AFFORDABLE, SUSTAINABLE, ESSENTIAL DWELLINGS: A HYBRID SINGLE-FAMILY HOME SOLUTION TO HAWAI'I'S HOUSING CRISIS

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David Rockwood, Ashok Das, Kevin Miyamura, and Geoffrey Lewis challenged me throughout my project by always asking deep yet practical questions and by demanding rational answers and well-communicated design. They continue to ask “Did you consider…”

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Abstract

Dwelling costs (design, materials, construction) often prohibit residents from considering custom single-family homes. Existing homes and production homes are often not optimized for individual family lifestyles, climate, or environment – they are often one-size-fits-all, cookie-cutter homes rather than simply a suitable dwelling (the Urban Dictionary defines “cookie-cutter” as “marked by sameness and a lack of originality; mass-produced. Often used to describe suburban housing developments where all the houses are based on the same blueprints and are differentiated only by their color.”[1])

Sustainable building emerged to combat diminishing resources and to better promote stewardship of the environment. Often, green building materials and techniques are more expensive.

Essentialism applied to single-family residential architecture dictates right-sized, functional homes satisfying needs (rather than wants) and facilitating living (lifestyle).

I will identify methods to improve affordability, sustainability, and suitability of single-family homes. Consider an analogy of human wellbeing. Successful dieting/fitness depend on eating the right quantities of healthy food and exercising; more importantly, successfully achieving holistic health depends on modifying behavior and establishing healthy habits. How do we build at reduced cost and with less environmental impact by *right-sizing* dwellings and using

[1] "Cookie-cutter." Urban Dictionary. Accessed April 03, 2019. https://www.urbandictionary.com/define.php?term=cookie-cutter.

lightweight and/or less material? I will utilize analytical research, case study research, and applied research with qualitative and quantitative analysis to address single-family dwellings in Hawai'i. The outcomes will include: 1) a single-family dwelling system incorporating tensile fabric in the spirit of affordability, sustainability, and essentialism and, 2) potential paths to address obstacles to lean structure construction and acceptance/adoption. This research is relevant and critical as we approach the sustainable yield point for affordable housing and natural resources in Hawai'i, and it could cultivate a collective cultural mindset whereby affordable, sustainable, essential living becomes the status quo, a norm, a healthy habit.

Figure 1a Hyperbole: from commoditized production home to custom Microhouses

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Introduction

The single-family home in Hawai'i, specifically on the island of O'ahu, is unaffordable. Living on a remote island dictates efficient management of resources. Production homes and existing homes, which are often older-generation production homes, do not meet the needs of residents. There is a housing crisis on O'ahu.

I considered personal influences and experiences to develop potential solutions to this housing crisis. I live in a lightweight home. I have traveled a great deal, and it is always interesting to see housing in foreign countries, especially developing countries. Generally, they seem less regulated, less permanent, less luxuriant, more functional, and more creative with respect to unconventional materials and construction. I enjoy indoor/outdoor living, and I consider my yard my favorite room "in my house." I have been profoundly influenced by the native Hawaiian emphasis on stewardship of the land, the concepts of aloha ʻāina, mālama ʻāina, and kuleana, whereby the land is revered as the source of nourishment and our eldest ancestor to which we owe a responsibility. Finally, I have been intrigued by temporary shelters and their potential application to more permanent dwellings. Think of tents, portaledges, expeditionary military shelters, and disaster relief shelters. This also includes the structures that provide shelter during temporary experiences, such as stadium roofs and airport terminals. Users linger but do not remain permanently, yet they still require shelter from the elements. When I consider these influences and

experiences, I wonder if we can save materials to reduce cost, reduce impact, and enhance our living.

This thought process led me to these research questions:

- How do we build at reduced cost and with less environmental impact by right-sizing dwellings and using lightweight and/or less material?
- What are the bare essentials for a dwelling in the tropics?
- How do we retain appropriate structural integrity and durability and meet building and energy conservation codes?
- What are the obstacles to lean structures?

The premise and questions can be displayed visually. The analogy of human

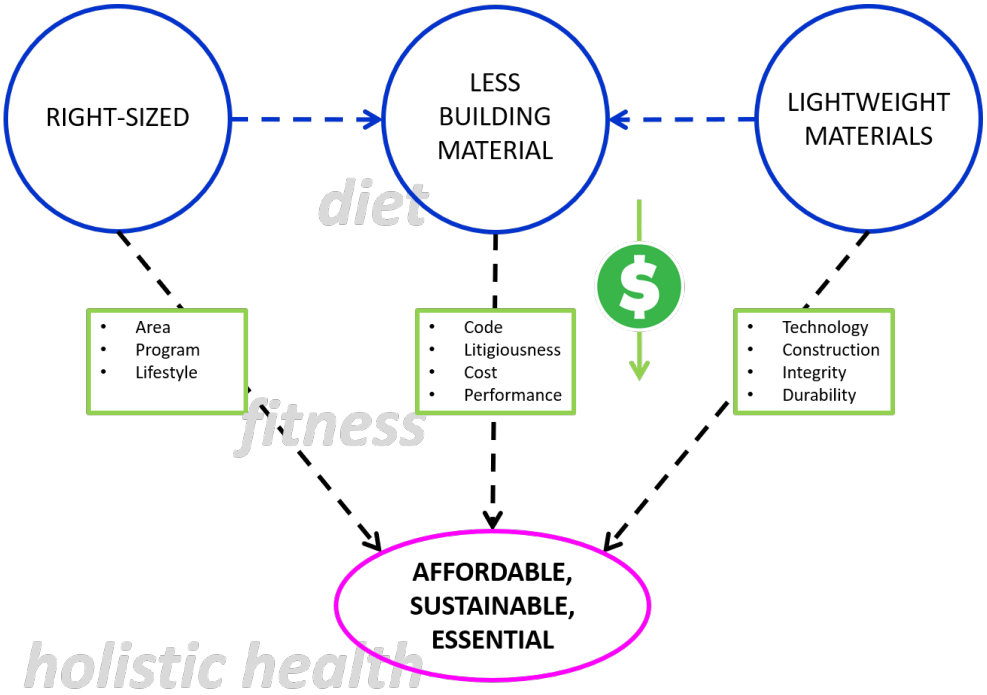

Figure 1b Affordable, Sustainable, Essential Dwellings: a diet and fitness plan

wellbeing introduced in the abstract is superimposed on the illustration: the diet components of the fitness plan in the circles, the fitness considerations in the rectangles, and the resultant holistic healthier in the ellipse.

I posit that designing, constructing, and offering smaller, lighter weight single-family dwellings optimized for lifestyle, comfort, climate response, and energy efficiency will improve affordability, sustainability, and suitability.

Right-sizing dwellings and using lightweight and/or less material will reduce cost and environmental impact. To right-size dwellings, designers must focus on the bare essential qualities, the attributes/features required to support a 21st century lifestyle in the tropics. These qualities and features reflect needs and low cost/high value wants; they reflect how the occupants use a dwelling – lifestyle. In these terms, the existing stock falls short of meeting resident needs. Resident satisfaction is a broader study, but for the purposes of this discussion, I am speaking mainly in terms of program and lifestyle. Considering program, many production homes have formal living and dining spaces, yet these spaces are rarely used for these purposes, often falling unused or becoming repurposed. Considering lifestyle, many production homes are delivered with tight envelopes and air conditioning despite residents' affinity towards indoor/outdoor living. It is common to see homes with garages converted to living/relaxing spaces, cars parked in yards, and outdoor recreation equipment (surfboards, stand up paddle boards, kayaks, canoes, etc.) stacked under eaves.

Designers and builders have constructed homes using lightweight materials/construction techniques in Hawai'i. While their products provide the

appropriate structural integrity and durability, many of the materials and techniques are no longer viable. For example, production homes built in the 1950s have walls constructed of one inch thick, tongue and groove redwood planks, single wall construction. Aspects of this construction technique fall short of current building and energy conservation code standards, and it has fallen out of favor with preference given to construction techniques popular on the mainland.

Exploring innovative, lightweight materials/construction techniques, specifically how to engineer tensile fabric construction to meet building and energy conservation codes, will advise lower cost single-family dwelling design. Reducing overall wall weight as compared to wood or metal stud framed double-walls will also reduce environmental impact; using less material is inherently more sustainable.

Further, identifying and addressing barriers to lean structures – including building and energy conservation codes and public perception – will pave the way for affordable, sustainable, essential dwellings to become the residential standard.

Literature Review

I reviewed existing material in four general categories: the housing crisis in Hawai'i, essential attributes of a dwelling, design responses featuring essentialism and lightweight materials/construction techniques, and barriers to lightweight construction.

Housing crisis in Hawai'i. I reviewed federal/state government and National Association of Realtors data related to Hawai'i housing affordability and availability. This data highlights aspects of the single-family home market and demographics, specifically earnings and cost of living, on Oahu. I also reviewed dissertations related to homeownership, the "American Dream," and the commoditization of housing. This material revealed misalignment between ideals/perceptions and reality and between the vision of developers, designers, and homeowners. The data and discourse indicate that single-family homes in Hawai'i are unaffordable and existing and production homes do not meet the needs of residents. I considered single-wall construction, both as a characteristic of the existing housing inventory of homes and as a potential solution/inspiration for more affordable dwellings.

Essential elements of a dwelling. Arguably, conspicuous consumerism has contributed to the housing crisis. I considered housing from a human rights perspective by reviewing United Nations and International Labor Organization housing standards. This material establishes the bare minimum housing requirements specifically for exploited populations in developing nations. I considered prominent opinions from different eras, including le Corbusier, Victor Papanek, and Phyllis Richardson, to identify which housing features are needs and which are wants. Witold Rybczynski's *Home: A Short History of an Idea*[2] provided insight into how housing features and perceptions have changed over

[2] Witold Rybczynski. *Home: A Short History of an Idea*. Great Britain: Simon & Schuster, 2001.

time, while Paul Oliver's *Dwellings: The House across the World*[3] offered more modern views from around the globe.

Design responses featuring essentialism and lightweight materials/construction techniques. Ken Isaacs and Victor Papanek are two mid-century designers who offered lightweight living systems rooted in essentialism. They espoused light-living and nomadism "shunning the consumer-laden values of the American dream."[4] Like Isaacs and Papanek, Frei Otto emerged from the post-World War II with a passion for lightweight construction achieving economy of resources through tension structures. I reviewed their collective writing and work to identify materials and techniques that could be applied to single-family dwellings in Hawai'i. In doing so, I focused on tensile fabric. I reviewed literature about tensile fabric material properties, engineering, design, fabrication, and experiential qualities authored by experts including Frei Otto, Robert Kronenburg, Walter Bird, Romualdo Rivera, and Craig Huntington.

Barriers to lightweight construction. The two primary obstacles are code and public perception. I reviewed building and energy conservation codes to identify specific challenges. I also visited the Honolulu County Department of Planning and Permitting to better understand the code adoption/amendment and permitting processes here on O'ahu. I delved further into public perception by reviewing the same dissertations related to the American Dream to better

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[3] Paul Oliver. *Dwellings: The House across the World*. Austin: University of Texas Press, 1990.

[4] "Enter the Matrix: An Interview with Ken Isaacs." Walker Art Center. Accessed April 03, 2019. https://walkerart.org/magazine/enter-matrix-interview-ken-isaacs.

understand the evolution of middle-class views in the United States and probable reaction to lightweight construction.

I identified common themes and connections in this broad range of material to establish a research foundation and approach for the design phase of my project.

Methodology

I applied several methods to collect, analyze, and synthesize concepts and information.

- Analytical Research. Identify and describe Hawai'i's housing crisis through lenses affordability, availability, suitability
- Case Study Research. Identify and analyze relevant design inspirations and precedents to advise a solution set
- Analytical Research. Consider design, fabrication/construction, human comfort, and climate response while balancing affordability, and sustainability
- Analytical Research. Analyze code/regulation/policy to identify barriers to lightweight materials/construction techniques
- Applied Research. Design, document, and experiment with tensile fabric.
- Qualitative/Quantitative Analysis. Collaborate with local fabrication experts to advise design and material experimentation; incorporate lessons learned and feedback to refine design.

Project Core Elements

I also want to briefly mention what I call “thesis core elements.” These are the tenets of my thesis that are important to me and are not prescribed.

- The degree is a Doctor of Architecture. Therefore, in my mind it is important that I discuss the built environment, think Architecture, Engineering, Construction, different from Landscape Architecture or Urban Planning, which were also part of my design education.
- The DArch degree is different from a PhD, and to reflect the difference, my thesis will be equal parts dissertation and design, rather than purely written work.
- My committee chair is an architect, and I sought multi-disciplinary committee members and advisors representing engineering, industrial design, fabrication/construction, planning, real estate, and single-family home specialties.
- In order to validate materials, construction concepts, and experiential qualities of my design, it is important to me to experiment with fabrication and prototyping.
- Finally, I was motivated by an advisor who suggested that a Master of Architecture knows a typology well; a Doctor of Architecture pioneers a typology!

Project Process

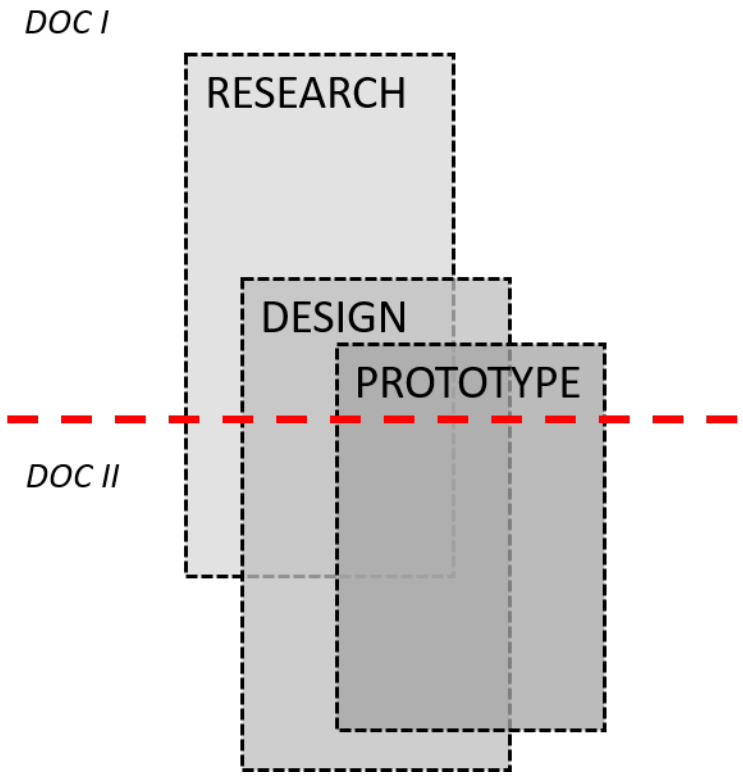

Figure 1c Project Process 1. Research 2. Design 3. Prototype

Part 1 | RESEARCH

1. Problems

In the introduction, I opined that there is a housing crisis in Hawai'i particularly on the most populated island, O'ahu. While this opinion is broadly shared and understood by O'ahu residents, it bears explanation and analysis for those unfamiliar and as a basis for considering potential solutions. To better understand and describe the issue, I viewed it from three lenses: affordability, availability, and suitability.

1.1 Affordability

The single-family home on O'ahu is unaffordable. While there are several metrics and analyses that describe the state of housing affordability, I will provide a working definition and present some simple statistics.

According to the United States Department of Housing and Urban Development (HUD) "affordable" housing refers to spending 30% of income or less for housing including utilities; families paying more are "cost burdened and may have difficulty affording necessities such as food, clothing, transportation and medical care."[5]

I compiled the data presented in Table 1.0 from the State of Hawai'i Department of Business, Economic Development & Tourism Research &

[5] HUD.gov / U.S. Department of Housing and Urban Development (HUD). Accessed April 03, 2019. https://www.hud.gov/program_offices/comm_planning/affordablehousing/.

Economic Analysis as a basis of comparison between conditions in Hawai'i and in the rest of the United States.[6]

METRIC		HAWAI'I	U.S.	RANK
Economic	Per Capita Personal Income: 2017	$52,787	$51,640	17
	Regional Price Parities: 2016 (U.S.=100)	118.4%	100.0%	1
	Median Household Income: 2017	$77,765	$60,336	4
	Median Family Income: 2017	$91,460	$73,891	6
Social/	Percentage of Family Households: 2017	69.9%	65.5%	2
Demographic	Multigenerational Families: 2017	11.1%	5.9%	1
Housing	Home Ownership Rate: 2017	58.5%	63.9%	47
	Monthly Owner Cost > 35% of Household Income: 2017	29.5%	20.7%	2
	Monthly Gross Rent > 35% of Household Income: 2017	46.4%	40.4%	2
	Median Monthly Gross Rent: 2017	$1,573	$1,012	1
	Median Monthly Owner Cost with Mortgage: 2017	$2,337	$1,513	3

Table 1.0 Economic, Social/Demographic, Housing comparison Hawai'i versus United States

Most of these metrics are intuitive or self-explanatory, but I will provide an explanation for Regional Price Parities (RPPs). "RPPs measure the differences in price levels of goods and services across states and metropolitan areas for a given year and are expressed as a percentage of the overall national price level for each year, which is equal to 100."[7] This reflects cost of living. I drew the following basic conclusions from this data:

- Hawai'i has the highest cost of living in the United States
- While incomes in Hawai'i are higher than in most states, a greater percentage of residents are housing cost burdened

[6]"Research & Economic Analysis." Department of Business, Economic Development & Tourism. Accessed April 04, 2019. http://dbedt.hawaii.gov/economic/.

[7] "Hawaii Rankings and Comparisons." Hawaii Rankings and Comparisons. Accessed April 03, 2019. http://dbedt.hawaii.gov/economic/ranks/.

The National Association of Realtors (NAR) analyzes home sales information and uses United States Census Bureau and Federal Housing Finance Board data to develop affordability indexes. I will introduce and discuss the Housing Affordability Index and the Affordability Distribution Score. The NAR Housing Affordability Index (HAI) "measures whether or not a typical family could qualify for a mortgage loan on a typical home."[8] It considers the median home price, median family income, and the prevailing mortgage interest rate. A Housing Affordability Index of 100 reflects that the typical family has exactly enough income to qualify for a mortgage loan on a median-priced home assuming a 20% down payment.[9] The 2016 United States composite HAI was 167.1; the HAI for Honolulu for the same period was 70.1.[10] This indicates that the typical United States family had 67.1% more income than necessary to qualify for a mortgage loan on a median-priced home, while the typical family in Hawai'i fell 29.9% short. The NAR Affordability Distribution Score differs from the HAI in that it considers all income percentiles rather than only the median family income, and it weighs active inventory of available homes on the housing market rather than those already sold.[11] For the one-year time period between October

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[8] "Methodology." www.nar.realtor. Accessed April 03, 2019. https://www.nar.realtor/research-and-statistics/housing-statistics/housing-affordability-index/methodology.

[9] Ibid

[10] Ibid

[11] "REALTORS® Affordability Distribution Curve and Score." www.nar.realtor. Accessed April 03, 2019. https://www.nar.realtor/research-and-statistics/housing-statistics/realtors-affordability-distribution-curve-and-score.

2017 through September 2018, the Affordability Distribution Score for the United States was .84; the score for Hawai'i for the same period was .51.[12] According to NAR, "A score of one or higher generally suggests a market which is affordable while a score smaller than one is an indicator of a relatively less affordable market."[13] The score .84 suggests that housing is generally unaffordable in the United States; housing is most affordable in the Midwest and Alaska, and the least affordable in Hawai'i.[14]

24/7 Wall Street reviewed "The State of the Nation's Housing 2018," a report compiled by the Joint Center for Housing Studies of Harvard University to list the cities where Americans are struggling to afford their homes. Honolulu ranked eighth in the nation. 24/7 Wall Street offered this commentary:

> Home prices have risen far faster than incomes in the Honolulu metro area. San Jose and Los Angeles are the only U.S. metro areas with higher median home sale price-to-income ratios than Honolulu. The typical home in Honolulu sells for 9.2 times the area's median household income, more than double the national sale price-to-income ratio of 4.2…18.8% of Honolulu households earning at least $75,000 spend 30% or more of their income on housing, the largest share of any U.S. metro area.[15]

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[12] Ibid

[13] Ibid

[14] Ibid

[15] Samuel Stebbins, and Evan Comen. "Cities Where Americans Struggle to Afford Their Homes." 247wallst.com. December 18, 2018. Accessed April 03, 2019. https://247wallst.com/special-report/2018/07/10/cities-where-americans-struggle-to-afford-their-homes/.

