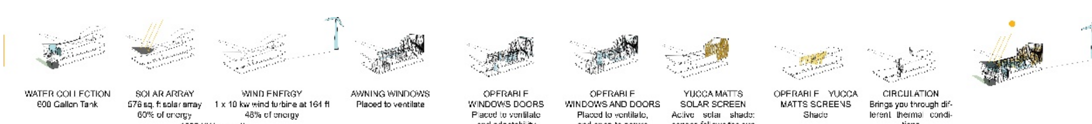


Figure 39: Interactive Diagrams Yucca Valley [image created by Rachel Mihaly]

The above image shows the performative, interactive features of the larger building in Yucca Valley.

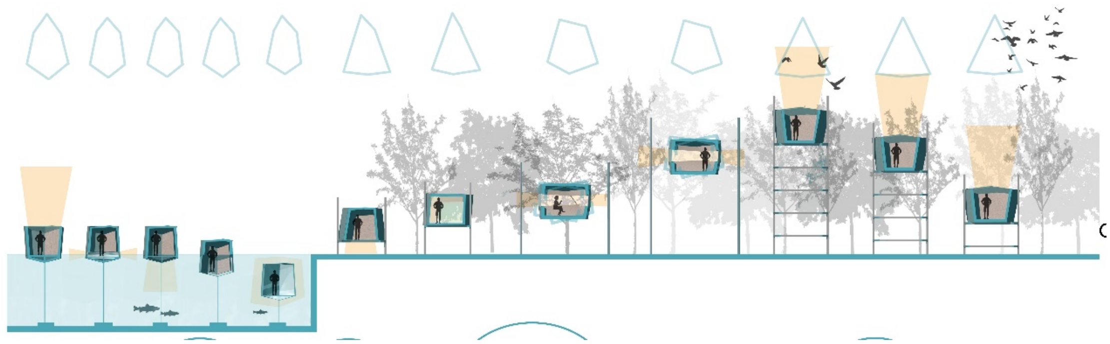


Figure 40: The Bedrooms Squamish [image created by Rachel Mihaly]

The above image shows the different bedrooms in Squamish, and illustrates how the isolated views and different locations can create very concentrated views and learning of the site.

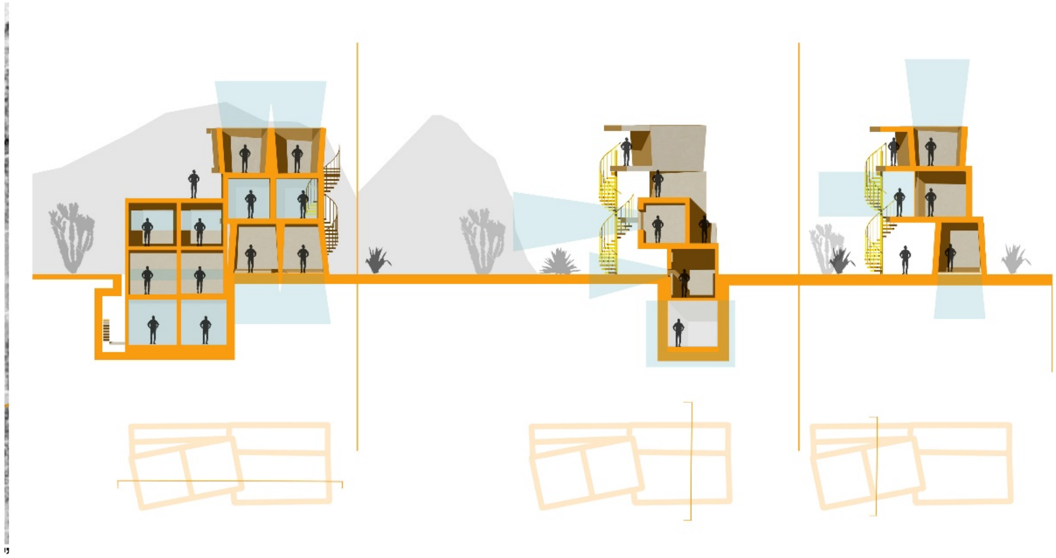
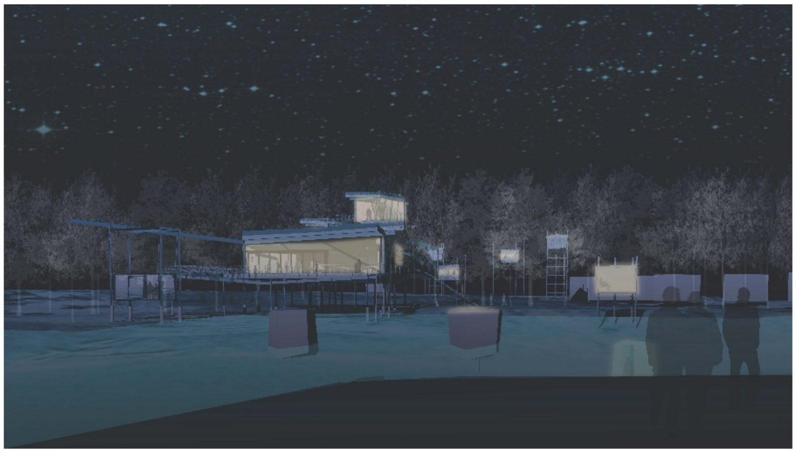


