[H]URBAN

APPLICATION OF HEMP-BASED BUILDING PRODUCT IN THE DEVELOPING URBAN CENTER OF KAPOLEI, HAWAIʻI

A DARCH PROJECT SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAIʻI AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Dedication

I want to dedicate this project to those who have come before me, my kūpuna; their guidance has motivated this long and arduous journey, transforming a dream and desire to create into a reality thoughtfully and meaningfully.

Acknowledgments

First, I would like to thank my committee chair, Judith Stilgenbauer, for her continued support throughout this project. Your mentorship has allowed me to explore design education in ways that I had not previously envisioned, and your motivation allowed me to make this academic journey my own. My sincerest gratitude to my committee members, Bundit Kanisthakhon and Joey Valenti, who has been instrumental in developing my design education. Thank you, Joey, for taking on the responsibility as one of my committee members and offering your insight towards a design project such as this. To Bundit, I am deeply grateful for your “out of the box” insight and energetic direction. Both of you have guided me from the beginning, supporting every creative appetite.

I would also like to take this opportunity to acknowledge my family and friends outside the world of design education. Despite my many absences from regular events and milestones during my academic journey, all of you have expressed immense support and have encouraged me to continue this intellectual pursuit. Your reassurances have silenced my doubts, solidifying my decision and devotion towards completing my task.

Finally, I would like to express my most profound appreciation and aloha to my daughters, the foundation of my never-ending inspiration. Each of you brings various perspectives but continues to be a source of astonishment and amazement. Thank you for being the beautiful, strong, caring, and individual young women that you are!

Abstract

The globalized industrial process has altered the practice of architecture where design and construction that once sourced local, sustainable building products is now replaced with heavy importation of these materials, and subsequent products, for use in the building industry. This dissertation responds to the unsustainable practices that have become commonplace within the building industry and how these practices have negatively affected our environment globally and locally. The exponential growth of our urban cores has contributed to the continued use of unsustainable building materials and products to provide housing for the increasing population while subsequently producing unhealthy interior building environments. The reaction to this, and the foundation of this project, is to explore the feasibility of alternative building material and product derived from a plant criminalized due to its association with a euphoric-inducing family member – the alternative material being derived from the hemp plant. How can the use of hemp expand upon the building and design industry while increasing the industry's environmental stewardship responsibilities? How does this use benefit our exterior and interior environments? And how can a building product be continuously applied through the reusing, recycling, and upcycling of a hemp-based building product. The product of this design research is more than just a commodity for the building industry. Still, an initiative in which the processes to produce a hemp-based product is outlined within a framework incorporating cultural perspectives with contemporary practices while accounting for the environmental impacts at every stage of the process.

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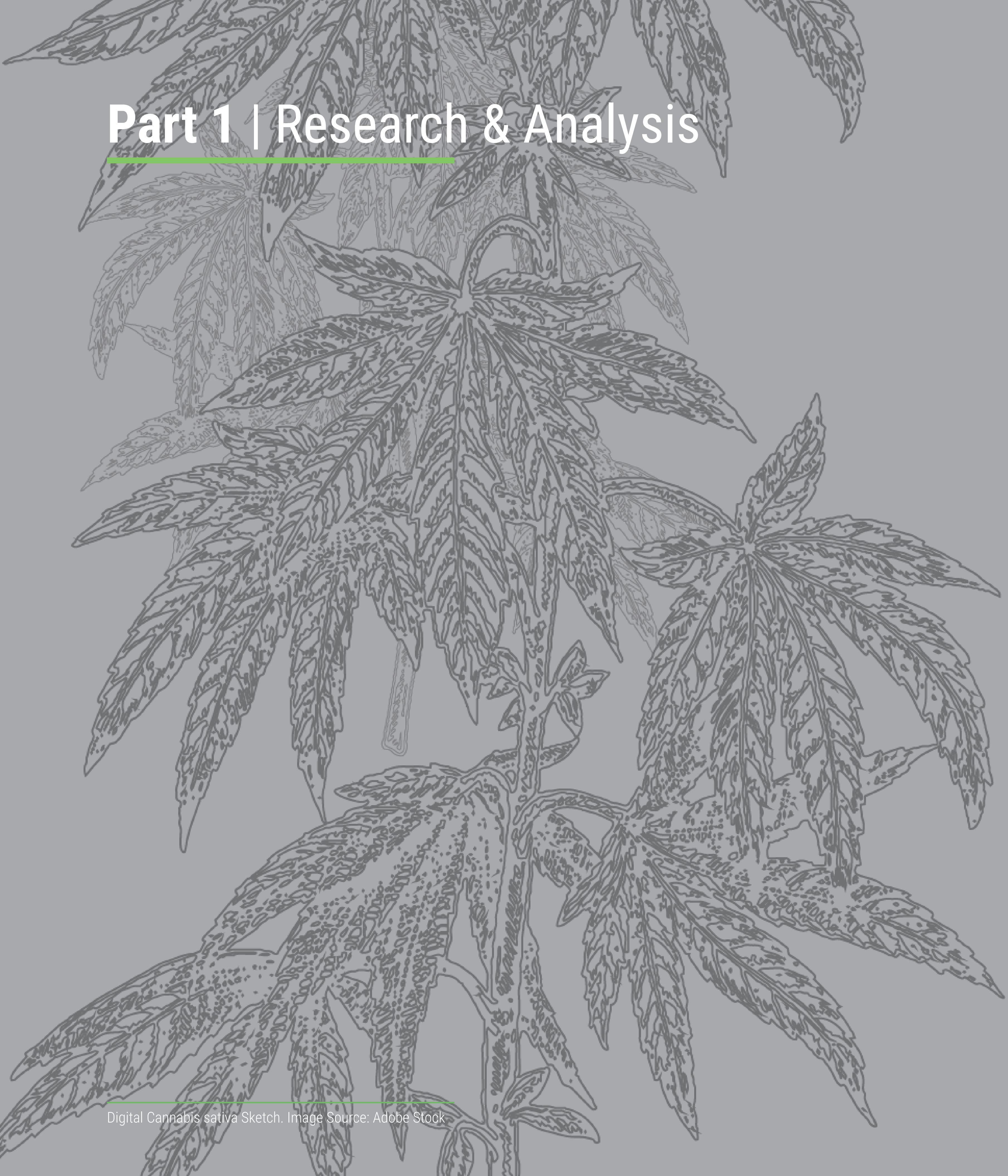


Digital Cannabis sativa Sketch. Image Source: Adobe Stock

Chapter 1: An Introduction

1.1 Inspiration

The inspiration for this research began on a couple of separate occasions during my undergraduate studies exploring environmental design. These instances offered insight into what my research topic would be without me knowing it. The first instance came during a third-year studio project where the professor asked us to design a small temporary shelter for displaced families while exploring alternative building materials. Before this project, I had never really thought about an alternative building material or applied alternative materials to a project I had designed. Finding a suitable alternative building material for this project was meant to be quick. As I stumbled through my search, I came across a product that utilized industrial hemp as a building block for structures; the product was called hemp-concrete.

My second inspiration came during an American Institute of Architecture Students (AIAS) conference, Forum. The conference intends to gather students from around the nation in one city yearly. Forum allows students to learn from other chapter leaders, discuss relevant issues to architecture and design education, and hear from leading professionals in architecture and education. It was during a lecture that introduced the idea of growing our structures. An architect was presenting the talk. For this particular lecture, he suggested that rather than cultivating traditional materials needed for conventional construction, why wouldn't we grow our structures instead, literally. It was a thought-provoking and inspirational talk; however, exploring alternative building materials' applications arose again during the lecture, and a research topic suddenly became apparent.

Lastly, the drive to explore an alternative building material became an obvious inspiration while looking for solutions for construction that was environmentally responsible, ecologically sustainable, and economically viable. The building industry's profit priority has devastated environmental and ecological systems, sustaining significant damages while forestry companies harvested conventional materials. These inspirations have navigated me towards exploring the possibilities of alternative building materials and the roles and applications of a hemp-based building product in the building industry.

Figure 1.2 Word cloud expressing the many benefits associated with industrial hemp. Image Source: Adobe Stock

1.2 Project Statement

The research for this project was in partial reaction to the environmental effects that threaten coastal communities worldwide. The island archipelago of Hawai'i has a large coastal population and already experiencing some of the effects of a changing environment; researching solutions only seemed logical as a student pursuing architecture. Researching possible solutions brought the objective of this project towards exploring the versatility and feasibility of a building product that utilizes hemp. This research would include the material's life cycle, exploring how it could be cultivated, harvested, produced, and applied as a building product in the local building industry throughout Hawai'i. Outside entities heavily influence Hawai'i's building industry. Identifying those entities and how they affect the environment and the industry became factors into further research of hemp-based building material. These factors guide this research towards finding solutions to increase the local supply of building materials and, lastly, circling back to the importance of our responsibility to the environment. This responsibility is rooted in the culture of the native Hawaiians. The importance of this obligation transcends this research but understanding the context of hemp-based building material and its relevance towards sustainable cultivation practices can transform the building industry into better stewards.

Before the last century, hemp had been a significant crop for human society. Hemp has seen many applications, from its uses as a fabric in textiles to its applications in Roman-era concrete construction. However important hemp may have been in the past, this project aims to bring hemp to the forefront of the building industry. Accomplishing this task will highlight a hemp-based product's benefits to the built environment while promoting hemp's environmentally responsible and ecologically restorative qualities. By exploring hemp's qualities as an alternative building material, designers and architects can market a hemp-based product as a material source that is inherently free of volatile organic compounds (VOCs), which have been present in the past and present building materials.

An avenue of research pertinent to this project explores how industrial hemp cultivation could occur in Hawai'i while ensuring its impacts on the unique Hawaiian ecology are minimal. The research will examine the pros and cons of growing hemp in Hawai'i while searching for a site to benefit local economies. Ultimately, the ideal scenario for industrial hemp cultivation would consider a location and population suitable for its growth while possessing enough space to expand an industrial hemp operation that would be able to harvest, process, and supply a locally manufactured hemp-based building product.

1.3 Defining a Sustainable Building Material

The building industry consists of a complex system of coordination requiring resources, vision, and knowledge to ensure its continued success. Despite the enormous challenges and risks inherent in construction, the building industry has continued to establish great strides in innovating architecture and construction practices. As equally astonishing as the resulting structures produced by the building industry, the planning and logistics of large-scale projects also carry moments of wonder from professionals and inhabitants alike. Historically, the building industry has been at the forefront and a measure of scale towards the prosperity and progress of a given society. This is partly due to professionals within the industry overcoming incredibly complex obstacles, solving challenges unique to each community. However, regardless of the initial amazement of these modern architectural achievements, we have continued to understand that the traditional materials used to create these modern structures are simply unsustainable.

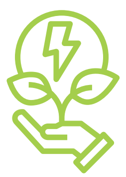
If the materials we use in construction are considered unsustainable, how do we define sustainable building material? The current dilemma that disrupts every community is that of climate change. The building industry spurred some of the effects of climate change, with many construction materials requiring a large energy consumption during production. Societies across the planet have begun to understand that the resources we use to produce these materials are finite. The over-harvesting of resources has depleted large swaths of forests. The pollution that it causes during its production generates elevated concentrations of Carbon Dioxide (CO_2) in our atmosphere, all contributors to the phenomenon of global warming. The challenge for the building industry is to examine and explore methods focused on providing a sustainable building product.

The building industry has recognized its role and has begun to react to the modern environmental problems associated with climate change. They've done this by implementing design innovations that focus on the level of 'green' incorporated into a project's design. Implementation of green designs is mainly related to optimizing a building's energy consumption or improving a building's performance. This practice is becoming increasingly acceptable and is a step in the right direction; however, it lacks its observations of the entirety of a project. Focusing on how a building performs doesn't consider the integrated life cycle of the materials used. This translates into defining a sustainable building material by considering how a building product is produced, its abundance, and accessibility. The following is a list of criteria that should provide a sufficient definition of sustainable building material.

Ecologically Conscience – the material's cultivation, production, transportation, and usage should be beneficial or non-threatening to the native ecological systems and the environment.

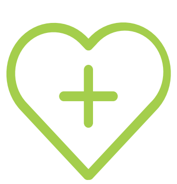
Renewable & Reusable – materials used in construction and throughout the building industry should be sourced from renewable resources, meaning that a natural resource must possess the ability to replenish and replace the portions that have been consumed for use through natural processes. These resources include materials harvested from trees and plants or from any part of the natural environment that possesses the ability to regenerate those extracted resources. Most of the structures we inhabit have a service life, they ultimately are demolished and the materials disposed of. For this reason, the materials used in the construction of our structures must be reusable. A materials reusable quality could be considered in three ways. The first is the recycling of the material into another reusable product. The second method is by utilizing the existing material to serve another purpose or upcycling the material. The last quality is that the material is made of an utterly bio-degradable substance, ensuring that it doesn't create other waste at the end of the material's life cycle.

Abundance – the abundance of material plays a vital role in classifying it as a sustainable material. The material quantity should also be a factor of its locale, alleviating the reliance on long-distance shipping. Transportation adds another factor to a material's abundance, accessibility. A material that is considered a sustainable building material should be relatively accessible to the project site.



Conservation of Energy & Carbon Neutrality – our current production methods rely heavily on a system that consumes a finite resource as its energy source. In establishing a definition for a sustainable material, this standard practice should be lessened to a significant degree. Additionally, with the rise in renewable energy technologies, sustainable materials should rely entirely on these technologies as their energy source. With the current climate crisis, sustainable building materials would aid in mitigating the causes of GHG emissions. This aid is achieved by ensuring that the material's entire life cycle and its relationship to carbon dioxide are as minimal as possible. Today, the building industry relies heavily on carbon-intensive materials like aluminum, plastics, foam insulation, and concrete.

Quality & Durability – maintenance and aftercare of any product are always of concern to clients of any project. Therefore, sustainable building materials are composed of elements that ensure high quality while also durable enough to withstand the elements. Ensuring that a sustainable product is of good quality and durable establishes its longevity, equating to utilizing fewer materials for a replacement product.



Health & comfort – for many decades, the building industry has, unknowingly at the time, applied products to structures that have come with detrimental side effects to the building occupant's health. Inherently toxic substances in materials have leached out, making their way into our bodily systems, causing what is now known as Sick Building Syndrome. Producing products from sustainable materials should utilize every effort towards ensuring that the materials do not contain any toxic substances to humans. In tandem with health, assuring the building's comfortability for its occupants is an essential quality of sustainable building material. Providing structures and dwellings with materials that positively affect its interior spaces' climatic conditions allow occupants to have a level of assurance that their homes are safe and healthy. A sustainable material that could ensure proper comfortability is temperature, humidity, lighting, airflow, and noise.

Multi-use & Flexible – some of the materials used today are highly customizable, making their use towards other applications difficult. A sustainable material should be versatile in its applications. A material's versatility allows for higher demand and more extensive production. With increased production comes decreased manufacturing time and energy waste. With the supply of a sustainable material that satisfies the demand, structures are constructed cheaper and more straightforward.

In conclusion, whether built or natural, sustainable materials change the way humans interact with our environments. We have grown conscious of our past using unsustainable materials and have begun moving toward sustainable prosperity.

Figure 1.3 Government Opportunity

1.4 Opportunity

In the past several year's hemp cultivations has seen a resurgence. President Barack Obama signed the Agricultural Act of 2014, which contained an amendment to legalize industrial hemp production. Section 7606 of this Act brought excitement to grassroots organizations advocating for hemp's return as an agricultural commodity in the United States. This section allowed for the cultivation of hemp for research purposes "under an agricultural pilot program or other agricultural or academic research." The establishment of an agricultural pilot program allowed colleges and universities to examine the "growth, cultivation, and marketing of industrial hemp." The State would monitor these programs, and the State would ensure that these programs would only be conducted at institutions of higher learning or state departments of agriculture. After President Obama signed, this act legislation for the cultivation of industrial hemp was introduced in Hawai'i.

The Trump administration further progressed the cultivation of industrial hemp with the Agriculture Improvement Act of 2018. This 2018 Farm Bill "legalized [industrial] hemp production for all purposes within the parameters laid out in the statute." A central point of the statute is that industrial hemp, defined as "any cannabis plant, or derivative thereof, that contains not more than 0.3 percent delta-9 tetrahydrocannabinol (THC) on a dry-weight basis," will no longer be considered as a schedule 1 controlled substance under the Controlled Substance Act (CSA) of 1971. The U.S. Drug Enforcement Agency (DEA) defines a schedule 1 substance as a "substance or chemicals. . .with no currently accepted medical use and a high potential for abuse." Industrial hemp's cousin, marijuana, is on this list of substances, and for decades, hemp carried the same criminal stigma as marijuana. The Act also emphasizes that each state would still maintain its decision to enforce laws on industrial

hemp production and whether or not they would feel a need to legalize its cultivation and production within their state. Upon the enactment of the 2018 Farm Bill, the Department of Agriculture (USDA) would establish licensing requirements and regulations of hemp cultivation and production. These regulations would make industrial the cultivation and production of industrial hemp only available to those who possess a valid USDA-issued license.

On August 27, 2020, the State of Hawai'i signed into law Act 014, "legalizing the growth of hemp in the state through the U.S. Department of Agriculture Domestic Hemp Production Program." This Act presented the opportunity for the commercial cultivation of industrial hemp in Hawai'i. Farmers in Hawai'i would still need to acquire a hemp production license from the USDA while complying with the rules and regulations that the USDA had put in place to cultivate and produce industrial hemp. Some of the rules and regulations that the USDA implemented would play into the viability of hemp production and its use as an alternative building material. The essential regulations guiding hemp production that this research and design will follow are:

- Hemp growth can only occur in the state agricultural district.
- Hemp shall not be grown 500 feet of pre-existing real property comprising a playground, childcare facility, or school.
- Hemp shall not be grown within 500 feet of any pre-existing house, dwelling unit, residential apartment, or other residential structure that the license holder is not owned or controlled.
- Hemp shall not be grown in any house, dwelling unit, residential apartment, or other residential structure.

An essential component to this new Act is that although individuals must possess a valid USDA hemp cultivation and production license, the USDA would not regulate any of the processing and manufacturing of hemp-based products.

These three instances spanning over the last decade have presented many with the opportunity to explore the various uses of industrial hemp. With the governments from the federal level to the state enacting laws that decriminalize hemp and regulate its production, states like Hawai'i can begin to explore other agricultural commodities for the future.

