

A NEW HAWAI'I TROPICAL HOUSE:
Creating a healthy pre-fabricated residential architecture and community

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For Sandra Lee, who inspired this project

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ABSTRACT

Residential architecture in Hawai'i has failed its inhabitants on many levels since the indigenous grass covered hale pili structures evolved into a western style of building. The way homes are designed, sited and built creates an architecture with several social, cultural, climatic and environmental issues as well as the potential for physical and mental health problems. This dissertation attempts to understand what these problems are, how they have been addressed in the past and how future architects and builders can progress to a higher standard of a Hawai'i tropical home.

Understanding the most popular residential building styles after Western contact, and analyzing case studies of contemporary, County and State initiated or approved residential developments compared with the presented climatic and environmental data for each of the climate zones in the state, lays the ground work for the standard of the current housing stock.

An investigation of the physical and mental comfort and health effects related to building materials and methods, the climate and their relation to the indoor environment uncovers numerous chemicals, VOCs and toxins such as mold (mycotoxins) which may be present in Hawaiian homes. Research into natural ventilation systems, light and the connection to the outside environment all help to recognize the health issues and the cultural and social importance of the symbiosis of the built environment with the natural environment.

A study of the positive and negative aspects of the typical building materials in Hawai'i opens up the research and promotion of locally sourced building materials. This project finds that there are potential local materials which would be physically healthy, structurally efficient, culturally sensitive and environmentally responsible. These are thermally modified eucalyptus and ironwood timbers made into pre-fabricated cross nailed timber panels and locally sourced pre-cast concrete.

These materials are used to create a new Hawai'i tropical house which would provide inhabitants with a safe, healthy and culturally significant home. The conclusion of this project is a documented design for the new Hawai'i home designed as part of a community, similar to that of Regen Villages which is self-sufficient, regenerative and environmentally sustainable.

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Source: ReGen Villages 227

PREFACE

In what way shall we build? What building method and materials are appropriate? Will the architecture be significant? Beautiful? Useful? Will it matter? Will people care, and more importantly, will it inspire them? Will it make them happy? Will they feel connected to their culture or religion or provide a sense of place? These are the questions that haunt the architect; that we must continually ask and strive to answer. One might read these first few lines and wonder why would you want this responsibility, this burden? To the architect these are not burdens but challenges. To many of us, architecture is one of the ultimate expressions of humanness; it is how we express ourselves and communicate with each other.

But where do we start? How does one set out to tackle the architectural issues of the modern day? I'm sure every architect has felt the jolt of panic that occurs when you are completely lost in a design. There is a sense of hopelessness and isolation that seems to creep up when you just can't seem to rise to the challenge that has been laid before you. I believe we must remember our Vitruvian values of *utilitas, firmitas and venustas*. As Marcus Vitruvius Pollio believed when he wrote *De architectura* in the 1st century B.C., a building must exhibit these three traits or it will not be successful. It would take an entirely separate dissertation to attempt to understand everything that Vitruvius meant by these terms, but we can use their meanings to find inspiration and a guide for our architectural challenges today:

Utilitas, utility or function. A building should have a function or a specific use.

Firmitas, firmness or strength. A building should be well-made, structurally efficient and sound.

Venustas, beauty or delight. A building must be beautiful (in arrangement, proportion and character); it must be inspirational.

If we keep these three values in symbiotic harmony, then we have already made a significant leap in creating a successful architecture. It is with these values as a guiding principle that I have set out to solve an architectural challenge that the Hawaiian Islands face. That is, simply, we do not have

a residential architectural typology that completely fulfils these Vitruvian values. Further, the current typology is culturally insensitive and creates an environment of physical and mental sickness.

Since contact with Captain Cook in 1798 and 1799, Hawaiian architecture has always been slightly out of place. The leap from the hale pili to Western housing occurred with no regard to the vernacular or regional characteristics, climate or cultural values. Despite its own flaws, traditional Hawaiian housing was at least more suited to the environment for which it was built; the building materials and methods were unique to its locale. Perhaps it is the remoteness of the islands or maybe it is just an overwhelming colonial mindset and focus on tourism that has kept architectural progress to a relative standstill. In fact, in many ways architecture in Hawai'i has gone backwards. The plantation style of architecture, which has now seen a cookie cutter resurgence in recent times, is perhaps the closest the state has come to a successful and widespread housing typology. As close as it is, this style still has problems with pests, a reliance on imported materials and difficulty adapting to different climate types. Further, the original intention behind this architecture was much more of indentured servitude than it was the pursuit of a climatic and culturally sensitive architecture.

There have been attempts at developing a more universal tropical housing typology. Possibly the most famous (or infamous) example of this would be La Maison Tropicale by Jean Prouvé. The self-made French architect developed prefabricated aluminum homes specifically for French colonies in west Africa in the late 1940s. The idea was to create affordable, easy to assemble houses which were suited to the tropical African climate. Arguably, Prouvé accomplished his goals, but the architecture was unpopular and only three were built in Niamey, Niger and Brazzaville, Congo. Prouvé's mistake was that he failed to recognize the cultural significance that architecture has on a people. While he failed culturally, he excelled at pushing a Modernist idea that simple, pre-fabricated houses could be beautiful, useful and structurally efficient.

In the contemporary sense there is, in addition to the age old issues of architecture, an ever-growing environmental and moral awareness of human beings place on this planet. Meaning, it is not good enough to create something which fulfils the Vitruvian values alone, it must also consider the local and global environments. Sustainability, if I may try to wrestle that word back from the marketing buzzword that it has become, has made it to the forefront of the architectural profession. This is more than adding a few solar panels to an otherwise typical house, though, it is the effort and implementation of specific knowledge on how an architecture sits on the land and how its inhabitants

and that architecture can develop a symbiotic relationship which society, culture and the environment.

Regen Villages, for example, is a future development in Almere, Netherlands. The architects and developers of this community have demonstrated the importance of a regenerative architecture with closed-loop, self-contained, communities which can grow their own food, recycle its waste and produce enough energy to offset the energy and material expenditures and alleviate the carbon footprints associated with building homes.

Hawai'i is exceptionally unique and has its own set of challenges for residential architecture. The harsh and diverse climate, relative isolation and a shrinking indigenous culture are all variables which need to be addressed in future designs.

Finally, it must be said that little attention seems to be paid throughout the global architecture community to building houses which are not only beautiful, functional and structurally safe but also which create healthy indoor environments. Perhaps the most misunderstood or possibly ignored issue relating to residential architecture, especially in Hawai'i is what materials and ways of building create a healthy home. This dissertation will attempt to address all of these issues, to some degree mentioned in this preface.

PART 1: PRE-DESIGN

Investigation of Architecture + Design Factors –
History, Culture, Climate + Environment

CHAPTER 1:

INTRODUCTION

Residential architecture in Hawai'i has evolved over the centuries to become relatively similar. Standardized building materials and construction methods which reference the International Building Code (IBC) or the International Residential Code (IRC) for approval and permitting have led to a system of design and construction sameness which lacks imagination and promotes economy over physical and mental well-being. It often comes as a surprise for tourists and visitors to Hawai'i that the homes we live in are essentially identical to those found in the Continental United States. Perhaps it shouldn't though, as most of the 21st century homes across the country have a familiar look and feel which rely on a "typical" system of design and construction. While variations of the typical home exist depending on budget, proximity to certain building materials, environmental requirements and/or climatic effects, generally an architect or builder would not need specialized knowledge of the area in which they are working to create the typical and often anticipated architecture many of us have been raised with.

There are exceptions of course. As the project budget increases, the level and cost of design, construction materials and building methods tend to increase as well. That is not to say that all affordable housing is built wrong and all expensive "designer" homes are built right. In fact, often very expensive homes in Hawai'i are built using the exact same methods as affordable houses but they incorporate more lavish finishes and materials and are sited on more expensive plots of land. The primary objective of this dissertation is to research and formulate a residential design which is sympathetic and beneficial for the specific Hawai'i climate and culture, as well as to create a healthy indoor environment for its inhabitants. I believe it is important that this overall design is adaptable for all socio-economic levels. I do not believe in an architecture which is in and of itself prejudice to the economic bottom line; I believe all people deserve good architecture and good architecture should be scalable to all economic levels.

The focus of this project is not just an attempt to elevate the overall design of Hawaiian residential architecture, although that would be quite a lofty goal. Nor is this an attempt to recreate La Maison Tropicale or some other pre-fabricated architecture for Hawai'i. Again, the purpose of this research is to create a new type of single family residential architecture in Hawai'i for which its

inhabitants will be confident that their physical and mental health will not be compromised by the building materials and construction methods. It is my belief that this new Hawaiian tropical house will not only give its residents a healthy place to reside, but also create a stronger emotional connection to the 'āina, or land, and be much more culturally significant than what is currently available.

The research in this document will attempt to understand the current single family residential architecture typology that exists in the state through an investigation of typical building methods and materials, the various climatic conditions and the sociocultural values of the inhabitants. This investigation will help us to understand where and how residential architecture can be improved. To accomplish this, I will use Hawai'i Island as a microcosm of the state. Hawai'i Island is unique in that it contains every climatic and geographic condition in the island chain and could be completely self-reliant. The island contains large harbors, international airports, large agricultural and pasture lands, a growing tourism industry and large land areas available for residential growth. Interestingly, Hawai'i Island has potential to create its own building materials with large tracts of forest (timber), lava and basalt fields (masonry, concrete) and pasture lands (hemp, straw bale, rammed Earth).

To begin, this project will look briefly into the history of residential architecture on the Hawaiian Islands to understand the designs and styles which have existed over the years since before Captain Cook until the present day. Although I do not believe that recreating the vernacular will necessarily solve current residential architectural issues, I do think it is important to look to the past for inspiration and to investigate what has worked and what has not as a basis of understanding for moving forward.

Part of my argument will be an investigation of new single family developments initiated or funded by Hawai'i county. This will give a better sense of the accepted architectural style on the island and insight into the typical building materials and methods used. We will be able to understand the approach to single family residential architecture on Hawai'i Island by choosing developments that span the climatic and geographic variances that exist; i.e. windward, leeward, mauka and makai as Hawaiian regions are usually defined. Using the developments initiated by the County government will give insight into how the current industry attempts to tackle issues with the climate and local culture. Understanding where these designs excel and where they fail will provide a groundwork for the end design of this dissertation.

The second part of the investigation process is a thorough investigation of the Hawaiian tropical climate and varied geographic site conditions. Many of the issues related to the imported architecture in Hawai'i are due, in large part to the interaction between the building, environmental conditions, the site and its inhabitants. Understanding how the climatic conditions and site design affect the building types that currently exists is necessary to understand how to approach a new Hawaiian tropical house.

The next part of identifying the problem with imported architecture in Hawaii is to understand how the indoor environment causes issues with physical health. Some of these the issues are more clear cut than others, like health ailments that are caused by the nature of the materials themselves; think engineered wood flooring which contains toxic formaldehyde. Other ailments are due to an interaction of the materials with an outside influence unnatural to their intended use; think moldy drywall which becomes excessively moist from humidity or water damage. Identifying the potential sources of health problems by targeting specific materials and construction methods is the best way to prevent avoidable health problems. By researching and understanding the types of materials and methods currently used, and with knowledge of the climate and environmental factors, we should be able to understand how to properly redesign a Hawaiian tropical house to become a healthier and better place to live.

Mental health is also a concern and attention should be paid to the social and cultural effects that the imported architecture has on its inhabitants. It has been very well documented that architecture affects social and cultural behavior. It is the contention of this dissertation that designing a new Hawaiian tropical house to reflect a more culturally sensitive architecture which works with the typical Hawaiian lifestyle will positively affect mental health and wellbeing.

Once all the factors related to single family residential architecture are understood we can begin to think about and test specific design elements and building styles. It is clear throughout architectural history that ideas should be put into practice as a part of the complete evolution of the profession. The best I could hope for is that this dissertation influences some architects, builders, developers or state authorities to rethink the current building methodology. Whether this new Hawaiian tropical house is ever built is not as important as changing the current mindset on how we design and implement residential design in this state.

The result of this project will be a complete conceptual design of a new Hawaiian tropical house and community which embodies the Vitruvian values, Hawaiian culture and promotes the physical and mental health of its inhabitants. The design shall consider the Hawaiian climate, varied geography, environment as well as the social, economic, cultural and most importantly, physical and mental health of its people.

CHAPTER 2:

INDIGENOUS HAWAIIAN ARCHITECTURE: THE HALE PILI

When Captain James Cook first set foot on the Hawaiian Islands in 1798 and 1799, he would have seen the coastlines populated with steeply sloped, grass thatched structures called hales. While these simple structures were not as architecturally advanced as the Medieval castles or Gothic cathedrals of his homeland, they were well suited for their own tropical culture and climate. The hale is defined as a house or building in the Hawaiian language,¹ but to its people the grass or palm covered structures were integral parts of their social and cultural way of life. There were many types of hale and their design was typically designated by a kahuna who was an expert in the loina, or rules of the ancient Hawaiians.² The kahuna not only chose the site for the hale pili but planned how it should be oriented to take advantage of the wind, sun and rain.³

The orientation and design of the hale pili was also dependent on its function, who it was to be built for and the geographic area for which it was to be placed. Strict rules separated eating areas from sleeping areas, men from women and ali'i from commoner. Certain hale were designated for sleeping, food and supply storage, menstruating women, canoe or wa'a storage and some for rituals.⁴ Although it was common for Hawaiian people to spend most of their time outside, even for sleeping, the hale was an important part of their everyday lives and culture.⁶

It is thought by some that the eventual abolishment of the kapu system- which required separate areas, and therefore separate hales for gender, eating, sleeping, rituals and castes- was the beginning of a deterioration of 'ohana relationships and the function of traditional Hawaiian cultural practices.⁷ While it may be difficult to blame the loss of the hale pili as a building typology for the

¹ Mary Kawena Pukui and Samuel H. Elbert, *New Pocket Hawaiian Dictionary with a Concise Grammar and Given names in Hawaiian* (Honolulu, HI:University of Hawaii Press, 1992), 19.

² Mary Kawena Pukui and Samuel H. Elbert, *New Pocket Hawaiian Dictionary with a Concise Grammar and Given names in Hawaiian* (Honolulu, HI:University of Hawaii Press, 1992), 83.

³ "Hale Pili / Wao Kanaka," *Hawaii Alive*, accessed September 5, 2016
<http://www.hawaiialive.org/realms.php?sub=Wao+Kanaka&treasure=343&offset=0>

⁴ Mary Kawena Pukui and Samuel H. Elbert, *New Pocket Hawaiian Dictionary with a Concise Grammar and Given names in Hawaiian* (Honolulu, HI:University of Hawaii Press, 1992), 141.

⁵ William T. Brigham *The Ancient Hawaiian House*, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History, vol.2 no. 3, (Honolulu, HI, Bishop Museum Press, 1908), 76-80

⁶ *Ibid.*

⁷ E.S. Craighill Handy and Elizabeth Green Handy with the collaboration of Mary Kawena Pukui, *Native Planters in Old Hawaii: their Life, Lore, and Environment: Bernice P. Bishop Museum, Bulletin 233* (Honolulu, HI: Bishop Museum Press, 1991), 294-295.

deterioration of all aspects of Hawaiian culture, there is something to be said about how architecture and culture influence each other. This important notion should be kept in mind throughout the remainder of this dissertation, as it is this author's firm belief that residential architecture affects the way we live and interact with each other. The loss of certain architectural features that are directly informed by cultural or social practice will have a direct impact on future social and cultural practices.

The hale pili were typically built using similar materials, although the proximity of the hale was usually a determining factor in the specific types or species of native materials used. In general, the hale pili was made up of stone, timber and thatching materials and consisted of a few different styles.

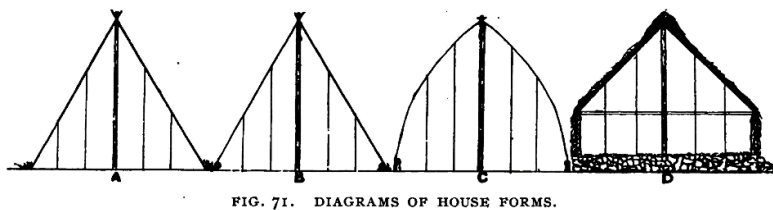


FIG. 71. DIAGRAMS OF HOUSE FORMS.

Figure 2.1: Evolution of the Hale Pili

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 88.

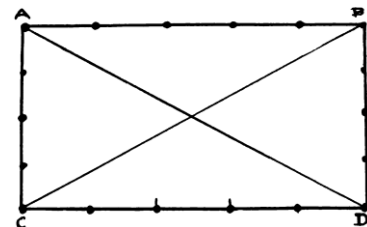


Figure 2.2: Hale Pili in Plan

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 92.

The above examples that William T. Brigham and his Bishop Museum team noted have some commonalities in their construction methods. In each, two main posts (pou hana) are used to support the ridge beam (kaupaku). In the older hale pili, the roof rafters extended from the kaupaku to the ground. The formed structure was essentially a roof lashed or tied down to stakes. As the hale pili evolved its structure became more advanced. In Figure 2.1, diagram C, the roof becomes more of a mansard style roof for additional structure. Brigham notes that Figure 2.1, diagram D eventually became known as a more structurally efficient and stable hale. In this example the rafters extend down to the exterior of the hale perimeter to a wall plate (lohelau) consisting of timber posts buried into the ground and/or stone (pohaku) foundation wall.⁸

⁸ William T. Brigham, *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History*, vol.2 no.3, (Honolulu, HI: Bishop Museum Press), 1908, 88-94.

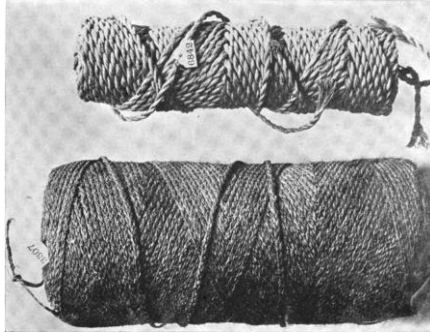


Figure 2.3: Hale Pili lashing fibers

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 87



Figure 2.4: Hale Pili Timber Posts, Rafters and Purlins

Source: Ibid, 94

The roof rafters and wall posts were then covered in purlins which were lashed into place with natural fiber. Typically, this fiber (Fig. 2.3) was coconut, olonā, ieie or sometimes hau and was used in all aspects of fastening and securing the hale pili from the ridge, purlins and rafter to wall connections (Figs. 2.4, 2.5).⁹

The material lashed to the purlins is the thatching for which the hale gets its name. Pili grass was most often used for its abundance along the coastline and the sweet smell it is famously known for giving off. Other materials used were loulu and other palm fronds that were braided or bunched together to create a waterproof seal. Brigham notes that some issues existed with the thatching and because the roof did not extend past the wall plate it was difficult to create a water tight seal.

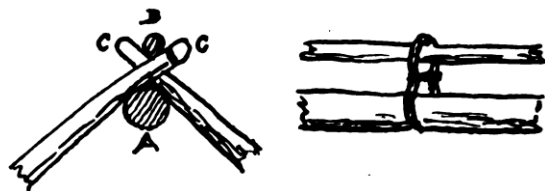


Figure 2.5: Hale Pili Lashing Examples

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 94.

Additionally, the thatching of natural material became host for insects and created health problems for its inhabitants.¹⁰ It is important to remember that the hale pili were not like the typical houses we are accustomed to today. In other words, the hale was thought of as a place to perform certain social or cultural

⁹ William T. Brigham, *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History*, vol.2 no.3, (Honolulu, HI: Bishop Museum Press), 1908, 88-94.

¹⁰ Ibid.

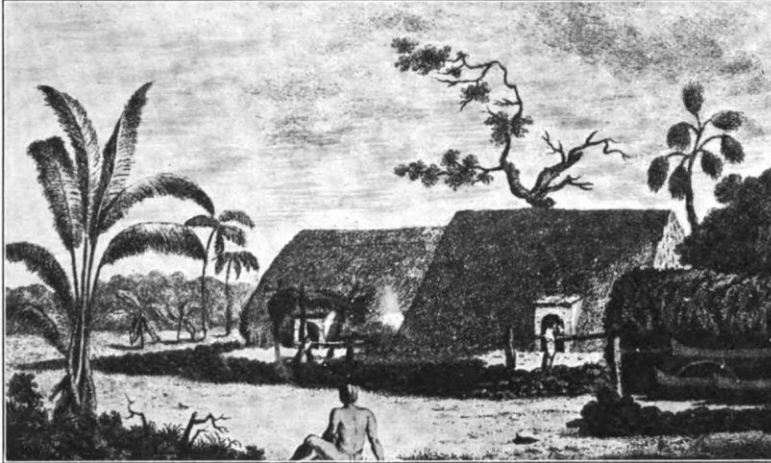


Figure 2.6: Village on Hawaii: W. Ellis

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 107.

disease and other health concerns that the hale pili began to show its limitations.

The hale pili did evolve over the years following contact with Westerners and missionaries. We can see from examples of the earliest hale pili to those which existed post contact that certain foreign elements began to show. The early hale pili in the era of Dr. William Ellis (Fig. 2.6) were simple, steeply pitched roof structures with a protrusion of a doorway to allow inhabitants to access the interior portion. Windows, traditional doors, interior partitions and flooring were not part of the typical design and were not present until much later. In later examples (Fig. 2.7), the addition of a covered lanai, Western style windows and the more familiar gable roof to wall plate shape existed. Eventually the addition of more traditional sawn timber used to frame doors, windows, lanais, railings

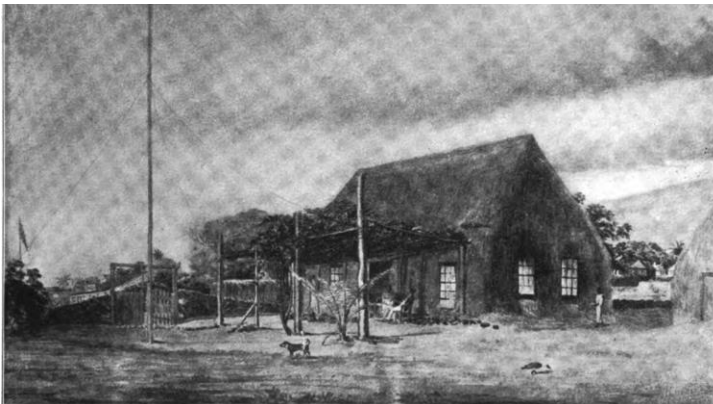


Figure 2.7: Hale Kamani at Lahaina

Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 89.

practices, to escape from bad weather, to store their belongings or to conceal oneself from a passing ali'i. The concern over insects or dust coming into the hale was not as important because the Hawaiian people spent much of their time outside. It is after contact with foreign people, insects,

and floors was adopted (Figs. 2.8, 2.9). It is here that Brigham believes the traditional hale pili was lost. Although thatching was used as the roof structure for some time, the simple native design was changed to suit the foreigners who built them.

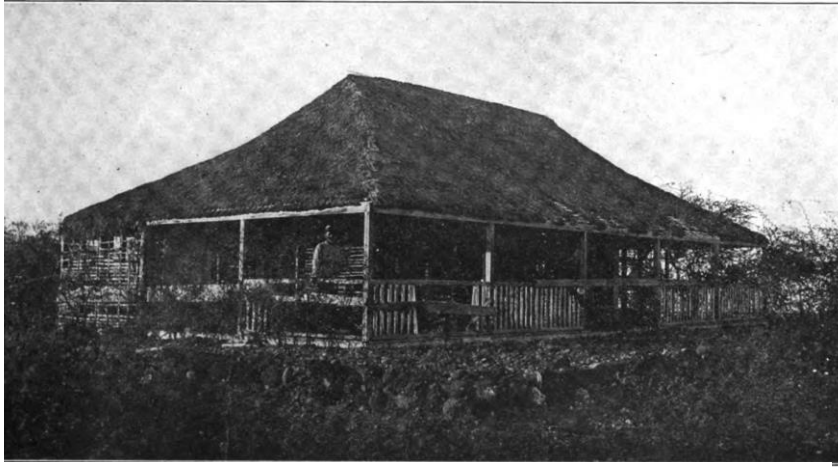


Figure 2.8: House of Kamehameha V at Kaunakakai

Source: Source: William T. Brigham *The Ancient Hawaiian House, memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology And Natural History*, vol.2 no. 3, Honolulu, HI, Bishop Museum Press, 1908, 111.

It is not to say that the evolution of the hale pili to incorporate foreign materials and methods was necessarily wrong. The reality is that the Hawaiian Islands were changing due to the presence and influence of the foreign peoples. The introduction of new pests, diseases and people required the hale to evolve more similarly to the traditional homes of Europe or the United States.

However, it can be said that the foreign influence on traditional Hawaiian hale building caused a shift in cultural practices and values. How the traditional Hawaiian hale would have evolved if foreign influence did not play a part is not significant because history tells us that architecture rarely



Figure 2.9: Henry Funk, *Alii Kekaihaakulou's Hale Pili*, Wailua River, circa 1900 , black and white photograph, Kauai Museum

Source:
https://commons.wikimedia.org/wiki/Category:Hale_Pili#/media/File:Hale_pili_in_East_Kauai,_photograph_by_Henry_Funk.jpg, accessed October 11, 2016

happens in a vacuum. Architectural influence and styles from outside cultures have always and will always impact how local building is perceived and designed. In Hawai'i today, we must not pine for the past or attempt to recreate the hale pili but instead look to the vernacular traditions for inspiration and lost knowledge.

The hale pili accomplished a few things that we can look to for inspiration for our new Hawaiian tropical house:

- used materials which were readily available, easy to replace and work with
- consisted of key structural elements and weatherproofing, no extra frills
- large open space, no major wall partitions
- provided protection from the harsh elements while working synergistically with the favorable ones
- kept rain and harsh sunlight out while the steep pitched roofs and breathable walls allowed for warm air to be exchanged.
- evolution of the hale pili included covered lanai areas to allow for indoor/outdoor cultural activities
- multiple smaller haies provided individual functions rather than one large multi-purpose space.

Some of the negative aspects of the hale pili given our current knowledge, social and cultural ideology include:

- primary materials for framing and weatherproofing were organic and susceptible to insects which may harbor disease (cockroaches, rats, fleas and eventually termites)
- connections made only with natural fiber lashing and buried timber posts have structural limitations; susceptible to rot, hurricanes, strong rain or wind, earthquakes; limits to size and occupancy
- building infill consisted of only organic thatching, allows dust and potential source for major fires
- traditional foundation of hale pili limits where they can be sited

Moving forward we can study the pros and cons of the hale pili and integrate the ideas which are applicable into 21st century Hawaiian residential architecture for the creation of a healthier, more climatically, culturally and socially sympathetic hale. We will use this knowledge and the knowledge gained from other building styles to inform our new design

CHAPTER 3:

EXOTIC + INVASIVE HAWAIIAN ARCHITECTURE: MISSIONARIES TO MODERNISM

The residential architecture that exists today is hardly a straightforward evolution from the hale pili discussed in the previous chapter. In fact, many types of architecture have been part of the Hawaiian story in a relatively short period.



Figure 3.1: Mission Frame House, King St, Honolulu, HI

Source: Historic American Engineering Record, Historic American Buildings Survey, Historic American Landscapes Survey, 1966. From Prints and Photographs Division, Library of Congress (HABS HI,2-HONLU,19—1) accessed September, 12, 2016. <http://www.loc.gov/pictures/item/hi0032.photos.057909p/resource/>

Perhaps the first major residential architecture type that found its way to the islands was the mission houses. These houses were built by relatively unskilled missionaries with imported materials from their native homelands. A good example of persisting mission house architecture is the Hale Lā'au, or the Frame House. This was the first mission house permitted to be built in Honolulu by the king, and remains the oldest wood frame structure still in existence in Hawai'i (1821).¹¹ Interestingly, the house was built as a prefabricated timber framed structure and shipped over from Boston to the islands. The lack of knowledge of the Hawaiian climate and inability to mill local woods meant the Frame House was predesigned in Boston without regard to the local environmental conditions. For example, the windows were originally relatively small, allowing more heat to remain inside the house. Too, the roof was built without eaves- a common characteristic in the American Northeast to combat against snow loads - permitting sun to blast the sides of the house and create unnecessary high heat gain and temperatures indoors. Initially, there were more windows on the sides of the house, but during its evolution these were removed and ventilation was compromised.¹² The foundation was originally

¹¹ "Historic Buildings," Hawaiian Mission Houses Historic Site and Archives (website), accessed September, 12 2016, <http://www.missionhouses.org/collections/historic-buildings>

¹² Spencer Leinweber, *lecture on the Frame and Chamberlain Houses for the Hawaiian Mission Houses(Historic Site and Archives, (Honolulu, HI, n.d.),* accessed September, 12 2016. <http://www.missionhouses.org/collections/historic-buildings>

adobe, a useful material in other parts of the world but an issue in Hawai'i. The quality of clay soil coupled with a relatively high water table quickly weakened the foundation and had to be fixed with coral blocks and, later, lime plaster.¹³ The productive changes along the way, like adding covered lanais for shaded outdoor space, were important steps in adapting the Frame House to the Hawaiian climate.

Overall, the Frame House was not well suited for the environment. In addition to the obvious flaws with the exterior design, the interior layout was in the Georgian style, i.e., rooms, and therefore people, were separated. This separation of inhabitants is opposite of the vernacular tradition of the hale pili where one big open space was available to all the occupants. Other mission houses in this area were later built with cut coral (Chamberlain House, 1831) and began to show some adaptations to the tropical climate. Nevertheless, the mission houses were ill suited for the environment and as with most residential architecture on the islands during the early 19th century they blatantly ignored local vernacular traditions.



Figure 3.2: Wai'oli Church, Hanalei, HI

Source: Historic American Engineering Record, Historic American Buildings Survey, Historic American Landscapes Survey, 1973. From Prints and Photographs Division, Library of Congress (HABS HI,4-HANLI,3--3) accessed September, 13, 2016
<http://www.loc.gov/pictures/resource/hhh.hi0021.photos.058511p/>

This is not to suggest all imported architecture is wrong. To the contrary, the combination of imported and vernacular seems to have the most desirable, or at least the most lasting result. For example, the buildings at Wai'oli Mission District show a much greater evolution toward the local climate, culture and respect for the vernacular. The Wai'oli Hui'ia Church (1841), in fact, had to be rebuilt twice because the original thatch structure built in the hale pili tradition was burned and later destroyed by a storm.¹⁴ The existing iteration is a

¹³ Ibid

¹⁴ Department of the Interior National Park Service, *National Register of Historic Places Inventory – Nomination Form, 10-300, Waioli Mission*, July, 1969, Washington D.C.: Library of Congress, accessed September 14, 2016. <http://focus.nps.gov/pdfhost/docs/NRHP/Text/73000676.pdf>

wood framed structure surrounded by a covered lanai supported by wood posts. The steeply pitched roof is framed by custom cut local timber which breaks at the wall plate to a lesser pitched roof covering the lanai. This roof style is an important evolution in Hawaiian tropical residential architecture and is rightfully one of the models for contemporary tropical design today. The steep pitch of the roof allows for high ceilings and aids in the removal of warm air from the large open interior spaces. The pitch also helps in quickly removing large amounts of rain in heavy storms. This style harkens to the vernacular with its high pitch and local hardwood rafters (like the hale pili), covered lanai and split pitch are progressions in roof design to an even more climatic and culturally sympathetic typology.



Figure 3.3: W.H. Shipman House

Source: <http://focus.nps.gov/AssetDetail?assetID=04530dcd-dd44-49c6-a685-179ec7002f68> accessed September 15, 2016.

Many other styles of residential architecture eventually made their way to the islands from Britain, the United States, Asia and other Pacific nations. Most styles were present somewhere in the islands at some point or another. By simply checking National Register of Historic Places for Hawai'i we can catch a glimpse into the various types of residential architecture which have existed over the years. The W.H.

Shipman House (Fig. 3.3) was in the Victorian style, the Lyman House in Cape Cod style, the Fred Baldwin House in the American Craftsman and the Lloyd Case House was Tudor.¹⁵ While some of these types of architecture had features or details suitable to the islands, generally they were not a

¹⁵ State Historic Preservation Office, database of Nominated and Listed Properties on the Hawaii and National Registers of Historic Places 9-15-2016, accessed September, 15, 2016, <http://dlnr.hawaii.gov/shpd/state-register/>.

Hawaiian tropical architecture in and of themselves and the adaptations were not natural to their intended styles.

The residential architecture type that has had the greatest influence on current design and building in Hawai'i is the Hawaiian plantation style. The height of the plantation era lasted over a hundred years from the mid-19th century to mid-20th century. Although the goal of plantation camp housing was economy over architectural evolution, it has had the greatest impact on the architecture that we see around the islands today. Arguably, the evolution of the original plantation house to the Dickey "Hawaiian" style homes are some of the most well suited houses for the island climate and culture.



Figure 3.4: Ewa Sugar Plantation Village

Source: <http://historichawaii.org/2014/02/28/91-1228-renton-roadewa-sugar-plantation-villages/> accessed September 15, 2016.

Plantation houses were simple by today's standards, consisting of primarily timber framed, single wall construction. Depending on their use and their location the roof structures were relatively simple, low pitched hip and gables structures with tin or wood shingles. They were almost exclusively on pier and post foundations with wood framed floors, doors and windows. The fenestrations were larger and more numerous than that of the mission houses which helped with natural ventilation. This reliance on timber and the construction methods used had benefits, but there were also some major issues that we can learn from.

The single wall construction was simple, easy to maintain and replace, and its lack of wall cavity eliminated a place for insects, rats, and contaminants (mold, dust, etc.) to hide. Plantation houses were also raised off the ground which accomplished a few things: first, the house was

adaptable to many geographic areas with minimal site work; second, the homes had minimal impact on the environment; finally, they were more resilient to flooding. The roofs were also simple and effective, usually consisting of exposed rafters with purlins to support the roofing material. The roof extended a few feet beyond the wall plate and the pitch was sufficient to shed rain off quickly and to shade the walls while remaining low enough to withstand wind. These houses were also typically sited in a way to maximize cross ventilation through the windows, and their covered lanais gave inhabitants a space to spend outdoors in a covered area.

Although this style of house was successful for the plantation camps and villages- becoming, at least in part, the basis for the future “Hawaiian” style- there were significant flaws that needed to be addressed. The single wall construction was only about 1” to 1-1/4” thick, which by today’s standards would give an R value of about 1.2-1.5.¹⁶ According to the International Energy Conservation Code (which I am not claiming to be the only correct source of climatically correct building standards in Hawai‘i), to meet compliance with energy efficiency and comfort standards the R value should be 13 for walls.¹⁷ The vertical board and batten or shiplap siding was the only barrier protecting the inside of the home from the elements. This meant that in heavier rains and strong winds the siding was susceptible to the full force of the water. Even on normal days the single wall construction did little to combat against heat and humidity penetrating the home, which meant a total reliance on proper orientation and natural ventilation to keep the space comfortable. Further, the reliance on complete timber construction meant that homes would be particularly susceptible to fire and termites, especially in areas where plantation houses would normally be built.

While most plantation houses in the late 19th and early 20th century were sited on actual plantations, the adaptation of this popular building type resulted in plantation home construction all over the state. In some areas, the houses could be extremely hot or cold and exposed to varying wind and rain patterns. I have personally been in single wall constructed plantation houses that were quite comfortable in Hāmākua, but too cold (and moldy) in Waimea and too hot in Kona on typically normal weather days. Interestingly, these are all located on the same island and within 60 miles of each other. Although slight variations in design and material can be seen across the state, the typical

¹⁶ United States Department of Energy (website). Energy Saver – Energy Efficiency in Log Homes. Accessed September 20, 2016. <http://energy.gov/energysaver/energy-efficiency-log-homes>.

¹⁷ 2015 *International Energy Conservation Code*, International Code Council, Inc, (Illinois: Publications, 2014).

construction method and materials used for plantation houses were not very adaptable to different climate types. The layout, the fenestration, the lanais and the roofs, however were recognized by many early 20th century Hawaiian architects.

It was not until C.W. Dickey and Hart Wood (who later renovated the Wai'oli Mission District) immigrated to the islands at the turn of the century that designing residential architecture suited to the climate and Hawaiian way of life became a primary concern. One of the most applicable quotes on Hawaiian architecture to this day was said by Hart Wood in 1920:

We often hear, that Hawai'i should have a distinctive style of architecture for her homes, but those who make the statement seldom realize that the development of an architectural style is not a matter of accomplishment by one generation. It takes hundreds of years to establish an accepted "style" – and then it will be, in all probability, a combination of several other "styles," molded to the especial requirements of a local condition.¹⁸

It is not the purpose of this dissertation to create a design which would become the "distinctive style" of Hawai'i or equal the summation of the "especial requirements of a local condition." Rather, it is to simply add to the evolution of Hawaiian residential architecture that began before any foreign architects set foot on the islands. Learning from the methodology of Dickey and Wood and the architects that proceeded them as part of the evolution toward a Hawaiian architecture.

¹⁸ Don Hibbard, Glenn Mason and Karen Weitze, *Hart Wood Architectural Regionalism in Hawaii*, Honolulu: University of Hawaii Press, 2010, 99.



Figure 3.5: Joel Bradshaw, *Canavaro House*, photograph, 2010

Source:

https://en.wikipedia.org/wiki/Georges_de_S._Canavaro_House#/media/File:Honolulu-George-deS-Canavaro-house.JPG accessed September 22, 2016

Dickey and Wood, together as a firm and individually, experimented with different styles of design. It was their notion, as well as most of the Honolulu architects at the turn of the century, that Hawaiian residential architecture should be a tweaked version of the Spanish and Italian Mediterranean styles (Fig. 3.5) which existed in Europe and California. Eventually, both architects realized that the Hawaiian style had to be something of its own, not just a version of an imported architecture. Although Dickey and Wood had shown an interest in a more regional style early in their careers, politically it was also the right timing for these two architects; the death of Queen Lili‘uokalani in 1917 was simultaneously a symbolic end to the Hawaiian monarchy and end to the overt effort to place an American or colonial influence on Hawaiian architecture. In other words, architects no longer had to try to insert their “flag waving” authority on island architecture and would be free to develop a unique regional style to the newly founded territory. Whatever the socio-cultural-economic reasoning was, the evolved residential work of Dickey, Wood and other like-minded architects of the time would eventually go on to inspire 20th century Hawaiian architects like

Ray Morris and Vladimir Ossipoff who arguably designed some of the most well suited houses for the Hawaiian climate and culture.

C.W. Dickey is often credited as the architect who developed the “Hawaiian” style; it is his four principles that have guided most other architects (including myself) to some degree in the pursuit



Figure 3.6: Joel Bradshaw, *C.W. Dickey's Own Home*, photograph, 2009

of a successful tropical house. Those principles are:

- Double-pitched hipped roof (roof centric design)
- Effective cross-ventilation
- Lanai's
- Large windows (or openings)

Source:

https://en.wikipedia.org/wiki/National_Register_of_Historic_Places_listings_in_Oahu#/media/File:Honolulu-CWDickey-House-Kalakaua3030.JPG accessed September 22, 2016

We see these principles at Wai'oli and other works by Dickey and Wood, but the summation of the “Hawaiian style” in the early 20th with the greatest and lasting impact on residential architecture was C.W. Dickey's own home (Fig. 3.6), and the proceeding Lewers and Cooke Ltd. Houses.

Ray Morris, who briefly worked in the office of Dickey and Wood, went on to become the head architect for Lewers and Cooke Ltd., a large building supply company during the early to mid-20th century. As with this project, Morris convinced his boss that Honolulu (and therefore the rest of the state) needed a better priced and better designed architecture. Morris looked to build upon the plantation style that was already popular (single wall, board and batten) by adding elements he learned from his time at Dickey and Wood, i.e., the four principles (specifically the roof and lanais).

The Lewers and Cooke, Ltd. catalog from this era gives insight into the specifics of the materials, construction methods and design intent of the Dickey inspired, Ray Morris designed homes. As previously mentioned, the basis of design for Dickey and Morris stemmed from plantation style homes. Thus, the Lewers and Cooke, Ltd. catalog emphasized different types of single wall

construction, pier and post foundations, T & G, board and batten and shiplap sidings, imported timber (Douglas fir, Pine, Redwood, Cedar), and hipped or gable roofs with covered lanais.¹⁹

The evolution from pure plantation style to the “Hawaiian style” promoted in the catalog is clear among the varied house plans and finish options. The exterior siding, one of my chief complaints of plantation style architecture, sees various levels of construction based upon price and material. Single walled types of T & G and board and batten were the cheapest type; they used the same piece of timber for both exterior and interior finish.

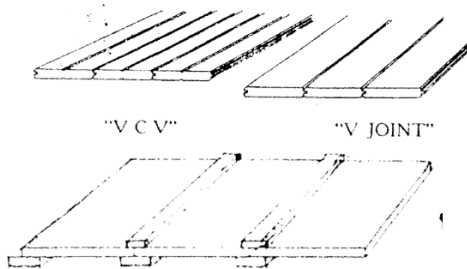
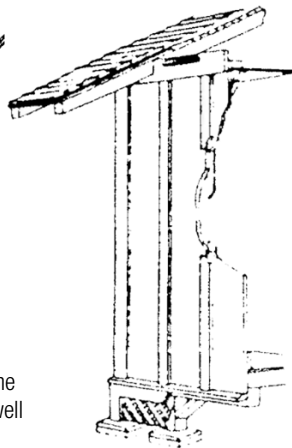


Figure 3.7: Single Wall Construction Types

Source: *Homes in Hawai'i, Suggestions for the Home Builder*, Lewers and Cooke, Ltd Catalog, pp. 7, Lowell Angell Collection (digital), Honolulu, HI



Double board wall types were an upgrade to single wall and included vertical boards similar to board and batten, but instead of battens they incorporated building paper as moisture protection and then nailed beveled horizontal

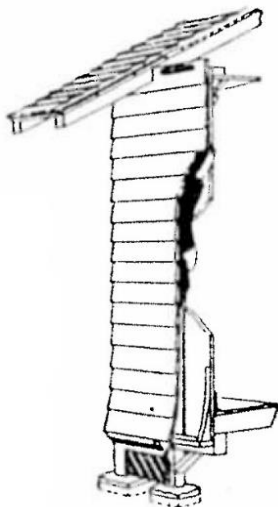


Figure 3.8: Double Board Types

Source: *Homes in Hawai'i, Suggestions for the Home Builder*, Lewers and Cooke, Ltd Catalog, pp. 9, Lowell Angell Collection (digital), Honolulu, HI.

timbers or lap siding planks over that. This provided additional structural support, moisture and thermal protection and a different aesthetic appeal.

The next type of exterior wall system was the shingled wall construction. This type used the same method as the double board method but instead of lap siding shingles, royals or shakes were nailed over 1" x 3" horizontal strips over the building paper. The catalog explains that this type of siding was climatically advantageous, “Various weather exposures are used according to the

¹⁹ *Homes in Hawai'i, Suggestions for the Home Builder*, Lewers and Cooke, Ltd Catalog, Lowell Angell Collection (digital), Honolulu, HI, 5-15.

surface pattern desire... Shingled Wall Construction is tight against wind and rain and has better insulation against heat.”²⁰

The catalog also includes double wall construction (Fig. 3.10). This evolution in building was incredibly important in the evolution of Hawaiian residential architecture, as it is the most common timber frame methodology still used today. Double wall construction used a floor plate which supports a 2” x timber frame to which exterior and interior finishes are attached with a cavity in between. The catalog explains that this method of framing is both “required by law in all two-story houses” and is “the most durable way of constructing frame buildings.”²¹ This type of wall could use any type of siding, including stucco which was applied on metal lath.

The next evolution in residential design that we see in the Lewers and Cooke, Ltd. catalog is in the roof design. Morris was directly inspired and informed on tropical roof design from his time with Dickey and Wood in the late 1920s. The catalog brags about local architects adopting “the graceful sloping lines of the Grass Hut that they might perpetuate for this community a distinctive style of architecture that can be known as ‘The Hawaiian Type’.”²²

Such a statement is quite obviously a nod to the hale pili tradition and the turn of the century renovations and inspirations like the buildings at the Wai’oli district. Adopting the split pitch roof in residential architecture was a significant step in combining vernacular elements into Hawaiian

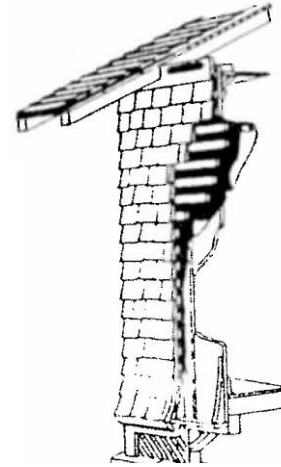


Figure 3.9: Shingled Wall Construction

Source: *Homes in Hawai'i, Suggestions for the Home Builder*, Lewers and Cooke, Ltd Catalog, pp. 10, Lowell Angell Collection (digital), Honolulu, HI.

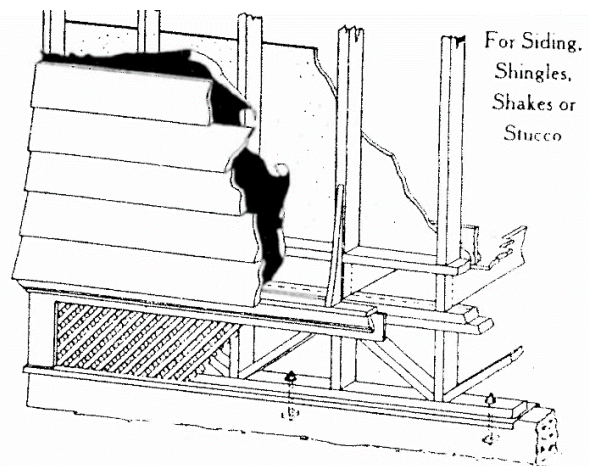


Figure 3.10: Double Wall Construction, Lewers and Cooke, Ltd.

Source: *Homes in Hawai'i, Suggestions for the Home Builder*, Lewers and Cooke, Ltd Catalog, pp. 11, Lowell Angell

²⁰ Ibid, 10.

²¹ Ibid, 11.

²² Ibid, 12.

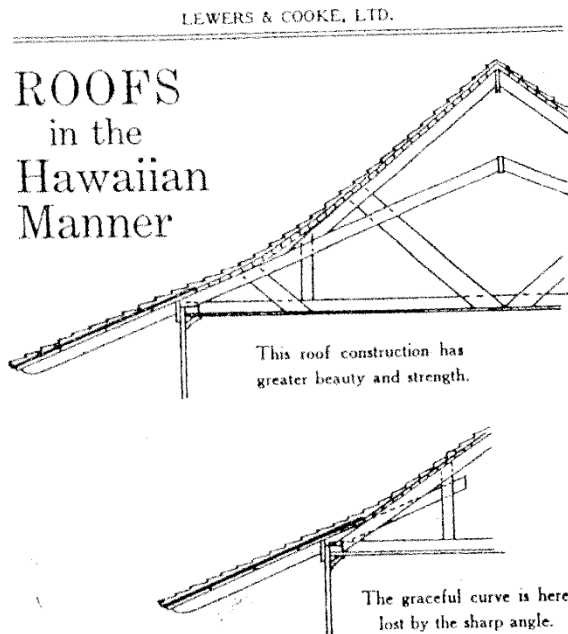


Figure 3.11: Roofs in the Hawaiian Manner

Source: Lewers and Cooke, Ltd. Catalog, Lowell Angell Collection, 12

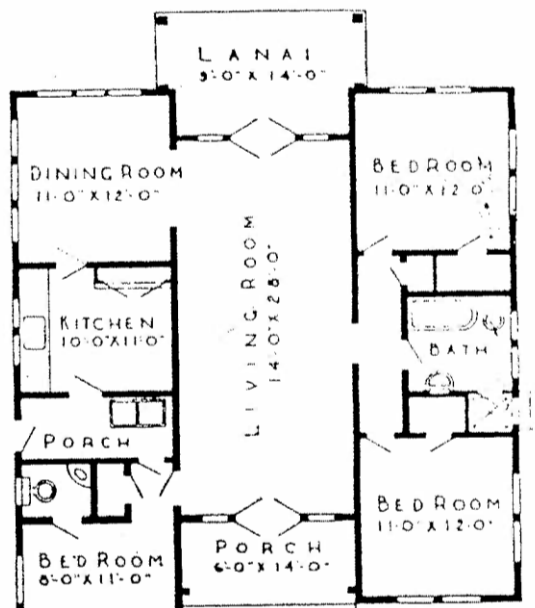


Figure 3.12: Lewers and Cooke, Ltd. Typical House Plan

Source: Lewers and Cooke, Ltd. Catalog, Lowell Angell Collection, 63

residential architecture language. The catalog rightfully brags “there are two practical features about roofs in the Hawaiian manner that make them particularly desirable for this climate. The high center hip leaves ample air space above ceilings to insulate against the sun’s heat, while the wide overhanging eaves relieve sun glare and allow windows to remain open during Hawai’i’s frequent refreshing showers.”

The floor plans of the Lewers and Cooke, Ltd. houses were also an evolution in design from the previous imported residential layouts. In Figure 3.12 we can see a clear axis down the center of the plan from front covered entry to rear covered lanai. This allows light and air to enter freely throughout the main gathering places. Additionally, this layout controls circulation centered around the main living room area and covered outdoor areas.

In Figure 3.13 we see the same strong central connection to the living space but with an even larger covered lanai with access to the kitchen. This plan promotes

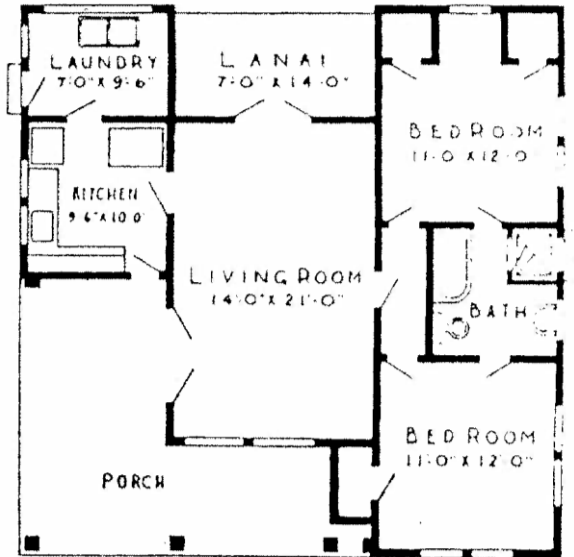


Figure 3.13: Lewers and Cooke, Ltd. Typical House Plan – 2

Source: Lewers and Cooke, Ltd. Catalog, Lowell Angell Collection, 35.

outdoor living and eating while minimizing interior dead zones like long hallways or closets. In both examples, large windows and doors help to create a naturally ventilated space.

Despite the many positive evolutions in design that the Lewers and Cooke, Ltd. houses had from their predecessors, there were still some major drawbacks. The houses continued to have difficulties adapting to different climate types. Heat, wind, rain and humidity vary greatly across the island chain and the primarily single or double board construction

did not provide much insulation from the elements. Additionally, these houses were offered as what we may call a kit home today. In other words, the purpose of these designs was to sell building materials. In general, most, if not all the materials were imported from out of state. Even if better alternatives existed locally, the supplier would push the materials which would make them the most profit. Best intentions aside, not using any local materials severely limited the regional aspects of the design. Arguably, the floor plans also seemed to reflect an imported ideal of residential experience which separates inhabitants based upon specific experiences in the living space, i.e., kitchen, living, bedrooms and utility spaces segregated from each other. The tradition of the hale pili were large open plans with distinct purposes helped inhabitants to socialize and perform cultural traditions.

Regardless of the building materials, methods or styles that were employed by Lewers and Cooke, Ltd. or other “Hawaiian style” houses of the early to mid-20th century, they were undoubtedly important in the evolution of the residential architecture we have today. When we look around the neighborhoods that rose out of missionary and plantation era Hawai‘i we see a vague resemblance of

what used to be there. The current single family architecture that has been built either mimics the aesthetic of plantation homes or is an imported “tropical” design from mainland United States.

By the mid-20th century, architects in the Hawaiian Islands began to experiment with the newly popularized Modern movement. This movement meant new materials, new ideals and new types of architects. Perhaps the most popular of them all was Vladimir Ossipoff, a Russian born, Japanese raised, California trained architect who moved to Hawai‘i in the 1930s. Ossipoff and other architects at the time were heavily influenced by Dickey, Wood and the Lewers and Cooke “Hawaiian style” residences. In the early work of Ossipoff we see clear direction from the previously mentioned styles. The Boettcher Estate in Kailua, built in 1937, has the deep eave, split pitched “Hawaiian roof”, board and batten siding, large windows and doors with operable openings to control the ventilation and, of course, large covered lanais.²³



Figure 3.14: Joel Bradshaw, 2009, *Boettcher Estate*, 248 N. Kalaheo Ave, Kailua, Vladimir Ossipoff

Source: https://en.wikipedia.org/wiki/Boettcher_Estate#/media/File:Boettcher-estate.JPG accessed September, 24 2016.

It is no surprise that the Boettcher Estate and other early residential works from Ossipoff were heavily influenced by Dickey, Morris and the like. The newly immigrated architect worked with Dickey on a few projects and was clearly influenced by his desire to work within the bounds of climate

²³ Karla Britton et al., *Hawaiian Modern: The Architecture of Vladimir Ossipoff*, (New Haven, CT: Yale University Press, 2007), 75.

and site. However, the influence of modernism and a profound understanding of place gave Ossipoff his unique design sensibilities. Ossipoff understood the evolution of Hawaiian architecture and he understood the culture which inhabited it. He would focus on the place where a home was to be sited, its climatic conditions and vernacular elements and combine those with the cultural requirements of the islands to create an architecture which succeeded both socially and environmentally. Ossipoff used his knowledge to focus on intermediate spaces between indoor and outdoor which we often simply call the lanai, as a place to shelter from the rain, sun and wind. He would also use his knowledge of the trade winds and the understanding of wind pressure differences to naturally ventilate a space to optimize thermal comfort.



Figure 3.15: The Lijestrund House, View from the side

Source: Bob Lijestrund Collection

It was Ossipoff's belief that good architectural planning could negate the need for mechanical ventilation, this is entirely evident in the Lijestrund House on Tantalus where the sloped terrain and wind patterns are advantageously controlled by the fenestrations and pressure differences.

The house is not only suited to its environment through orientation (ventilation, sun and rain), but to its terrain with its natural wood and stone frame, sweeping horizontal lines, large covered decks and focus on the views of Honolulu below. Culturally, the focus on outdoor space, views and materials are un-paralleled in similar work of its time. The Liljestrand house was finished in 1952, so unsurprisingly it contains strong modern elements using simple and exposed structural elements, large unobstructed glazing and relatively open plan.

The lessons we learn from Vladimir Ossipoff is that good Hawaiian architecture is not a vague or decorative nod to the vernacular just as it is not a bold, heavy and defiant shunning of the past. Ossipoff knew that simply dropping the modern buildings of his time in Hawai'i was wrong environmentally and culturally. He also knew that recreating the past, whether it was the original hale pili, missionary, classical, plantation houses or early Hawaiian style cottages of Dickey and Morris, would only get us so far. Moving forward we look to Ossipoff, and to his predecessors and his successors for inspiration, knowledge and a sense of the evolution of our architecture. We must understand, like Ossipoff, the importance of environment, climate, site and the culture to create a regional architecture that we can be proud to call Hawaiian.

One final note on this chapter; I would like it to be clear that the evolution of Hawaiian residential architecture did not happen in a sequential manner as it may appear during this chapter. There are many different architects, styles and influences that have existed over the years. Those mentioned in this chapter are just some of the most common styles which have clear correlations to the current style of building.

At this point I would like to take a step away from what has happened in the past and explore the current variables that must be studied and addressed in the design of a successful and healthy new Hawaiian home.

CHAPTER 4:

THE HAWAIIAN CLIMATE + GEOGRAPHY

Architecture is not just about designing buildings in space; instead it is about designing both the built and natural areas which make up the site. We must consider many environmental and geographic variables to design something which works harmoniously with its surroundings. We must understand the geographic and ecologic intricacies of the land just as we must consider the climate and how the factors of temperature, rain, humidity and wind relate to the land, a site and the planned structure. Surely, we should not use the same design for a home in the middle of a hot desert climate surrounded by lava rocks as we would a home in the rainforest. Doing so would most likely leave us with an architecture that fails in some aspect of thermal comfort, human health or environmental conservation. Sadly, this is the state of most Hawaiian residential architecture today.

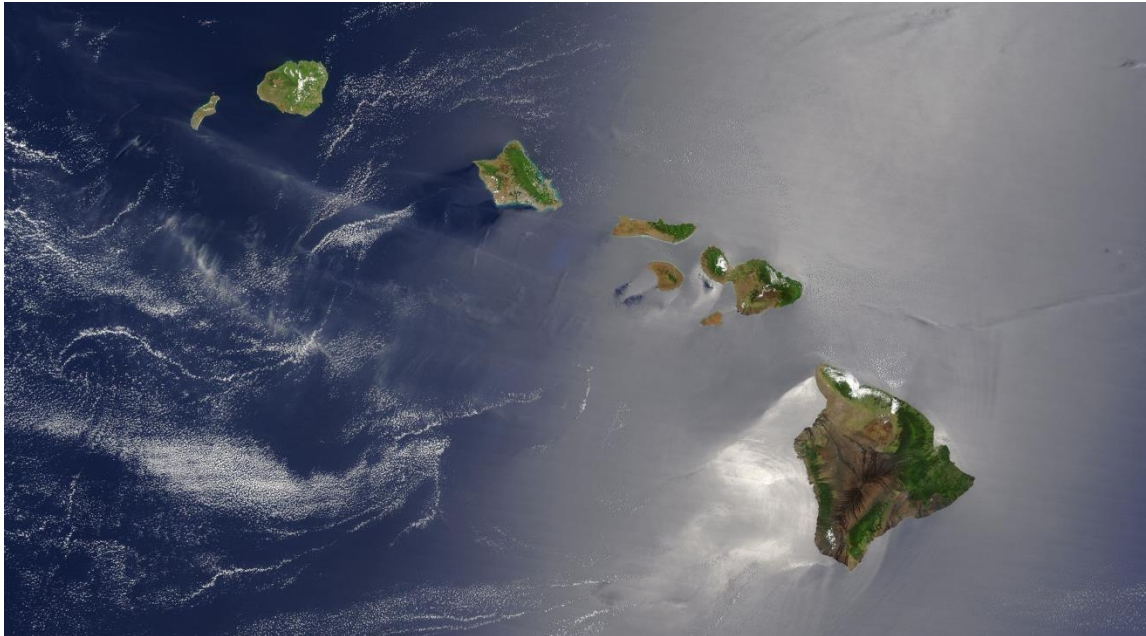


Figure: 4.1: The Hawaiian Islands by Satellite

"Source: Hawaiian Islands: Image of the Day". NASA Earth Observatory. May 27, 2003, <http://earthobservatory.nasa.gov/IOTD/view.php?id=3510> accessed November 28, 2016.