The Pew Research Center, which analyzes social and demographic trends, defines the middle class as those earning between two-thirds and double the median household income.[16] Based on this definition and the data in Table 1.0, the middle class earned between $39,822 and $120,672 nationally and between $51,325 and $155,530 in Hawai'i in 2017. High rates of home ownership are associated with middle class status. However, given the extreme cost of living and cost burden of homeownership, the middle class in Hawai'i have more difficulty breaking into the housing market.

1.2 Availability

After researching affordability of housing in Hawai'i, I analyzed housing availability; I wanted to understand what is available to potential homeowners. I didn't focus on the number of units required for the growing population, nor did I focus on potential sites for future development. O'ahu contrasts "town and country," where "town" refers to the dense urban environment of Honolulu and "country" refers to everywhere else. While most residents of O'ahu live in Honolulu, there will always be smaller, less dense "towns" on the island. These towns are similar to mainland suburbs consisting primarily of residential areas populated by single-family homes. Intuitively, the buildable area on the island is finite, and there are very real constraints including steep terrain and flood-prone, low-lying areas. Instead, I focused on the inventory of available homes. I

[16] "The American Middle Class Is Losing Ground." Pew Research Center's Social & Demographic Trends Project. December 10, 2015. Accessed April 03, 2019. http://www.pewsocialtrends.org/2015/12/09/the-american-middle-class-is-losing-ground/.

classified these as either existing, production, or custom homes. These are loose categories; each has unique characteristics which I will explore to evaluate suitability of the housing stock to potential homeowners.

Existing homes are the used cars of the housing market. Many of these were built during population/construction booms which occurred in the 1950s, 1960s, and 1970s spurred by Hawai'i statehood and national growth. They were the production homes of their time, but they retained some of the vernacular flavor of the plantation style. They have merits and drawbacks, and most have been modified from their original state to satisfy current owners' needs and desires.

Many of these early tract homes were built of single wall construction. I will describe this building technique, because, to some degree, it is unique to a time and place, being post-World War II Hawai'i. For a variety of reasons, the dominant house building technique was single wall construction, which featured load-bearing external walls without studs built of flat tongue and groove (T&G) boards arranged vertically. These walls were topped by a wood top plate, which served as a connection point for roof rafters. To form the connection between the vertical siding boards and the foundation, they were nailed to a wooden sill, which was connected to a rim joist for post and pier foundations or incorporated into the slab for slab on grade foundations. The roofs were typically light, non-engineered framing with shingles/battens or roof decking material directly

attached to the rafters.[17] Figure 1.0 contrasts single wall construction and double wall construction, which is the standard for today's production homes.

Figure 1.0 Single Wall Construction versus Double Wall Construction

Most if not all the materials were shipped to the Hawaiian Islands; shipping weight and volume equated to cost. Therefore, builders aimed to use the least amount of materials.

While the motivation for designing and constructing these lightweight houses was not affordability and sustainability, there are merits to the concept; these include simplicity in layout/construction and climate response. The houses did not require insulation because of relatively stable, moderate temperatures. Houses were more commonly oriented to capture trade wind cooling effects and

[17] "Guide to Hurricane Strengthening for Hawaii Single-Family ..." Accessed April 3, 2019. https://cca.hawaii.gov/ins/files/2016/01/Guide-to-Hurricane-Strengthening-of-Hawaii-Single-Family-Residences-Jan-2016.pdf.

deep roof overhangs prevented direct solar heat gain. Air conditioning was uncommon; it was a relatively new and expensive innovation. Post and pier foundations lifted the houses to discourage pests (mainly termites) and to capture trade winds. Tongue and groove redwood was available from nearby ports on the west coast of the United States. Redwood naturally deters termites.

While these houses were simply constructed and offered thermal comfort and pest resistance, they were not engineered to withstand extreme weather conditions. Today it is common and required by code to tie the structural components to each other and to the foundation. Hurricane ties reinforce the connections between roof and walls, and the walls are anchored to the foundation. Elevated wooden decks/foundations are anchored to the ground.

The single wall houses were porous; they breathed providing natural ventilation and thermal comfort. However, they also invited moisture, dust, noise, and pests (to include unwelcome human infiltration). Although available, the suitability of these existing homes is debatable. Additional aspects of their suitability will come to light as I introduce/discuss available production homes.

Production homes are the commoditized, mass produced homes of recent subdivisions. If existing homes are the used cars, these are new or lease trade-in cars of the housing market. "Developers use the same blueprints for homes in Virginia as they do in Oregon."[18] These homes reflect current trends in both development and in consumer perception.

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[18] James Powell, and Wittenberg, Gordon. Residential Frameworks for the Transient: A Critical Analysis of Object Event Relationships in Transient Residential Sites (1995): ProQuest Dissertations and Theses.

I reviewed several papers describing the American Dream and the state of housing in America to better understand the ideal, perceptions, and emotional attachments to the house. I do not intend to rehash these discussions, but I did develop a better understanding of the evolution of the physical house and the related consumer attitudes and perceptions. A short summary will help describe production homes (and existing homes) and set the stage for my remarks about solutions to the housing crisis. "The government backed suburban developments grew in popularity and have become the staple for the American Dream. Three distinct evolutions in the suburban home have taken place beginning with the 1950's Levittown home. Since then, the 1980's saw an enlargement of the Levittown idea with greater emphasis on privacy and the automobile and in the 2000's, the McMansion developed into estates for the material and consumer class."[19]

The Levittown Cape Cod model had two bedrooms, one bathroom, and a total 850 square feet. It did have a staircase to an unfinished second story beneath the gable roof which offered an expansion opportunity. While the Levitt's perfected the mass-production of houses, their success heavily relied on government backed loans, which offered the opportunity to purchase a home with little to no money down.[20]

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[19] Justin Obringer, Ambrose, Michael, Kelly, Brian, and Quiros, Luis. Re: America. Architecture, Propaganda, and the Dream (2012): ProQuest Dissertations and Theses.

[20] Ibid

In the 1980s, single family homes swelled to average four bedrooms, two and a half bathrooms and a total 2400 square feet. The greater area reflected added formal living and dining rooms (in addition to a family room), and a designated master bedroom with greater area and amenities. Even garages became bloated to accommodate two cars and storage for increasing collections of consumer goods.[21]

Finally, in the 2000s, obese McMansions emerged; six bedrooms, four and a half bathrooms, and a total 4800 square feet became standard. These plans showcased excessive programming including computer rooms, sun rooms, theaters, offices, and breakfast nooks (and other creatively named spaces). The master bedroom became a master suite, and garages again bulged to support three cars and even more stuff.[22]

Arguably, this trend suspended with the Great Recession, but the essence of the McMansion was seared into the psyche of generations of home buyers.

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[21] Ibid

[22] Ibid

US CENSUS BUREAU 2017 AMERICAN HOUSING SURVEY		
DETACHED, SINGLE STRUCTURE (SINGLE-FAMILY HOMES)		
FEATURE	2017	2011
Median Square Feet	1800	1800
Median Square Feet per Person	800	800
≤ .5 Persons per Room	74.5%	73.6%
≥ 1.51 Persons per Room	0.1%	0.1%
3+ Bedrooms	84.4%	83.7%
2+ Bathrooms	67.6%	62.6%
Separate Dining Rooms	58.8%	58.1%
2+ Living Rooms	46.0%	42.3%
Garages or Car Ports	83.0%	82.4%
Working Fireplace	49.3%	46.5%
Air Conditioning*	91.5%	78.4%
*central and/or window unit		
National data; 76,830 homes 2017, 73,761 homes 2011		

Table 1.1 Current Housing Trends

Table 1.1 presents data derived from the United States Census Bureau 2017 American Housing Survey representing the current housing trends, arguably what the average middle-class family is aspiring to own. This is national data reflecting only 76, 830 houses in 2017, but the survey is conducted regularly – there is value in analyzing trends. Comparison with 2011 data shows relatively little change.[23]

Considering this data, I hypothesized that residents of Hawai'i would disregard certain programs that have traditionally been included in mainland subdivision homes. However, I came to understand that what people want is based on what they know or see. People think of the houses they grew up in or

[23] Census Bureau. "American Housing Survey (AHS), AHS Table Creator." Census.gov. Accessed April 03, 2019. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html.

the houses they see in the media. These influences serve as the basis for an ideal home. I consider formal living and dining rooms vestigial, their use supplanted by more flexible, open spaces accommodating dining and family relaxation (often with television). However, many home buyers seek these formal spaces, and there is no shortage of furniture advertised to fill them. I have also seen residents transform these spaces into playrooms or home offices, which are often left out of production home program. Another relatively new influence is the reality-based, do-it-yourself, home improvement media, which encourages residents to create or to improve existing and production home spaces to better meet individual tastes, desires, and needs. To some degree this can be considered 'customizing' a cookie cutter home – an after-the-fact expression that would likely be included in the process had the dwelling been designed for the residents.

Custom homes are the homes designed for a specific client. Extending the car analogy, these would be high-end luxury cars or conversion vehicles tailored to the customer. Only "2% of housing in the US is produced through a client/architect relationship to build a custom home."[24] Intuitively, a custom home represents exactly what a homebuyer desires within the constraints of his/her scenario. Custom homes tend to be out-of-reach for the middle-class homeowner in Hawai'i due to perception, expense, and/or perception of expense.

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[24] Elizabeth Engler, and Grenader, Nonya. Homeowning: An Exploration of the Possession and Personalization of the American Dream (2005): ProQuest Dissertations and Theses.

Many have the impression that architects only design for wealthy clients. Consider this simplified derivation of design expense; if an architect's fee is 10% of the total project cost, and the median single-family home cost on O'ahu for 2017 was $755,000[25], a client would have a design expense of $75,500. Certainly, the cost-burdened middle-class homeowner isn't going to consider this expense a critical requirement when production homes, which represent the *ideal* home and meet most needs, are available.

As a conclusion to this discussion of available housing on O'ahu and as an introduction to a discussion on suitability, I offer Harry Seckel's comments:

> The average Islander sleeps indoors, has most of his meals indoors, and spends most of his evenings indoors in much the same manner as people elsewhere. Moreover, his indoors is shut off from the outdoors much as if he lived in a different locale. Certainly, his home life shows less regional character than his environment would lead one to expect. He is aligned to a civilization that was not developed in his very special setting. His social and cultural heritage stems from colder climes and grayer skies. He has inherited a set of living habits that were not designed for Hawai'i. Not only has he inherited mainland living habits, but he has inherited a mainland type house designed for mainland living. It is true that the seasonally used porch of the mainland is found in many island homes as the lanai of all year use. But, by and large, it is the mainland concept of a house that still predominates. The Islander lives in proximity to sea and mountains of surpassing beauty. He lives near trees, flowers, and shrubbery that are in evidence throughout the year. He lives in an incomparable climate. But he has not yet found the means for fully enjoying all this. To live in full and constant intimacy with his surroundings would require a very special dwelling designed for a manner of living that has not yet evolved. This places him in an awkward position. To live differently he would need a special house, and the special house will evolve only if he lives differently or wants to live differently. How can one expect a situation like this to resolve itself?[26]

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[25] Oahu Historical Data. Accessed April 03, 2019. http://www.hicentral.com/oahu-historical-data.php.

[26] Harry W. Seckel. *Hawaiian Residential Architecture*. Honolulu: Bishop Museum Press, 1954.

1.3 Suitability

My commentary about suitability is mainly based on my observations about dwelling in Hawai'i. The commoditized production home of the mainland subdivisions applied to Hawai'i is missing key elements of program that reflect residents' lifestyle. Among these are indoor/outdoor spaces, gathering spaces, recreational equipment storage, and parking. I frequently see residents hosting gatherings in their garages and carports. The mild, tropical climate affords residents the option of indoor/outdoor living. The warmest days of the year are tolerable given shade; add a trade wind breeze, and they would be considered comfortable. For existing homes without central air conditioning, these 'outdoor living spaces' become the most comfortable 'rooms' of the house. I have observed more families with portable canopies and folding tables and chairs than in any other place I have visited – the canopies create the spaces activated with portable furniture and populated by gathering families and friends. This program could be accommodated through dwelling design. Arguably, garages and carports were designed for automobile parking and storage. I have mentioned that the cars are often displaced by family gatherings; they are also displaced by recreational equipment storage. In our consumer society, it is not uncommon to see spaces designed for automobiles taken over by household goods and possessions, which have overflowed interior storage space. In Hawai'i, more so than in other locations, this includes recreational equipment, such as surfboards, kayaks, outrigger canoes, stand up paddle boards, fishing equipment, etc. The

official sports of Hawai'i are surfing and outrigger canoe paddling – watersports with bulky equipment. I frequently see surfboards, SUPs, and canoes in garages and carports – even tucked alongside homes under the eaves – often perched in user-designed/fabricated storage racks. Again, this program could be incorporated into the dwelling. Should indoor/outdoor spaces, family gathering spaces, and recreational equipment storage be integrated into dwelling design, the cars could have their carports back.

Another aspect of the mainland-style subdivision is disregard for passive cooling, ventilation, and daylighting strategies. If the primary strategy for cooling a home is mechanical air conditioning, then it is less important to orient the home to reduce solar heat gain and capture predominant winds. Unfortunately, many residents have grown accustomed to air conditioning and assume that it is the only strategy to achieve thermal comfort. This misperception extends beyond personal preference and drives the products of the commoditized housing industry. Production homes are automatically oriented towards the streets to which they are attached; driveways and walkways are automatically perpendicular to the street and the façade. Houses are arranged in blocks without consideration for how one house impacts the sun or wind effects for the adjacent houses. The resulting houses and neighborhoods expend more energy to achieve thermal comfort and are disconnected from the natural environment, which plays such a strong role in the lifestyle of Hawai'i's residents.

Central to Native Hawaiian culture are the concepts of aloha ʻāina, mālama ʻāina, and kuleana, which suggest that while the people are nourished

by the land, they have a responsibility to steward the land. The people of Hawai'i today come from many cultures, but these concepts are alive and visible. They are also frequently reminded that as residents of a remote island chain – often described as the most remote – resources are scarce and dependence on imported goods is volatile. Therefore, sustainability is more than a passing fad, but rather a tenable strategy to promote resilience and stewardship of the land. Residents have embraced ecological design measures such as harnessing solar electric and solar thermal energy, rain catchment, and increasing porosity for stormwater infiltration. These measures are incorporated in production homes to varying degrees, but arguably, they would be more effective if they were included in a dwelling/community design process rather than as optional add-ons.

The environment of Hawai'i is unforgiving towards many building materials that are standard in mainland subdivisions, especially those in more arid climates. Salt air corrodes metals. Moist air degrades drywall. Termites attack wood products. Even concrete can be challenged by the environment; surfaces crack/crumble and reinforcing bars swell. Moisture barriers can trap moisture inside a home encouraging mold and mildew. If developers overlook these challenges in favor of expediency and cost savings, their chosen materials and construction techniques may yield less-durable homes. I am not suggesting that all materials must withstand the environment; rather, designers should consider weathering and weigh options with respect to durability and maintenance, lifecycle and cost. A product designed to last for three years applied with consideration of maintenance/replacement may be preferable to one that will last

for 10 years but costs 10 times more. Similarly, why pay for a product that will last for 100 years if expecting to use the structure for only 10 years? Designing dwellings specifically for Hawai'i's environment and lifestyle affords the resident the ability to select appropriate materials and construction techniques.

2. Solutions

I began this inquiry from a sustainability angle, but I after living in Hawai'i for some time, I realized that the cost of living drives lifestyle to the point that most people only consider sustainability after they have considered affordability. The island world view dictates that islanders are aware of dependence on off-island resources. Arguably this dependence arose from a western world view and the associated, rampant consumerism; Native Hawaiians were self-sufficient pre-contact. Nonetheless, affordability became my primary overarching principle.

Cost as a starting point. By starting with the median household income, applying the HUD definition of affordability, and using a simple mortgage calculator, I can estimate a target affordable home cost for a middle-class homebuyer in Hawai'i. In theory, I could apply some assumptions and further distill this target cost to only reflect the cost of home design, materials, and construction (extracting land, utilities, insurance, etc.). Using this rationale, I derived a price range from $210,000 to $630,000. According to the Honolulu Board of Realtors, the median single-family home cost on O'ahu for 2017 was $755,000 and has exceeded $800,000 in 2018.[27] I quickly realized that land

[27] Oahu Historical Data. Accessed April 03, 2019. http://www.hicentral.com/oahu-historical-data.php.

value significantly drives home cost in Hawai'i! As an alternative approach, I excluded land cost from the calculations, and I set a cost goal of $55,000 for materials and construction alone. This is an extreme goal, which may be unachievable! I based this target solely on quick calculations and little awareness of material options, home features, or labor costs. I used a simple automobile loan calculation; this cost reflects a 3.11% interest rate for a 60-month term and results in a monthly payment of about $1000. Using my initial cost development rationale, this corresponds to an annual household income of $50,000, which is the low end of the median household income for Hawai'i's middle class. Alternative home buying models which would alleviate the burden of land expense and further consider short-term loans for design, materials, and construction only are suggested as vignettes in section 5.2.

Considering this cost as a starting point, a viable response to Hawai'i's housing crisis incorporates three solution tenets: right-sized, lightweight, designed. I am not suggesting a tiny house movement. Rather, for the sake of affordability and sustainability, I suggest that residents accept smaller dwellings without sacrificing function and comfort, which can be achieved through design. Smaller dwellings require less material. Lightweight materials/construction techniques require less material. Custom-designed dwellings can be optimized for lifestyle through design decisions catering to the specific user.

2.1 Right-Sized

In order to set a baseline of essential elements of a dwelling, I reviewed global, human rights-based initiatives. These initiatives are multi-faceted, and

much of their content/intent is beyond the scope of this discussion. However, they do serve as a starting point to develop assumptions and draw conclusions about what dwellings *must* be. Most people do not consider housing availability/adequacy from a human rights perspective; I consider this a reasonable approach because the concept of housing has become so detached from its connection to basic human needs, specifically shelter. The United Nations and International Labor Organization serve to protect the under-represented population typically in developing nations who could be taken advantage of by unscrupulous entities acting from a position of wealth and/or power. While this doesn't describe the situation in Hawai'i, I learned lessons from reviewing housing standards based on basic human rights.

The United Nations Human Rights Fact Sheet No. 21 *The Right to Adequate Housing* states "Adequate housing must provide more than four walls and a roof."[28] As an aside, this comment is interesting because it suggests that four walls and a roof are the standard/only building form for an adequate dwelling – I don't think it is to be taken literally. The remaining text details the conditions which need to be met for housing to be deemed adequate. Among these are security of tenure, availability of services, materials, facilities, and infrastructure, affordability, habitability, accessibility, location, and cultural adequacy.[29] While most of these are outside the scope of this discussion, affordability and

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[28] *The Right to Adequate Housing*. Geneva: Office of the United Nations High Commissioner for Human Rights, 2009.

[29] Ibid

habitability factor strongly on the list and are relevant. The further description of affordability offers: “housing is not adequate if its cost threatens or compromises the occupants’ enjoyment of other human rights.”[30] This directly reflects the previous discussion about cost-burdened residents and takes the concept further than the HUD definition to suggest that affordability is a right. In terms of habitability, “housing is not adequate if it does not guarantee physical safety or provide adequate space, as well as protection against the cold, damp, heat, rain, wind, other threats to health and structural hazards.”[31] The degree of adequacy is subjective; I recognize that what is considered adequate by society in Honolulu County is different than what is considered adequate in Ho Chi Minh City, Vietnam.