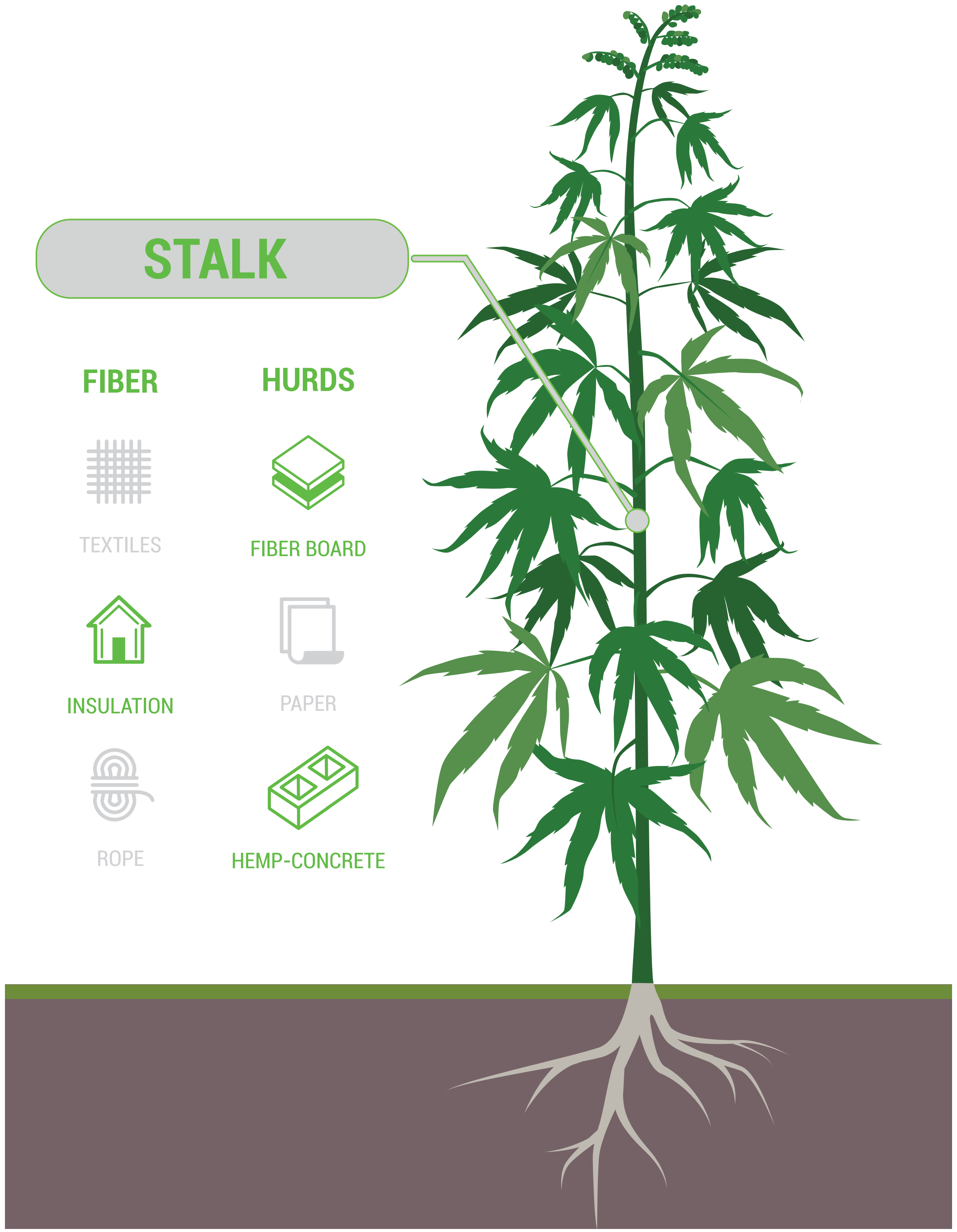


Figure 1.4 Hemp Stalk Uses and Commodities.

1.5 Agricultural Commodity

Industrial hemp has historically had an abundance of uses. Its presence has not been seen in Hawai'i in a traditional or contemporary agricultural context. Other introduced crops to the islands have made their way across the Pacific. Crops introduced by the native Hawaiian people were plants that Hawaiians brought as a vital food source to cultivate throughout the island chain for centuries responsibly. The arrival of westerners saw the agricultural landscape of Hawai'i change drastically. These western influences would introduce crops that would occupy large parcels of land for-profit and not necessarily for human consumption. Crops like pineapple, sugar cane, and coffee would become Hawai'i's three largest monoculture crops, effectively altering the views of an agricultural commodity from a crop that provides food and sustenance to one that was for-profit.

An important note is that this research looks to investigate industrial hemp cultivation and production in ways that mirror the traditional practices of native Hawaiians. The idea that an introduced crop can be responsibly and environmentally cultivated is this research's priority. However, the possibility of providing Hawai'i with an alternative source of economic stability through environmentally responsible agriculture, and the products derived from those crops, could be a secondary outcome that furthers the progression of industrial hemp cultivation in the islands of Hawai'i.

Figure 1.5 Physical similarities of hemp and marijuana. Source: Adobe Stock

1.6 Nomenclature & Uses

The botanical term for industrial hemp is *Cannabis sativa.* It shares the same botanical name as its cousin, marijuana. For this reason, industrial hemp cultivation had been made illegal through policies meant to deter the use and consumption of marijuana, a psychoactive substance possessing more than the 0.3 percent THC levels of its hemp cousin. However, the previously mentioned policies have made small strides to change the public views of these two species of *Cannabis sativa*. With education and familiarization, society will understand and distinguish these two plants and their different purposes and chemical makeup.

The physical similarities of hemp and marijuana are few. The closeness in their resemblances to one another has also played a role in hemp bias characterization. For this research, it is essential to distinguish between the two species of cannabis while informing the reader on the proper terms and vocabulary both in the agricultural and production realms.

Marijuana growers commonly keep their plants at a few inches or between 7 and 20 inches in height during their entire growth cycle. These growers purposefully limit the plant's height, often allowing the plant to auto flower, essentially transitioning the plant from a vegetative to a flowering state without the need for light. The marijuana plant is small and heavily branched, helping it produce

copious amounts of both stem and leaves. The venation of either hemp or marijuana leaves shows a typical vein pattern, but the marijuana leaves are generally more comprehensive than hemp.

Hemp plants have an average height of up to 16 feet when they are grown. The plant's stalk, which measures between a quarter of an inch to three-quarters of an inch in diameter, has few to no branches. Industrial hemp's leaves, which have a distinctive diagnostic venation pattern with multi-divided leaflets, are typically more concentrated near the plant's top and thinner than marijuana leaves. Currently, hemp's cultivation is directed towards the production of fiber and oil. The plant is grown in such a way so that it yields the highest amount of fiber while providing a sufficient number of seeds for oil extraction. Hemp fiber is harvested from the stalk and is the phloem or the outer tissue of the stalk. The portion of the plant that this research is primarily interested in is the shives, the inner core of the stalk, yet the remaining portion of the plant and its uses should be briefly explored.

1.7 Conclusion

With the loosening of regulation aimed at its psychoactive cousin, hemp cultivation and production have made strides towards traditional and contemporary products. Hemp uses vary from food to textiles to biofuels, plastic composites, and building materials. This doctorate project intends to thoroughly investigate and research a hemp-based product for the building industry that expands upon the industrial crop's current uses.

Figure 2.1 Coastal Erosion on O'ahu's North Shore. Image Source: Honolulu Star Advertiser.

Chapter 2: Climate-vulnerable Society

The island archipelago's vulnerability to the effects of climate change rests in its central location in the most expansive body of water on earth. For the islands, climate change presents itself as a threat from rising temperatures and rising oceans. The rising air and sea temperatures will begin to shift the rainfall patterns throughout the islands. This effect will also cause changing sea levels affecting more than a million Hawai'i residents that the National Oceanic and Atmospheric Administration (NOAA) classifies as living within a coastal county.[1] However, Hawai'i is also accountable for its contribution to the effects of climate change. According to the U.S. Energy Information Administration, ". . .more than four-fifths of Hawai'i's energy consumption is petroleum, making it the most petroleum-dependent state."[2] Efforts to scale back, and even eliminate, the state's dependence on its consumption of imported fossil fuels. The state's residents have recognized the importance of becoming less reliant on sources that the state contributes to climate change, asking their elected officials for policy change while tying it back to a Hawaiian cultural concept.

1 NOAA Office of Coastal Management, "Fast Facts, Hawaii." 2021, https://coast.noaa.gov/states/hawaii.html.
2 U.S. Energy Information Administration, "U.S. Energy Information Administration - Eia - Independent Statistics and Analysis," Hawaii - State Energy Profile Overview - U.S. Energy Information Administration (EIA), 2019, https://www.eia.gov/state/?sid=HI.

2.1 Aloha' Āina

As the island archipelago of Hawai'i rests seemingly motionless in the middle of the Pacific Ocean, its naturally beautiful landscapes ostensibly provide a feeling of care; care for the land, and the land will care for you. This Act of caring is expressed in Hawaiian as aloha' āina. Aloha' āina is a relatively modern term viewed as a rallying call during the Hawaiian Renaissance of the 1970s. During this time, a grassroots movement that sought the demilitarization of the island of Kaho'olawe, an island utilized as a strategic military munitions bombing and testing site, embraced the term. However modern the term, its foundation arises from a culture whose values are rooted deeply in a familial relationship to nature. To Hawaiians, aloha' āina is more than an expression spoken but an act invoking a reciprocal relationship between humans and the land; care for the land, and the land will care for you. In Hawai'i and throughout the world, this reciprocal familial relationship that humans once nurtured has been severed. This disconnect begins a chain of events in the form of climate change.

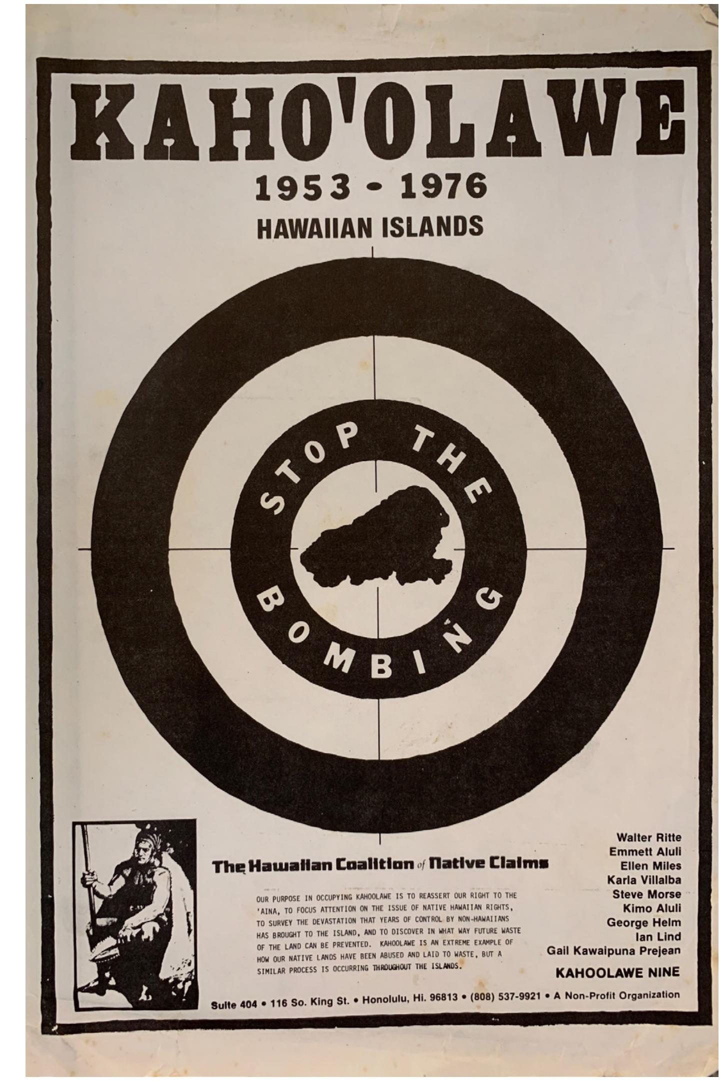


Figure 2.2 Poster reasserting native Hawaiian right to 'āina. Image Source: https://www.ilind.net/2018/11/22/throwback-thursday-stop-the-bombing-1976/

Figure 2.3 Water inundation in Māpunapuna industrial district, O'ahu, Hawai'i. Image Source: University of Hawai'i School of Ocean and Earth Science and Technology, SOEST.

2.2 Climate Change

Hawai'i's location makes it susceptible to the effects of climate change. The effects of climate change that residents have already endured are sea-level rise, coastal erosion, and water inundation. These effects, compounded by the unexpected frequency of natural disasters, put the population of Hawai'i in a particularly vulnerable situation. The island of O'ahu, where close to 70% of the state's population resides, is particularly vulnerable to sea-level rise and coastal erosion. Oʻahu's vulnerability resides in the fact that nearly 101,000 acres are classified as urban by the State Land Use Commission.[3] These urban areas predominantly occupy coastal regions on the island and hence experience the changing of the tides of sea-level rise, coastal erosion, and water inundation encroaching upon Oʻahu's urban core.

Understanding that our society is faced with a climate challenge, steps at the federal level has been taken towards achieving a long-term reduction in greenhouse gas (GHG) emissions. Policies like Representative Ocasio-Cortez's House Resolution 109, Green New Deal, call upon the federal

3 Dept. of BEDT Hawaii State Office of Planning, "Land Use Division," Office of Planning Land Use Division Comments, 2006, https://planning.hawaii.gov/lud/.

Figure 2.4 Representative Ocasio-Cortez's Green New Deal. Image Source: The New York Times

government to put forth the initiative towards weaning the United States off of fossil fuels. A study in 2016 sponsored by the U.S. Environment Protection Agency (EPA) stated that "greenhouse gas emissions totaled 6,870 million metric tons (15.1 trillion pounds) of carbon dioxide equivalents."[4] As the second-largest producer of greenhouse emissions, the United States has been slow towards adopting a policy towards mitigating GHG emissions. However, with policies like the Green New Deal, incentives like higher-paying jobs for clean energy industries are also proposed. , leaving the participation and initiative up to the industries producing GHG emissions. The federal government isn't the only level where change could happen; each state also possesses the power to institute changes in its GHG emissions.

Recognizing the effects of climate change, the State of Hawai'i has pushed towards reducing GHG emissions. The reduction of GHG emissions has included the introduction of policy changes at the state governmental level. In 2018 legislation was passed to make Hawai'i carbon neutral by the year 2045. This legislation, HB2182, was put into effect and established a Greenhouse Gas Sequestration, Task Force. This legislation went into effect on July 1, 2018, later referred to as

4 U.S. EPA. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2014, 2016,

Act 15. Legislative actions, such as Act 15, are not the only strides that the State of Hawai'i is pursuing towards mitigating GHG emissions. Policies like Act 83, Session Laws of Hawai'i 2014 of SB263 which "formally established the Hawai'i climate adaptation initiative to enable a coordinated approach among all agencies at all levels of government to plan for and address the effects of climate change to protect the State's economy, health, environment, and way of life."[5] In 2012 the legislature decided on a climate change adaption strategy that prioritized and encouraged the collaboration of agencies to identify their obligations as responsible environmental stewards and begin addressing Hawai'i's contribution to the effects of climate change. The list of sectors needing to identify how their conduct influences climate change ranges from agriculture to education. What is relevant to this research is the state highlighting industries that revolve around the built environment, water resources, and the economy.

The State of Hawai'i's importance is that change needs to happen within the building industry to reduce GHG emissions. This change of tone speaks to one of the primary questions that this research looks to address, how a hemp-based building product could reduce the effects of GHG emissions and climate change on a local level. A way to move forward, lessening our energy consumption, is by adapting to a building product that is locally produced. This adaptation reduces the transportation needs of imported building products. A hemp-based building product consumes less energy during its cultivation and production than traditional building products like cement.[6] Additionally, a building product locally cultivated, harvested, and produced could provide much-needed jobs for people in Hawai'i, stimulating the local economy. The effects of climate change are a fact that is becoming a fast-approaching reality for some. As the most isolated landmass globally, Hawai'i's coastal communities feel the effects of climate change to a greater degree. These experiences begin to become more "in-your-face" as these residents witness the outcomes of coastal erosion on their property. The urban core of Waikīkī has also witnessed the increased frequency of historical tides, flooding the busy streets in many of the community's low-lying areas. However, small Hawai'i's contribution to the larger picture of GHG emission taking part in lessening that contribution should

5 State, Hawai'i. SB263, 2019

6 Ingrao, C., Agata, L.G., Bacenetti, J., et. al, "Energy and Environmental Assessment of Industrial Hemp for Building Applications: A Review." 2015, 36

be a priority for the state, the building industry, and its people; exploring the positive effects of a hemp-based product would provide that contribution.

2.3 Conclusion

The building industry's contribution to GHG emissions through the products used to construct our buildings and the processes to which the industry obtains those products have contributed to environmental impacts that primarily affect coastal communities. From the top-down, the building industry should explore ways to mitigate processes that contribute to GHG emissions. At a local level, Hawai'i's willingness to enact policy towards finding solutions to its contribution to GHG emissions has yet to be quantified. Hawai'i's unique culture produces an understanding that we have a responsibility and an obligation to protect the environment, and in caring for the land, a reciprocal relationship is established. This "gut" feeling exists in many Hawai'i residents because it has been a way of life for many local people, whether Hawaiian or not.

Figure 3.1 Honolulu Harbor Docks.
Image Source: Honolulu Star Advertiser

Figure 3.2 The building density of Waikīkī at night.

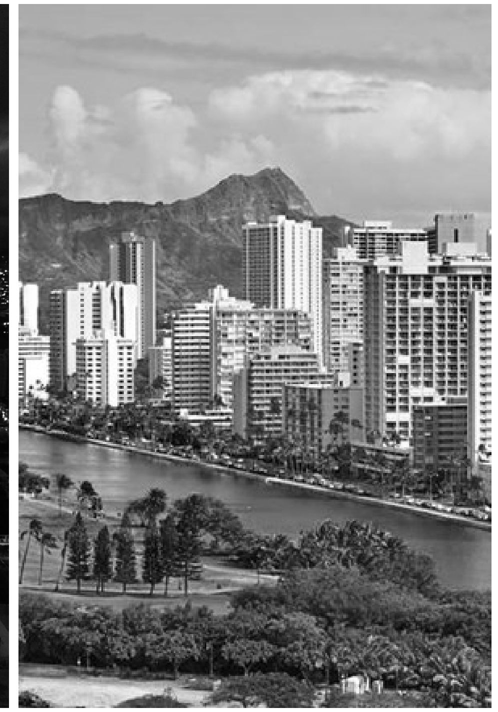


Figure 3.1 Buildings of Waikīkī during the day.
Source: Honolulu Star Advertiser

Chapter 3: A Vulnerable Reliance on Imported Goods

It's estimated that 90% of the food products that Hawai'i residents consume are imported.[7] If an essential need like food could be so heavily imported, why wouldn't building materials also be transported along with the food? In fact, according to the U.S. Census Bureau's foreign trade statistics, the ninth most imported product to Hawai'i is Portland Cement, a binder used to make concrete. The importation of Portland Cement saw a 12.9% rise in 2019 thru 2020.[8] The impacts of these two statistics are overwhelming and are especially felt during natural disasters or a global pandemic. During times of crisis, panic purchasing takes place, supplies run short, and the all too familiar reality of our reliance sets in. This reliance isn't just limited to store-bought products but our supply of building materials, affecting our built environment. Policies that exacerbate the situation have existed for too long, and their regulations are old and outdated. Locally produced materials are scarce because the price of land is high, with studies showing Hawai'i to be ranked the highest among the states.[9] Better policy, a local building materials market, and a lower cost of living would make for ideal conditions in Hawai'i.