4.1

CLIMATE

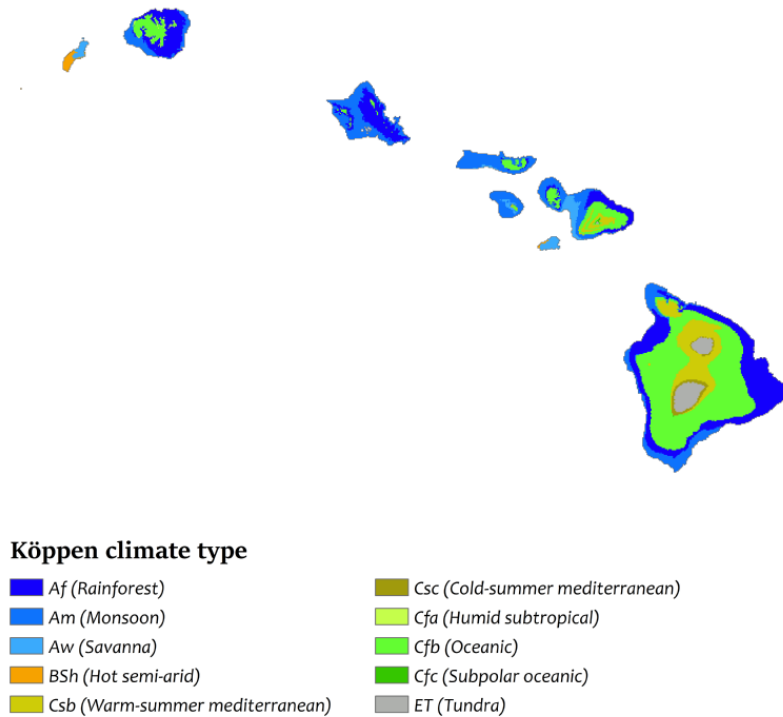
It is with good reason that the Hawaiian climate is referred to as paradise. Consistently warm temperatures with cool trade winds and balmy rain make it a place where one wants to be outside to live, work and play. Weather in Hawai'i is not like this year round though, and the islands can go through very wet or very dry seasons like most of the world. Regardless of the uncommon extremes in weather, it is this reputation for an easy, breezy climate and lifestyle which brings so many people to the Hawaiian shores. With an ever-growing population and need to expand our residential architecture, understanding the climate is essential in the design of future homes. One issue that architects face in Hawai'i is the numerous climates and variances in geography and vegetation, making it difficult to have a one size fits all solution to designing a Hawaiian home.

In fact, the climate in Hawai'i varies significantly throughout the island chain with changes which occur extremely rapidly over short distances. According to Thomas Schroeder, emeritus professor of meteorology at University of Hawai'i at Mānoa, "The gradients of weather we have in the state are remarkable." Rainfall is especially affected by the changes in temperature, elevation and proximity to water sources. Schroeder continues, "From one end zone to the other end zone in Aloha Stadium, the difference in annual rainfall would be 7 inches --that's greater than the difference between Chicago and Louisville. That's a world record."²⁴

²⁴ Diana Leone, "Rain supreme: Heavy showers and the gauges to measure them rest atop Kaua'i's Mount Wai'ale'ale," *Honolulu Star-Bulletin*, May 27, 2002, accessed September, 5 2016, <http://archives.starbulletin.com/2002/05/27/news/story3.html>.

These remarkable gradients that Schroeder references occur from the majority of the worlds climates that exist in the state ranging from hot semi-arid deserts to frozen tundra. Although we have many climates to deal with and the effects vary greatly across the state, most of the habitable portions of Hawai'i fall within a similar temperature and humidity range for the purpose of this design process. Further, we are primarily concerned about how temperature, humidity and precipitation create indoor environments and how they affect comfort and health. By using the Köppen climate classification

Köppen climate types of Hawaii



*Isotherm used to separate temperate (C) and continental (D) climates is -3°C
Data source: Climate types calculated from data from WorldClim.org

Figure 4.2: Adam Peterson, *Köppen climate types of Hawaii* is licensed under CC BY 4.0, <https://creativecommons.org/licenses/by-sa/4.0/>

Source: https://en.wikipedia.org/wiki/Climate_of_Hawaii#/media/File:HL_koeppen.png

system along with historical weather data we should be able to develop a thorough enough understanding of the most typical residential environment to aid our design process. Further, given the willingness to study and immerse oneself in the design, the information is out there to design each for each unique site condition.

The Köppen climate classification system, often referred to as the Köppen-Geiger climate classification system, was first published in 1900 and has been modified many times since as an empirical method of organizing and grouping climates based on biomes or major life zones.²⁵ This system gives us insight into temperature, precipitation, aridity and vegetation growth, all of which are important variables in good architectural design processes.

If we look at the Köppen map of the state (Fig. 4.2) we see that the state contains 10 different climate types, all of which occur in some degree on Hawai'i Island and many of which occur throughout the rest of the archipelago. If we compare Figures 4.2 and 4.3 we see that the most inhabited areas of the state (Fig. 4.3) primarily consists of Af (Rainforest), Am (Monsoon), Cfb (Oceanic), BSh (hot, semi-arid) Aw(Savanna) (Fig.4.2).

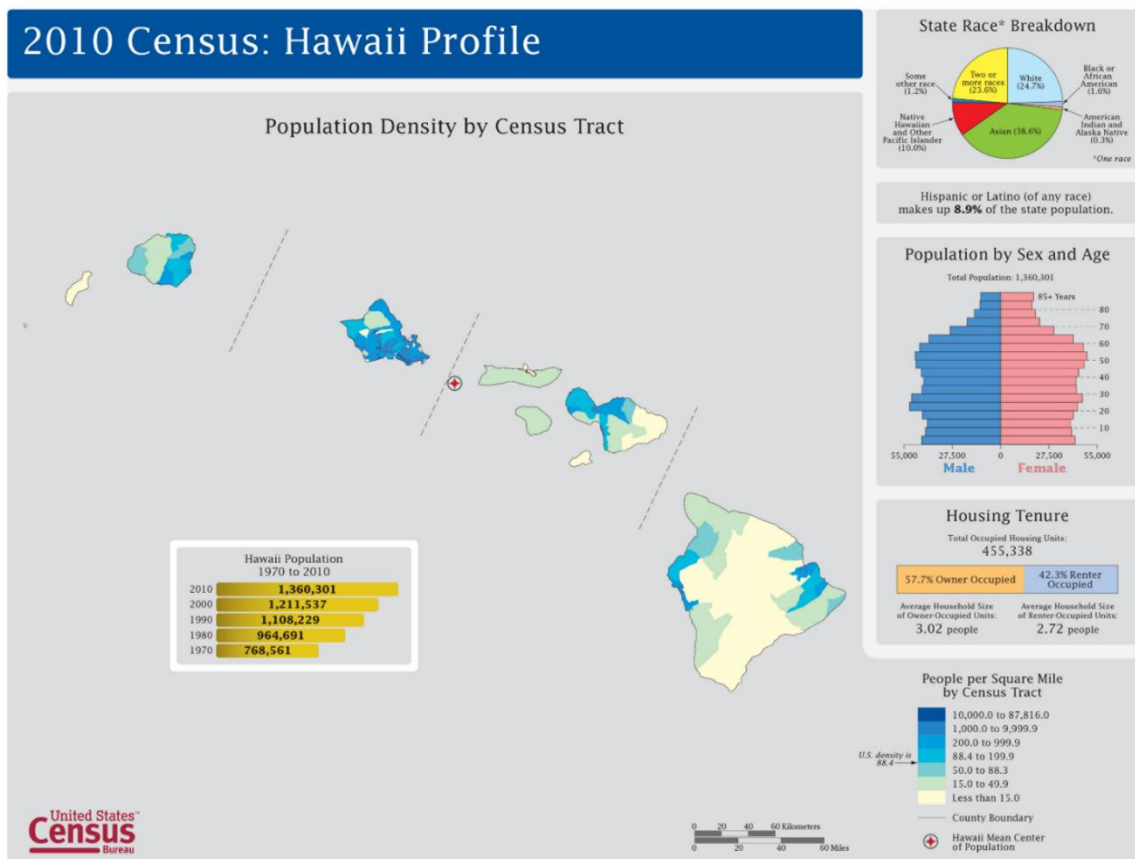


Figure 4.3: 2010 Census: Hawaii Profile, United States Census Bureau

Source: http://www2.census.gov/geo/maps/dc10_thematic/2010_Profile/2010_Profile_Map_Hawaii.pdf accessed September 27, 2016

²⁵ *Encyclopedia Britannica Online*, s.v. "Koppen Climate Classification," accessed October 15, 2016, <https://www.britannica.com/science/Koppen-climate-classification>

Looking closer at the climate types, we can clearly see the commonalities of moderate to high annual temperatures, humidity and precipitation.

Af; Rainforest, wet equatorial climate: Characterized by high temperatures (86 °F, Avg.) rainfall (59-394 inches) and humidity with little annual variation.²⁶ (Hilo, Kailua)

Am; Tropical monsoon and trade-wind littoral climate: High temperatures and humidity which resemble the wet equatorial climate but with more precipitation during hotter months than the Af type. The shorter dry season due to trade wind activity which elevates rainfall levels enough to not be considered Aw type (*Kapa'a*, Hāmākua).²⁷

Aw; Savanna, Tropical wet-dry climate: As the name indicates, this climate type is also similar to its other "A" type climates but with a more distinct wet and dry season. Aw climates have similar temperature (66-68°F winter, 75-81°F summer), humidity and annual precipitation levels but with a much wetter summer season (Parts of central Maui, North Kohala).²⁸

BSh; hot or tropical semi-arid climate: Variable temperature and rainfall conditions depending on the specific location. Typically for the state areas are hot with little rainfall and medium to high humidity (Waikoloa, Lāhainā, Honolulu).²⁹

Cfb, Oceanic, marine west coast climate: This climate type is characterized by precipitation which exceeds 197 inches annually which is similar to tropical "A" climates. Temperatures are typically lower ranging between 50-59°F and mild in the winter and up to 68°F and moderate in the summer months although Cfb climates in Hawai'i tend to be warmer and more humid (Waimea, Kula).³⁰

Although the Köppen climate classification system is widely used to understand climates around the world, to fully appreciate the local variances to the broader climate categories we should look at some data which is more specific to the state.

²⁶ *Encyclopedia Britannica Online*, s.v. "Wet Equatorial Climate," accessed October 15, 2016, <https://www.britannica.com/science/wet-equatorial-climate>

²⁷ *Encyclopedia Britannica Online*, s.v. "Tropical Monsoon and Trade Wind Littoral Climate," accessed October 15, 2016, <https://www.britannica.com/science/tropical-monsoon-and-trade-wind-littoral-climate>.

²⁸ *Encyclopedia Britannica Online*, s.v. "Tropical Wet Dry Climate," accessed October 15, 2016, <https://www.britannica.com/science/tropical-wet-dry-climate>.

²⁹ *Encyclopedia Britannica Online*, s.v. "Mid Latitude Steppe and Desert Climate," accessed October 15, 2016, <https://www.britannica.com/science/mid-latitude-steppe-and-desert-climate>.

³⁰ *Encyclopedia Britannica Online*, s.v. "Marine West Coast Climate," accessed October 15, 2016, <https://www.britannica.com/science/marine-west-coast-climate>.

TEMPERATURE

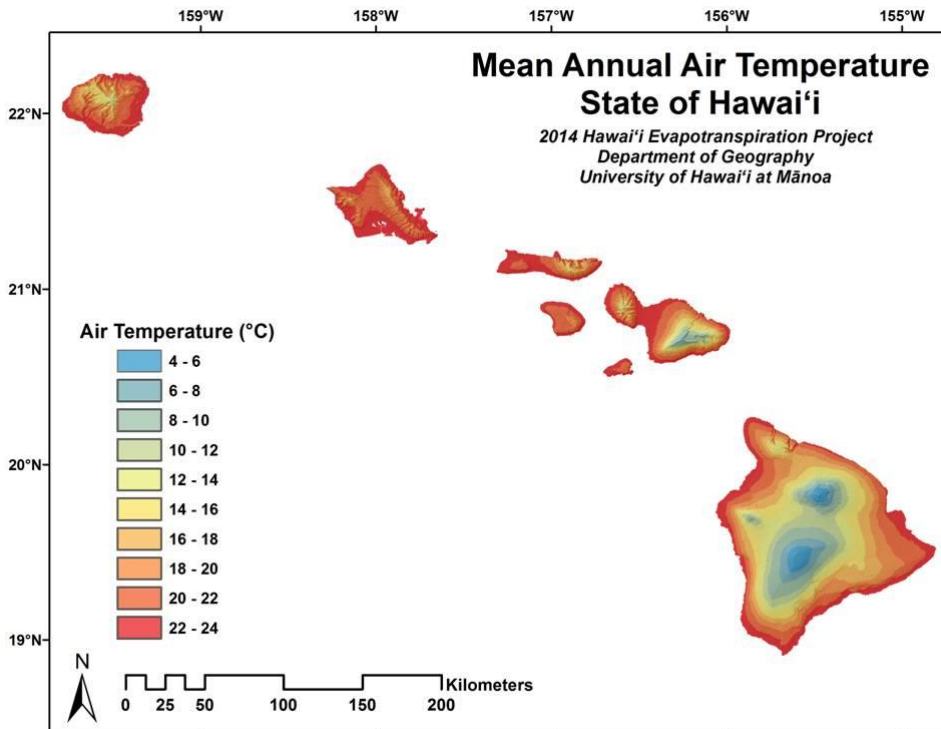


Figure 4.4: Mean Annual Air Temperature State of Hawai'i

Source: T.W. Giambelluca, et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i, 2014

If we keep in mind our population density (Figure 4.3), we see that the annual average air temperature in most of the state is between 18-24°C (64.4 - 75°F). These figures are consistent with our Köppen climate classification types, although monthly averages vary depending on the time of year. We are concerned primarily with how the climate affects our architecture on a perennial basis, not just during the warmer summer months or cooler winter months. Although 64.4 - 75°F is generally comfortable, the combination of incorrect building methods and materials can create an indoor environment with very uncomfortable temperatures and humidity levels. We will see later in this dissertation that such an indoor environment not only causes issues with thermal comfort, but may also lead to more serious health issues as well.

WIND SPEED

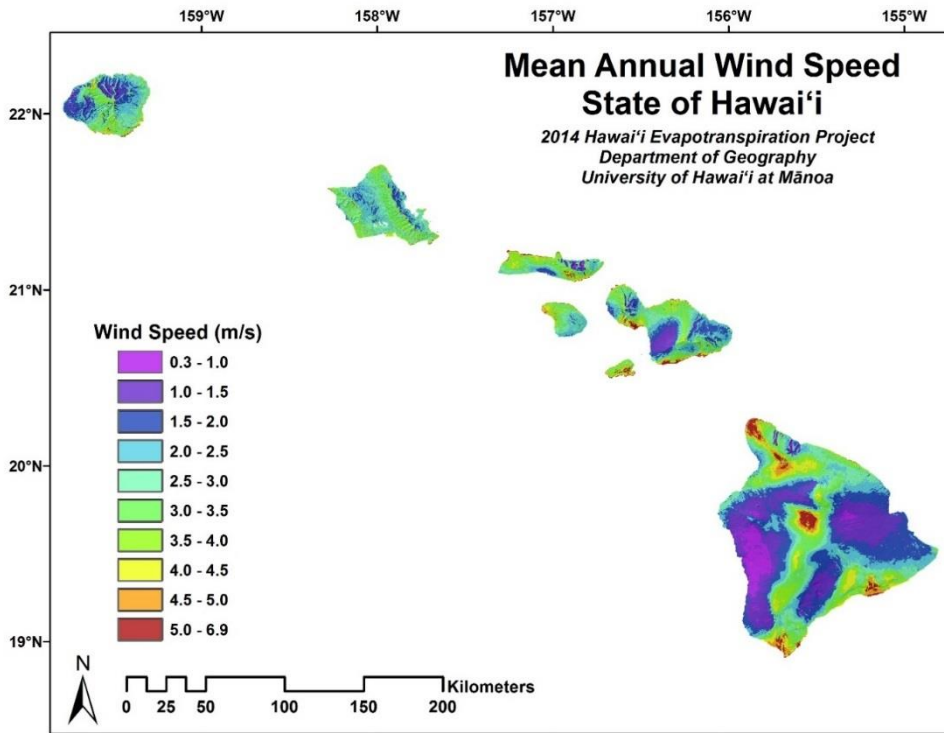


Figure 4.5: Mean Annual Wind Speed State Hawai'i

Source: T.W. Giambelluca, et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i, 2014

Figures 4.5 and 4.6 are closely related as wind speed and humidity levels are correlated. Typically, trade-winds or elevated wind speeds lessen humidity. Conversely, when wind speed drops humidity is elevated. If we compare these two figures we can see that areas of higher wind speed typically have less humidity. Wind is an invaluable resource in tropical architecture; natural ventilation helps to cool the home and dry the air to maintain indoor air quality. Both climatic factors are important for Hawaiian residential architecture and play heavily into the design process in later chapters.

RELATIVE HUMIDITY

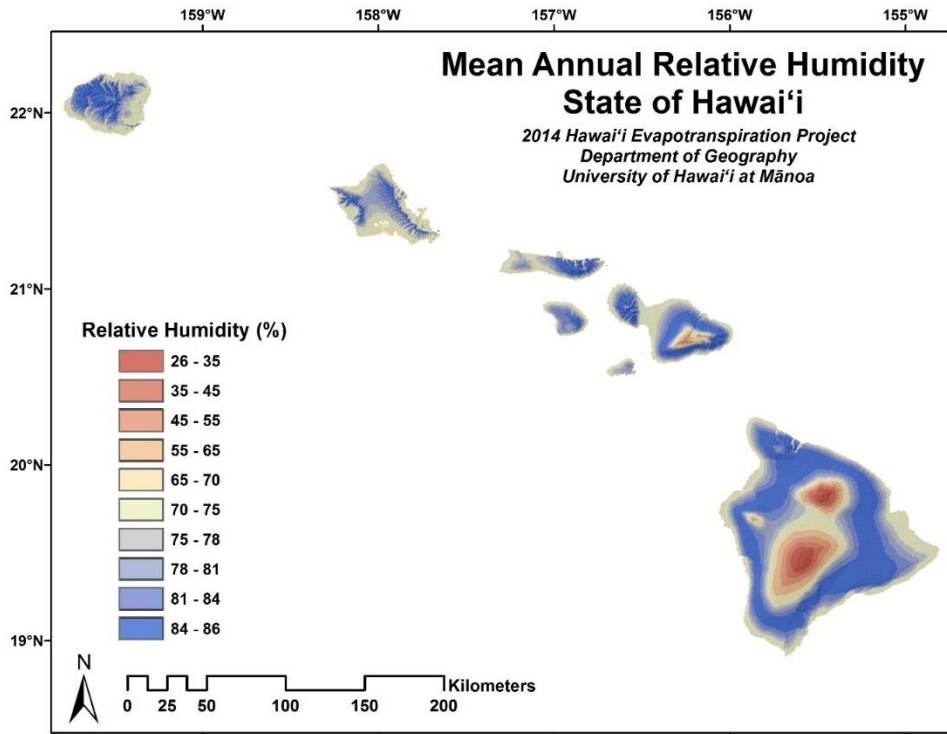


Figure 4.6: Mean Annual Relative Humidity State of Hawai'i

Source: T.W. Giambelluca, et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of

Humidity is especially important for us to understand when designing a new Hawaiian house. For many, indoor air and health problems are due to organic toxins and contaminants which are the result of excess moisture in the form of high relative humidity. This moisture can help produce super environments for the growth of molds as well as the off gasing of volatile organic compounds and chemicals. Humidity across the state is relatively high, in the high 70s to 80s annually.

RAINFALL

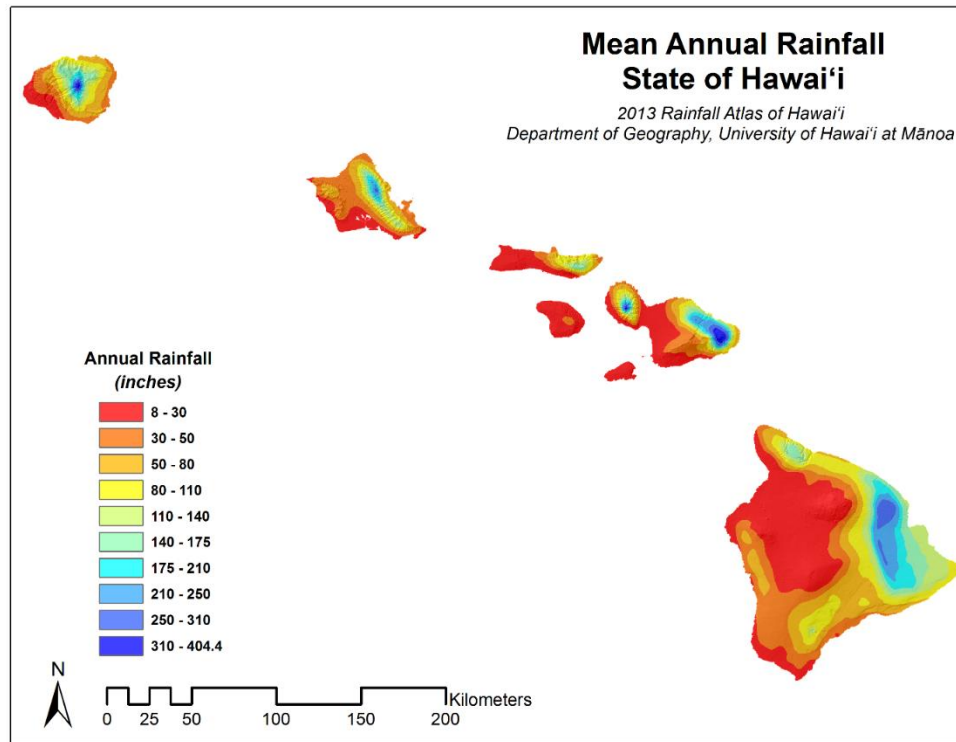


Figure 4.7: Mean Annual Rainfall - State of Hawai'i

Source: T.W. Giambelluca,,et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i, 2014.

Rain is a vital part of the Hawaiian climate. Not only does it help to cool and clean the air but it brings nourishment to the land and the various flora and fauna which inhabit it. Rainfall will be an important climatic factor in the design process of the new Hawaiian house with the primary concern on how to control where the water goes after it has fallen. Our concern is not the amount of rainfall but rather how we deal with it once it has reached the structure and the surrounding landscape. Fresh water is a precious resource on this planet so capturing some of the water that hits our new Hawaiian house will help to alleviate some of this need. Landscape and site design are also important aspects in controlling water and this project will attempt to use rainfall as a beneficial aspect of the overall design.

We should remember that rain which falls higher up in the mountains almost always travels down in elevation to the ocean. Consequently, rainfall that is uncontrolled may pass over contaminates- oil and car fluids, pesticides, herbicides, etc.- and potentially spread pollutants to other land areas and into the ocean. If we can recycle the water at the home site, then we may be able to help alleviate some pollution as a by-product of this new design. Further, preventing water from infiltrating the building where we do not want it is important in the protection of the architecture and limits potential areas of mold growth.

\

4.2

LAND COVER + ECOLOGY

Just as there are numerous climatic conditions in the Hawaiian island chain, there is a wide variety of geographic features, ecosystems and cultural resources which must be considered in Hawaiian residential architectural design. It is important to remember that we can't fully understand the best way to build for a specific site without understanding each of the variables that make a place unique. For example, the two images below look similar in terms of geography and landcover. They are both lush and green, slightly rolling landscapes and probably have fertile soft soil. However, the image on the left was taken in Waimea on Hawai'i Island where the climate ranges from Oceanic to summer Mediterranean according to the Köppen climate classification. Elevation is around 2676' above sea level, temperature averages range from low 60s °F in the winter to upper 60s °F in the summer. Humidity is high around 85%, winds average around 3.5 m/s and rainfall is about 35 inches per year.³¹³² The image on the right was taken in Honoka'a on the Hāmākua Coast, roughly 15 miles away. The Köppen climate classification for this area is a tropical monsoon or trade-wind littoral climate. Average temperatures are higher, ranging from high 60s °F in the winter to low 80s °F in the summer. This is partially because the elevation is much lower, around 500'.



Figure 4.8: Waimea, South Kohala

Source: Own work



Figure 4.9: Honoka'a, Hāmākua

Source: Own work

³¹ National Centers for Environmental Information (NCEI), *Climatological Data Annual Summary Hawaii and Pacific 2015*, vol. 111 no. 13, ISSN 0095-4373

³² T.W. Giambelluca, et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i, 2014.

The humidity is roughly the same although when trade winds dissipate humidity can get closer to 90%. Wind speed is about double at 6.9 m/s and rainfall is about triple at 90 inches per year.³³

By only looking at these two images it is hard to tell the difference. Waimea is much cooler with far more cloud cover and the level of moisture is higher due to a consistent spitting or misty type of rain. Honoka'a is much hotter and the humidity can feel more stifling, especially if it is not very windy. Although there is almost triple the average rainfall, it is sporadic and in larger quantities at one time. In my personal experience, it is not uncommon to have 8" of rain overnight as storms blow in off the coast. Looking at these images, it is important to remember that we should not assume when two different places look the same that they have the same climatic and geographic conditions.

In other places on the island the geographic features, soil types, ecosystems and climatic conditions can be much more varied, although as we will soon find out the architecture is not. On Hawai'i Island you can find vast deserts of A'a (Fig. 4.10) and Pāhoehoe (Fig. 4.11) lava flows, Eucalyptus (Fig. 4.12) and Ironwood (Fig. 4.13) forests, rainforests (Fig. 4.14), wind-swept grass lands (Fig. 4.15), old sugar plantation pasturelands (Fig. 4.16), sandy beaches (Fig. 4.17) and many other sub climates and environments just in the matter of a few hour drive.

³³ T.W. Giambelluca, et al, "Evapotranspiration of Hawai'i," Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i, 2014.



Figure 4.10 A'a Lava Field, Hualālai

Source: Own work



Figure 4.11 Pāhoehoe Lava Field, Anaeho'omalū

Source: Own work



Figure 4.12: Eucalyptus Forests, Āhualoa

Source: Own work



Figure 4.13: Ironwood Forest, Haina

Source: Own work



Figure 4.14: Kohala Rainforest

Source: Own work



Figure 4.15: Dryland Pasture, Lālāmilo

Source: Own work



Figure 4.16: Pa'auhau Plantation Land, Hāmākua

Source: Own work



Figure 4.17: Kauna'oa Beach, South Kohala

Source: Own work

Another thing to keep in mind when looking at these various images is that each area has certain cultural resources and traditions which may be important to the people who occupy them. I will talk more about culture later in this project but felt it is worth mentioning when discussing climate and site because these natural variables have influences on the societal evolution. In other words, one might live differently in an area which rains a lot versus in an area which is hot and dry. Consequently, certain cultural traditions may have been initiated out of these climatic and geographic variables.

As architects, designers and builders we would be foolish to think one type of house could be designed to satisfy all these climatic and geographic conditions. If this chapter does anything it should inform the reader that these numerous variables, whether subtle or dramatic, should be accounted for in the design process. In the next chapter, we will explore the reality on the ground today. With all these variables, we have one thing in common and that is the way we build houses. The climates and geography change, but the houses stay the same.

CHAPTER 5:

IDENTIFYING THE INVASIVE: HAWAI'I ISLAND CASE STUDIES

“Everyone, rich or poor, deserves a shelter for the soul.”

- Samuel Mockbee

Through the last chapter, we explored a brief evolution of Hawaiian residential architecture from pre-Captain Cook until the Modern era. In reading the previous chapter, one may assume that the evolution toward a more regional architecture in Hawai'i was not only inevitable but would be the highest priority of Hawaiian architects. The reality is that the Hawaiian modern movement led by Ossipoff gave way to post-modernism, and the post-war American dream of home ownership became more engrained in the lives of people in Hawai'i. Instead of focusing on the climate, culture and environment, the building industry focused on economy and building cheap imported houses. While it is always in vogue to blame big business and say that the construction and building industry pushed this style of building on the people, that is not the whole story. Architects have the ability to specify and design in a way that is environmentally and culturally responsible. There will always be developers who think of nothing more than the bottom line, but it is up to architects and designers to show the people in their community what other viable options exist.

Above all else, I hope that the remainder of this dissertation demonstrates that architecture which is sympathetic to the culture, climate and site of a region is possible for *all people, at all economic levels*. The notion that good architecture is only available to those who are willing or able to pay for it is a failure in the architectural profession and education system. Architects, draftsmen, designers and students must not only be bound by the ideals of business (although it is a necessary part of the profession); we must remember that every person can make a difference in the built environment. If we use the information that is out there and study our surroundings we can design houses for the homeless and the economically disadvantaged just as well as we do for celebrities, lawyers and businessmen.

What the following case studies demonstrate is that the housing currently being built for the majority of inhabitants in Hawai'i is wrong for their culture, climate, site and health. These homes are not just random developments cherry picked to prove a point; they are some of the newest residential developments, economically and culturally promoted by the County of Hawai'i. I purposely chose these examples because they demonstrate what the state and county governments feel is acceptable and even good for its inhabitants. Typically, these developments are for those who have some economic need and in many cases the only option for home ownership.

5.1

CASE STUDY 1 – KAMAKOA NUI

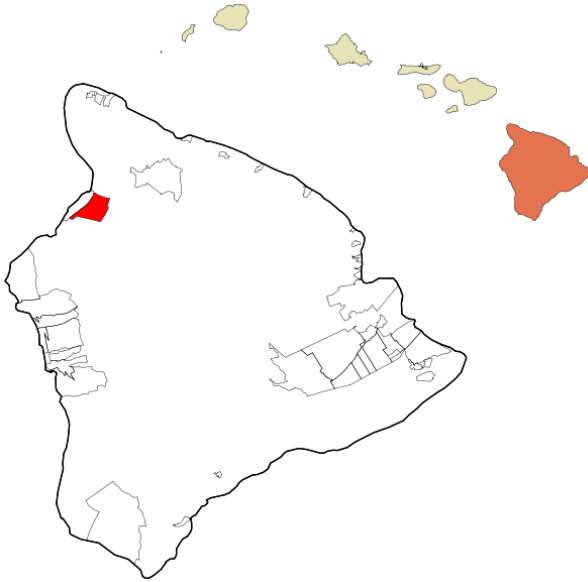


Figure 5.1: Arkyan, *Map of Hawaii Island, Waikoloa Village* is licensed under CC BY-SA 3.0, <http://creativecommons.org/licenses/by-sa/3.0/>

Source:
https://upload.wikimedia.org/wikipedia/commons/1/14/Hawaii_County_Hawaii_Incorporated_and_Unincorporated_areas_Waikoloa_Village_Highlighted.svg
accessed October 11, 2016

Kamakoa Nui is a large residential development located in the census designated place of Waikoloa Village on Hawai'i Island. The project began in the early 2000's, and in 2014 the first batch of houses were completed for residents who make 80-140%, or about \$94,700 on average of the median income for that area.³⁴ The first phase of the development is to have 91 single family homes (1,361 - 1,515 square-foot) and bungalows (1,108 - 1,482 square-foot) with future homes, developments and parks on the 275-acre surrounding area. House prices range between \$246,000 - \$296,000.

According to Kamakoa Nui's website, the mission of this development is:

*... to create an environment that cares for people and their surroundings to the highest degree and quality possible while meeting the demand for affordable workforce homes. It is the vision of the development team to integrate and respect the surrounding natural landscapes in creating a sustainable, livable community neighborhood.*³⁵

³⁴ "Kamakoa Nui workforce housing sales to begin," *Hawaii 24/7*, November 1, 2012,, accessed September 8, 2016, <http://www.hawaii247.com/2012/11/01/kamakoa-nui-workforce-housing-sales-to-begin/>

³⁵ Kamakoa Nui at Waikoloa (website), accessed September 9, 2016, <http://kamakoanui.com/>

CLIMATE & GEOGRAPHY:

Waikoloa is considered a *Köppen* BSh, hot, semi-arid desert climate. This area is hot with little rainfall and medium to high humidity almost year around. Elevation is approximately 900 - 1,000'. Average temperatures are between 76.6°F (spring) and 80.2°F (winter) with an annual average of 78.5°F.³⁶ Relative humidity is 82% on average while wind speed is 3.76 m/s.³⁷ Average rainfall for the area was 18.47 inches in 2015, with September being the wettest month (4.93") and December the driest (0.0").³⁸



Figure 5.2: Waikoloa Natural Landscape

Source: Own work

The geography of this area consists mostly of dryland Hawaiian introduced grasses, some Kiawe trees, barren A'a lava fields and red dirt.³⁹ The Kamakoa development has cleared and paved much of the first phases of the plan for the 91 homes, baseball field, parks and community areas. The

combination of natural landscape and hardscape and paved areas has most likely created an environment of additional heat.

To build residential housing in this area, special attention should be made to the specific aspects of climate and geography. The materials and construction methodology chosen should protect against the relatively high temperatures with proper insulation while providing outdoor and semi-outdoor space for the cultural lifestyle of these inhabitants. Building orientation, wall coverings,

³⁶ National Centers for Environmental Information (NCEI), *Climatological Data Annual Summary Hawaii and Pacific 2015*, vol. 111 no. 13, ISSN 0095-4373

³⁷ Giambelluca, T.W., X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. *Evapotranspiration of Hawai'i*. Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i

³⁸ National Centers for Environmental Information (NCEI), *Climatological Data Annual Summary Hawaii and Pacific 2015*, vol. 111 no. 13, ISSN 0095-4373

³⁹ *Ibid.*

roof and fenestrations should be situated to take advantage of the typical Hawaiian trade winds from the Northeast while providing protection from rain and storm winds from the Southwest. Layout of these homes should be open with minimal excess wall or structure to allow maximal natural ventilation.

ARCHITECTURAL METHODOLOGY:

The single family detached homes and bungalows are in either the “Plantation” or “National” styles. I prefer to call this way of building in the state as the “Neo Plantation” style; both for the decorative aesthetic look and the belief that these types of homes were built with a focus on economy over function or culture.



Figure 5.3: Kamakoa Nui Home, Under Construction, 2017

Source: Own work

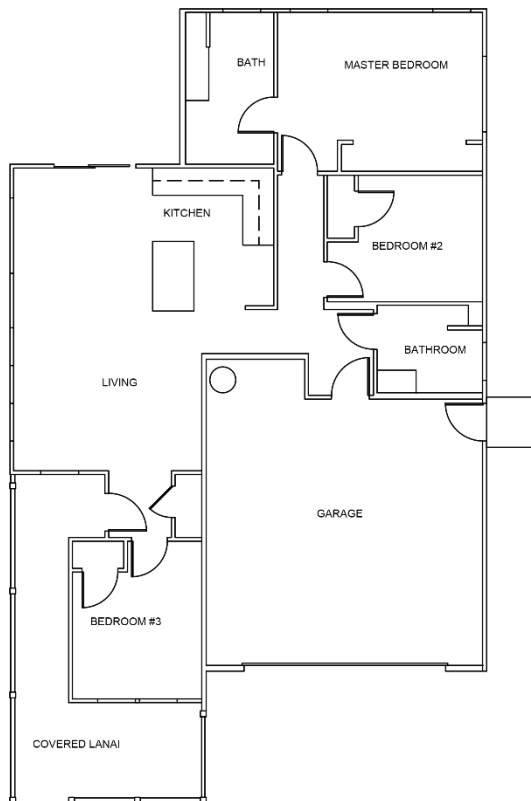


Figure 5.4: Typical Kamakoa Nui Floor Plan

Source: Own work from as-built measurements

The roofs are low slope hip and gable with board and batten or shiplap siding. Each home has a covered lanai and various single hung or sliding windows. Traditional entry doors and sliding lanai doors are used in designated locations. The homes are on concrete slabs on grade with attached garages and driveways. The floor plans are compact with relatively small bedrooms, kitchens and living areas. The floor plan in figure 36 of a typical A1 plan at Kamakoa Nui is the mid-sized type of single family detached homes on offer. The three bedrooms, two bathroom house is 1,260 sq. ft. of living area, 223 sq. ft. of lanai with attached 508 sf garage. It is difficult to designate which areas are central locations for circulation and living. While all the rooms border

the exterior of the house which helps for possible natural ventilation, the hallways and relatively closed plan break up the area enough to cause a hindrance for air movement. The front lanai is the only covered outdoor space and its layout does not allow for outdoor living. The front portion is disjointed from the home entryway with a small walkway which isolates the larger area from the indoor living area inside. The rear of the house does not have a covered portion exposing the walls and possible outdoor space to the elements. The only openings to the outside are one 3'-0" x 6'-8" entry door, one 6'-0" x 6'-8" rear sliding door and then the required garage openings.

Kamakoa Nui claims that the houses in the development are:

- High-quality construction materials
- Durable exteriors and interiors for longer life and easy maintenance
- Unique roof forms
- Wood overhangs
- Naturally attuned to take advantage of island climate
- Design themes that incorporate local climate and topography while honoring Hawaiian lifestyle and aesthetics

It is not necessarily a surprise that the development would boast about the type of materials and construction used on the homes; these are typical and accepted for building in the state. Understanding why these typical practices are wrong for the Hawaiian climate and culture should be evident once we understand how the construction methods and materials interact with their surroundings.

METHODS AND MATERIALS:



Figure 5.5: Kamakoa Nui, under construction 2017

The primary method of construction for these homes is cast in place, slab on grade concrete with double wall, wood framed structures and wood trusses. All the timber is imported dimensional Douglas fir or similar and the roofing structure is from traditional Douglas fir plywood. The exterior siding is some combination of board and batten and shiplap fiber

Source: Own work

concrete board. The windows and doors are vinyl or fiberglass sliding and single hung with ornamental wood shutters attached to the siding beside them. The roofing material is asphalt shingles which are nailed directly to the plywood underlayment.

The wall cavities are filled with batt insulation, as is the attic space. Interior walls of the homes are gypsum wall board, typical in the double wall new Hawaiian fashion. Other interior finishes (which we are less concerned about, although they are still important) are typical carpet, engineered wood flooring and inexpensive ceramic tiles.

THE PROBLEMS:



Figure 5.6: Exterior Side, 2 Story at Kamakoa Nui

Source: Own work

The primary issue with homes at this development is their misplacement in the climate. The homes have relatively small roof overhangs which expose most of the exterior siding, especially on the two-story models, to the hot sun (Fig. 5.6). This climatic exposure and wall construction means that a large amount of heat is transferred from the

exterior (concrete board) to the interior of the house. Although the walls contain insulation, the direct sunlight on the siding would increase the temperature on the wall to a point that the probable R value is insufficient. Interestingly, this would be less of an issue if the home was properly naturally ventilated and cool air could be drawn in from the outside while excess heat is expelled. Instead, the houses are designed in a way that would require them to be hermetically sealed from the outside and would need to utilize an air conditioning system to keep the inside temperature and humidity at a safe and comfortable level. The houses are also lined up right next to each other; even if the window placement and building orientation was perfectly suited to a natural ventilation system, the spacing between the houses would more than likely interrupt airflow patterns enough to make it inefficient at best. In Figure 5.6 we can see the inhabitants attempt to rectify the lack of proper mechanical or natural ventilation, after they moved in to the new home, with the inefficiency of a small window A/C

unit which is literally baking in the hot sun. The roof is also a concern as the thin asphalt shingles and plywood underlayment transfer heat relatively quickly to the large attic cavity. Without proper venting of the attic space, this area becomes a major concern for additional heat gain, even with “proper” R valued insulation at the ceiling lid.

The large windows, which the development promotes as a benefit to the thermal comfort of the home, are placed based solely on the interior function and occur in the same locations per each predetermined floor plan despite the buildings orientation. They are made from plastic, are not thermally broken and even the double paned glazing can't dispel heat gain when they are consistently exposed to direct 85°F summer sunlight.

Further, almost 100% of the materials used to build this house are either imported or fabricated synthetic materials. It is not to say that these materials could not be arranged in a way that would possibly work climatically, although it would probably not be efficient. The greater concern is the cultural, environmental and economic implications of using a completely imported material source. The only material which is partially local is the concrete; the water, sand and gravel all are brought in from local sources and the Portland cement is manufactured, in part, on island. Later in the dissertation a more thorough investigation of the cultural, environmental and economic implications of building materials will occur.



Figure 5.7: Typical Kamakoa Nui Interior

Source: Own Work

Another major issue with the typical construction methodology that Kamakoa Nui prescribes to is related to the inhabitant's health. Thermal comfort is only part of the inhabitant's exposure and experience in the indoor residential environment; we should be concerned with the indoor air quality, psychological health and material / chemical exposures as well. Briefly, the

double cavity wall construction can quickly become a breeding ground for mold and other toxins, interior materials and finishes can off-gas dangerous chemicals into the air. Psychologically, the floor plans can become segregating from the outside world. In the chapter designated to health and the Hawaiian residential architecture, a more thorough investigation of specific health problems will



Figure 5.8: Kamakoa Nui Street Scape

Source: Own Work



Figure 5.9: Kamakoa Nui Development Map

Source: Kamakoa Nui

occur.

Kamakoa Nui has dealt with the site similarly to most postmodern housing developments: segregation. Paved asphalt streets and alleys, cul-de-sacs and concrete sidewalks with little natural landscape leave the area in a state of virtual stasis. Neither the natural landscape nor imported

landscaping have been designed. The streets are completely transitional; no effort has been planned to connect the homes to community areas or places to gather out of the elements by foot. Traveling to and from any part of the development must be done by car or other non-pedestrian transportation; one would have to travel long distances without relief from the elements to reach future parks or community areas. The bungalows at the western border of the development, pictured in Figures 5.8 and 5.9, have front entries which transition to stairs and then to the sidewalk. This disjointed effort creates a primary entrance into the home from the alley street behind the home as the front sidewalk access is virtually unconnected from the rest of the existing development with vehicular entrances at the rear in alleyways.

5.2

CASE STUDY 2 – THE HOMES AT ULU WINI

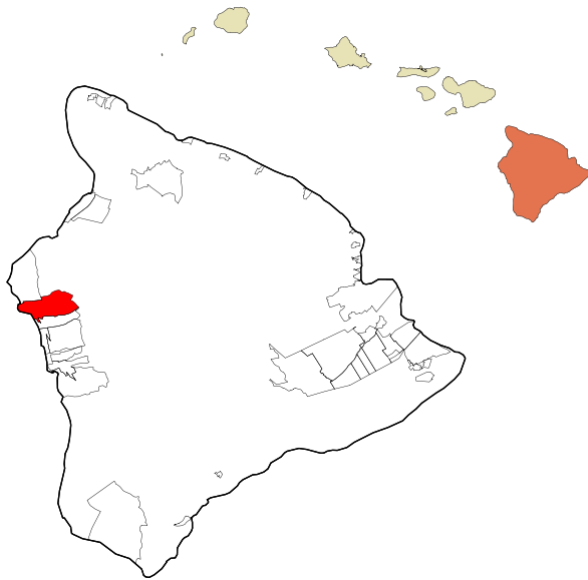


Figure 5.10: Arkyan, *Map of Hawaii Island, Kailua-Kona*, is licensed under CC BY-SA 3.0, <http://creativecommons.org/licenses/by-sa/3.0/>

Source:
https://upload.wikimedia.org/wikipedia/commons/e/e3/Hawaii_County_Hawaii_Incorporated_and_Unincorporated_areas_Kailua_Highlighted.svg accessed October 15, 2016

The Homes at Ulu Wini is a low-income rental and transitional housing development in Kailua-Kona on Hawai'i Island. Officially opened in November 2011, the 96-unit development was built by the Office of Housing and Community Development from Hawai'i county Capital Improvement Project funding and the U.S Department of Housing and Urban Development Neighborhood Stabilization Program grant. The approximately 17-million-dollar development includes employment training, case management, social services, childcare, laundry and playground areas. The 750 sq ft, two bedroom homes are split between 28

low-income units for those making between 30-50% of the mean area income and the remainder of the identical units for homeless families on 2-year work trade leases.⁴⁰ The effort to provide these houses and social services to those who are struggling to obtain housing of some kind due to economic or social concerns is admirable, to say the least. However, it is my belief that we can do much more to provide housing which is climatically, culturally and environmentally more responsive. As mentioned at the beginning of this chapter, we should be able to provide good residential architecture for all people, especially for those who have historically had the hardest time to achieve it.

⁴⁰ "Transitional housing project opens in West Hawaii," *Hawaii 24/7*, November 22, 2011, accessed October 2, 2016, <http://www.hawaii247.com/2011/11/22/transitional-housing-project-opens-in-west-hawaii/>.

CLIMATE AND GEOGRAPHY:



Figure 5.11: Kailua-Kona Landscape

Source: Own Work

Average rainfall for the area was 25.3 inches in 2015- January was wettest (2.65") and November the driest (1.5").⁴²

The geography of this area consists mostly of Hawaiian introduced deciduous shrub land mixed with barren A'a lava fields.⁴³ Much of the area around Ulu Wini is undeveloped until one travels further Mauka to residential areas or Makai to commercial areas. Primary access to the homes is from one road which connects the upper and lower highways. As with Kamakoa Nui, building in this area must consider the hot, dry, humid climate and attempt to take advantage of trade winds and the sloping terrain.

Kailua-Kona is considered a Köppen BSh, hot, semi-arid desert climate. This area is very like Waikoloa Village, hot with little rainfall and medium to high humidity year around. Elevation of the homes at Ulu Wini is approximately 1,000'. Average temperatures are between 72.4°F (winter) and 86.4°F (summer) with an annual average of 78.5°F. Relative humidity is 74% while wind speed is 1.9 m/s.⁴¹

⁴¹ Giambelluca, T.W., X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. Evapotranspiration of Hawai'i. Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i

⁴² Ibid

⁴³ National Centers for Environmental Information (NCEI), *Climatological Data Annual Summary Hawaii and Pacific 2015*, vol. 111 no. 13, ISSN 0095-4373

ARCHITECTURAL METHODOLOGY:



Figure 5.12: Central Courtyard at Ulu Wini

Source: Own work

The homes at Ulu Wini are built in the typical neo plantation style. Many of the materials and construction methods are similar or the same as Kamakoa Nui, although these homes are smaller apartment style units rather than single family detached homes. The buildings do not appear to have been designed specifically for the area; each identical building has been placed in many different orientations with a central courtyard regardless of wind, sun or rain patterns. All the windows are smaller sliding units and each has one entry swinging door for access. All units are identical 750 sq. ft, two bedrooms, one bathroom apartments with half ground floor ADA accessible and half of the second floor and require access by stairs. The development feels entirely sterile of cultural influence or social interaction. Upon my Saturday site visit I only saw one person leave their unit to head to their car and no one interacting outside.

METHODS AND MATERIALS:

The Ulu Wini units are comprised of cast in place concrete slabs on grade with double wall dimensional timber construction for the walls. Roofs are painted metal over simple wood framed or wood truss gable structures with perpendicular gable entries. Exterior siding is painted vertical T1-11 plywood sheathing with fiber cement horizontal planks at the building corners and for the window trim. Windows are synthetic vinyl or fiberglass and do not appear to have insulating properties. From the exterior, it is difficult to tell that this development was built in Hawaii, besides a few tropical plants sprinkled around the site. Even then, one would not be surprised to find this exact same building in California, Texas or Florida.



Figure 5.13: Exterior, Ulu Wini Siding

Source: Own work

Interiors of the units are gypsum wall board with vinyl or linoleum flooring and composite doors, kitchen cabinets and counter tops. Generally, the units are left barren with little connection to the outside; those who are moving in would be justified in feeling that they are moving into low income housing. It is every ounce as minimal and uninspired as the reputation that public housing has always had.



Figure 5.14: Interior, Home at Ulu Wini

Source: Own work

THE PROBLEMS:



Figure 5.15: Ulu Wini Window Fan

Source: Own work

utilize box fans affixed to their windows (Figure 5.15).

As previously mentioned, the two-story buildings have relatively simple gable roofs with small overhangs which provide little exterior shading. The combination of minimal shading from the roof and the un-studied placement of each building causes large portions of most of the buildings to be exposed to direct sunlight or rain (Figure 5.16). In some cases, the long or larger side of the building could be exposed from the time the sunrises until the sun sets without relief. This causes both



Figure 5.16: Ulu Wini Exterior Exposure

Source: Own work

As with Kamakoa Nui, the homes at Ulu Wini are not designed with climate, culture or site in mind. The material selections (all imported) lend themselves to a much more moderate climate; even when insulated “correctly” the homes will still be uncomfortable to live in. Just as some of the inhabitants in Waikoloa Village had to attempt to rectify the lack of proper ventilation with windowed A/C units, the residents at Ulu Wini choose to

increased thermal transfer from the exterior wall into the interior space or the inability to leave windows opened in a non-air conditioned space during rain. The orientation is also detrimental for possible natural ventilation with units facing

every different direction and interior layouts not providing openings at either side of the trade-wind direction. All of which cause the homes to be potentially thermally uncomfortable.

Without getting into the theoretical argument behind the term “sense of place” I would like to assert that the homes at Ulu Wini are lacking in any distinguishing factor or designed elements which have reference to the culture which they are built for. Although it is slightly refreshing that their minimal budget has at least spared them from the decorative add-ons like the fake wood shutters of Kamakoa Nui. To be clear I am not at all trying to promote aesthetic decorations that say “Hawaiian architecture” but instead to reference some cultural or social practices like covered outdoor communal spaces, connections between indoors and outdoors and selection of building materials which suit the local for the project. In my opinion this would be a much more successful attempt at a Hawaiian residential development.

The central courtyard was perhaps an attempt at creating an outdoor gathering space or place for residents to spend time outside. However, there is little open space around each building which disrupts airflow and creates an uncovered and uncomfortable space to be in. Just walking from one side of the courtyard to the other one immediately looks for protection from the elements.

It is not to say that this development has done everything wrong, the fact that these places exist is still better than nothing. The resources residents have at Ulu Wini, to have a safe place to dwell with social services and amenities, is a blessing. However, I believe with the right design and materials we can create better houses for all people in the state.

5.3

CASE STUDY 3 – DEPARTMENT OF HAWAIIAN HOMELANDS - LĀLĀMILO - PHASE 1

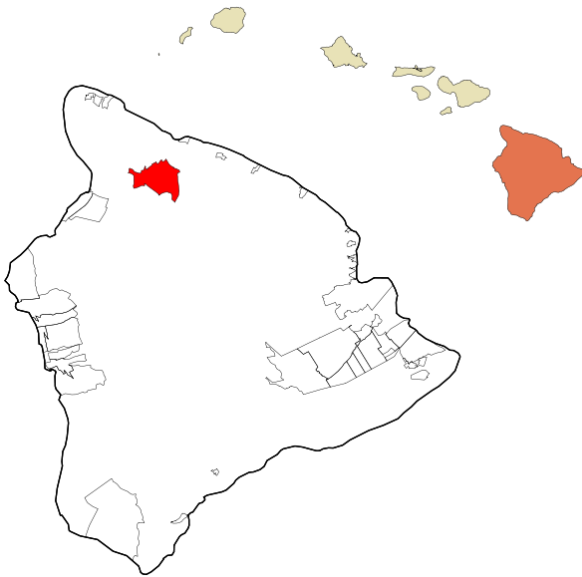


Figure 5.17: Arkyan, *Map of Waimea, Hawai'i Island*, is licensed under CC BY-SA 3.0, <http://creativecommons.org/licenses/by-sa/3.0/>

Source:
https://upload.wikimedia.org/wikipedia/commons/9/95/Hawaii_Count_y_Hawaii_Incorporated_and_Unincorporated_areas_Waimea_Highlig hted.svg accessed September 7, 2016

The **Lālāmilo - Phase 1** homes are located in Waimea (Kamuela) on Hawai'i Island. The first phase of 28 homes was completed in June 2011 while the additional 160 houses that are part of phase 2 have yet to begin construction.

The homes in this area are roughly 1200 sq ft living area, with a 480 sq ft attached garage and 400 sq ft of covered lanai space. The homes are primarily single story, three bedroom, two bathroom detached residences, with some variations and two story homes at the Eastern end of phase 1. They are all built with the same construction materials and methods and all climate and site data is identical.



Figure 5.18: Typical DHHH Lalamilo Phase 1 Home

Source: Own work

CLIMATE AND GEOGRAPHY:



Figure 5.19: Waimea Landscape

Source: Own work

Waimea is considered a Köppen - Csb, warm or cold, summer Mediterranean climate and has quite varied weather conditions throughout the year due to its relatively high elevation (2,676' above sea level). Average temperatures are between 61.4°F (winter) - 67.6°F (summer) with an annual average of 64.5°F. Relative humidity is 86% while wind speed is 3.27 m/s. Average rainfall for the area was 36 inches in 2015, with December as the wettest month (4.7") and September as the driest (1.6").

⁴⁴⁴⁵ Rainfall in Waimea can be deceiving as it typically can rain small amounts every day causing wet conditions year-round. Orographic lifting and rising warm, moist air from the coast up the mountain also cause many cloudy and (eventually) rainy days.⁴⁶ Swings in temperature do occur and it is not uncommon for summer days to exceed 80°F and winter nights to drop below 50°F, which is probably one of the largest swings for inhabited areas in the state.

⁴⁴ National Centers for Environmental Information (NCEI), *Climatological Data Annual Summary Hawaii and Pacific 2015*, vol. 111 no. 13, ISSN 0095-4373

⁴⁵ T.W. Giambelluca, X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. Evapotranspiration of Hawai'i. Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai'i

⁴⁶ T.W. Giambelluca, Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte, "2013: Online Rainfall Atlas of Hawai'i." *Bull. Amer. Meteor. Soc.* 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

The geography of Waimea is primarily planted perennial grassland which was introduced during the height of the cattle ranching era. However, to the North in the higher elevations exists wet mesic forest and montane rainforest, toward the West dry forest and grassland, the South deciduous shrub land and East tree (Eucalyptus) plantations.⁴⁷ To build in Waimea one should consider the geography carefully as rain and drainage are important factors. Having the ability to close the home up while remaining thermally comfortable is of the utmost importance as it would not be uncommon for it to be hot and sunny during the day and cold and wet at night.

ARCHITECTURAL METHODOLOGY:



Figure 5.20: Typical Two-Story DHHL *Lāʻāmilō* house

Source: Own work

Perhaps the most surprising part of learning that these homes were DHHL houses in Lāʻāmilō is the fact that they are so “typical”. If you took these homes and placed them in Kamakoa Nui or vice versa you would struggle to find a difference. It is not just

these two developments either, much of the DHHL housing around the state is in this similar neo plantation style. Unsurprisingly, this style is used for the same reason that it was in Kamakoa Nui and Ulu Wini, it is cheap and easy to build. The homes utilize the same design methodology with small covered lanais, attached garages and bedrooms surrounding a small central living space. The rooms are separated by hallways which segregates social interaction to one space.

⁴⁷ Giambelluca, T.W., X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. “Evapotranspiration of Hawaiʻi.” Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawaiʻi.

METHODS AND MATERIALS:

The DHHL houses follow a very similar building methodology as the previous two case studies; cast in place concrete slab on grade, double wall dimensional lumber for the walls, wood trusses with asphalt shingle roofing in low slope hip or gable styles with vinyl windows and doors. Exterior siding is board and batten in the typical neo plantation style; thick enough T1-11 to obtain necessary shear by code with nailed on dimensional lumber battens to create the look of old single wall construction. Interiors are gypsum wall board with engineered, manufactured and composite flooring, cabinets and countertops. Besides the concrete, all materials appear to be imported from out of state.

THE PROBLEMS:



Figure 5.21: KEEP OUT: DHHL Homes

Source: Own work

At this point it should be obvious that the Lālāmilo phase 1 houses have many of the same issues as the previous case studies. While the primary issue with Kamakoa Nui and Ulu Wini was their misplacement with the climate, the DHHL homes lack an inspiring design suitable to the cultural and social practices of the intended inhabitants. (It is not to say that the homes do not have climatic concerns, because they do, or that the building methodology doesn't cause physical and mental health problems, because it can). When we think of the Department of Hawaiian Homelands and the architecture that should represent the Hawaiian people, it seems like there has been a complete disconnect between the culture and the houses pictured in Figures 5.18, 5.20 and 5.21).

From the exterior one would never guess that this house was designed for native Hawaiian people. There are covered lanais, but they are small and only serve as covered entries. The siding is essentially a façade of what used to be a stigmatizing architecture in the plantation era, while the

synthetic roof and window materials create a very imported packaged home look and feeling. In the chapter on native Hawaiian architecture we learned of a culture centered around living outdoors and connecting to the ‘āina or land. The word ‘āina can be translated as *that which feeds us*, so naturally it would be desirable to create a connection to the land which they used to grow, hunt and fish for their food, where they gathered materials to build their homes and performed social and cultural rituals.⁴⁸ The native Hawaiian cultural practices have evolved with time, of course, but generally those who identify themselves as Hawaiian still have this connection to the ‘āina.

In Figure 5.22 we see a development which has ignored any kind of treatment to the site. Ideally, there would have been an architecture which seamlessly blends inside to outside surrounded by a performative landscape which inhabitants could use as sustenance or for economic benefit. But much of the area is at the mercy of unmanaged weeds and concrete. The homes are plopped upon lots haphazardly, without regard to sun, wind or rain. The stark contrast between package homes and a barren landscape creates an un-inspiring segregation from the beauty of the undeveloped landscape which surrounds it.



Figure 5.22: Lāiānilo Phase 1 Site

Source: Own work

⁴⁸ Mary Kawena Pukui and Samuel H. Elbert. *New Pocket Hawaiian Dictionary with a Concise Grammar and Given names in Hawaiian*, s.v. “āina,” Honolulu, HI: University of Hawaii Press, 1992.

5.4

CASE STUDY CONCLUSIONS

The reoccurring theme from each case study is a feeling of misplacement; these homes are alien to the very specific climatic, cultural and geographic needs of the island. I believe that by looking at these three developments we are able to obtain some insight into the state sponsored and socially accepted architectural methodology in Hawai'i. Kamakoa Nui, The Homes at Ulu Wini and the DHHL Lālāmilo Phase 1 houses are not exclusive to this way of building and many more case studies in the various climates around the islands could demonstrate that there is an incredible shortage of housing which attempts to design within the especial requirements of climate, culture and environment. However, these three studies should help frame the argument that at many socio-economic levels the accepted way of building in the state is failing its inhabitants.