The International Labor Organization Housing Standards state that “housing should ensure ‘structural safety and reasonable levels of decency, hygiene and comfort’.”[32] Some of the specific requirements include: “adequate natural light during daytime and adequate artificial light, adequate ventilation to ensure sufficient movement of air in all conditions of weather and climate, adequate supply of safe potable water, adequate sanitary facilities, adequate drainage, appropriately situated and furnished laundry facilities, and reasonable

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[30] Ibid

[31] Ibid

[32] "Workers' Housing." Workers' Housing. October 29, 2009. Accessed April 03, 2019. https://www.ilo.org/empent/Publications/WCMS_116344/lang--en/index.htm.

access to telephone or other modes of communications."[33] They continue by describing physical attributes e.g., the minimum dimensions of a sleeping space. The most translatable portion of the standard dictates that "In worker's sleeping rooms the floor area should not be less than 7.5 square meters (80.7 square feet) in rooms accommodating two persons…If a room accommodates more than four persons, the floor area should be at least 3.6 square meters (38.8 square feet) per person."[34] This links an activity or program to a floor area measurement.

The United Nations Human Settlements Programme identifies eight essential elements of a conventional dwelling: "(i) a room or suite of rooms; (ii) located in a permanent building; (iii) with separate access to a street or to a common space; (iv) intended to be occupied by one household, equipped with the following facilities within the dwelling: (v) kitchen or other space for cooking, (vi) fixed bath or shower, (vii) toilet and (viii) piped water."[35] The report also defines "basic dwellings" and "temporary housing units." Basic dwellings resemble conventional dwellings in permanency yet differ in appointed essential facilities.[36] Temporary units lack conventional dwelling durability and may only have some of the essential facilities, but they may be considered "somewhat

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[33] Ibid

[34] Ibid

[35] United Nations Human Settlements Programme. *The Challenge of Slums Global Report on Human Settlements 2003*. London: Taylor and Francis, 2012.

[36] Ibid

suitable from the point of view of climate and tradition."[37] Interestingly, the Programme loosely quantifies the limited time period for which a temporary housing unit may be suitable as "from a few months to ten years."[38] This report addresses structural quality and durability of dwellings by declaring "A house is considered 'durable' if it is built on a nonhazardous location and has a structure permanent and adequate enough to protect its inhabitants from the extremes of climatic conditions such as rain, heat, cold, and humidity."[39] Further, structural adequacy is related to both material and material state of repair.[40] The final relevant comments in the report relate to living area. A dwelling offers sufficient living area if there are three or less people per room.[41] While this falls short of relating program to floor area, it is a metric.

Most of the conclusions from this analysis of the right to adequate housing are obvious and these features are commonplace in Hawai'i given the standard of living in developed nations. However, I think it is worth distilling these requirements to advise program/floor area and to change perspective from the bloated production homes in American subdivisions to the bare-bones essential dwellings considered adequate by human rights organizations.

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[37] Ibid

[38] Ibid

[39] Ibid

[40] Ibid

[41] Ibid

In my discussion of available housing, I detailed the growth of the American production home from the 1950s to the 2000s; recall that the area grew from 850 to 4800 square feet! Also recall that the average area of a single-family home in the United States in 2017 was 1800 square feet. This suggests the total area of a production home but does not divide the area into individual spaces. A 2013 National Association of Home Builders study by Paul Emrath provides a percentage-based breakdown of spaces in new homes, which is reflected in Table 2.0.[42]

[42] "Spaces in New Homes." NAHB. Accessed April 04, 2019. https://www.nahb.org/research/housing-economics/special-studies/2013-spaces-in-new-homes.aspx.

AVERAGE PERCENT DISTRIBUTION OF FINISHED SPACE*		
ROOM	PERCENTAGE	AREA (SQFT)
Kitchen	11.6%	300
Family Room	11.5%	296
Living Room	8.6%	223
Dining Room	7.4%	192
Master Bedroom	12.0%	309
Other Bedrooms (2)	16.8%	432
Master Bathroom	6.0%	154
Other Bathrooms	6.3%	163
Laundry	3.7%	96
Foyer	3.4%	88
Other	12.7%	326
Total	100.0%	2579
*New average-sized homes 2012		

Table 2.0 Average Percent Distribution of Finished Space

I have arguably introduced two ends of the program/area continuum: bare essentials from a human rights perspective and developed nation production homes reflecting conspicuous consumerism. I posit that the right-sized dwelling falls somewhere in between. Phyllis Richardson speculated "most of us in the developed world could live with less than we have and still have a greater degree of comfort, pleasure, even luxury, than is strictly necessary."[43] The Right-sized dwelling both decreases total area and eliminates (or combines) spaces to reflect the act of dwelling. Corbusier described a house as "1. A shelter against heat, cold, rain, thieves, and the inquisitive. 2. A receptacle for light and sun. 3. A certain number of cells appropriated to cooking, work, personal life."[44] Table 2.1

[43] Phyllis Richardson. *Nano House: Innovations for Small Dwellings*. London: Thames & Hudson, 2011.

[44] Ibid

is a revised percent distribution of finished space table reflecting these cells (functional dwelling spaces) and their relative area.

RIGHT-SIZED PERCENT DISTRIBUTION OF FINISHED SPACE		
ROOM	PERCENTAGE	AREA (SQFT)
Kitchen	18.9%	160
Family Room	33.1%	280
Bedroom	17.0%	144
Bedroom	17.0%	144
Bathroom	8.3%	70
Laundry	5.7%	48
Total	100.0%	846

Table 2.1 Right-Sized Percent Distribution of Finished Space

Right-sizing encourages combining traditional program into common, flexible/free spaces that accommodate and facilitate a range of activities. It also reduces redundant amenities and diminishes emphasis on social hierarchy. For example, living, dining, and family rooms are combined in a large, open family room adjacent to the kitchen. The *master suite* becomes just another bedroom, and multiple bathrooms are replaced by a singular bathroom accommodating guests, adults, and children. This may seem spartan but more appropriately balances residents' needs, means, and values given the challenges of Hawai'i's housing crisis.

2.2 Lightweight

Why tension fabric? When I considered the range of lightweight materials/construction techniques, tension fabric seemed like an extreme option to achieve reductions in resources, cost, and weight. I was familiar with tension fabric applications, but most were either large-scale or temporary projects. While I could think of examples designed to withstand harsh weather conditions,

interestingly none of the examples were single-family dwelling scale. In theory, tension fabric could be applied to smaller structures in a mild climate. To determine the feasibility of this application, I considered the history of fabric structures, fabric properties, and forms before delving into the design process. Rather than introduce and discuss every aspect of tensile fabric structures, I will trace my course of discovery highlighting the inflection points which led to this discourse and my proposed design for a single-family dwelling in Hawai'i.

The oldest fabric structures were tent forms used by indigenous, nomadic people of the plains and deserts. Among these, the most recognizable are the tipi or teepee of North America, the yurt or ger of central Asia, and the black tents of the Middle East. Each of these structures consisted of wooden frames and coverings of animal hides or woven fabric. These tents were transportable and re-erectable, attributes which supported the tribes' way of life. These structures and derivatives are still in use today. Qualities of these ancient tents that are relevant to this thesis include: essential programming, lightweight fabric construction, transportability, ease of maintenance/assembly/disassembly, simplicity, durability, and modularity. While these structures are often referred to as "temporary," perhaps "transportable" is a more appropriate term, because these structures are durable and designed to be disassembled, relocated, and re-erected. They are temporary in site rather than temporary in structure. In fact, the structural frame was commonly integrated into the transportation system; this characteristic may have applicability in today's housing crisis.

Most structures in the built environment are compression systems, some derivation of post and lintel construction whereby loads of a building are directed downwards to the foundation through heavy elements. These systems balance inward-directed "pushing" forces, and they tend to be formally rectilinear, defined by straight lines and right angles. Tension systems balance outward-directed "pulling" forces. These systems are less common in the built environment, and they present opportunity in form and function. Merits of tension systems include economy of resources, unique, organic exterior form, comforting interior spaces, flexibility, and adaptability.

Perhaps the most important, and certainly the most relevant aspect of tension systems with respect to affordability is economy of resources. Tensile fabric can be designed to create a "minimal surface," which is "the smallest surface between closed linear configurations of any shape."[45] Like the axiom the *shortest distance between two points is a straight line*, "a membrane in which the stresses are of equal magnitude in every direction will always take on the shape of a minimal surface."[46]

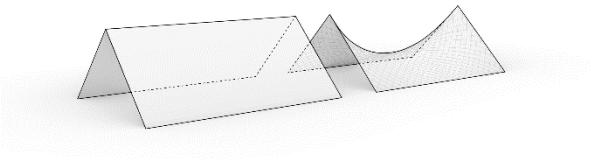

Figure 2.0 Gable Versus Minimal Surface

[45] Conrad Roland. *Frei Otto - Structures*. London: Longman, 1972.

[46] Ibid

The minimal surface, therefore, consists of less material and is lighter requiring less support structure – lean masts, cables, and point foundations rather than bulky posts, beams, and slabs. Consider the simple comparison of common roofing materials weights[47] – these represent the skin, but not the bones – in Table 2.2.

MATERIAL	WEIGHT (ppsf)
5/8" Plywood	1.77
29 Gauge Steel Decking	0.80
.45mm Composite Fabric (PVDF)	0.12

Table 2.2 Common Roofing Material Weights

There is also economy in assembly. "Tension buildings are erected in very short periods, hours or days rather than weeks or months."[48] Labor costs are a significant portion of project costs; because patterning and detailing take place in a controlled environment before assembly, tensile fabric structures are similar to other pre-fabricated building systems, which benefit from efficiencies in time, labor, and quality control.

This economy of resources is also inherently more sustainable. Since fabric could be applied to envelope (both wall and roof) and to interior partitions, conceivably, an entire single-family dwelling could be extremely lightweight.

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[47] "Weights of Common Building Materials." Steve DeRose's Guide to Emergency Preparedness: Materials Densities. Accessed April 04, 2019. http://www.derose.net/steve/resources/engtables/materials.html.

[48] Robert Kronenburg. "Tensile Architecture." *Architectural Design*, August 1995, 9-15.

Incorporating reusable/recyclable components (including the fabrics) and passive climate response/energy efficiency would amplify the sustainability.

The unique, organic exterior form of tensile fabric structures is at once eye-catching and familiar. It "is soft, free-form and organic evoking the geometry of nature rather than of man, of waves, clouds, and wind-blown snow rather than flat, pitched, or arched roofs."[49] In outward appearance, fabric architecture often seems to float and to be more related to the sky than to the earth it is anchored to. It evokes a sense of lightness and freedom. Often the fabric is light in color, although colors, printed images, patterns, and play of light and shade can be incorporated; these options coupled with the organic forms can be applied to truly integrate the exterior forms into a natural setting. While Frank Lloyd Wright celebrated the horizontal lines of the Midwest in his Prairie Style, we could celebrate the tree canopies, coastal hills, mountains, and waves in fabric here in Hawai'i.

The interior spaces also elicit a positive human response. Again, the soft, organic form coupled with diffuse, warm light feels like a comforting hug. Robert Kronenburg suggested "There is a unique feeling of protection that may be connected to a womb-like feeling, the inhabitant concealed within a protective, organic-shaped membrane that bears little resemblance to the conventional, hard, reflective, angular built form."[50] Color, print, and pattern options can boost

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[49] Ibid

[50] Ibid

this response while defining or enhancing interior space function and performance. For example, by incorporating varying color and light transmission qualities in the envelope, the designer can increase interior daylighting in a living space while decreasing it in a sleeping space – effectively incorporating skylights and interior surface reflectivity to optimize the daylight-electric light balance.

Tensile fabric assemblies are inherently flexible and adaptable. The history of fabric structures is replete with temporary and transportable systems ancient, indigenous, and modern. A dwelling should support lifestyle and respond to both resident needs and environmental conditions. Fabric is lightweight and manageable; it can be used to adapt to changing needs. Consider these examples. As siblings age, it may be preferred to provide individual bedrooms. Hanging a fabric partition would define new spaces and establish privacy yet is simpler and easier than constructing a wall. As we close an open window or sliding glass door when it rains, we could also zip or unroll and fasten a fabric insert in a fabric wall. As we deploy an inflatable mattress to accommodate a visiting guest, we could temporarily enclose an indoor/outdoor living space sheltered by a fabric roof. In these instances (and many others) the intrinsic adaptability of a fabric envelope/partition system meets changing demands of living with economy, utility, and practicality. Through fabric architecture, *expandable/reducible*, *mountable/de-mountable*, and *reconfigurable* will become the buzzwords describing lifestyle response in future dwellings.

2.3 Designed

I included *designed* as a solution tenet for two reasons. First, in my design education, I have observed application of critical and creative thinking to solve problems from hand-held to urban scale and in multiple disciplines. Yet when I read commentary about the state of architecture, I was flummoxed that the bulk of the built environment is not touched by an architect. Perhaps this is the main reason that available housing is not suitable? Secondly, given the state of architecture, the commoditization of housing, and public perception of the American Dream (conspicuous consumption), it will require design intervention to optimize living in right-sized, lightweight dwellings – accessible, affordable design.

Building (in) the Future: recasting labor in architecture, edited by Peggy Deamer and Phillip G. Bernstein, offers commentary about the current state of architecture. In his essay *Intention, Craft, and Rationality*, Kenneth Frampton argues that the profession of architecture has become overrun by society's consumerism and engulfed by the building industry's capitalist drive to produce commodities. He states, "building culture incorporates values that transcend our current proclivity for maximizing the production/consumption cycle in every facet of life,"[51] yet "the hard fact remains that some 90 percent of the annual built production in the United States still takes place without the intervention of any

[51] Peggy Deamer, and Phillip G. Bernstein. *Building (in) the Future: Recasting Labor in Architecture*. New York: Princeton University Press, 2010.

architect whatsoever."[52] He suggests that the future of architecture lies in reclaiming the design process. In his essay *Open-Source Living*, Kent Larson continues in the same vein by opining "The unfortunate reality, however, is that architects are largely irrelevant to the creation of most of the housing built in the United States. There is a profound disconnect between the preoccupations of architects and the low-quality, banal, generic commodity products produced by merchant developers that comprise as much as 90 to 95 percent of new houses and apartments."[53] Larson suggests that good design can be more accessible through open-source building, which helps residents understand their needs and connects client, designer, fabricator, and constructor through a network of shared knowledge and expertise. The search engine becomes a "design engine," which resembles a global network of design/production experts reactive and supportive to clients' needs. Larson describes flexible, component-based outfitting of structures and spaces permitting customization and reconfiguration to support evolving needs of the resident(s).[54] From these discussions, I concluded that most potential home buyers assume good design is out-of-reach, or perhaps don't consider design at all.

In his article *Everyone Deserves Good Design*, John Cary wrote: "Almost nothing influences the quality of our lives more than the design of our homes, our

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[52] Ibid

[53] Ibid

[54] Ibid

schools, our workplaces, and our public spaces. Yet design is taken for granted. People don't realize they deserve better or that better is even possible. For too long, design has been seen as a luxury, the province of the rich, not the poor, who often need it most. That can no longer be acceptable to those of us in the design field, nor to those affected by the field's too often anemic moral imagination, which is to say, absolutely everybody."[55] Similarly, Xavier Vendrell said "All people, rich and poor, deserve the benefit of good design."[56] when speaking about Rural Studio, the a student-centered Design/Build program in Auburn University's College of Architecture, Design and Construction. To me this is beyond a social equity issue; *everybody* deserves good design, and our planet deserves good design.

Design facilitates living and can improve quality of life. With respect to single-family home design, good design is inaccessible to potential home buyers due to perception, expense, and/or perception of expense. Public perception is that design professionals work for wealthy clients and that their services are exorbitantly expensive and luxurious, even superfluous. Architects' fees are commonly a percentage of the total cost of the project. By reducing the overall cost of a dwelling, design becomes more affordable, more accessible.

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[55] "Everyone Deserves Good Design." The On Being Project. Accessed April 03, 2019. https://onbeing.org/blog/john-cary-everyone-deserves-good-design/.

[56] Xavier Vendrell. "Rural Studio." Address, Building Voices Symposium, Hawai'i, Honolulu, April 22, 2017.

The solution tenets right-sized, lightweight, and designed are the framework I will carry into the design phase to develop smaller, lighter weight single-family dwellings optimized for lifestyle, comfort, climate response, and energy efficiency. Ultimately this framework will advance dwelling affordability and sustainability.

Part 2 | DESIGN

3. Design

During the research phase, I identified problems and explored solutions. During the design phase, I synthesized a focused solution, as much a new single-family dwelling as a structural system and way of thinking. The design result is not a one-size-fits-all dwelling; it is a typology defined by adherence to design values derived from my investigation of affordability, sustainability, and essentialism. To achieve the design result, I traced a path from the design problem through design inspirations, which ranged from nature to consumer products to temporary experiences in the built environment. The design result is illustrated by a dwelling representative of this new lightweight, essential, tropical typology, which has been designed for a specific client and a specific site. While a different client would have different needs, the design process, materials, and construction (elements which define the typology) would be applicable. In fact, as discussed in section 2.3, a core value of the typology is that it be *designed*, which implies an interaction between design professional and inhabitant.

3.1 Design Problem

Establish a lightweight, essential, tropical typology for single family dwelling which would not render a middle-class homeowner cost burdened.

3.2 Design Core Values

To guide my trajectory from design problem to design result, I implemented a collection of constraints and restraints, which ensured that I achieved affordable dwellings while remaining true to the basic tenets of the thesis (lightweight, essential, designed). If my singular focus was lightweight

material, I could design an essential house of paper (or of straw in the case of the three little pigs). However, I developed a hierarchal list of design core values that includes additional priorities such as safety, comfort, and energy efficiency. The principles of affordability (primary) and sustainability (secondary) overarch solution tenets and design lenses. At no point in the design process should the overarching principles be ignored; should there be a design decision that pits tenet/value against another tenet/value, this chart advises the greatest benefit.

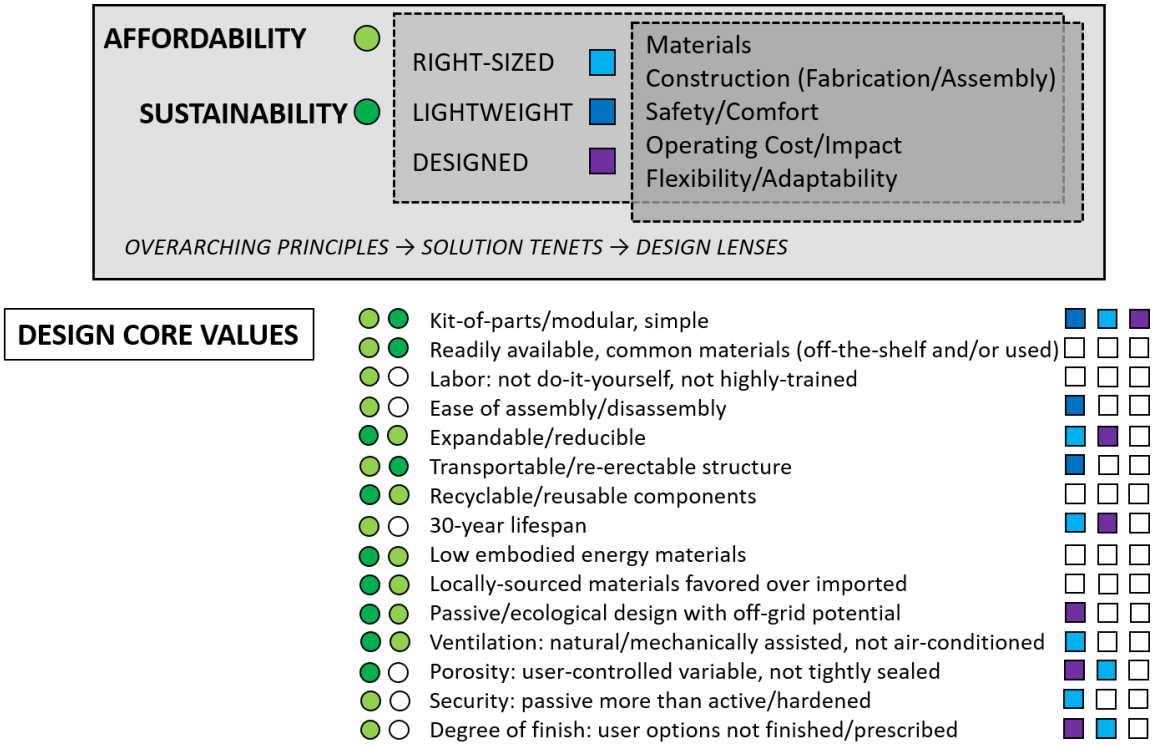

Figure 3.0 Design Core Values

I will further clarify these design core values by offering why they are integral to the lightweight, essential, tropical typology and how they can be realized.