7 Office of Planning Department of Business Economic Development & Tourism, "Increased Food Security and Food Self-sufficiency Strategy," 2012, 6
8 Data Dissemination Branch Foreign Trade Div., "Hawaii State Imports," Hawaii State Imports, February 1, 2021, https://www.census.gov/foreign-trade/statistics/state/data/imports/hi.html.

3.1 An Import-dependent Society

The island chain that comprises the islands of Hawai'i is the most isolated landmass in the world. The remoteness of Hawai'i has made it a trophy destination for some and a once-in-a-lifetime experience for most, a destination that reinforces Hawai'i's resilience to imported goods. While the rest of the world imagines Hawai'i as paradise, its residents pay an extremely high cost due to many factors, such as reliance on imports. It's estimated that 90% of Hawai'i residents consume products imported to the state each year.[10] The impacts of this overwhelming statistic are commonly experienced during a natural disaster, a strike by the dockworkers, or a situation that we have become all too familiar with within the last year, a global health pandemic. In a global health pandemic, Hawai'i residents flocked to stores acquiring as many products as they deemed as necessities, creating shortages that lasted for months. This panic purchasing exposed Hawai'i's reliance on imported goods and the uncertainty that follows any instance that disrupts the frequent flow of shipments into Honolulu Harbor. This reliance isn't only limited to the importation of store-bought products but also plays a vital role in Hawai'i's building industry and real estate and construction costs.

9 Missouri Economic Research and information Center, "Cost of Living Data Series," Cost of Living Data Series | Missouri Economic Research and Information Center, 2021, https://meric.mo.gov/data/cost-living-data-series.
10 Office Of Planning, Department Of Business Economic Development & Tourism, Department Of Agriculture.

Figure 3.4 Comic strip illustrating the negative impacts of the Merchant Marine Act of 1920 or the Jones Act. Image Source: Grassroots Institute, https://www.grassrootinstitute.org/2021/05/waiver-goodbye-to-the-jones-act/

3.2 The Jones Act & Hawai'i's Building Material Industry

An entire research paper could be written on Section 27 of the Merchant Marine Act of 1920, better known as the Jones Act, and its effects on Hawai'i. The purpose of this Act was to ensure that "maritime industry for national defense and promote the nation's foreign and domestic commerce."[11] More specifically, Section 27 states that "all goods transported by water between U.S. ports be carried on U.S.-flagged ships that are built in the United States and 75% owned and crewed by U.S. citizens."[12] This section played a significant role in how maritime commerce was conducted in Hawai'i. Hawai'i was not admitted into the union at its enactment, making Honolulu Harbor a non-U.S. port. This meant that all shipments bound for Hawai'i had to bypass Honolulu Harbor and sail to harbors along the west coast of the continental U.S. before they arrived at their final destination in Honolulu.

The effects of the Jones Act further the perception of Hawai'i's reliance on imported goods by looking at how the importation of building materials and products add to the cost of construction for Hawai'i residents. A policy brief written by the Grassroots Institute of Hawai'i sought to reform the Jones Act and stated that "currently [the Jones Act] adds between $54.4 million and $255.9 million annually to the cost of real estate and construction services in Hawaii" and "overall. . .costs Hawaii's economy an extra $1.2 billion a year."[13] Complicating the situation further is the relatively small

11 Increased Food Security And Food Self-Sufficiency Strategy." Accessed November 22, 2021. https://www.ams.usda.gov/content/legal-opinion-authorities-hemp-production. AMP. "The Jones Act." American Maritime Partnership (blog). Accessed November 22, 2021. http://www.americanmaritimepartnership.com/u-s-maritime-industry/the-jones-act/.
12 Ibid
13 Ibid

Figure 3.5 Portland Cement. Adobe Stock

Figure 3.6 Steel Rebar. Adobe Stock

Figure 3.7 Construction grade lumber. Adobe Stock

building materials industry that exists locally in Hawai'i.

3.3 Locally Produced Building Materials

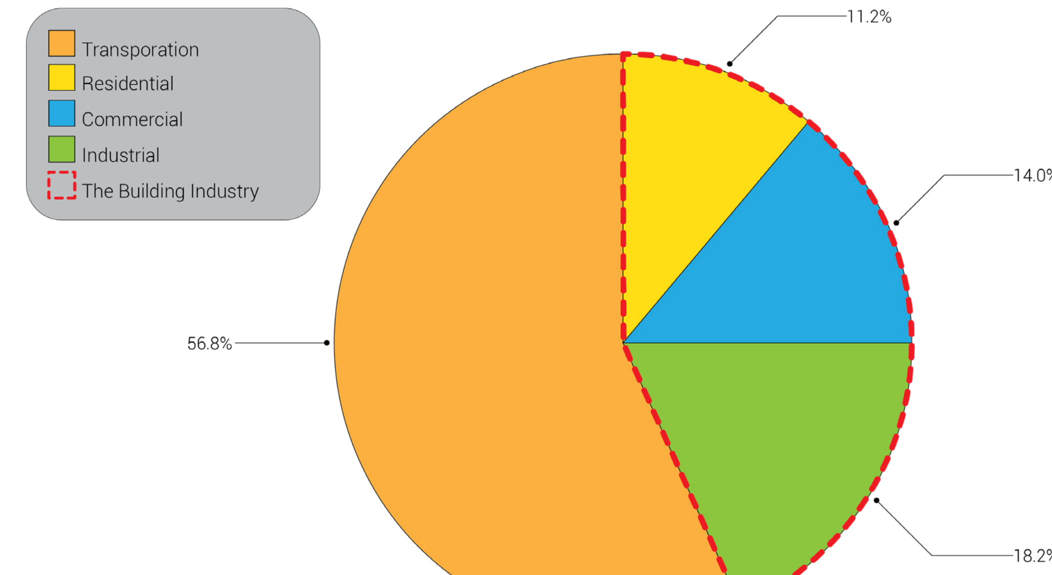
Local building materials in Hawai'i are produced significantly less than operations in the continental United States. Factors for this smaller production can be attributed to two variables, available space due to high land values and the lack of resources needed to produce construction grade building materials. There are two critical elements to the building materials industry that Hawai'i does not produce locally: solid wood materials used in conventional home construction and Ordinary Portland Cement (OPC), the binder used in concrete construction. These two products are frequently transported from the continental U.S., further exacerbating Hawai'i's dependence on imported goods. Crops of locally grown hemp could offer a solution to the availability of building materials to the State of Hawai'i. Its ability to increase offers local manufacturers of building products a raw material that can be molded and shaped into a commodity of the local building industry. Despite land costs, this hypothetical solution could start small, gradually growing as the demand for more hemp-based building material is needed.

Solid wood materials are an example of a building product not supplied locally. Reasons for a small locally produced solid wood material stem from enterprises whose operational infrastructure cannot support the need to produce a commodity that is competitively priced to markets in the continental U.S. A study conducted by the Division of Forestry and Wildlife of the Department of Land and Natural Resources (DLNR) examining the disparity of a market that produced local hardwoods stated that a demand exists within Hawai'i, but that inconsistencies hinder demand in the supply and quality of hardwoods.[14] The inconsistencies were expressed through the interview process of the study of groups and individuals. Both interview subjects elaborated that wood curing and drying methods were inconsistent, sawing quality was inconsistent, and continuity in the sourcing of timber products posed an issue. The study stated that "virtually no [local hardwood producer] has been able to repeatedly supply a quality product in reliable and significant quantities over a prolonged period."[15]

The second building industry commodity that lacks a local process in Hawai'i is the production of cement. Cement is a fine powder that is a mix of limestone, clay, and iron ore. These ingredients are heated to a temperature of 2642°F where it produces "clinker – the main ingredient of cement – that is finely grounded with gypsum and other chemical additives to produce cement."[16] Cement is then used as a binder in a mixture of aggregate and water to produce concrete. Structures that utilize a concrete material for their construction can be seen throughout the urban core on O'ahu, where three-fourths of the state's population resides and approximately 100,000 acres dedicated to urban use, 26% of the landmass on the island.[17] This urban core and its infrastructure network where concrete plays a heavy role in the building materials industry.

The two previously mentioned examples of solid wood material and cement binding products provide an incentive for researching and analyzing a hemp-based building product that can be produced locally. This incentive provides an alternative product that can aid in a building industry that focuses on the environmental impacts while providing spaces for people to inhabit. There is a definite need for locally produced building material with reliable and consistent qualities while being available in significant quantities. A hemp-based building product may not ultimately become a suitable substitute for products like solid wood or cement. Still, it could prove a viable alternative to be utilized within the building industry through research.

14 Dudley, Nicklos S. "Hardwood Lumber and Wood Product Market Analysis for Hawaii or Hawaii Hardwood Market Study for The State of Hawaii Department of Land and Natural Resources," 2004, 67.
15 Ibid
16 Hawaiian Cement, "Cement," Hawaiian Cement, July 15, 2020, https://hawaiiancement.com/products/cement/.
17 Ibid



The **BUILDING INDUSTRY** accounts for **43.4% OF ENERGY CONSUMPTION.**

Figure 3.8 Graph of the importation of petroleum and the consumption of energy. Data Source: Energy Information Administration, State energy Data System.

3.4 The Impacts of an Import-reliant Society

Hawai'i's reliance on importing its building materials has contributed to the high cost of real estate. With the rising prices of the shipping of imported building materials, the consumer absorbs the cost. The burden of absorbing rising shipping prices and exponential real estate increase has translated to a cost of living that puts Hawai'i at one of the most expensive places to live. One study by the Missouri Economic Research and Information Center conducted a cost-of-living analysis in 2019. The study's findings report that Hawai'i has the highest cost-of-living index in the nation with an index score of 198.6 out of a national average index of 100, surpassing states like California and New York by more than 50 the District of Columbia by 39 points.[18]

Besides importing 90% of food consumed and the attributed costs of shipping building materials, Hawai'i also imports petroleum which accounts for 60% of its imports.[19] An energy consumption study conducted by the State of Hawaii Department of Business, Economic Development and Tourism (DBEDT) and Hawaii State Energy Office concluded that the petroleum imported accounts for 71% of electricity consumed while also fueling public and private ground transportation, commercial

18 Cost of Living Data Series, "Cost of Living Data Series," Cost of Living Data Series | Missouri Economic Research and Information Center, 2019, https://meric.mo.gov/data/cost-living-data-series.
19 Blaze Lovell, "Report: Hawaii Is Still Heavily Dependent On Fossil Fuels," Honolulu Civil Beat, November 21, 2020, https://www.civilbeat.org/beat/report-hawaii-is-still-heavily-dependent-on-fossil-fuels/#:~:text=Petroleum%20also%20accounts%20for%2060,transportation%20and%20electric%20power%20generation.

Figure 3.9 Solar energy storage projects moving towards a goal of 100% renewable energy usage by the year 2045.
Image Source: Kaua'i Island Utility Cooperative, KIUC.

aviation, marine transportation, and the U.S. military.[20] The image that these studies and articles begin to paint is far from the perceived notion of paradise but a grim reality that puts Hawai'i in a severe predicament should imports cease or the price of petroleum fluctuate.

Because of shipping costs and imports, the reality of living in Hawai'i today is a stark contrast to the way native Hawaiians lived in traditional times, maintaining self-sufficiency independent of outside resources. This contradiction between traditional and contemporary has made Hawai'i virtually dependent on imports for its survival. However, the future may not be as bleak as it sounds. Politicians and policymakers have taken the information produced by these studies and set high targets towards Hawai'i becoming less dependent on fossil fuels. The state envisions a goal of harvesting clean, renewable energy, achieving 100% reliance on renewable energies by 2045.[21] This

20 Hawaii State Energy Office, "Hawaii Energy Facts & Figures," November 2014, http://energy.hawaii.gov/wp-content/uploads/2014/11/HSEO_FF_Nov2014.pdf
21 Hawaii Clean Energy Initiative, "Hawaii Clean Energy Initiative," Hawaii Clean Energy Initiative Comments, 2015, http://energy.hawaii.gov/testbeds-initiatives/hcei.

initiative would make the State of Hawai'i the first in the nation to become 100% reliant on renewable energy and independent on its reliance on fossil fuels.

3.5 Conclusion

In conclusion, Hawai'i has experienced a high reliance on imported goods. These goods include, but are not limited to, fossil fuels, food, and building products. This reliance has been heavily shaped by exterior policies like the Jones Act that influenced Hawai'i's maritime commerce before Hawai'i became a state. Despite being admitted into the union, Hawai'i still feels the effects of a policy like the Jones Act as its reliance on shipped goods continues. Residents shoulder the burden of inflated shipping costs on building materials, perpetuating a vicious cycle that exacerbates that high cost of living and real estate prices. Despite enterprises and operations within the building industry supporting a need for a locally produced building product, the infrastructure to encourage such ventures ceases to exist within any of Hawai'i's major islands.

Ultimately, the reliance on imported products for Hawai'i and its residents has created fears of uncertainty should imports halt for any length of time. This uncertainty partially drives policy changes into exploring alternative avenues towards lessening the gap of a society reliant on imported goods to be self-sufficient and resilient. With policy changes and innovative solutions geared towards achieving 100% renewable energy by 2045, Hawai'i has earned recognition as a leader in clean energy production while embracing innovative technologies towards accomplishing its goal.

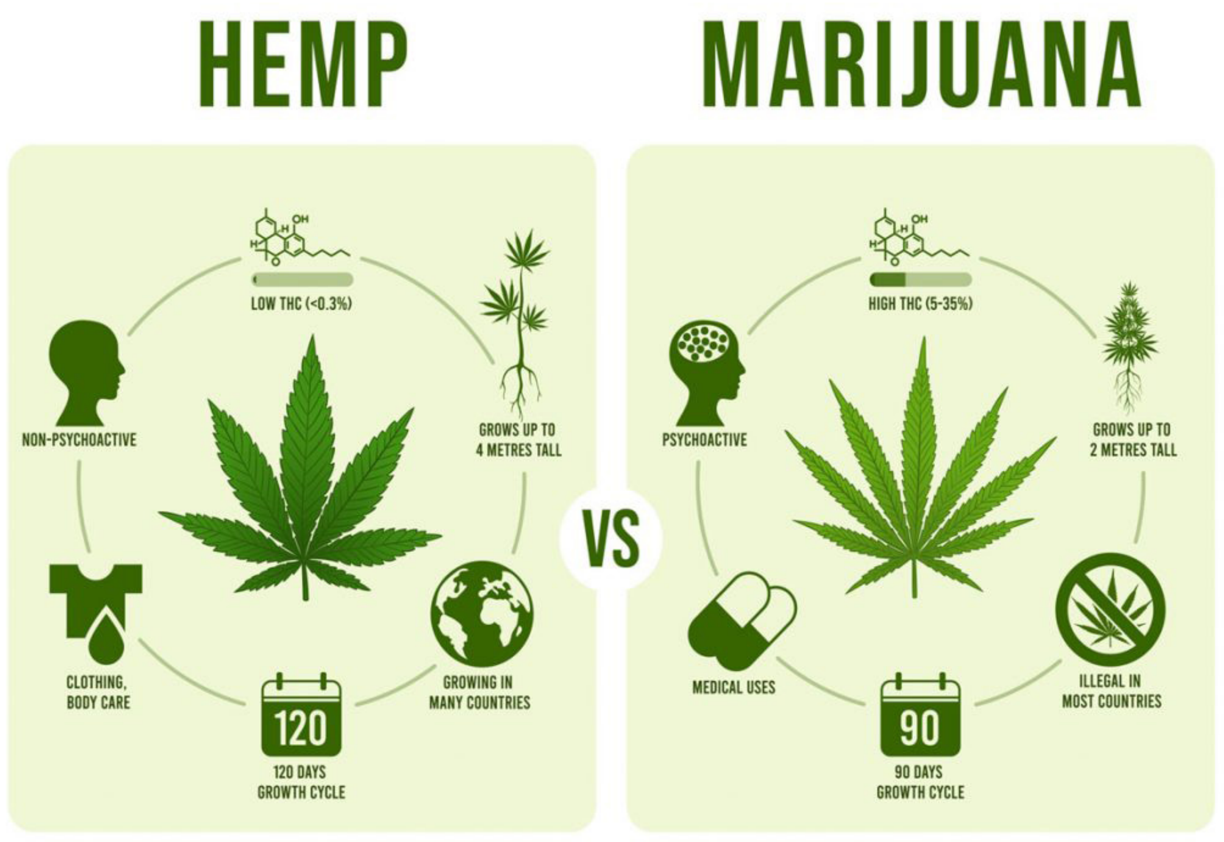


Figure 4.1 Hemp vs. Marijuana. Image Source: Adobe Stock.

Chapter 4: Cannabis sativa

Hemp is a variety of the *Cannabis sativa* plant. It shares similar characteristics to a cousin of the same species, marijuana. This relationship has placed hemp in the same category about its legal status as its cousin marijuana. However, as most of us know, being in the same family as an individual that may project an unwanted image does not translate to all of that family possessing that image. The same goes for hemp and marijuana.

Figure 4.2 The physical distinctions of hemp and marijuana. Image Source: Adobe Stock.

4.1 Physical Characteristics

For someone unfamiliar with hemp and marijuana, the differences between the two could go unnoticed. Both are from the same family, genus, and species; their physical characteristics could seem similar, but a closer look at both would demonstrate the subtle differences. When observing the leaves of the two plants, the marijuana leaf exhibits a broad-leafed shape throughout the entire height of the plant. For hemp, its leaves are generally slimmer and concentrated at the upper portion of the plant. When viewed at a distance, the marijuana plant is shorter and broader, resembling more of the characteristics of a bush. At the same time, hemp is much taller and slimmer, resembling characteristics of bamboo. The cultivation of hemp for fiber or seeds produces plants up to 20 feet in height. Viewing either plant next to one another, one could see the differences in their physical appearance.

Figure 4.3 The difference in chemical makeup of hemp and Marijuana. Image Source: Adobe Stock

4.2 The Chemical Makeup of Hemp & Marijuana

The difference in chemical makeup between hemp and marijuana is the most significant force that drives the legalities of the two plants. For decades, hemp was grouped in the exact likeness to that of marijuana. With efforts to legalize hemp to produce fiber, oils, and building materials, research utilizes its chemical makeup to distinguish hemp from marijuana. The differences between hemp and marijuana are its chemical composition and the content of tetrahydrocannabinol (THC). In marijuana, THC is the main chemical responsible for the plant's psychoactive effects producing a feeling of euphoria when ingested. On average, marijuana has between 5-20% THC content, while some premium strains of marijuana can have 25-30% THC. This percentage of THC content continues to hinder the legal use of marijuana at the federal level and in many states. For hemp, its THC content reaches a maximum level of 0.3%, essentially making it impossible to feel the same psychoactive effects that its cousin, marijuana, produces. What hemp does produce is cannabidiol (CBD) which provides numerous unique benefits.