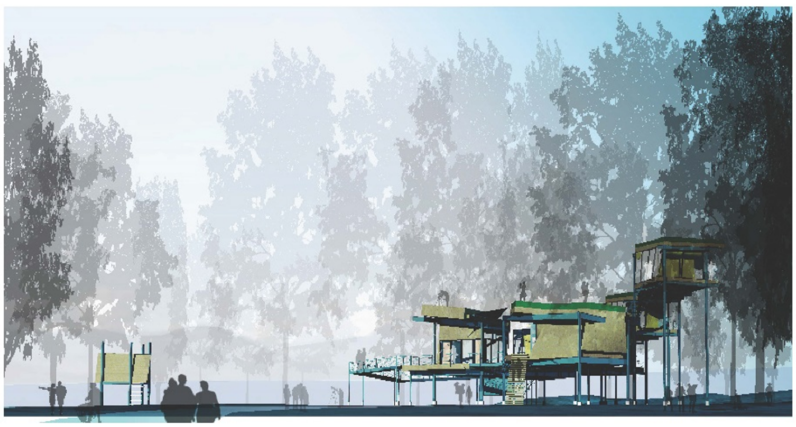
Figure 41: The Bedrooms Yucca Valley [image created by Rachel Mihaly]

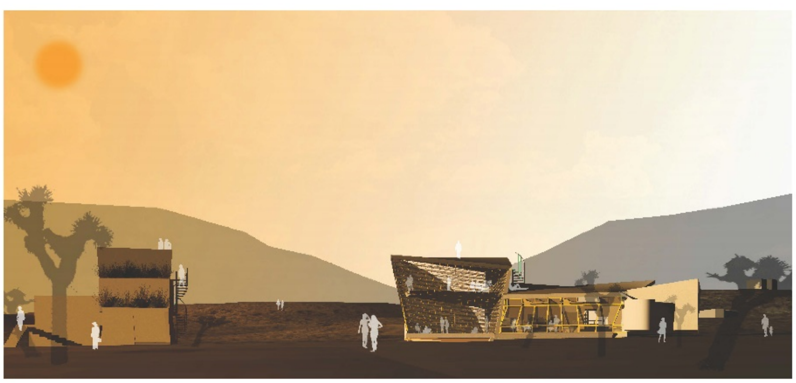
The above image shows the bedrooms in Yucca Valley and also illustrates the phenomological and "passive" learning through concentrated views.

Figure 42: Living Building Challenge [image created by Rachel Mihaly]

The above image shows the different petals of the living building challenge. The purple indicates the petals I have added to the living building challenge. What is in grey signifies that it was not addressed in this thesis, and would like to be in the future. What is circled in orange indicates that the environmental living learning center in Yucca Valley was able to achieve it, and what is circled in blue indicates what the environmental living learning center in Squamish was able to achieve.







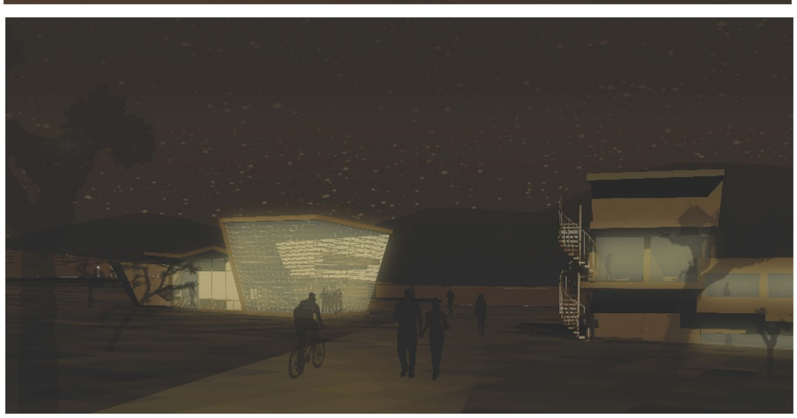


Figure 183: Perspectives [image created by Rachel Mihaly]

Bibliography

Addington, Michelle, and Daniel L. Schodek. *Smart Materials and Technologies: For the Architecture and Design Professions*. Oxford: Architectural, 2005. Print.