Kit-of-parts/modular, simple. Employing a kit-of-parts and modular design promotes flexibility and adaptability and limits fabrication and assembly challenges. Homeowners aren't distracted by the mystery of building materials

and construction techniques; they can see the components, how they are assembled, and how they create the spaces for dwelling. This facilitates the designer-client interaction and is inherently more affordable and sustainable.

Readily available, common materials (off-the-shelf and/or used). Specialized components have higher associated design, fabrication, and shipping costs. Readily available materials cost less due to economy of scale. This aspect if amplified if the materials are used in other applications, which would also mean there is a greater likelihood that used materials could be reused. Reusing materials is both cheaper and more sustainable.

Labor: not do-it-yourself, not highly-trained. The homeowner avoids higher labor costs by requiring both fewer laborers and less-highly-trained laborers to erect the dwelling.

Ease of assembly/disassembly. This aspect is related to labor cost; if the dwelling is easy to assemble, it requires less labor. This is also related to supporting the mobility of homeowners, who, when choosing to relocate, could transport their home rather than purchase another.

Expandable/reducible. The homeowner has the flexibility to react to changes in program, floor area, and features if adaptability is designed into the dwelling system. Life changes such as adding a child or a home office can be accommodated rather than requiring a different home or expensive remodeling.

Transportable/re-erectable structure. This complements the ease of assembly and labor-related values by supporting homeowner mobility and

affordability. This also supports a used dwelling resale market suggested in the vignettes in section 5.2.

Recyclable/reusable components. Tensile fabric and steel are less renewable than wood, but they are recyclable and reusable.

30-year lifespan. This value doesn't intuitively scream affordability or sustainability, but by designing a dwelling to last only as long as it will be relevant, suitable, and lived-in, I am aligning resources to needs temporally. By defining the lifespan, I am able to identify limiting material factors and select materials and construction/assembly techniques that are appropriate. As I mentioned earlier, a product designed to last for three years applied with consideration of maintenance/replacement may be preferable to one that will last for 10 years but costs 10 times more (operations and maintenance cost versus procurement cost). Similarly, why pay for a product that will last for 100 years if expecting to use the structure for only 30 years? Often the final phase of a building project, disposal, is ignored. By designing lifespan, I can prescribe disposal. For example, the tensile fabric roof has a lifespan of 30 years, after which it can be recycled. The steel structure that supports it has a much greater lifespan; it could be reused, repurposed, or recycled.

Low embodied energy materials. Embodied energy is the sum of the energy required to gather/process natural resources, manufacture, and deliver

building materials, products, and services. For example, while aluminum would be lighter than steel, it has more than four times the embodied energy.[57]

Locally-sourced materials favored over imported. By locally sourcing materials, homeowners stimulate the local economy and reduce building material embodied energy. While this option is more sustainable, it may not be the most affordable; design decisions should reflect an appropriate balance.

Passive/ecological design with off-grid potential. This value encompasses a variety of techniques to improve home energy performance and user comfort by optimizing climate response with low impact to the environment. Measures include site orientation to limit direct solar heat gain and to capture predominant winds and daylighting. Other techniques consider the broader environment such as water conservation, catchment, and reuse.

Ventilation: natural/mechanically assisted, not air-conditioned. Intuitively, natural ventilation is more affordable than air conditioning, which includes not only the initial cost of the equipment, but also continuing operating cost. Less obvious is the cost of building materials and construction techniques required to insulate and control moisture to optimize the air conditioning systems.

Porosity: user-controlled variable, not tightly sealed. This value is complementary to natural ventilation and daylighting. The homeowner can

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[57] "Table of Embodied Energy or Primary Energy of Materials. Enrique Azpilicueta. Topics [T]tectonica." Online. Accessed April 03, 2019. http://www.tectonica-online.com/topics/energy/embodied-energy-materials-enrique-azpilicueta/table/31/.

control the porosity of the envelope to balance natural light, shade, ventilation, privacy, and security based on preference and comfort.

Security: passive more than active/hardened. Passive security is largely product-less, and therefore more affordable. While fabric structures and porous envelopes don't seem particularly secure, good design can enhance privacy, security, and protection.

Degree of finish: user options, not finished/prescribed. Homeowners can select from a range of options within a cost/comfort/amenity continuum. This constrains cost and tailors the dwelling to the inhabitant.

Using these design core values as a compass, I navigated design inspirations to extract the forms, elements, and interactions that would define the typology.

3.3 Design Inspiration I: Ken Isaacs and Frei Otto

I began exploring lightweight structures to meet the requirements of a studio project to design affordable housing for homeless. I reasoned that homeless are used to a lower standard, and therefore, they lack the perception of an ideal home as a prerequisite for their dwellings. I saw this as an opportunity to provide humble, yet respectable dwellings focused on shelter. My material inspirations were boat enclosures made of canvas and transparent vinyl – lightweight, inexpensive, flexible, readily available, familiar (nontechnical).
I have lived in existing homes, production homes, and a custom home. The existing, single wall construction home I live in has a large screened room

serving as the main dining and family gathering space. This space is open, flexible, and porous. It is porous in the sense that people can circulate through all four “walls” – it is a rectangular space – and in the sense that the portion of the space that is screened allows free, natural ventilation. This space is comfortable and functional. However, it is a shock to any visitor who is accustomed to mainland-style production homes; it has a third-world quality, decidedly unsophisticated, yet surprisingly appropriate and practical. In terms of cost, it eclipses standard walls and windows, and it achieves a phenomenological effect that standard walls and windows struggle to approach – the sense of indoor/outdoor living and a calming oneness with the natural surroundings. I would describe this design direction as simple, yet inexpensive and elegant; design with emphasis on human needs, yet never ignoring human experience or aesthetics.

From this design direction, I arrived at affordable, sustainable, essential. The Hawai’i housing crisis requires outside-the-box thinking and material/structural innovation. I was originally inspired by Ken Isaac’s and Frei Otto’s built forms, but as I researched their work, I became even more inspired by their philosophies and approaches. It was not lost on me that they entered the design world in the post-World War II period motivated by intense optimism and humanism. Ultimately, I decided to combine their visions and infuse them with the people, place, and time of today’s O’ahu in hopes of addressing the housing crisis. I will present and analyze representative works.

Ken Isaacs

> When I was first discovering & applying the Matrix Idea I couldn't help wondering why people had to shackle themselves to some kind of corporate clerkship for twenty years to get the money for a home in the country. Why wasn't it possible to apply your best consciousness & information to develop a new shelter? It had to be compact and mobile using a minimum material list and buildable in your apartment with simple tooling. Fabricate the parts in winter, slip into a van or wagon in spring & trek to a short-term-leased spot on a farmer's back 40 & set her up in a day. It's kind of like 'freedom now' instead of waiting until you can 'afford' it. Living put off is lost.[58]

Ken Isaacs, a designer and architect, "challenged conventional definitions of modernism through designs that sought radical solutions to the spatial and environmental challenges of modern life."[59] He espoused accessible design and human-centered design with a focus on lifestyle and design for living. Isaacs stated "I decided, in the late 1940s, to commit my energies to the development of alternatives. Not panaceas but new prototypical systems in architecture, living equipment, fabricating means and communications."[60] He developed the concept of the Matrix, which is both an architectural concept and a philosophical one. It is a total environment integrating all functions of living; it is at once physical, spatial, active, emotive, etc. To understand the matrix concept, consider a family room in a home and list every pursuit which could be conducted there. Activities include sitting, watching television, chatting, surfing the internet,

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[58] Ken Isaacs. *How to Build Your Own Living Structures*. New York: Harmony Books, 1974.

[59] "Enter the Matrix: An Interview with Ken Isaacs." Walker Art Center. Accessed April 03, 2019. https://walkerart.org/magazine/enter-matrix-interview-ken-isaacs.

[60] Ibid

playing games, storing possessions, etc. Now consider a furniture-scale system that facilitates all of these activities, all of this *living*. It might consist of seating, surfaces, cubicles, screens, projectors, speakers, electrical connections, Wi-Fi, etc.

Isaacs's matrix consisted of Living Structures, "unitary, multifunctional living environments based on a network of grids that are easily assembled and embrace simplicity of form." Living Structures unified the functions of furniture and home and evolved into nomadic, sustainable architectural dwellings or Microhouses.[61]

Isaacs called his first book *Culture Breakers, Alternatives & Other Numbers*. He recognized that his concepts "rejected (or 'broke') the middle-class cultural values that defined the American postwar period, with its emphasis on individualism, capitalist expansion, and material consumption."[62] He shunned "the consumer-laden values of the American dream. The result was a lifelong commitment to a populist form of architecture that, because of its low cost and ease of construction, allowed a broad range of publics to participate in the design process."[63] Isaacs reasoned that if people would eschew traditional furniture and bloated homes to adopt Living Structures and Microhouses, they would better facilitate living through design and, at the same time, save money and reduce

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[61] Ibid

[62] Ibid

[63] Ibid

impact on the environment. This approach emphasizes the inextricably linked core principles of my design.

Figure 3.1 Ken Isaacs *Living Cube*

The Living Cube is a Living Structure designed in 1954. It is constructed of 2"x2" lumber and plywood, and it is assembled using machined bolts, washers, and nuts.[64] Living Cube has integrated lighting and electricity, and it accommodates sleeping, relaxing, studying, dining, storing, and ventilating with elements analogous to a bed, a lounge chair, a desk, a closet, and a duct/register. This structure is comparable to multiple rooms in the average home and/or multiple pieces of furniture. Isaacs commented "All of the members of the unit are 72" long and pack in a case less than 12" square. Easy to move and ship, LIVING

[64] Ken Isaacs. *How to Build Your Own Living Structures*. New York: Harmony Books, 1974.

STRUCTURES are also simple and inexpensive to produce. Initial cost to the user is a fraction of the aggregate cost for furniture of the old culture."[65]

Figure 3.2 Ken Isaacs *Beach Matrix*

The Beach Matrix is a Microhouse designed in 1967. It is constructed of a canvas panel, 1" galvanized steel pipe, 2"x4" and 2"x2" lumber, plywood, and concrete "feet," and it is assembled using two and three-way fittings, tension cables, machined bolts, washers, nuts, and wood screws.[66] It accommodates sleeping, lounging, cooking, dining, and storing, and it "has a minimum of enclosed space. Its openness is well-suited to its location."[67] This structure is designed with full consideration of how people enjoy the beach! Additionally, Isaacs considered the mobility aspect of human experience. He said "One of the values intrinsic to this type of structure is the ease with which it can be

[65] Ken Isaacs. *Culture Breakers: Alternatives & Other Numbers*. New York: MSS Educational Publishing, 1970.

[66] Ken Isaacs. *How to Build Your Own Living Structures*. New York: Harmony Books, 1974.

[67] Ken Isaacs. *Culture Breakers: Alternatives & Other Numbers*. New York: MSS Educational Publishing, 1970.

assembled or broken down for relocation."[68] This value is suggested in the vignettes in section 5.2.

Figure 3.3 Ken Isaacs *8' Microhouse*

8' Microhouse was detailed in *How to Build Your Own Living Structures*, which Isaacs wrote in 1974. It is constructed of 2"x2" lumber, plywood, plexiglass, and galvanized steel, thin-walled conduit, and it is assembled machined bolts, washers, nuts, and wood screws.[69] It accommodates all of the functions of a house and related furniture. This is a tiny house in today's sense; like many who have joined the movement Isaacs realized "With the elimination of furniture and the integration of living equipment, it was possible to design living shelters using

[68] Ibid

[69] Ken Isaacs. *How to Build Your Own Living Structures*. New York: Harmony Books, 1974.

surprisingly small cubages."[70] Isaacs said: "Put traditional, separate pieces of furniture in a tiny shelter, and you have a shack, uncleanable, crowded and impossible to live in. The old ideas of furniture have always interfered with the development of truly compact, ecologically correct homes."[71] This underscores his devotion to sustainability and the "least alteration of the natural balance of the environment."[72]

These examples illustrate Ken Isaac's products as well as his process and core values. He promoted anti-consumerism, environmental-consciousness, accessible design, simplicity. He said "At some point, man must order his relationship to the physical environment toward harmonious coexistence rather than the short-term, mindless piracy of the planet that has marked his history to this point."[73] His work embodies affordable, sustainable, essential, and it is an ideal starting point for design.

Frei Otto, an architect and structural designer, applied a "strict and systematic adherence to the rule of material economy and subordination of

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[70] "Enter the Matrix: An Interview with Ken Isaacs." Walker Art Center. Accessed April 03, 2019. https://walkerart.org/magazine/enter-matrix-interview-ken-isaacs.

[71] Ken Isaacs. *How to Build Your Own Living Structures*. New York: Harmony Books, 1974.

[72] Ken Isaacs. *Culture Breakers: Alternatives & Other Numbers*. New York: MSS Educational Publishing, 1970.

[73] "Enter the Matrix: An Interview with Ken Isaacs." Walker Art Center. Accessed April 03, 2019. https://walkerart.org/magazine/enter-matrix-interview-ken-isaacs.

extraneous considerations."[74] His experiences as a pilot, as a prisoner of war responsible for leading construction teams to repair damaged structures, and as a budding designer in war-ravaged, occupied/divided Berlin influenced his core values of lightweight and adaptable architecture, environment and ecology, orientation towards the future, and social responsibility. Working with limited resources, he found that "by increasing the amount of tension and concentrating compression in a few short struts, as in a fish-belly lattice girder, it was possible to reduce the volume of material."[75] He focused on tensile fabric structures appreciating both their relative weightlessness and their inherent flexibility to adapt to changing patterns of human use. He stated: "Buildings, therefore, cannot and should not be rigid structures, into which we must be squeezed, but must be along with us, a living growing environment which eventually should be replaced."[76] Otto espoused sustainability long before it had a label; not only was he adverse to littering the landscape with heavy, permanent, outdated structures, he identified that doing more with less is congruent with stewardship of the environment.[77] In the Museum of Modern Art retrospective, Ludwig Glaeser comments:

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[74] Philip Drew. *Frei Otto: Form and Structure*. London: Crosby Lockwood Staples, 1976.

[75] Ibid

[76] Ibid

[77] Ludwig Glaeser. *The Work of Frei Otto*. 1971.

> Frei Otto not only considers the temporary nature of his membrane structures desirable but admits that his objections to making architecture stem from his reluctance to fill the earth's surface with lasting buildings. He hesitates to pursue a project unless he is certain that its realization will be temporary enough not to be in man's way.[78]

Otto's consideration of temporal is similar to Ken Isaac's interest in structures that are easily assembled, disassembled, and re-erected; again, this value is suggested in the vignettes in section 5.2. Minimal use of materials and sustainability are core to my design and are visible in the following examples of Otto's early work with membranes.

Figure 3.4 Frei Otto *Bandstand at Cassel*

The Bandstand at Cassel was the first of Otto's tent structures to be constructed (1955), and it consisted of a cotton membrane having pre-stressed edge cables supported at two high and two low points.[79] The membrane was roughly one millimeter thick, and the steel cables sewn into the edges were 16 millimeters in diameter. Pinewood poles supported the high points, and concrete blocks buried in the soil supported the low points. This is an example of a minimal surface, which "is the smallest surface between closed linear configurations of any

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[78] Ibid

[79] Conrad Roland. *Frei Otto - Structures*. London: Longman, 1972.

shape."[80] It is anticlastic or saddle-shaped, that is, curved oppositely in two perpendicular directions. The membrane spans 18 meters; "pure membrane structures are only suitable for very light small- and medium-span structures (< 50 m)."[81] The bandstand provided shelter for musicians at the Federal Garden Exhibition and was meant to be a temporary structure. It would be very difficult to erect a shelter with less material!

Figure 3.5 Frei Otto *Café at Interbau*

At the 1957 Interbau Building Exhibition in Berlin, Otto constructed a number of membrane structures with "humps" or high points. The Café consisted of perlon fabric membrane with prestressed edge cables secured by parallel guys; eight

[80] Ibid

[81] Philip Drew. *Frei Otto: Form and Structure*. London: Crosby Lockwood Staples, 1976.

internal poles of differing lengths outfitted with bearing heads created the high points in the membrane.[82] Again, this was a temporary structure, which measured 24 meters by 28 meters and provided seating for 800 visitors.[83]

Figure 3.6 Frei Otto *Orchestra Canopy at Interbau*

Also at the 1957 Interbau Building Exhibition, the simple canopy erected for the Berlin Radio Symphony Orchestra had high and low points.[84] This unique design was constructed “of light plastic-coated cotton fabric pressed upwards in the

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[82] Conrad Roland. *Frei Otto - Structures*. London: Longman, 1972.

[83] Ibid

[84] Philip Drew. *Frei Otto: Form and Structure*. London: Crosby Lockwood Staples, 1976.

middle, and restrained at four low points which served as rain water drains."[85] Different from the café design, this membrane measured 17.5 meters by 22.5 meters and was supported along its perimeter by 14 tubular steel guyed struts.[86] Otto developed a pattern vocabulary through an experimental form-finding process; for a given application, he would identify suitable forms and select the most appropriate by considering context and aesthetics.[87]

These examples represent Otto's early work and provide a glimpse of his process and motivations. He was relentless in his pursuit of featherweight structures; in his words, "My architectural drive was to design new types of buildings to help poor people especially following natural disasters and catastrophes."[88] He too, like Ken Isaacs, exemplifies affordable, sustainable, essential.

Interestingly, Phillip Drew offered a criticism of Frei Otto that aligns well with Ken Isaacs' focus. He suggested there is a "weakness of many of his projects where the connections between the roof and its setting have not been managed with sufficient confidence, sensitivity and understanding. There is in Frei Otto's work a general failure to transform the pure rationale of structure into

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[85] Ibid

[86] Ibid

[87] Ibid

[88] Marcus Fairs. "Frei Otto Is 2015 Pritzker Prize Laureate." Dezeen. May 07, 2015. Accessed April 03, 2019. https://www.dezeen.com/2015/03/10/frei-otto-is-2015-pritzker-prize-laureate/.

total architecture."[89] By combining Otto's adaptable, minimalist roof structure with Isaacs' flexible, multifunction Living Structures, I can achieve total architecture, infused with the spirit of affordable, sustainable, essential. Ken Isaacs offered this sketch (Figure 3.7) with the following label:

Figure 3.7 Ken Isaacs *Separation of weatherproofing from interior structure*

"This home is one of the earliest embodying the principles of separation of weatherproofing from interior structure. The sheltering vault may be concrete or plastic. This idea makes possible an entirely new freedom of clarity in the house"[90] I propose a hybrid represented by this illustration.

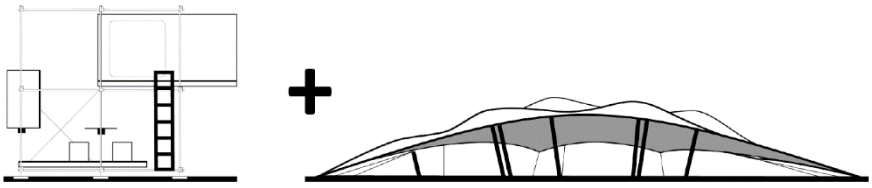

Figure 3.8 Hybrid: Living Structure + Membrane Structure

[89] Philip Drew. *Frei Otto: Form and Structure*. London: Crosby Lockwood Staples, 1976.