Certainly, there are many examples of residential architecture in the state which follow in the footsteps of Ossipoff's climatic and culturally sensitive Liljestrand house. World renowned architects have applied their talents and resources to create residences which work harmoniously with Hawaiian climate, culture and environment. Typically, these homes would be for those with a budget far beyond the mean annual income of most of the Hawaiian population. One of the main goals of this dissertation is to use the knowledge gained from the history of residential architecture, these case studies and the following research on climate, culture and environment to create an adaptable kit of parts scalable to residents of all socio-economic levels. The house should be not just for those fortunate enough to afford the services of world renowned architects, but for the transitional, poor, middle class, Native Hawaiians and anyone else looking for a home which speaks to the physical and emotional needs that architecture may provide.

CHAPTER 6:

THE HAWAIIAN INDOOR ENVIRONMENT: HEALTH + SICKNESS

Heal: to make (someone or something) healthy or well again⁴⁹

When we think of home, many thoughts and feelings typically come to mind. It is the place we grow up, where we bond with our families, play with our pets and celebrate our birthdays. When we are young it is where we got ready to go to school and as we get older it is the place we are so relieved to return to after a long day at work. Most of all, it is the place where we feel safe, where we go to seek shelter from the ills of the world and protection from the elements. To many, the house is the most important architecture that they will ever interact with.

Despite thousands of years of architectural development, the home is not a completely safe place to be. While some would assume that I am talking about forces of nature, I am not. To be sure, earthquakes, tsunamis, hurricanes and floods are significant risks to homes and their inhabitants, especially on a volcanic island in the middle of the ocean. However, a significant amount of research and design development has gone into studying and alleviating these threats. The threat I am talking about has to do with a lack of understanding of the proper way to design and build homes for Hawai'i's climate and culture.

I believe that Hawaiian houses are particularly susceptible to issues with indoor air quality (IAQ), wet-building syndrome in the form of mold, volatile organic compounds and the off gassing of building materials, as well as other illnesses related to improper or insufficient ventilation and light. These indoor health problems have been well documented and researched over the last 30 years, however very few of the many dangerous health issues have been prevented by premeditated architectural design decisions.⁵⁰ Instead, the building industry has continued to build houses in a similar fashion causing a great number of homes to become sources of illness. Even when it is understood that the houses being built may be causing health issues, the solution is often some kind

⁴⁹ Merriam-Webster's Online Dictionary, s.v. "heal," accessed October 4, 2016, <http://www.merriam-webster.com/dictionary/healing>

⁵⁰ Environmental Protection Agency, *Indoor Air Facts No. 4 Sick Building Syndrome*. Air and Radiation (6609J), MD-56. February, 1991, (Revised, 2014), accessed https://www.epa.gov/sites/production/files/2014-08/documents/sick_building_factsheet.pdf.

of mechanical conditioning and filtration system to cool and clean the air, which feels more like sweeping dust under a rug rather than fixing the problem.

For this project, I want to focus only on the indoor health problems related to the combination of typical building materials and methods with the specific climate and geography off Hawai'i. While there has been significant research on sick building syndrome (SBS) and contaminants in office, institutional and industrial buildings, this dissertation will only focus on the residential aspects of indoor air quality and other health related building variables. Variables related to SBS, radon, smog, tobacco smoke, CO2 emissions and other external and often urban scale toxins, although important, will not be discussed as they are not relevant to this specific dissertation and the scope of the project.

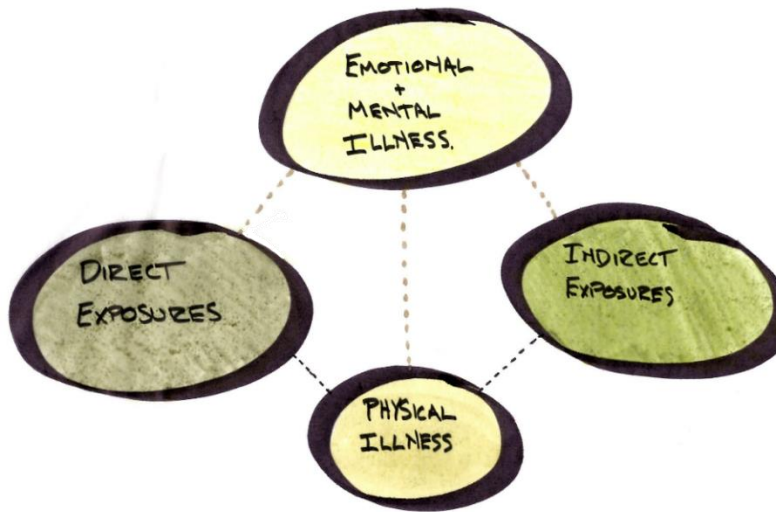


Figure 6.1: Exposure and Illness Diagram

Source: Own work

I have identified three major categories of health concerns in Hawaiian residential architecture. Two of these categories present as physical in nature, which I will call *direct* and *indirect* health exposures. The third category presents as emotional or mental illness and may derive independently or may be related to emotional trauma

stemming from direct and/or indirect health exposures. While not typically discussed, we must not play down the severity of emotional and mental illness that may exist from how inhabitants live in the indoor environment; it is easy to become overly concerned with the more acute or harmful toxins that may be present, losing sight of the harm that other preventable variables relate to our instinctive human needs.

Briefly, direct exposures cause health complications simply by interaction with humans in their intended use, think asbestos panels or lead paint which cause respiratory problems. Indirect exposures are those that may not be always present or may not cause health complications outside of the home environment, think drywall which becomes wet and grows toxic mold. In both direct and indirect health issues, illnesses may develop from acute or from long term exposure and health complications may range from mild to severe. Although the types of exposures may be different, illnesses and their symptoms may be similar or even the same.

6.1

DIRECT EXPOSURES

Direct exposures are those which are typically toxic in nature, regardless of the methodology of building used. The primary direct exposures that cause illness are volatile organic compounds (VOC), which are undoubtedly present in the aforementioned case studies. The carbon-based compounds are considered volatile because they can evaporate or become airborne at normal conditions of indoor temperature and pressure.⁵¹ Per the Environmental Protection Agency, there are different categories of VOCs including: semi-volatile (SVOCs), volatile (VOCs) and very volatile organic compounds (VVOCs). The level of volatility is correlated to how high or low the boiling point of the compound is. The lower the boiling point the higher level of volatility and therefore the more likely it is for chemicals to be released from a material (in our case, building materials) into the air. VVOCs, in fact, can be so volatile that they are entirely in the gaseous state making them difficult to measure while the less volatile compounds may be found more commonly as liquids or solids on materials or in the form of dust or other liquid.⁵²

The EPA regulates the level of VOCs in the outdoor environment by limiting emissions of compounds into the atmosphere to avoid the buildup of ozone. It is more difficult regulating the indoor environment as it is nearly impossible to judge how many furnishings and what types of materials are used in each home. However, national and international organizations do exist to provide labeling on materials and products with specifics about health, odor, irritations, toxicity and carcinogenicity. Yet, there is not currently is not a standard or method of keeping track of VOC labeling to adequately provide consumers with meaningful or comparable information. For example, a paint which claims low or zero VOC may be referring to standards of VOC



Figure 6.2: INHALATION HAZARD 2

Source: *Emergency Response Guidebook*, U.S. Department of Transportation, 2204, pp. 16-17, https://commons.wikimedia.org/wiki/File:HAZMAT_Class_2-3_Inhalation_Hazard.png accessed October 15, 2016

⁵¹ Environmental Protection Agency (website), "Indoor Air Quality: Technical Overview of Volatile Organic Compounds," accessed October 13, 2016, <https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds#2>.

⁵² *Ibid.*

regulations for outdoor emissions only.⁵³ Environmentally friendly or green labels on building materials and products may confuse consumers into thinking that the products are safe for them to breathe, but they have only to do with their effect on the outdoor ozone. For the indoor environment, there is much less information and regulation to protect inhabitants. For now, it is up to architects and the building industry to design homes with the least possible VOCs, as that should be a primary goal for human health.⁵⁴

VOCs in the indoor environment usually come in a few forms, i.e., raw building materials and finishes, treatments or furnishings to the home.

The building materials in the typical Hawaiian home which contain VOCs are:

- Vinyl products (windows, doors, flooring)
- Wood composites (siding, decking, trim)
- Engineered or laminated wood (plywood, chipboard, MDF, paneling, flooring, beams)
- Some Gypsum Wallboard
- Insulation (Binder)
- Carpet
- Paint, Stain, Sealer
- Adhesives for wallpaper, caulking, sealants
-

These common materials contain harmful VOCs which cause various health problems.

⁵³ Environmental Protection Agency (website), "Indoor Air Quality: Technical Overview of Volatile Organic Compounds," accessed October 13, 2016, <https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds#2>.

⁵⁴ Ibid.

FORMALDEHYDE

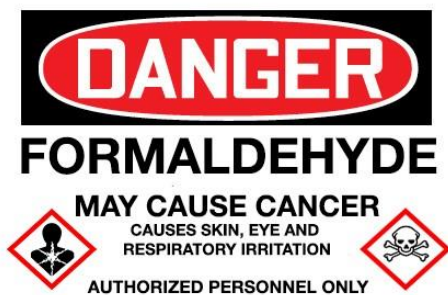


Figure 6.3: Danger - Formaldehyde

Source: The University of Vermont, Environmental Health and Safety Formaldehyde Program, http://www.uvm.edu/safety/sites/default/files/uploads/un%20organized/form_sign_ghs.jpg accessed October 17, 2016

the indoor environment is extremely likely. This type of direct exposure can cause respiratory problems, dermatitis, sensitization of the skin and respiratory tract and possibly certain types of cancer.⁵⁶ This compound is most often used as a binder for things like insulation and in the production of composite or engineered materials like flooring, paneling and trim. Generally, most finishes that consumers purchase at big box hardware and building supply stores contain at least some products with this VOC.

Formaldehyde, is the most common and probably the greatest concern because of its known environmental and carcinogenic effects.⁵⁵ Research shows that acute exposure to formaldehyde causes irritation to eyes, respiratory tract, headache, heart palpitations and even death. We are not as concerned with acute exposure as building materials typically do not have high enough concentrations to cause immediate health problems. Chronic exposure to formaldehyde, however is a great concern as the continued exposure over a long period in

SOLVENTS

Other common VOCs in building products are solvents like acetaldehyde, acetone, toluene, isocyanates, xylene and benzene. These solvents are used in a wide variety of applications from additives in paint, stain and varnishes, sealants, caulking, adhesives, carpeting, cork, laminate and linoleum flooring, particle board, chipboard, paneling and some plastic materials. Essentially, solvents are used in almost all mass-produced building products and furnishings as binders, thinners, drying agents or stabilizers.⁵⁷ These VOCs have different health effects on human beings, but generally they pose respiratory, central nervous and carcinogenic concerns.

⁵⁵ International Agency for Research on Cancer. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*. Vol. 100F. *Formaldehyde*. Lyon:France, 2012, accessed October 17, 2016 <http://monographs.iarc.fr/ENG/Monographs/vol100F/mono100F.pdf>.

⁵⁶ Center for Disease Control. Occupational Safety and Health Guideline for Formaldehyde, Potential Human Carinogen,1988, accessed October 16, 2016, <https://www.cdc.gov/niosh/docs/81-123/pdfs/0293.pdf>.

⁵⁷ Dafni A. Missia, E. Demetriou, N. Michael; E.I. Tolis and J.G. Bartzis, "Indoor exposure from building materials: A field study," *Atmospheric Environment*. (2010): 44 (35): 4388–4395.

Benzene is known to increase risk of leukemia, toluene with lung cancer and xylene as well as other solvents increase the risk of non-Hodgkins lymphoma.⁵⁸

PHTHALATES

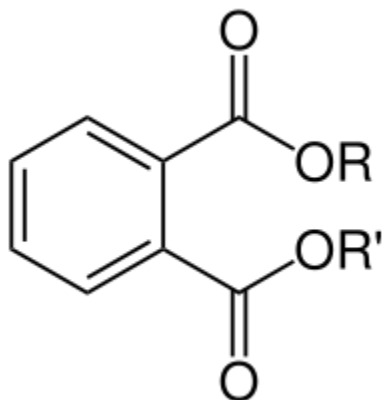


Figure 6.4: Bryan Derksen, Chemical composition of Phthalates, 2007

Source:
<https://en.wikipedia.org/wiki/Phthalate#/media/File:Phthalates.svg> accessed November 8, 2016

While not specifically a VOC, phthalates are common chemicals used in the production of PVC and other plastics to increase their stability, flexibility, and longevity.⁵⁹ In addition to PVC pipe, phthalates are used in wall coverings, wood finishes, flooring, windows and doors and other plastic based finishes and materials. These chemicals are a concern in exposure through the air, through waterlines as well as by touch. While the full effect of phthalates is not fully understood, it is thought that they are carcinogenic and may possibly cause reproductive and respiratory issues.^{60,61}

Some research has shown that potential health problems such as rhinitis,⁶² and asthma⁶³ in younger people and insulin resistance and obesity⁶⁴ in adults may occur from chronic exposure to the chemical.

⁵⁸ R. Clapp, M Jacobs and E Locheler "Environmental and Occupational Causes of Cancer: New Evidence, 2005–2007." *Reviews on Environmental Health*, 23(2), 1-37. Berlin: Germany, 2007.

⁵⁹ National Institutes of Health, Tox Town (website), "Phthalates," accessed October 20, 2016.
https://toxtown.nlm.nih.gov/text_version/chemicals.php?id=24.

⁶⁰ National Toxicology Program. "13th Report on Carcinogens." Accessed October 24, 2016.
<https://ntp.niehs.nih.gov/annualreport/2015/2015annualreportdownloadpdf.pdf>

⁶¹ C.G. Bornehag, B. Lundgren, C.J. Weschler, T. Sigsgaard, L. Hagerhed-Engman and J. Sundell, "Phthalates in indoor dust and their association with building characteristics," *Environmental Health Perspectives*, 113 (2005), pp. 1399–1404.

⁶² J. Jouni, J. Jaakkola A. Leromnimon and M. Jaakkola, "Interior Surface Materials and Asthma in Adults: A Population based Incidence Case-Control Study," *American Journal of Epidemiology*, 164:742-749 (2006).

⁶³ CG Bornehag, J. Sundrell, C. Weschler T. Sigsgaard, B. Lundgren, M. Hasselgren and L. Hagerhed-Engman, "The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case-Control Study," *Environmental Health Perspectives*, 112:1393-1397 (2004).

⁶⁴ Stahlhut R, E. Wijngaarden, T. Dye, S. Cook, and S. Swan, "Concentrations of Urinary Phthalate Metabolites are Associated with Increased Waist Circumference and Insulin Resistance in Adult U.S. Males," *Environmental Health Perspectives*, vol. 115, no. 6, 2007.

SUMMARIZING VOCs

The majority of mass produced building products, finishes and furnishings contain compounds and chemicals that may cause health problems through chronic exposure in the indoor environment. While knowledge of VOCs and other harmful building products has become more widely spread, it is difficult to gauge levels of these harmful products without a clear guidelines and regulation to monitor their use. Even with EPA regulation on VOCs it is typically to prevent environmental harm rather than health complications to humans in the indoor environment. Further, due to their presence in most finishes and furnishings it would be difficult to gauge how many harmful pollutants are in each individual house as the levels would vary significantly depending on where the materials are from and how many exist in each home.

SOLUTIONS:

There are usually a few options when you are trying to solve a human health problem; prevention, mitigation or a combination of the two. The obvious solution to harmful direct exposures like VOCs, solvents and other chemicals would be prevention, to simply avoid using products which contain them. During the design phase, architects and contractors could work to choose building materials which contain little or no pollutants. With the current building methodology and materials which are typically used in Hawaiian residential architecture this would be incredibly difficult to achieve. Even with the proper design and concentrated effort on the part of design and building professionals to reduce the amount of negative health exposures in the building materials, it would still be nearly impossible to control inhabitant behaviors or commercial interests. Home owners may install or change their own finishes or buy furnishings which contain the pollutants and without a real system is in place to monitor and regulate these compounds and chemicals, homeowners will continue to be at risk of exposure. Even though it is partially the purpose of this dissertation to choose building materials and construction methods which reduce harmful exposures, it is important to still have a design which can mitigate the potential contamination of the indoor environment.

We must also remember that not all building materials and finishes are equal in the levels of harmful pollutants that they expose people to in the air of the indoor environment. There are a few variables which can change the number of contaminants, given the same material and same VOC or

chemical. These are ventilation, temperature and humidity. Put simply, the indoor climate can and will affect the level of harmful indoor air pollutants.

Ventilation is probably the greatest determining factor as to the level of harmful exposures indoors. It does not require much specialized knowledge to understand that if the indoor air is exchanged with the outdoor air (in the case of natural ventilation) then the pollutants are temporarily reduced or removed from the indoors.⁶⁵ The amount of air changes per hour (ACH) is usually the unit of measure which explains how often this air is exchanged, the more ACH the more often the air is refreshed. While there are some places in the world where the outdoor air is more polluted than the indoor air and in those cases different types of mechanical filtration and ventilation systems may be required, Hawaii generally has good air quality and we will be focusing on naturally ventilated spaces. More information will be presented regarding ventilation later in this project.



Figure 6.5: Air Purifying Respirator

Source: U.S. Centers for Disease Control and Prevention, 2005, https://commons.wikimedia.org/wiki/File:Air-Purifying_Respirator.png accessed October 13, 2016

Temperature and relative humidity are also important indoor climatic factors which effect VOCs and other chemical pollutants from being released into the air. We must only look to the name of this category of compounds to understand why. *Volatile organic compounds* are unsurprisingly, volatile. In chemistry, volatility is the propensity of a substance to vaporize or turn into a gas.⁶⁶ While volatility usually is used to explain how liquids vaporize into gases, in many cases VOCs which off gas from solid building materials do so through a process of sublimation. This is when substances vaporize from a solid to a gas without first turning into a liquid.⁶⁷ VOCs, by definition have high vapor pressures at room temperature and therefore a

low boiling point. Given that temperature and vapor pressure are factors in volatility and sublimation, it is known that VOCs will off gas more when temperature rises. For example, the boiling point of the VOC formaldehyde is -2°F this means a material containing this VOC will off gas even at normal

⁶⁵ Kang Hu and Qun Chen, "Ventilation optimization for reduction of indoor semi-volatile organic compound concentration based on the variational principle," *Building and Environment*, 94 (October, 2015).

⁶⁶ Canadian Centre for Occupational Health and Safety, "MSDS – An Explanation of Common Terms," P96-1E, (Revised, 1996), accessed September 24, 2016 <http://ccinfoweb.ccohs.ca/help/msds/msdstermse.html>.

⁶⁷ *Merriam-Webster's Online Dictionary*, s.v. "sublimate," accessed October 5, 2016 <https://www.merriam-webster.com/dictionary/sublimation>.

room temperatures. When the temperature increases so does the substances vapor pressure and therefore more off gassing occurs.⁶⁸

Relative humidity also influences VOCs and off gassing.⁶⁹ While not as directly correlated as temperature, relative humidity does play a role in the transport of VOCs around the indoor environment.⁷⁰ Humidity probably helps the transport of vaporized VOCs by capturing the compounds in their gaseous state in the saturated air making it more difficult to remove the contaminants from the indoor space. Humidity also plays a role in the movement of VOCs from the air to surfaces which inhabitants may encounter.

It should be noted that different VOCs and chemicals have different levels of volatility, minor increases in temperature and humidity will not affect all materials in the same way. However, the important point is to remember that controlling the indoor climate is not only for human comfort but to control the off gassing of any building material and overall VOC level in a home.

⁶⁸ Peder Wolff, "Impact of Air Velocity, Temperature, Humidity and Air on Long-Term VOC Emissions from Building Products," *Atmospheric Environment*, vol. 32, no 14/15, (1998). Pp. 2659-2668.

⁶⁹ P. Markowicz and L. Larrsson, "Influence of relative humidity on VOC concentrations in indoor air," *Environmental Science and Pollution Research International*, 5772-9 (April, 2015), accessed November 3, 2016 doi:10.1007/s 11356-014-34678-x

⁷⁰ Ibid.

6.2

INDIRECT EXPOSURES

While direct exposures were those which pose health risks by the nature of their chemical makeup and intended use in the built environment like engineered wood or paint, indirect exposures are those which pose health concerns and exist due to a malfunction or improperly designed architecture. There is one main type of indirect exposure; that is mold due to wet building syndrome. The other type of exposure is somewhat of a grey area between direct and indirect exposures; that is contaminated dust particulates which may be or contain mold, chemicals, VOCs, other irritants or bacteria and viral properties.

DUST AND PARTICULATES

Most people are aware of dust and other particulates in the indoor environment. People tend to dust, wipe, mop and vacuum their homes to remove non-descript specs of matter off their walls, floors and furniture because they generally understand the need to keep their homes clean. How, then, does a home that is cleaned consistently seemingly get refilled with more of the nearly invisible specs of matter? Dust and other particulates can accumulate in the indoor

environment in a few ways. They may come in from the outside from windows and doors, on people and pets, insects and varmint and from building materials or anything else brought in from the outside.⁷¹⁷² But besides the moral desire for our homes to look clean, why is it so important to remove or reduce the amount of dust in our living areas?

Dust is essentially the agglomeration of small, lightweight particles of a wide variety of organic and inorganic substances. There are a few health concerns with dust and other particulates



Figure 6.6: Dust

Source: Own work

⁷¹ Tracy L. Thatcher and David W. Layton, "Deposition, resuspension and penetration of particles within a residence," *Atmospheric Environment*, vol 29, no 13, (July 1995), pp. 1487-1497.

⁷² A. Hunt, DL. Johnson and DA. Griffith, "Mass transfer of soil indoors by track-in on footwear," *The Science of the Total Environment*, 370(2-3): 360-71 (September, 2006).

that are of note for human health in the indoor environment. The dust itself can be an irritant and cause health problems; this is true of shredded fibers from carpet, pieces of building materials like drywall, paint, flame retardants materials or other household items and pollutants. For example, flakes of paint may contain lead, carpet may contain chemicals related to its manufacturing and furniture may shed flame retardant chemicals into the air. Dust and particulates can also become a medium for which chemicals, VOCs, bacteria and viruses can bind to.

Particulates which are floating around the house or settle on materials or furniture can also become contaminated with mold, pollen, lead, arsenic, pesticides, formaldehyde, phthalates, fertilizers or other toxic substances.⁷³ Upon aerosolization they can infect humans through contact with the skin or inhalation into the respiratory tract.⁷⁴ There are many health effects which can be associated with exposure to indoor dust and particulates which may vary according to geographic location, climate and other factors such as cleanliness of the home, building materials and furnishings used and types of construction. This includes respiratory tract infections, headache, central nervous system problems, eye, nose and throat irritations and potentially more severe or life threatening issues like cancer.⁷⁵

Dust is here to stay, though. Perhaps constantly cleaning the inside and outside of the house would thwart off most of the dust and particulates but even then, new dust will be created from the home or brought in by its inhabitants every day. Besides suggesting a change in human behavior (removing shoes, cleaning pets, changing clothes before entering, etc.) there is not much we can do about dust in the homes except prevent the contamination of the dust by exposures. Mechanical systems and a closed, sealed home may capture some of these floating particles but as I will discuss later, these systems can actually produce ozone which is unhealthy at any quantity⁷⁶, be costly and require maintenance to prevent further exposures. One potential way of reducing illness due to dust and particulates is to create a system of natural ventilation which dilutes the inside air sufficiently to remove harmful dust before it has a chance to become contaminated with household chemicals.

⁷³ Tuula Husman, "Health effects of indoor-air microorganisms," *Scandinavian Journal Work and Environmental Health*, 22;1:5 – 13 (1996).

⁷⁴ *Ibid.*

⁷⁵ Environmental Protection Agency (website), Indoor Air Quality: Biological Pollutants' Impact on Indoor Air Quality, accessed October 27, 2016 <https://www.epa.gov/indoor-air-quality-iaq/biological-pollutants-impact-indoor-air-quality>

⁷⁶ Environmental Protection Agency (website), Ozone Pollution, accessed October 27, 2016 <https://www.epa.gov/ozone-pollution>.

Later in the project I will explore reducing exposure by natural ventilation which is filtered by planted screens, well landscaped building sites, building materials which contain less harmful compounds and new building techniques.

MOLD

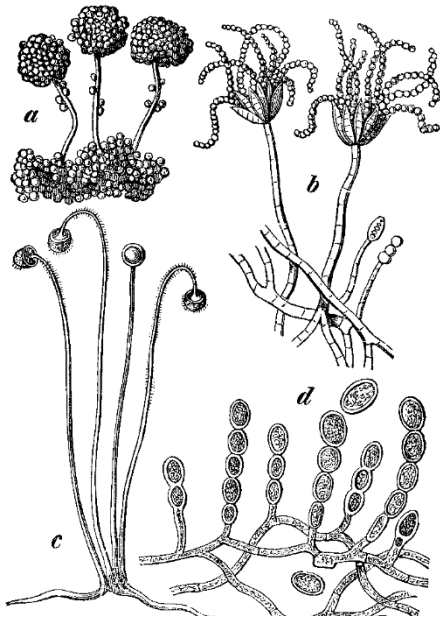


Figure 6.7: Different species of mold

Source: Nase skodljive rastline, Celovec, 1892,
<https://commons.wikimedia.org/wiki/Mold#/media/File:Nsr-slika-151.png> accessed November 8, 2016

Mold is a mass of mycelium hyphae and fruiting bodies belonging to the Fungi kingdom.⁷⁷ Mold is vitally important to Earth's ecosystem and human existence, without it the process of decomposition and biodegradation would be hindered. Although this biodegradation is unwanted on our food supply like the bagels from Costco or the heirloom tomatoes from the farmers market, it is necessary to break down other natural materials in the environment. Mold is basically the garbage man for nature's waste and although we may not want it in our homes it is essentially everywhere on Earth and we are constantly surrounded by it.

Additionally, mold has become an important part of our food supply providing nutrition in various human

cultures around the world. Some foods that exist are because of mold like some kinds of cheese, soy sauce, cured meats, tempeh and while not specifically a mold, the fungi's fruiting body called mushrooms are an important source of nutrients, vitamins and minerals for many people. Humans have also been able to develop supplements and pharmaceuticals from mold; most notably the antibiotic penicillin which was derived from *penicillium notatum*⁷⁸, some drugs used to lower cholesterol and an important immunosuppressant called cyclosporine derived from *tolypocladium inflatum* which helps those who have just undergone organ transplants.⁷⁹ While there are over 1000 species of mold, most do not cause human beings any harm. There are literally countless mold spores floating around

⁷⁷ Encyclopedia Britannica Online, s.v. "mold," accessed October 28, 2016, <https://www.britannica.com/science/mold-fungus>

⁷⁸ Encyclopedia Britannica Online, s.v. "penicillin," accessed October 28, 2016 <https://www.britannica.com/science/penicillin>

⁷⁹ Rehacek Zdenek and De-xiu Zhao, "The biochemistry of cyclosporine formation: a review," *Process Biochemistry*, vol. 26 issue 3, (June 1991,) pp. 157-166.

in the environment in most places in the world and even without realizing it we see it every day. We do not see the masses of furry black, green, yellow or white mold unless the growing conditions and nutritional requirements are available for it to amass in large numbers for an extended period of time. This would occur in older produce or food items, where significant water damage has occurred or any other places where moisture is left unchecked. Most of these molds are perfectly safe or even beneficial to humans, however, some molds produce toxic spores called mycotoxins which can cause minor to extremely severe health issues in people depending on their sensitivity.

MYCOTOXINS

Mycotoxin comes from the Greek meaning fungus (myco)⁸⁰ poison (toxin)⁸¹. Greek etymology has it fairly close; mycotoxins are “secondary metabolites produced by micro fungi that are capable of causing disease and death in humans and other animals.”⁸² Despite the Greek name, the term was coined in 1962 after an unexplained large number of turkeys died. What researchers found out in the aftermath was that a secondary metabolite of mold called *Aspergillus flavus* (an aflatoxin) had contaminated the ground peanut turkey feed.⁸³ Although scientists may have known that some mold spores could pose health risks to humans and animals, this situation made it more clear that large numbers of living things could quickly become poisoned from fungi.

There are typically two ways that humans and animals become infected with mold mycotoxins. Mycoses explains the growth of fungi on a living host, like athletes foot or aspergillosis.⁸⁴ Many of these mycoses are caused by opportunistic fungi which gain access to the host through the pulmonary tract (i.e. the air we breathe) or the skin.⁸⁵ Mycotoxicoses, on the other hand, is “poisoning by natural means” and are similar to heavy metal or pesticide poisoning.⁸⁶ Often mycotoxin poisoning of any kind is compounded or exacerbated by other illness or deficiency causing serious health complications.⁸⁷ Although exposure and contraction of fungal pathogenic diseases may occur from

⁸⁰ Online Etymology Dictionary, s.v. “myco-,” accessed October 28, 2016, http://www.etymonline.com/index.php?term=myco-&allowed_in_frame=0

⁸¹ Online Etymology Dictionary, s.v. “toxin,” accessed October 28, 2016 http://www.etymonline.com/index.php?term=toxin&allowed_in_frame=0

⁸² J. W. Bennett and M. Klich, “Mycotoxins,” *Clinical Microbiology Review*, (July, 2003): 16, accessed October 29, 2016 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC164220/>

⁸³ *Ibid.*

⁸⁴ *Ibid.*

⁸⁵ K.J. Kwon-Chung, and J. E. Bennett, “Medical Mycology,” *Revista do Instituto de Medicina Tropical de Sao Paulo*, vol34, no. 6 (Nov. / Dec. 1992), ISSN 1678-9946.

⁸⁶ J. W. Bennett and M. Klich, “Mycotoxins,” 16.

⁸⁷ R. A. Calderone and R. L. Cihlar (ed.), *Fungal pathogenesis: principles and clinical applications*, New York, N.Y.: Marcel Dekker, Inc, 2002.

food born contamination and skin contact, for the purpose of this dissertation we will focus on mold in the indoor environment and the mycotoxin exposures of mycoses and mycotoxicoses as they are derived from breathing airborne spores of poisonous mold species.

Mycoses and Mycotoxicoses symptoms can be categorized as acute to severe and symptoms ranging from mild to life threatening. Generally, acute exposures tend to have quick and more clear symptomatology. Headache, dizziness, respiratory problems, irritation of the eyes, nose and throat are some of the symptoms that may accompany short term high concentrations of mycotoxins.⁸⁸ Low dose, long term chronic exposures tend to have harder to diagnose more serious or irreversible diseases like cancer, cognitive impairment, chronic immune response syndrome (CIRS), respiratory problems and kidney toxicity.⁸⁹

There has been a large amount of research on mycotoxin biology, toxicology and the effects of molds on human and animal health.⁹⁰⁹¹⁹²⁹³⁹⁴⁹⁵⁹⁶⁹⁷ It should be clear that the effect of mold and the secondary metabolite spores which produce mycotoxins have a major impact on human health. Ensuring that these spores are controlled and removed from the indoor environment is especially important for overall human physical and mental health.

There are many types of mold species which produce harmful mycotoxins in the indoor environment. The most common species of indoor mold are *Alternaria*, *Aspergillus*, *Cladosporium* and *Penicillium*.⁹⁸⁹⁹¹⁰⁰ The most well-known mold species in the public eye is *Stachybotrys chartarum* (black mold). This specific mold is often one of the main villains for blame in sick building syndrome

⁸⁸ R. C. James, "General principles of toxicology," In *Industrial toxicology*, eds. P. L. Williams and J. L. Burson (New York, N.Y.: Van Nostrand Reinhold, 1985) 7-26.

⁸⁹ Ibid.

⁹⁰ Betina, V., "Bioactive molecules," In *Mycotoxins: Chemical, Biological and Environmental Aspects*, vol. 9, (Amsterdam, The Netherlands: Elsevier, 1989).

⁹¹ A., R. Ciegler, W. Detroy, and E. B. Lillejoj. "Patulin, Penicillic acid and other carcinogenic lactones, in *Microbial Toxins*, vol. VI: Fungal toxins, ed. A. Ciegler, S. Kadis and S. J. Aji, (New York, N.Y.: Academic Press, 1971), 409-434.

⁹² S. Kadis, A. Ciegler, and S. J. Aji (ed.), *Microbial toxins, vol. VIII, Fungal toxins*, (New York, N.Y.: Academic Press), 1971.

⁹³ W. F. O Marasas and P. E. Nelson, *Mycotoxicology*, University Park, PA: The Pennsylvania State University Press, 1987.

⁹⁴ J. L. Richard and J. R. Thurston, (eds). *Diagnosis of Mycotoxicoses*. (Dordrecht, The Netherlands: Martinus Nijhoff Publications, 1986).

⁹⁵ J. V. Rodricks, C. W. Hesseltine and M. A. Mehlman, (eds.), *Mycotoxins in Human and Animal Health*, (Park Forest South, Ill. Pathotox Publishers, Inc., 1977).

⁹⁶ T. D. Wyllie and L. G. Morehouse, (eds.), *Mycotoxic Fungi, Mycotoxins, Mycotoxicoses: An Encyclopedic Handbook*, vol. 1, (New York, N.Y: Marcel Dekker, Inc., 1977).

⁹⁷ Ibid.

⁹⁸ R. E. Dales, R. Burnett, and H. Zwaneburg. "Adverse health effects among adults exposed to home dampness and molds," *American Review on Respiratory Disease*, (March, 1991), accessed November, 1 2016. Doi: 143:505-509

S. Graveson, J. C. Frisvad, and R. A. Samson, *Microfungi*, (Copenhagen, Denmark: Munksgaard Publications, 1994.)

¹⁰⁰ J.D. Miller, "Fungi as Contaminants in Indoor Air," *Atmospheric Environment*, 26 (1992): 2163-2172.

(SBS) along with general poor ventilation, cleaning supplies, off gassing of VOC laden materials and a lack of natural light.¹⁰¹

Stachybotrys chartarum is probably the mold which is most well-known due to the 1994 publication by the CDC blaming eight cases of infant pulmonary hemorrhage in Ohio to its exposure.¹⁰² There is evidence to support that this and many other molds are found in the indoor environment and a number of which are known toxicogenic types.¹⁰³ Different than VOCs, mycotoxins are not volatile so direct inhalation of mycotoxin spores or fragments of mold and dust must occur. Although the evidence clearly points to mycotoxins as sources of health problems and the presence of mycotoxins indoors is well known, it is difficult to assess which types of mold, the level of exposure and the specific illnesses related to these variables.¹⁰⁴

There are some tests which are available which allow homeowners to determine what type of mold and how many spores may be inside their homes at any given time. The Environmental Relative Moldiness Index (ERMI) and HERTSMI-2 tests use dust gathered over a specific length of time in a suspected water damaged home to determine the level of contamination that exists. ERMI tests 36 common indoor molds while the HERTSMI-2 tests for five of the most toxic molds. As I previously mentioned with VOCs and other direct exposures, we should focus our design efforts to avoid the problem related to water damage so tests like these are only necessary in the extreme situations or in acts of God where flooding is unavoidable. Currently, the prevalence of water damaged buildings (those which have some fungal growth) is thought to be 10 to 50% in Australia, Europe, India, Japan and North America, per the World Health Organization¹⁰⁵ and 15-40% according to a different study for North American and North European homes.¹⁰⁶

¹⁰¹ Godish, T, Sick Buildings: Definition, Diagnosis and Mitigation, (Boca Raton, FL: Lewis Publishers, 1995).

¹⁰² Centers for Disease Control and Prevention, "Acute pulmonary hemorrhage/hemosiderosis among infants- Cleveland, Ohio, January 1993-November 1994," *Morbidity and Mortality Weekly Report*, 43 (1994): 881-883.

¹⁰³ K.M. Hendry and E.C. Cole, "A review of mycotoxins in indoor air," *Journal of Toxicology and Environmental Health*, vol 38, iss. 2 (April, 2002): 183-198, accessed November 2, 2016. <http://dx.doi.org/10.1080/15287399309531711>

¹⁰⁴ Jarvis, B. B., "Chemistry and toxicology of molds isolated from water damaged buildings," In *Mycotoxins and food safety*, (eds.) by J. W. deVries, M. W. Trucksess, and L. S. Jackson, 43-52, New York, N.Y: Kluwer Academic/Plenum Publications, 2002.

¹⁰⁵ WHO Regional Office for Europe, *WHO Guidelines for Indoor Air Quality: Dampness and Mould*, accessed November 4, 2016, www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf.

¹⁰⁶ S. K. Sivasubramani, R.T. Niemeier, T. Reponen and S.A. Grinshpun, "Assessment of the aerosolization potential for fungal spores in mouldy homes," *Indoor Air*, vol 14. no. 6. (December, 2004): 405-412.

MOLD GROWTH

Mold growth is controlled by a few variables; mold spores, temperature, moisture and nutrients.

Mold spores must be present for the fungi to reproduce and spread. The spores range in size from 3-40 microns (human hairs are 100 microns) so unless they are growing in a colony they are impossible to see with the human eye (without magnification) and controlling them is extremely difficult in both naturally ventilated and mechanically ventilated buildings. This is because mold spores are constantly around us, there is no way to completely rid the environment of them and frankly we wouldn't want to. Even if a home is sanitized and cleaned frequently mold spores may travel back inside from clothes, pets and outside air. Further, when mold spores multiply they do so by the millions; uncontrolled mold growth may lead to a costly remediation issue due to countless spores constantly floating around the home. It is of the utmost importance to control mold growth by controlling the other variables which allow them to reproduce since controlling the spores themselves is nearly impossible.

Temperature between 70 and 90 °F is optimal for mold growth but some genera may live in temperatures as low as 32 °F and up to 120 °F.¹⁰⁷ This does not come as a surprise as we can see some species of mold growing in our refrigerators and even in the hot and dry desert. Unfortunately, the range of human comfort falls well within the range of optimal mold growth too. This means controlling temperature as a means of controlling mold growth is impossible. In fact, sources of cooling and indoor climate control can often exacerbate a mold issue; this will be discussed further, later in this project.

Nutrients are required for all living things, mold included. Anything with carbon can be used as food for mold, which is a vast majority of materials in the world. Building materials, especially those derived from wood, paper and fabric are particularly vulnerable to mold growth. Even dust has enough nutrients for mold sustenance which means that if other materials like concrete, plastic or

¹⁰⁷ Centers for Disease Control and Prevention, "Mold Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods," *Morbidity and Mortality Weekly Report*, 55 (2006). accessed November 5, 2016. <https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5508a1.htm>

glass become saturated with dust they can become hosts for mold as well. Mold spores can also bind to other specs of dust and travel throughout the home this way. Controlling the source of food for mold would also be an extremely difficult to impossible way of controlling its growth.

Moisture is the only reliable and effective way to prevent mold from growing. According to the Center for Disease Control, the primary method of limiting mold growth indoors is by reducing moisture.¹⁰⁸ Large colonies of mold growth is almost always an indicator of water or moisture infiltration of the building envelope.¹⁰⁹ This may come from a leaky roof, windows, water pipes, water intrusion due to flooding, condensation due to improper insulation and / or heating, ventilation and air conditioning system (HVAC) or often the case in Hawaii, elevated humidity and lack of proper ventilation.¹¹⁰

The specific level of moisture needed for growth varies by genera of mold. Although there is evidence that demonstrates mold growth on some building materials can occur as quickly as 24 to 48 hours of consistent wetness¹¹¹ and will almost always occur after flooding.¹¹² Researchers into indoor mold growth use a variable called *water activity* (a_w) ($a_w \times 100 = \% \text{ relative humidity}$) of building materials to determine the specific moisture content required for mold to grow.¹¹³ Generally the longer a_w is over .75 for a specific building material, the greater chance mold grows on that material.¹¹⁴ Determining the a_w for a building material in residential houses in Hawaii could only be done on a case by case basis due to the numerous variables which may occur. As we know, flooding or direct wetting of a material from leaking or flooding causes an increased a_w which usually leads to mold growth. However, increased a_w may also occur from condensation and humidity and can be more difficult to control. In any type of building, reducing overall a_w would prove to create a healthier indoor environment. The easiest way to do this is to ensure proper and sufficient ventilation to dry the air and reduce surface a_w .

¹⁰⁸ Ibid.

¹⁰⁹ Ibid.

¹¹⁰ Ibid.

¹¹¹ S.C. Doll., Determination of limiting factors for fungal growth in the built environment Cambridge, MA: Harvard University School of Public Health. (2002).

¹¹² Centers for Disease Control and Prevention, "Mold Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods," *Morbidity and Mortality Weekly Report*, 55 (2006). accessed November 5, 2016. <https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5508a1.htm>

¹¹³ K. F. Nielsen, G. Holm, L.P. Utrup and P.A. Nielsen, "Mould growth on building materials under low water activities. Influence of humidity and temperature on fungal growth and secondary metabolism," *International Biodeterioration & Biodegradation*, vol. 54, (2004): 325–336.

¹¹⁴ H. Viitanen, et al. "Moisture and bio-deterioration risk of building materials and structures," *Journal of Building Physics*, vol. 33, (2010):201–224.

SOLUTIONS

In the case of both dust and mold there are a few things that can be done to improve indoor air quality and reduce illness. First, is to ensure that there is proper ventilation diluting the inside air with fresh outside air. Even though dust and mold exists outside as well, air flow helps to reduce the levels of particulates and spores in the air. Reducing the amount of building materials and furnishings which unnecessarily contain paper, fabric and other materials which mold and dust can easily collect on is another important way of reducing the odds of toxic exposure. One of the most important things architects and builders can do to prevent exposure to mold, dust and other particulates is to avoid the use of double wall (cavity wall) construction. Often, in cases of water intrusion through the building envelope or roof, parts of the home can become saturated and mold growth may occur. This is a major issue as unknown mold growth can spread and create a significant health issue without the knowledge of the homeowner. Cavities in the wall and roof also become breeding grounds for insects and other living critters like mice or rats, places where dust from construction or insulation can gather and eventually be dispersed throughout the living area. Whenever possible, solid wall construction could reduce some of these negative effects.

6.3

EMOTIONAL + MENTAL HEALTH

Emotional and mental health is probably one of the hardest types of illness to diagnose and talk about. People do not generally want to talk about the state of their mental health so information on methods of improving their emotional state can be difficult. Further, quantifying variables which add to emotional stress in the built environment are not well documented and can sometimes be subjective. There are a few things for which we can find research on and make intuitive suggestions for. These are fresh air, ample natural light, connection to nature and perhaps somewhat subjectively, architectural design which elevates the typical home environment.

NATURAL LIGHT + NATURAL RELATEDNESS

Numerous studies have been done regarding exposure to natural light in the workplace for overall productivity and health.¹¹⁵¹¹⁶¹¹⁷ Research shows that exposure to natural light during the day, especially the early parts of the day has a significant role in establishing normalcy in the circadian rhythm.¹¹⁸ Normalcy of the circadian rhythm aids in healthy sleeping patterns which are a primary controlling factor for general physical and mental health.¹¹⁹ Additionally, exposure to daylight has been shown to lessen depression and other mental or emotional disorders like agitation, seasonal affective disorder (SAD) and help in improving overall health and healing.¹²⁰¹²¹¹²²¹²³ Natural light usually translates into a greater connection to nature and the outside world. This may manifest as more windows and doors, skylights or indoor / outdoor spaces like lanais or covered gardens. This connection has been coined by researched John Zelenski and Elizabeth Nisbet as “nature

¹¹⁵ Barry Haynes, “The impact of office comfort on productivity,” *Journal of Facilities Management*, vol. 6 (1), (2008).

¹¹⁶ B. Thayer, “Daylighting and Productivity at Lockheed,” *Solar Today*, vol.9 (1995): 26-29.

¹¹⁷ T Roenneberg, T. Kantermann, M. Juda, C. Vetter and K.V. Allebrandt, “Light and the human circadian clock,” *Handbook of Experimental Pharmacology*, vol. 217 (2013):311-31

¹¹⁸ *Ibid.*

¹¹⁹ B. Bower, L.M. Bylisma, B.H. Morris and J. Rottenberg, “Poor reported sleep quality predicts low positive affect in daily life among healthy and mood-disordered persons,” *Journal of Sleep Research*, vol. 12, no. 2 (June, 2010) 323-32.

¹²⁰ K.M. Beauchemin and P.Hays, “Sunny hospital rooms expedite recovery from severe and refractory depressions,” *Journal of Affective Disorders*, vol. 40 no. 1-2 (September, 1996): 49-51.

¹²¹ G.M. Wallace-Guy, D.F. Kripke, G. Jean-Louis, R.D. Langer, J.A. Elliott, and A. Tuunainen, “Evening light exposure: implications for sleep and depression,” *Journal of the American Geriatrics Society*. Vol. 50 No. 4. (April,2002): 738-9.

¹²² P.Graw, S. Recker, L. Sand, K. Kräuchi K and A. Wirz-Justice, “Winter and summer outdoor light exposure in women with and without seasonal affective disorder,” *Journal of Affective Disorders*, vol. 56 no. 2-3 (December, 1999):163-69.

¹²³ R. Kaplan and S. Kaplan, “The experience of nature: A psychological perspective” (New York, N.Y.: Cambridge University Press, 1989).

relatedness” and has many important consequences for human life. According to the research this nature relatedness is a different and separate connection than those of family or society and can improve and often predict happiness and health regardless of other variables.¹²⁴¹²⁵ This connection has also been shown to create greater feelings of environmental sustainability instigating humans toward efforts to preserve and promote the natural world.¹²⁶ Additionally, natural light and the connection to nature through more green space has been linked to lessening of stress¹²⁷

The introduction of fresh air into the home can be a controversial topic depending on where one lives. In certain parts of the world, outdoor air quality has deteriorated enough to where it is generally unhealthy to breathe. This may be from VOCs, CO₂, smog, ozone or other particulates which have increased to a point to cause harm to human health. In Hawai‘i the outdoor air quality has historically been good, although at times certain islands suffer due to volcanic emissions of SO₂. However, the consistent rain and trade winds keep a steady supply of fresh clean air blowing through the state. Good architectural design will embrace wind patterns through proper placement of fenestrations and orientation of the building to ensure consistent airflow throughout the indoor space. Research demonstrates that fresh air is important for our physical and mental state. In the indoor environment, natural ventilation can help with thermal comfort and the reduction of pollutants, as we will explore later in the dissertation. In general, fresh air (more oxygen) improves happiness and health,¹²⁸ lessens depression¹²⁹ and increases overall vitality.¹³⁰

¹²⁴ R. S. Ulrich, “View through a window may influence recovery from surgery,” *Science*, vol. 224 (1984): 420-422.

¹²⁵ R. S. Ulrich, “Effects of gardens on health outcomes: Theory and research,” In *Healing Gardens: Therapeutic Benefits and Design Recommendations*, (eds.) C. Cooper-Marcus and M. Barnes, 27-86. New York, N.Y.: John Wiley, (1999), accessed November 7, 2016. <http://www.majorfoundation.org/pdfs/Effects%20of%20Gardens%20on%20Health%20Outcomes.pdf>.

¹²⁶ Elizabeth K. Nisbet and John M. Zelenski, “Happiness and Feeling Connected : The Distinct Role of Nature Relatedness,” *Environment and Behavior*, vol 46. no. 1 (January, 2014): 3-23

¹²⁷ C. W. Thompson, J. Roe, P. Aspinall, R. Mitchell, A. Clow and D. Miller. “., Mitchell, R., Clow, A., Miller, D, “More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns,” *Landscape and Urban Planning*, vol. 105 no.3 (2012): 221-229.

¹²⁸ Li Q, et al., “Effect of phytoncide from trees on human natural killer cell function,” *International Journal of Immunopathology and Pharmacology*, vol. 22 no. 4, (2009):951-959

¹²⁹ Tests and Procedures – Hyperbaric Oxygen Therapy,” Mayo Clinic, accessed November 8, 2016. <http://www.mayoclinic.org/tests-procedures/hyperbaric-oxygen-therapy/basics/why-its-done/prc-20019167>

¹³⁰ Bernstein, J. et al. “Vitalizing effects of being outdoors and in nature,” *Journal of Environmental Psychology*, vol. 30, Iss. 2, (June 2010): 159–168.

GOOD DESIGN

Many authors and architects have attempted to understand how architecture effects living and happiness. In “The Architecture of Happiness”, author Alain de Botton asserts that all aspects of architecture influence happiness and unhappiness.¹³¹ While De Botton has strong opinions on the premises of architecture and happiness he even acknowledges that beauty (and therefore happiness) is in the eye of the beholder. That being said, I think it is without a doubt that most people would prefer to spend time in a room designed by a world-renowned architect like Kengo Kuma over that of a typical hospital room or jail cell. Without going off on too much of a tangent on this enormously huge topic, I wanted to touch on a few design variables which may affect mental health and happiness.

Variables related to light, nature and fresh air are things which are innate to human need while “good” design is more subjective and probably mostly based on experience and social cues. What exactly makes good design is difficult to say, but there are some things which I have identified as variables of good design:

- **Order** – Not necessarily a specific or standardized layout of design but generally some kind of order in design allows for inhabitants to understand their surroundings. Confusion generally does not make people happy.
- **Safety** – People want to know that they are safe (structurally) and protected from the elements.
- **Material** – I believe that the materials which surround us have an effect on our state of mind. Figured exotic wood may make us feel a connection to nature, concrete can be a signal for structural safety or imposing entombment and plastic can make us feel like we are in a high-tech space age space or a cheap or “fake” environment. Additionally, materials should only be chosen if they do not pose an inherit risk to human health, i.e. we would never use asbestos in homes knowing what we know now, just as we should not use other materials with VOCs, chemicals or potential to become contaminated with mold.

¹³¹ Alain De Botton, *The Architecture of Happiness*, (New York, N.Y.: Pantheon, 2006).

- **Site** – Placement of the building and connection from indoor spaces to outdoor spaces can make or break a home. I believe that a home in one area may be a good fit in one spot and a terrible fit in another. Homes should be designed for the site which they are located.
- **Culture** – Not a shallow reference to the past or cliché material choices to represent an idea of culture. Instead, the design should reflect the cultural variables which are important to a society. I.e. in Hawaii having a lanai is an important place to socialize and live.

I believe that acknowledging and attempting to work through these variables can have a dramatic effect on mental health and happiness.

CHAPTER 7:

VENTILATION

Ventilation is the process of exchanging or replacing air from a space with air which has better air quality. This process can be accomplished by the movement of air from outside to inside, through a space (naturally) or from individual areas to a filtration and distribution system to be dispersed around the rest of the building (mechanically). Ventilation does a variety of things in the built environment. It dries the air by reducing overall humidity, it dilutes the inside air from native pollutants, removes particulates from the air and recycles fresh air in its place.¹³²¹³³ Ventilation also helps in creating an atmosphere of thermal comfort; in hot and humid climates, the introduction of airflow can cool and dehumidify the air which may otherwise be outside the comfort zone. The important aspects of ventilation are rate (air changes per hour), airflow direction (which way the air moves through a building) and airflow pattern (how the air is moved to each space).¹³⁴

Homes may be successfully ventilated naturally, mechanically or incorporate a hybrid system of the two. In each type of home specific requirements, design elements and materials are needed for the ventilation to function properly, efficiently and safely. Typically built homes in the state like those in the case study chapter are designed in a way that they would need to be mechanically ventilated to achieve enough air changes per hour and the proper level of dehumidification to maintain thermal comfort and safety. This is because the floor plans often have dark internal spaces and smaller fenestrations which reduce the ability for air to flow naturally through the space. This means that these homes should be hermetically sealed with specific vapor barriers, waterproofing membranes, walls / roofs with sufficient R values / insulation and openings should have reflective or insulating properties to reduce moisture and heat gain into the indoor areas. When these variables are implemented correctly the mechanical distribution system can be adapted to any floor plan layout in virtually any climate or location. However, when homes are designed like those in the typical Hawaiian

¹³² D. Etheridge and M. Sandberg, *Building ventilation — theory and measurement*, (Chichester, UK: John Wiley & Sons; 1996).

¹³³ Hazim B. Awbi, *Ventilation of buildings*, 2nd ed. (New York: Taylor & Francis: 2003).

¹³⁴ J. Atkinson, Y. Chartier, C.L. Pessoa-Silva, et al., (eds.) *Natural Ventilation for Infection Control in Health-Care Settings*, (Geneva: World Health Organization: 2009).

house and do not use a mechanical ventilation systems or they do not implement the specific design requirements needed for them to operate safely and efficiently many issues can arise for health, comfort and safety. In the remainder of this chapter I will explore the benefits and concerns with each type of ventilation.

AIR CHANGES PER HOUR (ACH)

It is difficult to determine the minimum air changes per hour necessary to provide good air quality or thermal comfort, it is even more difficult to determine what a home's level of ventilation is without testing them on a case by case basis. Ideally residential architecture should appeal to the highest standard of indoor air quality as the home is the place where we spend so much of our lives. While we may not need the level of indoor air quality an operating room requires, it seems like using health care IAQ design guidelines as the bar for this project is conservative to say the least.

The American Institute of Architects (AIA) standard for many health care facilities, scientific research labs or other places where indoor air quality is important, ranges anywhere from 2 to 25 depending on the specific requirements for each space.¹³⁵ So a general diagnostic examination room may only need 2 ACH while a critical care operating room may need 25.¹³⁶ ASHRAE standards seem to be slightly more conservative with most types of facilities needing 2-6 ACH while more critical health areas require 15¹³⁷. In many of these scenarios the only viable option is a mechanical ventilation system due to the consistently high demand for filtered air, negative pressure, relative humidity and temperature.¹³⁸

For residential buildings, there is an ASHRAE Standard (62-2001) which says that there should be a minimum of 0.35, but this does not explain how or where that 0.35 should be attained.¹³⁹

¹³⁵ American Institute of Architects, *AIA Guidelines for Ventilation in Hospitals and Outpatient Construction*, Washington D.C. accessed November 15, 2016, <http://www.industrialairsolutions.com/contamination-control/hospital-air-purifiers-pdf/AIA-Guidelines-patient-care-construction.pdf>.

¹³⁶ *Ibid.*

¹³⁷ Paul Ninomura, Chris Rousseau and Judene Bartley, "Updated Guidelines for Design and Construction of Hospital and Health Care Facilities," *ASHRAE Journal*, vol. 48 (June, 2006).

¹³⁸ American Institute of Architects. *AIA Guidelines for Ventilation in Hospitals and Outpatient Construction*.

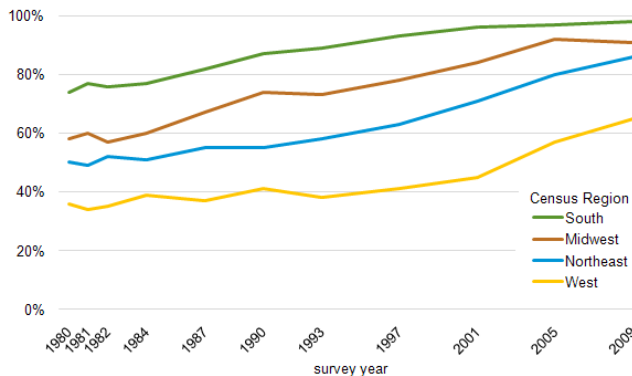
¹³⁹ Max Sherman and Nance Matson, "Residential Ventilation and Energy Characteristics," *ASHRAE Transactions*, vol. 103. iss. 1 (1997):717-73, accessed November 11, 2016, http://www.engg.ksu.edu/files/engext/ventilation/resventw_fm5.pdf

In other words, is that 0.35 ACH per room, for the whole house? It also does not acknowledge the criteria of indoor air quality associated with this specific number of ACH. Additionally, this does not account for other variables related to naturally or mechanically ventilated systems. As a general rule of thumb, somewhere between 2-5 ACH would undoubtedly supply enough fresh air for dilution and disbursement of indoor air pollutants in a residential setting.

MECHANICAL VENTILATION

Heating Ventilation and Air Conditioning (HVAC) systems have been around since the early 20th century and in climates where temperatures can raise above or drop below levels of human comfort they are often preferred or needed to achieve a space of sufficient thermal comfort and ventilation. In fact, according to Figure 7.1 from the Energy Information Administration, there has been a steady rise in the percentage of homes with air conditioning systems since the early 1980s to approximately two thirds of homes in the U.S. HVAC systems are also implemented frequently for specific building types which require consistent ventilation for their programmatic needs, as previously mentioned about hospitals or research facilities. For the purpose of this dissertation we will only talk about ventilation and air conditioning systems, although some locations may warrant heating, the vast majority of the state is hot and humid as shown previously in the chapter regarding climate. There are many issues with mechanical ventilation and residential architecture in Hawai'i related to the environment, health, economy and culture.

Figure 1. Steady rise in air conditioned homes in all regions of the U.S. percent of homes with AC



Source: U.S. Energy Information Administration, 2009 Residential Energy Consumption Survey
Figure 7.1: 2009 Residential Energy Consumption Survey

Source: U.S. Energy Information Administration, 2009, www.eia.gov accessed November 10, 2016

Environmentally, air conditioning systems rely on mechanical equipment and chemicals (refrigerants) to cool the home. HVAC systems in the United States and Europe were heavily criticized for their use of trichlorofluoromethane (CFC11, R11) and its supposedly safer replacement hydrochlorofluorocarbons (HCFCs; R22) refrigerants and their role in ozone depletion and climate

change.¹⁴⁰ In response, some newer even more “environmentally friendly” alternatives like the popular R-410A refrigerants (brand name Puron) are now being used. Unfortunately, even this type of refrigerant has a massive environmental impact; although R-410A does not contribute to ozone depletion it does have 1,725 times the effect of CO₂ on the environment.¹⁴¹

Mechanical systems also require energy to run and raw materials to produce. Without direct offset from alternative energy sources, like photovoltaic systems, geothermal or wind power, HVAC often relies on fossil fuels produced by power companies. According to the United States Department of Energy, 6% of the National energy use is from cooling.¹⁴² This energy use creates approximately 177,000,000 metric tons of CO₂ every year, a significant factor in climate change.¹⁴³ In Hawai‘i specifically, approximately 84% of the energy production comes from either oil (70%) or coal (14%).¹⁴⁴

¹⁴⁰ “Ozone Layer Protection: Ozone-Depleting Substances,” Environmental Protection Agency, accessed November 14, 2016, <https://www.epa.gov/ozone-layer-protection/ozone-depleting-substances>

¹⁴¹ Forster, P., V. Ramaswamy, P. Artaxo, T. Bernsten, R. Betts, D.W. Fahey, J. Haywood, et al. “2007: Changes in Atmospheric Constituents and in Radiative Forcing,” in: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, (eds.) Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller. (Cambridge, United Kingdom and New York, NY: Cambridge University Press), accessed November 12, 2016. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf>

¹⁴² “Energy Saver- Air Conditioning,” United States Department of Energy, accessed November 19, 2016, <https://www.energy.gov/energysaver/air-conditioning>.