4.3 THC vs. CBD

As previously mentioned, the THC content of marijuana, and its effects on people who ingest it, have been the main driver towards maintaining its illegal status. The psychoactive properties of THC offer medical benefits that are outside the realm of this research. However, as long as THC content and its effects are associated with negative aspects, the grouping of both hemp and marijuana in the same category will persist. However, hemp is not without its contribution towards medicinal uses. A

shared resource provided by hemp is CBD oil, typically harvested from the hemp plant's seeds. CBD has anesthetic properties that aid in pain relief. CBD also works as an anti-inflammatory and anti-anxiety medication without the psychoactive tendencies of THC. The two main chemical compounds found in hemp and marijuana both have their medicinal uses, but the current policy towards the legal status of the two plants is unequal.

4.4 Conclusion

Despite being a variety of the same plant species as marijuana, the characteristics of hemp vary considerably. From its physical characteristics to its chemical makeup, hemp is unique in qualities and uses. Although both plants can be used for medical purposes where hemp diverges significantly in its uses in other forms and industries.

Figure 5.1 Hemp fiber. Image Source: Adode Stock.

Figure 5.2 Car panel made from hemp plastic. Image Source: https://hashmuseum.com/en/cannabis-knowledge/industrial-hemp/hemp-based-plastic/

Chapter 5: Hemp, a Commercial Commodity

Historically, hemp has had many uses throughout society. It has been cultivated and used to produce various products that include textiles, rope, food, paper, bioplastics, biofuels, and building products. Over the generations of its use, hemp has proven to be a versatile plant with a wide array of uses. In exploring hemp as an alternative building material, some of its other uses could also be explored further in Hawai'i, benefitting the economy and the residents.

5.1 A Nutritional Source

Hemp as a source of nutrition comes from the consumption of its seeds. Hemp seeds are a great source of protein and iron. The seed can be eaten raw or ground into a powder-producing hemp meal. Hemp seeds can also be made into a liquid and consumed in baked goods or as milk. The nutritional value of hemp is as plentiful as its uses. The amino acid content, an essential building block to human health, in hemp seeds is comparable to the amino acid content in eggs, milk, meat, and soy, providing 64% of our daily protein value.[22] Some of the other nutritional benefits of hemp are its dietary fiber, vitamins, and minerals.

5.2 Hemp Fiber Applications

Hemp fiber has been prevalent throughout history. Its extensive use as rope for naval operations has encompassed centuries of sea voyaging. Early European explorers utilized hemp fibers to produce the sails and the ropes that ushered their exploration worldwide. Hemp fiber was used to make canvases for artists to use, and in fact, the word "canvas" derives its origins from cannabis. One of the hemp fiber's first recorded use was as a textile in ancient China. The fibers from hemp are extracted during the harvesting and processing phases. Fibers are made from the outer "bark" and separated from the inner shive of the stem.

5.3 Bio-products

More recent uses of hemp include bioplastics, biofuels, and composite materials. Hemp-based bioplastics are biodegradable, making them environmentally friendly alternatives to conventional

22 Callaway, J.C., "Hempseed as a nutritional resource: An overview," 2004, 69

plastics. These hemp-based plastics could potentially replace other plastics used in the building industry like polyvinyl chloride (PVC), a commonly used product in the plumbing application of our structures and buildings. As a biofuel, a term used for fuels derived from plants, hemp could be applied as biomass to be used in power plants, creating a cleaner source of energy in comparison to fossil fuels. As a biofuel, hemp is primarily used to produce cellulosic ethanol derived from the fruit and grain of hemp or hemp fibers. Some of the more recent uses of hemp are seen as a composite material. The automotive industry has made significant progress in incorporating hemp-based composite materials as interior panels for automobiles. Various companies like BMW, Ford, GM, and Honda have begun to use hemp as an alternative composite material in their automobiles.

5.4 Remediation Properties

As stated earlier, hemp cultivation requires minimal water usage, significantly conserving natural resources that could be utilized elsewhere. An added benefit to hemp's cultivation is its use as a remediation crop. Growing hemp allows the plant to filter the water of impurities caused by contaminants from sewage and livestock operations. Additionally, the phytoremediation properties of hemp also enable it to break down or store a variety of pollutants and toxins within our soils caused by stormwater runoff containing heavy metals from automobiles. Hemp's capabilities extend further than its soil remediation properties. Hemp can replenish the soil of nutrients lost during preceding crop harvests as a cover and rotational crop. Hemp crops utilized for this purpose would expand a farmer's crop potential while reducing the usage of dangerous and toxic artificial fertilizers. Hemp cultivation extends profoundly into the soil, literally with roots that grow deep into the earth. The root structure of hemp provides two benefits. While in its growing phase, the deep roots hold the ground together, reducing soil erosion. After hemp is harvested, the deep penetrating roots have loosened the soil allowing for subsequent crops to reach vital nutrients, water, and oxygen within the soil.

5.5 Conclusion

The plethora of uses for hemp has progressed through centuries of human society. It has grown from its applications in textiles to a product that allowed humans to explore the entirety of the globe through long sea voyages. It's proven to be a suitable source of nutrition while making its way into

our modes of transportation. However, with all of the commercial uses of hemp being consumed in today's market, none of the previously mentioned products utilizes the critical ingredient for a hemp-based building product, the woody stalk of the plant. With the progression of building technologies, hemp usage has the potential to grow just as fast as it can be cultivated and harvested. Further exploration of hemp-based building material would add to the versatility of hemp to the local market and economy of Hawai'i and contribute to the ambitious challenge that Hawai'i has set in place – to reduce its emissions and become the first carbon-neutral state by the year 2045.

Figure 6.1 Hemp hurds, the foundation of a hemp-based building product. Image Source: Adobe Stock.

Chapter 6: Hemp, Uses in the Building Industry

The utilization of hemp as a building material has seen a resurgence. The building industry's growing interest in exploring the uses of green building materials presents an attractive option for products derived from hemp. With the advancement of building technology and methods, a hemp-based building product has become a more realistic alternative application. Applications have proven to be a clean, chemical-free building material and a viable alternative to traditional concrete. Inherently wasteful, traditional concrete employs hydraulic binders like Portland cement, whose manufacturing process is carbon-intensive.

Driven by environmental and energy-efficiency saving metrics for building envelopes, hemp-based building products have begun to call attention to a challenge that has slowly developed over the last ten-plus years. This challenge would be much in line with Hawai'i's goals to become carbon neutral by 2045. The objective of this challenge would be to discover alternative aggregates to incorporate into green concretes. Utilizing plant materials as bio aggregates, green concretes can contribute to carbon sequestration and balance the effects of climate change. Locally, hemp cultivation could be

a model to support the state's efforts towards reforestation, an effort aiding in achieving the targeted goal of carbon neutrality by 2045. As a carbon sink, hemp has an extraordinary ability to absorb carbon, storing this sequestered carbon in two ways. The first is hemp's capacity to store carbon in its root system. A study of hemp as a more sustainable annual energy crop stated that upon harvesting, the "carbon is stored underground in roots and rhizomes and following decomposition some of this carbon remains sequestered within the soil for long periods."[23] The second method of carbon sequestration happens in the portion of the plant above ground. This section of the plant sequesters carbon from our atmosphere, where it remains for the duration of the hemp-based building material's life cycle. As a material, the initial amount of energy embodied in hemp production is considered relatively low compared to traditional building materials. The extent of its carbon sequestration capabilities in conjunction with the relatively low energy consumption during production makes hemp a prime candidate as a sustainable building material locally grown in Hawai'i.

Establishing hemp as a sustainable building material has motivated innovative thinkers towards pursuing the capabilities of a hemp-based building product. The use of hemp as a building product is not a new idea; it has been utilized for many applications in the built environment for thousands of years. With new and emerging technologies, hemp's progress to the forefront of the building industry has enormous potential, but its advancement has been slow. This slow progression is due to legal matters that characterize hemp similarly to its psychoactive cousin, marijuana.

Researching hemp's current uses in the building industry is vital for finding an alternative application for a hemp-based product. Categorizing each of hemp's applications into typologies will further assist in understanding the many different applications of hemp-based products. These typologies are used to classify the building methods of case studies to support an individual hemp-based building product. Each typology consists of technologies and practices that have established hemp's use as feasible modes of construction and are listed in the order of the most commonly applied method to applications that are still being developed. The four typologies are monolithic wall infill, insulation, prefabricated wall systems, and composite structural members.

23 Finnan, John, and David Styles. "Hemp: A more Sustainable Annual Energy Crop for Climate and Energy Policy." 2006, 156

Despite the legalities, building products employing hemp as a material are becoming exceedingly common. The process of these applications is researched further while identifying case studies that have successfully utilized these products. The first of these products is a hemp-lime composite concrete that is the most widely used commodity.

6.1 Hemp-concrete

Hemp concrete is the most widely used application of a hemp-based building product in current use and utilizes the first typological method, monolithic wall infill. Hemp concrete is a hemp-lime concrete or a hemp-lime bio-composite mix that consists of hemp shive (i.e., hemp hurd), a byproduct of hemp fiber production, a lime-based binder, and water. The lime-based binder composition varies according to the preferred physical and mechanical (i.e., density) properties. Still, it is typically composed of hydrated lime and natural hydraulic lime (NHL) or ordinary Portland cement (OPC). Natural hydraulic lime is utilized in conjunction with hydraulic binders to expedite the time needed for the hemp concrete to set. The explicit use of only natural hydrated lime requires weeks and sometimes months to achieve the adequate strength required of hemp concrete.[24]

Extensive research has been conducted on hemp concrete's thermal, acoustic, and mechanical properties. It has a low density, works well as an excellent thermal and acoustic insulation, and can regulate humidity passively in a built environment. However, hemp concrete's positive attributes come with inherent disadvantages towards its use within the building industry. Hemp concrete has low compressive strength making it a material lacking the density needed to be considered a structural material. Additionally, hemp concrete's resistance towards deformation, or its elastic modulus, is significantly lower than construction materials used in similar applications. As a result, hemp concrete is typically used as infill material, requiring a certain degree of structural support in timber stud wall construction.

Once harvested, the woody inner stalk of the hemp plant, typically referred to as the hurd or shive, is processed and milled to roughly 3/8-5/8 of an inch. This portion of the hemp plant becomes the

24 Arehart, J.H., Nelson, W.S., Srubar III, W.V., "On the theoretical carbon storage and carbon sequestration potential of hempcrete," 2020, 1

Figure 6.2 Hemp concrete product. Image Source: Archdaily, https://www.archdaily.com/955176/hempcrete-creating-holistic-sustainability-with-plant-based-building-materials

aggregate and is mixed together with a lime binder and water to create the infill hemp concrete material. This process is typically done on-site, requiring laborers to pour and compact the hemp-concrete material into the formwork layer by layer, making most hemp concrete applications labor-intensive. The infill of hemp concrete creates solid, monolithic walls that allow the building envelope to passively regulate humidity, creating healthy indoor environments adding to the health of the building's occupants. Once the hemp concrete infill material has adequately cured, the formwork can be removed. A natural lime or clay plaster finish can be applied to the interior and exterior of the building's envelope. The building's exterior may also be finished with alternative natural materials like slate, timber, or stone; however, the use of these materials alters the porosity of the hemp concrete infill inhibiting the material's natural breathability. The vital aspect of this process is that the materials used as a finish to the interior and exterior of hemp concrete walls should be of a breathable material, aiding in hemp concrete's natural characteristics as a building material in a wall assembly.

The beneficial qualities of hemp concrete's use as a building material extend beyond its natural breathability. As stated previously, hemp concrete construction also provides excellent thermal and acoustic qualities, further eliminating the use of typical construction products made from harsh and hazardous materials. Utilizing hemp as a building material has many advantageous qualities,

Figure 6.3 Hemp concrete infill form. Image Source: Alex Sparrow, The Hempcrete Book.

Figure 6.4 Hemp concrete infill exterior wall. Image Source: Alex Sparrow, The Hempcrete Book.

providing higher-quality interior environments; however, the beneficial qualities of hemp concrete start at the beginning phases of its life cycle. Regardless of hemp concrete's structural qualities, the following vital points firmly establish hemp concrete as a suitable alternative sustainable building material per the definition of sustainable building material in Chapter 1, section 1.3.

- Hemp is a fast-growing plant that can yield two crops per growing season depending on the climate.
- Hemp's accelerated growth provides enough raw material towards constructing a 1,500 square-foot home, growing hemp on only 4.25 acres.
- Hemp has minimal water requirements, needing on average 25-30 inches of rain per year.
- Hemp is resistant to insects, including termite resistance and pests, not requiring pesticides and herbicides. This benefit provides a healthy, non-toxic building material alternative. This advantage also makes hemp an attractive material for use in Hawai'i, a place known for termite infestations.

- Hemp-concrete s composition has measurable attributes towards resistance to fire, adding to the health and safety of the occupants of a dwelling utilizing hemp-concrete.
- Hemp-concrete stores heat within the thermal mass of its walls, helping regulate indoor air temperatures of our structures, adding to the comfortability of interior spaces.
- Hemp-concrete continuously sequesters carbon from the atmosphere throughout its life cycle.
- Hemp-concrete is resistant to mold and is also moisture absorbent.
- Hemp-concrete is 100% recyclable.

As with any list of pros for a particular product, there are inherent cons that parallel it. The most significant disadvantage of hemp-concrete is its inability to perform as a structural product. It lacks the strength to withstand the downward forces of a building on its own hence requiring internal structural components like timber, metal, or concrete. Cost-effectiveness and time efficiency are two other factors that hinder hemp-concrete 's progression in the building industry. Hemp-concrete isn't cost-effective because of the lack of abundance; this has a large part in its legal status within the United States. Hemp-concrete construction is very laborious and, therefore, not very time efficient. Each layer of the wall must be hand-packed while ensuring consistency in the hemp-concrete mix and the compaction methods. These two factors of cost-effectiveness and time efficiency are why the building industry maintains the use and practice of traditional building methods and materials; professionals are reluctant to use hemp-concrete due to its unfamiliar construction methods. Whatever the challenges with utilizing hemp-concrete as a sustainable building material, designers and architects are still finding innovative ways to apply it and its qualities to daily structures.

Figure 6.5 Nelson Residence, Maui, Hawai'i. Image Source: American Lime Technology (Builder: George Rixey, Rixey Co.; Photographer: Travis Rowan, Living Maui Media)

- **Case Study A**: Nelson Residence, Typology: Monolithic Wall Infill

Situated on the island of Māui, the Nelson residence was the first hemp-concrete construction to happen in the State of Hawai'i. Design by architect George Rixey the home was the first of two homes built on the property. Due to the high cost of living and the low housing stock throughout Hawai'i, the state has assigned special zones in residential areas calling them 'Ohana lots. An 'Ohana lot is much like a lot designated for an Accessory Dwelling Unit (ADU). A lot's designation as an 'Ohana lot allows the property owner to construct an additional dwelling with total square footage not to exceed 800 square feet for a lot size of 5,000 square feet or more.[25] This policy change is intended for parents or relatives to reside on the property while the nuclear family lives in the larger home.

The construction of the walls is a typical hemp-concrete monolithic infill system structurally supported by timber framing. The walls were built out to 8 inches thick, a typical minimum thickness for hemp-concrete wall construction. During construction,

25 Land Use Ordinance, Relating to Accessory Dwelling Units, 2015, 3

Figure 6.6 Hemp concrete Accessory Dwelling Unit (ADU). Image Source: Maui Jungalow, https://www.mauijungalow.com/2016/06/tour-of-first-hemp-house-on-maui.html

the clients had grown to appreciate the natural qualities of hemp-concrete with its unique texture and tactility. Because of this, they opted to seal the exterior of the walls with a natural sealer allowing for the home's walls to remain breathable. The residents lived in this small 'ohana home for a year while their main home was constructed, whose walls are also constructed using hemp-concrete. Although the scale of this precedent may be smaller than a typical application, this home's construction establishes a precedent, and the potential, for hemp-based building products being promoted in the local building industry of Hawai'i.

Figure 6.7 Martin-Krop Residence, Asheville, North Carolina. Image Source: Inhabitat.com

- **Case Study B**: Martin-Korp Residence, Typology: Monolithic Wall Infill

Located in Asheville, North Carolina, the 3,4000 square foot Martin-Korp residence features a modern design while incorporating alternative sustainable materials constructed within its walls. The home was designed by Anthony Brenner and David Mosrie of Push Design, and in designing the home, they felt a need to provide their clients with a home that possessed a healthy degree of breathability. In this precedent, the clients were inspired to construct their home using hemp-concrete based on Frank Lloyd Wright's philosophy of organic architecture. His philosophy stresses designing structures that were in harmony with humanity and its environment.

Despite its name, hemp-concrete construction traits are more commonly associated with infill wall construction made from straw bales rather than concrete but provide design and construction solutions unique to the hemp-based product. The hemp-concrete walls' insulating R-value, a unit of measurement for a two-dimensional thermal barrier equating to its thermal resistance, is rated at R2.5 per inch. The walls for this home were built to

Figure 6.8 Front of Martin-Korp residence. Image Source: Inhabitat.com

12 inches thick, bringing the total R-value of the walls to R30, double the required code regulation for exterior walls in North Carolina.[26]

The home was the first of its kind in North Carolina and the nation and has set the precedent of how homes in this region of the United States can utilize hemp-concrete as a sustainable construction material. However, the continued use of hemp concrete in North Carolina has been slow to progress due to the inaccessibility of hemp material. The hemp used to construct the Martin-Korp residence was imported from Europe. It is legal to cultivate and harvest hemp in Europe—importing the material added to the construction cost, both being an adverse reality of hemp's further progression in the building industry. Perhaps the precedent of all precedents in the topic of establishing a starting point for hemp-concrete construction in the United States, the Martin-Korp residence launched discussions on hemp's feasibility as a commodity in the building industry market.

26 (ICC), International Code Council. "2018 North Carolina State Building Code: RESIDENTIAL Code: ICC Digital Codes." 2018 NORTH CAROLINA STATE BUILDING CODE: RESIDENTIAL CODE | ICC DIGITAL CODES, 2018. https://codes.iccsafe.org/content/NCRC2018/chapter-11-re-energy-efficiency.

Figure 6.9 The Hemp House, Mullumbimby, Australia. Image Source: build.com.au/case-study-hemp-house

- **Case Study C**: The Hemp House, Typology: Monolithic Wall Infill

  Located in Mullumbimby, New South Wales, Australia, the Hemp House was constructed as a precedent for cost-effective ecological housing. Designed by a local Australian firm, Barefoot Sustainable Design, the hemp house's design stressed the importance of building with a sustainable material like hemp and utilizing recycled materials for different portions of the home, including materials like recycled concrete and timber.

  The home was designed to accommodate a family of four. It exceeded all sustainability criteria using hemp-concrete as a primary building material while addressing other factors towards sustainability. Its northerly orientation and large eaves block out the hot summer sun and collect prevailing breezes, ensuring maximum indoor comfort and naturally cooling the home. This case study showcases how partnering a hemp-based building material like hemp-concrete with other reusable and recyclable materials can emphasize the constructed spaces of a structure.