[90] Ken Isaacs. *Culture Breakers: Alternatives & Other Numbers*. New York: MSS Educational Publishing, 1970.

3.4 Design Inspiration II: Case Studies

From my investigations of Ken Isaacs and Frei Otto, I advanced my design core values, process, and concept. Through additional case studies, I distilled the design criteria, materials, and form. These case studies ranged from nature and everyday objects to historical examples to built work. I will briefly describe each and identify the key features that moved me.

Nature.

Often design solutions can be derived from nature, whether complex biomimicry or simply imitation of a pleasing form. Among the simplest inspirations for shelter is a tree canopy.

Figure 3.9 Tree Canopy

In Hawai'i where the ambient air temperature and climate are relatively mild, one needs little more than the airy branches and leaves to limit direct solar heat gain while permitting natural ventilation and daylighting. Broad leaves may even provide protection from light rain. In addition to their human comfort contribution, I find the canopies pleasing in form. Key features: local (sustainable) materials, climate responsive, minimal program, indoor/outdoor living, aesthetically pleasing.


Figure 3.10 Coastal Hills, Windward O'ahu

The coastal hills of windward O'ahu are also an inspiration. While they offer little in terms of shelter, I simply find the form pleasing. In fact, the shape of the coastal hills and the broad, elliptical tree canopies are very similar and complementary. I can envision a structure that mimics this form integrating the built form and the natural. Frank Lloyd Wright captured the horizontal lines of the American plains in his Prairie Style; perhaps the lightweight, essential, tropical typology can evoke the coastal hills and tree canopies of the Hawaiian landscape. Key feature: aesthetically pleasing.

Indigenous Architecture/Vernacular Architecture.

Similar to drawing inspiration from nature, modern designers often look to indigenous and vernacular architecture as inspirations. Indigenous architecture is derived from the indigenous people, and the term carries a connotation of pre-machine-age. Vernacular architecture is derived from practices and materials of a specific time and place. Sometimes these are one and the same, but to provide examples from Hawai'i, I suggest the Native Hawaiian hale is indigenous architecture while the plantation-style home is vernacular architecture related to the sugar plantations of the early 1900s. In terms of inspiration, both indigenous and vernacular have merit; they typically reflect efficient use of relatively scarce

materials and refinement over time passed through generations of understanding. The first wood-framed house was built in Hawai'i in 1821 by missionaries who shipped building supplies from the mainland. [91] This began a tradition of western-influenced building that has been in place for nearly 200 years. Polynesians built dwellings in the islands for more than 1000 years before these wood-framed houses! The hale forms evolved over generations optimizing use of available resources (construction materials/technique) and support of lifestyle (program); this refinement could be thought of as natural selection applied to the built environment. While early non-natives introduced a foreign building style, savvy builders identified and applied beneficial aspects of indigenous buildings, which gave birth to vernaculars.

I gravitated toward three examples of indigenous architecture: the Bedouin Black Tent, Seminole Chickee, and Yokut Lodge. Each applied available resources to optimize security, climate response, and support of the indigenous lifestyle unique to the people/place and refined over centuries.

Figure 3.11 Bedouin Black Tent

[91] Nicholas Civitano, Martin Despang, William Chapman, and Mark A. Mahaney. A New Hawai'i Tropical House: Creating a Healthy Pre-fabricated Residential Architecture and Community (2017): ProQuest Dissertations and Theses.

The Bedouin Black Tent is still in use today by nomadic people of North Africa and the Middle East. They are traditionally made of woven goat or camel hair rugs, which form the floor, walls, and roof when tensioned over a wooden frame. The tents are easily disassembled, transported, and re-erected, and they provide a convective cooling effect in the harsh desert heat.[92] Key features: lightweight, transportable, re-erectable, minimal program, climate responsive.

Figure 3.12 Seminole Chickee

The Seminole Chickee was used by the Seminole tribe in Florida. Like the Black Tent, it supported a nomadic lifestyle; although, the Seminole were on the move because they were pursued by the United States military during the Seminole Wars! The Chickee was an adaptation that consisted of a wooden frame lashed together and covered with palmetto fronds. It could be quickly assembled with readily available materials. It featured an elevated floor plate to provide protection from pests and open gables to promote natural ventilation.[93] Key features: lightweight, elevated floor plate, local (sustainable) materials, climate responsive, minimal program, indoor/outdoor living.

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[92] Oliver, Paul. *Dwellings: The House across the World*. Austin: University of Texas Press, 1990.

[93] https://www.researchgate.net/figure/Seminole-chickee-in-MacCauleys-report-MacCauley-1887-Courtesy-of-the-National_fig1_255907070

Figure 3.13 Yokut Lodge

The Yokut tribe lived in the San Joaquin Valley of Central California. Their dwellings were made of wooden frames and tule fibers. The image of their lodges struck me because it is similar to Ken Isaac's drawing separating the weather barrier from the living structure (Figure 3.7). The lodge supported an indoor/outdoor, communal lifestyle. Key features: lightweight, local (sustainable) materials, climate responsive, minimal program, indoor/outdoor living.

Every Day Shelters.

I considered every day shelters as design inspirations. Through these I identified key features which advised my refinement of lightweight materials/construction techniques and my selection of design criteria based on essential needs and lifestyle. These products/systems support active families and facilitate "indoor"/outdoor living. These systems also fall into the category of

recreational equipment, which the user must store as I identified in the discussion of program appropriate for living in Hawai'i.

Figure 3.14 E-Z UP Instant Shelter

The portable 10' x 10' canopy is a mainstay of family sporting events. The E-Z UP Instant Shelters designed in the early 1980s is arguably the first in the industry and is a representative example. The canopies incorporate four, extendable, light gauge steel or aluminum legs and a folding, accordion-style, peaked overhead frame.[94] The user removes the system from its sack, unfolds/extends the frame, and stretches the fabric canopy over it. The shelter provides shade and protection from precipitation; there is a continuum of ruggedness and accessories available. It can be anchored to the ground with stakes. Key features: lightweight, transportable, re-erectable, minimal program.

[94] "Our Story." E. Accessed April 03, 2019. https://www.ezup.com/explore/why-ezup/our-story

Figure 3.15 Shade Shack

Beachgoers appreciate pop-up beach shelters, such as the Shade Shack, which claims to be “the original instant pop up sun shelter.”[95] The shelter consists of a polyester fabric shell with fiberglass rods sewn into the edges.[96] This product comes in a small circular travel pouch; when it is removed by the user, it automatically unfolds to provide two or three walls and a ceiling/roof supported by the integrated fiberglass rods. The Shade Shack can shelter three to four people from direct sunlight, and like the 10’ x 10’ canopy, it lacks a floor. It has pockets low on the walls which can be filled with sand to anchor the system to the ground; stakes are also an option. Key features: lightweight, transportable, re-erectable, minimal program.

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[95] "Shade Shack." Demco Inc. Accessed April 03, 2019. http://www.demcoincorporated.com/

[96] Ibid

Figure 3.16 Otentik

Another option for beachgoers is the Otentik, a family-sized beach tent consisting of a microfiber fabric canopy supported by two (or more) collapsible aluminum poles, ropes, and anchors, which are essentially fabric bags designed to be filled with sand.[97] Again, this system offers shelter from sun and light precipitation, and it is wind resistant. Different from the Shade Shack, it can shelter five people and is more flexible in its configuration depending on the number of poles used and how they are placed.[98] Otentik's designers also aimed to provide an aesthetic product; beauty was a stated design goal.[99] Key features: lightweight, transportable, re-erectable, minimal program, aesthetically pleasing.

In addition to examples from nature, indigenous tribes, and every day shelters, I also reviewed re-erectable structures, and both single-family home- and large-scale tension structures. By now it is clear that these case studies

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[97] "The Original Sunshade." Otentik. Accessed April 03, 2019. https://www.otentik.com/.

[98] Ibid

[99] Ibid

incorporate common key features. For the remaining eight examples I will offer less background and summarize the key features for each case study category.

Re-erectable Structures.

Figure 3.17 Moloka'i Ranch Bungalows

Figure 3.18 InterShelter

Figure 3.19 Event Rental Tent

The Moloka'i Ranch Bungalows or "tentalows" were fabric stretched over a galvanized steel frame with mesh windows much like a camping tent. While less glamorous than the lodge, they responded well to the climate. The roof was lifted

above the walls allowing the breeze to flow through the mesh windows and promote convective current. Interestingly, when the resort closed, the bungalows were disassembled on Moloka'i, shipped to O'ahu, and re-erected to provide homeless shelters in Waianae.[100]

I visited The Shelter, a First Assembly of God ministry supporting homeless single mothers. It features 12 InterShelters, which are similar to igloos in form, but they are constructed of 22 overlapping fiberglass panels. The system has been used for applications including disaster relief shelters and expeditionary medical facilities, and it is easily transportable as the panels stack like plates. These are not tensile fabric, but they are definitely lightweight. I found the permitting process interesting – while the structures can be assembled in 3-4 hours, the "temporary use project" took two years to permit and the permit has to be "renewed" every 180 days.[101]

I found many examples of event rental tents ranging in size and utility/elegance, but curiously the practice is more common outside the United States. Most examples were in New Zealand, South Africa, and Europe. The tents offered creative features; many incorporated ephemeral lighting effects and outdoor furniture.

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[100] MOLOKAI DIVING ECO TOURS -- Photos of Molokai Lodge Kaupoa Beach Village -- U.S. Dive Travel. Accessed April 04, 2019. https://usdivetravel.com/R-Hawaii-Molokai-Resort-Vacation-4.htm.

[101] "The Shelter | Ministries." First Assembly of God. https://www.firstaog.com/ministries/the-shelter/.

Again, these re-erectable structures embody the same key features: lightweight, transportable, re-erectable, climate responsive, minimal program, indoor/outdoor living, elevated floor plate, and aesthetically pleasing.

Single-Family Home-Scale Tension Structures.

The single-family home-scale tension structures I researched included two construction techniques: tensile fabric over metal frame and tensile fabric over a cable-mast support system (hypar and conical tents). While still temporary dwellings, these examples made real for me the possibility that more permanent dwellings could be accepted by the public.

Figure 3.20 Cocoon

Figure 3.21 Tent House

Figure 3.22 Hoanib Skeleton Coast Camp

Cocoon is offered by the Autonomous Tent Company. The example in Figure 3.20 is a “tent” at Treebones Resort in Big Sur, California.[102] Tensile fabric is at once the roof and exterior walls; a glazed curtain wall frames views of the Pacific Ocean – the tent system has infil options for the façade.

Tent House was designed by Sparks Architects for a site in Eumundi, Australia. It incorporates a “fly” roof over an insulated “box” to form a three-bedroom dwelling with a central open plan.[103] Like the Yokut lodge and Ken Isaac’s drawing, Sparks’ design separated the weather barrier from the living structure beneath.

The Hoanib Skeleton Coast Camp is a Wilderness Safaris camp in Kaokoveld, Namibia. The camp consists of eight tents featuring conical tensile

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[102] "Autonomous Tent 2.0." Autonomous Tent 2.0. Accessed April 04, 2019. http://www.autonomoustent.com/.

[103] Leiva, Sabrina. "Tent House / Sparks Architects." ArchDaily. February 23, 2017. Accessed April 04, 2019. https://www.archdaily.com/805984/tent-house-sparks-architects?ad_medium=gallery.

fabric tents raised over wooden decks with wood-framed walls. Specific attention was afforded to touching the earth lightly.[104]

The themes remain consistent: while less re-erectable, these easily assembled case studies repeat key features: lightweight, climate responsive, minimal program, indoor/outdoor living, separation of weather barrier and living structure, and aesthetically pleasing.

Large-Scale Tension Structures.

I included two large-scale tension structure case studies for two reasons: 1) I visited both, 2) they are lasting proof of the function and utility of tensile fabric in temporary structures and temporary experiences even in harsh environments.

Figure 3.23 Circus Tent

Figure 3.24 Denver International Airport

[104] Wilderness. Accessed April 04, 2019. https://wilderness-safaris.com/our-camps/camps/hoanib-skeleton-coast-camp.

Cirque du Soleil continues a long-standing tradition of traveling entertainment presenting the Luzia touring show in a transportable/re-erectable "circus tent" throughout North America.[105] The system is surprisingly robust housing electrical systems, mechanical ventilation, and other amenities associated with more permanent structures.

The Denver International Airport incorporates a tensile fabric, conical tent roof. People I have spoken to are unfamiliar with the terms "tensile fabric" and "tension structure," but many have experienced this airport or other temporary experiences similarly sheltered. When I started my research, I asked myself "if the Denver International Airport can weather high winds and snow loads, why can't tensile fabric shelter a small dwelling in Hawai'i?"

At this scale, design features are prioritized differently, yet these examples still reinforce key features related to my solution tenets. Key features: lightweight, climate responsive, separation of weather barrier and living structure, and aesthetically pleasing.

The case studies validated a hybrid design, highlighted the key features that define the hybrid, and offered practical design/construction insight.

3.5 Design Criteria

To further develop the lightweight, essential, tropical typology, I applied my design core values and inspiration to a hypothetical client and site. It was

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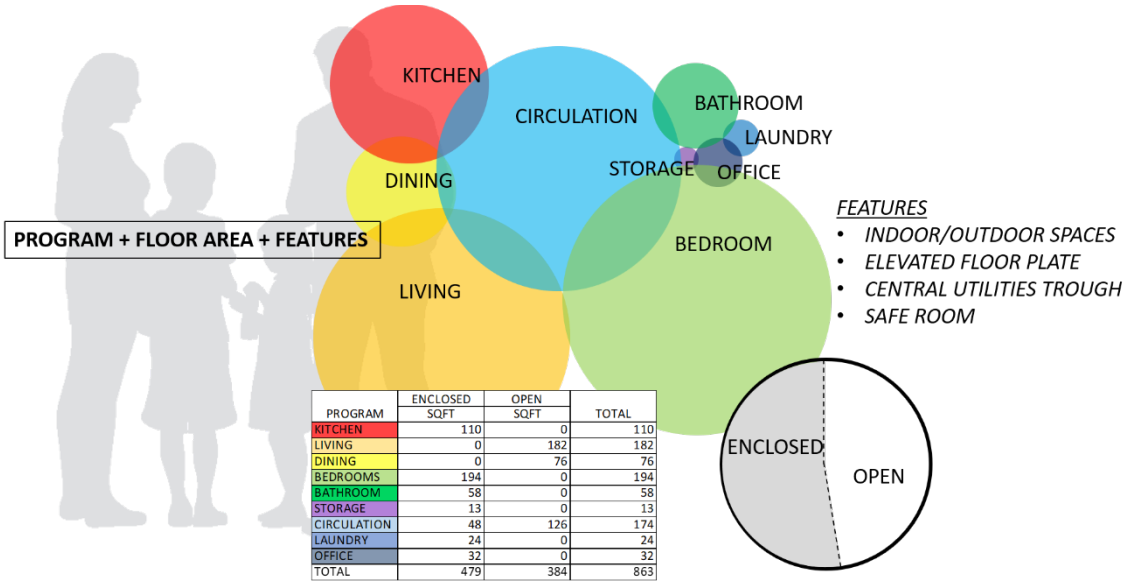
[105] Cirque Du Soleil. "LUZIA | Touring Show." Cirque Du Soleil. Accessed April 04, 2019. https://www.cirquedusoleil.com/luzia.

clear to me that the hybrid dwelling combining a Living Structure and a Membrane Structure would satisfy the solution tenets, but to refine the concept into a buildable design, I needed to consider real design parameters. The clients represent an active middle-class family, young professionals saddled with education debt yet hoping to transition to home ownership while raising two young children. They struggle to find a lifestyle balance between enjoying outdoor family fun and working to afford the high cost of living in Hawai'i. They are encouraged by the prospect of owning their own home while leasing the land it rests upon – an opportunity to build equity and financial stability in a nice neighborhood for the burden of a typical car loan rather than a typical mortgage. The site is a 10,000 square foot lot in the community of Kailua. Similar parcels sell for more than a million dollars frequently with aged existing homes of little value. The landowner envisions leasing a total of four plots on the lot to similar families.

Given the client and site, I developed design criteria consisting of program, floor area, and dwelling features reflecting the needs of the client, the climatic conditions, and the design core values. The design criteria is captured in Figure 3.0 Design Core Values and in Figure 3.25 Program, Floor Area, and Features.



PROGRAM	ENCLOSED SQFT	OPEN SQFT	TOTAL
KITCHEN	110	0	110
LIVING	0	182	182
DINING	0	76	76
BEDROOMS	194	0	194
BATHROOM	58	0	58
STORAGE	13	0	13
CIRCULATION	48	126	174
LAUNDRY	24	0	24
OFFICE	32	0	32
TOTAL	479	384	863

Figure 3.25 Program, Floor Area, and Features

These features are included in the spirit of the design core values and in response to some of the suitability challenges of available housing. I will briefly discuss the merits and application of these features.

Indoor/outdoor spaces were introduced and discussed in section 1.3. The mild, tropical climate affords residents this option/indulgence. Considering indoor/outdoor living, there is a luxury/cost continuum: one end of the spectrum features expensive, folding/retractable walls, while the opposite end of the spectrum eliminates the walls altogether. For the cost burdened, the lure of indoor/outdoor spaces is the increased space at no additional (or minimal) cost. Outdoor spaces in Hawai'i offer similar comfort yet are less bounded than indoor spaces increasing capacity and flexibility of program and providing the intangible benefits of exposure to nature. Likewise, proponents of modern styling and sustainable design would prefer operable, floor-to-ceiling glazing to capture daylighting and natural ventilation, but the expense of these systems affects affordability. While this is chiefly a comfort-related feature, it also contributes to

passive/ecological design, ventilation, and porosity, which are design core values.

An elevated floor plate was also briefly mentioned during our discussion of housing availability, specifically existing houses, section 1.2. This feature involves lifting the structure off of the ground; rather than the typical slab-on-grade of today's production homes, I will implement point foundations using earth anchors to "touch the earth lightly" and raise the dwelling. This will discourage pests (mainly termites), mitigate dust infiltration, and capture trade winds. This feature complements indoor/outdoor living and is also closely related to the design core values passive/ecological design, ventilation, and porosity. In addition, using earth anchors satisfies values related to readily available materials, labor, ease of assembly/disassembly, and transportability/re-erectability.

The central utilities trough is an affordability and flexibility/adaptability measure. Similar to a cable tray for routing communications and electrical cables, the trough would accommodate all utilities paths, including water supply, beneath the elevated floor. Similarly, the utilities in the living spaces will all be arranged over the trough in adjacent spaces. This serves several functions: simplified routing reduces utilities-related materials (cable, pipe, etc.), central access facilitates future modification/addition, and consolidation of utilities in a trough beneath the floor limits the requirement for utilities chase or hollow walls in the living spaces. This feature supports design core values kit-of-parts/modular, simple, ease of assembly/disassembly, and expandable/reducible.

The safe room offers additional safety and personal property protection and complies with code requirements for wind-borne debris protection. Think of the safe room as a hardened shelter within the lightweight shell of the dwelling. This also offers opportunity to mitigate other challenges associated with a lightweight, porous dwelling, namely security and dust/moisture mitigation. While the Membrane Structure is designed to withstand extreme weather events, a porous home is susceptible to dust and moisture infiltration. This can be problematic if a moisture barrier is misapplied – moisture can become trapped if spaces can't "breathe" leading to mold and mildew propagation. While larger living spaces are open to natural ventilation and daylighting, smaller spaces within the bathroom, laundry, and storage core can be hardened, secured, and moisture-free. For example, compartments in the storage area could have a moisture barrier to prevent family photographs or mementos from being damaged by high humidity and/or lockable, hidden compartments for high-value items such as jewelry. The safe room is ultimately a risk mitigation measure, affording the resident a safe place to weather a storm or protect personal property against low likelihood extremes of climate and crime. This feature is related to the overarching principal of affordability, the solution tenets lightweight and essential, and design lenses of materials, construction, and safety.