¹⁴³ *Ibid.*

¹⁴⁴ “Hawaii Energy Statistics,” Hawaii State Energy Office, accessed November 23, 2016, <http://energy.hawaii.gov/resources/dashboard-statistics>.

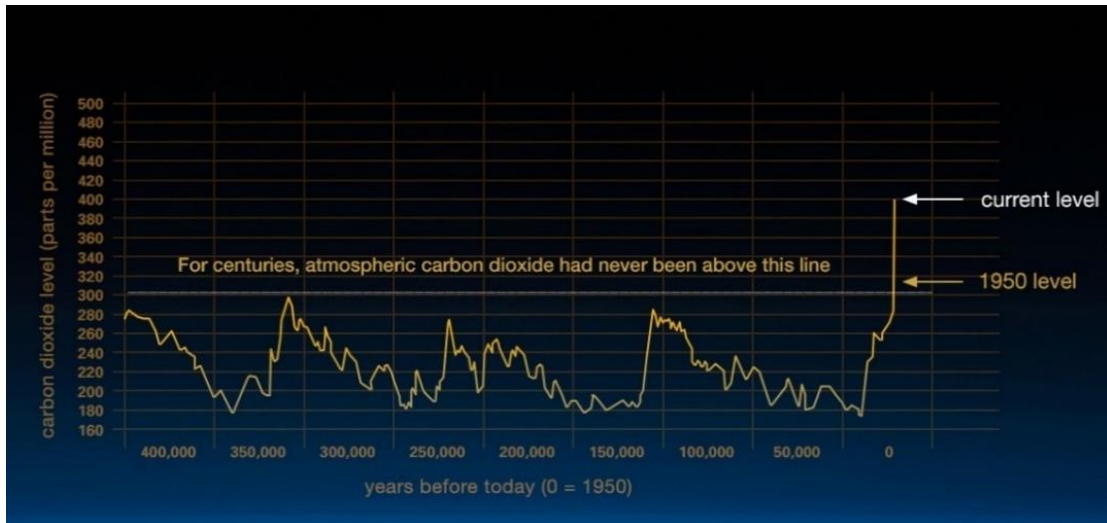


Figure 7.2: Current CO₂ Levels

Source: Vostok ice core data/J.R. Petit et al., NOAA Mauna Loa CO₂ record

The raw materials and energy needed to manufacture and install these systems creates additional CO₂ which causes harm to the ozone and pollution of the soil, water and air.¹⁴⁵ There is evidence that points to increased CO₂ levels and sea level rise¹⁴⁶, sea temperature rise¹⁴⁷, ocean acidification^{148,149}, global temperature rise¹⁵⁰, the melting of the ice sheets¹⁵¹, decreases in snow cover,¹⁵² glacial retreat¹⁵³ and increases in extreme weather events.¹⁵⁴ All of these vital signs of climate change have significant cause and effect relationships for living creatures on planet Earth.

¹⁴⁵ "Global climate Change – Vital Signs of the Planet," National Aeronautics and Space Administration, accessed November 22, 2016, <https://climate.nasa.gov/evidence/>.

¹⁴⁶ J. A. Church and N.J. White, "A 20th century acceleration in global sea level rise," *Geophysical Research Letters*, vol. 33. iss. 1, (2006), accessed November 24, 2016. doi:10.1029/2005GL024826.

¹⁴⁷ Levitus, et al. "Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems," *Geophysical Research Letters*, vol. 36 iss. 7. (2009), accessed November 24, 2016. 10.1029/2008GL037155

¹⁴⁸ Pacific Marine Environmental Laboratory (website), Carbon Program – What is Acid Acidification? accessed November 25, 2006, <http://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F>.

¹⁴⁹ C. L. Sabine et.al., "The Oceanic Sink for Anthropogenic CO₂," *Science*, vol. 305 no. 5682 (July, 2004): 367-371.

¹⁵⁰ I. Allison et.al., *The Copenhagen Diagnosis: Updating the World on the Latest Climate Science*. (Sydney, Australia: UNSW Climate Change Research Center, 2009).

¹⁵¹ "Earth Observatory – Gravity Recovery And Climate Experiment (GRACE)," National Aeronautics and Space Administration, accessed November 25, 2016, <http://earthobservatory.nasa.gov/Features/GRACE/>.

¹⁵² C. Derksen and R. Brown, "Spring snow cover extent reductions in the 2008-2012 period exceeding climate model projections," *Geophysical Research Letters*, vol. 39 iss. 19, (October, 2012).

¹⁵³ National Snow & Ice Data Center, World Glacier Inventory, accessed November 28, 2016, https://nsidc.org/data/glacier_inventory/

¹⁵⁴ "U.S. Climate Extremes Index (CEI): Introduction," National Oceanic and Atmospheric Administration, accessed November 28, 2016, <https://www.ncdc.noaa.gov/extremes/cei/index.html>.

In a somewhat sad, vicious circle, the erratic temperature and climate changes associated with large carbon footprints and the chemicals used in HVAC will undoubtedly create an increased need for HVAC to maintain human comfort and IAQ.

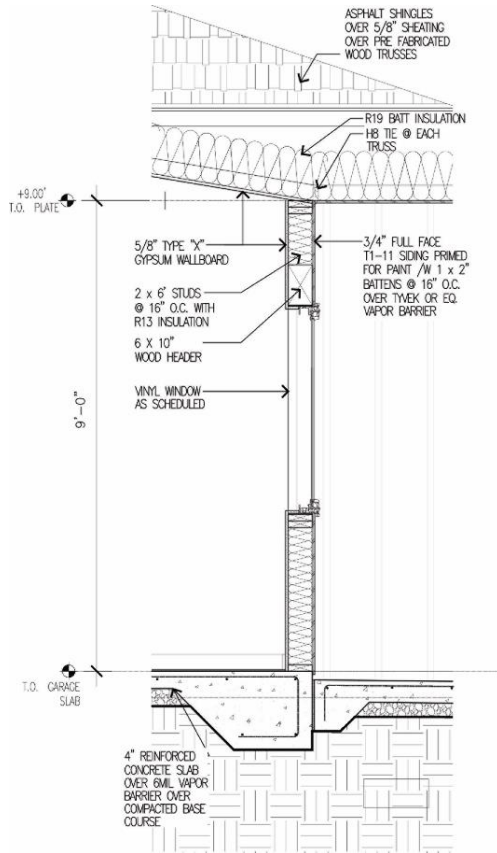


Figure 7.3: Typical Hawaiian House Wall Section

Source: Own Work, Built Kailua-Kona, 2017

As previously mentioned, mechanical ventilation requires a specific type of home to be efficient. Hermetically sealing and insulation are needed to ensure the efficiency of the system. In warm tropical climates like Hawai'i, preventing warm air from entering the home through infiltration (cracks, or gaps in the building envelope) is required to maintain efficiency and prevent condensation on building materials. Consequently, windows and doors are meant to be shut and sealed and sunlight reflected or blocked from the inside while the building envelope and insulation must be efficient and maintained. These typical homes use the double wall system (Figure 7.3) of building which means there is an exterior layer, an insulated cavity and an interior layer of the wall. The exterior wall and foundation must prevent all water, moisture and heat from moving to the inside. The system is entirely dependent on the

vapor barriers, insulation and air tight sealing of the building envelope to prevent moisture and heat from moving from the exterior to the interior. For the purpose of a healthy indoor environment we must be incredibly conscious moisture or condensation in the wall cavity. Just like a cold soda can which is taken out of the cooler on the beach sweats as soon as it is exposed to the warm air, the home can do the same. If warm air leeches from the exterior through infiltration and touches the conditioned surfaces of the wall, then that wall will sweat. As we already know, this increased a_w will almost certainly lead to mold growth on the walls and often in the wall cavity where it is difficult to

detect. The mold spores, created in the wet wall cavity are small and light enough to travel from the cavity into the house causing exposure to harmful mycotoxins.

The mechanical system itself can also have issues with condensation and excess moisture, especially if some of the equipment is located in a poorly ventilated or insulated attic spaces. The ducts and filters will eventually become infiltrated with mold spores through the registers and returns, regardless of how sealed the home is. Usually this is from normal inhabitant living behavior, moving from outside to inside may lead to contamination. If excess moisture builds up from condensation or from high humidity during low A/C use mold and dust can start infesting this ventilation system. This literally creates a mold, mycotoxin, bacteria and virus distribution system throughout the indoor environment. VOCs and other chemicals can also be distributed through the ventilation system depending on the quality of the system and how it is maintained. In one study done by NASA, researchers discovered that when a space is sealed from the outside and only mechanical systems of filtration are used, a buildup of VOCs and chemicals will eventually pollute the air to unsafe levels.¹⁵⁵ Often, mechanical filtration systems may capture VOCs and particulates and release ozone in exchange, which is also unsafe at even very low levels.¹⁵⁶

Economy is also an issue with mechanical systems. The systems themselves are often too expensive for many homeowners to purchase, install and maintain. On average it costs roughly \$18,000 to install central A/C in Hawaii.¹⁵⁷ According to the United States energy.gov, 29 billion dollars are spent Nationally every year to power air conditioners.¹⁵⁸ On average, it costs Hawai'i residents even more, as the price of electricity is typically double than that of the rest of the country.¹⁵⁹ This usually translates into a situation where homeowners in Hawaii are left with homes designed for mechanical ventilation and the inability to purchase a system, buy the right type of equipment or properly maintain the system. An example of this would be when homeowners buy

¹⁵⁵ Wolverton BC, et al. *Interior Landscape Plants for Indoor Air Pollution Abatement. Final Report—September 15, 1989*, Stennis Space Center, MS:Science and Technology Laboratory, John C. Stennis Space Center, National Aeronautics and Space Administration (1989).

¹⁵⁶ Indoor Air Quality: Guide to Air Cleaners in the Home, Environmental Protection Agency, accessed November 28, 2016, <https://www.epa.gov/indoor-air-quality-iaq/guide-air-cleaners-home>.

¹⁵⁷ "Hawaii Homeowners Guide to Energy, Comfort & Value," State of Hawaii Department of Business, Economic Development & Tourism, accessed November, 30, 2016, <https://energy.hawaii.gov/wp-content/uploads/2011/10/Hawaii-Homeowners-Guide.pdf>.

¹⁵⁸ "Energy Saver – Energy Saver 101 Infographic: Home Cooling," United States Department of Energy, accessed November 30, 2016, <https://www.energy.gov/articles/energy-saver-101-infographic-home-cooling>.

¹⁵⁹ "Hawaii Energy Statistics," Hawaii State Energy Office, accessed November 30, 2016. <http://energy.hawaii.gov/resources/dashboard-statistics>.

houses in developments like Kamakoa Nui and can't afford to air condition them ala Figure 5.6. Small window units and fans are installed to try and improve thermal comfort but these are typically inefficient, ineffective and potentially dangerous.

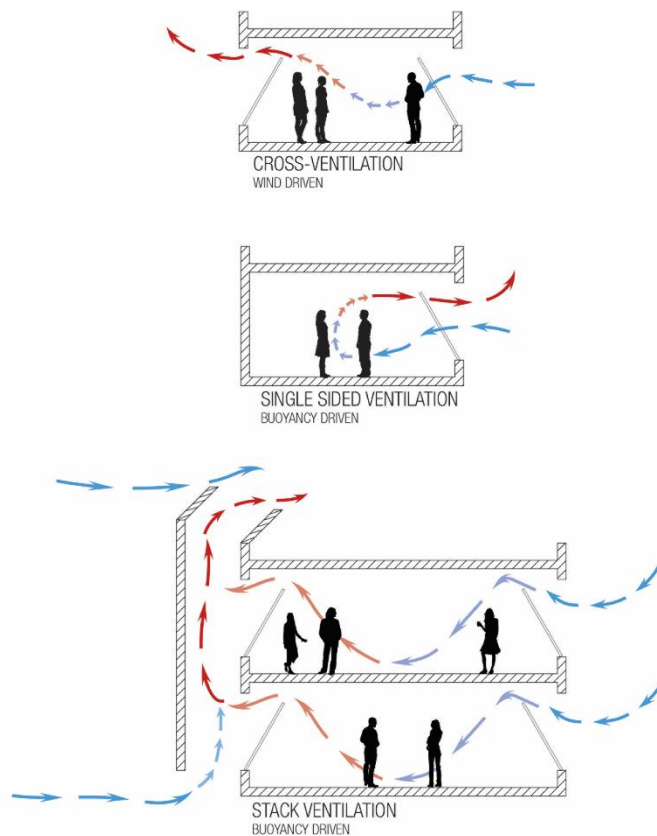
These homes are especially of concern because not only are they poorly designed for mechanical systems that are often not implemented, but they are also not designed properly for natural ventilation. This means indoor air quality suffers due to insufficient air changes per hour, increased temperatures, humidity and an increase in a_w on building materials. Consequently, the indoor air becomes saturated with mold spores, mycotoxins, VOCs and chemicals causing the aforementioned health concerns.

The other concern must do with how homes designed to use mechanical ventilation effect social and cultural behavior. As previously mentioned, mechanically ventilated homes require specific designs to work properly. If we analyze each of these requirements, we end up with a home which does not necessarily work with the Hawaiian culture or way of life.

Any culture which spends as much time outdoors for social and cultural events as the Hawaiian population would surely place an importance on the connection to the environment and the land. We know this to be a fact as the value of the 'āina is especially important to the people who live on the Hawaiian Islands and any Hawaiian architecture should reflect that connection. However, the mechanically ventilated home is virtually sealed off from the outside and the connection between inside and outside suffers. It is not impossible to create a home which can be mechanically ventilated and still provide this connection to the environment, but it is often at great expense and does not present itself in the typically built residential architecture.

Even if you had the money available to create this type of home, I believe residents of these islands would prefer to be in a home which is naturally ventilated, where the line between indoors and outdoors is blurred and the risk of health problems due to mechanical ventilated are not a concern.

NATURAL VENTILATION



METHODS OF NATURAL VENTILATION

Figure 7.4: Methods of Natural Ventilation

Source: Own work

Natural ventilation is simply the supply and removal of air from the indoor environment only by natural means. This is accomplished by wind, pressure and temperature differences between the inside and outside of the building caused in part by the orientation of fenestrations to natural wind patterns without the aid mechanical fans or other electric equipment. There are many types of natural ventilation including cross-ventilation (wind driven), single sided ventilation (buoyancy driven) and the stack effect (buoyancy driven). Natural ventilation has many benefits over mechanical systems and can be easy to incorporate into a building as long as a concentrated effort early in the

design process is made to account for some of the disadvantages of the system.

There are many advantages of a proper functioning natural ventilation system. Natural ventilation should not cost anything above normal design and construction costs, it is purely a matter of design knowledge. There are no pollutants or contaminants like CO₂ or refrigerants to cause harm to the environment. There are no places for contaminants to become trapped and dispersed to other areas of the home. Condensation is not an issue in Hawai'i because the natural temperature differences from outside to inside are not great enough to cause sweating on the walls and ceilings. Natural ventilation also removes polluted indoor air with fresh outside air, flushing out potential VOCs, chemicals and other harmful pollutants. When functioning properly, naturally ventilated spaces can

reduce indoor air temperature and humidity to comfortable levels. It is not to say that natural ventilation is perfect and there are some issues that should be addressed.

Perhaps the greatest issue with natural ventilation is the expectation and conformity of architects, builders and developers to the typical residential planning and architecture typology. Natural ventilation can only take place if there is an opportunity for air to be drawn into the indoor space. If we take a typical house like those in the case study and site it on a lot which has been planned to be part of a close proximity, cul de sac style neighborhood it would be much more difficult to design an effective natural ventilation system. If we expound upon this, we should understand that the typical type of house has an interior plan which does not lend itself to natural ventilation. Interior rooms and walls often cause interruptions to the airflow and standardized windows and doors make it difficult to create either the necessary pressure differences or open air space to bring air into the home.

COMPARISON OF VENTILATION TYPES		
VARIABLES	NATURAL	MECHANICAL
COST	ONLY DESIGN KNOWLEDGE	HIGH
MAINTENANCE	LOW	HIGH
ENVIRONMENTAL IMPACT	NONE	HIGH; VARIABLE ON ENERGY METHOD
INDOOR AIR/ QUALITY	GOOD; VARIABLE ON SITE CONDITIONS	LOW TO MODERATE; VARIABLE ON SYSTEM TYPE, MAINT. & DESIGN
DUST / MOLD / OUTDOOR POLLUTION	MODERATE; VARIABLE ON DESIGN MITIGATION	LOW TO MODERATE; VARIABLE ON INHABITANT IMPACT
NOISE POLLUTION	VARIABLE ON SITE CONDITIONS	LOW
EFFICIENCY	GOOD; VARIABLE ON CLIMATIC CONDITIONS	VARIABLE ON SYSTEM & BUILDING DESIGN
CULTURAL IMPACT	INDIGENOUS; ALLOWS FOR NATURAL AIR AND LIGHT	INVASIVE; SEALED HOUSE, IMPORTED MATERIALS

Figure 7.5: Comparison of Ventilation Types

Source: Own work

Some of the other issues with natural ventilation include the intrusion of dust and other airborne particulates, mold spores, automobile exhaust, noise pollution and other outdoor VOCs from the built and natural environment. These potential pollutants can easily infiltrate the average naturally ventilated home if there is not an additional designed element to help alleviate some of these concerns. Of course, these elements would vary depending on the location of the home. For example, on most areas of Hawai'i island there would be little concern of automobile exhaust or say, industrial pollution from a steel mill. However, there may be some concerns with mold spores, which are in abundance in the tropical climate, dust from large plots of undeveloped land and Vog, which is the mixture of sulfur dioxide and other volcanic gases emitted from Kilauea volcano. Vog is a big concern for residents of this island, per the United States

Geological Service, the volcano emits anywhere from 2,000 to 4,000 tons of SO₂ per day¹⁶⁰ and may cause many health issues such as headache, respiratory issues, watery eyes, sore throat¹⁶¹ and one study finds it may raise blood pressure or lead to a deterioration of existing health problems.¹⁶²

Another issue with natural ventilation has to do with the variability of the climate. In cross-ventilated systems especially, wind driven forces are the determining factor on the potential rate of natural ventilation through a space. If there is no wind than it is difficult to reach the minimum differences in pressure to draw the air from the windward openings (positive pressure side) to the leeward openings (negative pressure side). Conversely, in strong wind events like storms, hurricanes or unusually strong trade or Kona (leeward) winds, naturally ventilated spaces can become too windy causing issues with thermal comfort, dust infiltration and other safety issues.

While not usually a problem in most areas of the state, naturally ventilated homes require windows to be open leaving residents susceptible to noise pollution from the outside. In many of the issues related to natural ventilation, designed mitigation efforts can help alleviate the problems to create a successful ventilation system year around.

HYBRIDYZING

One method for improving natural ventilation systems is to incorporate some means of auxiliary ventilation through ceiling fans, motorized vents and operable louvers and screens. Ceiling fans can help systems which use the stack effect to draw hot air up and out of the space and in other systems where airflow rates are low because of too little or too much wind (and having to shut the windows) they can provide additional cooling and air circulation. Motorized vents can also be used in areas where excess heat or humidity are created like the kitchen, restrooms and laundry areas. Operable louvers can also be used either through a system of human mechanization or electrical control to control wind or airflow in higher wind situations.

¹⁶⁰ "Frequently Asked Questions about Air Quality in Hawaii," Hawaii Volcano Observatory, United States Geological Survey, accessed November 14, 2016. https://hvo.wr.usgs.gov/hazards/FAQ_SO2-Vog-Ash/P1.html

¹⁶¹ "Frequently Asked Questions and Answers on Vog and Volcanic Emissions from Kilauea," Hawaii State Department of Health, accessed November 22, 2016, http://health.hawaii.gov/cab/files/2013/05/kilauea_vog_qa_1.pdf.

¹⁶² Bernadette M. Longo, "Adverse Health Effects Associated with Increased Activity at Kilauea Volcano: A Repeated Population-Based Survey," *ISRN Public Health*, vol. 2013 ID 475962 (2013).

BUILDING PERIMETER + SITE DESIGN

As with most variables related to residential architecture the areas surrounding the home are important parts of a natural ventilation system. In fact, by using some designed mitigation techniques we can potentially alleviate some of the issues mentioned above.

One of the main issues that are concern to this project is the infiltration of mold spores, dust and other particulates, chemicals VOCs or pollutants. While the typical natural ventilation system draws outside air through window openings the only protection from these potential contaminates are window screens and consistent cleaning of the indoor space. There are a few possible solutions when we begin to think about the surrounding site conditions. First, if we carefully integrate landscape design into the project we can attempt to control dust and other airborne pollutants. With any landscape a certain amount of dust will always exist and new dust is created everyday by the natural processes in plant growth and breakdown. In Part 2 of this dissertation a more concentrated effort will be made to documenting and designing the specific landscape around the design portion of this project. However, as a rule of thumb, designing the site to minimize dust through the proper land cover and layering of the site will undoubtedly reduce infiltration of these particulates.

While it would seem like an easy solution to the indoor air problems related to mold, dust, particulates or indoor VOCs and chemicals would be some type of mechanical filtration, air cleaner or HEPA filtering fan, some research has shown that the equipment itself can actually increase the indoor concentrations of ozone.¹⁶³ Even under the best circumstances of building material selection and design, when indoor to outdoor air exchange is not of acceptable levels, a buildup of VOCs and



Figure 7.6 ZooFari, *Epipremnum aureum* vine (Devil's Ivy), 2010 is licensed under CC BY-SA 3.0, <http://creativecommons.org/licenses/by-sa/3.0/>

Source:
https://upload.wikimedia.org/wikipedia/commons/f/f0/Epipremnum_aureum_vine.jpg

¹⁶³ N. Britigan, A. Alshawa and SA Nizkorodov, "Quantification of ozone levels in indoor environments generated by ionization and ozonolysis air purifiers." *Journal of the Air and Waste Management Association*, vol. 56 no. 5 (May, 2006):601-10.

pollutants can occur.¹⁶⁴ One possible solution to decreasing these pollutants is the use of live plants which could remove VOCs, chemicals and toxins from the air and give off fresh oxygen in return.¹⁶⁵ There are many types of plants which can provide a multitude of air purifying benefits to the indoor space. For example, a study by NASA researcher Bill Wolverton used a type of pothos called *Epipremnum aureum* (devil's ivy) shown as Figure 7.6, which was grown on an activated carbon filter system to reduce air levels of trichloroethylene and benzene in a Plexiglas box from 36ppm to almost nothing in only 2 hours.¹⁶⁶ In another study, researchers used 28 different type of plants to test their ability to filter VOCs and chemicals like toluene, benzene, aliphatic hydrocarbon (octane), halogenated hydrocarbon [trichloroethylene (TCE)], and terpene (α-pinene).¹⁶⁷ Of these plants, *Hemigraphis alternata* (purple waffle), *Hedera helix* (English ivy), *Hoya carnosa* (Variegated wax plant) and *Asparagus densiflorus* (Asparagus fern) had “superior removal efficiencies” for all of the pollutants tested, *Tradescantia pallida* (purple heart) was able to filter four of them successfully.¹⁶⁸ In another unpublished study by Wolverton and more recently by Xu Z, et al. found potted spider plant (*Chlorophytum comosum*), aloe (*Aloe vera*) and golden pothos (*Epipremnum aureum*) plants were able filter the very common VOC formaldehyde from polluted indoor environments.¹⁶⁹ If we recall that many building materials use benzene, toluene and formaldehyde as chemicals and solvents in their manufacturing these studies may provide insight into ways of potentially reducing indoor contaminants.

In addition to the plants ability to filter chemicals out of the air, providing ground cover and possibly built screens of plants near openings to the indoor environment may help to reduce dust and particulate infiltration. As secondary benefit, the psychological benefits of having plants and the natural environment as part of the everyday indoor living experience cannot be overlooked. Studies have been done proving the effect of plants on happiness, productivity,¹⁷⁰ and health.¹⁷¹

¹⁶⁴ G. Adamkiewicz, A.R. Zota, M.P. Fabian, T. Chahine, R. Julien, J.D. Spengler and J.I. Levy, “Moving environmental justice indoors: understanding structural influences on residential exposure patterns in low-income communities,” *American Journal of Public Health*, 101, Supp. 1 (December, 2011):S238-45

¹⁶⁵ Wolverton BC, et al. Interior Landscape Plants for Indoor Air Pollution Abatement. Final Report—September 15, 1989. Stennis Space Center, MS:Science and Technology Laboratory, John C. Stennis Space Center, National Aeronautics and Space Administration (1989).

¹⁶⁶ *Ibid.*

¹⁶⁷ DS Yang et al, “Screening indoor plants for volatile organic pollutant removal efficiency,” *HortScience*, vol.44 no..5, (August,2009):1377–1381.

¹⁶⁸ *Ibid.*

¹⁶⁹Xu Z, Wang L and H. Hou. “Formaldehyde removal by potted plant-soil systems.” *Journal of Hazardous Material.*” Vol. 192 no.1 (August, 2011):314-8.

¹⁷⁰ T Bringslimark, T. Hartig, and G.G. Patil, “Psychological benefits of indoor plants in workplaces: Putting experimental results into context.” *HortScience*, vol.42 no. 3(June, 2007):581–587.

¹⁷¹ Son, K. C. “Indoor plants help people stay healthy,” *Joongang Life Pub, Co, Seoul, Korea* (2004).

SUMMARIZING

It is difficult to define the exact number of ACH or air velocity needed for optimal thermal comfort and indoor air quality in naturally ventilated systems. It is also difficult to further test this in the design phase; wind tunnel software in architecture seems to be consistently unreliable and specialized knowledge of these programs is required which many architecture firms do not have the time or resources to commit to. This is especially true because the necessary ventilation needed for these thermal comfort and IAQ is largely dependent on the specific climatic conditions (temperature, relative humidity) at each site and other factors like acclimation, clothing insulation, metabolic heat and radiant temperatures of building materials and indoor equipment (ovens, computers). Simply, if it is more hot and humid, more airflow is needed to create the desired cooling and ventilating effect. If we use the ASHRAE and AIA suggestions for healthcare facilities as a lofty bar to reach than we know somewhere between 2 to 5 ACH would be optimal. Although depending on other variables and inhabitant behavior ACH of less than 2 would probably be sufficient. Further, given the researched quantities of 0.25m/s to 1 m/s (even up to 1.5 m/s if it is really hot) for optimal thermal comfort we could safely assume that these numbers will reduce overall relative humidity and temperature to a point to minimize VOC off gasing and building material aw.

We must also keep in mind naturally ventilated systems are largely based on good design, fairly consistent climatic conditions and inhabitant cooperation to work efficiently. However, I believe this chapter has shown that the potential outcomes of natural ventilation greatly outweigh those of mechanical ventilation systems. We simply cannot afford mechanical ventilation systems in all of the residences on the Hawaiian Islands. The environmental, cultural, economic and public health consequences are far too great to continue to use a system of thermal comfort that puts so much else at risk. The design portion of this project will delve deeper into the application and design of some of the mitigating and targeted solutions to the negative aspects of natural ventilation.

PART 2:

A NEW HAWAIIAN HOUSE: DESIGNING A KIT OF PARTS

CHAPTER 8

THE SEARCH FOR NEW HAWAIIAN MATERIALS

The Hawaiian building industry is faced with a crisis of building materials. If you asked most architects and builders how many local building products they use to build homes in the state, I bet most could not name more than one or two. In fact, the only real building products that originate from the islands that have any sort of consistent use would be A'a, or Pāhoehoe lava rocks as masonry stones and a few local timbers like 'ōhi'a for columns or koa for finish carpentry. It is the contention of this dissertation that a Hawaiian residential architecture should attempt to incorporate local building products whenever possible; it is important environmentally, economically and culturally. The issue is that there are very few existing options for viable structural and accessory building products in the state. I would assert that when you import nearly 100% of the building products used in your architecture from over 2,000 miles away, while you are surrounded by viable building products than you are facing a moral dilemma that must be resolved.

Hawaiians used natural products like those seen in the hale pili to construct homes because these were the materials available to use around them. These homes were typically masonry foundations with timber frames lashed together and plant materials thatched into a roof. The Hawaiian builder was a maker; he could take raw materials and fashion them into effective building products. This project strives to do the same.

If we recall from the brief history of Hawaiian architecture early in this dissertation, foreigners did not follow in the methodology of the local people and instead brought building materials with them. I believe a large part of the long history of climatically and culturally misplaced architecture began with the idea that imported goods were superior to the indigenous materials that existed on the islands. There is a reason for this and I believe that a large part of why we tend to default to the existing and well known options of building materials, despite their potential negative aspects is for the sake of cost and convenience. However, projects like this are an attempt at demystifying the alternatives and hopefully bringing light on the conversation of how we can substitute the existing imported goods for our own local supply of building materials.

PRE-FABRICATION v. TRADITIONAL HOUSING

For residential architecture, there are generally two architectural methodologies. The “traditional” timber constructed home, for example, would incorporate many dimensional studs with cavity insulation, with exterior and interior wall coverings over a concrete poured in place slab or post and pier foundation with windows and doors set into the framing and trusses or rafters with a variety of roofing material. Each piece of the building is separate and must be fashioned together with a variety of connectors, screws, nails and bolts.

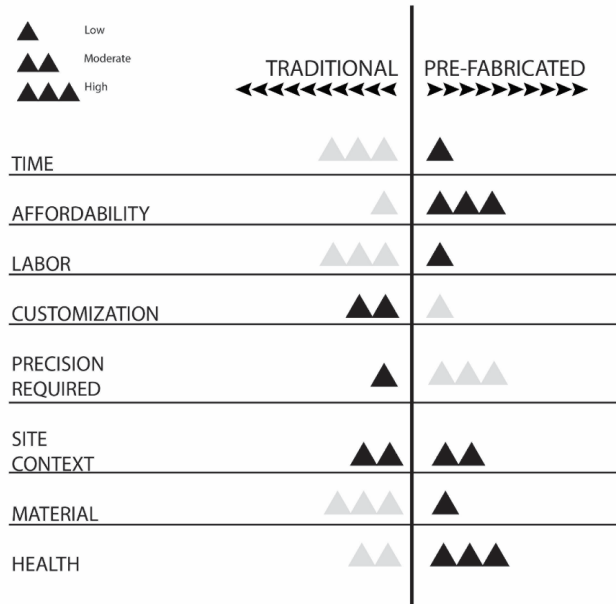


Figure 8.1: Comparison of Residential Construction Methods

Source: Own work

The other type of construction is pre-fabricated or modular construction. For this building type, entire sections of the house are pre-built out of a variety of materials in as few of pieces as possible. The idea is that once the pieces are delivered to the job site they can quickly be assembled by a few workers. The above diagram compares the typical types of traditional and pre-fabricated residential buildings. There are exceptions to each, for example a very well designed traditional house can be healthier, more cost efficient and cheaper than a pre-fabricated one. As with any type of architecture or building method, proper design and attention to detail will result in a better product.

Generally, the argument for pre-fabrication is that it is cheaper, faster and requires less labor. Typically, wall systems incorporate connections to the foundations, roofing and utilities so less overall coordination is needed on the project. Essentially, you buy or have designed a pre-built home that just needs to be fastened together on site. The benefits of this are great and often the money and time saved on pre-fabrication can make the difference in the ability of a person or family to afford their own home. Pre-fabricated homes are also typically more energy efficient, environmentally friendly and can incorporate solid building products like pre-cast concrete, cross laminated timbers or steel panels.

Pre-fab does have disadvantages, though. There is a much higher level of precision needed during the design phase in understanding how the pieces are constructed and the tolerances they have. If one piece ends up being too short or too long it can be the difference of the house coming together or being structurally sound. There is also less customization with pre-fabricated houses. Besides some interior furnishings, many pre-fabricated housing companies offer a few designs and that is all you can choose from. Pre-fabrication usually means special equipment to manufacture the pieces and special skills may be needed to assemble them on the job site. Pre-fabricated can also mean pre-assembled. This is where homes are built in the traditional sense but in large sections to be assembled later. This can have many of the same issues that a normal home may have regarding health and climate. Finally, when you choose a pre-fabricated home it may not necessarily work with the cultural or climatic conditions on the site for which it was chosen for. This can cause health and comfort issues as well as a misplacement of the architecture amongst existing socio-cultural conditions.

Traditionally built houses take much more time, usually on the design and the construction end, require many more people, labor hours and material. Due to this, traditional houses are usually more expensive so many people may not be able to afford their own homes. There are some advantages, though, like the level of precision, which is usually lower depending on the construction type. Traditional houses can be more customized, although that usually means higher cost. This customization typically allows architects and landscape architects the ability to design for specific sites without the restrictions pre-fab components may have.

No system of building is perfect and depending on the level of effort during the design phase, both can work well. However, Hawai'i has a need for more affordable and healthy homes which can be easily adapted to the various climatic, site and cultural conditions unique to this island chain while always understanding its environmental impact. As previously mentioned Hawai'i currently relies on a traditional building style with imported materials. This has led to an architecture which is unhealthy and harder to adapt to local needs. Although a traditional system could very well be designed it would require an even more specialized design for each site due to the structural and aesthetic logic of the "typical" home. This means a large population of architects and builders committed to designing an affordable home with the climate, human health, culture and both the local and global environment in mind. Local materials are also not conducive to this style of building requiring either specialized labor or materials which are too expensive for the average homeowner. This means that the traditional

architecture relies on imported materials which has socio-economic and environmental concerns attached to it. It is my contention that a pre-fabricated system of building with local materials would provide a solution to these concerns. I am not suggesting that the materials suggested in the design portion of this project are the only way to build a pre-fabricated home in Hawai'i. Substitutions or variations of material and structure options are absolutely possible. I.e. the primary design features concrete structural beams, these could very well be replaced with glulam beams, although their profile and size would be much different. Similarly, the wood panel systems for the roof and floor could be substituted for AAC or lightweight concrete panels. The purpose of the following chapters is purely for the understanding of the various pre-fabricated timber and concrete options and how they may work with Hawaiian resources and needs. I am in no way suggesting that my design or materials chosen are the only way to build, although they do embody the spirit of the goals of this dissertation.

8.1

STEEL

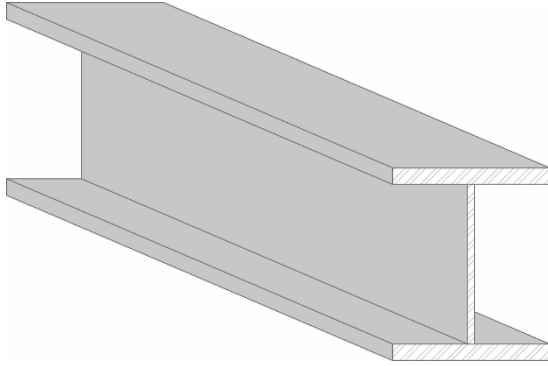


Figure 8.2: Steel I-Beam

Source: Own work

The primary types of structural materials are steel, concrete, masonry and timber. Due to the isolation of the Hawaiian archipelago, its geology, land cover and environmental makeup the efficacy of each material is variable. Steel is the only structural material which cannot be considered a local product; there is no way to manufacture raw materials from Hawai'i into a local steel.¹⁷² There is no denying the durability and structural benefits of

steel, its compressive and tensile strength are surpassed only by certain types of carbon fibers or synthetic materials. It is resistant to fire, (although it loses strength and can fail if it is not protected from extreme heat) and an argument can be made that its recyclability makes it more environmentally friendly than other materials. However, we would need to either import the finished steel products or create a steel industry and import the raw materials to make it locally. Even with its ability to be recycled, the production and re-production of steel still has a major impact on the environment and the addition of CO₂ to the atmosphere. Additionally, the harvesting of the iron ore from the Earth is often associated with significant environmental damage.

Steel must also be protected from the tropical climate and salt air to avoid issues with rust so heavy painting or a protective covering of some kind must be used. When used as a siding or roofing material, special attention must be made to the wall or roof construction to avoid heat transfer from exposed metal surfaces to the rest of the house. This project will minimize the use of steel to reinforcement and where necessary, structural connections.

¹⁷² Hawaii Volcano Observatory, Ancient Hawaiians: Plenty of Oars but no Ores, United States Geological Survey, accessed November, 16 2016, https://hvo.wr.usgs.gov/volcanowatch/archive/2009/09_09_24.html

8.2

CONCRETE



Figure 8.3: Alfred Essa, *The Salk Institute*, 2006 is licensed under

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Source: <https://www.flickr.com/photos/tatler/339218853> accessed November 15, 2016

Concrete can be found almost everywhere in the world in one form or another. Much of the built environment features concrete in the form of roads, bridges, dams, houses, large buildings and skyscrapers. It is incredibly strong in compressive strength and when properly reinforced can span great distances, resist tensile forces, wind driven pressure and earthquake damage. Depending on its use it can be molded into almost any shape and has a variety of finishes. Concrete is also completely resistant to termites and other insects, is not combustible and is incredibly fire resistant. Once cured, concrete is stable and does not release chemicals into the air and when maintained will resist mold and other harmful pollutants. Concrete has a high thermal mass which can be beneficial or detrimental depending on the location, climate and the design. In the tropics, we want to avoid high thermal mass unless it is protected from the direct sun. When combined with other materials which may have higher thermal conductivity and lower thermal mass like timber, protected concrete can help absorb heat and regulate indoor air temperatures.

There are a few different ways to make concrete and each has varying degrees of strength, usability, durability and environmental impact. All concrete mixes are made with a few key ingredients which include water, aggregate (sand and/or gravel) and some type of binding agent. Sometimes additives are used, but these are generally only when special requirements need to be met like extended or accelerated curing, viscosity etc. Currently, concrete in Hawai'i is made with imported Portland cement products and either imported or local aggregates. However, concrete could be potentially made from 100% local materials making it a more environmentally friendly building product.

Hawaiian Cement is the largest supplier and manufacturer of concrete supplies in the state. They previously manufactured raw Portland cement from imported clinkers and are now importing finished Portland cement to their facility on Oahu for distribution throughout the islands. They have also demonstrated the ability to produce the sand and aggregates necessary for high quality concrete production from local quarries with special manufacturing equipment.¹⁷³ There are also numerous other quarries and manufacturing plants producing primarily basalt sand and aggregate for concrete use



Figure 8.4: James cox, Caesarea Concrete Bath, Israel, 2009 is licensed under CC BY-SA 3.0, <https://creativecommons.org/licenses/by-sa/3.0/deed.en>

Source: https://commons.wikimedia.org/wiki/File:Caesarea_Concrete_Bath.jpg accessed October 17, 2016

already on the islands. The only product which is not directly from the islands are the binding agents. The binding agent has varied over the course of time, region and technological understanding. Historically, the first concretes and mortars which resemble the modern iteration were developed by the Romans, although they probably used a binding agent which came from the Greeks.¹⁷⁴¹⁷⁵

¹⁷³ "Hawaiian Cement uses Sandvik technology to produce sand." Aggregate Research. Accessed November 12, 2016. <https://www.aggregate-research.com/news/hawaiian-cement-uses-sandvik-technology-to-produce-sand/>

¹⁷⁴ M. Jackson, G. Vola, D. Vsiansky, J. Oleson, B. Scheetz C. Brandon and R. Hohlfelder, in press, "Cement microstructures and durability in ancient Roman seawater concretes," edited by J. Valek, C. Groot, and J. Hughes. *Historic Mortars, Characteristics and Tests*, Springer – RILEM.

¹⁷⁵ Axel Boëthius, Roger Ling, and Tom Rasmussen, *Etruscan and Early Roman Architecture*, (New Haven, CT: Yale University Press, 1978) 128-129.

This binding agent was made up of burnt, crushed Limestone to make Lime and volcanic ash with high silica and aluminum oxide content called Pozzolana.¹⁷⁶ On its own, Pozzolan does not bind concrete together, but the combination of its high silica and / or aluminum oxide content with Lime (calcium hydroxide) and water causes a chemical reaction called pozzolanic activity.¹⁷⁷ The result of this reaction is calcium silicate hydrate which is what binds and gives strength to concrete. Pozzolan concrete also has enhanced water and salt resistance over ordinary Portland cement based concretes.¹⁷⁸

BINDING AGENTS

In modern application, Portland cement is the most common binding agent. It was developed in the mid-18th century in England is used in place of pozzolana¹⁷⁹ and is the result of heating limestone and clays to high temperatures, grinding the result (clinker) and adding other constituents like gypsum to the mix.¹⁸⁰ This is then added to sand, gravel and water to form concrete. There are other binding agents which are used on their own or as part of a mixture with Portland cement including fly ash or organic plant materials like hemp.

Fly ash is the powdery residue leftover from coal fired kilns and power plants. The ash which is now captured magnetically, in the flues or on the bottom of the ovens is often a discarded by product of energy production. Per the EPA, of the 110 million tons of coal combustion residuals (CCRs) including fly ash, bottom ash or boiler slag generated in 2012 about 40% was recycled and 60% discarded into landfills.¹⁸¹ Due to its chemical makeup, fly ash can be used at about 60% of the cement mixture of concrete with the remaining portion coming from Portland cement.¹⁸² This project will not incorporate fly ash concrete due to the environmental impact, the fact that it is not produced in the state and because it must be used in conjunction with Portland cement anyway.

There are a few reasons why concrete in its most typical form is often said to be the most environmentally impactful building material. The cement industry is said to produce about 5% of the

¹⁷⁶ P.K. Mehta, "Natural pozzolans: Supplementary cementing materials in concrete," *CANMET Special Publication*, SP86-8E, (1987).

¹⁷⁷ Ibid.

¹⁷⁸ F. Massazza, "Concrete resistance to seawater and marine environment," *il Cemento* 1 (1985): 3-25.

¹⁷⁹ Robert G. Blezard, "The history of calcareous cements," *Lea's chemistry of cement and concrete*, 4 (1998): 1-23.

¹⁸⁰ "User Guidelines for Waste and Byproduct Materials in Pavement Construction," Report FHWA-RD-97-148 U.S. Department of Transportation, Federal Highway Administration accessed November 15, 2016 <http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/97148/072.cfm>.

¹⁸¹ "Frequent Questions the Coal Ash Disposal Rule," Environmental Protection Agency, accessed November 12, 2016, <https://www.epa.gov/coalash/frequent-questions-about-coal-ash-disposal-rule#1>.

¹⁸² Michael Thomas, "Optimizing the use of Fly ash in concrete," *Portland Cement Association*, (2007).

global CO₂; for an indispensable building material, whose industry is growing 2.5% annually¹⁸³ with the production of cement reportedly expected to rise from 2.55 billion tons as of 2006 to around 4 billion tons by 2050, this has significant environmental repercussions.¹⁸⁴ The reason cement causes so much CO₂ is due to the incredibly high energy output needed to heat limestone and clay to produce Portland cement products. Per the United Nations Environment Programme to produce 1 ton of cement you need 4.7 million BTUs or about 400 pounds of coal, generating almost a ton of CO₂.¹⁸⁵ Portland cement is usually heated in kilns powered by fossil fuels and the heating of limestone also releases CO₂, so the entire process is a high source of greenhouse gases, one of the highest, per the EPA.¹⁸⁶

There has been research and application of other alternatives to Portland cement and fly ash with varying degrees of success. Perhaps the most well-known is called Hempcrete. This type of concrete uses part of the hemp plant mixed with lime and water to form a lower density, lower strength bio-composite material. There are some benefits of hempcrete over traditional concrete like its neutral or even negative carbon footprint, its lighter weight, breathable, has good insulating properties and thermal mass. However, the lower strength means it must be used on conjunction with other supporting materials and requires the necessary hemp production to supply the high silica shivs.¹⁸⁷ Use of hempcrete could be implemented in some types of residential architecture if the necessary hemp production could begin in the state for the future, but for this project it will not be used.

Another extremely interesting and intriguing supplementary replacement for Portland cement was developed by a company called Calera. The process includes capturing CO₂ from flue gas and directing it through a source of alkalinity and calcium to form calcium carbonate. The source of alkalinity can be from industrial waste products like calcium hydroxide or from other separate sources like caustic soda and calcium chloride, both by products of other chemical processes. Most interesting is the ability to direct the CO₂ emissions through salt water which contains sufficient alkalinity and calcium naturally, the result is the same calcium carbonate which can be used as a replacement for Portland cement.¹⁸⁸ Calera's system has undergone some different processes and use of saltwater may require more energy

¹⁸³ "Cement Sustainability Initiative," World Business Council for Sustainable Development, accessed November 17, 2016.

¹⁸⁴ "IPCC Fourth Assessment Report: Climate Change 2007," 7.4.5.1 Cement. Intergovernmental Panel on Climate Change, accessed November 14, 2016, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch7s7-4-5.html

¹⁸⁵ "Greening Cement Production has a Big Role to Play in Reducing Greenhouse Gas Emissions," Environmental Science Alert, United Nations Environment Programme, accessed November 29, 2016, http://na.unep.net/geas/science/alert_2010_10.php.

¹⁸⁶ Lisa J. Hanle, "CO₂ Emissions Profile of the U.S. Cement Industry," Environmental Protection Agency, (2004), accessed November 27, 2016, <https://www3.epa.gov/ttn/chief/conference/ei13/ghg/hanle.pdf>

¹⁸⁷ Steve Allin, *Building with Hemp*, (Seed Press, 2005), 146

¹⁸⁸ Calera (website), accessed November, 28, 2016. <http://www.calera.com/>.

than other methods. Regardless, the ability to capture up to 90% of emissions from power plants to make a carbon neutral building material is interesting and further research should be done in the future when more information is available on the process and resulting calcium carbonate cement product.

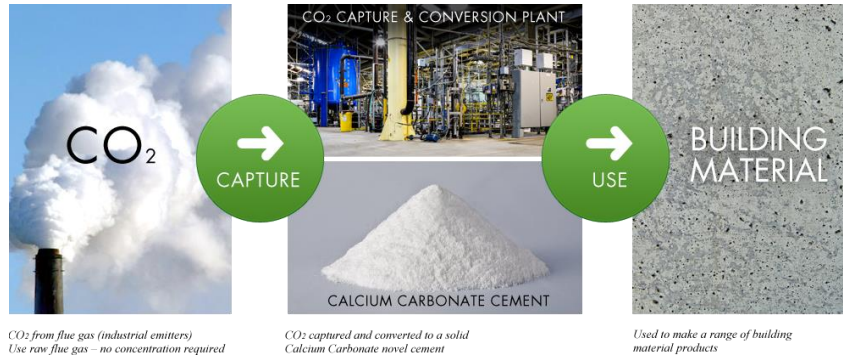


Figure 8.5: Calera CO₂ Capturing, The Process

Source: <http://www.calera.com/beneficial-reuse-of-co2/process.html> accessed November 3, 2016

If we as architects and builders are to use concrete in Hawai'i a few things should be addressed. We should attempt to use as many local products as possible to expand the local economy and to reduce the environmental impact of imported building products. This can be done by using local aggregates to create a more regional feel and culturally connected material. We should try to supplement or replace Portland cement whenever possible due to the absorbent amount of CO₂ produced in the process. Finally, we should try to use pre-cast or pre-stressed concrete to speed up the building process, reduce costs and attempt to develop an architectural language of simplicity.

Out of these goals, supplementing and replacing Portland cement is the most difficult. Local aggregates are in abundance and have been proven to create high quality concrete. Grace Pacific Rocky Mountain Prestress (GPRM Prestress, LLC) provides a wide assortment of Prestress / Precast Concrete Institute (PCI) certified structural and architectural products. Completely replacing Portland cement would be difficult with the current technology however there is some evidence to suggest that a creation of a local Pozzolana and production of lime from local limestone could be one solution.

HAWAIIAN POZZOLANA

There are a few differences and advantages of using a pozzolana based concrete over one with Portland cement. One of the main differences is Portland cement and pozzolana is their chemical makeup. Portland cement is a compound of calcium, silicates and hydrates while pozzolana is calcium-aluminum-silicate-hydrate; the former has more silicon and the later has added aluminum. The difference in the compounds has to do with the way this added aluminum binds the concrete together and the crystalline structures create a stable and durable mix.¹⁸⁹¹⁹⁰ The concrete is extremely long lasting, has enhanced waterproof qualities and is more resistant to saltwater.¹⁹¹ Our architectural mentor Vitruvius wrote about the first recipes for the pozzolana concrete in *De Architectura*, noting the use of lime and volcanic ash to create a durable building product. The effects and research of this over 2,000-year-old construction method gives us the opportunity to use a product that could replace up to 40% of the worlds Portland cement use. Further, the limited percentage of added lime and much lower heating requirements to produce the product will drastically save on CO₂ emissions creating a much more environmentally friendly concrete.¹⁹²

The main question then is: can we produce the sufficient volcanic ash and lime locally to create a concrete from 100% Hawaiian materials. Volcanic ash is typically comprised of lithic fragments (pulverized rock) and glass spheres and shards. As it is produced naturally, Hawaiian ash is more lithic and less glass-rich than that of other volcanic ashes which have been traditionally used for pozzolana.¹⁹³ However, if a process could be researched to separate the higher silica content glass from the lithic material then perhaps the local ash product could at least supplement the use of Portland cement we could reduce the impact of concrete even more.

¹⁸⁹ "Roman Seawater Concrete Holds the Secret to Cutting Carbon Emissions," Berkeley Lab's Advanced Light Source, accessed November 18, 2016. <http://newscenter.lbl.gov/2013/06/04/roman-concrete/>

¹⁹⁰ Marie D. Jackson, Juhyuk Moon, Emanuele Gotti, Rae Taylor, Abdul-Hamid Emwas, Cagla Meral, Peter Guttman, Pierre Levitz, Hans-Rudolf Wenk, and Paulo J. M. Monteiro, "Material and elastic properties of Al-tobermorite in ancient Roman seawater concrete," *Journal of the American Ceramic Society (August, 2013)*, 1-9.

¹⁹¹ Donald A. St. John, Alan B. Poole and Ian Sims, eds. *Concrete Petrography: A Handbook of Investigative Techniques*, 2nd ed, (Arnold, 1998).

¹⁹² "Roman Seawater Concrete Holds the Secret to Cutting Carbon Emissions."

¹⁹³ "Frequently Asked Questions about Air Quality in Hawaii," Hawaii Volcano Observatory, United States Geological Survey, accessed November 14, 2016. https://hvo.wr.usgs.gov/hazards/FAQ_SO2-Vog-Ash/P1.html

AUTOCLAVED AERATED CONCRETE (AAC)



Figure 8.6: Autoclaved Aerated Concrete (AAC)

Source: Own work

Autoclaved aerated concrete (AAC) is a unique type of concrete which is almost a hybrid of a masonry unit and a cast concrete product. AAC uses a combination of fine aggregates, Portland cement and an expansion agent like Aluminum. AAC undergoes a chemical process where the aluminum powder reacts with calcium hydroxide to form hydrogen. This process expands the concrete mixture and when the hydrogen dissipates voids filled with air are left. The mixture is then placed in the autoclave to undergo a steam pressure hardening process. The result is a lightweight but highly thermally insulating modular concrete

unit. Although AAC uses Portland cement, the expansion and air in the finished product means less raw material is used for the same amount of space. Further, the material is fire resistant, provides a solid insulating construction without cavities or need for rigid or batt insulation. Most importantly for this project, AAC contains air bubbles as shown in Figure 8.7 which helps in the diffusion of water, by absorbing moisture and reducing humidity. This means less chance for mold and the release of mycotoxins which would negatively affect indoor air quality. AAC also has less thermal mass than typical concrete making it more beneficial for exposed or partially exposed areas.

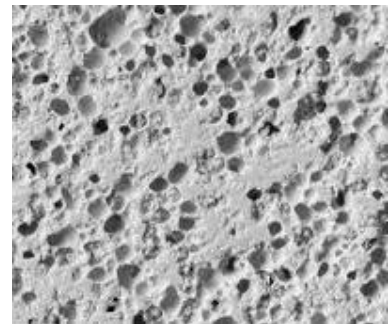


Figure 8.7: AAC up-close

Source: Own work

There are some disadvantages to AAC, specifically the compressive strength is lower than traditional concrete, about 50% less or 1,160 PSI. AAC often requires the use of mortar, a coating of plaster or stucco and depending on the necessary insulation walls can be exceedingly thick. However, this lightweight product that can be adapted to a roofing or flooring panel where compressive strength is not as critical.

PRE-CAST CONCRETE

Without re-iterating too much, concrete is an extremely taxing material on the environment so I would only recommend its use if it was at least manufactured with local aggregates to cut down on the environmental burden of importing heavy raw materials which we have on the islands. The addition of supplements to Portland cement or alternatives as mentioned in the previous chapter I believe are possible and with further research and development these should be incorporated in the future. In any case, it is hard to deny the structural ability of concrete and especially the ease at which pre-fabricated pre-cast concrete pieces can be produced. I mentioned previously that GPRM in Kapolei, Oahu is already creating many precast products for use in tall buildings, roadways, bridges and other large projects. Their ability to produce pre-cast pieces for a project like this would only be a matter of designing the specific structural pieces for production. Other pre-cast manufacturers could be set up if the market would support their use making the product even less costly. There are a few reasons why pre-cast concrete should be chosen for the new Hawaiian home.

The most obvious advantage for precast concrete parts is the ease and speed of installation. Pieces can be designed with simple connections and fit together on site with a crane and a few people. Material costs are cheaper because the pre-cast manufacturer will be buying or producing raw materials in bulk giving them more control and consistency of the product for their money. Pre-cast concrete parts are made using reusable molds making different shapes and sizes, steel reinforcement and concrete pouring more efficient, easier and more controlled. When simple components can be repeated in the design the process is more affordable and streamlined only requiring a few different types of molds for even very large projects. In the most cost efficient pre-cast structures, architects, engineers and pre-cast manufacturers limit the different individual pieces to only a few variations; repeatability is affordability. The molds are also usually in very controlled environments taking weather delays and other variables out of the equation and allowing proper curing times before the pieces are needed for installation. When they are installed in the field they are already at full strength, there are no issues with curing from weather delays or other variables which can compromise the product.

Poured in place concrete has some disadvantages when compared to its pre-made sibling. When concrete is poured in place it requires forms which must be made or put together on site by skilled workers. Reinforcement steel must then be set and tied in place by skilled steel workers, and then concrete is poured and finished by skilled masons. Concrete must either be bought and delivered

to the site which may require special coordination or machines to pump the product or mixed on site which requires mixing machines, extra labor and potentially consistency issues with the mix. Once the concrete is set and finished extra curing time is required before other stages of the project can commence. There are also limitations to what can be done with poured in place concrete. In other words, it would be incredibly costly, inefficient and difficult to make forms to span or cantilever large distances or create specialized types of structural forms.

Pre-cast concrete, when protected from the direct heat of the sun provides a thermally stable, strong, quick and healthy component for use in this project. There are no chemicals to pollute indoor air and when maintained, mold and other contaminants are unlikely to form. With the addition of local aggregates and binding agents the product is also more environmentally sustainable and culturally significant. Concrete is also termite proof, extremely fire resistant and when properly reinforced can withstand earthquake and wind forces. Pre-cast structures are also easily made into elevated structures giving them advantages during flooding. For these reasons this project will incorporate pre-cast concrete parts for the key structural portions of the project.

8.3

MASONRY



Figure 8.8: Pāhoehoe, 'A'ā and River Rocks

Source: Own work

Masonry in the form of natural stones or pōhaku in Hawaiian, exist in a few usable types in Hawai'i. These are 'A'ā and Pāhoehoe lavas and more smooth basalt river rocks and field stones. There are other types of stone in Hawai'i but the most common and usable for construction are these. Coral was used as a masonry unit for a time in the state and can be seen at Kawaiha'o church, the Chamberlain house, and other early western influenced Hawaiian buildings. However, the cutting and removal of coral from the ocean has significant environmental and ecological impacts and is no longer used as a construction material locally.

There are a few big advantages to using masonry in Hawaiian residential architecture. The product is locally sourced and is incredibly abundant. Lava rocks and other stones give architecture a regional character and feel which is unique to the islands. They are culturally significant as heiaus, buildings and walls have been built out of them for centuries. Hawaiian masonry can be successfully dry stacked reducing the need for mortar or otherwise constructed in a manner like other masonry walls. When designed correctly a masonry wall can be incredibly strong and can carry significant loads and when protected from the sun and properly ventilated work well climatically. Masonry is also healthy, not requiring chemicals or harboring VOCs which may make inhabitants sick. Finally, locally sourced masonry does not have an impact on carbon emissions and typically the environmental and ecological impact is negligible.

Despite these advantages there are some issues with masonry which make it difficult to use. Hawaiian masonry can be expensive depending on the source. Native lava rocks and other stones are either acquired from private quarries, private land or acquiring a permit from necessary land owners to pick or harvest the stones from the land. Lava rocks and other stones are also heavy and require many pieces to form walls making installation time and labor costs very high. Further, there is a high level of skill involved with building solid and accurate walls making large scale use of masonry cost or time prohibitive. For this project, we will not focus on masonry as a primary structural system. This dissertation attempts to create a kit of parts available to architects and builders to adapt to the numerous architectural variables and design challenges that the islands face. Masonry has a special place in Hawaiian culture and architecture but the time for installation and difficulty of adapting individual stones to other pre-fabricated systems takes it out of the scope of this project.

8.4

GLAZING + SYNTHETIC MATERIALS

Materials which often show up in typical houses in Hawai'i and the rest of the world are glazing (glass) and other manufactured materials. These include plastics like PVC, vinyl, fiberglass, synthetic materials like waterproofing membranes and carbon fiber or other high strength polymers materials.

The most common of this section is glazing, often referred to simply as glass. Most homes have glass in their doors, windows and bathrooms and other buildings in the world often have facades made almost completely out of glass. It is an amazing material which can be used in a variety of structural and nonstructural applications. This is because glass provides a unique answer to the age old architectural design issue of providing light and visual connection to the outside while still providing a layer of protection. This protection can be from the wind, sun or rain or from dust, insects or intruders.