Figure 6.10 The Flat House, Cambridgeshire, United Kingdom. Image Source: The Guardian, Photographer: Oskar Proctor.

- **Case Study D**: The Flat House, Typology: Prefabricated Wall System

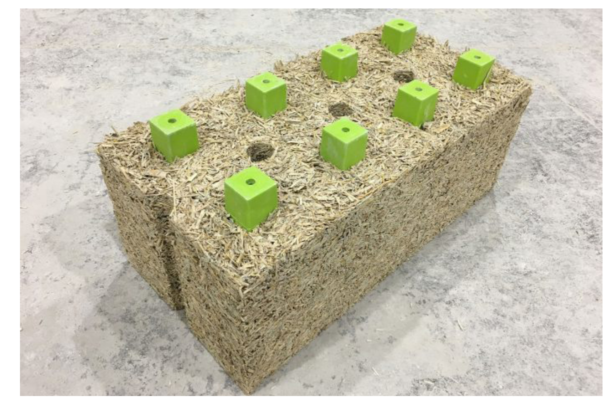
  Designed by Materials Culture and Practice Architecture, the Flat House is situated in Cambridgeshire, United Kingdom. The home was erected on the Margent Farm, which operates as a research and design facility expanding on the applications of sustainable bio-plastics made from hemp and flax. The home's designer intended to construct a dwelling using hemp as its primary source of building material while prototyping methods towards applying a sustainable prefabricated wall assembly. They intended that the prototype wall assembly could be scaled for different applications. A joint project between the designers, engineers, and material specialists, the group developed an infilled prefabricated panel. Naturally, the hemp was grown on the farm, therefore, alleviating the need for material transportation. Twenty acres of farmland was all that was needed to cultivate hemp used in the prototyping of the home's prefabricated panels. These twenty acres allowed the collaborative team to harvest and produce the elements of the walls system, erecting the walls in only two days. This precedent exemplifies the results of a collaborative effort towards creatively searching for solutions that guide us away from the continued use of unsustainable materials in our structures.

Figure 6.11 The Harmless Home, Vancouver, British Columbia, Canada. Image Source: Just BioFiber

- **Case Study E**: The Harmless Home, Typology: Structural Member

  Marketed as the most sustainable, safest, and energy-efficient home, the Harmless Home in Vancouver, British Columbia, Canada, utilizes cutting-edge green technology to construct its core structure. The technology that it uses is a formed structural block resembling a massive Lego brick. These compressed blocks are made with the same three ingredients as any other hemp-concrete structure but with one significant difference; they possess an internal structural frame allowing the hemp-concrete brick to be a load-bearing member. Hemp-concrete blocks structure the walls of the home and are constructed similarly to traditional brick and mortar applications. The difference in installing the hemp-concrete block is that it can use a natural joint compound like mortar or not; the application depends on the load-bearing capacity of the wall. These hemp-concrete blocks inherit all of the environmentally sustaining qualities of a typical hemp-concrete infill wall system with the added benefit of being a structural member. This case study provides a solution to one of hemp's most significant disadvantages as a non-structural and load-bearing product.

Despite the pros and cons of hemp-concrete, the building industry recognizes a need for change towards sustainable products and materials. As seen from the case studies, a hemp-based material like hemp-concrete provides numerous environmental and health benefits. It is applied as a monolithic infill wall system, offering a unique tactile and visual appearance to the structure. These case studies also showcase the collaborative efforts of architects, designers, and engineers to solve complex issues of time efficiency and structural capacity. The benefits of hemp-concrete extend into different hemp commodities where various installation methods broaden hemp's relevance as a sustainable material to the building industry.



6.12 Hemp concrete structural block. Image Source: Just BioFiber

6.13 Hemp concrete structural block components. Image Source: Just BioFiber

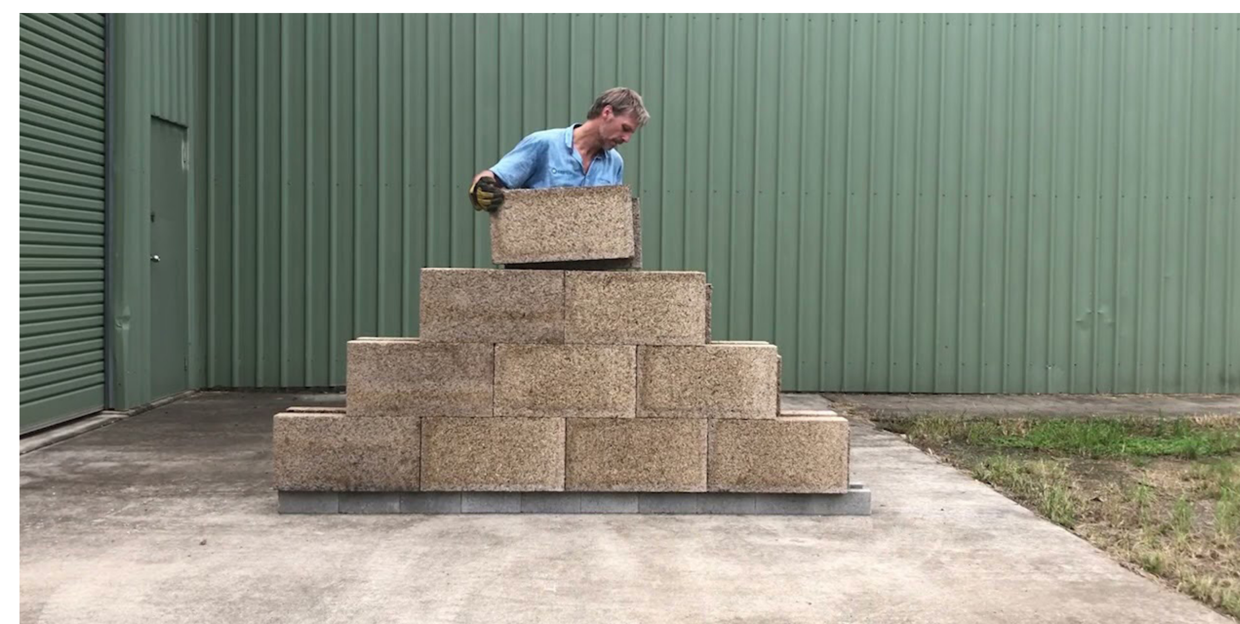


Figure 6.14 Hemp concrete block stacking. Image Source: Just BioFiber

Figure 6.15 Hemp insulation. Image Source: Adobe Stock

6.2 Hemp Insulations

The building industry utilizes many forms of insulation products to shield our structures from thermo exchanges. Insulating against these thermo exchanges varies depending on the location of the structure. For this reason, the building industry has many options when it comes to what types of materials are used as insulation in our structures. This section will examine the composition of hemp batt insulation, comparing it to other traditional and contemporary insulations. These insulations use a variety of materials, from organic and natural to chemically derived products. Additionally, the natural qualities of hemp that establish it as a sustainable material will be assumed while comparing it to other forms of building insulation.

The composition of hemp batt insulation consists of the hemp fibers, or the inner portion of the stalk frequently referred to as the hurd. The hemp batts are created by intertwining the hemp hurd and combining them with a binder. Typically, hemp batts are composed of 92% hemp material and 8% textile polyester fiber. They come in various standard dimensions, ensuring that the hemp batts are easily installed in typical home construction. Hemp batts can accommodate walls constructed from 2x4 or 2x6 lumber with widths that span standard wall assemblies of sixteen inches on center and

twenty-four inches on center applications. The installation of hemp batt insulation does not require personal protective equipment (PPE) as other insulation applications do; it is non-toxic, doesn't off-gas any harmful vapors, and doesn't cause skin irritation. Therefore, installation can be done with minimal tools and equipment. During its installation, a powered saw is required due to the product's

6.16 Hemp wood composite products. Image Source: HempWood

high density.

6.3 Hemp Composite Products

Relatively newer products involve composite products that consist of production methods, unlike the two previous examples of hemp-concrete and hemp batt insulation. One product that is currently being developed for the building industry is HempWood®. HempWood® is an engineered wood product made from hemp stalks. These stalks are crushed and soaked in an all-natural soy-based adhesive. Once the hemp hurds has met the desired absorption rate, the product is dried, pressed with 3,000 tons of pressure, and baked in an oven.[27] These manufactured compressed wood products are then sawn to the desired dimensions and installed. Manufactured HempWood® can be applied to projects consisting of flooring, cabinetry, furniture, and hobbyist woodworkers. This hemp product is sustainable and eco-friendly and can make various products that traditional lumber can produce. Like other hemp-based building products, HempWood® has the same qualities and is classified by the Occupational Safety and Health Administration (OSHA) as a non-hazardous material with a flammability hazard rating of one while all other hazard ratings are at zero.

27 HempWood, "HempWood Documents - HEMPWOOD.COM - Useful Information," HempWood.com, June 15, 2021, https://hempwood.com/hempwood-documents/.

6.17 Hemp plaster layered on stone carvings and used to aid in preservation. Image Source: Sanskrit Magazine, https://www.sanskritimagazine.com/india/cannabis-weed-bhang-preserved-ancient-indian-artwork-sacred-ellora-caves-1500-years/

6.4 Miscellaneous Uses of Hemp

Not assigned to any established typology within this research, the hemp-based products of this section intend to highlight some of the smaller-scale applications of hemp in the building industry. Although minor in scale, these hemp-based commodities offer beneficial qualities to the building products market, and their integration into our buildings provides healthier indoor spaces. These products are just as versatile as hemp and can be applied to a multitude of projects.

6.4.1 Plasters

As mentioned earlier in this research, hemp has been used for many centuries, with its first recorded accounts of use being in China. Naturally, hemp spread throughout Asia and began to be applied in many ways and forms. Hemp plasters have been in existence for thousands of years. A mixture of hemp hurd, clay, and lime plaster, hemp plaster has been credited with having exceptional preservation qualities. In a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage site use of hemp plaster aided in the preservation of paintings and carved stone in the Ellora Caves in India. A study conducted by Dr. Rajdeo Singh of the Archaeological Survey of India's science branch stated that "the use of hemp helped the caves and most of the paintings remain intact"[28] through 1,500 years of exposure to the elements.

28 Singh, Rajdeo. "Scientific Preservation of Ajanta Murals Delhi: Agam Kala Prakshan", 2019,

6.4.2 Oils and Varnishes

Applications of hemp oils extend to moisture inhibitors in the form of oils and varnishes used as moisture barriers for other products. The oils and varnishes derived from hemp oil are natural alternatives for protecting building products like wood flooring from pests and mold. As a wood finish, hemp oils and varnishes allow air and vapor to pass through while preventing moisture from penetrating the material.

6.5 Conclusion

Innovations in hemp-based building materials technologies are seeing more and more uses and applications. From a concrete-like material utilized in various wall applications to a plaster that has protected marvelous art pieces for 1,500 years, hemp is gaining a presence in the building industry. This portion of the research has exposed me to the numerous benefits that are essentially built-in to the makeup and characteristics of hemp. Ultimately, what I have come to conclude is hemp's versatility seems boundless. A hemp-based building product could potentially have just as many functions in the building industry as in the commercial industry.

Part 2 | Design Strategies & Applications

Figure 7.1 Building Sketch.

Figure 7.2 Diagram of the beginning stages of the Nahele i Nāhale Initiative.

Chapter 7:
Nahele i Nāhale, Establishing a Farm-to-Structure Initiative

From the case studies and typological examples of the last chapter, we can start envisioning how a hemp-based building product would be utilized in the local building industry. With all of hemp's beneficial environmental qualities, this project begins to explore the applications of hemp into the local agriculture and building environments on the island of O'ahu. This speculative process begins with establishing a site and a scale suitable for further developing a hemp-based building product. The series of actions should revolve around an indigenous resource management perspective. The practice towards developing a hemp-based building product begins with addressing the embodied environmental concerns addressed in Chapter 1, Section 1.2 while noting that Cannabis sativa is an introduced crop. Identifying a suitable site for local cultivation would begin to frame a concept that most have become familiar with, farm to table. However, rather than providing a local food source to the residents of Hawai'i, the development of this initiative would be considered a farm to structure operation or, in a Hawaiian term, "Nahele i Nāhale."

The Hawaiian word *nahele* translates to a "forest, grove, wilderness, bush; trees, shrubs, vegetation, weeds."[29] Utilizing this somewhat broad Hawaiian definition encompasses much of the English words used to describe the materials used in constructing dwellings, timber materials grown in wooded areas. The same concept would be applied to the cultivation of a hemp-based building product, except that the hemp would be grown in a more controlled environment due to its legal status as a newly approved industrial crop. The second Hawaiian word in the farm to structure initiative defines structures that we consider dwellings or homes. In Hawaiian, the word *hale* translates to "house, building, institution, lodge, station, hall; to have a house."[30] The prefix *nā* indicates a quality or state that the preceding word possesses, and for this term, Nāhale translates to homes. This idea and branding of a hemp-based building product as Nahele i Nāhale also represents cultural practices that early Hawaiians exercised when deciding the viable and various materials used to construct their structures. However, the viability of building material in early Hawaiian times also combined the availability, locality, and proximity of the chosen material to the site where the structure would be constructed.

29 UHHilo. "Nahele — Wehe2wiki2 Hawaiian Language Dictionaries." Accessed November 22, 2021. https://hilo.hawaii.edu/wehe/?q=nahele.
30 Ibid

7.1 The Importance of Native Hawaiian Resource Management

Establishing a hemp-based building product cultivation and production process in the context of the indigenous Hawaiian culture is critical to the sensitivity of the unique ecological systems throughout the Hawaiian archipelago. The proposed Nahele i Nāhale initiative aims to implement the responsible resource management practices that native Hawaiians have utilized for generations while introducing a crop not native to the unique ecological systems that remain on the island of O'ahu. In the past, foreigners have irresponsibly introduced flora to these islands to progress these crops solely for profit while taking little to no consideration of the environmental impacts. Although the Nahele i Nāhale initiative would operate in a contemporary business model, its foundation would focus on the positive environmental impacts of hemp cultivation while supporting the State of Hawai'i's environmental impact goals covered in Chapter 3, Section 3.2.

From the cultural perspective of native Hawaiians, resource management encompassed many layers. Still, foundationally their practices ensured that materials used in constructing their structures had a level of abundance that was feasible for its use and harvested from a location close to the established settlement. Another aspect of native resource management was examining and understanding the secondary uses of the material. The native and cultural understanding of these qualities surrounding a material used as a source for constructing their structures embodies the previously defined concept of a sustainable building material, a topic discussed in Chapter 1, Section 1.3. Therefore, the Nahele i Nāhale initiative would learn from traditional precedent on resource management implementing native Hawaiian practices focused on responsible cultivation, production, and management of a locally produced building material. These resource management practices would ensure that cultivation, production, and management practices adhere to an environmental standard that assists and positively impacts the environment—ensuring that former practices harmful to the environment would not be repeated with the introduction of hemp. Due to hemp's introduced status, care should be taken to ensure that the crop's cultivation does not disrupt the ecological systems of O'ahu and further perpetuate the misuse of one of Hawai'i's most precious resources, land.

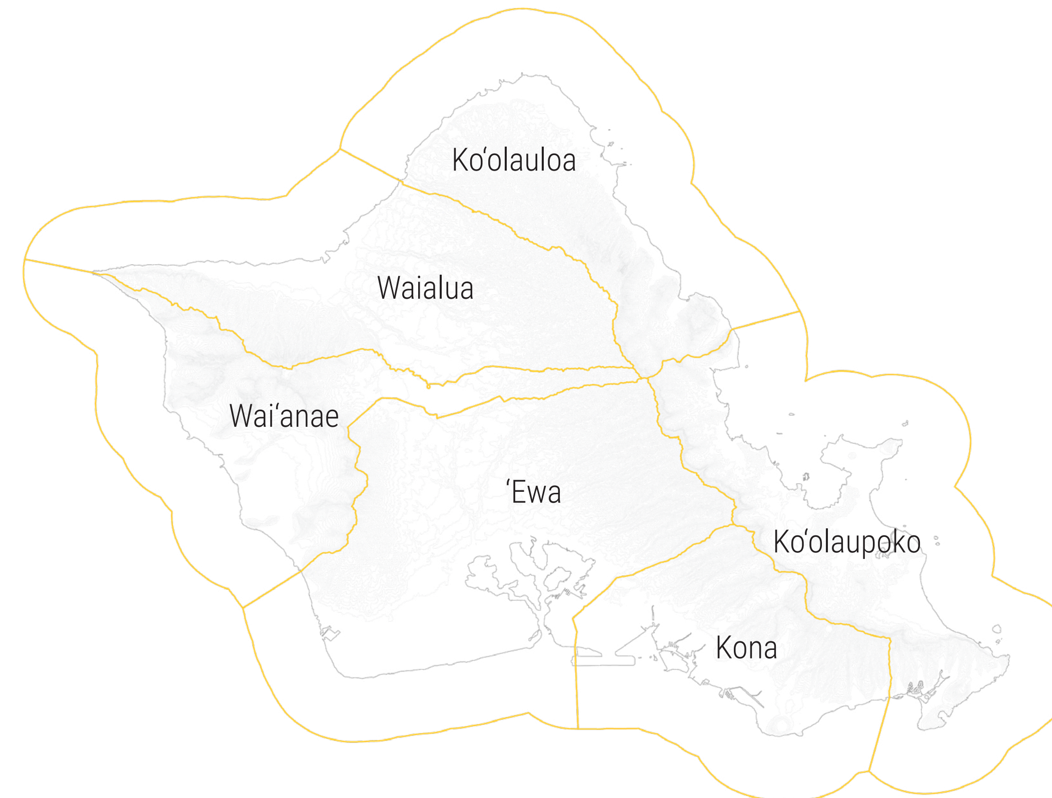


Figure 7.3 Traditional Moku, districts, of O'ahu. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

Figure 7.4 Traditional Ahupua'a, land division, of O'ahu. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

7.2 Native Hawaiian Resource Management

The native Hawaiians that resided on O'ahu possessed an intricate knowledge of the productivity of the land while understanding the potential to propagate specific plants based on their needs. Some of the plants that Hawaiians propagated were native, while others were introduced during the Polynesian migration of Hawaiians to the islands. An essential understanding in the context of the Nahele i Nāhale initiative is that native Hawaiians responsibly cared for the plants they introduced to these islands. They were aware of the delicate balance that could be disrupted should their responsibility towards the care of the introduced plant become too relaxed. The same approach would be applied to hemp cultivation as the raw material for a building product.