3.6 Design Process

The typical process for design of a single-family residence would follow these steps:

1. Interview and initial discussions with the client
2. Information gathering and documentation

3. Schematic design
4. Design development
5. Construction documentation
6. Construction administration.

The process for this project differs for two reasons: this is a hypothetical design representative of an innovative typology, and the dwelling has a tensile fabric roof, which requires a slightly different approach. In lieu of an interview and initial discussion with the client and information gathering and documentation, I have presented a lengthy background encompassing research methodology, design philosophy, existing conditions, and design inspiration, all of which have been distilled into design core values and criteria. The next step, schematic design, would typically analyze site, program, floor area, adjacency, circulation, lighting, and ventilation (among other considerations) to develop a massing model. However, because I combined a Living Structure and a Membrane Structure, I also conducted tensile fabric membrane form finding. As I progressed through schematic design, form finding, and design development, the parallel processes of massing and form finding mutually advised each other to ultimately meld into a singular system of envelope, partition, and space. I pursued construction documentation only in exploration of code compliance and fabrication exploration. For example, I completed partial structural analysis to determine the size of system components, and I completed tensile fabric load analysis to generate a pattern to cut the membrane. Figure 3.26 is an illustration of an initial

concept sketch, and Fig 3.27 is a concept collage of the hypothetical, representative design.

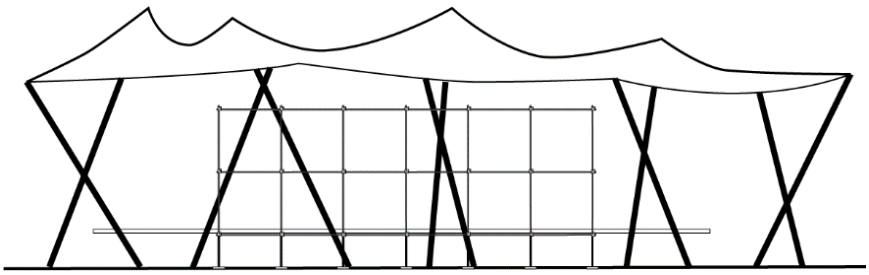


Figure 3.26 Initial Concept Sketch

Figure 3.27 Concept Collage

Before I further describe the design process or present the design result, it is important to reiterate that the design products reflect a representative design for a hypothetical client/site. This is important because I set out to establish a lightweight, essential, tropical typology. The typology is a system of components that can be optimized for a specific client/site/time – considering the temporal aspect underscores the importance of design core values ease of assembly/disassembly, expandable/reducible, etc. The primary components are the Living Structure and the Membrane Structure. The Living Structure is a "matrix" of 2" galvanized steel pipes that creates a cradle for an elevated, wood-

framed floor plate and attachment points for infil walls and services. The matrix can be customized to meet the clients' needs in terms of plan and area. For example, the matrix system can support one bedroom or more. The Membrane Structure is a tensile fabric membrane supported by masts and cables (or straps). This too can be customized through the client-architect interface in terms of the number of humps and corners – perhaps defining spatial hierarchy, interior spatial qualities, or exterior formal appearance. There are carefully considered supporting components and options that both express the typology and enable resident lifestyle.

Figure 3.28, System Options, details some of these supporting components and options. I will describe three examples: screw-type earth anchor point foundations, standard pipe fittings, and wall options.

Screw-type earth anchors, such as American Earth Anchors Penetrator, can support both tension and compression loads. [106] The matrix rests on extendable "legs," which incorporate a threaded rod to accommodate slope and uneven terrain. These legs rest on the anchors – point foundations supporting compression loads. The anchors also support tension loads where Membrane Structure guy wires are connected. All of the anchors are connected rigidly to support live loads such as wind uplift and down force. Since the anchors are screwed into the ground, they touch the earth lightly and can be removed and

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[106] "American Earth Anchors." Penetrators™ | Screw-Type Ground Anchors. Accessed April 04, 2019. https://americanearthanchors.com/products/ground-anchors-penetrators/.

reused. The matrix can also be expanded much more easily given its point foundation as compared to slab on grade.

Standard pipe fittings such as Kee Klamp enable the client and architect to place walls and wall panels within the matrix. Fittings can be load bearing or simply attachment points for wall panels as illustrated in Space Division and Wall Infil portions of Figure 3.28. The fittings also facilitate using the matrix pipes to route electrical wiring.

Wall options are nearly infinite! The client may choose to leave gaps in the matrix empty to promote ventilation and frame views. Other options include a spectrum of rigid and flexible materials of varying characteristics, including plywood, corrugated plastic, and fabric. The client and architect should discuss concerns such as moisture/dust infiltration, pests, noise, security, daylighting, ventilation, and wind-borne debris hazards to select the optimal material. Fabrics alone offer a range of options; Serge Ferari offers the Protect line with imbedded steel mesh for security and the Alphalia line with acoustic properties.[107] Curtains are also an option!

Other supporting components and options are illustrated in Figure 3.40 Assembly/Re-erection. Now that I have presented the primary components and supporting components/options, it is clear that the collective system defines the typology, which can be tailored for a specific client/site/time.

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[107] "Serge Ferrari - Flexible, Innovative Composite Materials." Serge Ferrari - Flexible, Innovative Composite Materials. Accessed April 04, 2019. https://www.sergeferrari.com/us-en.

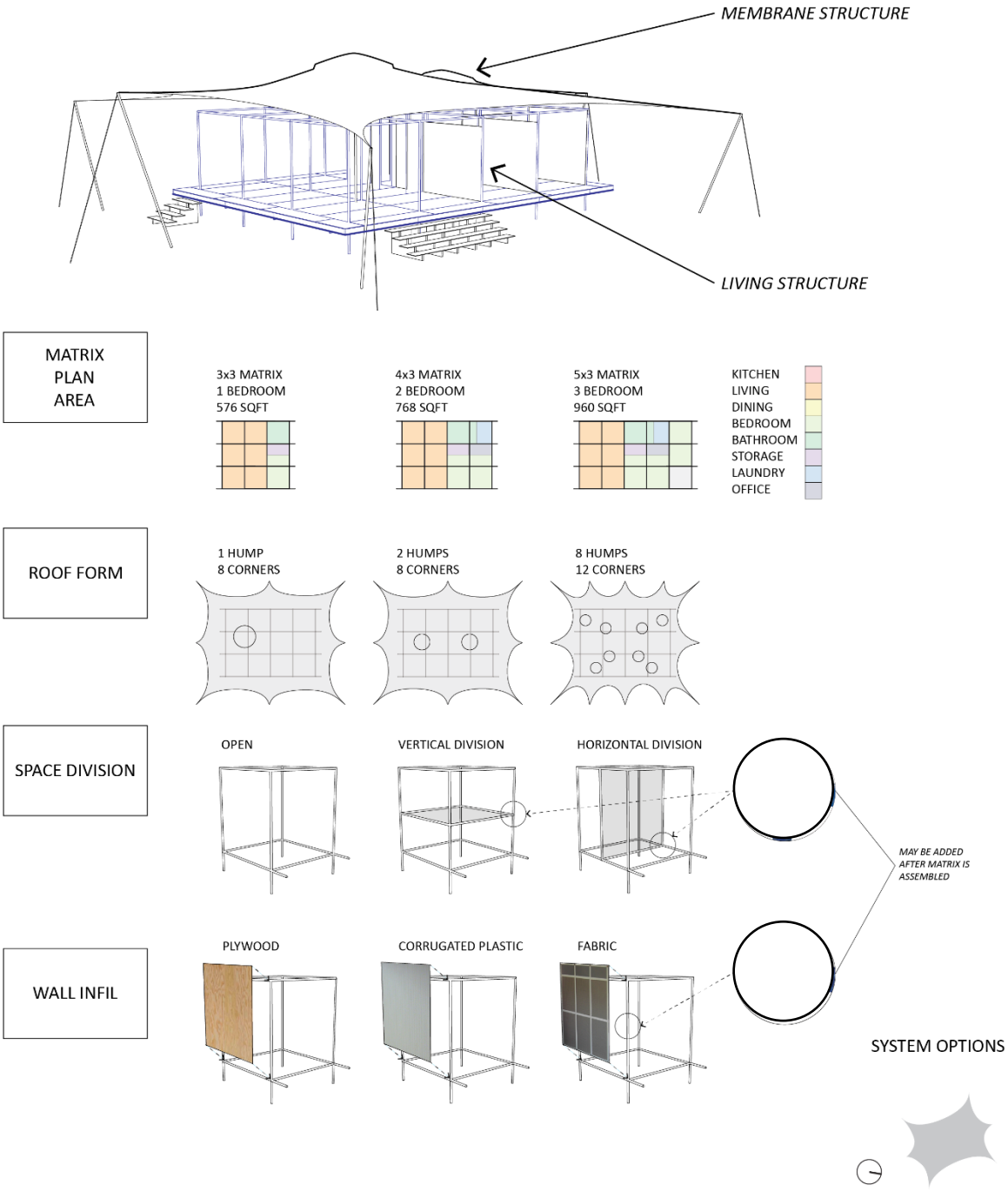

Figure 3.28 System Options

A cursory look at the dominant climate influences in Kailua are detailed in Figures 3.29 and 3.30. I concluded that the long axis of the dwelling should be oriented towards the trade winds to capture natural ventilation and to limit direct solar heat gain. When siting the dwelling, I would consider adjacent structures

and vegetal effects on wind flow and shade – staggering dwellings can focus flow.

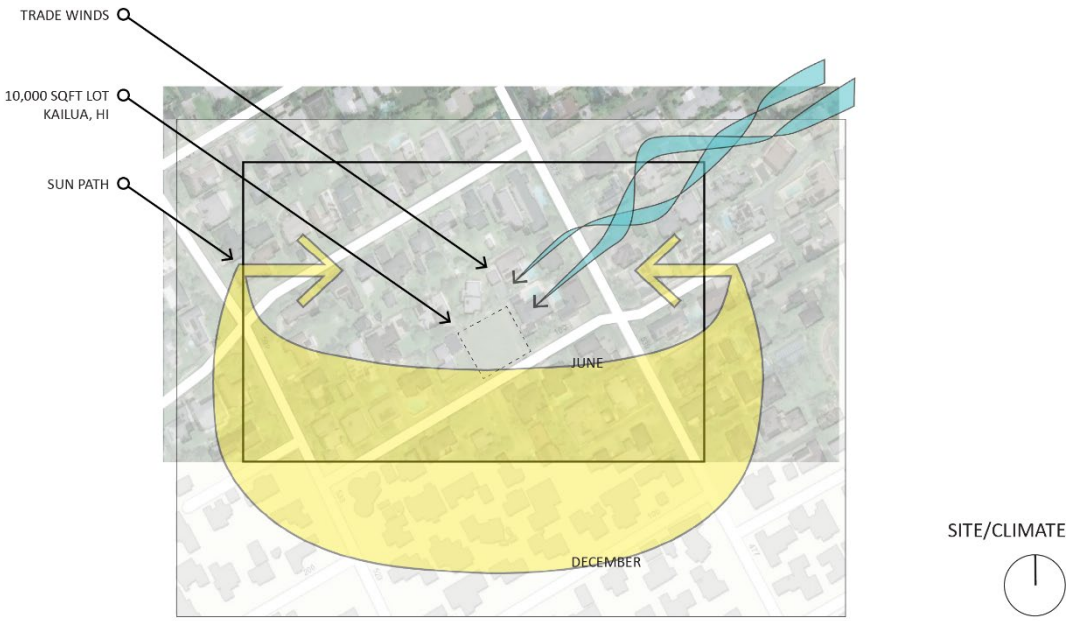

Figure 3.29 Site/Climate

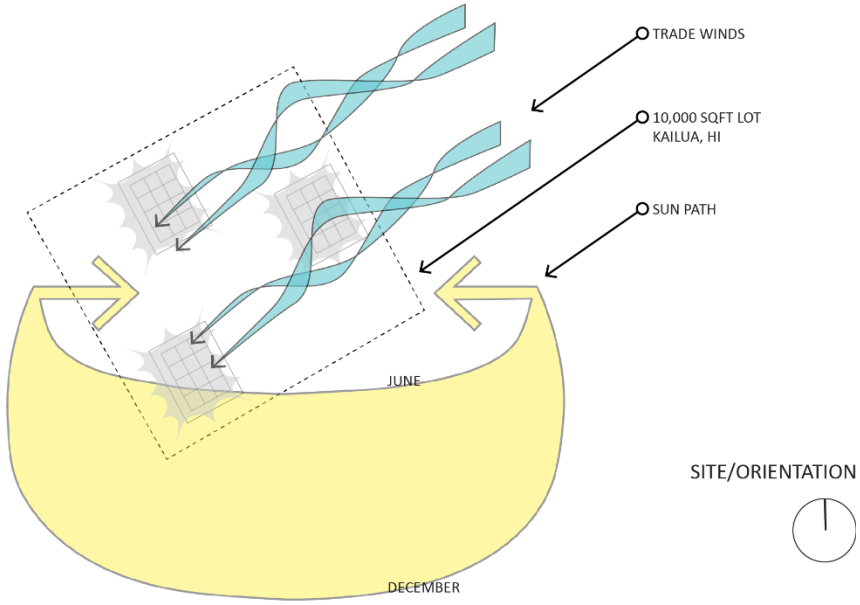

Figure 3.30 Site/Orientation

Through a process of form finding, I experimented with different roof forms to identify a visually appealing exterior form which also provided quality interior spaces. Figure 3.31 illustrates my process using Rhino, Grasshopper, and Kangaroo software as suggested by Romualdo Rivera.[108]

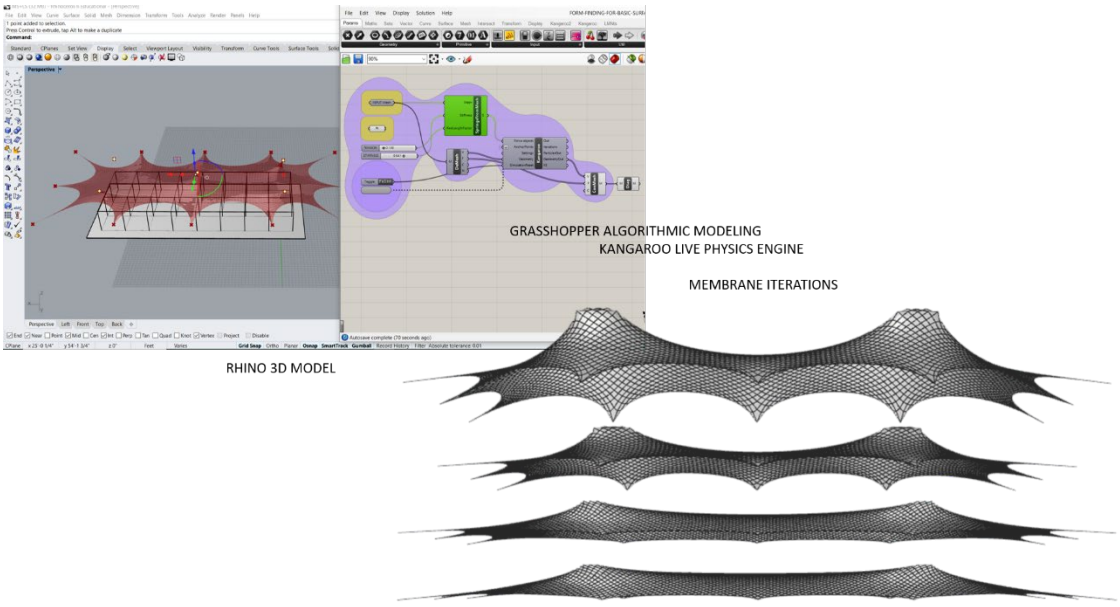

Figure 3.31 Form Finding: Rhino/Grasshopper/Kangaroo

To determine the best floor plan to support the client, I considered program, adjacency, area, circulation, and wall placement impacts to indoor/outdoor lifestyle and privacy. This exercise is illustrated in Figure 3.32 which was both a design tool and a diagram communicating the end result.

[108] Rivera, Romualdo, and Gabriella DenBlanken. *Membrane Structures: First Steps toward Form Finding*. San Juan, Puerto Rico: Membranas Estructurales, 2014.

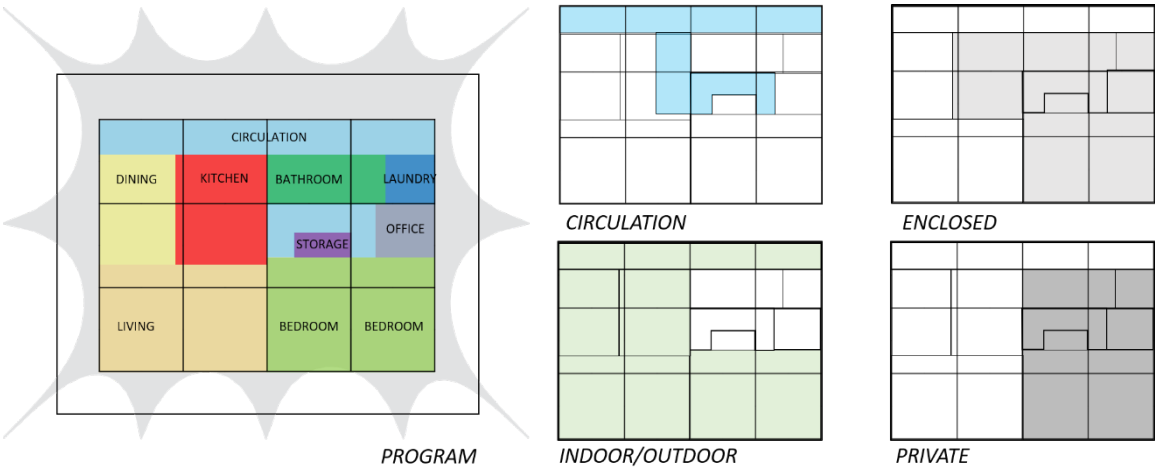

Figure 3.32 Plan, Program, Spatial Diagrams

Similarly, Figure 3.33 was a design tool to ensure walls and utilities were integrated appropriately into the matrix and utilities trough. I additionally considered how to integrate the system of masts and cables supporting the Membrane Structure. Realizing that additional masts and guy cables become obstacles to circulation and require additional materials, I refined the final membrane design to have two humps and sic corners.

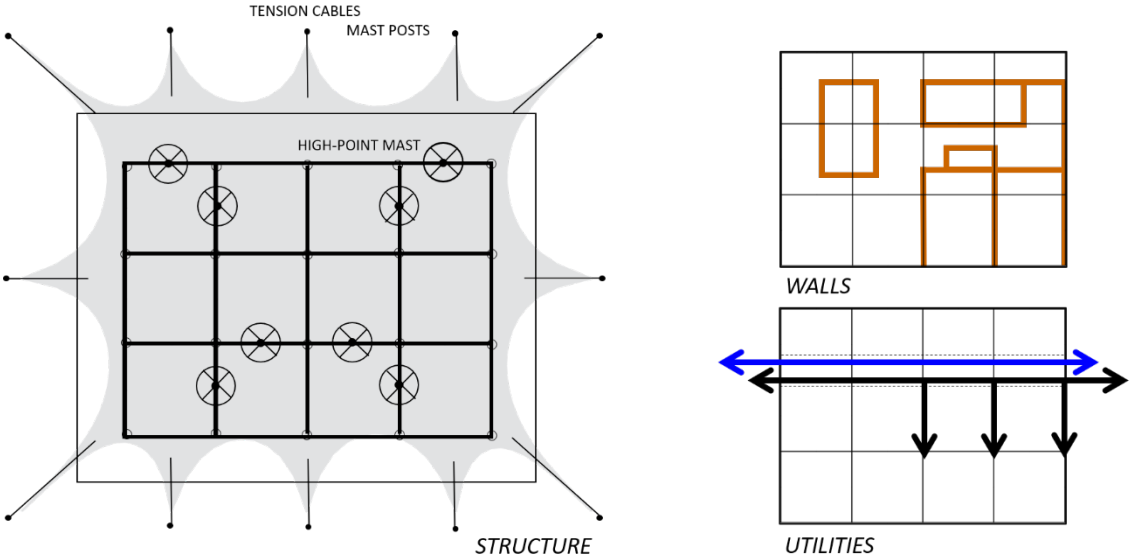

Figure 3.33 Plan, Structural Diagrams

3.7 Design Results

Figures 3.34 through 3.42 represent the design results. Additional figures are included in Appendix B. For each of the figures, I will highlight design features that characterize the system/typology.