The primary issue with glass is that it is not a good insulator on its own and without the proper construction assembly it can often create excess heat or cold gain making heating and cooling costs expensive or create uncomfortable spaces in naturally ventilated spaces. Glass is also expensive, must be shipped into the state, is difficult to install or repair and has high energy costs associated with it. Minimizing use of glass requires a design which incorporates other methods of providing light and air while still providing the other protections that may be required.

Synthetic materials, plastics and polymers will not be discussed in this project. These products often contain VOCs or other hazardous materials, are not manufactured in the state and cause damage to the environment in their development and use. The nature of construction is that often some of these materials are used to provide utilities in the form of wiring and plumbing or are needed to prevent intrusion of water into a building because other alternatives are not available. For this project, I will minimize their use to only areas where it is absolutely necessary.

8.5

TIMBER



Figure 8.9: Stack of Timber, Bureau of Land Management, Oregon

Source: <https://www.blm.gov/or/resources/forests/timbersales.php> accessed November 16, 2016

Timber of some kind or another can be found in most of the world and has been used as a building product for thousands of years. Although there are much older pieces of architecture standing made of masonry and concrete, old timber buildings exist like Hōryū Buddhist temple in Nara, Japan completed in 607 C.E. There are many reasons why architects and builders have chosen to use timber over the course of history. Depending on the species timber it can be incredibly strong and durable and can be adapted to many different types of construction. Timber can also be easily sawn and fashioned into several sizes for columns, beams, planks, slats, shingles, shakes, trim and other finish carpentry. Throughout the last hundred years or so, timber has also been adapted into many engineered products to increase strength, adaptability as well as to make new products out of otherwise wasted byproducts such as oriented strand board (OSB) or medium-density fibreboard (MDF).

To analyze timber for its strengths and weaknesses in architecture we must first keep in mind that timber or lumber is simply the processed wood from trees. It is a natural material that has many variables which effect the properties and character of the finished product. For example, timber is anisotropic, meaning it has different properties in different directions. Simply, it is much stronger parallel to grain than perpendicular to grain. It is both strong in compression and tension, depending on the type of timber and the direction of the grain structures. Timber is also hygroscopic meaning it evaporates or absorbs moisture (either from surface wetting or humidity) to maintain equilibrium with its surrounding environment. This moisture content is largely controlled by temperature and humidity and is what causes wood to swell or shrink in wet or dry conditions. These natural properties lend

themselves to many beneficial applications in architecture but to fully take advantage of their use thoughtful design and respect for the materials natural limitations should be realized.

Some of the major advantages of timber, especially solid timber construction, is that the wood typically does not contain VOCs or chemicals which could compromise indoor air quality. Larger solid timbers are also resistant to fires, the initial charring of the wood creates a temporary protective layer and slows down the burning while the internal part of the timber retains structural integrity.¹⁹⁴ Wood also has a decent R-value of approximately 1.41 per inch (2.54 cm) for most softwoods and 0.71 for most hardwoods,¹⁹⁵ and can be enhanced with layers in certain type of wall assemblies. For solid walls sufficient R values can be achieved while a low thermal mass reduces excess heat gain.

Perhaps the greatest benefit of using timber is that it can be a very renewable resource, depending on the genus. Trees which are harvested responsibly can be replanted or regrown in a way that balances the ecosystems which they are taken from. Additionally, new trees can be planted and forests expanded so the resource has a steady supply of mature trees to draw from. The benefit of timber as a renewable resource is two-fold. First, timber can remain in steady supply and costs can maintain a consistent growth. Second, trees absorb CO₂ and release oxygen during photosynthesis and can reduce greenhouse gas in the atmosphere. In fact, one tree can absorb several tons of CO₂

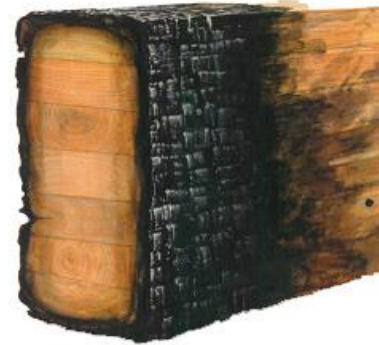


Figure 8.10: *Charred Timber Glulam*, American Wood Council, 2015

Source:
<http://www.awc.org/pdf/education/mat/AWC-MAT252-1-Glulam-CLT-NLT-151217.pdf>
accessed December 7, 2016

during its lifetime¹⁹⁶ while growing into a mature tree which can potentially be used for building. Logging has typically had a stigma attached to it—hippies chaining themselves to trees while the guy with the beard and the flannel shirt sits in the heavy equipment waiting for the lawyer to give him the go ahead to knock it down. However, there is a difference between cutting down old growth hardwood trees in the Amazon, never to be replanted versus harvesting deadfall, pine trees killed by boring beetles or

¹⁹⁴ "Technical Report 10 – Calculating the Fire Resistance of Exposed Wood Members," *American Wood Council*, 2016, accessed December 1, 2012 <http://www.awc.org/pdf/codes-standards/publications/tr/AWC-TR10-1604.pdf>.

¹⁹⁵ "Energy Saver – Energy Efficiency in Log Homes," United States Department of Energy, accessed September 20, 2016. <http://energy.gov/energysaver/energy-efficiency-log-homes>.

¹⁹⁶ McPherson, E.G. and J.R. Simpson, "Guidelines for calculating carbon dioxide reductions through urban forestry programs," *General Technical Report, PSW-171*, (Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1999).

using modern forest management and ecosystem research to sustainably grow timber stands. On the Hawaiian islands there is potential resource for thousands of acres of timber which could be sustainably harvested.

There are a few things to consider when using timber, however. Timber must be protected from the weathering effects of the harsh UV rays and moisture so prevalent in Hawai'i. When wood remains wet for long periods of time it can rot from fungus causing structural failure or form mold which pollutes indoor air quality. UV light also can cause surface degradation and protection from sunlight is required to maintain the original quality of the wood. Although heavy timber has good fire resistance due to the char effect, it is still combustible so wood structures are always at a risk for fire.

For Hawaiian architecture, the biggest issue facing timber use is termite invasion. There are about 7 types of termites in the state but the Formosan subterranean termite and West Indian dry wood termite cause the most damage.¹⁹⁷ Per the College of Tropical Agriculture and Human Resources (CTAHR), these termites cause over 100 million dollars' worth of damage to buildings per year. Different types of termites invade homes in different ways, the Formosan subterranean termite lives primarily underground but can travel short distances (if they stay in a moist environment) to feed. Dry wood and wet wood termite species can live in dry and wet wood respectively and can remain above ground. To prevent termites from feeding and damaging the home wood products and home sites are typically treated with chemicals. There are and have been many timber preservatives used to prevent termite damage. This includes chromated copper arsenate (CCA), (which is no longer used in the US and many other places in the world due to the leeching of arsenic into the environment), copper azole, alkaline copper quaternary and most commonly in Hawai'i, borate based preservatives. Each preservative has pros and cons, specifically with the risk to human health and the level of protection they give. For example, copper based preservatives are often very effective but the heavy metals and other ingredients mixed with them can cause human health problems.¹⁹⁸ Boric acid, oxides and salts (borates) are thought to be low toxicity but generally the salt leeches out over time, especially in moist environments like Hawai'i.¹⁹⁹ Despite the few cons of timber use it is still the most common construction type for

¹⁹⁷ Woodrow, R. J., J. K. Grace, and Julian R. Yates, *Hawaii's Termites--an Identification Guide*, Cooperative Extension Service, College of Tropical Agriculture and Human Resources, (University of Hawaii at Manoa, 1999).

¹⁹⁸ "Chromated Copper Arsenate," Toxnet, National Library of Medicine, accessed December 1, 2016. <https://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+7705>

¹⁹⁹ M. Saadat, "Factors affecting distribution of borate to protect building envelope components from biodegradation" (master's thesis, University of Toronto, 2012), <http://hdl.handle.net/1807/33518>

residential architecture in the United States. An added benefit is when a local timber supply can potentially alleviate the burden of importing other products from out of state or country.

In Hawai'i, Native Hawaiian peoples used timber to frame their hale pili as it was a readily available and workable material. It was also imported by missionaries to build their homes and both imported and native species have been in continual use since. In fact, imported timber was one of the driving inspirations for this project. As someone who lives on the Hamakua Coast of Hawai'i island, I am surrounded by a vast number of usable timbers. However, typically built homes in Hawai'i almost exclusively use imported light timber (Douglas Fir, Pine) framing from the Pacific Northwest while our own supply of timber is ignored and left to spread uncontrollably or harvested and shipped off the island. There are a few types of timber this project is interested in due to the available acreage of supply, environmental impact and economic potential.

There are many interesting genus of timber that exist in Hawai'i due to the various climatic and environmental conditions that exist here. Everything from the natives like 'ōhi'a , koa, kou and milo to the introduced eucalyptus, ironwood, redwood, cypress, sugi, Norfolk and Cook Island Pine, albizia, African Tulip, many varieties of mahogany, mango, mangrove and kiawe. There are of course many, many other species of trees which may be suitable as timbers but a few types of trees are of note because of their sheer abundance, their status as invasive or high risk weeds or because of specific structural or aesthetic appeal. This project will focus on a few genus of trees on Hawai'i island which have been used for construction here and in other parts of the world. These are the hardwood eucalyptus, ironwood, and as a secondary suggestion, mangroves (Figure 8.11)



Figure 8.11: Eucalyptus, Ironwood and Mangrove

Source: Own work

8.51

SELECTION CRITERIA

I have developed a specific selection criteria on why these three types of trees have been singled out by this dissertation as potential sources of local timber. These criteria are not a linear checklist but rather important variables for tree selection that should be met if architectural timber harvesting were to occur. They are culture, weed assessment, environment, population and properties.

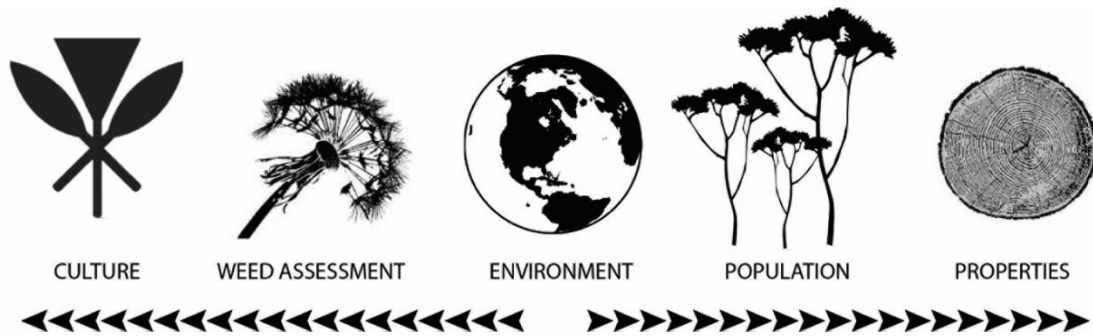


Figure 8.12: Hawai'i Timber Selection Criteria

Source: Own work

The criteria is:

CULTURE- *Does the tree have any cultural value or significance? Would using it be offensive or beneficial for the Hawaiian way of life?*

For example, timber like koa is aesthetically beautiful and mechanically makes great timber for building. However, this native trees is a precious plant in Hawaii and it is generally frowned upon to cut a healthy koa down for the purpose of building a home. Most koa used for furniture or building today is deadfall and because it is relatively rare the wood is very expensive. On the other hand, ironwood is a major weed species and has little cultural value. If other criteria were met this tree could be a potential timber resource. Cultural importance may vary from person to person but generally there are certain species of trees that due to their history in the Hawaiian way of life, their

population or their intrinsic value are significant enough that their use for a new type of residential architecture would simply not make sense.

WEED ASSESSMENT – *How invasive is the tree species? Does it spread too rapidly, cause harm to the environment, economy and/or human health?*

HAWAII PACIFIC WEED RISK ASSESSMENT SYSTEM

The Hawai'i Invasive Species Council, a State interdepartmental collaboration funds the Hawai'i Pacific Weed Risk Assessment System (HPWRA) which ranks plant species in Hawai'i for their potential as weeds. While this system is not the be all, end all resource that determines if a tree should qualify as a weed it is said to be 95% accurate at catching would be invasive plants. The HPWRA uses 49 questions regarding a plants biological, ecological and invasive properties which botanists

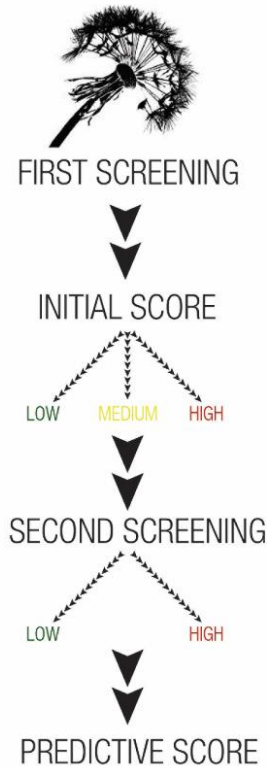


Figure 8.13: Hawai'i Pacific Weed Risk Assessment System

Source: Own work

and researchers can then answer to give an initial score of low, medium or high risk. After this, another screening is done and a predictive weed assessment score is assigned. The higher the more of a risk the plant is, currently, the highest rank is lantana camara at 32 and the lowest is thuja "Green Giant" at negative (-)14. all of the species of timber that I chose for this project are very high risk on the HPWRA.

ENVIRONMENT – *Would harvesting the tree harm the environment / ecosystem that it is growing in? Would it benefit the environment if it was removed and/or turned into a new crop?*

Trees play an important part in ecosystems that they are part of. They provide homes for animals and insects and their presence in the soil can either be beneficial or detrimental. Certain trees fix nitrogen in the soil, others steal it, some release chemicals which make it hard for other plants to grow, some reduce soil pH and some shade out other plants from their canopy or droppings. When a tree species has been selected for harvesting attention should be made to how removing that tree will affect the ecosystem it is part of. Further, after the tree(s) are removed will they be replanted, cycled with other tree species or will the land be left to



Figure 8.14 Alan L, *Native Hawaiian Hawk*



Figure 8.15: Maile Lei, Picked from Hawaii Island Forest

whatever plant takes over?

Deforestation, clear cutting and

improper forest management are serious issues and can leave ecosystems scarred for long periods of time²⁰⁰ as well as attributing to climate change.²⁰¹ In Hawai'i, deforestation not only affects plants, animals and insects but also influences our watersheds, and has serious cultural, social and economic implications.²⁰² Studying the variables related to the harvesting or planting of tree species should be carefully studied before choosing a tree species for timber

production.

Source: Own work

²⁰⁰ D.H. Grossman, "Early recovery of a Hawaiian lowland rainforest following clearcutting at Kalapana on the Island of Hawaii" (PhD diss, University of Hawaii, 1992).

²⁰¹ "Clearcutting and Climate Change," Center for Biological Diversity, accessed December 2, 2016. http://www.biologicaldiversity.org/programs/public_lands/forests/clearcutting_and_climate_change/

²⁰² G. Timmons and Sam Gon III, *Last Stand: The Vanishing Hawaiian Forest* (Honolulu, HI: The Nature Conservancy of Hawaii, 2003).

POPULATION – *How many of the tree species exist? Is it a large enough population that a consistent timber supply could be achieved?*

This criterion is probably the most straightforward and requires less investigation and explanation than the others. Simply, if a tree is exceedingly rare it would not make a good candidate for multiple residential projects. If large numbers exist and the other criteria are met, then that species would probably be more desirable for future timber production.



Figure 8.16: Eucalyptus Forest near Honokaa

Source: Own work

Population is highly correlated with environmental factors and the inherit properties of each species. In other words, some trees grow quickly in a variety of soils like ironwood and others which may be even better suited for timber but grow slowly or require special environmental conditions.

PROPERTIES – *What are the inherit mechanical properties of the timber? Is it strong or weak, does it check, crack or warp? What are the physical properties, does it have natural resistance to insects, will it hold up in the climate?*

There are many mechanical and inherit properties of trees which are correlated to the other search criteria for a good local timber species. For instance, the growth rate and density of each species of tree is directly related to their environmental impact, weed assessment, growth rate and tree density. In other words, if a tree can multiply rapidly and in great numbers they may have a greater effect on the soil chemistry, ecosystem diversity and economic viability.

Properties such as their specific gravity, strength characteristics, timber defects (cracking, splitting, warping) and termite resistance are also important variables in timber selection. A tree which grows fast and in large numbers but is relatively weak or susceptible to disease or termites would need intervention to make it usable. For instance, Joseph Valenti of University Of Hawai'i at Mānoa School of Architecture, in his doctorate dissertation chose to use one of the highest risk invasive species of albizia for use in Hawaiian architecture. However, Valenti notes that the inherit mechanical and physical properties of albizia, are like ponderosa pine and would benefit from engineered wood techniques like cross lamination or interlocking cross lamination to give them more structural capability, adaptability and economic viability.²⁰³ Valenti, like this dissertation aims to take advantage of a local invasive species to create a new type of Hawaiian architecture.

²⁰³ Valenti, Joseph J. "[Re]Scaling Urbanism: Fostering Low-Tech, Digitally Fabricated, and Transient Structures Through Innovation in Local Renewable Material," doctorate diss., University of Hawaii, 2016, ProQuest (AAT 1095969).

SUMMING UP

Timber can be acquired from a vast variety of tree species, regardless of this checklist. Even tree species which are proven like typical Douglas fir or American pine do not fulfil all of the search criteria but the ability to adapt these species with engineered techniques, chemical treatment and proper forest management makes them incredibly viable as building materials. It is not the purpose of this dissertation to challenge the fact that a Douglas fir glue-lam beam or 2" x 4" pine board are viable building products, because they have been proven for years with millions of houses and buildings. Rather, like Valenti I would challenge that a local timber supply would make more sense environmentally, economically and culturally than an imported source.

The main issues with my selections are regarding their environmental impact and inherit properties, as will be explained in the following section. However, it is important to remember a few things before moving forward. First, any monocrop will cause harm to the environment, eventually, if it is not properly managed, rotated or planted with symbiotic partner plants. Second, many technologies, engineering systems and design mitigations are available to adapt issues with inherit properties or external forces (termites, climate). Finally, all timbers have positives and negatives for their use in architecture. It is not solely the purpose of this project to say one species of wood is the answer to Hawaiian residential architectures problems. Rather it is the summation of the research and the designed kit of parts that could adapted to various types of building materials.

LOCAL TIMBER SELECTIONS

As previously mentioned there are a few specific timber species that I have targeted for use in this project. These are Eucalyptus, Ironwood and Mangrove. I believe there is also great potential for albizia as a supplementary timber but rather than try and recreate the work of Valenti, I decided to work with other species to expand the potential of a local timber source. Each of these timbers went through the selection criteria and each have inherit benefits and issues. However, I believe the adaption of these timbers combined with specific designed technologies create a new and viable building product for local use. After researching each material I will choose to focus on those with the greatest potential for the designed and physical portions of this project.

EUCALYPTUS

Eucalyptus in its many varieties has been planted all throughout the Hawaiian islands as a plantation crop, primarily for the purpose of reforestation, combustible fuel in the form of pulpwood, as a wind break and as a usable building timber from as early as 1870.²⁰⁴

According to Forest Solutions, Inc, a tree plantation management company on Hawai'i island, approximately 140,000 acres and roughly 14 million trees are planted in the eucalyptus plantation areas shown in Figure 8.17. Subtracting the approximately 800,000 native trees, there are around 13 million trees

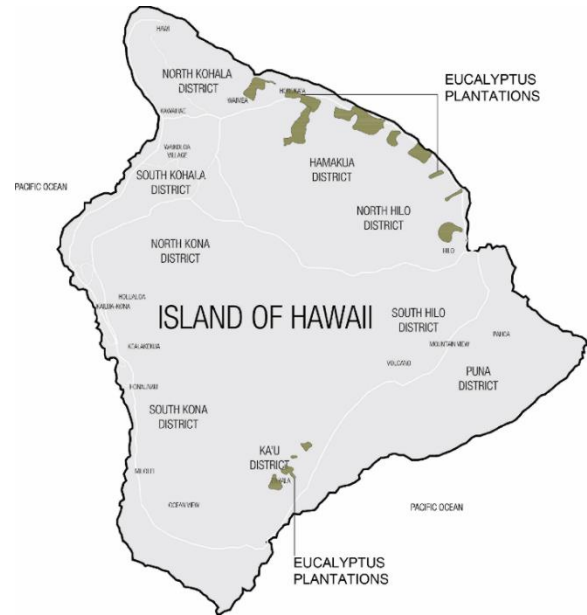


Figure 8.17: Eucalyptus Plantations Hawaii Island

Source: Own work

with timber potential on Hawai'i island alone. There are approximately 500 species of eucalyptus in their native Australia, about 90 exist on the Hawaiian islands and 13 of those exist in plantation



Figure 8.18: Hamakua Eucalyptus Harvest

Source: Own work

quantities.²⁰⁵

The most common eucalyptus in Hawai'i island plantations are eucalyptus grandis and saligna and hybrids of the two. There are reportedly millions of board feet of these species of eucalyptus on the Hawaiian islands with timber potential.²⁰⁶

²⁰⁴ Matt Piercy, "Seeing The Forest Through The Trees," North Hawaii News, accessed December 3, 2016, <http://www.northhawaii.com/seeing-the-forest-through-the-trees/>.

²⁰⁵ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: Eucalyptus, eucalypt" College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003, accessed December 2, 2016, http://www.ctahr.hawaii.edu/forestry/trees/CommonTreesHI/CFT_Eucalyptus.pdf

²⁰⁶ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: Eucalyptus saligna," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003.

EUCALYPTUS GRANDIS (Rose Gum)

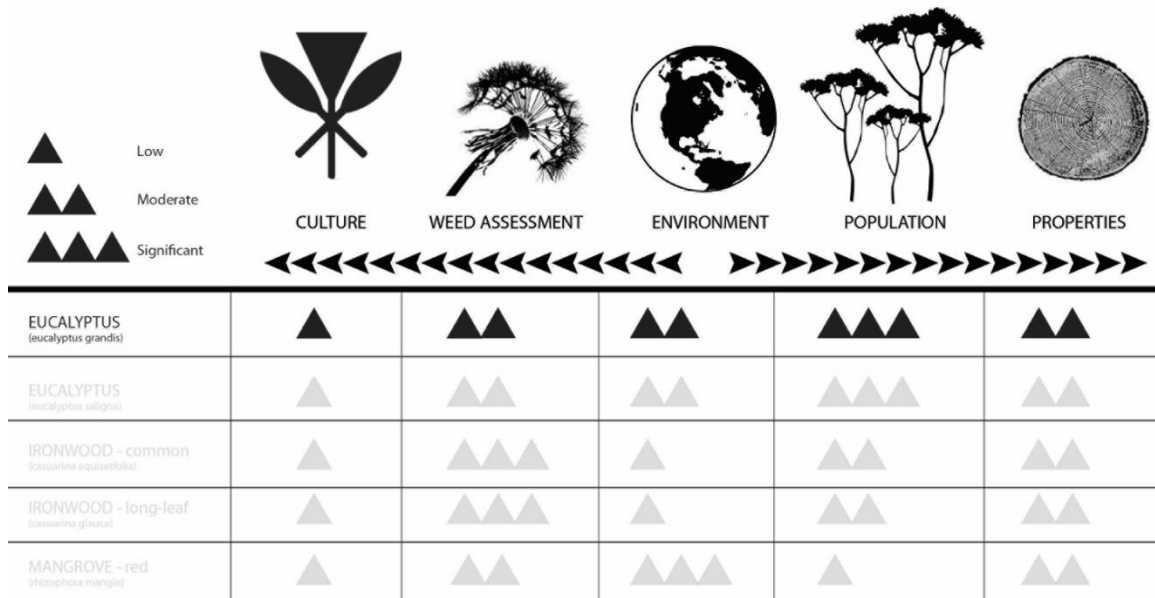


Figure 8.19: Eucalyptus Grandis, assessment

Source: Own work

Per the HPWRA, eucalyptus grandis is ranked “High Risk” at 11 making it a strong candidate for timber production. Special attention should be paid to environmental issues due to the exceedingly large populations of eucalyptus with relatively few companion plants. Research over soil chemistry, microbiological properties and ecosystem imbalance is mixed but as with any crop, extensive research should be done to understand each ecosystem.²⁰⁷ This is an introduced species with little or no cultural significance. The trees are slender (2-3’ diameter), grow very high (140-180’) and have few branches for up to 2/3 of the trunk providing potentially long uninterrupted pieces of timber.²⁰⁸ The wood ranges in color from pink to light brown with straight grain. Strength, durability and density are variable but generally the wood is harder and denser on the outside and less density on the inside with an average specific gravity of 0.57. The timber is used in Australia and Brazil as a structural and architectural timber but currently is only used for pulpwood in Hawai‘i.²⁰⁹ The Centre de cooperation international en recherche agronomique pour le developpement or the French Agricultural Research

²⁰⁷ Danju Zhang, Jian Zhang, Yang Wanqin and Fuzhong Wu, “Effects of afforestation with Eucalyptus grandis on soil physicochemical and microbiological properties,” *Soil Research* vol. 50 no. 2 (January, 2010).

²⁰⁸ Elbert L. Little Jr. and Roger G. Skolmen, “Common Forest Trees of Hawaii: Eucalyptus saligna,” College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003,

²⁰⁹ Ibid.

Centre for International Development (CIRAD) has done research on eucalyptus and its mechanical and structural properties. According to their research eucalyptus develops growth stresses, however using appropriate sawing techniques and producing short lengths of wood and is ideal for engineered products such as, glue laminated timber, cross laminated timbers as well as flooring, screens, windows and other construction timbers.²¹⁰ Eucalyptus grandis shows promising strength and durability properties; it has medium overall shrinkage, medium specific gravity, a crushing strength of approximately 60 MPa, a bending strength of 100MPa and a modulus of elasticity of 15 (x1000) MPa which has been listed as medium in strength.²¹¹

C.C. Gerhards of the Forests Products Laboratory did extensive testing on eucalyptus in Hawai'i and compared both grandis and saligna to that of shagbark hickory, and said few trees species were as strong in compression in the United States.²¹² According to Gerhards, saligna and grandis have a static bending modulus of elasticity of 1,980,000 psi, modulus of rupture of 11,500 psi and average shear strength of 1,470 psi.²¹³ When compared to the typically used Douglas fir and most species of pine, eucalyptus grandis and saligna are stronger.²¹⁴ Although eucalyptus has a reputation for being more difficult to work with, the mechanical properties of grandis and saligna lend themselves well to structural building products if they are properly sawn and treated. Added dimensional stability from thermal modification which will be discussed later in this project makes eucalyptus an even stronger candidate for local timber production.

Eucalyptus grandis is one of the primary trees in the plantations and millions of board feet are potentially available. Grandis is resistant to decay and dry wood insect borers but is susceptible to termites and would need treatment.

²¹⁰ "Eucalyptus grandis," Tropix 7, CIRAD (March, 2012) accessed December 4, 2016
<http://tropix.cirad.fr/FichiersComplementaires/EN/Asia/EUCALYPTUS%20GRANDIS.pdf>

²¹¹ Ibid.

²¹² C.C. Gerhards, "Some strength and related properties of green wood of Hawaiian Eucalyptus Saligna," Research Paper FPL09, Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, (May 1963): 7.

²¹³ Ibid, 7-9.

²¹⁴ *Wood Handbook: Wood as an Engineering Material*, centennial ed. General Technical Report 190 (Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, April, 2010) accessed December 5, 2016
http://www.woodweb.com/Resources/wood_eng_handbook/wood_handbook_fpl_2010.pdf

EUCALYPTUS SALIGNA (Sydney blue gum)

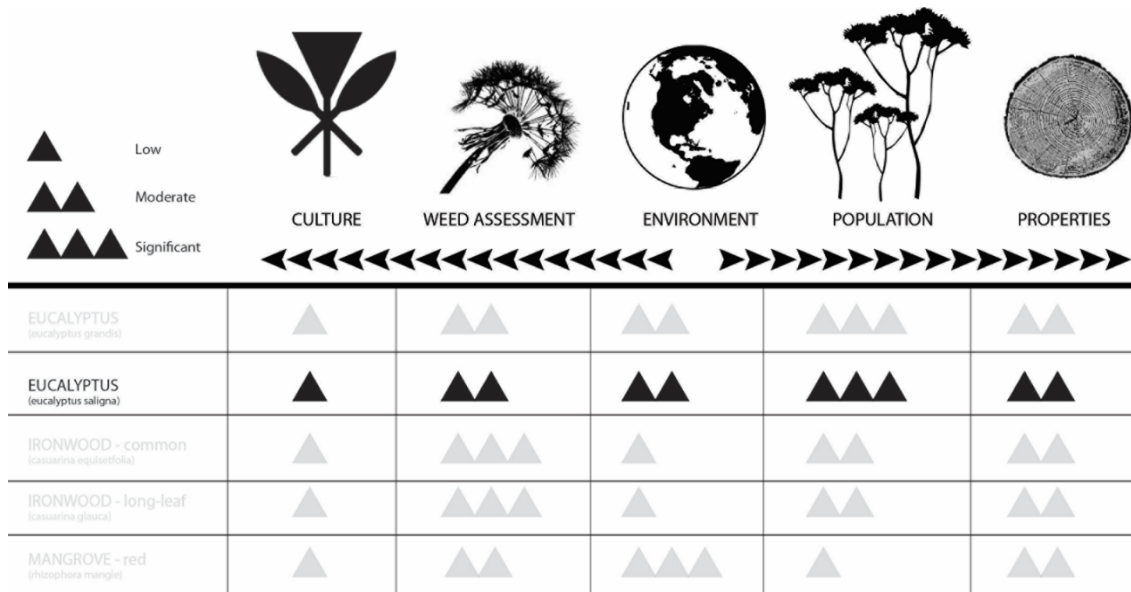


Figure 8.20: Eucalyptus Saligna, assessment

Source: Own work

Eucalyptus saligna is ranked as a 7 per the HPWRA also indicating “High Risk” like its grandis relative. This is an introduced species with little or no cultural significance. Large stock of the tree lends itself to possible timber production but like grandis special attention should be made to the specific environments which they may be pulled from. Saligna is slightly larger than grandis, ranging from 130-200’ + with a trunk diameter of 2-4’ of consistently straight timber without branches for 2/3 of the trunk height.²¹⁵ Trees grow rapidly and can reach close to 100’ within 5 years. Wood is darker than grandis presenting as pale brown to light reddish brown with either straight or interlocking grain. Saligna is heavy, and like grandis the density is variable throughout the tree but generally has a specific gravity of 0.61.²¹⁶ In other countries saligna is used for construction although in Hawai’i it is only harvested for pulpwood.²¹⁷ Strength and durability characterizes as discovered by C.C. Gerhards and discussed in the previous section on E. grandis lend themselves well for structural timber and engineered building products. At least 18 million board feet are estimated to be on the Hawaiian islands although that number is likely to be higher since the College of Tropical Agriculture

²¹⁵ Elbert L. Little Jr. and Roger G. Skolmen, “Common Forest Trees of Hawaii: Eucalyptus saligna,” College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003.

²¹⁶ Ibid.

²¹⁷ Ibid.

and Human resources published information about the species.²¹⁸ *E. saligna*, like *E. grandis*, is not resistant to termite damage but has moderate resistance to decay.

²¹⁸ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: *Eucalyptus saligna*," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003.

IRONWOOD – (casuarina equisetifolia)

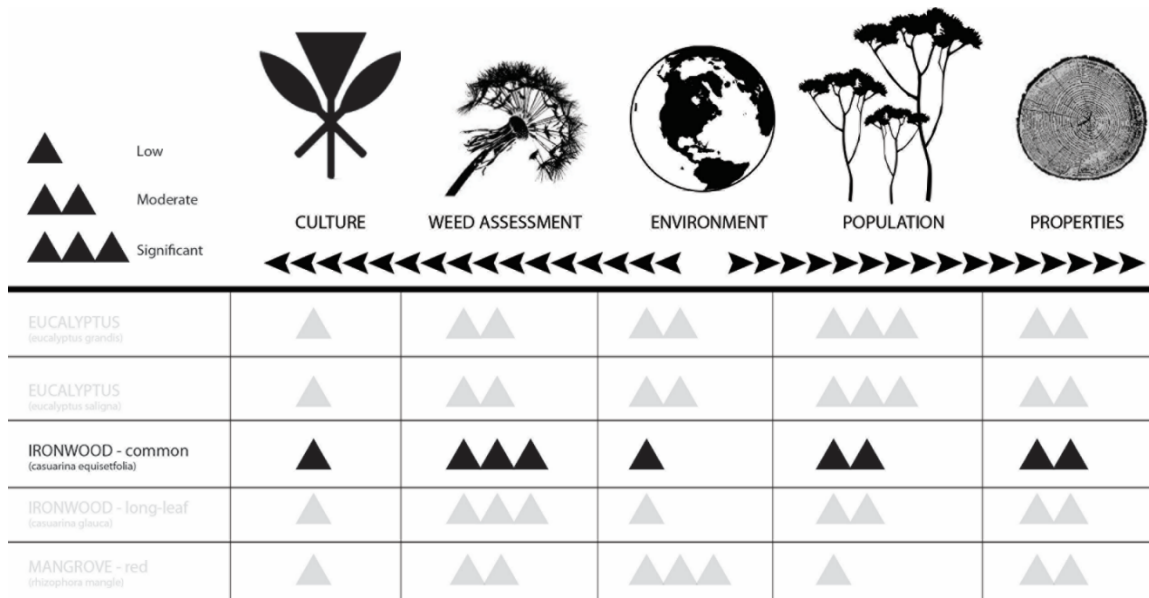


Figure 8.21: Casuarina equisetifolia assessment

Source: Own work

Ironwood (*casuarina equisetifolia*) ranks 21 per HPWRA making it one of the highest weed risk assessment trees on the list. This is an introduced species with little or no cultural significance. This type of ironwood is the most common planted in Hawai'i and adapts well to many climate types and environments. The tree grows to a medium to large size, about 50-100' tall with a 1-1.5' diameter trunk.²¹⁹ The wood is very dense and hard with a specific gravity of 0.81 with fine textured pink and light brown sapwood and dark brown heartwood.²²⁰ In research done on *C. equisetifolia* and its potential as a structural timber product, researchers have found that it has high density and strength properties and could be used for construction²²¹ although it tends to check from the heartwood and

²¹⁹ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: Casuarina equisetifolia," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003, accessed December 4, 2016 http://www.ctahr.hawaii.edu/forestry/trees/CommonTreesHI/CFT_Casuarina_equisetifolia.pdf

²²⁰ *Ibid.*

²²¹ M.Q. Chowdhury, F. Ishiguri, K. Iizuka. et al. "Radial variations of wood properties in Casuarina equisetifolia growing in Bangladesh," *Journal of Wood Science*, vol. 55 iss. 2 (April, 2009): 139 – 143. doi:10.1007/s10086-008-1004-2.

careful sawing is required. Modulus of elasticity is 1,549,000 psi and crushing strength parallel to grain of 6,820 psi²²² making Ironwood a good candidate for timber use.

Ironwood species are nitrogen fixing and help with erosion control. It scores high on the weed assessment because of its ability to spread and grow quickly (80' within 10 years), on a variety of soil types like sand (due to its excellent salt tolerance) and poor soil and ability to grow from sea level to 3000'²²³ Special attention should be made to ironwood populations and if used as a timber species research into the ecosystems for which they are being harvested from would be highly advisable. While not planted as a plantation species, populations are harder to estimate. CTAHR estimates at least 70,000 trees at the time of their publication but many have been planted on private lands and as



Figure 8.22: Ironwood in Haina

Source: Own work

windbreaks throughout the state. Ironwood has spread rapidly onto state land and it would be safe to assume many hundreds of thousands to millions of trees exist on thousands of acres dispersed throughout the state. Ironwood is currently used for furniture and for fuel but has been used as a building product elsewhere. Ironwood is susceptible to termites and should be carefully treated for construction use.²²⁴ Best use of the timber would be for engineered structural products.

²²² "Sheoak," The Wood Database, accessed December 6, 2016 <http://www.wood-database.com/sheoak/>.

²²³ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: Casuarina equisetifolia," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003. accessed December 4, 2016 http://www.ctahr.hawaii.edu/forestry/trees/CommonTreesHI/CFT_Casuarina_equisetifolia.pdf.

²²⁴ Ibid.

IRONWOOD – (*casuarina glauca*)

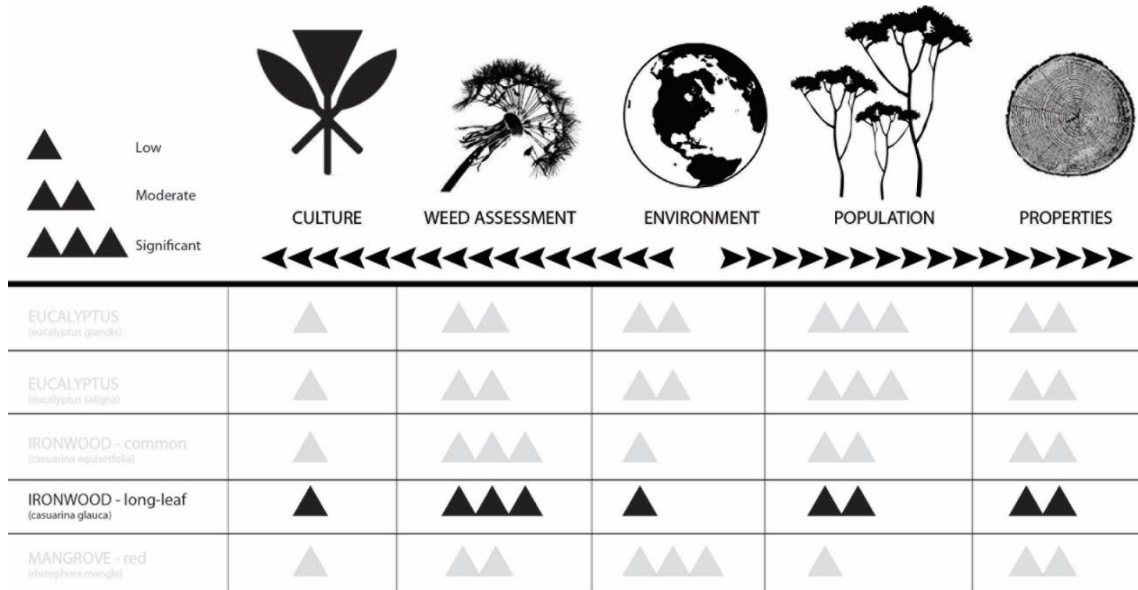


Figure 8.23: Casuarina glauca assessment

Source: Own work

Ironwood (*casuarina glauca*) ranks 20 per HPWRA making it one of the highest weed risk assessment trees on the list. This is an introduced species with little or no cultural significance. This type of ironwood is the second most common ironwood species planted and is similar in its characteristics to its relative. This tree is a medium size (40-50') with a straight 1.5 diameter trunk.²²⁵ The wood is similar *casuarina equisetifolia* with pale yellow sapwood, dark brown heartwood with fine textured, figured, hard wood.²²⁶ Currently the only real use in the state is for fuel but elsewhere it is used for construction. This species is also nitrogen fixing and helps with erosion control but spreads very rapidly and can cause harm to environments due to the density and the effect it has on the forest floors. Estimates for populations were over a million at time of CTAHR publication but it is safe to assume that with its ability to spread quickly there are many more trees across the state.²²⁷ This species is also susceptible to termites and should be preserved if it is to be used as a timber species. Best use of ironwood would be for engineered structural products.

²²⁵ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: *Casuarina glauca*," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003. http://www.ctahr.hawaii.edu/forestry/trees/CommonTreesHI/CFT_Casuarina_glauca.pdf. Accessed December 4, 2016.

²²⁶ *Ibid.*

²²⁷ *Ibid.*

MANGROVE – (Rhizophora mangle)

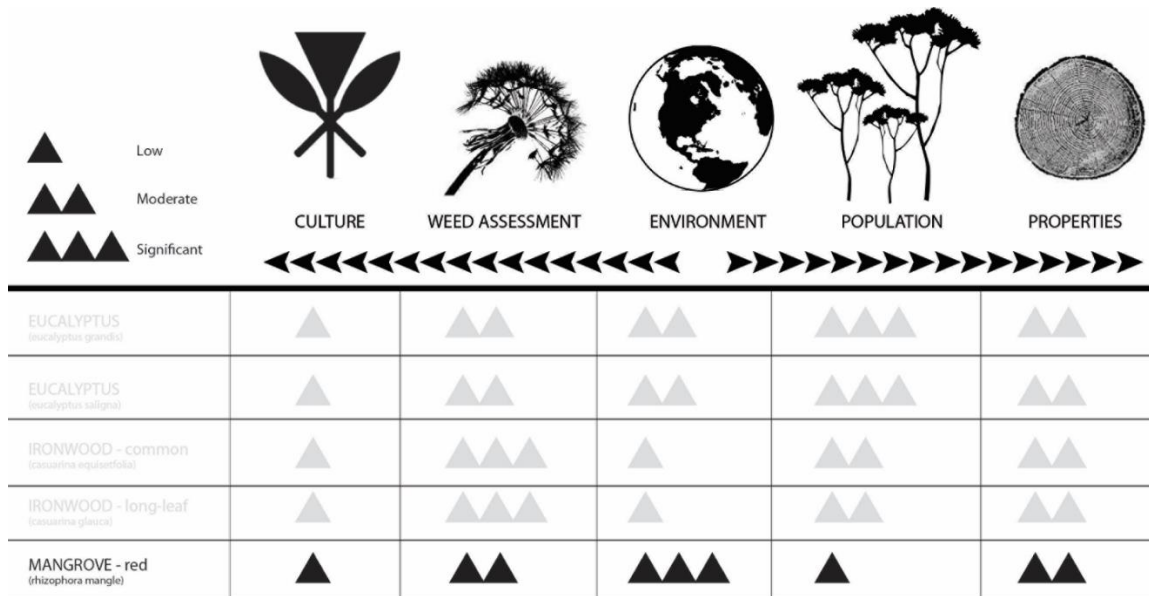


Figure 8.24: Rhizophora mangle assessment

Source: Own work

Mangrove (*rhizophora mangle*) ranks 13 per HPWRA due to its ability to quickly spread on the shoreline, in saline marshes and in the shallows of the ocean. Mangrove trees are relatively small, approximately 33' with 8" diameter trunks and clusters of supporting root structures. The wood varies from light brown sapwood to reddish to dark brown heartwood. The wood is very hard and heavy with a specific gravity of 0.9 to 1.2, durable in the soil and partially susceptible to dry-wood termites.²²⁸ Mangroves are an interesting tree on the Hawaiian Islands as it is not their natural habitat but they have a profound effect on the areas they grow. In other places in the world they provide essential habitats for wildlife and help to maintain a healthy ecosystem.²²⁹ In Hawai'i, mangroves are rumored to interrupt native fish and marine ecosystems, however research suggests that mangroves typically grow where human introduced erosion or sediment deposition and their effect on water quality is generally positive.²³⁰

²²⁸ Elbert L. Little Jr. and Roger G. Skolmen, "Common Forest Trees of Hawaii: Rhizophora Mangle," College of Tropical Agriculture and Human Resources, University of Hawaii. Reprint, 2003, accessed December 8, 2016 http://www.ctahr.hawaii.edu/forestry/trees/CommonTreesHI/CFT_Rhizophora_mangle.pdf

²²⁹ James A. Allen, "Mangroves as alien species: the case of Hawaii," *Global Ecology and Biogeography Letters*, vol. 7 (1998): 61-71, accessed December 6, 2016 http://www.fs.fed.us/psw/publications/allen/psw_1998_allen001.pdf.

²³⁰ *Ibid.*

The ease of reproduction and flourishing populations may have other benefits like tsunami and hurricane protection ²³¹ and as a possible source for timber. Other research suggests the mangroves may displace some animals and provide homes for alien species so any reproduction of mangroves in the state would benefit from extensive site research on the ecosystems that they are growing or planned to be planted in.²³² The smaller size of mangrove trunks lends itself more toward an engineered wood product than that of solid timber construction.

²³¹ F Danielsen,, MK Sorensen, MF Olqig, V Selvam, F Parish, ND Burgess, T Hiraishi, et al., "The Asian tsunami: a protective role for coastal vegetation," *Science*, vol. 310 iss. 5748 (October, 2005): 643.

²³² R. A. Chimner, Fry, B., Kaneshiro, M. Y., & Cormier, N. "Current Extent and Historical Expansion of Introduced Mangroves on Oahu, Hawaii," *Pacific Science*, vol. 60 iss. 3 (2006): 377–383.

TIMBER CONCLUSIONS

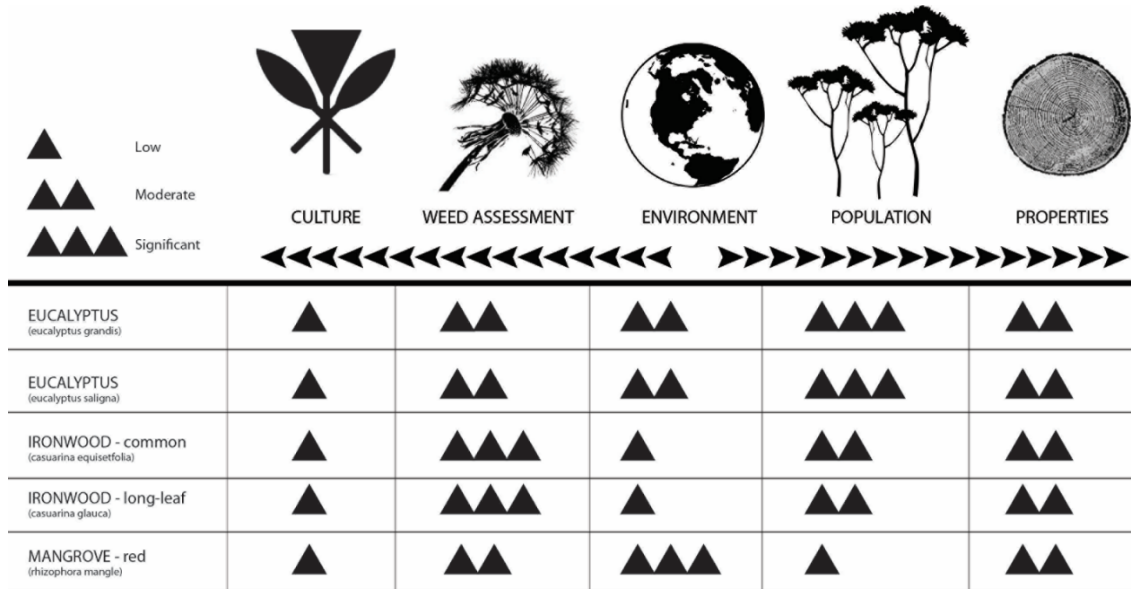


Figure 8.25: Timber Assessment Conclusions

Source: Own work

All five of these wood species have potential as timber species in Hawai'i. There are many other species which could be targeted as well like albizia, kiawe, and some species of fir and pine. However, these 3 genus of trees provide a good sampling of the most common, quick growing types of invasive tree species which may be used for timber. One important note to conclude this section; no plant should be planted or harvested as a monoculture. Even if these genera of trees end up being a viable and used source of building timber there should be extreme caution and careful research conducted on the various ecosystems for which they are to be planted. It would be my suggestion that an interdisciplinary team of professionals and researchers be used if large scale production of one species of tree is to be planted. It should not come as a surprise that planting one type of crop over and over on a piece of land will have profound environmental implications and responsible forest management techniques should be used whenever possible.



Figure 8.26: Shipping away the eucalyptus

Source: Own work

One of the driving inspirations for this project are these two pictures above. I have been involved in architecture, design and building for many years on Hawai'i island so I understand that most homes use imported timber species regardless of the style or budget while we are surrounded by a potentially affordable, environmentally sustainable supply of wood. Witnessing truck after truck hauling usable timber from the Hawaiian forests to Kawaihae harbor to ship them out of the country while the next ship is delivering timber from the mainland seems counter intuitive at best.

8.52

ENGINEERED TIMBER PRODUCTS: OVERVIEW

Many types of engineered wood products have been developed to improve the quality of timber construction. Generally, engineered products can be separated into structural and non-structural type products. Non-structural engineered products like particle board and medium-density fiber board use wood particles and adhesives or binders and are either compressed and extruded or heated with high temperature and pressure to form sheets. Some of the other non-structural products are those like flooring and paneling.



Figure 8.27: Oriented Strand Board

Source: Own work

There are many types of structural engineered products of varying strength, durability and cost. Oriented Strand Board (OSB) is higher quality than particle board and MDF as it uses strands or “flakes” of wood instead of particles but still uses adhesives to compress



Figure 8.28: GluLam Beams

Source: Own work

the product into sheets. Plywood is even higher quality than OSB and uses thin veneers of wood and a system of cross graining with adhesives to form a stronger and more stable engineered sheet. Larger timbers can be engineered as well like glued laminated timbers. Glulam's as they are commonly called, use varying quality dimensional timbers like 2 X 4” or 2 x 6” boards which are typically finger-jointed and glued together to form various beam profiles, cambering and radii. These beams are usually much stronger and versatile than similar sized solid timber beams and can use smaller lengths and lesser grade wood to bridge longer spans and support more load.²³³ Engineered products can also usually be created in larger depths and sizes than traditional sawn lumber and their construction makes them

the product into sheets. Plywood is even higher quality than OSB and uses thin veneers of wood and a system of cross graining with adhesives to form a stronger and more stable engineered sheet. Larger timbers can be engineered as well like glued laminated timbers. Glulam's as they are commonly called, use varying quality dimensional timbers like 2 X 4” or 2 x 6”

boards which are typically finger-jointed and glued together to



Figure 8.29: Laminated Veneer Lumber (LVL)

Source: Own work

²³³ *Glued Laminated Timber Product Guide*, APA – The Engineered Wood Association, accessed December 6, 2016, <https://www.apawood.org/publication-search?q=x440>

less prone to shrinkage and other normal wood defects.²³⁴ Many other engineered products exist like “i” joists which plywood with two dimensional timbers on the top and bottom to form strong joist products or laminated veneer lumber (LVL) which sandwich thin slices of wood to form beams or joists.

PRE-FABRICATED TIMBER PRODUCTS

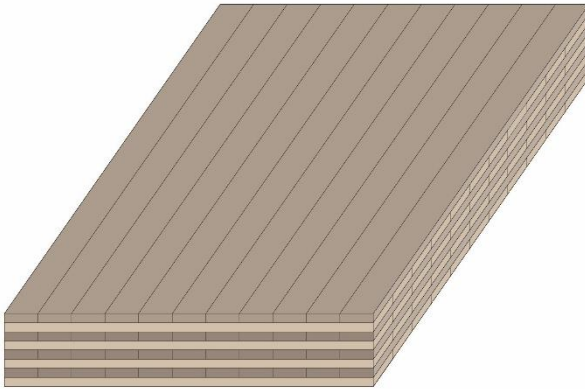


Figure 8.30: Cross Laminated Timber (CLT)

Source: Own work



Figure 8.31: Dalston Lane, under construction 2016

Source: Waugh Thistleton Architects

insulating qualities. It is affordable and can be installed quickly by fewer skilled laborers in many different climatic and site conditions. CLT panels are also adaptable to other materials creating flexibility in design and aesthetic value.²³⁵ CLT technology has allowed architects and builders to design a variety

²³⁴ Ibid.

²³⁵ Layne Evans, “Cross Laminated Timber: taking wood buildings to the next level,” *Engineering News-Record*, (October, 2013) accessed December 7, 2016 <http://www.rethinkwood.com/sites/default/files/Cross-Laminated-Timber-CEU.pdf>.

of building types from homes to institutional buildings and more recently even tall buildings entirely out of timber. CLT is an environmentally sustainable and economical solution to building which formerly could only be done in concrete and steel.²³⁶ Dalston Lane (Under construction, 2017) by Waugh Thistleton Architects is currently the largest (although not the tallest) CLT building in the world at 10 stories and 121 units and is entirely made from CLT walls, floors and stairs.²³⁷ Other CLT buildings currently under construction have reached heights up to 15 stories. While the size and height of CLT is not of concern for our Hawaiian house, the pre-fabricated versatility, relative lightness and structural benefits of CLT are of note for this project and perhaps as an alternative to concrete and steel in the urban areas of Oahu.

Without a doubt engineered wood products help to save product waste and the added benefits make them highly attractive in construction. In fact, it is hard to find a timber framed home, especially in Hawai'i that does not have some engineered products.

One of the primary drawbacks to these engineered products is the method of their manufacturing. They are all laminated or compressed in some way that uses adhesives, binders or chemicals to make them stay together. If we recall from the chapter on health and the indoor environment, these products contribute significantly to poor indoor air quality and increase risk of health complications. Cross laminated timber shows exceptional promise for use in Hawaiian architecture and some alternatives which do not use adhesives, chemicals or other health complicating additions like paint and stain (especially for exterior use). These options are interlocking cross laminated timber (ICLT), Brettstapel and Cross Nailed Timber (CNT) with special borate infused, thermal modification treatment applied for climatic protection, insect resistance and fungal protection creating a locally grown healthy pre-fabricated material.

²³⁶ *The Case for Tall Wood Buildings*, mgb ARCHITECTURE + DESIGN, (February, 2012) <http://www.woodworks.org/wp-content/uploads/CWC-Tall-Walls2.pdf>.

²³⁷ "Dalston Lane," Waugh Thistleton Architects, accessed December 9, 2016 <http://waughthistleton.com/dalston-lane/>.

INTERLOCKING CROSS LAMINATED TIMBER (ICLT)

ICLT was pioneered by the University of Utah's Integrated Technology in Architecture Center (ITAC) as an alternative to traditional CLT panels. ICLT uses a patent pending CNC milled tongue and groove pattern to "lock" the layers into place. This system of joinery removes the need for adhesives or other connectors and makes them easier to disassemble for recycling beyond the buildings lifespan. One of reasons ICLT was developed was to make use of substandard or off grade wood products while avoiding adhesives and VOCs. CLT already has the advantage of using lesser quality wood to achieve higher structural and dimensional quality and the ICLT process builds upon that.²³⁸ ITAC uses "beetle kill pine" or pine which has been infested and killed by boring beetles as their primary wood species. This timber is



Figure 8.32: ICLT Panel

Source Sanders, Steven L. Behavior of Interlocking Cross-Laminated Timber (ICLT) Shear Walls, Masters Thesis, Brigham Young University, Provo UT, 2011

considerably substandard on its own due to the nature of its origin and usually left for rot or burned as fuel. Similarly to ITAC, research by Valenti, 2016 at University of Hawaii School of Architecture employed the use of Hawaiian albizia (*alcataria moluccana*), which has poor wood quality on its own in a ICLT modular system to create a more stable product for transitional housing in Hawai'i.

Per Sanders, 2011, ICLT panels provide more structural support than traditional CLT panels, although they tend to drift more due to their construction.²³⁹ Regardless, it is still sufficiently resistant to drift and provides superior structural ability. The main disadvantages of ICLT are the methods of manufacturing. Although the purpose is to employ wood of lesser quality which can be obtained cheaply (i.e. beetle kill pine, albizia) the process requires special machinery and the additional steps of milling and labor fitting the dovetails together almost like a puzzle.

²³⁸ "Interlocking Cross Laminated Timber (ICLT)," Integrated Technology in Architecture Collaborative, accessed December 9, 2016 <http://itac.utah.edu/ICLT.html>.

²³⁹ Steven L. Sanders, "Behavior of Interlocking Cross-Laminated Timber (ICLT) Shear Walls" (Masters thesis, Brigham Young University, 2011) accessed December 8, 2016 https://ceen.et.byu.edu/sites/default/files/snrprojects/636-steven_l_sanders-2011-fsf.pdf.

NAIL LAMINATED TIMBER / BRETTSTAPEL



Figure 8.33: Nailed Laminated Timber

Source: <http://structurecraft.com/materials/mass-timber/nail-laminated-timber> accessed January 11, 2016

sheathing and the requisite adhesives used in the product would need to be replaced with some type of non-VOC laminating process. This could possibly be at least one layer of timber in the opposite direction laid on top of the NLT panel.



Figure 8.34 Brettstapel Construction

Source: Own Work

Brettstapel, originally developed by a German engineer called Julius Natterer in the 1970s, is similar to NLT. It also uses individual pieces of smaller dimensional timber, usually of lesser grade or quality which are stacked and fastened together and sometimes covered with some type of sheathing. Brettstapel, originally used nails and screws but eventually evolved to using wooden dowels placed horizontally or diagonally to hold the individual timbers together. Often these dowels are of lesser moisture content than that of the timber pieces; once these pieces equalize in moisture content the wall panel becomes incredibly resilient. The advantage of Brettstapel over NLT is that it can be produced entirely of timber products making it one of the healthiest pre-fabricated timber products on the market. These types of panels are often made with V shaped grooves for acoustic insulation and to add a visual texture. The width of the boards can also be staggered to

Nail Laminated Timber (NLT) is a versatile and strong, massive timber product that has been primarily used in a variety of projects for walls, roofs and floor systems in Europe. The typical system stacks and fastens timber boards side by side with nails or screws and is then covered in sheathing for additional structural diaphragm strength. Although these wood panels would be preferable to cavity wall stick framed houses that are so typical in the Hawaiian Islands, the required



Figure 8.35 Hundegger PHE (Brettstapel) Roof Panel

Source: Hundegger Ag

reduce overall weight and to create different visual appearance.

Like other solid timber products, solid Brettstapel panels demonstrate increased fire resistance and improved insulating qualities over regular dimensionally framed walls. Brettstapel is efficient especially when supported on its ends in the lateral direction making it ideal for pre-fabricated roof and floor panels which do not require multi-directional load support.

MASSIV HOLZ MAUER METHOD / CROSS NLT

Cross Nailed Laminated Timber, (CNLT) provides arguably the best of all variables solution for a pre-fabricated structural panel system. Hans Hundegger AG, a machinery company from Germany perfected a process called Massiv Holz Mauer (MHM) to select, saw, mill and join layers of wood into a cross laminated panel using fluted metal (aluminum or stainless steel) nails or some companies even use wooden dowels similar to the Brettstapel method.