Agkathidis, Asterios, and Gabi Schillig. *Performative Geometries: Transforming Textile Techniques*. Amsterdam, The Netherlands: BIS, 2010. Print.

Agkathidis, Asterios. *Computational Architecture*. Amsterdam: BIS, 2012. Print.

Ball, Philip. *The Self-made Tapestry: Pattern Formation in Nature*. Oxford [England: Oxford UP, 1999. Print.

Benyus, Janine M. *Biomimicry: Innovation Inspired by Nature*. New York: Morrow, 1997. Print.

Beorkrem, Christopher. *Material Strategies in Digital Fabrication*. N.p.: n.p., n.d. Print.

Beylerian, George M., Andrew Dent, and Anita Moryadas. *Material ConneXion: The Global Resource of New and Innovative Materials for Architects, Artists, and Designers*. Hoboken, NJ: J. Wiley, 2005. Print.

Bovill, Carl. *Fractal Geometry in Architecture and Design*. Boston: Birkhäuser, 1996. Print.

Bucknell, J. *Climatology; an Introduction.* London: Macmillan, 1964. Print.

Burry, Mark. *Scripting Cultures: Architectural Design and Programming*. Chichester, UK: Wiley, 2011. Print.

Cotgreave, Peter, and Irwin Forseth. *Introductory Ecology*. Oxford: Blackwell Science, 2002. Print.

Cross, Nigel. *Design Thinking: Understanding How Designers Think and Work*. Oxford: Berg, 2011. Print.

Dahl, Torben. *Climate and Architecture*. Milton Park, Abingdon, Oxon: Routledge, 2010. Print.

DeYoung, Donald B., and Derrik ,. Hobbs. *Discovery Design: Searching out the Creator's Secrets*. Green Forest, AR: Master, 2012. Print.

Dollens, Dennis. *Digital-botanic Architecture*. Santa Fe: SITES, 2005. Print.

Douglis, Evan. *Autogenic Structures*. New York: Taylor & Francis, 2009. Print.

Estvez, Alberto T. *Genetic Architectures = Arquitecturas Geneticas*. Santa Fe: Sites, 2003. Print.

Frisch, Karl Von, and Otto Von. Frisch. *Animal Architecture*. New York: Harcourt Brace Jovanovich, 1974. Print.

Gissen, David. *Subnature: Architecture's Other Environments*. New York: Papress, 2009. Print.

Hardy, Steve. *Environmental Tectonics: Forming Climatic Change*. London: AA Publication, 2008. Print.

Haskell, David George. *The Forest Unseen: A Year's Watch in Nature*. New York: Viking, 2012. Print.

Hawkes, Dean. *Architecture and Climate: An Environmental History of British Architecture, 1600-2000*. London: Routledge, 2012. Print.

Kemsley, Roderick, and Christopher Platt. *Dwelling with Architecture*. London: Routledge, 2012. Print.

Klooster, Thorsten, Niels Boeing, Simon Davis, and Almut Seeger. *Smart Surfaces: And Their Application in Architecture and Design*. Basel: Birkhäuser, 2009. Print.

Lim, Joseph. *Bio-structural Analogues in Architecture*. Amsterdam: BIS, 2009. Print.

Lynn, Greg, and Mark Gage. *Composites, Surfaces, and Software: High Performance Architecture*. New Haven, CT: Yale School of Architecture, 2010. Print.

Mayer, H. , J., and Neeraj Bhatia. -*arium: Weather Architecture*. Ostfildern: Hatje Cantz, 2010. Print.

Mazzoleni, Ilaria, and Shauna Price. *Architecture Follows Nature: Biomimetic Principles for Innovative Design*. N.p.: n.p., n.d. Print.

McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point, 2002. Print.

Menges, Achim, and Sean Ahlquist. *Computational Design Thinking*. Chichester, UK: John Wiley & Sons, 2011. Print.

Rudofsky, Bernard. *Architecture without Architects.* N.p.: Academy Ediitions, 1964. Print.

Schoenauer, Norber. 6,000 Years of housing The Pr-Urban House Volume 1. New York, 1981. Print

Spuybroek, Lars. *Textile Tectonics*. Rotterdam: NAi, 2011. Print.

Thibodeau, Gary A., and Kevin T. Patton. *Structure & Function of the Body*. St. Louis, MO: Mosby, 2004. Print.

Tsui, Eugene. *Evolutionary Architecture: Nature as a Basis for Design*. New York: John Wiley, 1999. Print.

Weinstock, Michael. *The Architecture of Emergence: The Evolution of Form in Nature and Civilisation*. Chichester, U.K.: Wiley, 2010. Print.

Wines, James, and Philip Jodidio. *Green Architecture*. Köln: Taschen, 2000. Print.

Yeang, Ken. *Designing with Nature: The Ecological Basis for Architectural Design*. New York: McGraw-Hill, 1995. Print.