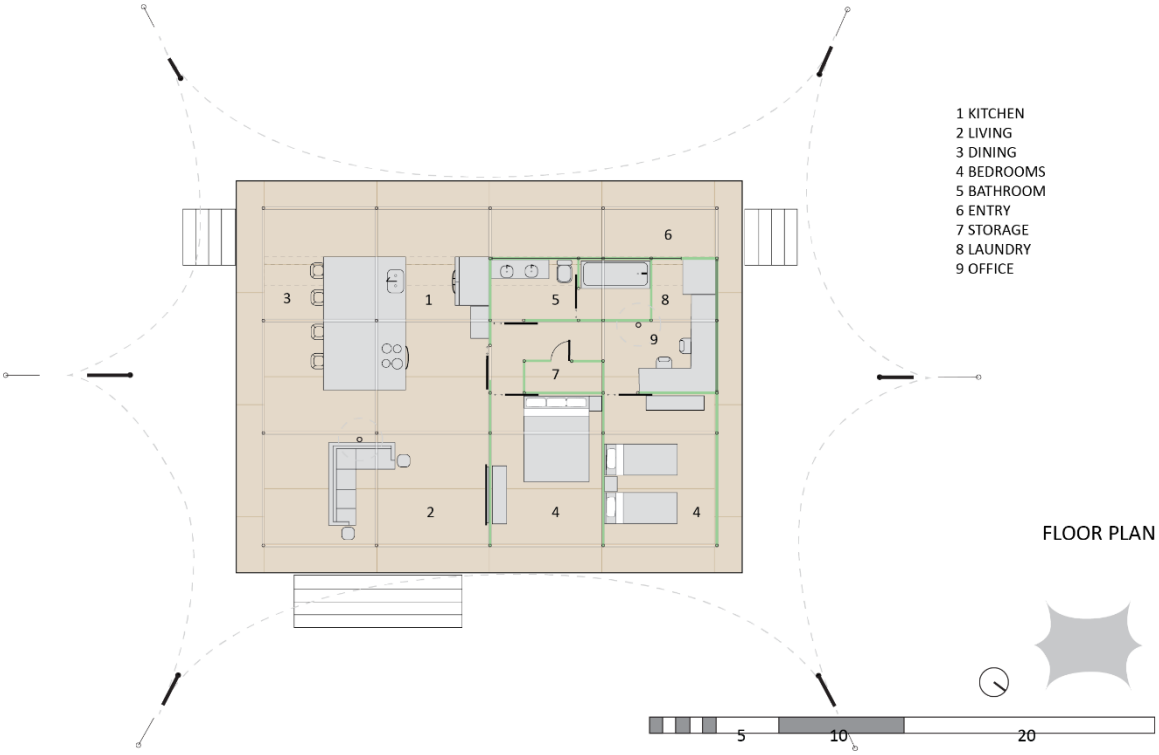

Figure 3.34 Floor Plan

The dwelling has the essentials and while the spaces are smaller that typical production homes, they feel larger due to the open plan and a less defined indoor-outdoor boundary. The walls are fabric and the materials were selected and placed to create a moisture/dust/pest barrier, provide security, and protect residents from wind-borne debris hazards. The structure is lightweight; the spaces are right-sized; the clients benefitted from dialogue with the designer.

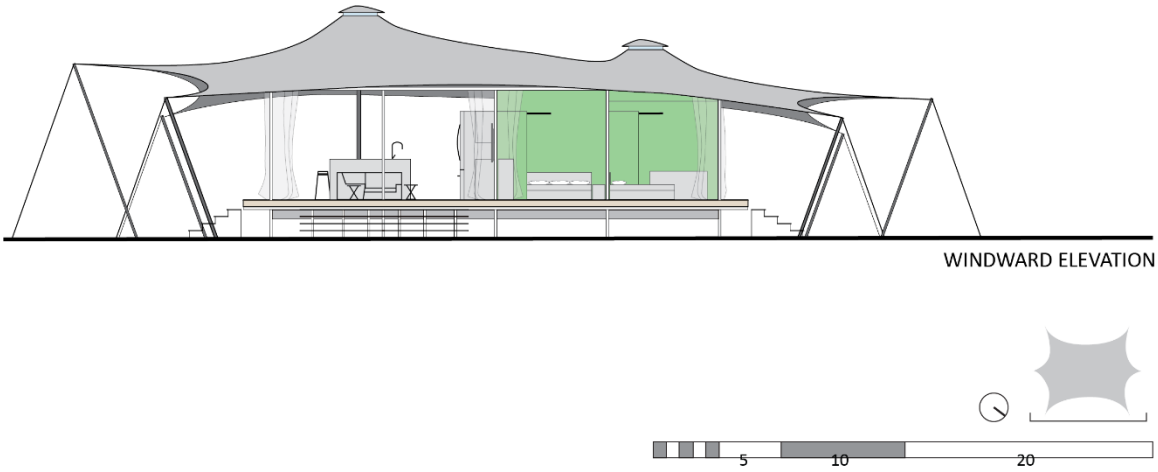

Figure 3.35 Windward Elevation

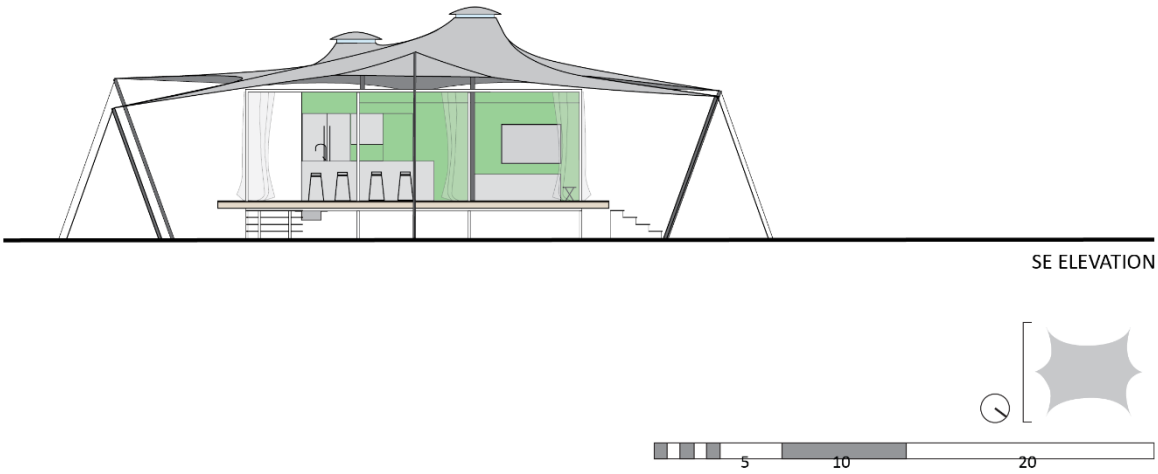

Figure 3.36 SE Elevation

In elevation, the relationship between the Living Structure and the Membrane Structure is revealed. It is not hard to imagine the influence of the tree canopy and coastal hills forms. Curtains provide a user-operated, adjustable tropical screen.

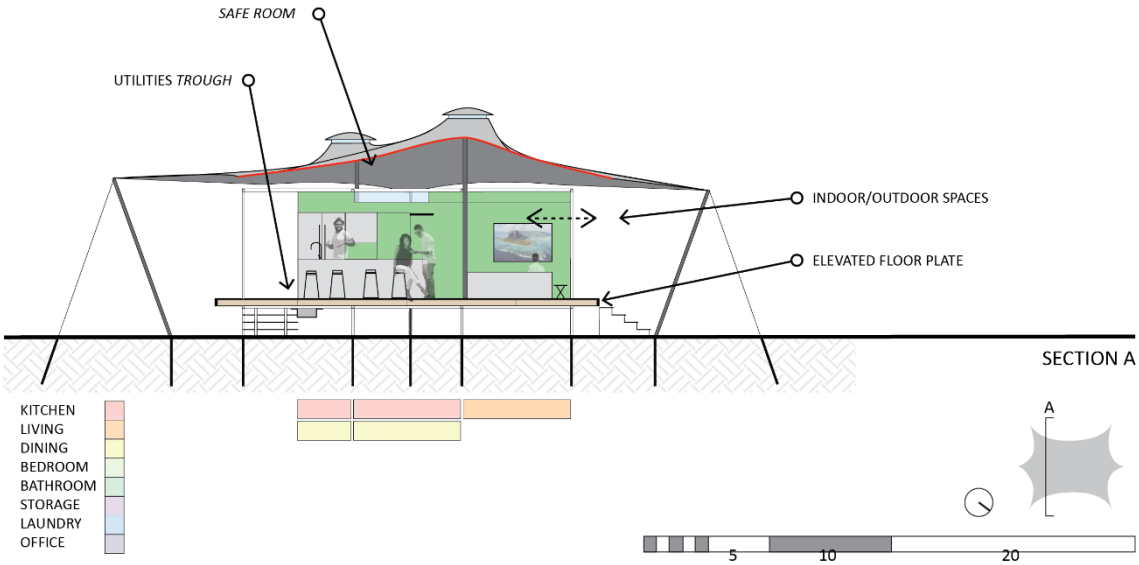

Figure 3.37 Section A

The section highlights program and features. Seeing the spaces in use and visualizing the climatic influence, one can sense achievement of human comfort and indoor/outdoor lifestyle.

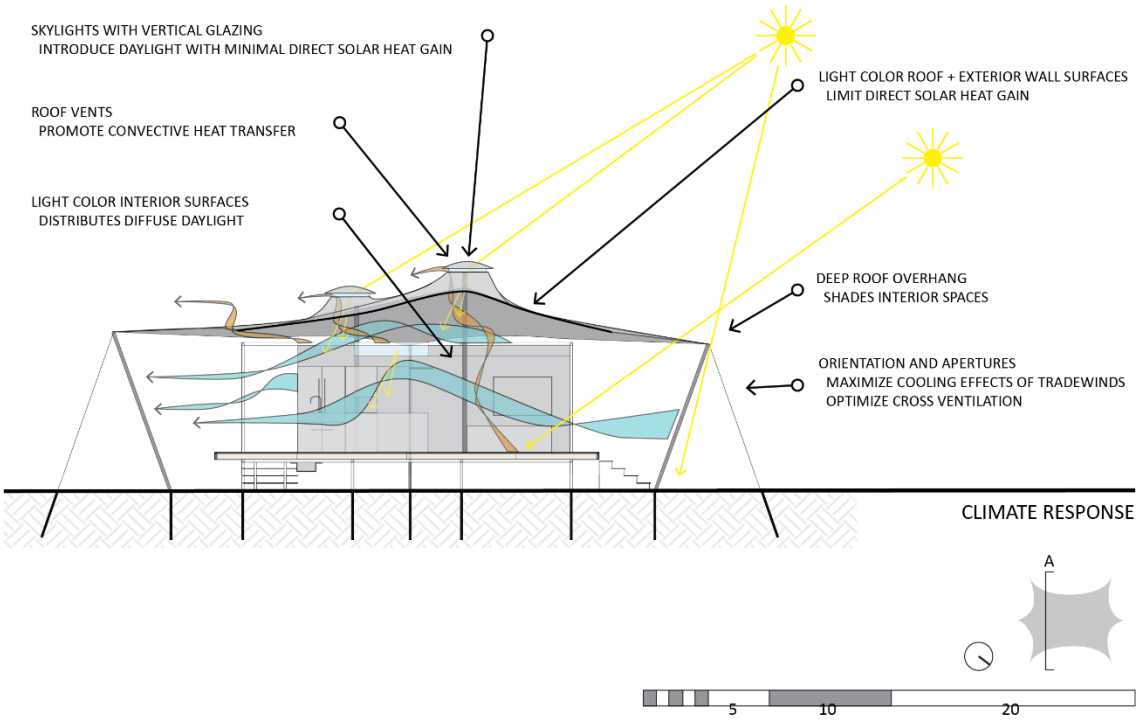

Figure 3.38 Climate Response

Figure 3.39 Exploded Axonometric provides an illustration of the primary and support components and options. This view also emphasizes how light and ephemeral the dwelling is.

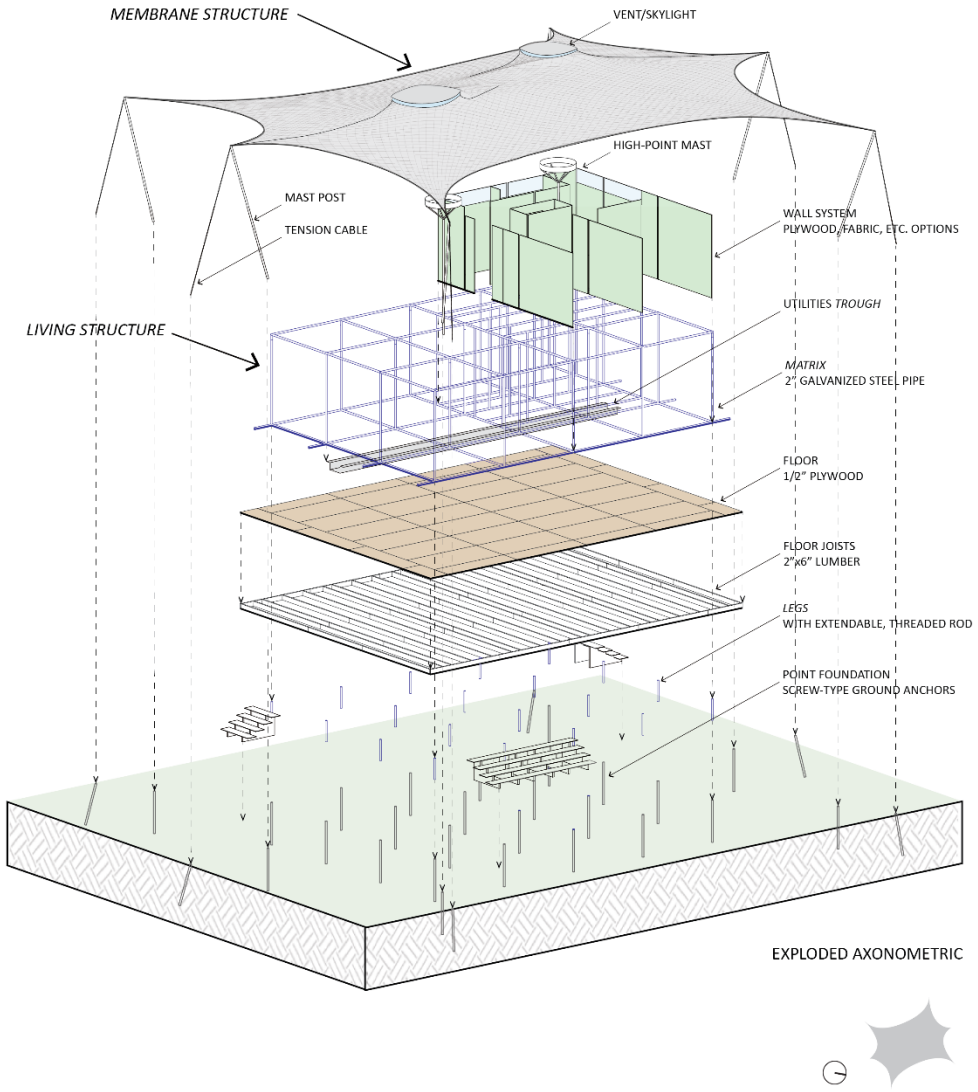

Figure 3.39 Exploded Axonometric

The Assembly/Re-erection diagram details the assembly process and identifies how a design philosophy can lead to product selection in support of the design core values. Quick disconnect fittings and rubber tension straps make this system manageable and safer for the layman/resident. A webbed edge

condition on the membrane is preferred; if the edge condition were steel cable as is often applied, the membrane would be difficult to manage and transport during disassembly and re-erection.

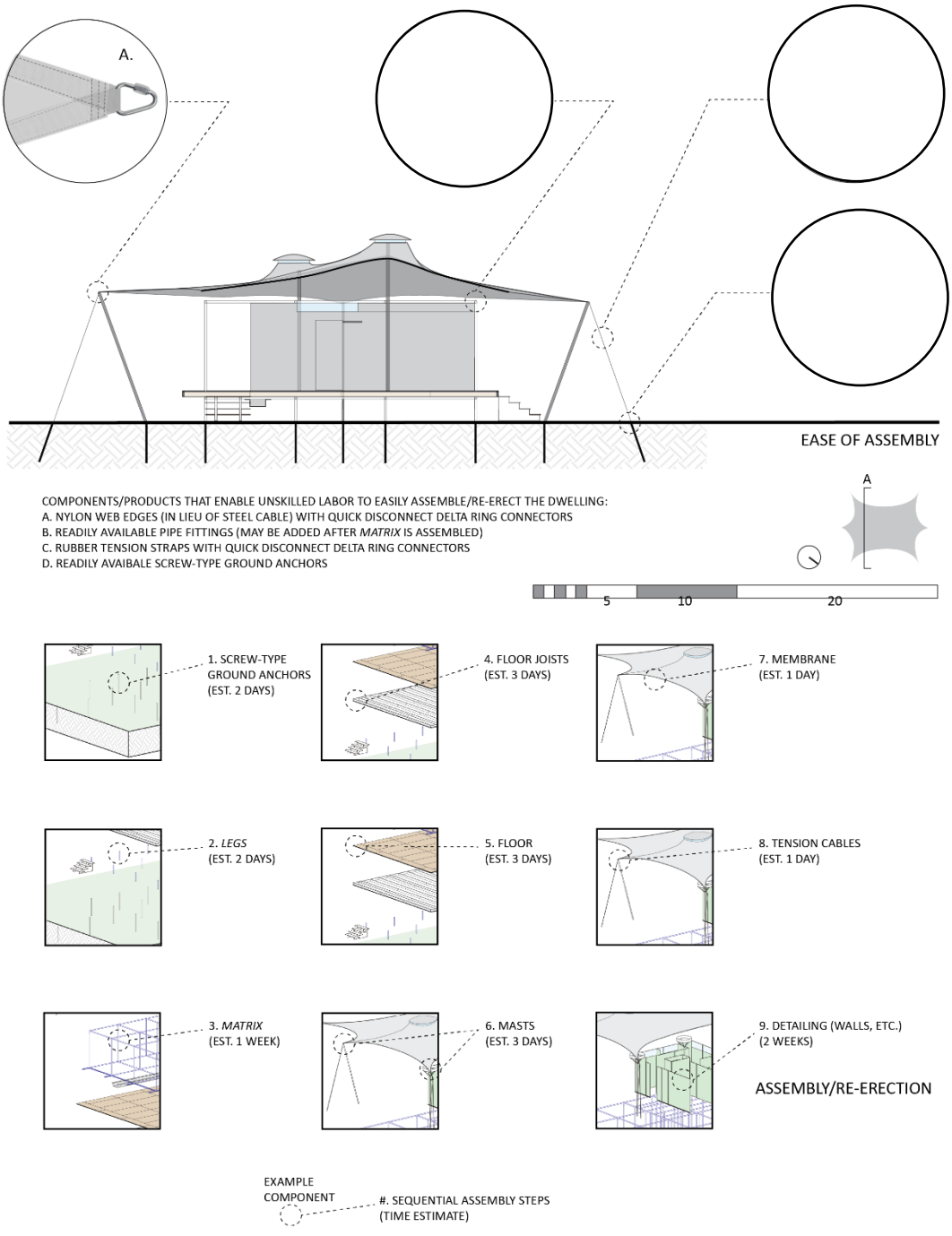

Figure 3.40 Assembly/Re-erection

Finally, Figures 3.41 and 3.42 illustrate the aesthetic appeal of the tensile fabric roof organic form while suggesting the quality of the interior spaces.