Complementary to the knowledge of productive landscapes, the native Hawaiians managed their resources within a unique system to each island. Rather than drawing arbitrary lines to divide the land amongst the people, they utilized the natural characteristics found throughout the landscape. Today, the practice of native resource management is generally referred to as the Ahupua'a land division system. Although understood as the Ahupua'a system, the ahupua'a was the intermediate land division within the larger moku (district) and the smaller 'ili (land section) land division. Figure 7.2 illustrates the more significant size moku land division of the island of O'ahu, while Figure 7.3 delineates the multiple ahupua'a within each moku. As illustrated in Figure 7.3, the ahupua'a system of the land division was based on the physical boundaries of the landscape and would frequently be contained within a valley. Generally, an ahupua'a stretched from the mountain top to the shoreline and further into the ocean. The native Hawaiians managed the landscape's resources within these areas, perpetuating their responsibility towards caring for the land. Although native Hawaiians resided within the ahupua'a, it was understood that certain areas, or zones, produced particular plants suitable to their settlement's needs. These vegetation zones varied in the types of flora due in part to areal and elevational differences[31]. With these differences, native Hawaiians were able to cultivate various crops specific to the needs of their immediate communities.

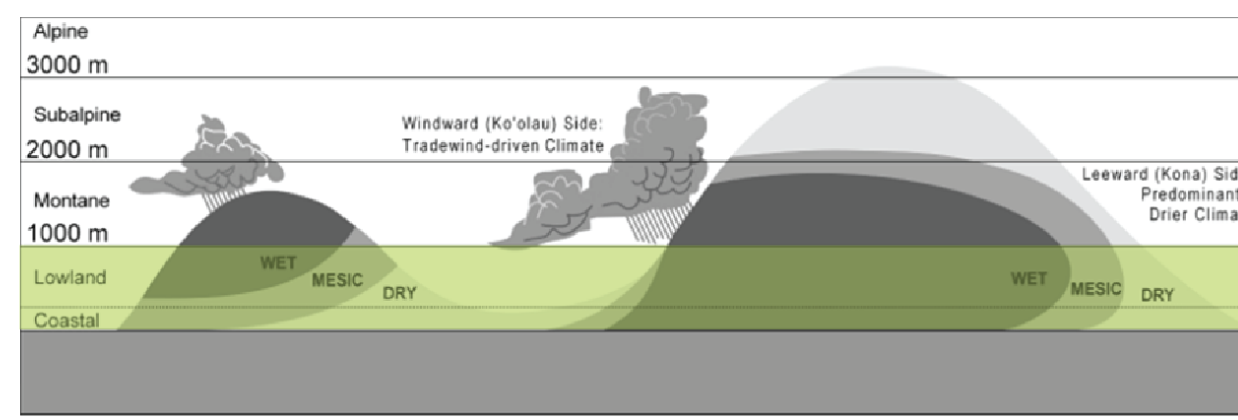
31Ibid

7.3 Hawaiian Vegetation Zones

Each island throughout the Hawaiian archipelago possesses highly diverse vegetation patterns. At a macro (archipelago) scale, these patterns are determined by the island's topography, elevation, rainfall, and soil qualities. At the micro (island) scale, the productivity of these vegetation zones could be separated by the island's windward and leeward sides. Within the landscape of the archipelago existed eight zone classifications, as seen in Table 7.1.

Identifying areas in the coastal upland, or the kula regions, on the island of O'ahu as viable regions for hemp cultivation can be identified by the maps in Figure 7.4. These areas of O'ahu are consistent with the general growing conditions for hemp while also representing areas of the island where farming and agriculture are currently in place. Figure 7.5 illustrates the areas of O'ahu identified by the State of Hawai'i as AG-1 Restricted Agricultural Zones (red) and AG-2 General Agricultural Zones (green) with the areas of interest for the cultivation of hemp outlined in yellow.

Variation in topography affect vegetation zones



Variation in Rainfall

Dry	<1.2 m rain per year
Mesic	1.2 to 2.5 m rain per year
Wet	>2.5 m rain per year

Figure 7.5 Coastal Upland, Kula Regions, of O'ahu. Image Source: Kikiloi, 2016

Hawaiian Vegetation Zone Classification

KUA	Kualono (summit ridges and peaks) Kuamauna (of higher mountain side- small trees grow) Kuahea (place of stunted trees) Kuahiwi (backbone ridge of mountain)	Alpine Stone desert Alpine Scrub Cool Dry Forest
WAO	Wao n ā hele (wilderness below the mountains) Wao lipo (dark, thick large trees) Wao eiwa (large trees) Wao ma ‘ukele (“kele”- rainb elt- large trees) Wao akua (wilderness not frequented- for gods) Wao kanaka (wilderness people frequented)	Rain Forest Mesic Forest
Ref. Unknown	‘Ama ‘u (fern belt zone) ‘Apa ‘a (dry and arid zone- “hard baked”) ‘Ilima (‘ilima growth zone) Pā he ‘e (slippery because of mud or pili grass zone)	Dry Forest
KULA	Kula- Kula uka (upland plains) Kula- Kula waena (middle plains) Kula- Kula kai (seaward plains)	Coastal
KAHAKAI	Kahakai- kahaone (sandy beach) Kahakai- kalawa (curve of the shoreline) Kahakai –‘aekai (waters edge)	Strand

Table 7.1 Hawaiian Vegetation Zone Classifications. Data Source: Kikiloi, 2016

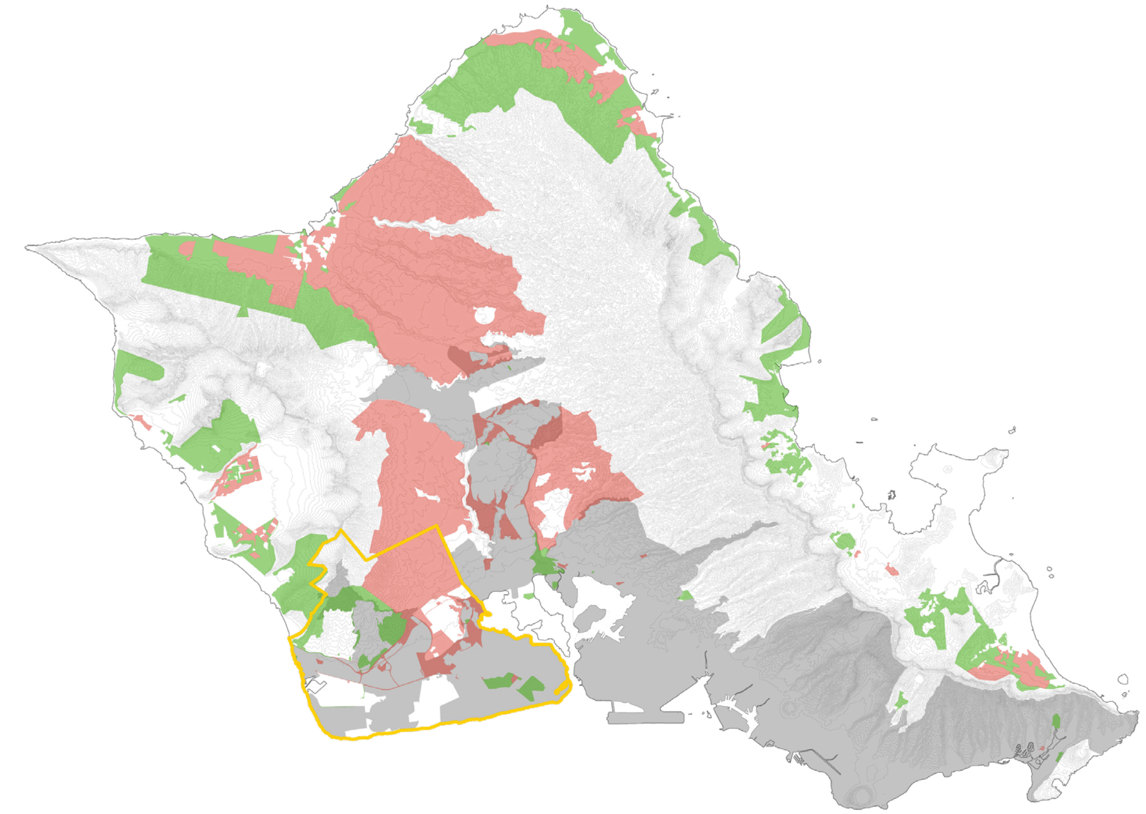


Figure 7.6 Agricultural Zones of O’ahu. Data Source: GIS data obtained from Hawai’i State Office of Planning, Hawai’i Statewide GIS Program, Geospatial Data Portal. Open source material.

7.4 Site Selection, Regional Cultivation

In keeping with native practices, ensuring proximity of sourcing the raw materials to construct buildings and structures, the moku of ‘Ewa was selected. As illustrated in Figure 7.6, the moku of ‘Ewa encompasses a large portion of central and south O’ahu. Within this moku, the kula regions of central O’ahu have been traditionally used to cultivate various crops. What is also significant about the moku of ‘Ewa is the continued growth and development within the district.

Currently, the primary zone designation by the State of Hawai’i in the moku of ‘Ewa is AG-1 Restricted Agricultural District, with a few locations designated as AG-2 General Agricultural District. A key point in the State’s purpose and intent of land zoned with an AG-1 designation is that:

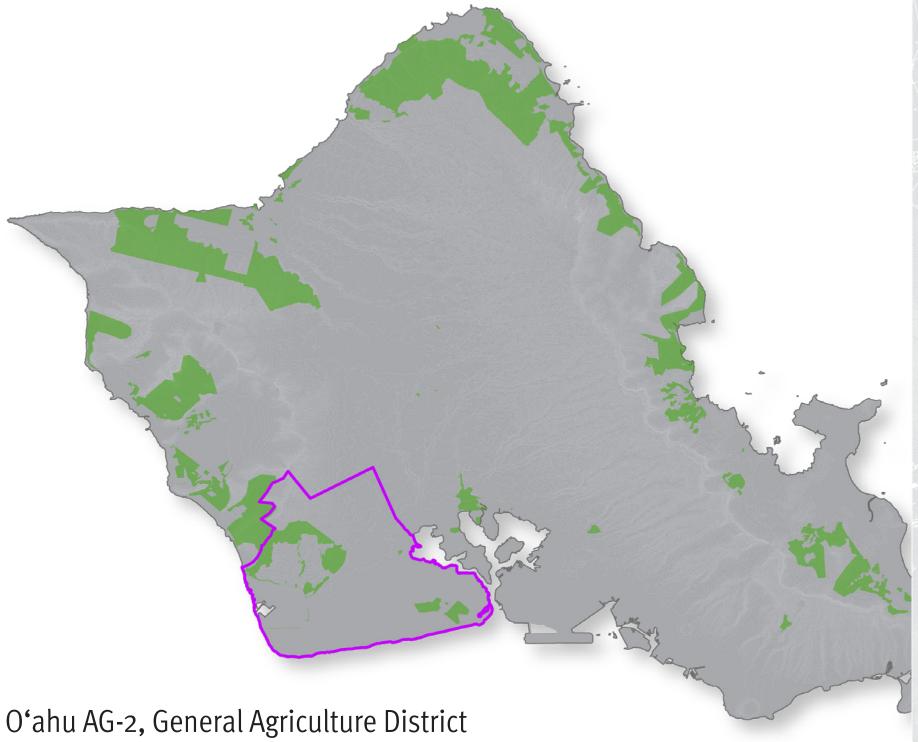
Honolulu Zoning District Classifications and Map Designations

§21-3.50 Agricultural Districts—Purpose and intent.

(b) The intent of the AG-1 restricted agricultural district is to conserve and protect important agricultural lands for the performance of agricultural functions by permitting only those uses which perpetuate the retention of these lands in the production of food, feed, forage, fiber crops and horticultural plants. Only accessory agribusiness activities which meet the above intent shall be permitted in this district.

(d) The intent of the AG-2 general agricultural district is to conserve and protect agricultural activities on smaller parcels of land.

(e) The following guidelines shall be used to identify lands which may be considered for the



O‘ahu AG-2, General Agriculture District

AG-2 general agricultural district:

(1) Lands in the state designated agricultural or urban district and designated agricultural by adopted city land use policies.

(2) Lands which are predominantly classified as other under the agricultural lands of importance to the State of Hawai‘i system; and

(3) Lands which are used or are suitable for agricultural purposes and where a substantial number of parcels are less than five acres in size.

§21-3.50-2 Agricultura cluster—Site standards.

(a) The minimum land area required for an AG-1 district

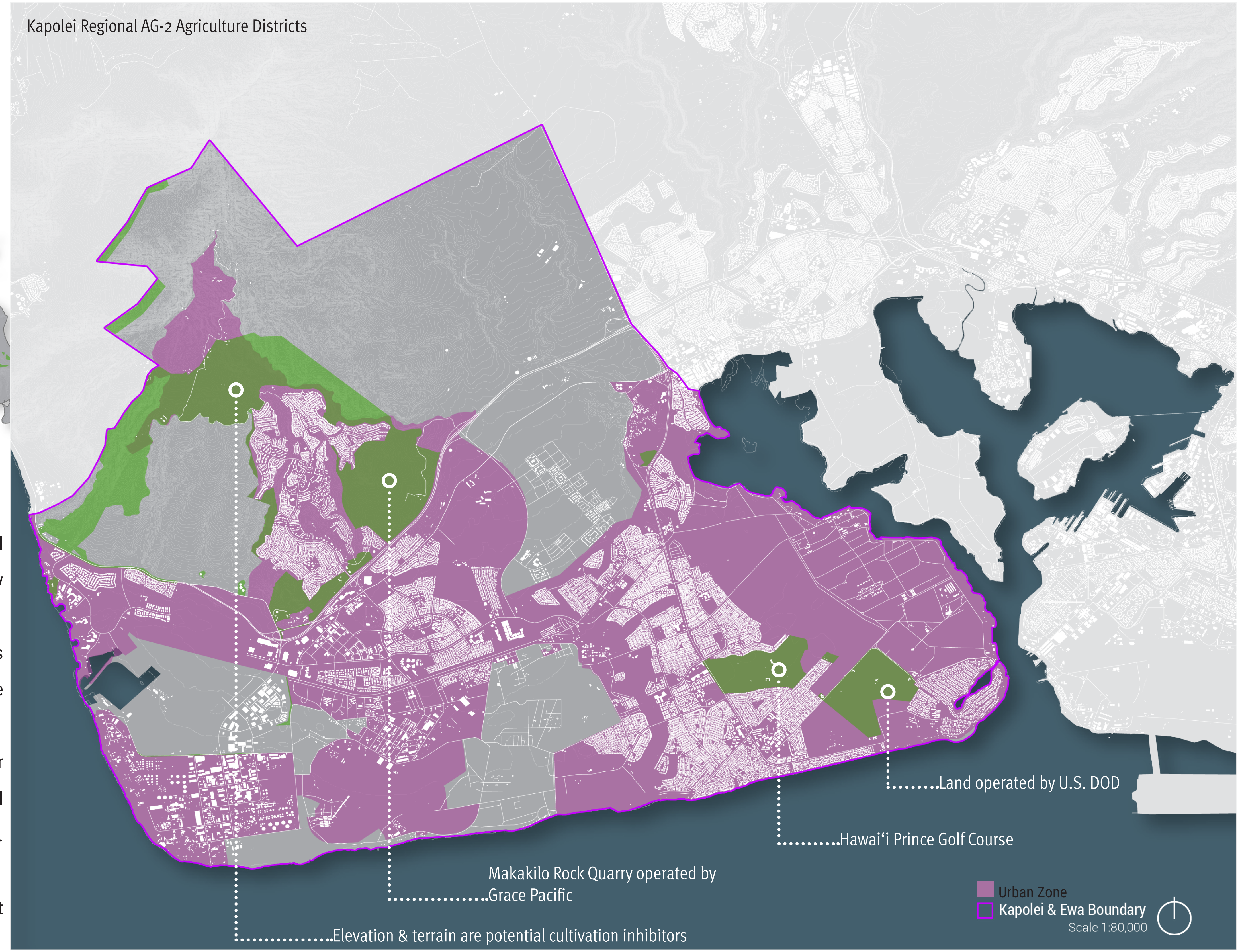
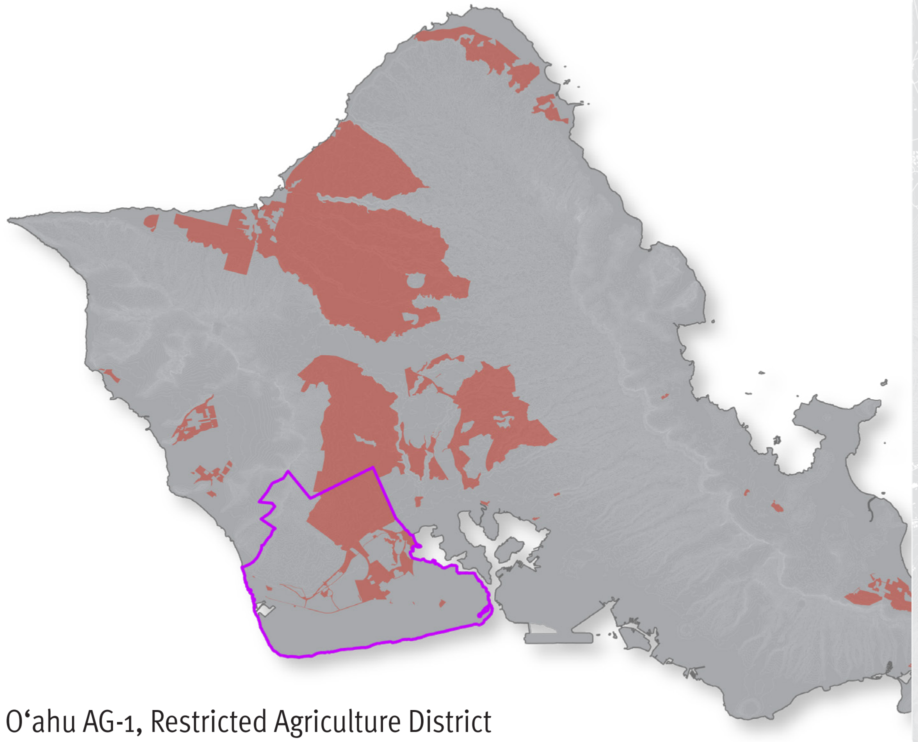


Figure 7.7 Graphic of AG-2 Land Use Zones overlapped with urban designations. Data Source: GIS data obtained from Hawai‘i State Office of Planning, Hawai‘i Statewide GIS Program, Geospatial Data Portal. Open source material.



O'ahu AG-1, Restricted Agriculture District

Speculative Cultivation Area

- Area ≈ **2,600 hectares**

agricultural cluster shall be 15 contiguous acres. The minimum land area required for an AG-2 district agricultural cluster shall be six contiguous acres.

The State's definition of AG-1 and AG-2 districts provide a site for hemp cultivation where hemp would fall under a crop designation as a fiber crop. Figures 7.7 and 7.8 showcase the feasible sites and their area in acres that could benefit the cultivation efforts of hemp. Establishing that hemp cultivation is an approved agricultural crop implementing farming initiatives that focus on growing hemp in the region would be the logical next steps in implementing the Nahele i Nāhale Initiative.