Figure 8.36: Massive Holz Mauer Production Machine

Source: Hundegger Ag



Figure 8.37: MHM CNLT Layout

Source: Hundegger Ag

The machine can automatically evaluate each board, cut it to size, lay them down and nail them together so they are connected in the most stable manner.²⁴⁰ The MHM machine has a 5 axel saw which can cut at any angle and to specific specification by architects or builders. Due to the machines sophistication and manufacturing process, lesser quality “sideboards”, leftovers or generally lesser quality timber species can be used to create a highly adaptable, pre-fabricated, chemical and VOC free, structurally advanced “upcycled” product. This means timber from species with inherent mechanical weaknesses like eucalyptus and ironwood which tend to check at the heartwood and need

²⁴⁰ “MHM Production Line,” Massiv Holz Mauer, accessed December 9, 2016 <http://www.massivholzmauer.de/index.php?id=47&L=1>.

special sawing can be used to create solid timber CNLT panels. As an added benefit, the panels are finished on the interior portions. This means that the environmental benefits of timber construction explained earlier are exceeded by using otherwise disregarded timber and enhanced by removing the need for other materials like drywall which can be sources of pollutants, additional cost and environmental burden.

The MHM CNLT panels have some other features which help with the unique climatic conditions and architectural needs of the Hawaiian Islands. MHM CNLT panels are considered a completely solid timber giving them increased fire resistance and insulating qualities. Although the panels are timber and



Figure 8.38: MHM Air Grooves

Source: Hundegger Ag

remain combustible, in the event of a fire the charring effect explained earlier gives them increased resistance and a longer “safe” structural timeframe for inhabitants to escape or the fire to be put out. The material is also low in thermal conductivity making heat transfer from fires slower delaying combustibility in adjacent areas. The panels do not have cavities so no fiberglass or foam insulations are required and no contaminants like mold or particulates can build up to worsen indoor air quality and inhabitant health. The air grooves cut into each board create a cushion of air giving the panels an R value of approximately 30% more than that of solid wood while maintaining a relatively low U value, depending on the thickness of the panel.²⁴¹ While there is an increased thermal mass, it is much less than that of concrete which is typically used in pre-fabricated wall and roof construction. Further, because the laminations alter direction the CNLT panel is structurally efficient multi directionally where Brettstapel panels may only be efficient in one direction.



Figure 8.39: MHM Wall Structure

Source: Hundegger Ag

The advantage of CNLT or Brettstapel over ICLT is simplified means of production (not having to select perfect timber) and the speed at which custom panels can be created. There is no additional labor in fitting the dovetailed pieces together and the nails should provide additional resistance for

²⁴¹ “MHM Production Line,” Massiv Holz Mauer, accessed December 9, 2016 <http://www.massivholzmauer.de/index.php?id=47&L=1>.

movement. The downside of the *MHM* CNLT panel process is that like ICLT it requires specialized equipment to manufacture. This is true of most pre-fabricated materials and in some ways could be looked at as a potentially positive outcome in Hawai'i. Essentially, a single or small group of investors could purchase a MHM machine and quickly begin production of the panels. Alternatively, a simplified CNLT or Brettstapel panel could be constructed locally without additional machinery individually or by small groups of people. For a CNLT panel the concept is the same as the manufactured panels; boards would be laid out flat and subsequent layers in opposing directions would then be placed on top, nailed or screwed (depending on the timber) into place creating custom size panels one board at a time.

8.53

THERMALLY MODIFIED TIMBER (TMT)

Thermally modified timber (TMT) is a type of timber treatment which permanently alters the inherent properties and chemical composition of the wood. There are a few different methods of TMT but all rely on partial pyrolysis (heating without the presence of oxygen)²⁴² to alter the state of the timber products. Generally, thermal modification is done in a specialized kiln with varying levels of high heat (160 °C - 230°C) and pressure for 12 hours or more. Once the wood is heated to a specific temperature and the moisture content is drastically reduced it is typically reconditioned or cured to a stable moisture content of around 5%.²⁴³



Figure 8.40: Thermal Modification Kiln at the Natural Resources Research Institute

Source: Matt Aro, NRRI

The result of this process significantly alters many of the natural qualities of the wood as seen in the samples of treated Douglas fir, ironwood and eucalyptus the University of Minnesota at Duluth Natural Resources Research Institute (NRRI) graciously modified for this project. The most noticeable changes are in the appearance, weight and the smell of the wood.

²⁴² "What is Pyrolysis," Biomass Pyrolysis Research at the Eastern Regional Research Center, USDA ARS, accessed December 10, 2016 <https://www.ars.usda.gov/northeast-area/wyndmoor-pa/eastern-regional-research-center/sustainable-biofuels-and-co-products-research/docs/biomass-pyrolysis-research/what-is-pyrolysis/>.

²⁴³ Petteri Torniainen, Diego Elustondo and Ola Dagbro, " Industrial Validation of the Relationship between Color Parameters in Thermally Modified Spruce and Pine," *Bioresources*, vol 11 no. 1 (2016):1369-1381.

TMT has a slightly sweet “roasted” smell which lessens over time, weighs less and has a darker appearance which is consistent with similar research.²⁴⁴ This varies by species and how long and how high of a temperature the wood was treated in.



Figure 8.41: Thermally Modified Douglas Fir, Ironwood & Eucalyptus (clockwise from top)

Source: Images: Own work; Timber Modification: NRRI

The TMT process also does a few things which are particularly intriguing for this project. The process changes the entire molecular structure of the wood's cell wall; this is apparent in figure 8.42, which shows the end grain of each species of wood altered throughout the entire section of the cut. There is a degradation of hemicelluloses, α -cellulose, restructuring of lignin, expulsion of volatile compounds like resin, a decrease in pH and a significant reduction in OH-groups.²⁴⁵ This is a very scientific way of saying that the internal wood structures go from being highly hygroscopic (absorbs and expels moisture relative to surrounding environment) to hydrophobic (resistant to moisture absorption completely) by preventing the wood cells from filling with water. This has a few very important implications for finished TMT wood products. Visually, this can be seen in Figures 8.41-8.42 where the lighter colored, pre-

²⁴⁴ Srinivas Kavyashree and Krishna K. Pandey, “Effect of Heat Treatment on Color Changes, Dimensional Stability, and Mechanical Properties of Wood,” *Journal Of Wood Chemistry And Technology* vol. 32 , Iss. 4 (2012).

²⁴⁵ “Definition of Terms: TMT, Thermowood,” Institut für Hotztechnologie Dresden, accessed December 10, 2016 https://www.iht-dresden.de/fileadmin/user_upload/pdf/IHD/wissensportal/Merkblaetter/TMT/Merkblattsammlung_E.pdf.



Figure 8.42: End-Grain Before & After Modification (From top: Douglas Fir, Ironwood, Eucalyptus)

Source: Images: Own work; Timber Modification: NRRI

modified samples have an open grain and cellular structure and the darker, treated samples which have a tighter and sealed grain structure.

The hygroscopic nature of untreated wood can cause structural and aesthetic issues in building products and woodworking because of swelling (warping) and shrinking (cracking). Changing the structure of TMT to a hydrophobic material makes it much more dimensionally stable in the tangential and axial directions.²⁴⁶ The resistance to moisture makes TMT highly resistant to fungal rot which can occur even at low moisture contents²⁴⁷ and has significant effects on the long term structural ability of wood. Structurally, TMT decreases bending and tensile strength but increases the hardness, stiffness,

modulus of elasticity and compressive strength and lowers deflection in some wood types.²⁴⁸ The resistance to moisture also means mold will not as easily grow (less sugar or food in the wood) which is harmful to human health. TMT also makes wood more UV resistant making it optimal for exterior uses without the need for sealers or other chemicals.

TMT also becomes more resistant to wood decaying insects like boring beetles because the breeding and feeding substrates have been removed from the wood. Although termites can't digest TMT they are known to still feed on it. However, research has shown that a combination treatment of boric acid / polyglycerol methacrylate before thermal modification provides additional insect, fungus and termite resistance.²⁴⁹ In fact, it was shown that the borate treatment tends to leech out less after thermal modification with at least 10% retained after immersion in distilled water.

²⁴⁶ S. Lekounougou and D. Kocaefe, "Effect of thermal modification temperature on the mechanical properties, dimensional stability, and biological durability of black spruce (*Picea mariana*)," *Wood Material Science & Engineering* vol. 9, Iss. 2, 2014

²⁴⁷ "Definition of Terms: TMT, Thermowood"

²⁴⁸ Michiel J. Boonstra, Joris Van Acker, Boke F. Tjeerdsma and Edo V. Kegel, "Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents," *Annals of Forest Science* vol 64, no. 7 (2007): 679-690. Hal-00884121.

²⁴⁹ S. Salman, Pétrissans, A., Thévenon, M.F. et al. "Development of new wood treatments combining boron impregnation and thermo modification: effect of additives on boron leachability," *European Journal of Wood Products* vol. 72 iss. 3 (2014): 355.

Finally, thermally modified woods have been shown to retain the highest level of survivability and structural strength compared to glulam, LVL or untreated timber after exposure to high heat from a simulated fire.²⁵⁰ When combined into a solid panel, TMT structures would have even higher fire and combustibility resistance.

THERMALLY MODIFIED CROSS NAILED LAMINATED TIMBER PANELS

PRE-FABRICATED THERMALLY MODIFIED CROSS- NAILED LAMINATED TIMBER

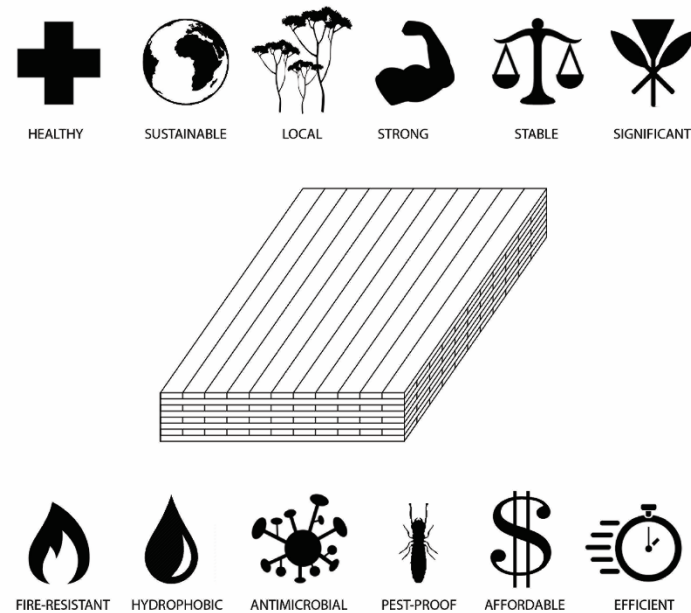


Figure 8.43: The Benefits of the CNLT TMT Panel

Source: Own work

alleviate any concern with the reduction of strength lost during heating. These pre-fab panels could be used for the many structural needs of the roof, floor or walls while other trim, rain screens or planks could be individual TMT boards.

The important implications of thermal modification on this specific project is the improvement of many wood species in terms of dimensional stability, fire, moisture and UV, termite, insect and fungal resistance as well as overall stiffness. These factors are important in all construction but show exceptional promise for Hawai'i because some of the local timber species (ironwood/eucalyptus) have some stability and termite issues. Using thermally modified local timber in a CNLT MHM panel, Brettstapel or other engineered solid wood component would also to help

²⁵⁰ D. Pieniak, Ogrodnik P, Oszust M, Niewczas A. "Reliability of the thermal treated timber and wood-based materials in high temperatures," *Eksploatacja i Niezawodność – Maintenance and Reliability* vol. 15 no. 1 (2013):18–24.

8.54

TIMBER PANEL INVESTIGATIONS



Figure 8.44: Felling ironwood timber

Source: Own work

As the previous section mentioned, NRRI was able to thermally modify timbers which I sourced near my home on Hawai'i island over the last few years. Due to the nature of the virtually untested species of local timber, I wanted to be sure that they could both take the thermal modification and could be fashioned into the solid timber panels for which this project discusses. In order to this the eucalyptus and ironwood timbers, which were previously cut and air dried along with locally purchased treated Douglas fir were sent to NRRI at the outset of this project in Fall of 2016. The timber was returned with an additional supply of thermally modified Southern yellow pine. The result of the

modification was successful as seen in section 8.42.

Once the timber was returned I set out to test how it would hold up to mechanical fastening (as products which incorporate adhesives would not pass for a healthy building material). These fasteners include coiled aluminum ring shank nails to be used with a pneumatic nail gun, galvanized steel 16d nails and exterior grade screws.



Figure 8.45: Fasteners

Source: Own work



Figure 8.46: Fastening systems in thermally modified timber

Source: Own work

I performed testing on each of the thermally modified species, ironwood casuarina equisetifolia, eucalyptus saligna, Douglas fir and Southern Yellow pine. I did not have the means, testing equipment nor the supply of timber to gather empirical data on the specifics of fasteners with these modified timber species, nor is that the intention of this project. However, I was able to use some of the pieces of wood and test them with each of the three fastening methods to gain a better understanding of this local timber and new timber panel method. Each board was originally tested nailing or screwing one piece of timber into the same species of timber to replicate possible timber panel laminations. Once the initial testing was done, samples of each were fastened using each method into one piece of Douglas fir to demonstrate the success of each method.

The aluminum coiled ring shank nails were provided by Hundegger AG in Germany and were fitted into my own pneumatic nail gun. Generally, all the timber species held up to pneumatic nailing to a large degree with only minor splitting occurring on one of the boards. The relative softness of the nails caused some issues with the local timbers and required higher psi to drive the nails at least flush with the surface of the wood.

In the testing of the hand- hammered galvanized nails, one piece of Douglas fir split completely along the grain and while the eucalyptus and ironwood did not split they were both much harder than the fir and required extra force to drive the nails in. Depending on the thickness of the timber, hand nailing these local timbers may require extra man hours or pre-drilling of the wood.



Figure 8.47: Split Douglas Fir

Source: Own work

In the pre-drilled exterior screwed samples, all timbers held up and were securely fastened. While this method took the most time it proved easiest to ensure a consistent lamination of one timber to another. In a system like the MHM panel production machinery the fastening happens at the manufacturing of the panel. For larger scale projects or developments if CNLT was to be used this would be the quickest and architects and contractors could take full advantage of the cost, time and accuracy benefits of pre-fabricated timber panels.

A different approach would be smaller production lines where of workers could be used to ideally pneumatic nail or pre-drill and screw together timber laminations for panel production. For the sweat equity types, one of two people could lay out the boards and choose a fastening system that works for them.



Figure 8.48: Thermally Modified Brettstapel (Elevation View)

Source Own work

I chose to demonstrate both the Brettstapel and cross nailed laminated timber panels made from thermally modified Southern Yellow Pine. I chose this timber over the local sources purely because of the quantity and size of timber I had available. As previously mentioned the method for creating this type of panel is to lay the boards face to face and fasten them to each other one at a time. These panels can then be faced with a diaphragm of sheathing or doweled horizontally or diagonally to increase shear strength. I chose to screw each lamination together forming a strong bond between each board. The widths of the timber differs from one board to the next by an inch, this relief would create a different acoustic response



Figure 8.49 Thermally Modified Brettstapel
(Perspective)

Source: Own work

From an aesthetic point of view, the relief gives texture and the staggering of the boards creates shadows as light moves across its surface. Brettstapel can also be made with boards of the same width.

The next panel I researched in making is a thermally modified cross nailed laminated roofing panel. These panels can be used for walls, floors or roofs depending on the amount and size of the laminations. For this 1:1 scale model I chose to demonstrate it as the roof panel.



Figure 8.50 Thermally Modified Cross
Lamination Layup

Source: Own work

To make a CLT panel you lay boards out in one direction, ideally cut to the overall width or height of the panel. The next layer is then stacked on top of the first but in the opposite direction, nailing or screwing each board to the one underneath. Subsequent layers are added in opposing directions and fastened as they are placed. This process forms the basis for any cross laminated panel system; the crossing of the laminations provides the multi directional strength of the panel from individual boards into a solid timber. For this roof model, a layer of ethylene propylene diene terpolymer (EPDM)

waterproof membrane is added, followed by thermally modified timber purlins and finally thermally modified timber planks to provide additional insulating, UV and moisture protection of the roof assembly.

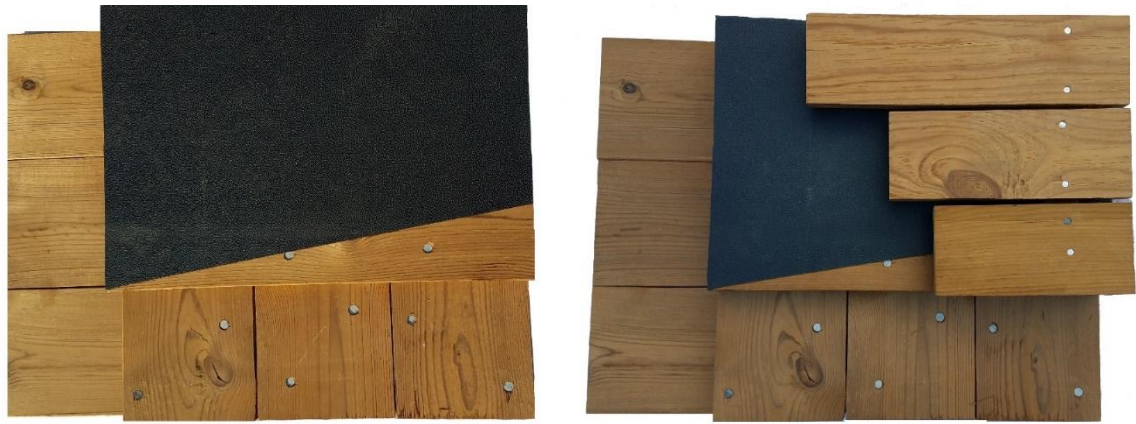


Figure 8.51 TMT CNLT, EDPM / Roofing Planks

Source: Own work

As previously mentioned in this chapter, this type of construction has many benefits through its pre-fabricated economic and time saving potential, climatic resistance, insulating qualities, fire resistance, positive health and environmental aspects social importance through locality of the materials, the panels provide an organic, warm and finished interior with a highly adaptable exterior surface for a variety of finishing options. I chose to use simple waterproof membrane and timber planks but other types of roofing material could easily be adapted or fastened to the panels just as one would do with a sheathing layer in typical construction.



Figure 8.52 TMT CNLT Roof Panel (Section)

Source: Own work

Although many types of materials have been discussed to this point of the dissertation and especially in this chapter, my research points to only a handful which check all of the boxes for a new healthy Hawaii tropical house. These materials are locally made pre-cast concrete and various locally sourced timber products which ideally feature thermal modification to increase climatic and fungal resistance as well as dimensional stability of the otherwise moderately unstable local hardwoods. It is not to say that a house could not be designed and built in the state with other materials or by using other methods, because there have been. However, I believe these materials provide the most adaptable solution to a variety of design challenges in a variety of climatic conditions which we have throughout the island chain.

CHAPTER 9:

A NEW HAWAII TROPICAL HOUSE

Historically, folk architecture in hot and wet climates throughout the world addressed the exigencies of climate with minimal structure that supported a roof with effective insulating properties, perhaps adding an elevated living platform to remove the inhabitants from the intrusion of vermin and surface moisture. In sum, one lived under an insulating umbrella, keeping the sun and rain at bay while admitting as much moving air as possible.

– *Hawaiian Modern*, pg. 74



Figure 9.1 A New Hawaiian Tropical House

Source: Own Work

If I want readers to take anything away from the preceding chapters in this dissertation it is not so much a justification for an individual piece of architecture; rather the goal is and has been from before this document was written to attempt to convince the architectural, engineering and construction industry in Hawai'i that the way we currently go about our architectural endeavors is as inherently flawed as it is invasive. More than anything this document should stress the importance of designing a home in Hawai'i in a way that is healthy and comfortable for its inhabitants. The focus of the design should stress a symbiotic and harmonious result of the many unique variables which present in every local design challenge. There should be a conscious effort to understand the culture for which the design is for, the site for which the building shall be sited, the climate for which it is part and how these effect levels of ventilation, light and indoor health and comfort. There should be an investigation into the various building materials and methods and the inherit risks and benefits of each when factored into specific architectural variables.

Perhaps more than anything I want to stress that the proceeding design is in no way the only way to build a house in Hawai'i which fulfils the goals for which this dissertation hopes to achieve. Different materials, methods, types of construction and architectural methodologies could be applied and the result could still be climatically appropriate, culturally significant and could solve the many potential health problems associated with the typical way of building a home in Hawai'i.

If one recalls the chapter on the history of Hawaiian architecture it almost seems like there was a conscious effort to avoid any kind of symbolism, decoration or regional attribution to Native Hawaiian architecture. The only time one would really see something that looks like a Hale Pili in Hawai'i would be either as a garish tourist driven attraction whose primary goal is to appeal to the sentimentalities of the "exotic" and paradisiac island getaway, or in some rare instances as an educational tool for some organizations to try and teach Hawaiian history. This sometimes manifests as temporary buildings where children or interested parties can learn things like pili grass lashing or occasionally as recreations of Hawaiian wa'a haes for paddling teams throughout the islands. In some of the more "designer" homes throughout the state one might see glimpses of the steep pitched "A" frame roof with manufactured "thatching" material on the underside popping up in the living room of multi-million dollar homes (this would fall under the kitschy category).

In many ways I understand this desire to avoid the direct symbolism attributed to the Hale Pili or “A” frame. Creating an “A” frame home in Hawai‘i feels like a Post-modernists overt attempt to recreate some pieced together historical architecture for no other purpose but to create something different. When one first sees images of the design for this project they may have this feeling; this is just an attempt to recreate the Hale Pili. In fact, it was my goal to *avoid* anything that looked overtly “Hawaiian” for this reason. That is because throughout history we have seen the majority of “Hawaiian” type residential architecture fail in all the important aspects of design the preceding chapters have called for.

Then one comes across the quote from the beginning of this chapter which can be found on page 74 of the highly-praised *Hawaiian Modern: The Architecture of Vladimir Ossipoff*:

Historically, folk architecture in hot and wet climates throughout the world addressed the exigencies of climate with minimal structure that supported a roof with effective insulating properties, perhaps adding an elevated living platform to remove the inhabitants from the intrusion of vermin and surface moisture. In sum, one lived under an insulating umbrella, keeping the sun and rain at bay while admitting as much moving air as possible.

This quote stuck in my head while researching this project and I very much took it as inspiration. The key to designing for these islands is simplicity. In a way, the problem is massively complicated but the solution can be entirely simple. Given the justification for pre-fabricated concrete and timber pieces I thought about how that elevated platform and roof may look and set out to achieve a simple way to combine the needs of the roof and platform in a simple and repeatable structural form.

The first step was to design a simple and easily repeated pre-cast concrete structure. If one recalls from the section on pre-cast concrete, repeatability of elements means affordability of the project. For ease of construction and affordability I wanted to limit the pre-cast elements to the simplest forms that I could. Knowing that one of the simplest and most efficient architectural forms is the triangle I imagined a system of concrete beams which, in part, supported themselves. This creates an efficient structure with just two beams leaning into each other. This house, then, only incorporates two very simple concrete beam profiles, one for the elevated floor and lanai beams and one for the primary structure.



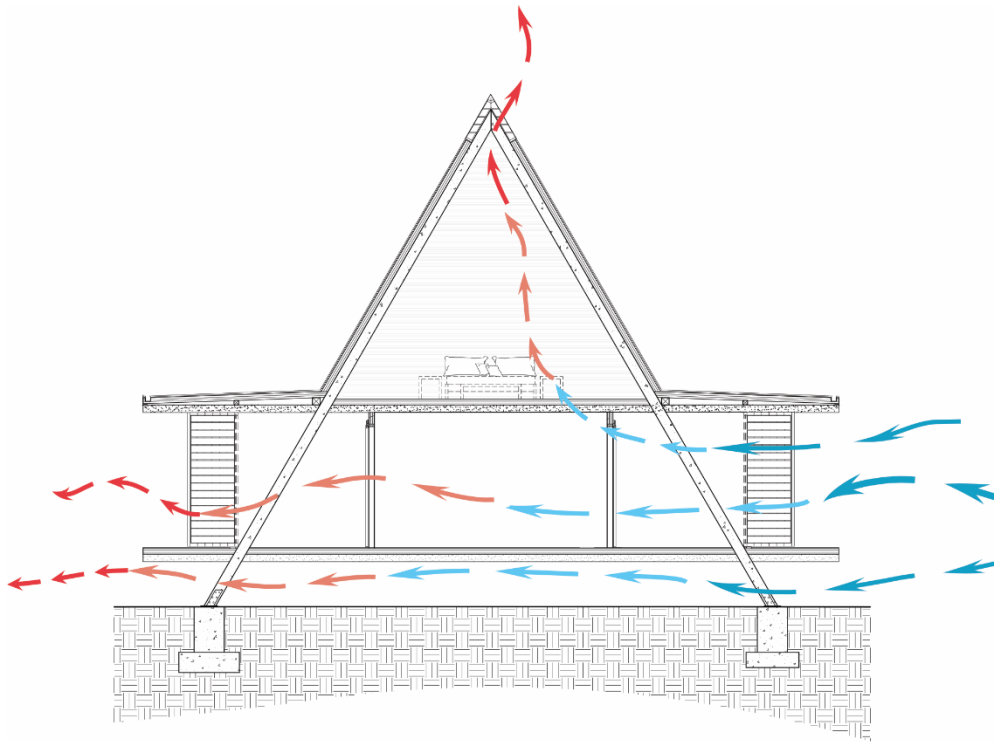
Pre-Cast Concrete Structure



Figure 9.2: Pre-Cast Concrete Structure

Source: Own Work

The primary structural beams form a 60 degree angle from their connection at the peak down to pre-cast concrete footings where the structure meets the land. The secondary beams are attached to the by sitting on welded or bolted, pre-cast “shelves” on elevated portions of the main structure. Each pre-cast “rib” is efficient on its own and can be repeated as many times as desired to form the primary structural skeleton of the home. In this home, the pre-cast rib is repeated seven times. While other simple concrete forms could have been incorporated like a simple post and lintel, the 60 degree slope of this structure gives efficient slope for drainage while providing maximum surface area for water catchment or solar panel arrays. Additionally, the high interior ridge minimized excess radiant heat gain while allowing for more space for natural stack ventilation through louvered ridge windows to occur.



NATURAL VENTILATION DIAGRAM

Figure 9.3: Natural Ventilation Diagram for A New Hawaii Tropical House
Source: Own work

The next step was to create the elevated floor, which will sit directly on the pre-cast concrete members. This elevated floor accomplishes a few things; first, inhabitants are off the ground in case of flooding events and second, airflow is allowed under the structure to reduce excess moisture and heat buildup. The floor material is a thermally modified cross nailed laminated panel (RE: Proceeding, Floor Panel Plan) separated into 10 individual units.

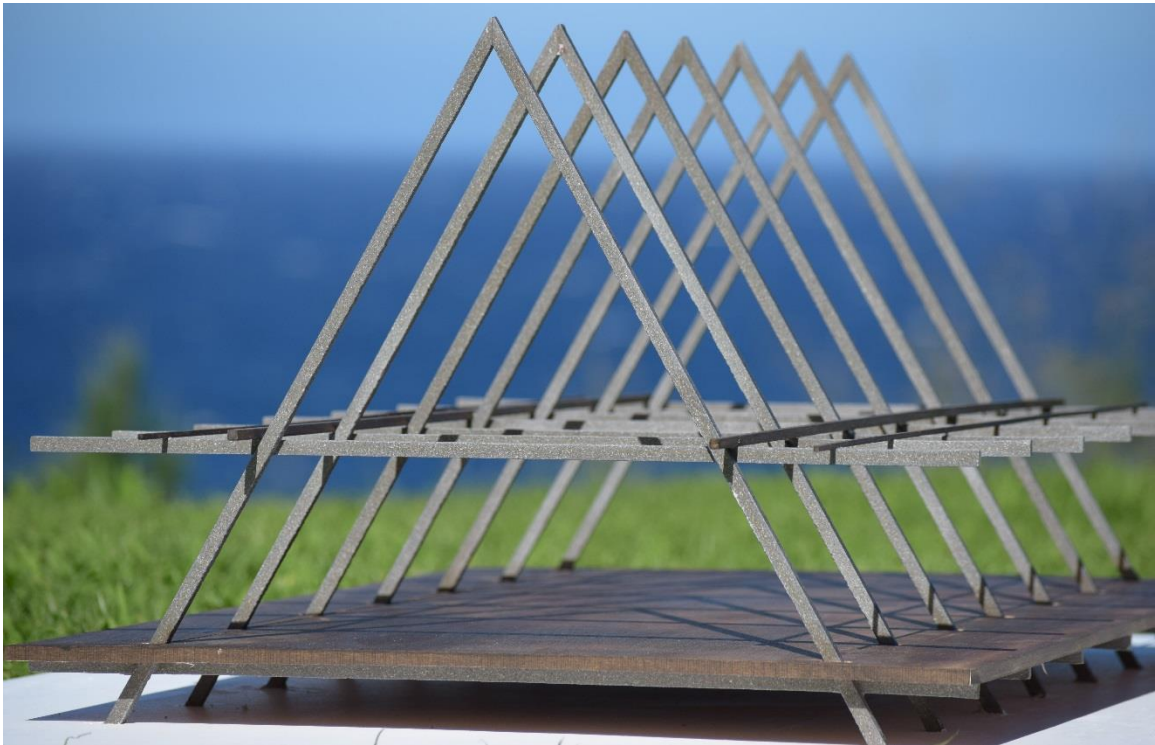


Figure 9.4: Floor Panel Model
Source: Own work

This floor construction is sufficiently insulated and with thermal modification the reduction of moisture helps to alleviate any fungal growth. Over this floor, the wall panels are installed. In this iteration the walls are either thermally modified CNLT or Brettstapel panels which are placed in a central living area to maximize open living areas (RE: proceeding Floor Plan).



Figure 9.5: Thermally Modified Walls

Source: Own work

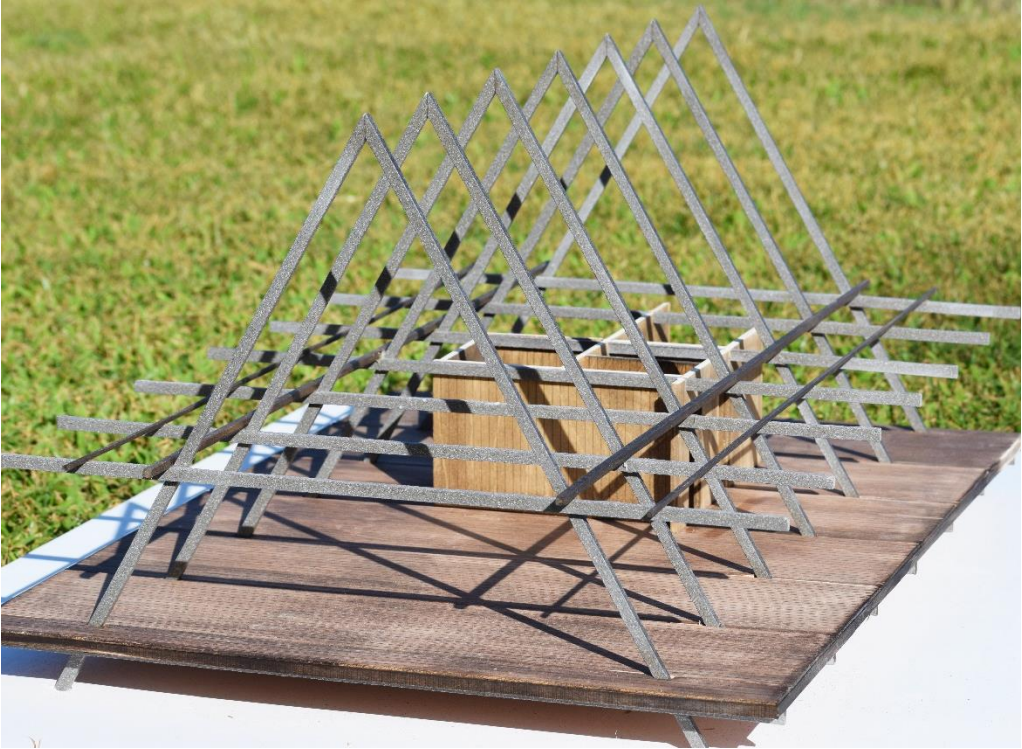


Figure 9.6: Thermally Modified Walls, Perspective

Source: Own work

Thermally modified beams are added to provide both proper rise for the lanai roof as well as an area to receive future sliding doors.

The lanai and roof feature similar thermally modified CNLT panels, with the addition of a waterproof membrane and thermally modified purlins and planks to help with climatic resistance (RE: proceeding Details, AA-1, AA-3).



Figure 9.7: Thermally Modified Lanai Panels and Interior Walls

Source: Own work

The concrete lanai beams support the thermally modified roof panels while descending through the floor to the foundation. This beam system allows for maximum airflow and light without the need for additional supports at the perimeter or interior portions of the home.



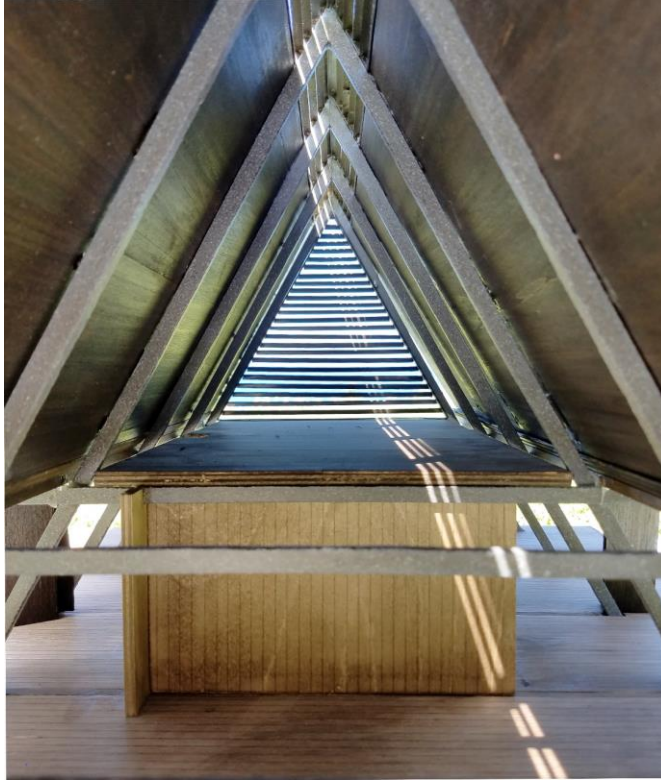
Figure 9.8 Lanai Roof + Loft Floor
Source: Own work



Figure 9.9: Thermally Modified Roof

Source: Own work

The interior loft floor / lower level ceiling is then placed before the primary roof panels are added. Next the thermally roof panels are attached to the precast concrete beams. The final step is to add the skin of the home; thermally modified adjustable louver windows and sliding door panels. The windows are added at the ridge and at the “gable” ends of the roof. These windows allow airflow and aid in the natural ventilation of the home but can be closed when it rains to prevent moisture intrusion.



Built in drainage diverts the water through a drainage pre-cast in the concrete beam (RE: proceeding Detail AA / 3). The doors are sliding panels with louvers which can be opened to a minimum profile to allow maximum airflow and light or closed to prevent dust, insects or intruders from entering the home.

Figure 9.10: Gable End Louvers

Source: Own work



Figure 9.11 Thermally Modified Louver Doors – The Skin

Source: Own work

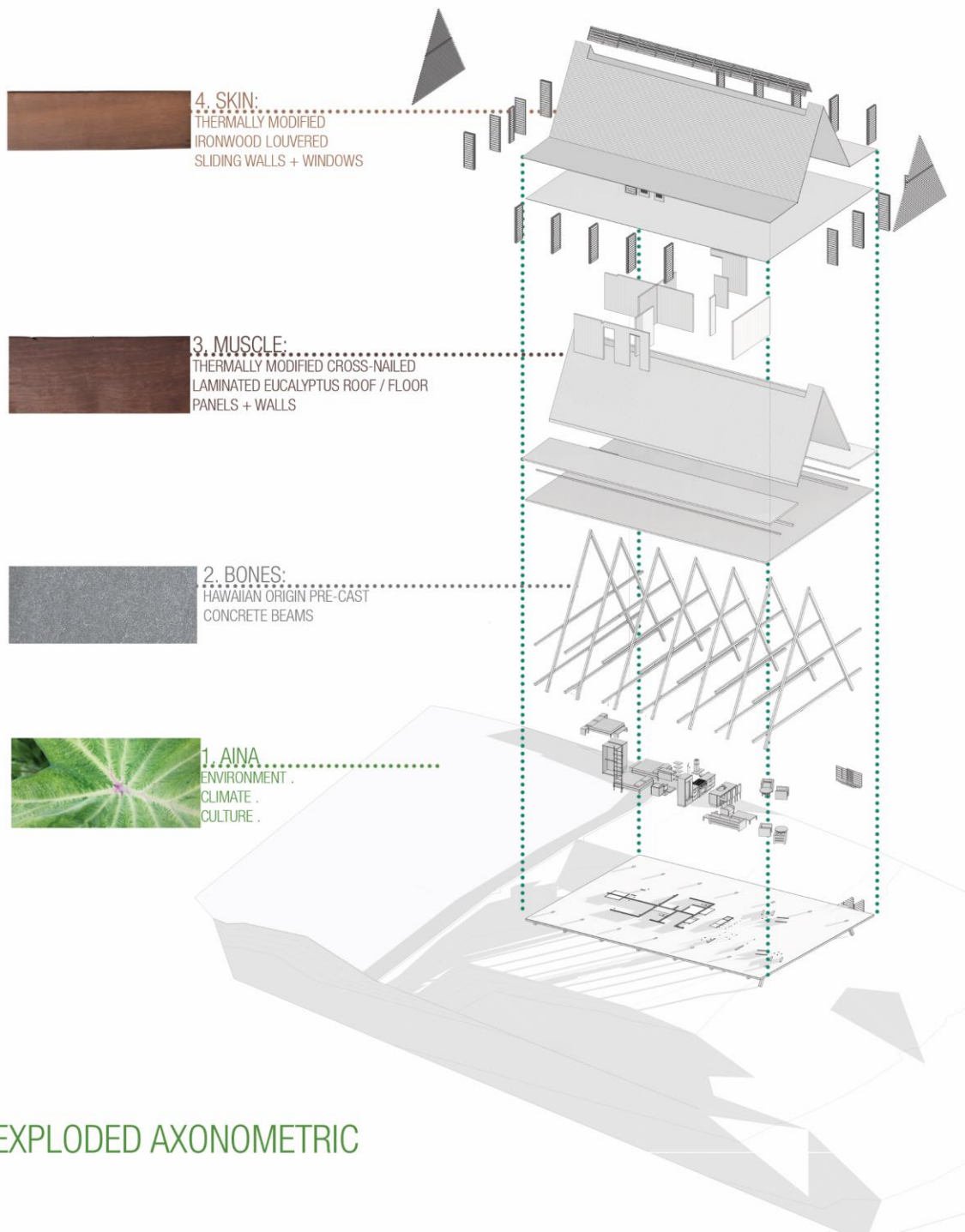


Figure 9.12: Exploded Axonometric

Source: Own work

The process of construction is simple and could be completed by a few workers with a crane. The panels could be pre-fabricated from a manufacturer, built by a small group of people or by a homeowner in the sweat equity sense. The pre-cast concrete structure is simple and its repeatable members are structurally and cost efficient, especially if the home was to be built as part of a community.



Figure 9.13 Interior Structure

Source: Own work

Importantly, this home contains building materials which would resist the effects of the harsh climate, reduce the growth of mold, not give off harmful VOCs or other toxic substances and would be done by using materials we currently have in the state.



Figure 9.14: Light Filled Bedroom; Afternoon Sun

Source: Own work

The house is completely open; maximum airflow and light are allowed to the interior but can be controlled, giving inhabitants a direct connection to the land which the home is sited without the need for typical doors and windows which hermetically seal the home and require unhealthy air conditioning systems.



Figure 9.15 Light Filled Bedroom; Morning Sun

Source: Own work



Figure 9.16 Living + Lanai

Source: Own work



Figure 9.17: A view from inside...

Source: Own work

Inhabitants in this house should not feel like they are in the typical house, they should feel connected to the site for which the house is located. It is without the traditional inside / outside delineations of living room to lanai but rather the space should read and feel as one continuous living lanai.

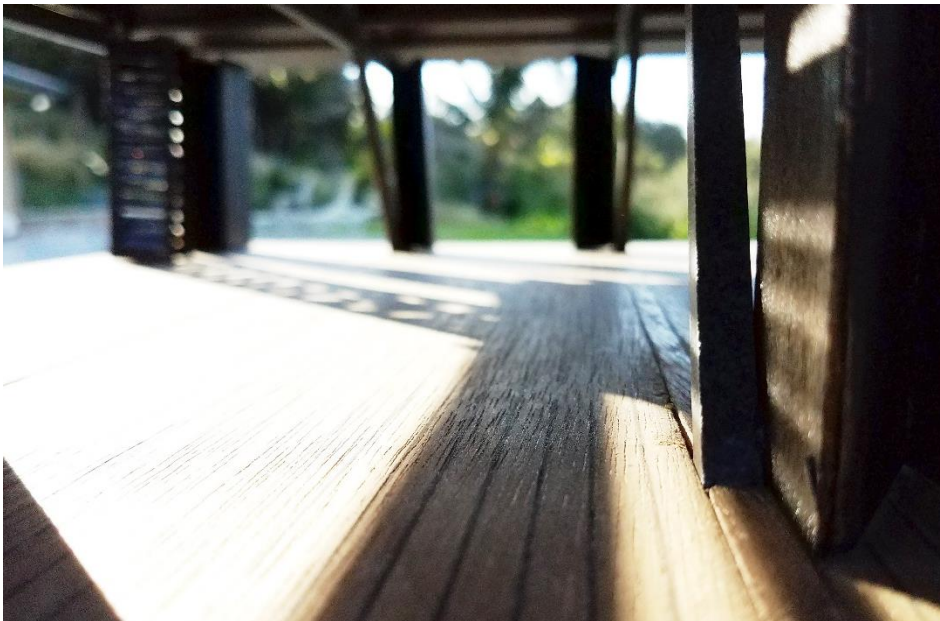


Figure 9.18: Living Lanai

Source Own Work



Figure 9.19 Living Lanai to Bedroom

Source: Own work

From any vantage point in the home there is a clear view to the outside world, only the utility rooms are partially enclosed while the kitchen and living areas blend with each other and to the outside.



Figure 9.20 Inside / Outside

Source: Own work

The elevated structure is adaptable to many sites throughout the state by properly sizing the footing to specific soil conditions. This means that the home could be placed on sandy coastlines, lava rock fields or in soft, cindery soils and still allow for airflow under the home and prevent surface water intrusion.



Figure 9.21: Exterior Perspective

Source: Own work

The material palette, through natural lava aggregate and thermally modified timbers speaks to vernacular Native Hawaiian traditions but the pre-cast concrete and cross nailed laminated timber construction moves the home away from a traditional “A” frame or a kitschy rendition of a hale pili to a more contemporary and fitting Hawai’i tropical home.



Figure 9.22: Looking Up

Source: Own work



Figure 9.23: The Bones

Source: Own work



Figure 9.24: Louvered Light

Source: Own work

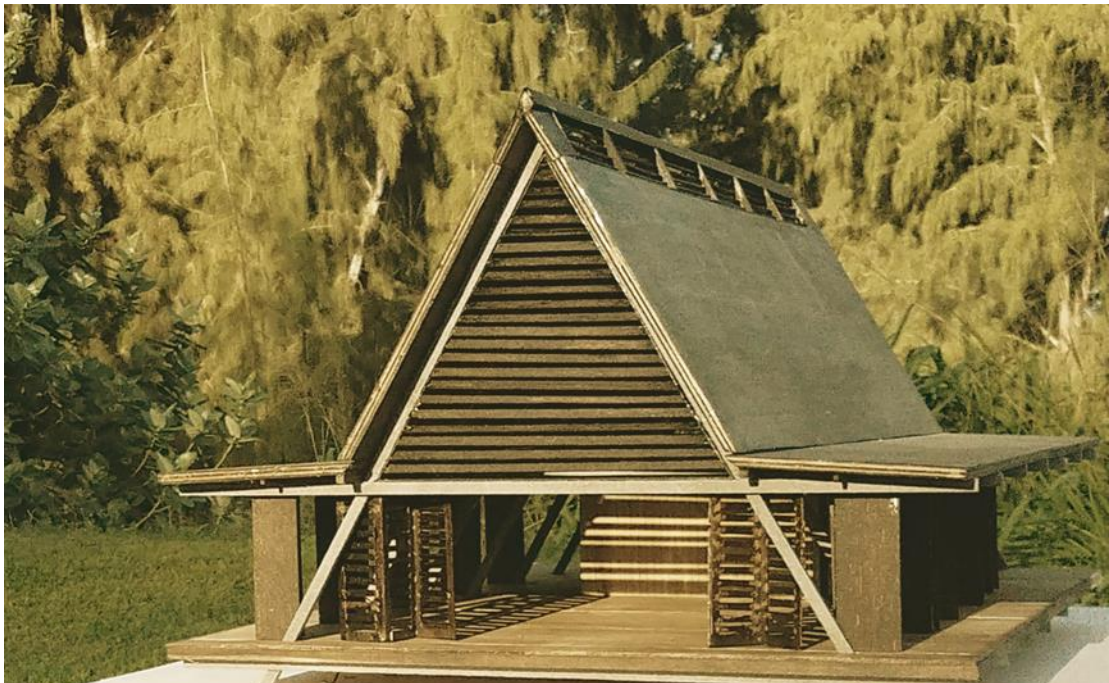


Figure 9.25 Amongst the ironwood trees

Source: Own work

9.1

DESIGN DOCUMENTATION: DRAWINGS FOR A NEW HAWAII TROPICAL HOUSE

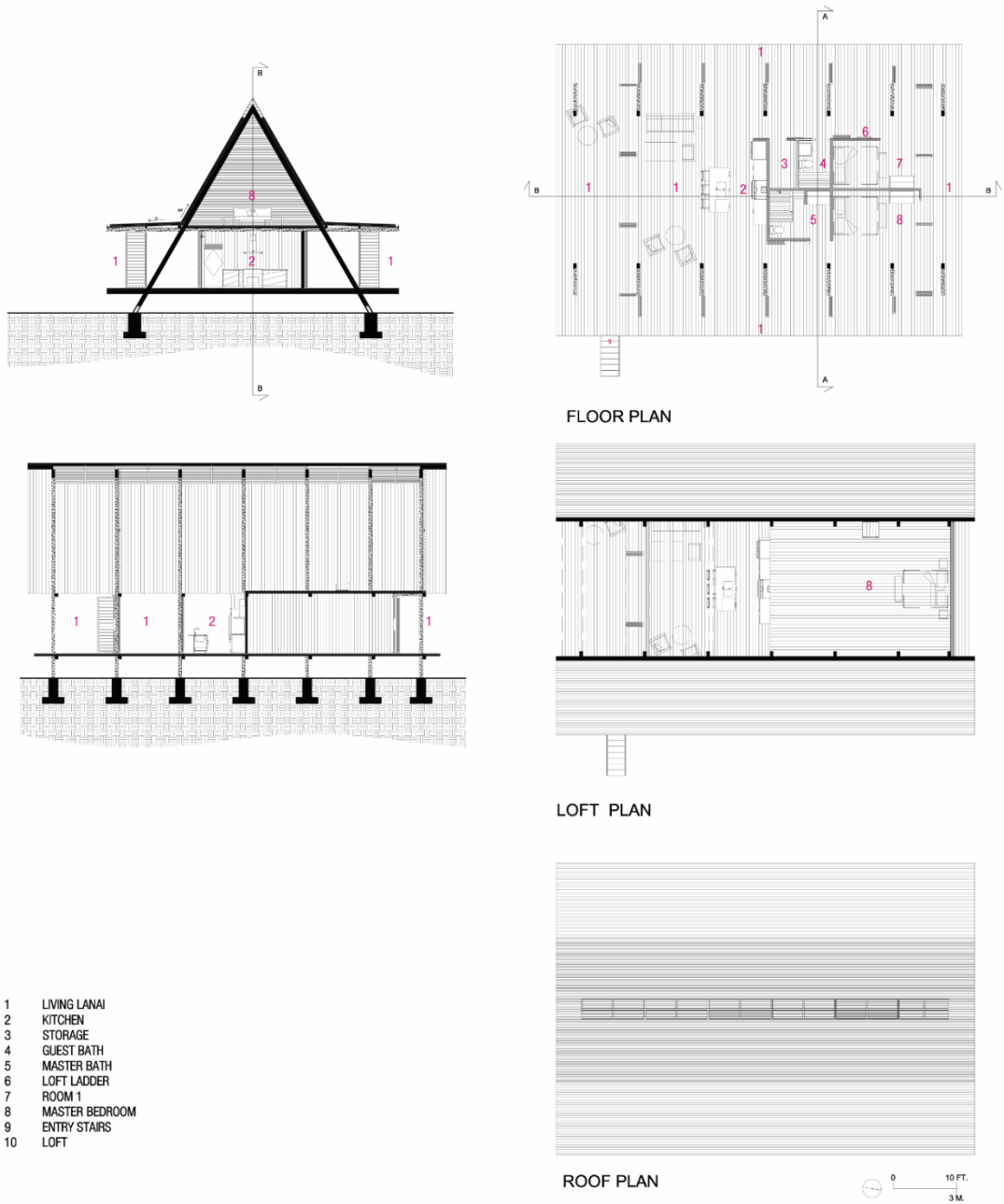
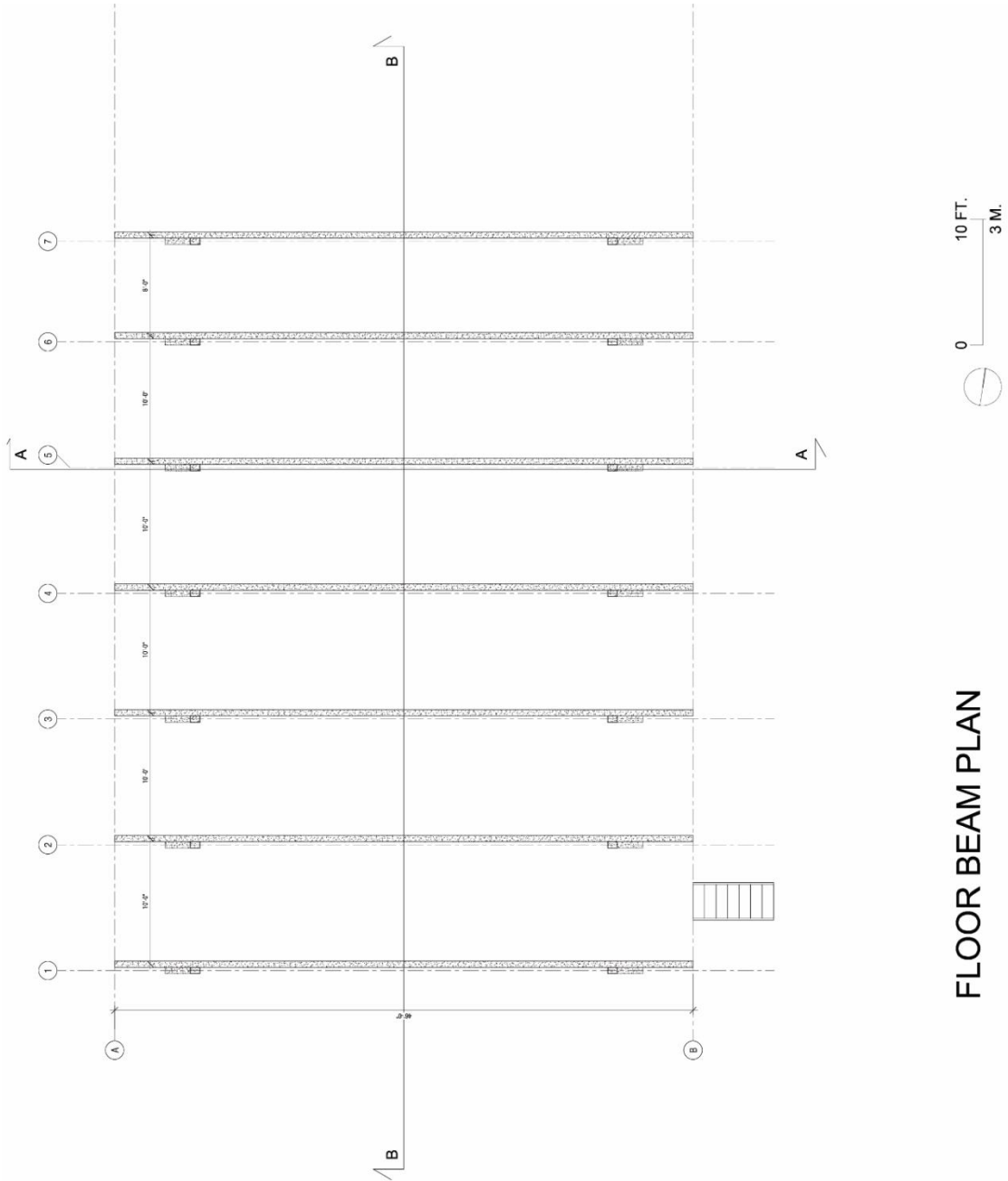


Figure 9.26: Documentation Overview

Source: Own work



FLOOR BEAM PLAN

Figure 9.27: Floor Beam Plan

Source: Own work

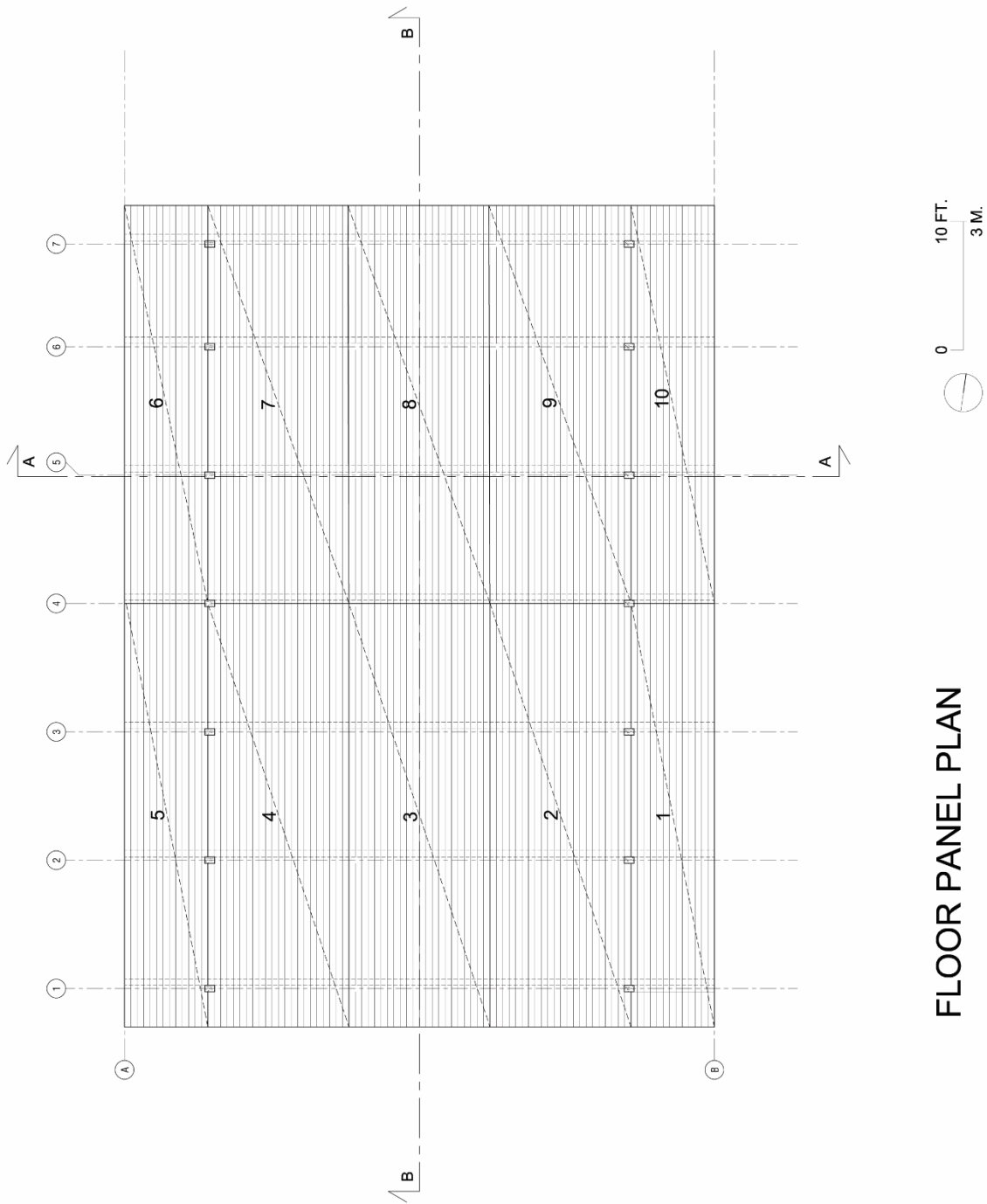
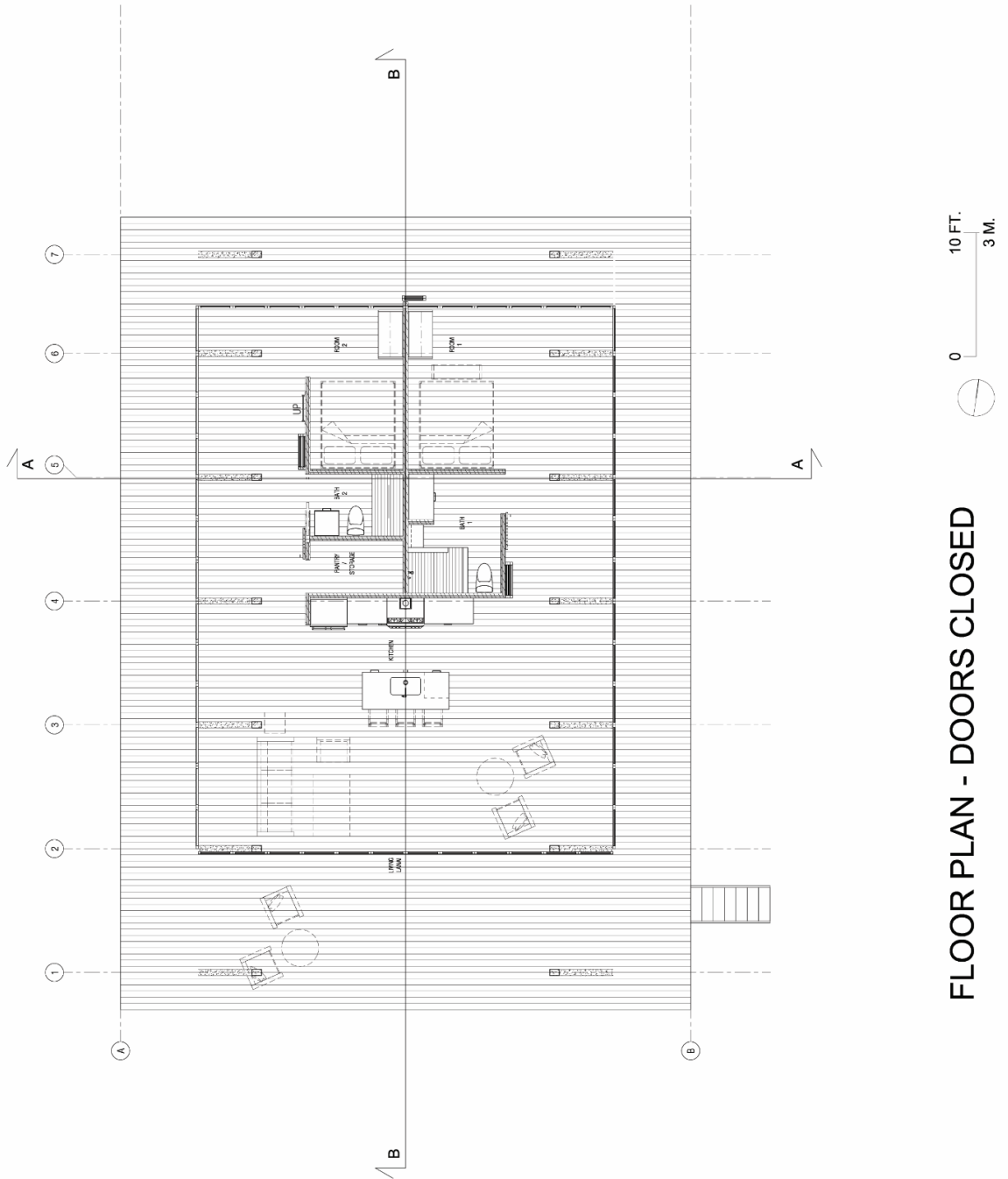