Figure 3.41 Rendered Exterior Perspective (NW)

Figure 3.42 Rendered Interior Perspective (S)

Part 3 | PROTOTYPE

4. Prototype

When I presented my Project Core Elements, I established that my DArch thesis would be equal parts dissertation and design rather than purely written work. I also established that the Project Process consisted of three phases: Research, Design, and Prototype. While I could complete the project through research and design alone, I felt that the prototype phase was critical. In studio projects, the focus is often narrow due to time and curriculum limitations – rarely, if ever, do we research, design, document, construct, and evaluate a project. The prototype phase serves three purposes: to advance my knowledge of architecture, to advise research and design, and to validate the design materials, construction concepts, and experiential qualities. This first purpose is purely epistemological; how would I know that I know unless I build, unless I carry a project from idea to product evaluation? The other purposes are more realistic and practical. I didn't want this to be a "paper project;" I wanted to know that it could be built and lived in, or at least identify the obstacles that I didn't predict or address. Additionally, while the prototype phase was limited by time and resources, I wanted to initiate fabrication of a large-scale model, representative dwelling components/modules, and/or details to assess future applicability and further research/development. Ultimately this phase is better labeled "Collaboration and Material Exploration!"

4.1 Prototype Objectives

Simply put, my prototype objectives were to put hands on materials, to work alongside tensile fabric design/fabrication professionals, and to build

something that would enable me to evaluate whether the design would comply with the design core values, specifically buildability and livability.

4.2 Prototype Inquiry

To initiate the prototype phase, I collaborated with Tropical J's, a local shade and outdoor products design and manufacturing business. Tropical J's has a history of collaboration with the University of Hawai'i schools of architecture and engineering; their projects include tensile fabric applications ranging from hand-held umbrellas and furniture to awnings and free-standing shade structures. They are capable of designing, patterning, cutting, and welding/stitching tensile fabric. Their facility and expertise also enable them to design, fabricate, and assemble support structures and hardware of a variety of materials including wood, steel, and aluminum.[109] I visited Tropical J's during the research phase of my project, and during the design phase, I presented the design concept and schematics. I generated a list of questions to launch the prototype phase and to establish objectives and expectations.

During this phase, I hoped to assess, incorporate, or invalidate design features by exploring the following questions:

- Would a double membrane roof improve thermal comfort? Could the lower membrane be separated from the outer/upper membrane by a spreader at the support poles? How much separation is optimal?

[109] "Tropical J's | Residential and Commercial Awnings." Tropical Js. Accessed April 03, 2019. https://www.tropicaljs.com/.

- How do I incorporate a convective exhaust vent to improve ventilation/circulation and extract warm air?
- How do I cap the exhaust vent to prevent moisture intrusion?
- How do I enhance daylighting and reduce radiant heat gain through material selection? Can translucent panels be offset in a double membrane to optimize daylighting and aesthetic effect?
- To achieve structural stability, what is the appropriate size of support members, cables, anchors? Can these be incorporated into the Living Structure beneath the Membrane Structure?
- How do I achieve the humped tent profile? Frei Otto used a spreader that he designed; could we employ a spreader similar to the camouflage netting spreader that the military uses?
- Could interior walls be fabric welded to the lower membrane? Could these interior walls house a conduit to route electricity and to anchor the wall to the floor?
- Which membrane materials offer the optimal balance of properties in compliance with design core values?
- How do I ensure ease of assembly/disassembly, transportation, and re-erection without highly-skilled laborers?

4.3 Prototype Progress

The prototype phase was drastically abbreviated due to competing priorities! We did succeed in continued dialogue whereby practical design/fabrication expertise and feedback advised the design result. This process was iterative and resulted in a more well-developed product reflecting the responses to my questions. Tropical J's and I had a common understanding or the design core values, which was critical to this progress and design refinement – I learned a great deal every time we collaborated. I will continue collaboration and material exploration in hopes of fabricating elements of this design!

5. Conclusion

My project was equal parts dissertation and design guided by a panel of experts representing architecture and planning, practice and academia. Along the way, I was steered by research and experiences to answer questions and to validate ideas.

I set out to understand people/housing in Hawai'i, to explore innovative, lightweight materials/construction techniques, to understand building and energy conservation codes, and ultimately to advise lower cost single-family dwelling design.

I aimed to apply the research through design response in the spirit of affordability and sustainability. I also hoped to identify and address barriers to lean structures and to introduce a lightweight, essential, tropical typology for single family dwelling which would not render a middle-class homeowner cost burdened.

5.1 Top-level Findings

There is a housing crisis in Hawai'i; it is characterized by challenges in affordability, availability, and suitability exacerbated by conspicuous consumerism and a lack of grassroots design.

Right-sizing lightweight dwellings optimized for climate response and lifestyle support through client-designer interface can pare the crisis.

A hybrid dwelling system consisting of a tensile fabric Membrane Structure and a modular Living Structure would combine the essence of Frei Otto and Ken Isaacs to achieve affordability and sustainability.

Building and energy conservation code is flexible enough to evolve and afford pioneering innovation alternative compliance. Perceptions are changing driven by affordability and fear of climate change.

The hybrid dwelling system is a lightweight, essential, tropical typology which would not render a middle-class homeowner cost burdened.

5.2 Future Research

In addition to continuing the prototype phase, I have suggested areas for further research. In my mind, these are "vignettes," opportunities to reconsider how we view housing in the future. I use the term "vignettes" because as I recognized these opportunities, I also realized that I didn't have the time to develop/understand the scenarios – they became storyboards.

- Zoning. Land lease residential and/or communal housing zoning would alleviate the land cost component of housing affordability and perhaps reinvigorate community.
- Home buying finance model. The 30-year loan has out-lived its practicality. If homes cost considerably less because they are smaller and lightweight and because the land cost component is removed, home loans could more closely resemble automobile loans.
- Mobile, easily transportable and erected 'kit' homes (may incorporate shipping container). This concept better supports the mobility in our lives. Who remains in a home for the term of their home loan?
- Home resale resembling used car sales. If homes become inexpensive, lightweight, transportable structures, there could be a used market allowing entry-level and transitional homebuyers to start small and/or temporary.

Appendix A: Additional Figures

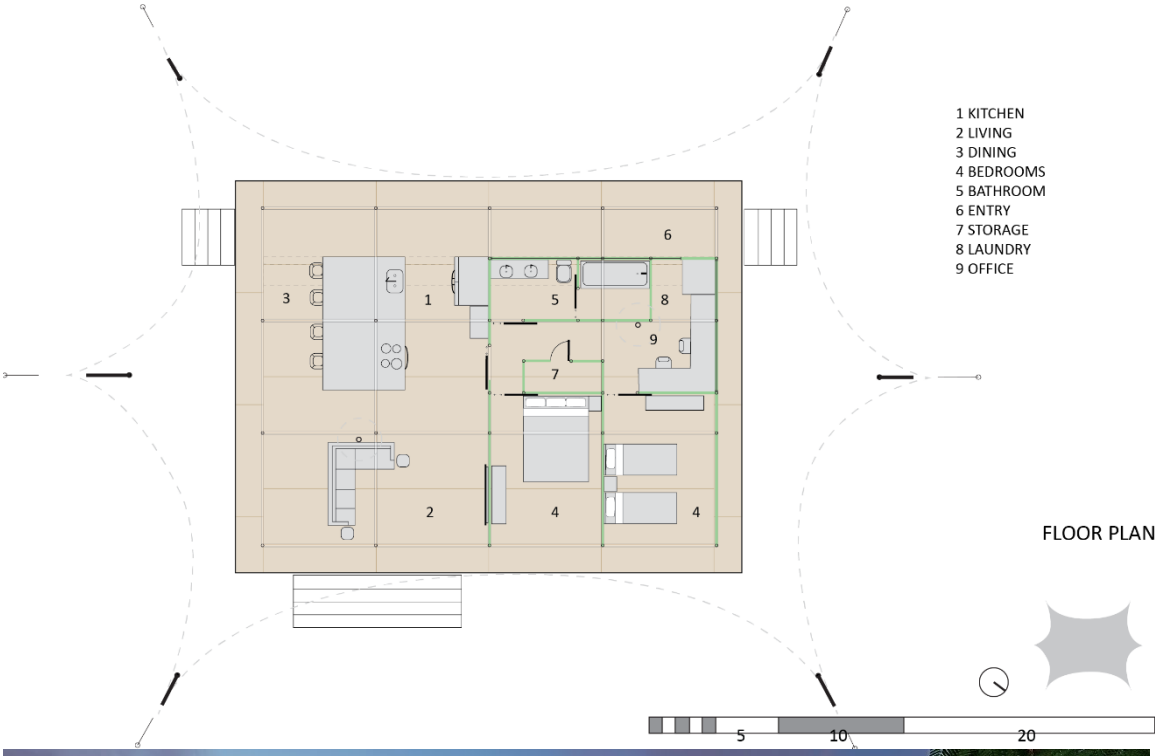

Figure A.1 Floor Plan and Rendered Perspective (NE)

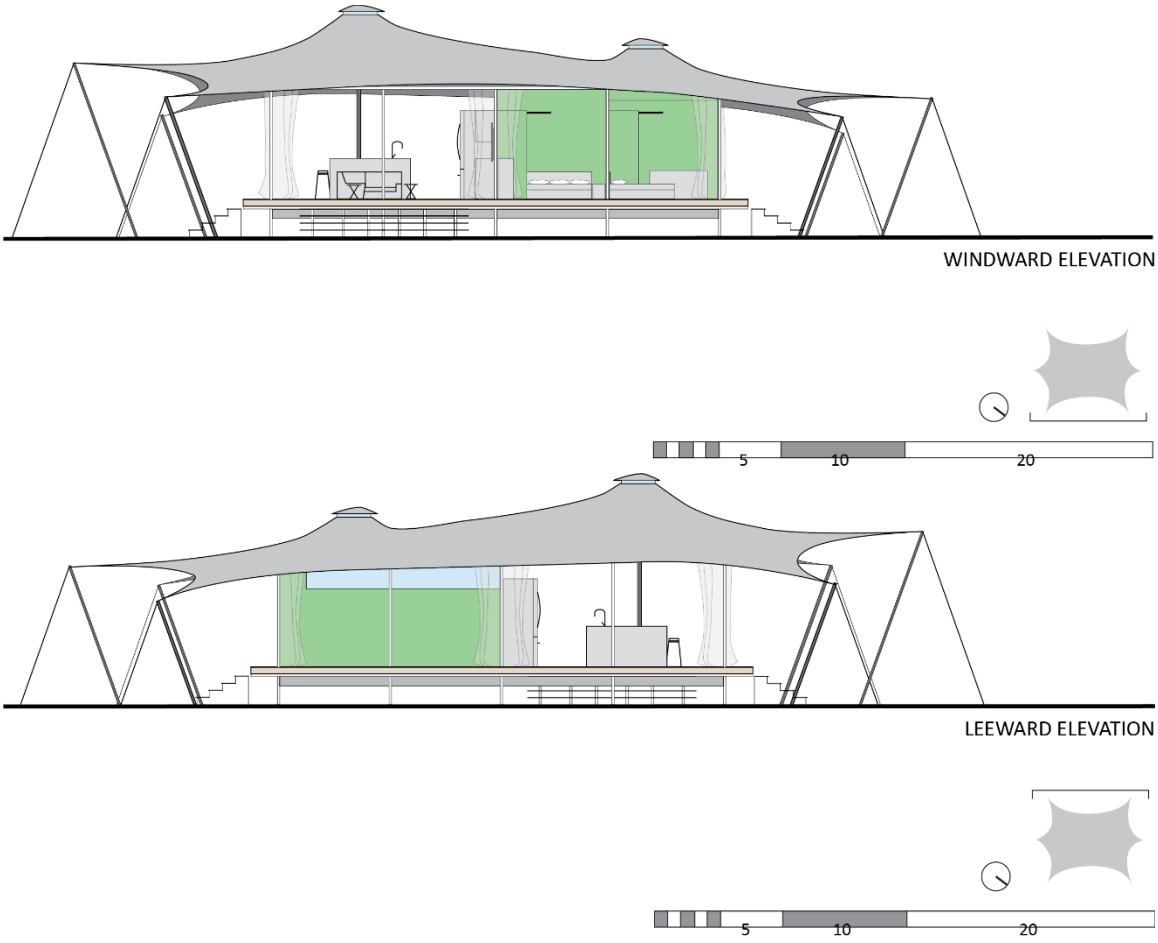

Figure A.2 Windward and Leeward Elevations

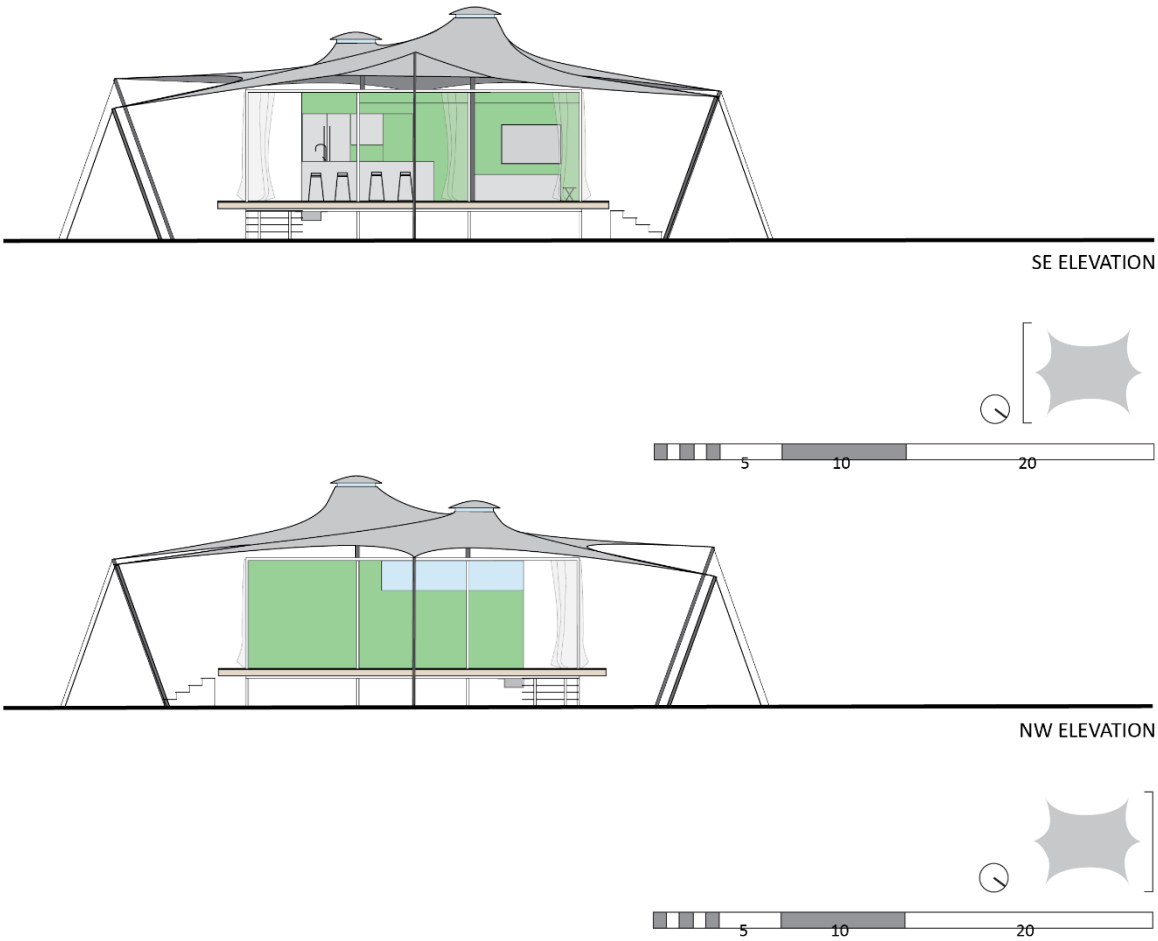

Figure A.3 SE and NW Elevations

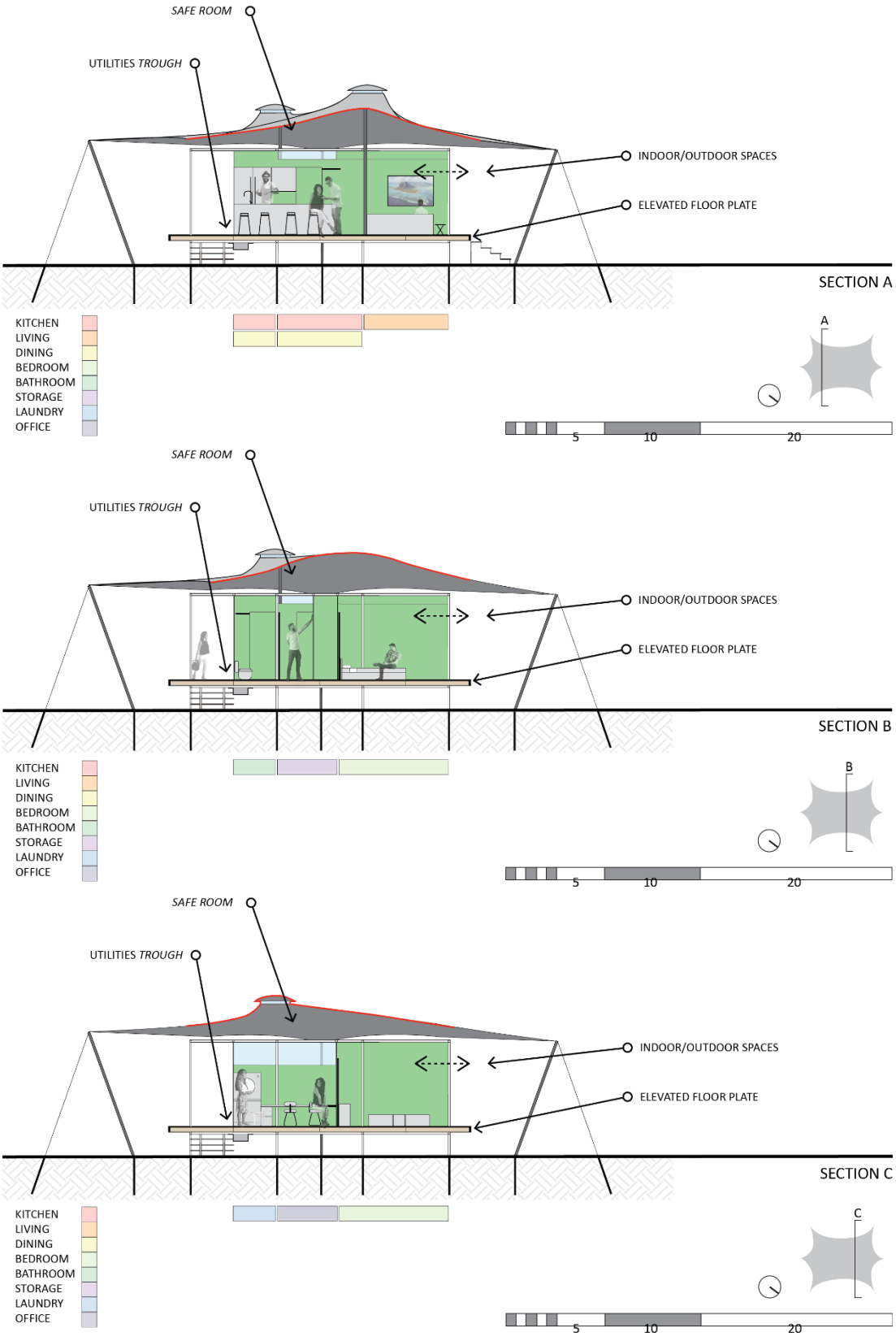

Figure A.4 Sections A, B, C

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2018 International Energy Conservation Code. Country Club Hills, IL: International Code Council, 2018.

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