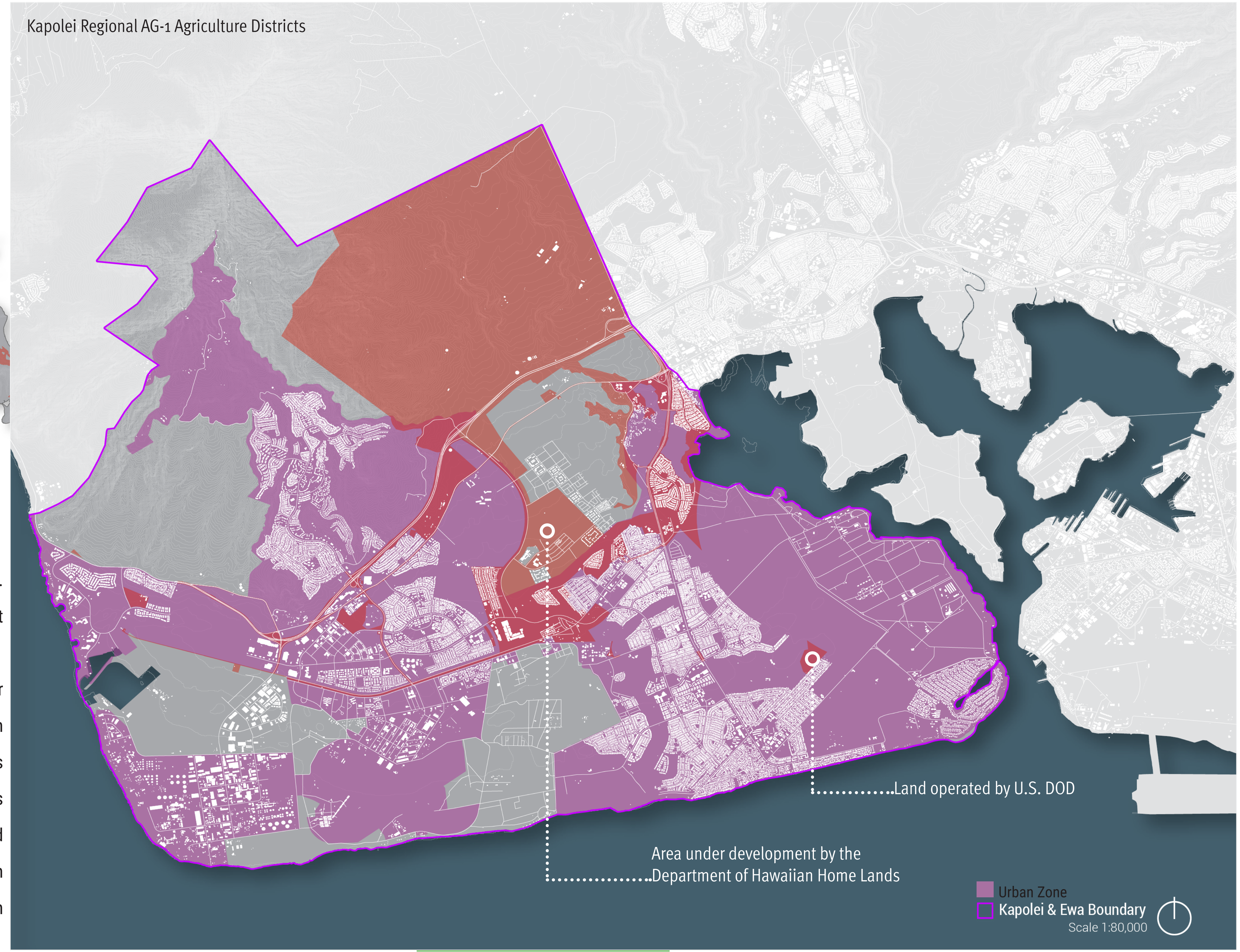


Figure 7.8 Graphic of AG-1 Land Use Zones overlapped with urban designations. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

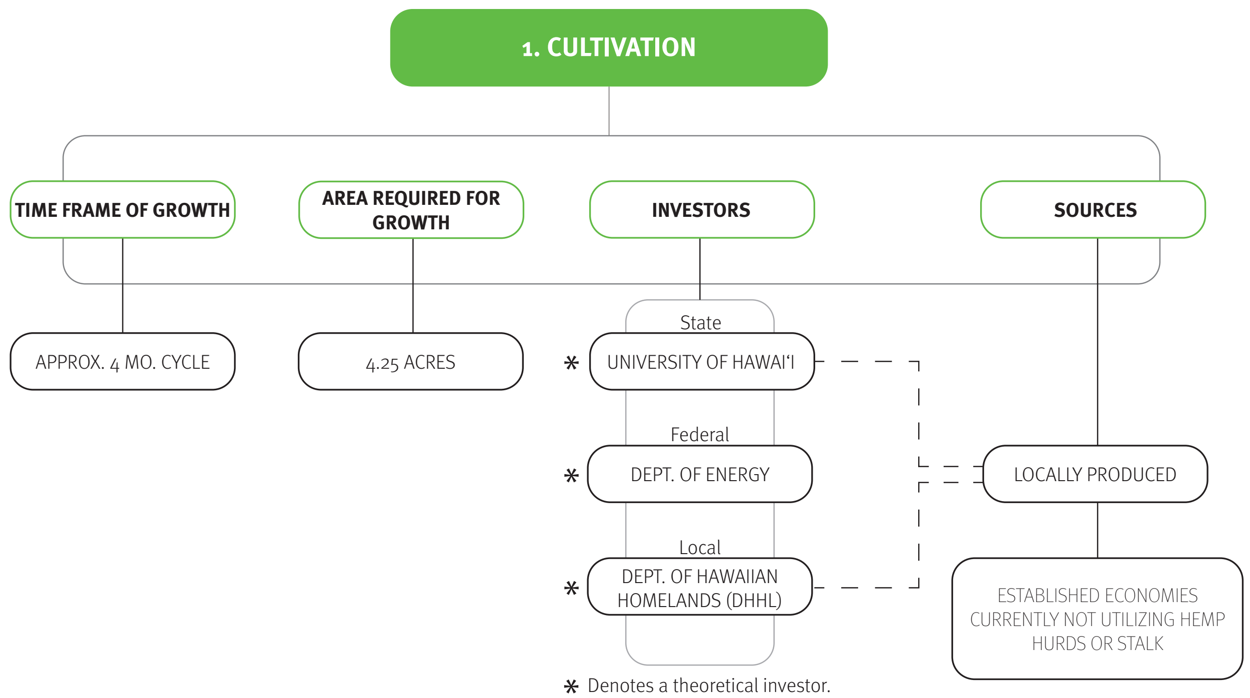


Figure 7.9 Hemp Cultivation Diagram.

7.5 Framework: Hemp Cultivation

The cultivation of hemp is very similar to the cultivation of traditional row crops. To achieve the number of raw materials needed for a hemp-based building product, the focus of this section will provide a scenario where hemp cultivation takes place within the kula lands of ʻEwa. A secondary aspect benefit to hemp cultivation is its phytoremediation properties. These properties would function as a cover crop for farmers improving the soil and water quality of the land. As a cover crop, hemp cultivation encompasses environmental concerns and issues associated with contemporary agricultural practices. This scenario would be based on the availability of agricultural lands as established in the previous section. A requirement of these lands would be its proximity to the next phase of the Nahele i Nāhale initiative, which covers the production of a hemp-based building product covered in a proceeding section.

Within the Nahele I Nāhale initiative framework, hemp cultivation would occur as a cover crop within farms that have an already established farming operation within the State of Hawaiʻi's designated agricultural districts. This farming method provides farmers with a secondary economic commodity while restoring the depleted nutrients from their previous crop. Additionally, the time frame for a parcel of hemp to grow is significantly less than traditional cover crops. At the early stages, numerous outside entities could cover the financial resources for establishing hemp cultivation. Due to the previously mentioned 2018 Farm Bill, hemp as an agricultural commodity rather than a controlled substance provides many opportunities for funding sources at all levels—federal, state, and local. For the hypothetical purposes of this proposed framework, Figure 7.9 illustrates the entities where external funding resources could come from. An added benefit to implementing hemp cultivation with the productive routine of established farms is standard farming equipment for harvesting. Due to its similar farming methods to traditional row crops, hemp cultivation does not require special equipment. The harvesting can be accomplished with standard farming equipment and machinery. It should also be noted that the State of Hawaiʻi currently has 48 licensed hemp farmers throughout the state, with nine registered to the island of Oʻahu. With the unknown size of the farming operation of these established hemp farms, the output of raw material needed towards producing a hemp-based building product is unknown. However, the current license holders provide a unique opportunity to purchase the portions of the hemp plant not used by their chosen market. An example of this would be a license holder whose hemp commodity involves CBD oil production. In this example, the stalks of the industrial hemp plant become an inherent byproduct of CBD oil production and therefore can be purchased, processed, and utilized in a hemp-based building product.

With these two scenarios of hemp cultivation occurring within the moku of ʻEwa, the remaining efforts would be prioritized towards the proper care of the hemp crop. In approximately three to four months, depending on climatic conditions, a single crop of hemp can be harvested, moving forward to the next stage of the framework for the Nahele i Nāhale initiative, harvesting, and processing.

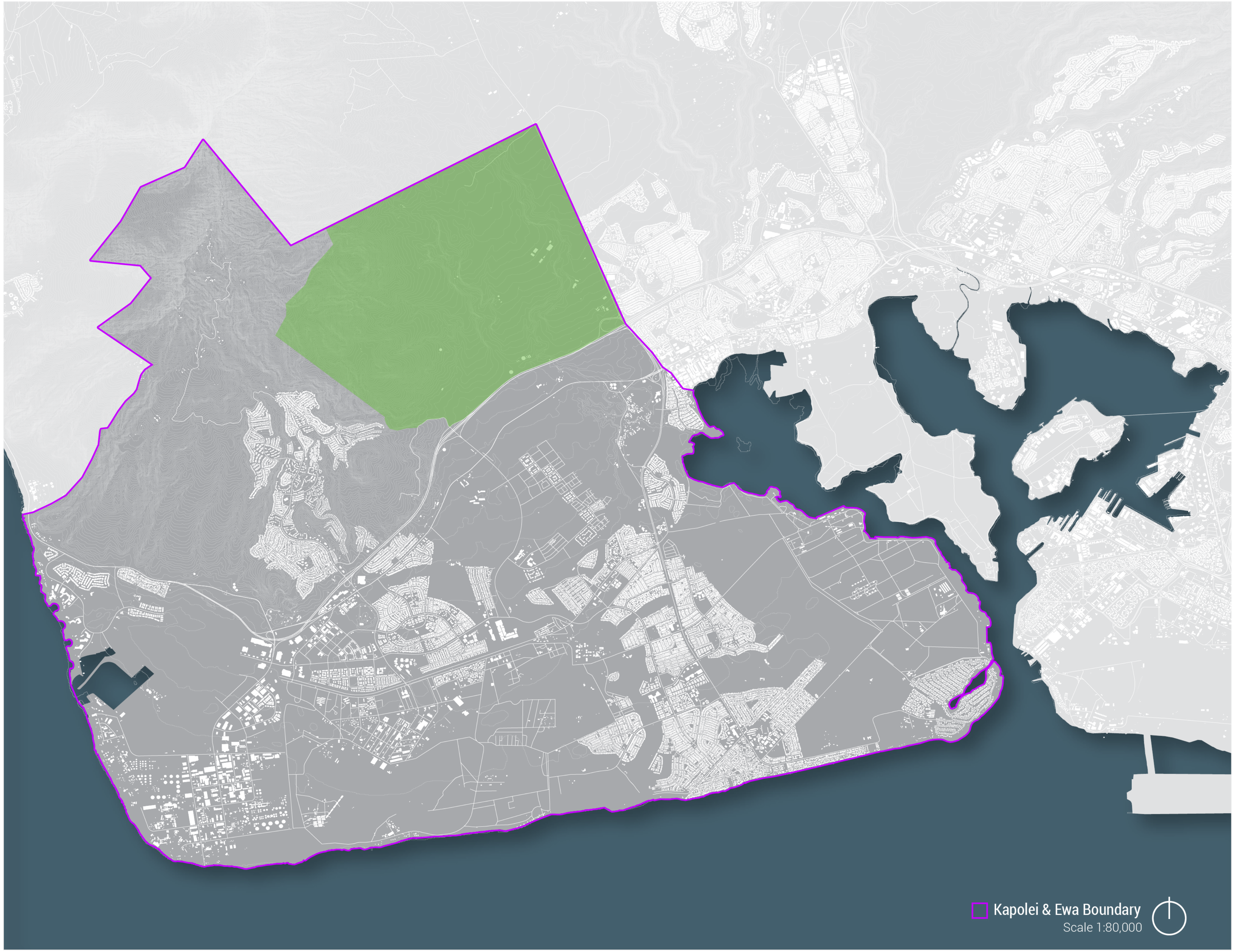


Figure 7.10 Regional Cultivation Site. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

Cultivation area needed for a 1,500 sqft home:

- 1 hectare
- 1 hectare produces 900 lbs of hemp

Typical duration of cultivation:

- 4 months
- 3 crops per year given ideal growing conditions

Selected Cultivation Area (max.)

- Area ≈ **1,900 hectares**

Potential Growth (max.)

- 1 hectare = **900 lbs of hemp**

1,900 x 900 = **1.71 million pounds**

Carbon Sequestered (max.)

- 1 ha = 2,200 lbs of CO_2 absorbed

1,900 x 2,200 = **4.18 million pounds of CO_2**

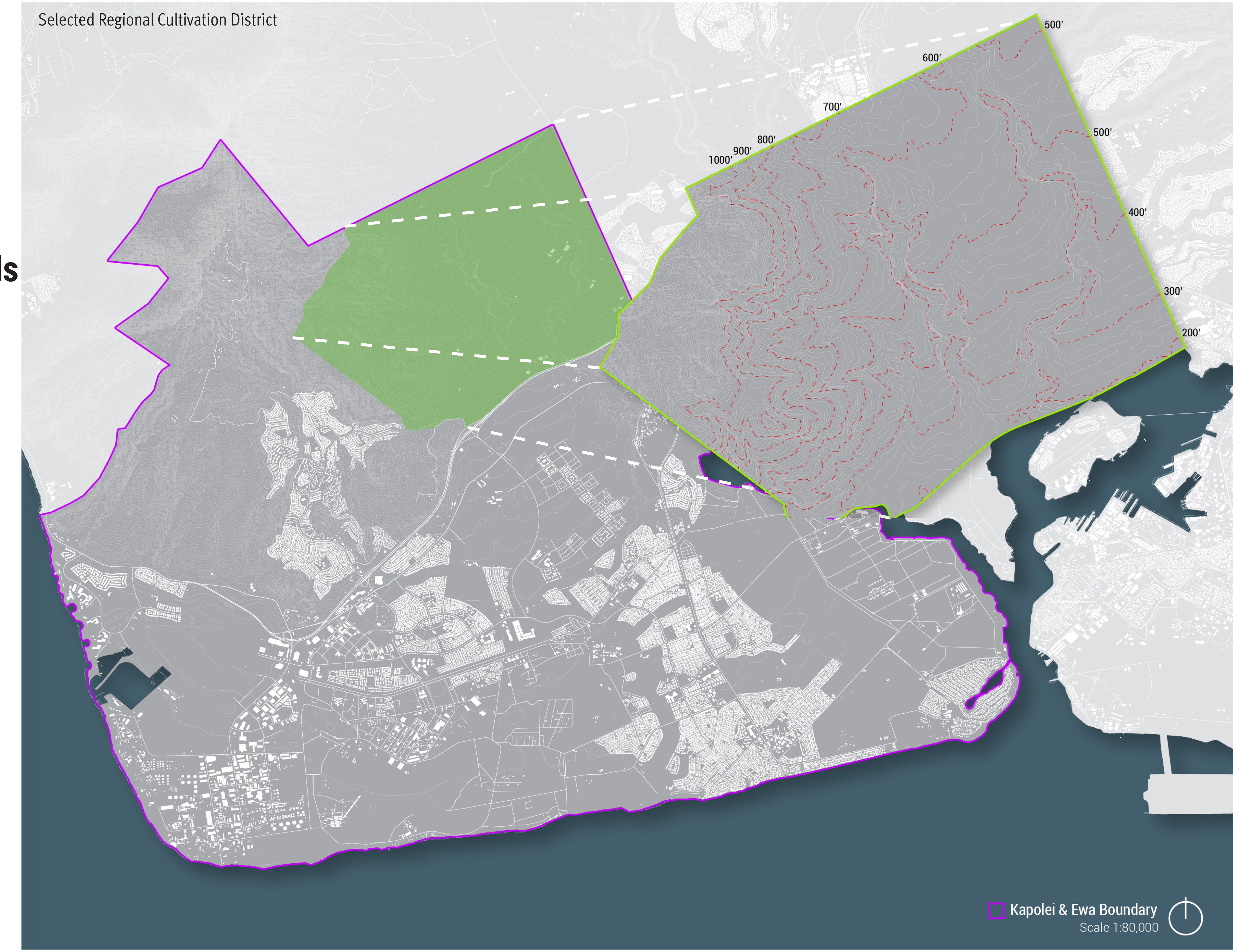
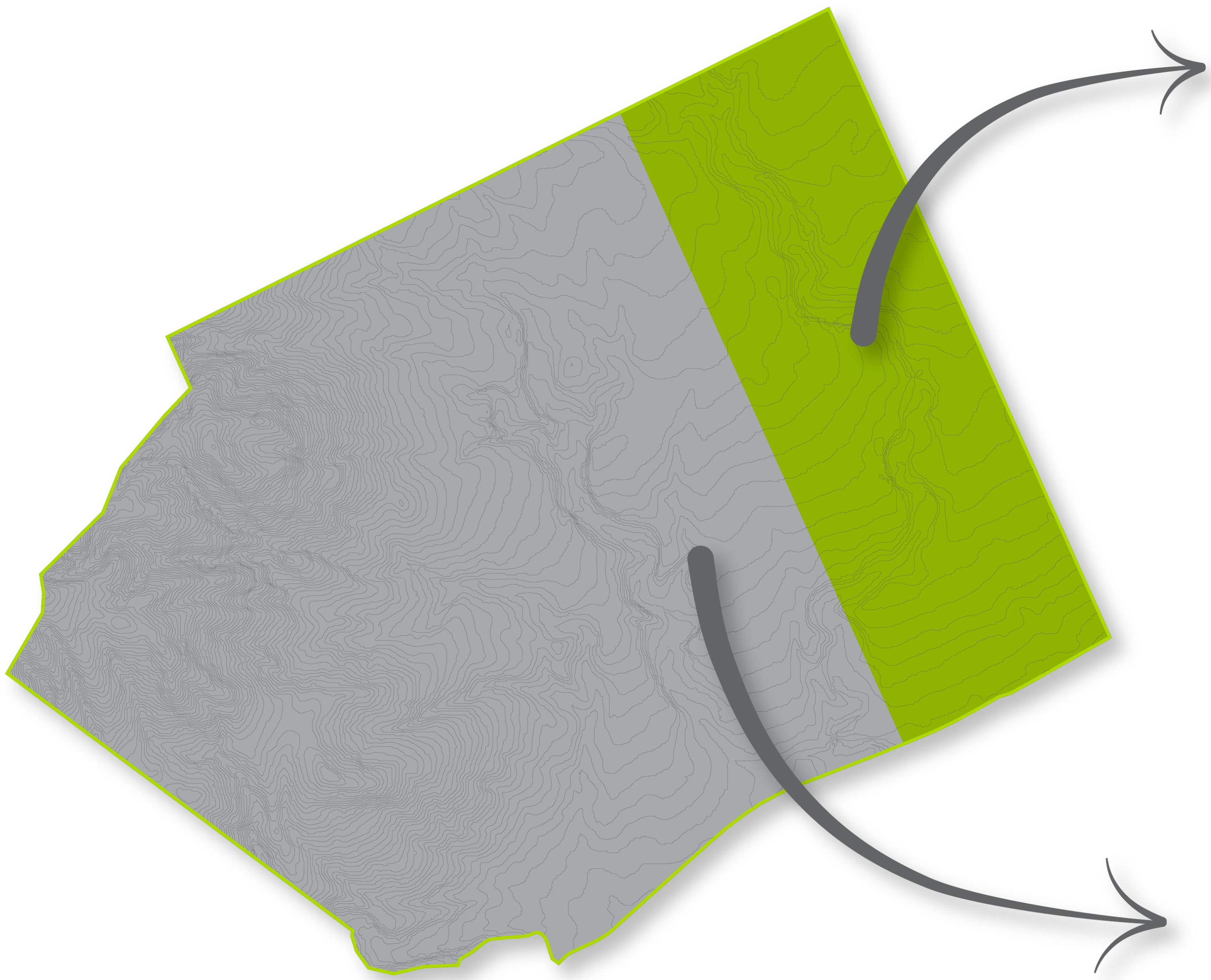


Figure 7.11 Regional cultivation site potential. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.