Figure 9.28: Floor Panel Plan

Source: Own work



FLOOR PLAN - DOORS CLOSED

Figure 9.29: Floor Plan – Doors Closed

Source: Own work

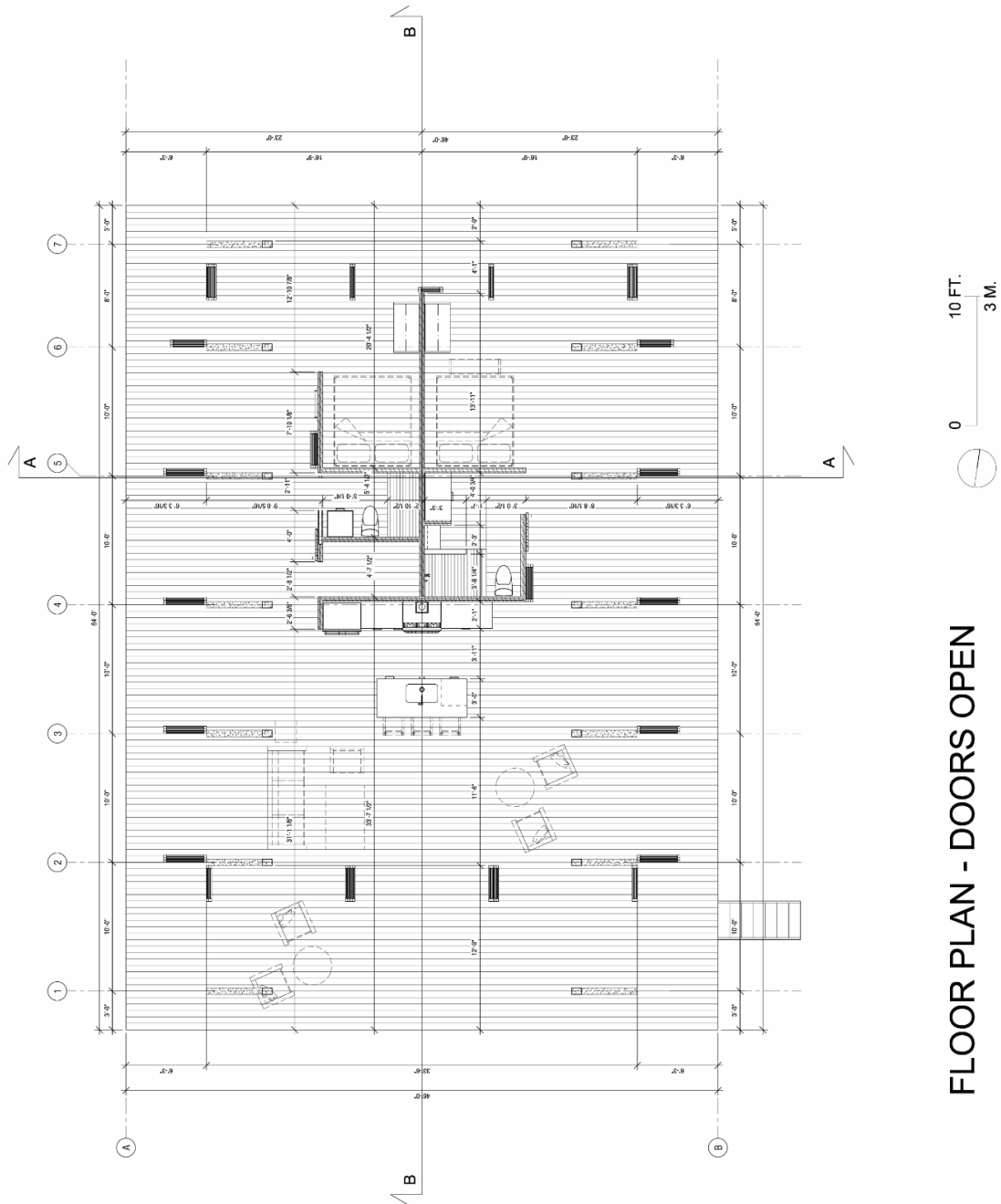
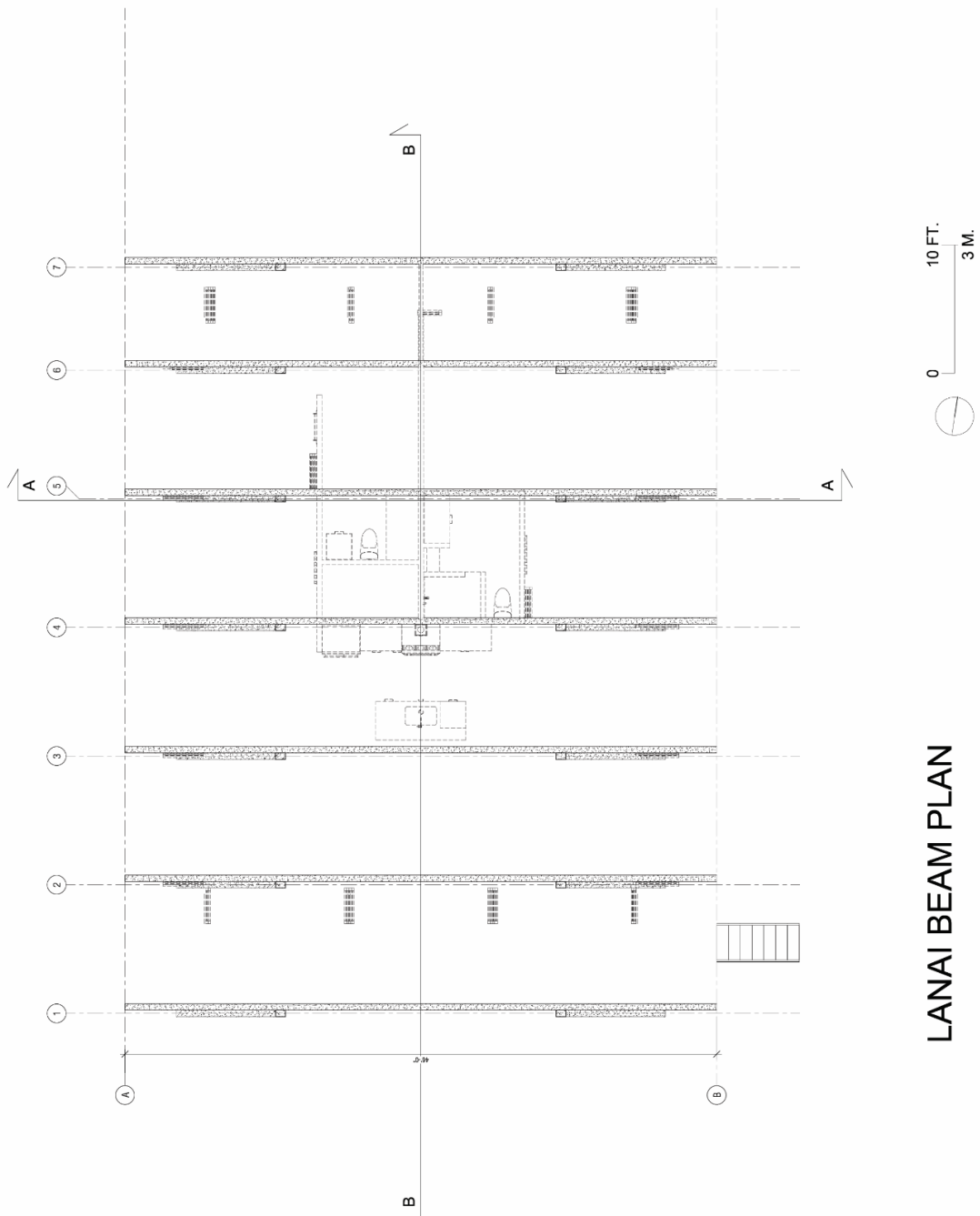


Figure 9.30: Floor Plan – Doors Open

Source: Own work



LANAI BEAM PLAN

Figure 9.31: Lanai Beam Plan

Source: Own work

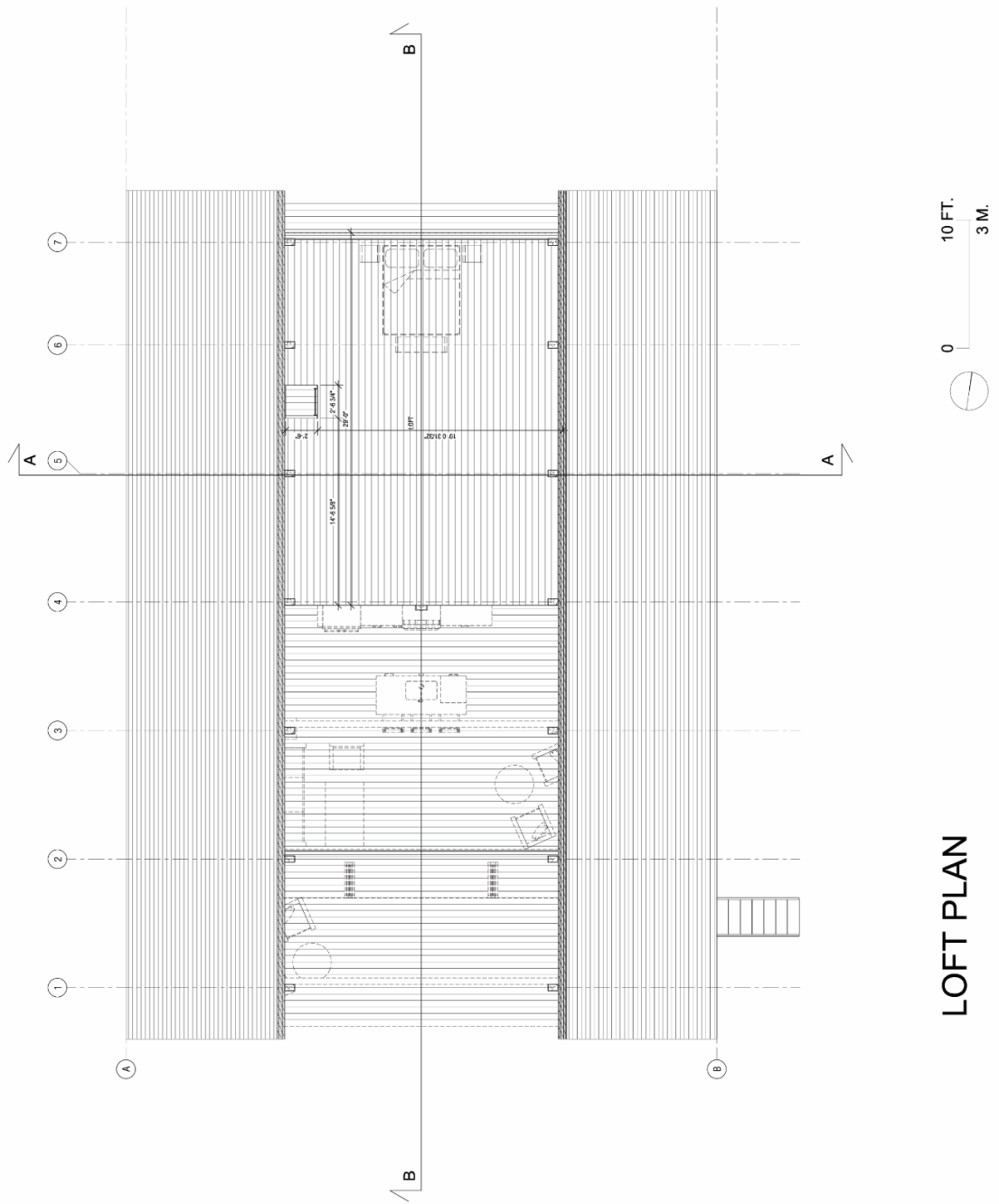


Figure 9.32: Loft Plan

Source: Own work

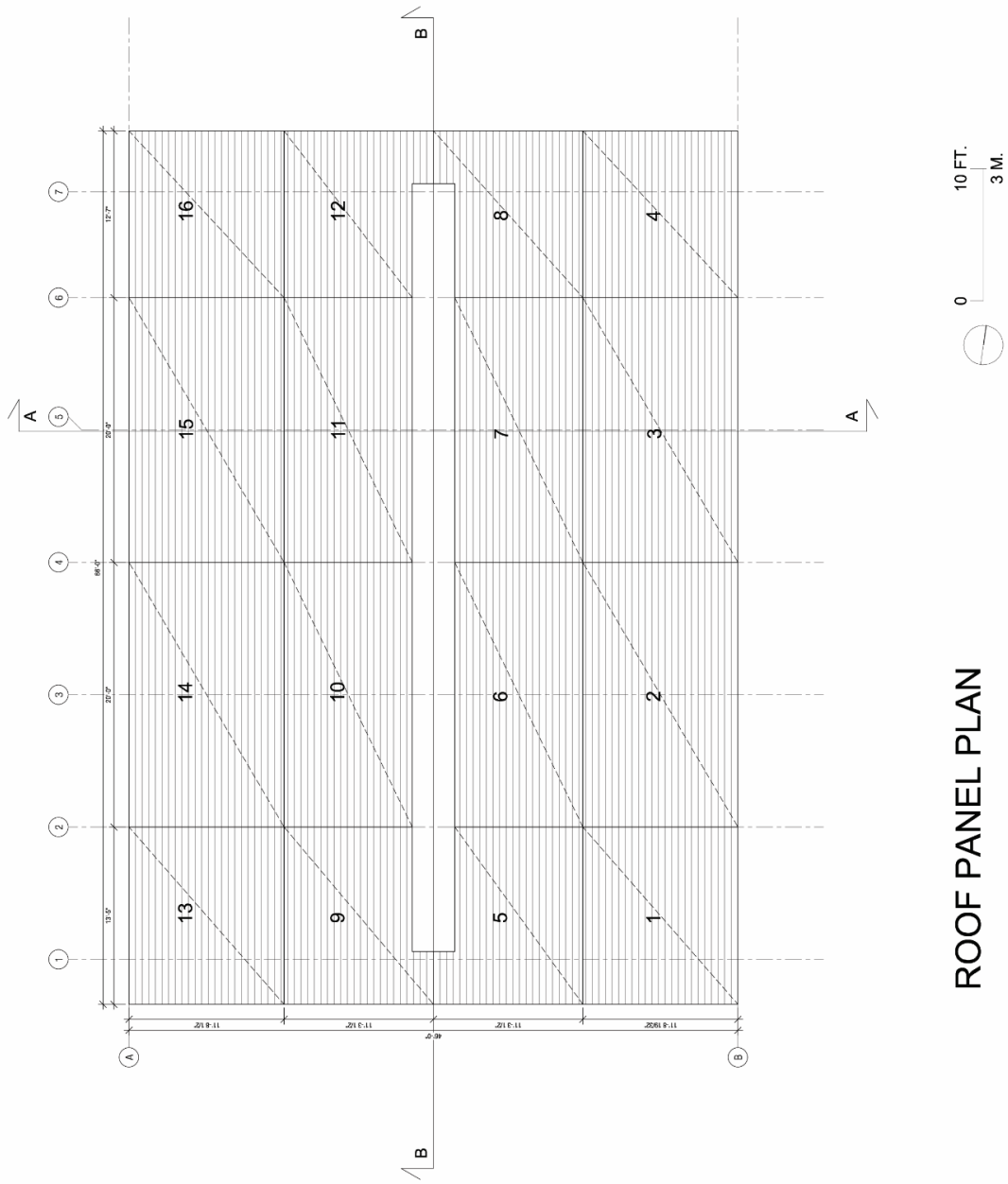
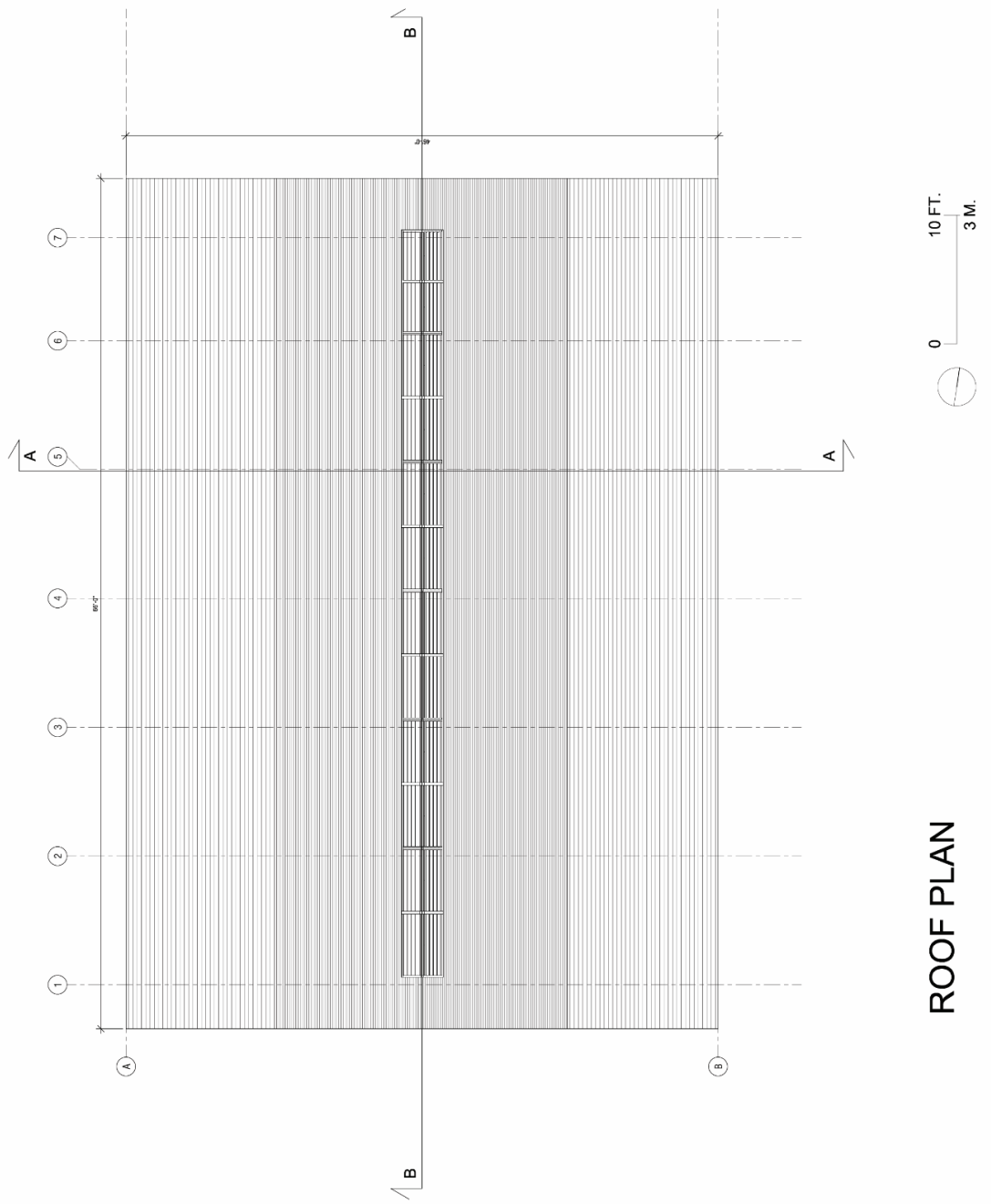


Figure 9.33: Roof Panel Plan

Source: Own work



ROOF PLAN

Figure 9.34: Roof Plan

Source: Own work

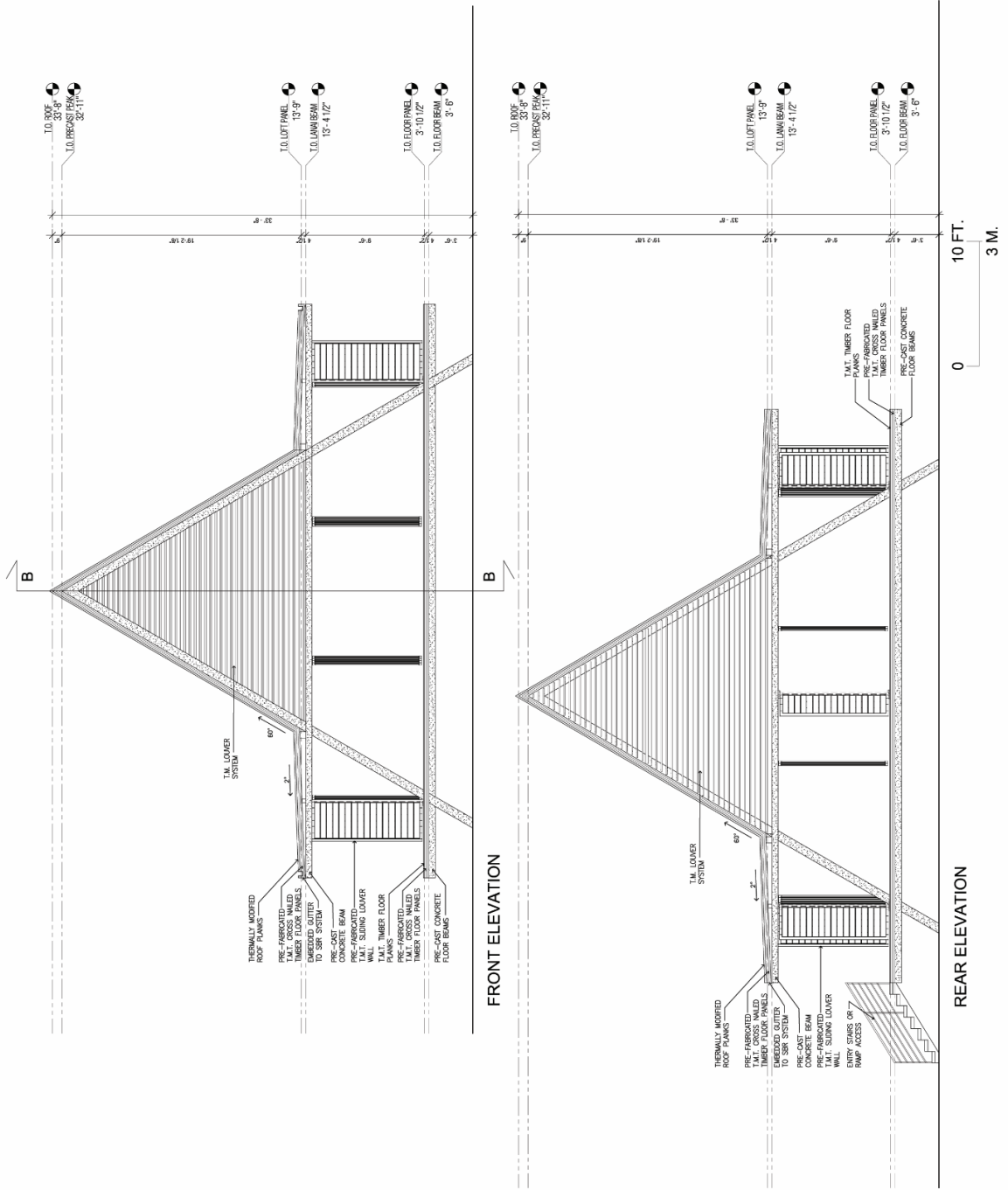


Figure 9.35: Elevations – 1

Source: Own work

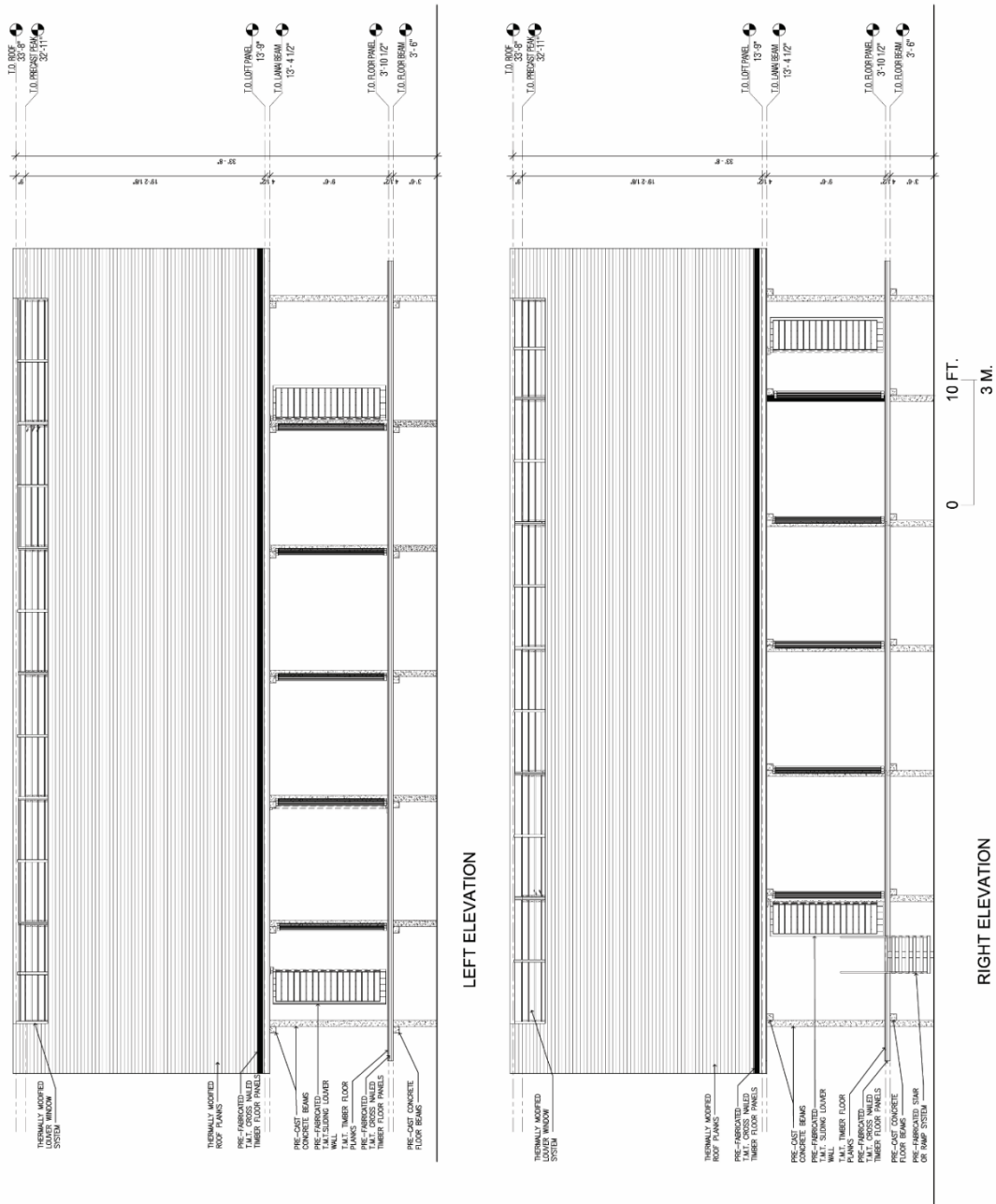


Figure 9.36: Elevations – 2

Source: Own work

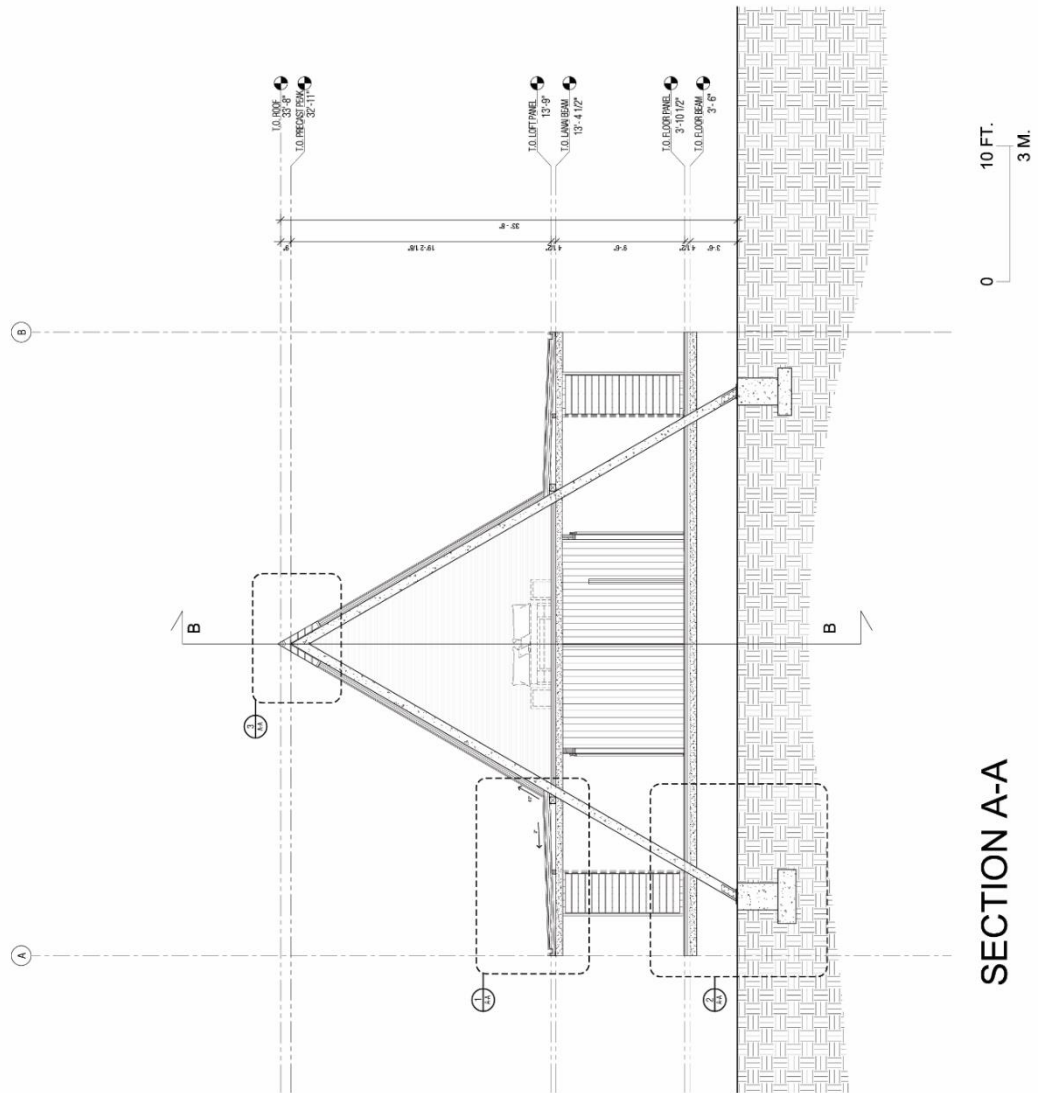


Figure 9.37: Section A-A
Source: Own work

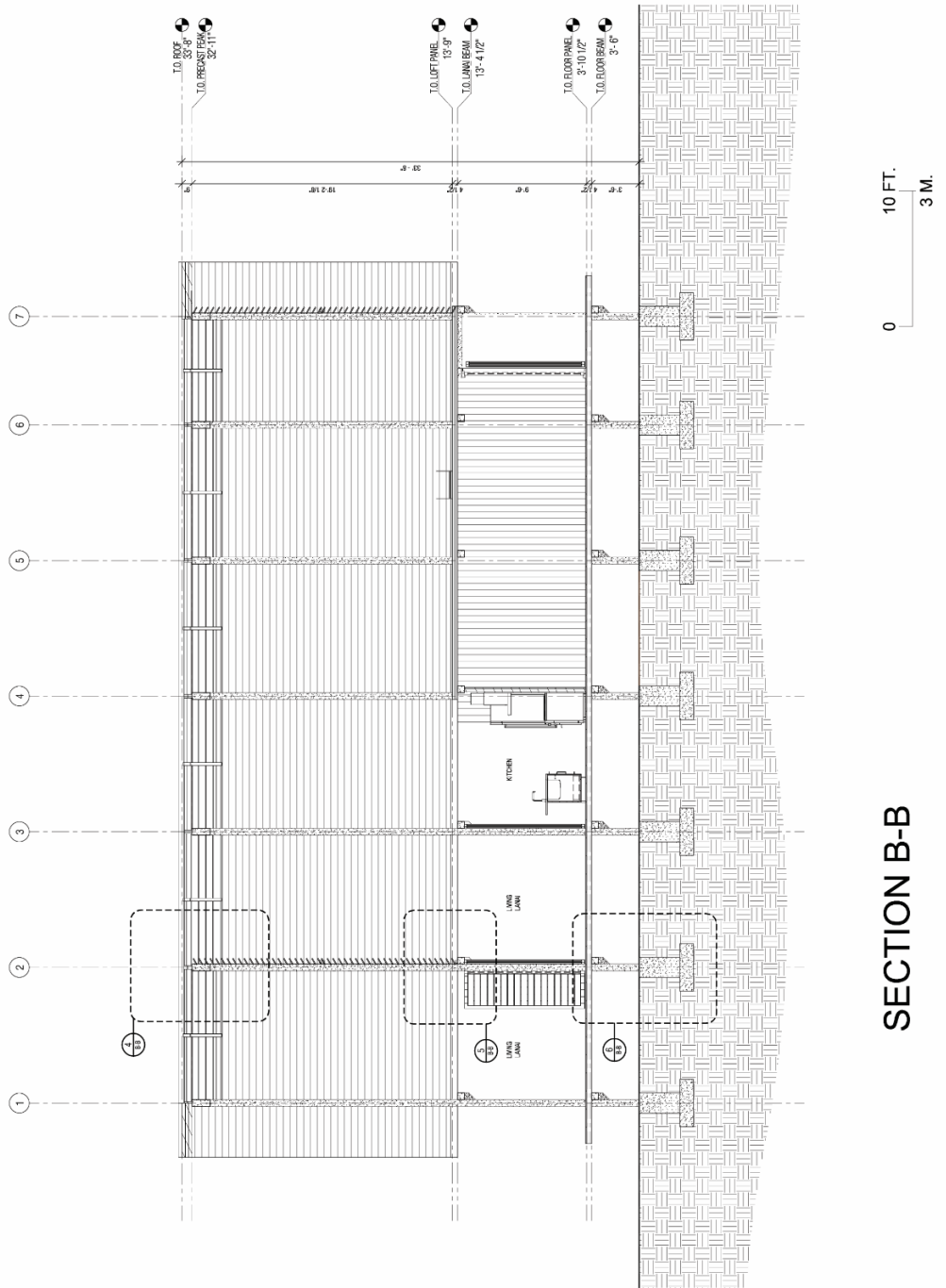
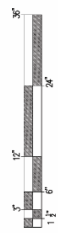
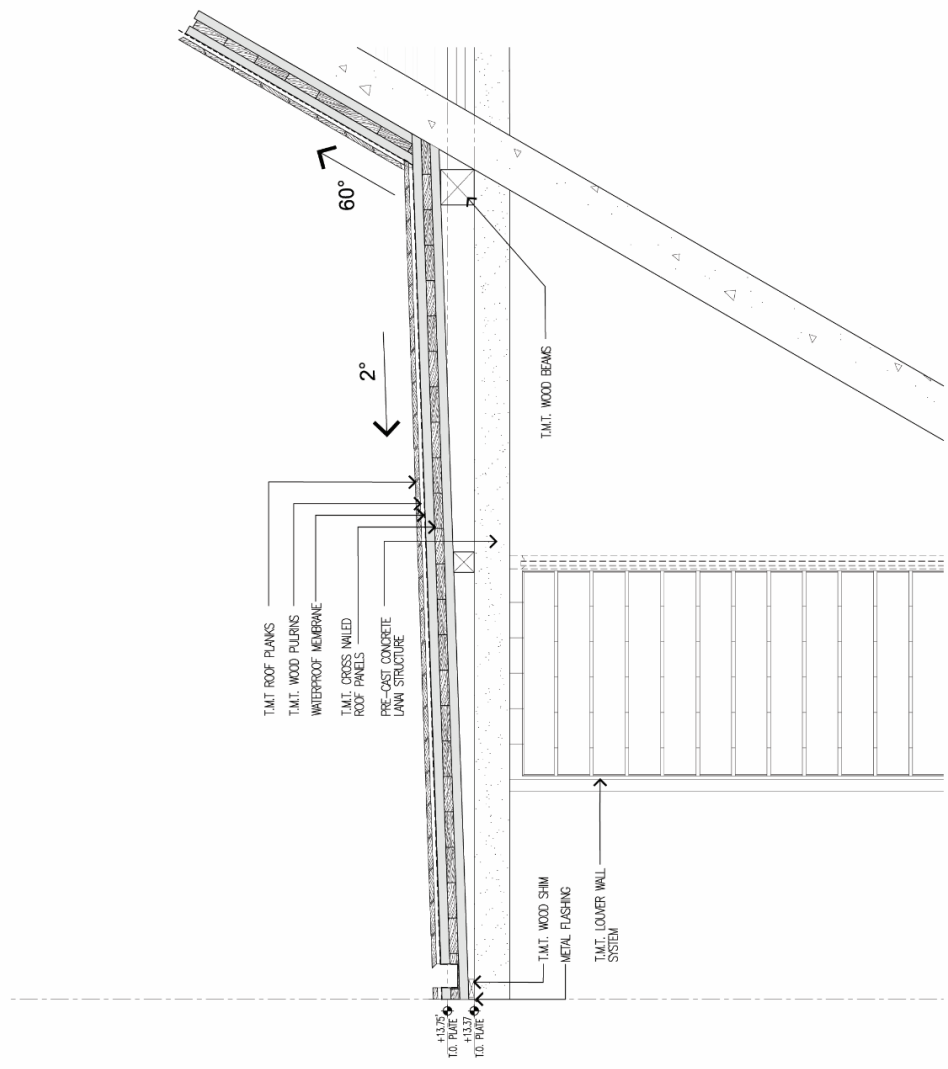


Figure 9.38 Section B-B
 Source: Own work



SCALE
1/2" = 1'-0"

DETAIL
1/A-A

Figure 9.39: Detail 1/ A-A

Source: Own work

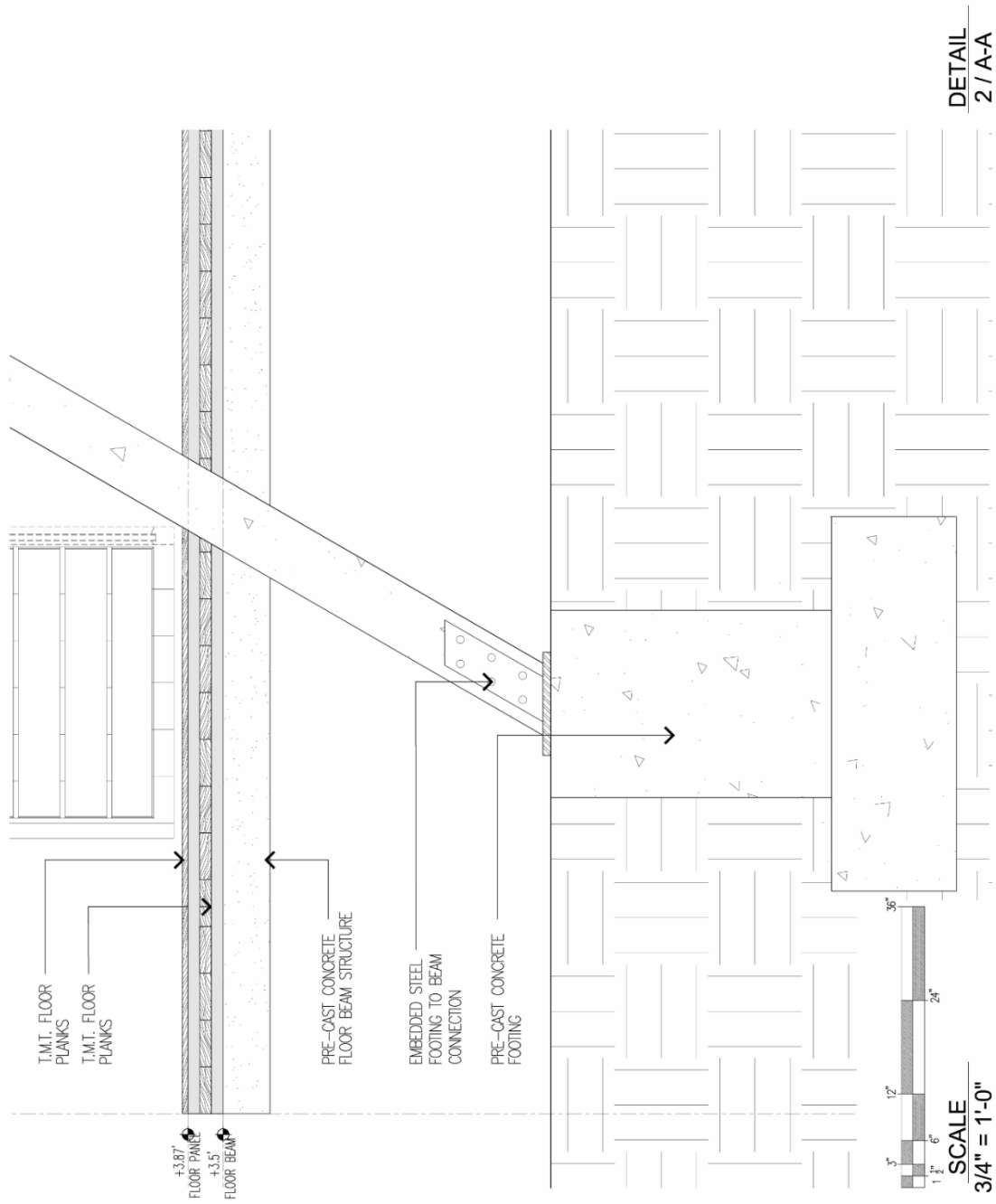


Figure 9.40: Detail 2/A-A

Source: Own work

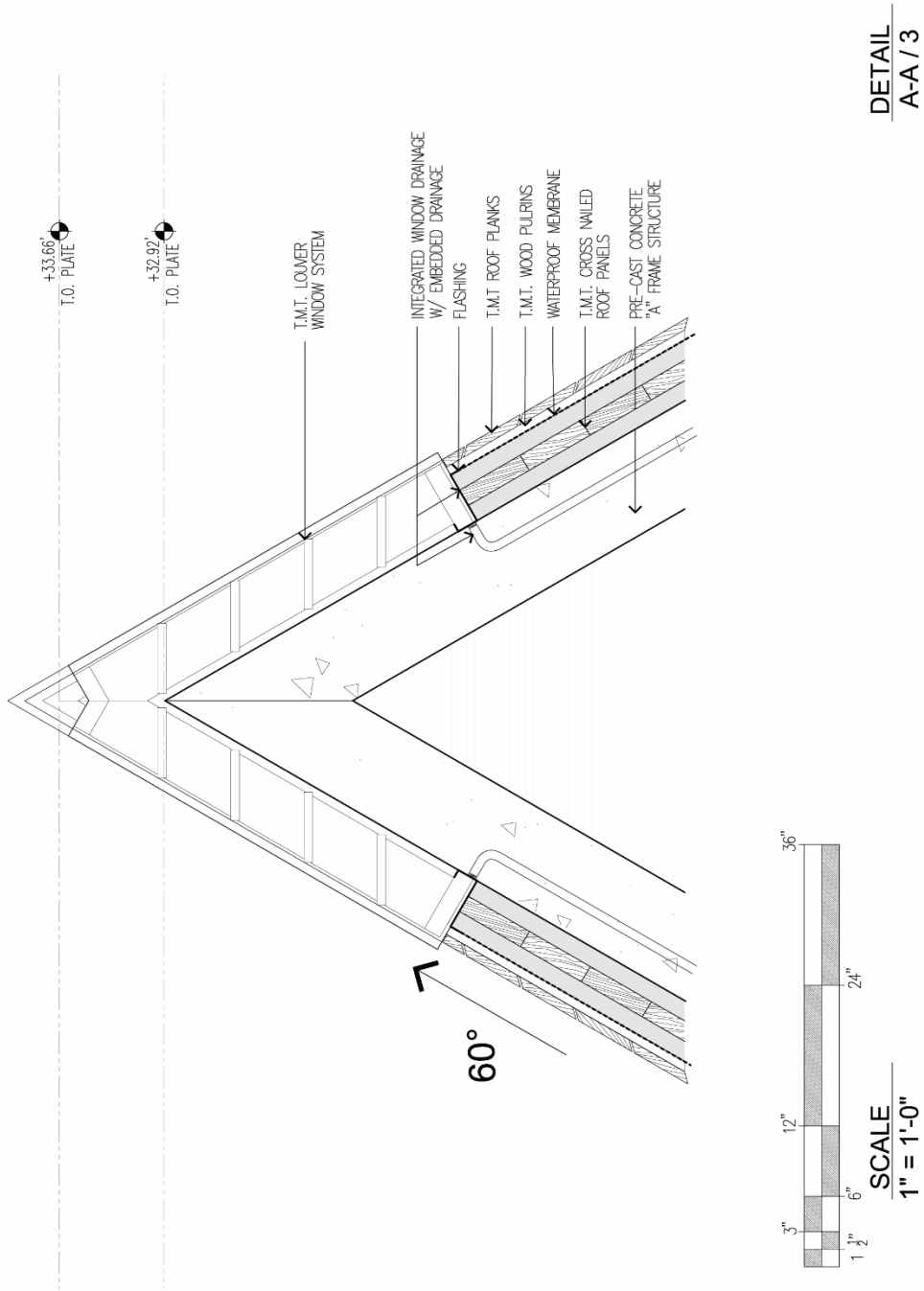
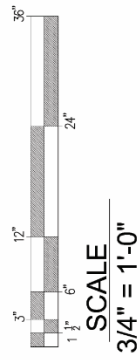
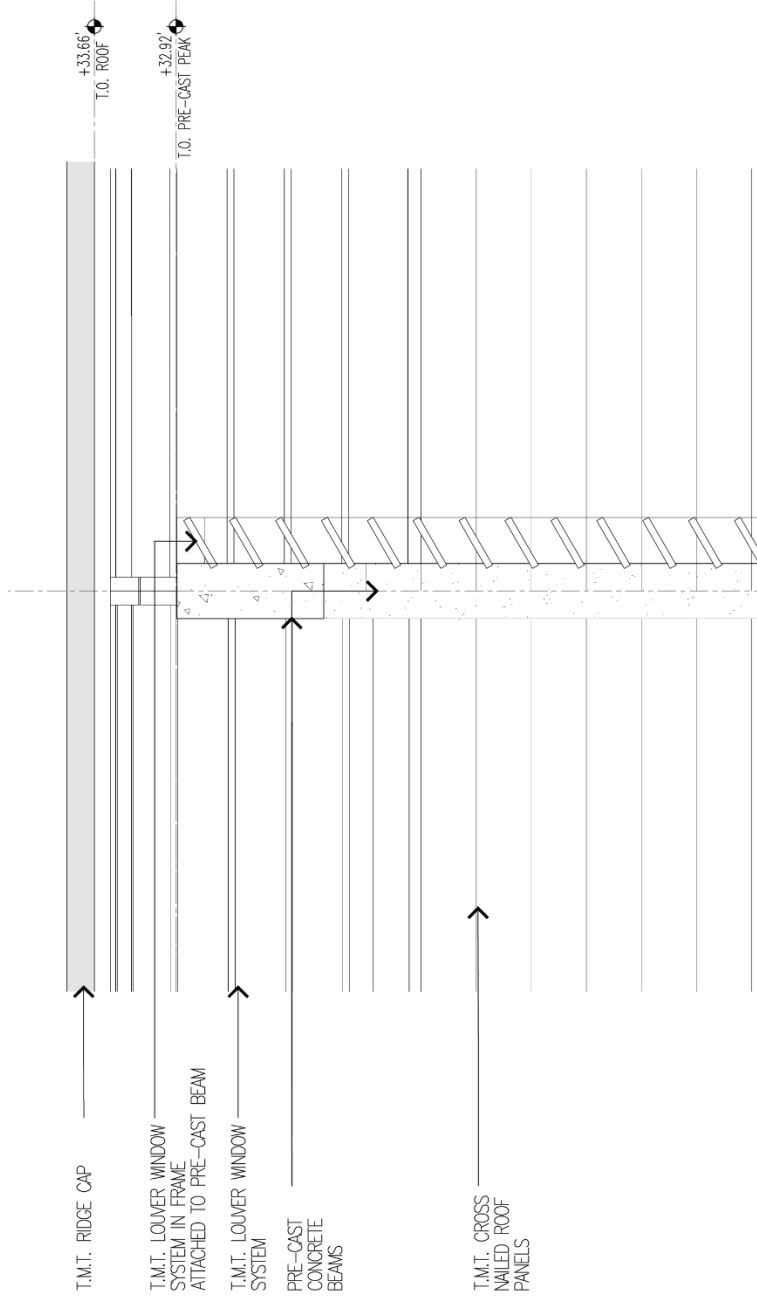


Figure 9.41: Detail 3 / A-A

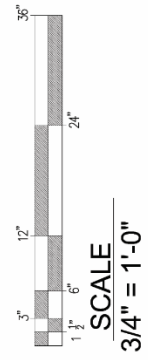
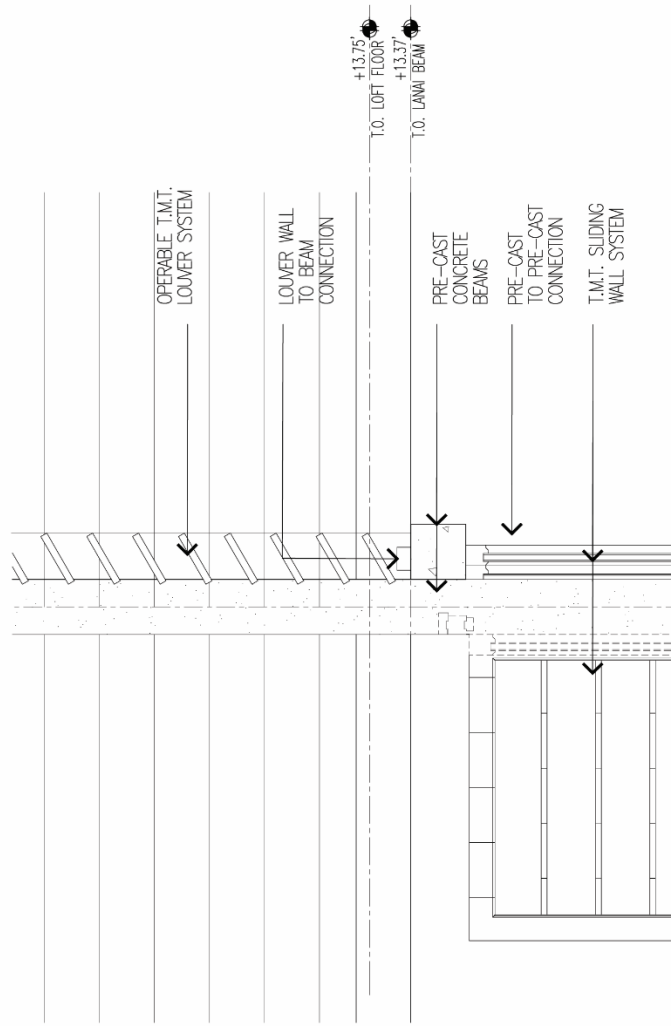
Source: Own work



DETAIL
B-B / 4

Figure 9.42 Detail 4 / B-B

Source: Own work



DETAIL
B-B / 5

Figure 9.43 Detail 5/ B-B

Source: Own work

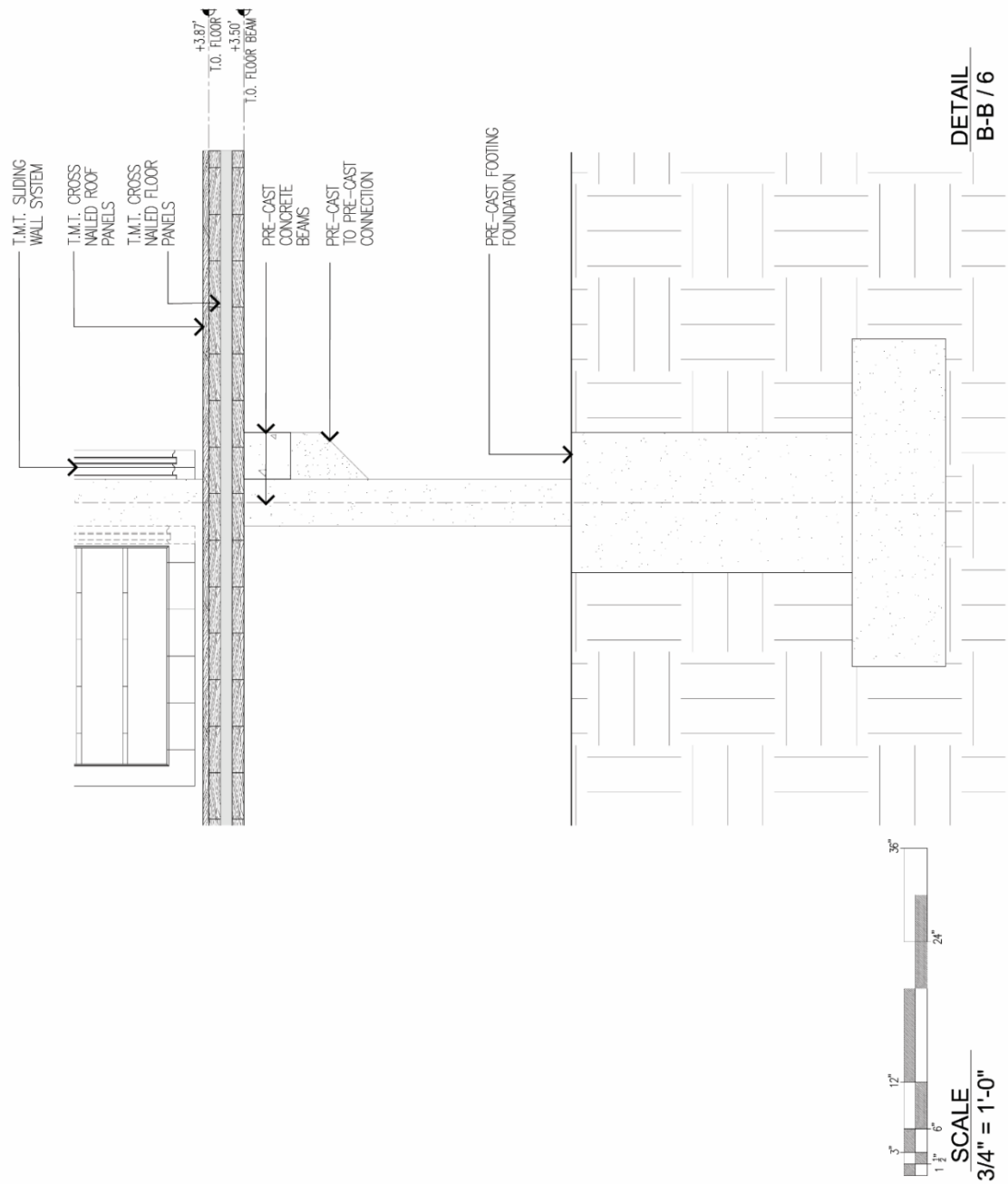
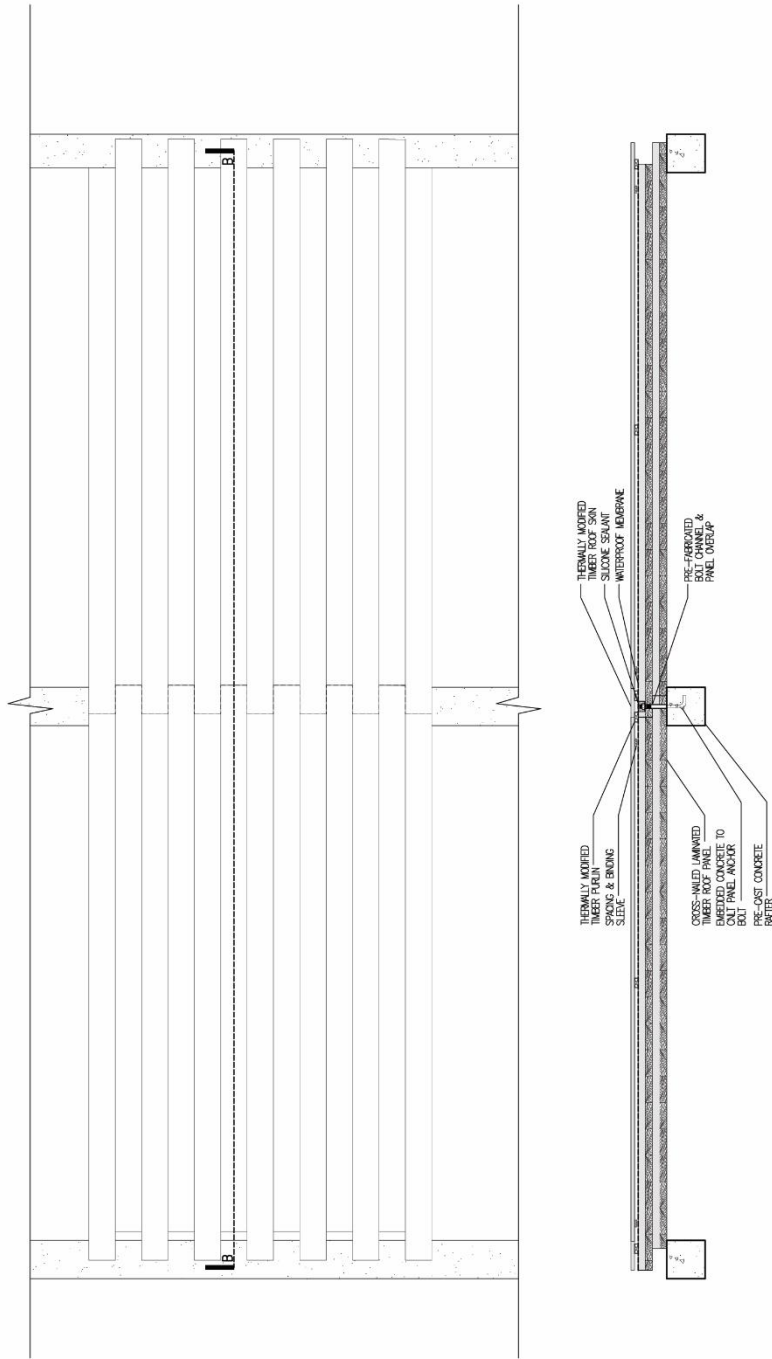



Figure 9.44 Detail 6/ B-B

Source: Own work





 SCALE
 3/8" = 1'-0"

PANEL TO PANEL
 CONNECTION DETAIL

Figure 9.45: Panel to Panel Connection Detail
 Source: Own work

CHAPTER 10: THE SITE: CLIMATE + ORIENTATION + UTILITY

Architecture is the collaborative effort between architects, designers, builders, and other specialists who bring their knowledge to create the built environment. Each profession brings valuable insight into the best way to create buildings and their surroundings. However, the relationship between architects, engineers and contractors is well established and much more black and white than the relationship between architects and landscape architects. This relationship is unique in that they both must deal with the site and its relationship to the living world around it to create a functional, safe and environmentally responsible architecture. The line between these professions *should be* blurred (albeit the focus of each is somewhat different) to successfully fulfill their roles. In their traditional scopes, the architect is more concerned with overall design and coordination while the landscape architect is more concerned with the specifics of the installed or natural environment. In this project, we will focus on the built and natural environment interactions as one; architecture which doesn't fully integrate, understand and appreciate its surroundings will surely be a failure. There are many parts of the site which we must consider including climate, building placement / orientation, circulation, landscape and sources of energy and water.

CLIMATE

Climate should play a role in almost every stage of architecture and design. The style of architecture, type of structure, materials we use, surrounding landscape and environment are effected, at least in part by the wind, rain, temperature and humidity of an area. I have already discussed the varied climates which exist in the state as well as the effect of designing a home without considering the climate which may cause health, thermal comfort and environmental issues. The climate is not something that we necessarily need to fear, rather we should consider how we can design a home in a way that creates a symbiotic relationship between nature and the built environment. In many ways, the tropical climate can be harsh; strong winds, high UV indexes and heat, rain and humidity are all possible at any time. Conversely, abundant sunshine, consistent temperature, rainfall and trade winds allow for the use of alternative energy sources, naturally ventilated and open structures and water catchment systems. While alternative energy sources require the financial means to procure and integrate into architecture, material selection, orientation and proper design are usually a matter of applied knowledge.

PHOTOVOLTAIC (PV), WIND + OTHER ALTERNATIVE ENERGY SYSTEMS



Figure 10.1: Photovoltaic Array, Nellis Air Force Base, Nevada

Source:

https://commons.wikimedia.org/wiki/File:Giant_photovoltaic_array.jpg



Figure 10.2: Mason Bryant, Hawi Wind Turbine,

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<https://creativecommons.org/licenses/by-sa/2.0/deed.en>

Source:

https://upload.wikimedia.org/wikipedia/commons/9/98/Hawi_wind_farm_302986813_13df18323b_o.j

There are many types of alternative energy systems which can be integrated in, on or around residential architecture. The most common is the photovoltaic (PV) solar panel. This system captures light from the sun and frees electrons to produce electricity. The panels are usually wired to a PV system of batteries and other equipment to provide electricity for water heating, as a supplementary to grid power systems or as a standalone energy source.

Panels are installed on roofs or on ground mounted stands and positioned to obtain maximum light to charge batteries during the day. Advances in PV technology have made the systems more efficient, affordable and adaptable.

Wind power created from different types of wind turbines are another alternative energy system which can be incorporated on the Hawaiian Islands. The turbines are powered by natural wind flow and have the potential to create large amounts of renewable energy. At the residential scale, smaller wind turbines can be installed on the building or around the site to offset some or all the energy needs of a home.

Other renewable energy systems include hydropower which uses the movement of water to turn turbines, geothermal which uses the Earth’s natural heat and tidal energy which uses wave action in the ocean to create energy. While these systems are important and should be incorporated in a statewide renewable portfolio they are less applicable at the individual residential scale. According to the American Wind Energy Association and the Governor’s office, the state must meet Governor David Ige’s renewable portfolio standard of 100% clean energy by 2045 and a multi-faceted approach will be needed to fulfill this goal.²⁵¹

CATCHMENT + CLOSED SYSTEMS + DRAINAGE

Catchment systems use the roof and other parts of the building envelope to capture water from rain for both potable and non-potable uses. Depending on the type of system, water which is easily captured on roofs can be stored in tanks and filtered for drinking water or personal use. Alternatively, and much more affordably, water may be caught and used directly for landscaping areas around the home.

Catchment systems are a great way to alleviate some or all the need for county supplied water. Although

Hawai’i generally has consistent rain and avoids major droughts, we still consume over 12,000,000 gallons of surface and groundwater every day for domestic use.²⁵² Some water managers in the state

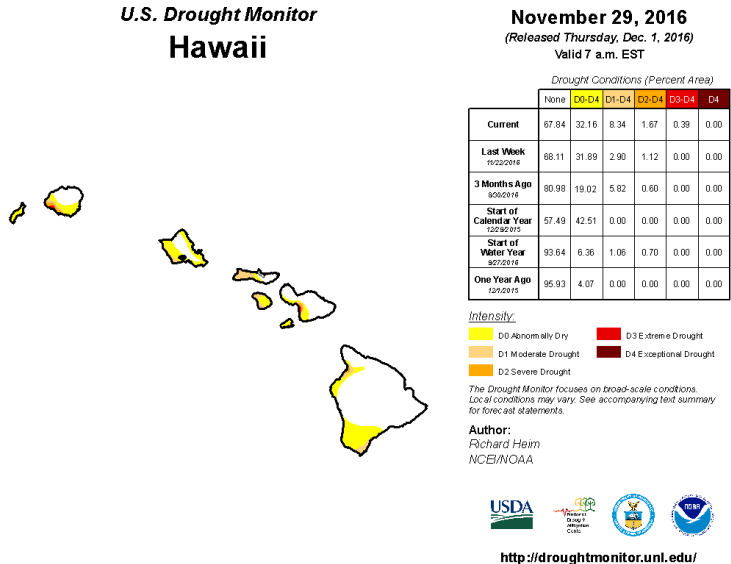


Figure 10.3: U.S. Drought Monitor - Hawaii

http://droughtmonitor.unl.edu/data/pngs/20161129/20161129_HI_trd.png accessed December 5, 2016

²⁵¹ “Press Release: Governor Ige Signs Bill Setting 100 Percent Renewable Energy Goal in Power Sector” Governor.hawaii.gov. June 8, 2015, accessed December 5, 2016. <http://governor.hawaii.gov/newsroom/press-release-governor-ige-signs-bill-setting-100-percentrenewable-energy-goal-in-power-sector/>

²⁵² Hutson, S., N. Barber, J. Kenny, K. Linsey, D. Lumia and M. Maupin “Estimated Use of Water in the United States in 2000.” U.S. Geological Survey Circular 1268, (released March 2004, revised April 2004, May 2004, February 2005).

believe that we may start developing regional water shortages and some mandatory conservation limits have been set across the state, while others believe our water supply will be sufficient until at least the 2020's.²⁵³ For a new type of residential architecture it would be irresponsible to not incorporate catchment systems wherever possible. Certain parts of the islands are very dry and having a source of water which can be captured and filtered easily will be a positive step for a growing island state. Areas where rain is more abundant will obviously be more likely candidates for catchment systems and will contribute to an overall statewide reduction in county supplied water use. As the population grows and the need for more locally based agriculture increases we will need all the water we can conserve. One method for reusing water is implementation of sequencing or single batch reactors, (SBR). These systems can be smaller home sized units or scaled all the way up to wastewater treatment plants. SBR systems have been around, in some iteration for over 100 years, although most interest and development was done during in the 1950s and 60s. Essentially the SBR equalizes, treats and clarifies wastewater in a single tank under specific time controlled sequences. The process goes something like this:

Wastewater from homes or other buildings is first passed through screens and other grit removal processes. It is then allowed to fill a reactor where an aerator mixes the water until the biological reactions can occur. The wastewater is then allowed to settle and the treated water is removed. This water, depending on the type of SBR and the process of biological reactions, time of aeration and settling can be drained as surface water in fields or in some cases be used to water agriculture. Some SBR systems exist where water is then further treated and returned to a potable source for consumption.²⁵⁴

²⁵³ Luisa F. Castro, "Water Issues in Hawaii: A Survey of Public Attitudes," *Water Issues* WI-2 (August, 2005) accessed January 10, 2017 <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/WI-2.pdf>

²⁵⁴ Wastewater Technology Fact Sheet, Sequencing Batch Reactors, United States Environmental Protection Agency, EPA 932-F-99-073 (September, 1999) accessed January 20, 2017 https://www3.epa.gov/npdes/pubs/sbr_new.pdf.

CHAPTER 11:

SITE SPECIFIC: CREATING A SUSTAINABLE NEW HAWAIIAN RESIDENTIAL COMMUNITY

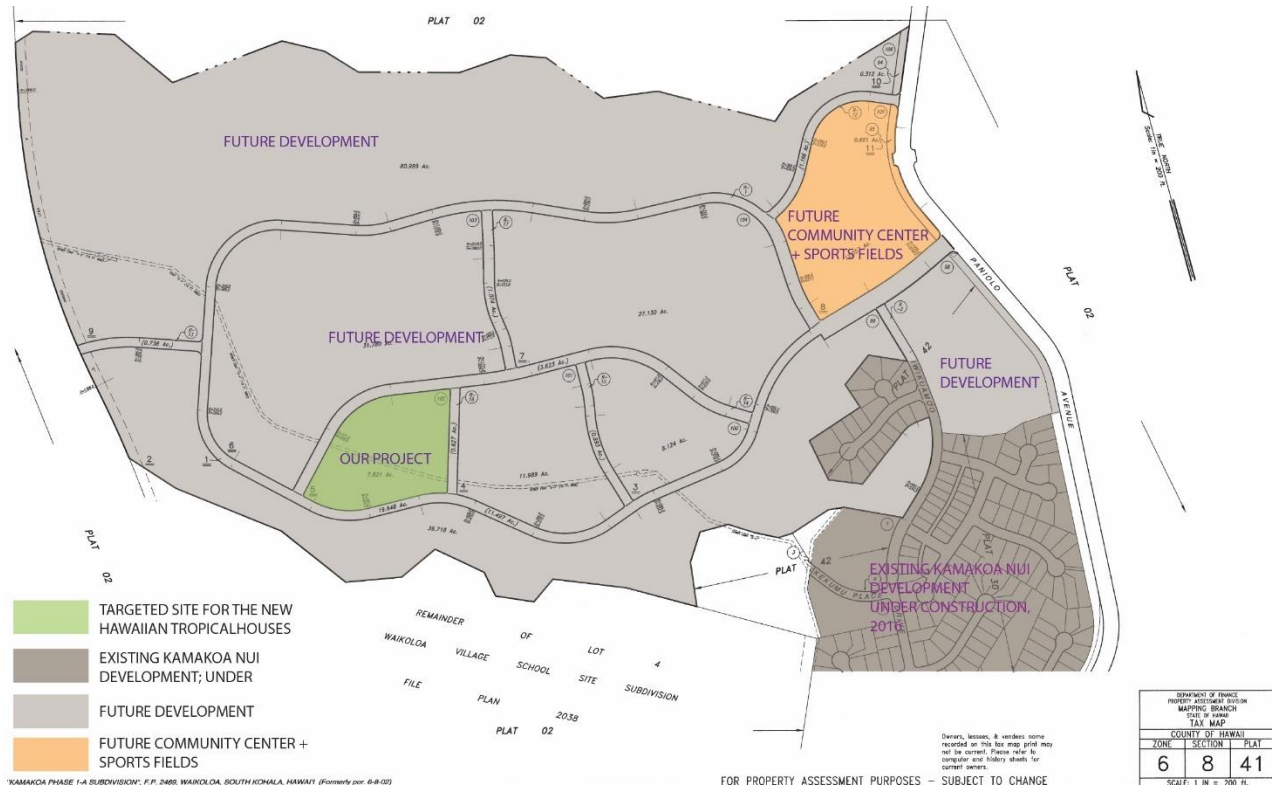


Figure 11.1 Kamakoa Nui Development Area

Source: Own work

The project site for the new Hawaiian community of homes is hypothetically located at the Northwest extent of Waikoloa Village. Looking at the illustrated plat map above indicates the location and proximity of the proceeding site information in comparison to the case study houses previously mentioned in the Kamakoa Nui subdivision. While the land highlighted in green is targeted as the site for my project it is currently slated as a future extension of Kamakoa Nui. Part of the justification for this site selection is its proximity to the case study houses in Chapter 5.1 and a purposeful and direct comparison of these “typically” built homes to the new Hawai’i home designed at the outset of Part 2. The Kamakoa Nui neighborhood is still under development and represents the most current and typical building techniques and land development as promoted by the County of Hawai’i. As a community that

is still being built I felt it was prudent to suggest an alternative housing and community type in the future development area which attempts to rectify the climatic, environmental and health problems mentioned in the first Part of this project. Secondly, this specific geographic location represents one of the more common climatic conditions in the state as a BSh, hot, semi-arid desert climate. The open space and undeveloped surroundings allow the opportunity to suggest alternative energy and land use strategies while being close enough to the electrical grid and County water supply to be used as a backup source. Further, the new community could be easily connected to the existing developed paved vehicular circulation areas for emergency vehicle and inhabitant access.

Part of the design for a new Hawai'i tropical home is that the construction methods and materials are adaptable to many different climate types and site conditions. In this chapter we explore a hot, arid climate but the home could be altered slightly and be located in most other areas of the state successfully. While not directly discussed in this project I believe the home would be well suited on its own as an individual house or homestead, as part of a community like it will be soon discussed or even adapted to more urban settings like that of parts of Honolulu. Again, I believe that the materiality of the home makes it well placed anywhere that it is sited.

Figure 11.2 on the following page helps to illustrate the site and its relative proximity to other areas on Hawai'i island. The site is located at the North West, leeward side of the island, approximately 45 minutes from Kailua-Kona, 25 minutes from Waimea and 1 – 2 hours from Hilo by car, depending on which road is used.

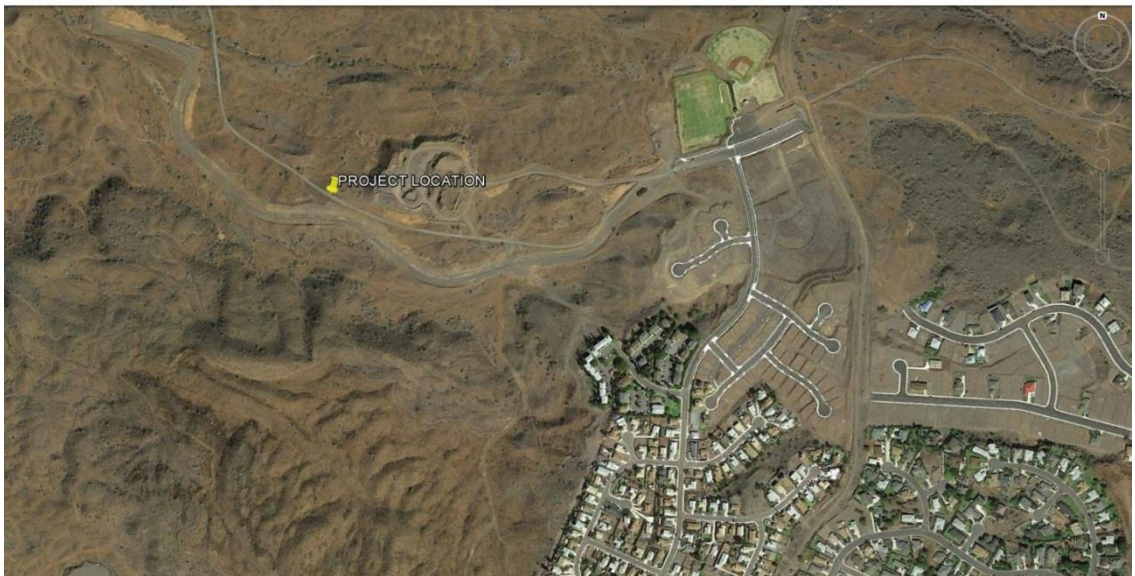
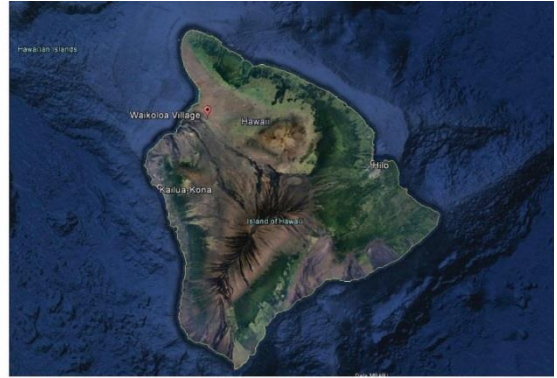
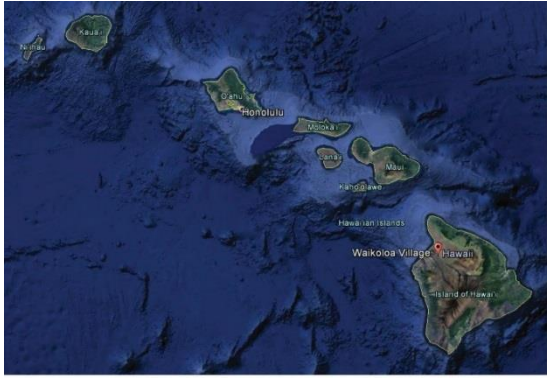


Figure 11.2 Waikoloa Village, Mapped

Source: Own work from Google Earth images



Figure 11.3: Entrance Gate

Source: Own work

The site is currently undeveloped but has direct access through a gravel road to the rest of Kamakoa Nui and thereby the town of Waikoloa Village. Water, sewer and electrical lines already exist and run past “Our Project” to the future development areas. Figure 11.5 demonstrates the access route from Waikoloa village, through Kamakoa Nui via Paniolo Ave. The entrance gate (Figure 11.3) is labeled on that diagram for reference.



Figure 11.4: Looking toward the Site

Source: Own work



Figure 11.5: Site Analysis

Source: Own work

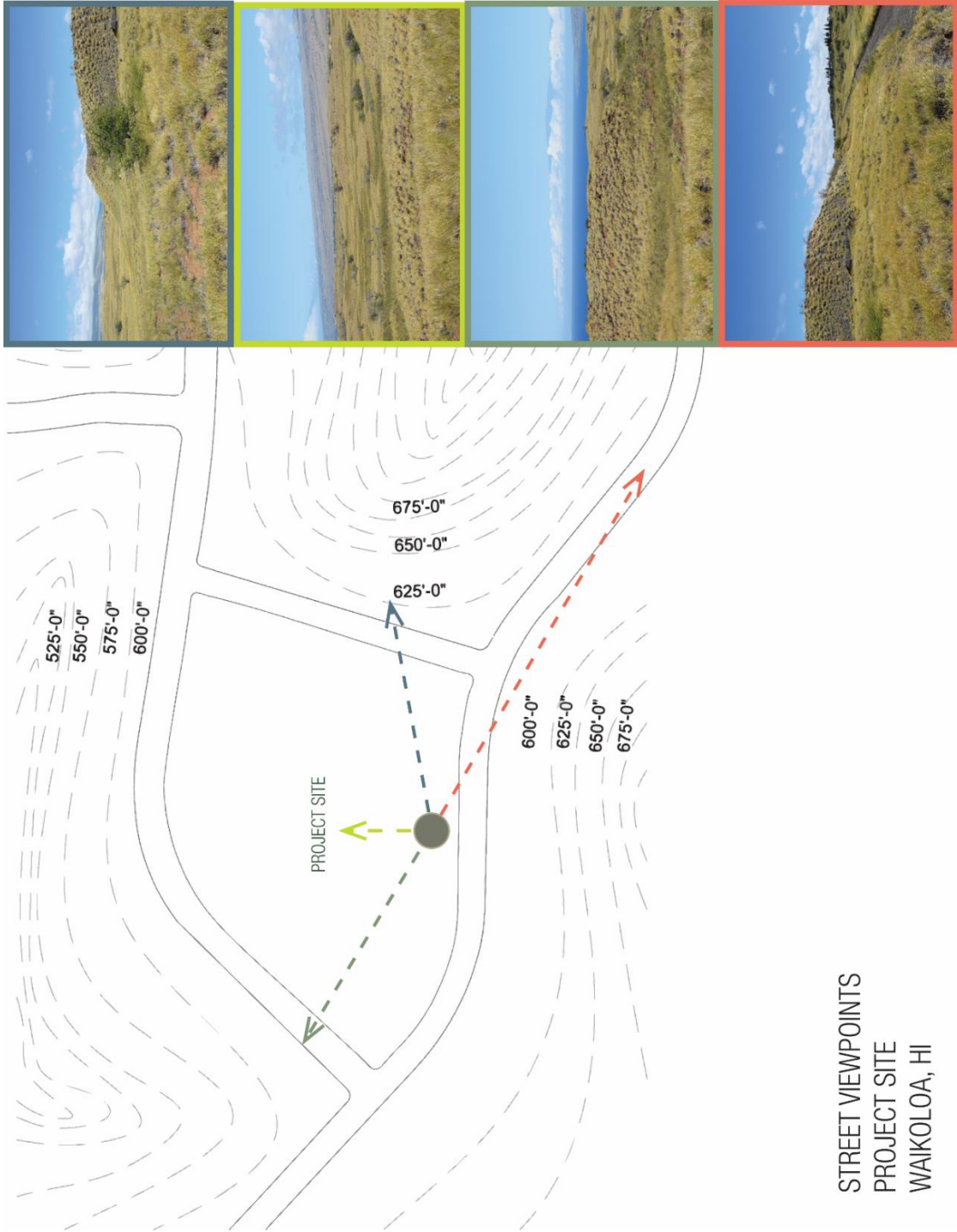


Figure 11.6: General Sight Views from the Main road

Source: Own work

CLIMATE + BUILDING ORIENTATION

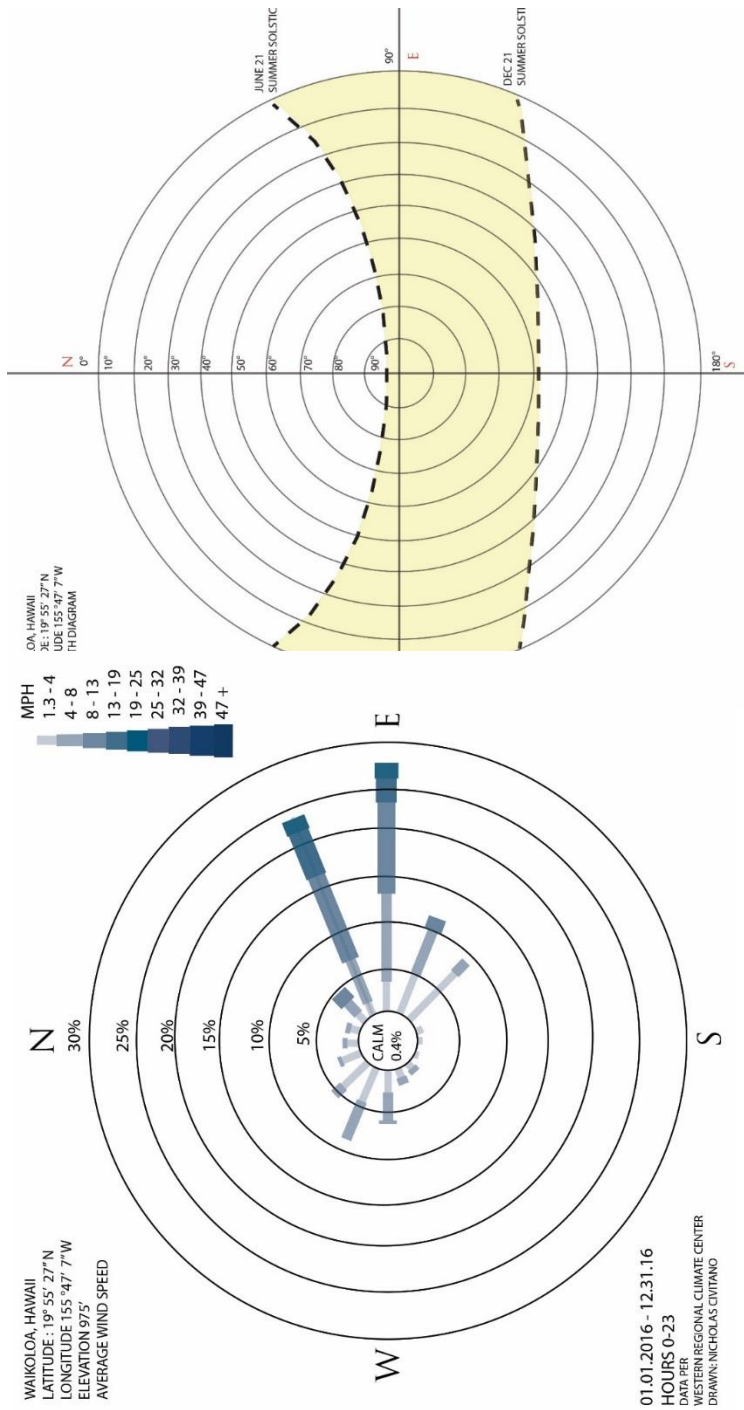


Figure 11.7: Solar Path + Wind Rose, Waikoloa, HI

Source: Own work

In properly designed communities, wind direction and sun path are two of the most important factors which should be considered. Building orientation is the important variable here and can be the difference of a natural ventilation system working properly. Further, proper orientation helps to minimize direct solar heat gain through unprotected areas of the home and to take advantage of direct light for P.V. systems.

These climatic variables are exceptionally important to factor in to the design for undeveloped areas. In other words, this site has no pre-existing buildings, trees or built areas which may block the sun or wind flow from the site area. Any added site interventions must consider how they will affect the inhabitants and homes around them. The wind rose is the primary concern for us; we are using a natural ventilation system for thermal comfort and we also wish to reduce moisture and to continually flush indoor air with fresh air from the outside. For this area, like the majority of the state, the

primary wind directions are East and Northeast during trade wind conditions (common) and Northwest and West directions during Kona wind conditions (uncommon). The design of the home features a very open plan and a building perimeter completely made of sliding louvered doors; wind can flow through the space from any direction to provide at least some degree of comfort and air circulation. However, orienting the home where the long sides face the directions of greatest airflow would help to generate the most ventilation possible. Further, orienting the short ends of the home in the Southern direction (toward the sun path) reduces solar exposure on the larger portions of roof. This orientation lessens direct solar heat gain from the roof structure to the indoor areas while maximizes airflow.

Part of the reason the design of the home is the way it is would be to function properly even if the building orientation is not completely ideal. The extra roof planks, thick solid timber panels and multitude of louvered openings all help to create, at minimum a comfortable indoor space.

Looking at the overall site concept (Figure 11.8-9), the majority of the homes orient with their long sides toward the East and NorthEast (or West, NorthWest, depending on trade or Kona wind events) and their short ends facing the South. This ensures the greatest possible benefit protecting inhabitants from the harsh sun and taking advantage of the consistent winds of the area.

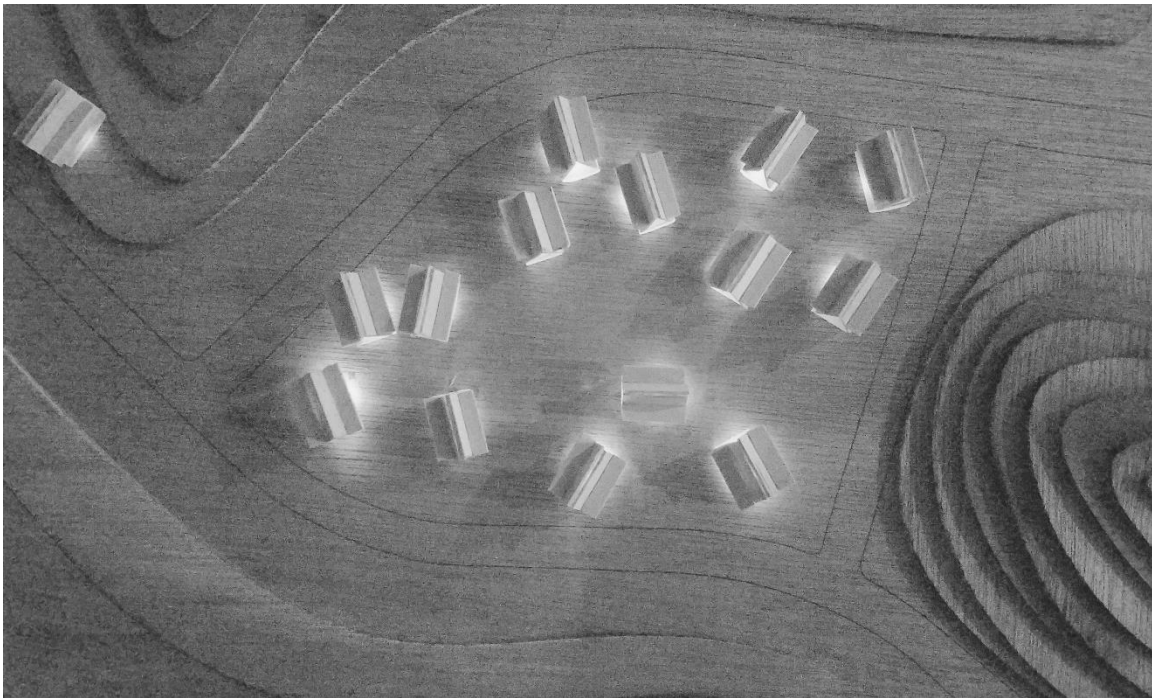


Figure 11.8 Site Model, Plan View at Night

Source: Own work

THE SITE CONCEPT



Figure 11.9: The Site Concept

Source Own work

There is quite a bit going on in this community and if it looks different from the nearby Kamakoa Nui neighborhood than I have at least partially accomplished one of my goals. The idea was to create a living community, one that could be (potentially) self-reliant, built relatively quickly and could expand or be adapted to other areas in the state.

ORIENTATION + SITE INTERVENTIONS

The first thing I hope readers notice is the location and orientation of each home on the site. This roughly 7-acre area consists of 14 homes, giving each approximately $\frac{1}{4}$ acre of immediate surrounding landscape to be used as personal productive gardening space and the rest devoted to productive agriculture, aquaculture, aquaponics and community areas. The placement of each housing “pod” of three or four homes is not random but rather works in conjunction with the natural landscape and grade of the land. The homes are placed on the higher elevation areas and surround the middle or low elevation portions of the site. This middle area is intentionally left low so natural drainage and diverted rainwater from catchment systems can drain and be stored in the central reservoir area. Figure 11.10 shows the current site conditions and the locations of each intervention on the site. The central reservoir is designed to be a common gathering area with a fishing palapa and barbeque area. This reservoir could be both a catchment and rainwater filled lake as well as being connected to the County water supply to maintain minimum water levels during dry seasons. This freshwater supply has potential to be for tilapia or other types of freshwater fish farming / aquaculture and aquaponics. These fish and aquaculture/ponic areas could be used as a food source for residents or potential income source along with produce farming on personal and community gardens and from the many citrus, mango and other fruit trees planted in the grove and throughout the site at the farmer's market areas. While it is not the purpose to necessarily suggest that residents must do some kind of work trade or other program to live in the community, I believe those drawn to this type of community would want the opportunity and the resources to grow produce in community and personal gardens. The site also contains administration and office areas and community playgrounds which would give residents additional resources for community events and social interactions.

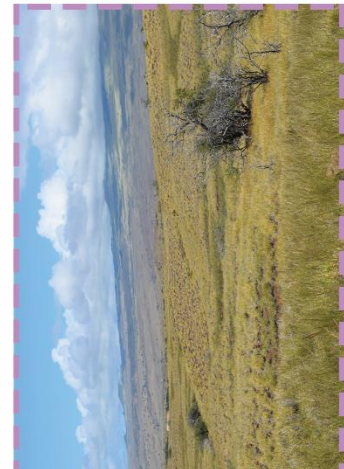


Figure 11.10: Sight Lines from Street showing existing land Heights

Source: Own work

LANDSCAPE



Figure 11.11 Pakalana Vine
(*Telosma cordata*)

Source: James Edward Smith &
James Sowerby, 1790

While many site interventions exist, it is the intention to minimize the impervious surfaces of the site. Building on the idea that the homes only touch the ground at the base of the structural ribs I believe it is important to plant only in areas immediately surrounding the houses with more traditional landscaping and garden plants. These may include some native and exotic plant species listed below as well as whatever produce producing plants residents would be interested in cultivating. Moving from the area directly surrounding the house, the landscape would transition to the existing lava and grasses and again to other groundcovers like native Pili grass surrounding site intervention areas like the playground, gardens, farmer's markets or central lake area.

TREES

Autograph
Avocado
Banana
Bestill
Citrus
Fig
Guava
Jatropha
Kiawe
Kou - Geiger (*sebestenia*)
Kou - Hawaiian (*subcordata*)
Loquat
Mango
Monkeypod
Papaya
Pink Tecoma
Plumeria - Dwarf
Plumeria - Singapore
Pua Keniken
Seagrape

SHRUBS

Adenium
Agave Attenuata
Bird of Paradise
Blue Plumbago
Blueberry
Bougainvillea
Brazilian Cherry
Cardboard Palm
Dwarf Bottlebrush
Dwarf Poinciana
El Dorado
False Eranthemum
Galphimia
Gardenia - Tahitian
Golden Duranta
Green Duranta
Hibiscus
Hymenocallis (Hualalai Lily)

Ixora
Mulberry
Naupaka
Passion Fruit
Pineapple
Plumeria - Dwarf
Plumeria Pudica
Raphiolepis
Snowbush
Song of India
Spider Lily
Ti

PALMS

Coconut
Foxtail
Manila
Pygmy Date palm

SCREEN SHRUBS

Crepe Gardenia
Dwarf Green Hau
Dwarf Schefflera
Green Duranta
Mock Orange
Native White Hibiscus
Podocarpus
Seagrape
Snowbush
Song of India
Variegated Hau

SCREEN VINES

Devil's Ivy
Pakalana

GROUNDCOVERS

Akia
Akuli-kuli
Dwarf Agapanthus
Dwarf Carissa - "Tuttle"
Hearts and Flowers
Iceplant
Lantana
Naio
Peanut Plant
Pili Grass
Pohinahina
Pothos
Turf
Variagated Dianella
Wax Ficus
Wedelia

If we look closer at a housing pod area (Figure 11.12-13), we see how the landscape could be hypothetically laid out. Notice the privacy screens which have multiple functions; first to provide some degree of privacy from neighbors but also as a pre-screening filter for the natural ventilation systems mentioned in Part 1 of this project. This is where a plant like Devils Ivy could be used to filter out any potential outdoor contaminants before they enter the home. The result is a simple and affordable privacy fence line made from wood posts and wire fencing, which is lush with ivy and screening shrubs and provides a filtering effect for indoor air quality. The lack of through streets, cul de sacs and other vehicular transportation through the site is also a purposeful design element to reduce pollution, noise and to attempt to create more community based interaction.

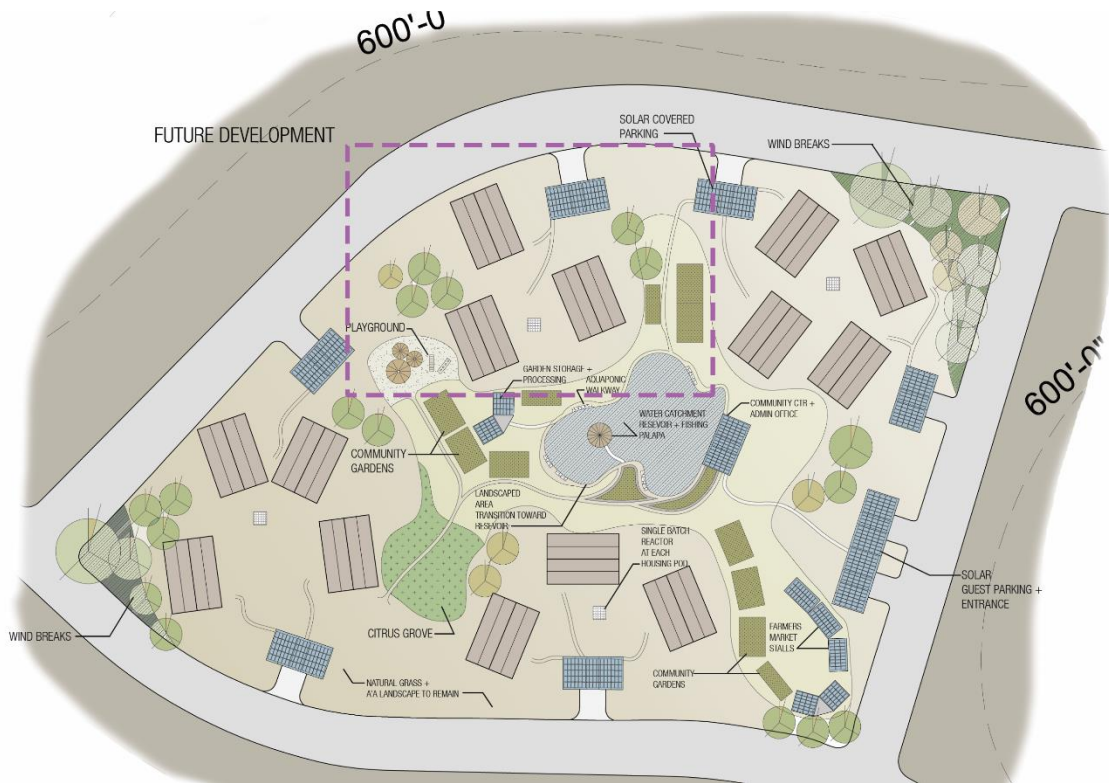


Figure 11.12: Site Concept; Targeted Housing Pod

Source: Own work

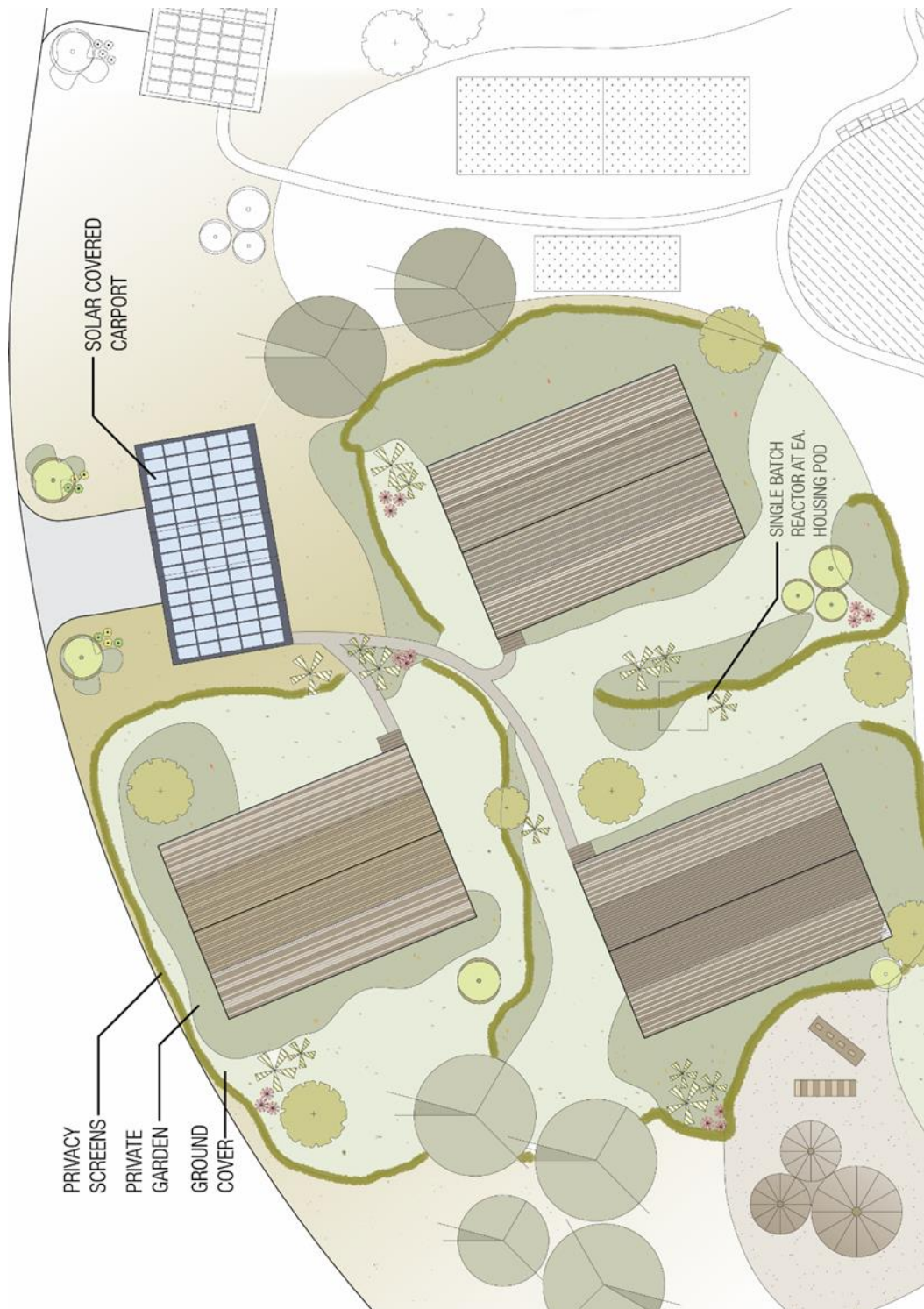


Figure 11.13: Site + Landscape Plan

Source: Own work

RENEWABLE ENERGY + ENVIRONMENTAL SYSTEMS

In terms of renewable sources of energy and water collection, each resident and guest parking area features open solar covered carports which collect solar energy to power community shared facilities as well as to provide energy for those residents who would be in need of economic assistance. Further, additional energy production in the form of roof mounted P.V. systems or wind turbines could be added to offset personal energy use. The roofs structure is quite large and could also be used as part of a water catchment system.

Single or sequencing bath reactors (SBRs) would ideally be placed at each home or at each housing pod area to treat and recycle wastewater from each home. Depending on the systems used the water could be discharged to the surrounding natural landscape or if the treatment process could be overseen and the process uninterrupted by chemicals it could potentially be used in the gardens and citrus grove areas.

As water is such a precious resource in a dry area, recirculating aquaculture systems (RAS) could be used in a small storage area near the catchment reservoir to further aid in the recycling of water. RAS systems convert ammonia laden water from fish waste by removing the solids and converting this into nitrates which could then be filtered out and the water returned to the reservoir. This helps keep the fish environments healthy. Further, a special type of hybrid RAS, aquaponic / aquaculture system could be incorporated which creates a self-contained closed loop system. Essentially, the ammonia from fish waste is converted to nitrate and then removed by the plants in the aquaponic tanks.²⁵⁵The fish are happy with clean water, the plants are happy with the natural fertilizer produced by the fish and the residents are happy with fresh fish and crops to eat and sell.

²⁵⁵ S. Diver, "Aquaponics Integration of Hydroponics and Aquaculture" (2006) accessed January 24, 2017. http://create.extension.org/files/2/28/Hydroponics_with_Aquaculture.pdf

SUMMING UP

There are many ways in which the community could be designed. Other types of renewable energy, water recycling and storage, and landscaping may be suggested depending on the site location and the potential residents. I felt it was important to include information about a potential, real site which could be hypothetically implemented in the near future. As I have mentioned previously, I believe the new Hawai'i home is versatile and adaptable to the many climate and site conditions the islands contain. Obviously, some variations or changes may need to be made if the house was to be built in a densely populated urban area, a wetter climate or in some of the many other unique site situations which exist. It is not to say that this house was directly designed for this specific site, however the design as presented in Chapter 9 is what I believe works for the most common, relatively hot, humid and tropically rainy areas in the state.



Figure 11.14: Site Model Perspective, Night

Source: Own work



Figure 11.15: Site Model Perspective, Day

Source: Own work



Figure 11.16: Site Model, Perspective, Afternoon

CHAPTER 12:

INSPIRATION + PRECEDENTS

A phrase that has stuck with me through the beginning of my architectural education at University of Hawai'i School of Architecture through writing this dissertation came in my first architecture history and theory class from Professor Kazi Ashraf who once told me that "architecture was never created in a vacuum." A building does not appear out of thin air, regardless of how brilliant we believe other architects and designers to be. The architectural masters like Vitruvius, Palladio, Mies van de Rohe, Frank Lloyd Wright, Le Corbusier, Geoffrey Bawa and countless others did not create from nothing. While an architect may claim that a design was not influenced by a specific building or style, one cannot deny the effect that the events of history and the current social and cultural influences have on both the conscious and subconscious of the designer.

Many architects use precedents as inspiration, some use objects or materials, some, feelings or cultural references. I believe that my own personal design ethos is informed a little by all of these things. In many ways, the discovery of thermally modified wood was a significant influence on the way this project came together. The efficiency and potential of pre-cast concrete was another important variable guiding my design. Living on these islands for the last 14 years and witnessing how we currently go about architecture and feeling like it has been lacking in any type of regional characteristic and cultural significance has been part of it. The effect of a home which was polluted by toxins and the effect they had on my own family is another.

Of course, there are many influences, both natural and built on the tropical paradise known as the Hawaiian islands for which I draw reference. The palm tree is one, with its perfectly strong trunk bending in the strong winds, rooting in the sandy soil and spreading with its resilient nut all over the Pacific. The many massive eucalyptus trees growing throughout the islands with their timber potential, the harsh, tectonic beauty of Pele's lava rock or the taro leaf which collects rainwater and diverts it to the life giving fields for which it grows.



Figure 12.1: Eucalyptus Robusta + Black Lava + Taro

Source: Own work

The hale pili and its existing iteration as canoe haies like those in Figure 12.2 Which exist across the coastlines in Hawai'i have always fascinated me with their simple, effective and naturally beautiful structures. Stone foundations, solid timber roof beams and natural thatching provided the perfect solution for the Native Hawaiians who had few building materials to work with.

A relatively recent (1968) take on the hale pili exist at the Hapuna Beach Campgrounds by the Rockefeller family. These "A" frame buildings (Figure 12.3) take an interesting approach to the structure and similarly use the roof beams as the entire structural element of the space. These camping haies are naturally ventilated and use minimal structure to provide protection from the sun and rain.



Figure 12.2: Canoe Hale, Mauna Lani Bay

Source: Own work



Figure 12.3: Hapuna Campgrounds

Source: Own work



Figure 12.4: Joel Abroad, *Canoe Shed, Hale'iwa*, is licensed under CC BY 2.0, <https://creativecommons.org/licenses/by/2.0/>
Source: <https://www.flickr.com/photos/40295335@N00/3311253066>

The canoe hale wa'a located on the North Shore of Oahu at Hale'iwa elementary was one of my first introductions to an all timber, contemporary take on the hale pili tradition. The way that the structure descends from the peak and directly into the concrete foundation has stuck with me as an efficient and beautiful way of designing a roof / wall systems. The expanded wings for extra storage space were also important additions which I used as inspiration for the wraparound indoor / outdoor space. The timber construction, especially with the surrounding ironwood trees, speaks to the natural landscape and I believe to be a thoughtful take on a Native Hawaiian tradition.



Figure 12.5: Honolulu Zoo Entrance

Source: http://modtraveler.net/city/honolulu_655/listing/honolulu-zoo/ accessed February 23, 2017

The entrance to the Honolulu Zoo by the famous Austrian born, Hawai'i based architect Alfred Preis. This Modern iteration of the "A" frame was used as the entrance and ticket counter for the Honolulu Zoo for almost 50 years until it was replaced in 2011. This was more than a simple throwback to native Hawaiian hale pili architecture. This undulating and updated take on the efficient A frame structure was effective in creating necessary shading while its shape looks as though it becomes part of the canopy from the opposite side. The natural material selections, simple concrete, stone and wood with a louvered panel on the opposite side work well with surrounding environment, blending into the landscape while allowing wind to flow freely through to the shaded space below.

I would be remiss if I didn't mention Andrew Geller, the "Architect of Happiness" who starting in the 1950s designed many vacation beach houses primarily on Long Island in New York. One of the most popular of these and the one most significant to this project was the Reese House built 1955. This project was featured on the front page of the New York Times Real Estate section on Sunday, May 5,



Figure 12.6: Reese House

Source: Andrew Geller Collection

1957. The importance of this home to this project is immense. Geller initially faced criticism from the building department regarding the unusual "A" frame design. The architect countered the criticism by claiming the shape came from local vernacular barn tradition.²⁵⁶ Long solid timber piles were driven into the sandy soil to create a solid foundation and to raise the home off the ground to avoid flooding. The roof shape rises from the ground to meet at the peak and form the "A" shape. This shape was touted to have created a "cool interior and to resist winds of hurricane force", as mentioned in the caption in the New York times article featured on Figure 12.5. Windows on the sides of the home allowed air flow and views to the surrounding environment. The interior was small but it opened up to the covered porch and allowed the owner, Betty Reese the open aired escape from her busy Manhattan life. Much like Geller I wanted to create a home which felt different from the typical and confined spaces that residents may feel in the homes they are used to.

²⁵⁶ Alastair Gordon, "Andrew Geller: Architect of Happiness, 1924-2011," Alastair Gordon, accessed February 8, 2017, <https://alastairgordonwalltowall.com/2011/12/26/andrew-geller-architect-of-happiness-1924-2011/>

In the Summertime, Living Becomes Even Easier at New Long Island Beach Cottage

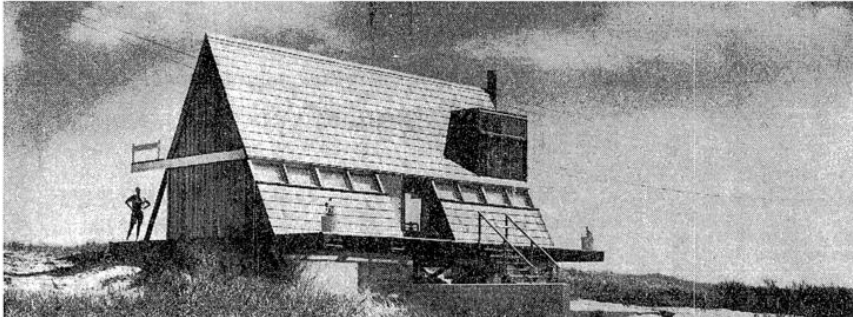


Figure 12.7 Reese House, New York Times Article

Source: New York Times, May 5, 1957

Unlike many “A” frame homes, Geller incorporated a contrasting second level which extended past the roof to form a deck and covered lanai area. There was no heating or cooling, and as a summer house its natural ventilation and openness to the outside was sufficient for thermal comfort. Local timbers clad the exterior of the home which seemed to naturally rise out of the sandy dunes.

In another older example, architect and furniture designer Jens Risom designed a pre-fabricated home in 1967 on Block island. Risom approached the issue of the remote island location with pre-fabricated pieces. At the time pre-fabricated homes still had the stigma of post War sameness and cheapness. Risom however believed that it was the most economical and



Figure 12.8: Risom House, Block Island

Source: LIFE Magazine, 1967

efficient solution to its remote locale. The designer used parts from a pre-fabricated A frame roof and mixed local reclaimed, weather wood to create a home which could be quickly assembled in the sometimes harsh and unpredictable climate for only \$20,000 dollars, at the time.

As mentioned in the beginning of this project, Jean Prouvé and the prefabricated La Maison Tropicale was a major inspiration and precedent for this project. The self-made French architect began his career as a blacksmith and metal artisan, but eventually opened up an atelier as an architect and supplier of metal products. After World War 2 there was a push for more mass produced and affordable building components and homes. Prouvé strongly believed in pre-fabrication and steel and had many commissions to design and provide quickly built structures. Prouvé was commissioned in 1949 to build 14, metal pre-fabricated homes in France but it was his work in Africa which was most significant to this project. Also beginning in 1949, Prouvé was commissioned to design, manufacture and send three pre-made homes to the Congo. These homes were to be affordable, quickly built and suitable for the tropical African climate.



Figure 12.9: Jim Linwood, *La Maison Tropicale*, 2008 is licensed under [CC BY 2.0](https://creativecommons.org/licenses/by/2.0/)

Source: https://commons.wikimedia.org/wiki/File:Prouv%C3%A9_La_Maison_Tropicale.jpg

Prouvé did many things right in the only three pre-fab buildings which were ever constructed. They were relatively easy to ship, fitting into the cargo hold of an airplane and able to be shipped from Europe to central Africa. They were quick to assemble as seen in various recent assemblies for public viewing in New York, 2007, at the Centre Pompidou in Paris and the Tate Modern in London, 2008. As I mentioned before this rediscovery of these industrial Modern homes has sparked a lot of interest in the architectural community. The homes contained some significant design details, besides their pre-fab nature which partially informed this project.

To begin, the foundations were adjustable piers which could be adapted to many different site conditions. Regardless of how the natural grade was the home could be built and would remain off the ground to avoid flooding. They were very open, with minimal structure centralized to support the insulated and “breathable” roof panels. Minimal structure existed at the perimeter of the homes, just thin metal strips to support the adjustable, louver sun and rain shades. This created shaded lanai’s which placed a barrier between the sun and rain from the interior wall and door panels. Although the material was steel, which transfers heat relatively quickly to the interior space, air channels between the top, exposed portion and the interior ceiling helped to flush hot air before it could infiltrate interior space. The metal panel doors with their hole openings cut out were operable and could be slid to help control ventilation and light.

There are countless other examples of natural materials, places, homes, images of Native Hawaiian hales and other pieces of architecture that I could claim as inspiration or precedent, but these above examples are those I felt had significant influences on the finished design.

From a site design and new type of community based precedent, ReGen Villages was a major precedent for this project. This ongoing project based in Almere, Holland features a 25 pilot home community designed by Danish architecture firm EFFEKT



Figure 12.10 ReGen Villages, Perspective

with many advanced technologies in regenerative resources and renewable energy production. Per ReGen villages, there are five principles behind the villages. “Energy positive homes, door-step high-yield organic food production, mixed renewable energy and storage, water and waste recycling and empowerment of local communities.”²⁵⁷

Source: ReGen Villages

²⁵⁷ ReGen Villages (website), accessed February 10, 2017 <http://www.regenvillages.com/#>

The homes are powered by solar panels and ventilated, heated and cooled by passive systems to reduce overall energy use by each home. Each home has a connected greenhouse so they can grow their own produce for consumption or sale and contributes to the passive system of the homes. The village contains electric car-charging stations, vertical aquaponics spaces, shared water storage and waste water reuse systems. There are places for community based events, dining, playgrounds and learning centers and even places for livestock.



Figure 12.11 ReGen Site Plan

Source: ReGen Villages

While none of these systems or interventions are revolutionary in and of themselves, the combination and implementation of these things together in one community is a major influence on the outcome of my own site design.

CONCLUSIONS

As much as I would like it to be, this dissertation is not the final solution to all of the problems that face residential architecture on the Hawaiian islands. I think architects generally have larger than average egos, and most think themselves as something special, but one would be foolish to think that only their ideas were worthy of implementation. Just as the most successful cultures on this planet were built on the ideas of free people from all backgrounds and orientations so too is the evolution of architectural progress. I do believe, however that the words, images and drawings in this project take us a little bit closer to a style of design and building which will do much more to serve the inhabitants of Hawai'i.

I also do not believe that I or those who think like me must convince the entire architecture and building industry in Hawai'i to change their ways. However, if this dissertation even influences a few that the way we currently build our residential architecture in the state is a product of an imported and invasive design method, than I believe that progress has been made.

This project is separated into two parts, the first focuses on framing the problem and researching potential options and solutions and the second is an applied, researched design implementing these solutions in a documented and partially built architecture. If I was to sum this project up in the briefest sense, I would explain it like so.

Since non-Native Hawaiian residential architecture began, architects and builders have failed in understanding and implementing many important variables in the design process. First, there has been a blatant disregard amongst most of the field toward and vernacular or regional design. This has left us with an uninspired and culturally insignificant style. Those involved in the process have chosen to rely on imported building materials which are more expensive and less efficient than potential local sources. They have implemented designs which may have worked in their homeland but have failed the local inhabitants in many ways. One of these failures is designing to combat the climate rather than creating a flowing and symbiotic natural system. Another is to use materials which are inherently toxic or have much less climatic potential than other options. Local sources of building materials exist, although at this point they are more difficult or often more expensive to use because of the

industries allegiance to the typical materials and building systems. Finally, the architecture does not work well with the environment and the site that it is located. Enforcing the suburban, cul de sac neighborhood typology in Hawai'i is culturally irrelevant and climatically ignorant. Living on an island chain in the middle of the Pacific ocean should create a mindset promoting sustainable, renewable and regenerative homes, systems and environments for long term prosperity. The culmination of all of these failures has left us with a residential architecture which can make its inhabitants mentally and physically sick. I believe this project identifies, suggests and begins to implement solutions to combat the problems.

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