Selected Regional Cultivation District

1 hectare needed for the construction of a 1,500 ft² home.

Figure 7.12 Raw material production and carbon sequestration potential. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

475 ha x 2 = 950

@ 1,500 ft²

Two crops per year for a total of eight months of cultivation

Rotating on only a 1/4 of total area

950ha x 2,200 pounds

= 2,090,000 pounds of CO_2 sequestered

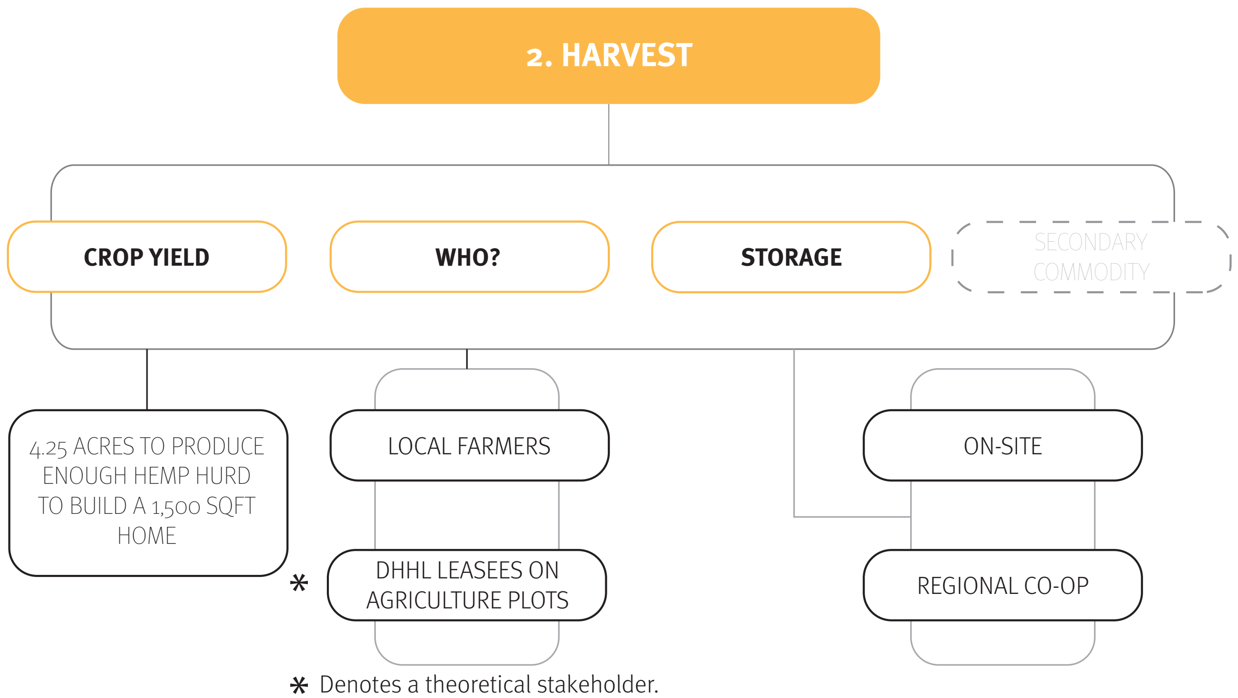


Figure 7.13 Hemp Harvesting Diagram.

7.6 Framework: Hemp Harvesting & Processing

As stated in the previous section, the cultivation of hemp is similar to that of traditional row crop cultivation. Therefore, the harvesting process of hemp is similar too and requires standard farming equipment and machinery used in the harvesting of other grain crops. Storage of the raw hemp materials would be temporarily accomplished at the farm until transportation to a collection and processing point. Ideally, the harvesting, storing, and processing of raw materials would occur on-site, where the cultivation occurs. This scenario may not always be obtainable due to the high cost of land in Hawai'i. As a result, of high real estate costs, a collection and processing site should be considered to manufacture hemp hurds for a building product.

This consideration towards a collection point of hemp for processing can also occur within the moku of 'Ewa. Just as the cultivation would occur within proximity to the project site, so would the collection and processing of raw hemp materials be done at a nearby facility. Two existing business and industrial parks are within the chosen moku of 'Ewa. The James Campbell Industrial Park, established in 1958, possesses the most potential due to the existing facilities in the area

that would be needed for the processing and production of a hemp-based building product. The Kapolei Business Park is also suitable to house a facility for the processing and producing a hemp-based building product. However, the Kapolei Business Park is still under development and could be considered a viable site for future operations. These areas possess the infrastructure needed for a hemp processing operation, where both parks are near and have adequate access to the H-1 Freeway. This access to the H-1 Freeway is essential for transporting the raw hemp material to the processing facility and for future applications of a hemp-based building product beyond the boundaries of the moku of 'Ewa.

Protecting the environment and limiting our carbon footprint are essential aspects of the Nahele i Nāhale Initiative. Factoring the carbon cost of transportation is an essential factor to consider. Therefore, calculating this impact provides a basis for understanding how every stage of the Nahele i Nāhale Initiative is linked to one another.

The average fuel capacity and consumption of a semi-truck were taken into consideration. The use of these trucks is prevalent throughout the island of O'ahu. Therefore, the equation for the carbon cost of transporting raw hemp material is illustrated. Additionally, with the information from the previous section, we can estimate how much cultivation area would be needed to offset the carbon cost of transportation.

Semi-truck carbon footprint figures

Average fuel capacity: 135 gal. per tank x 2 tanks = 270 gal.

Average miles per gallon (mpg): 6.5 mpg

Amount of CO_2 produced from burning one gal. of gas = 19.64 lbs.[32]

270 gal. x 20 lbs. = 5,400 lbs. of CO_2 per truck

The previous section shows that one-hectare sequesters 2,200 pounds of CO_2; therefore, the amount of hemp needed to offset the truck's carbon cost is approximately 2.5 hectares.

32 Physical and chemical properties of gasoline: Department of Energy (DOE)), Alternative Fuels Data Center (AFDC), Properties of Fuels.

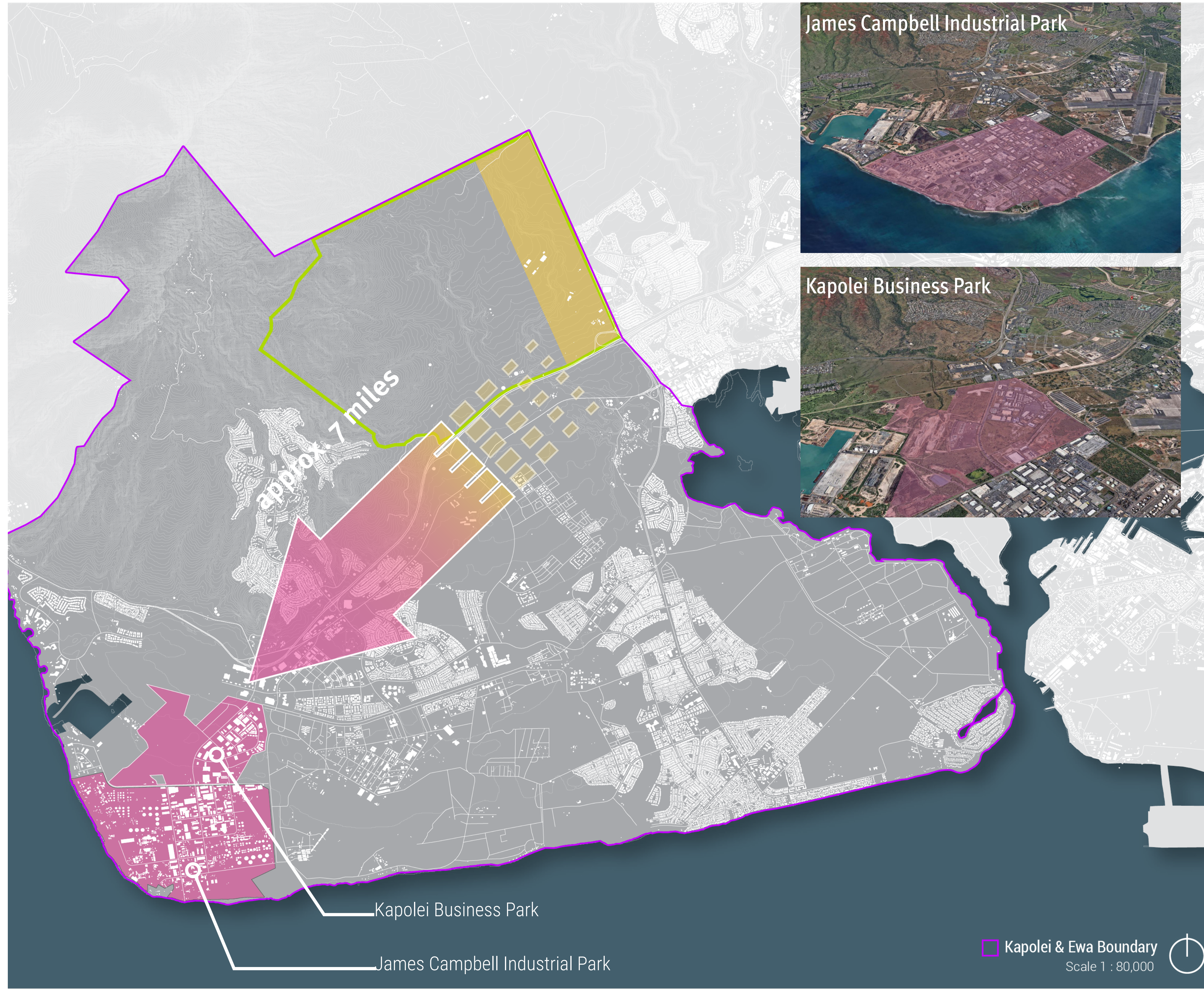


Figure 7.14 The carbon cost of transporting hemp material to the processing & production site. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

A processing facility for the scale and application of a proposed theoretical building design that utilizes a hemp-based building material would require the square footage comparable to the average suburban home of 1,500 square feet on the larger end. Gaining access to the equipment needed for processing would perhaps be the most challenging and most costly phase of the Nahele i Nāhale Initiative. This is in large part because the industrial hemp industry is particularly new to the State of Hawai'i and the current hemp operations in place operate on a much smaller scale. However, the initial investment of the equipment and machinery to process larger volumes of hemp would pay off should the right equipment be chosen.

Current processing methods outside of the State of Hawai'i occur using two techniques requiring machinery of varying sizes. These techniques could be easily implemented within a facility in the James Campbell Industrial Park but would require the initial importation of the machines. The most common method of processing the raw hemp material is through decortication and separation, where removing the bark of the hemp stalk happens. This process focuses mainly on the stalks of the plant and not the entirety of the hemp plant. Generally, this method is done using a hammer mill machine that grinds the hemp with steel hammers that rotate at high speeds. A hammer mill would be the economical option for the beginning of the Nahele i Nāhale Initiative. However, whole-plant processing machinery can provide alternative hemp commodities for future and more extensive operations, supporting a larger hemp market within the state. After the conversion of the raw hemp material into workable hemp hurds, the process of creating a hemp-based building material can begin.

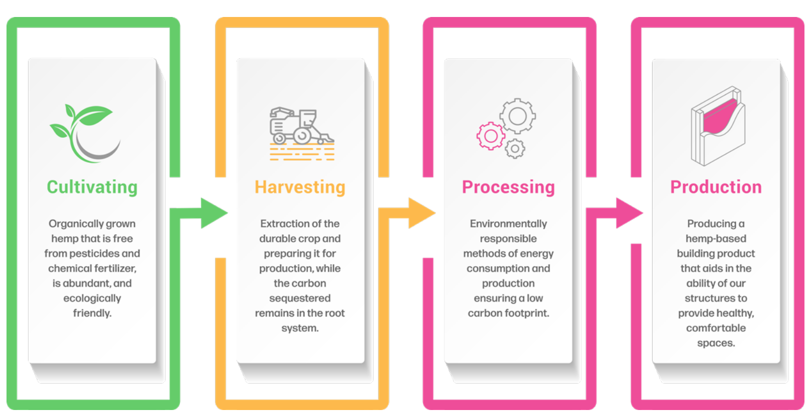


Figure 7.15 Hemp Processing Diagram

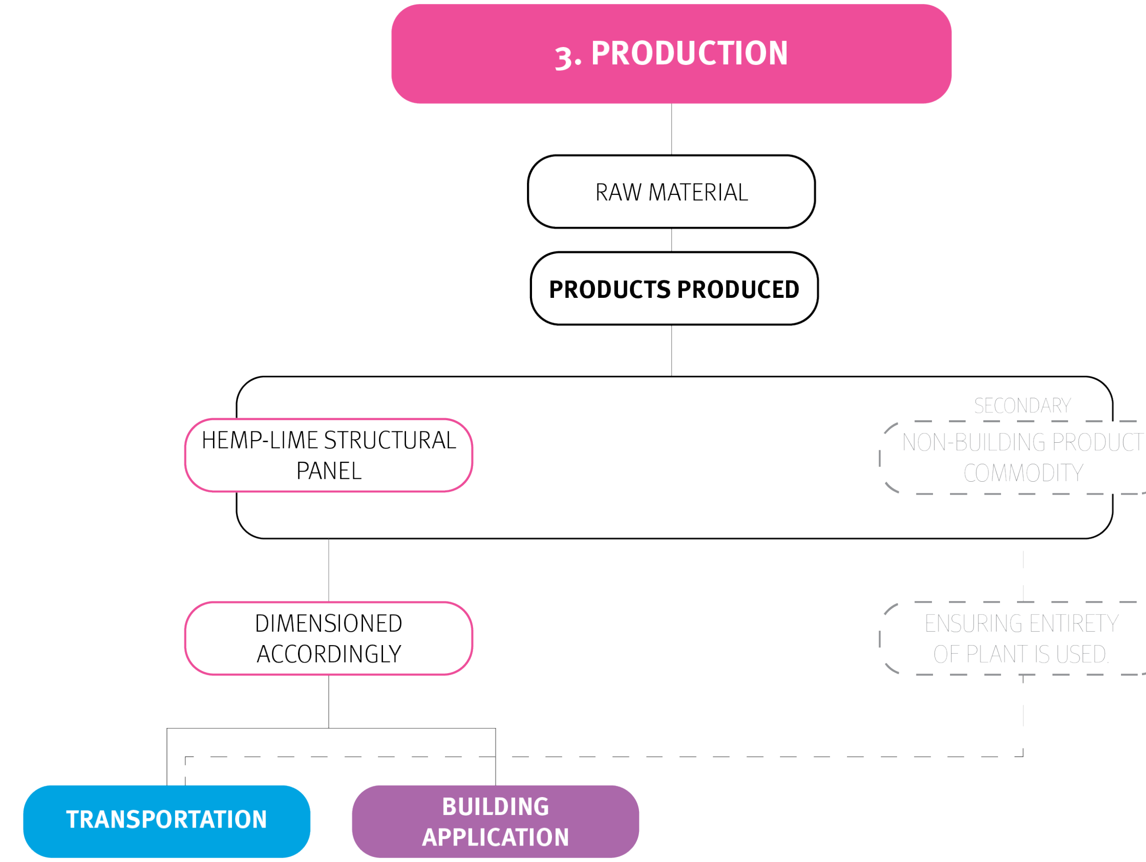


Figure 7.16 Hemp production diagram.

7.7 Framework: Hemp-Based Building Product

In the previous chapter, research into the common uses of hemp in the building industry culminated with a building product that utilized hemp and was combined with a lime binder. Commonly referred to as hemp concrete or hemp-lime, the method of use was typically done in constructing monolithic walls. The hemp-lime mixture was done on-site and compacted layer by layer within the constructed formwork or shuttering. This method of building with hemp was found to be the most common practice but was accompanied by a few disadvantages. Primarily this method of building with hemp was the most labor-intensive method of installation. It required tradesmen to mix the hemp-lime mixture in small quantities and "pour" it into the formwork. Furthermore, this laborious task was also accompanied by compacting each layer throughout the entire structure, ensuring the same amount of compaction quality throughout the entire build. The last disadvantage of this method is the cure

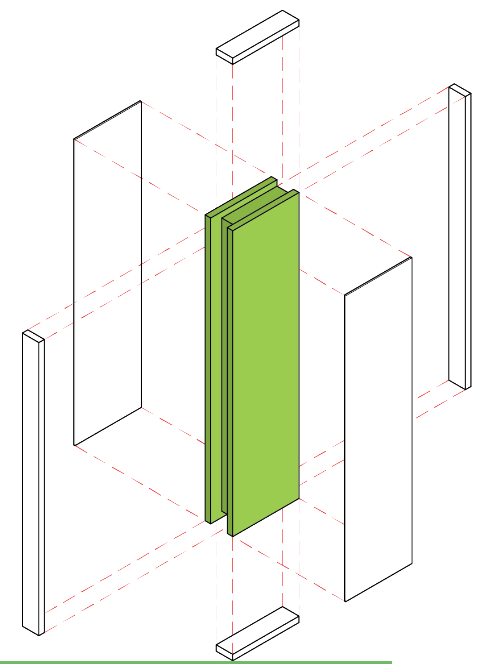


Figure 7.17 Diagram of precast hemp-lime wall system.

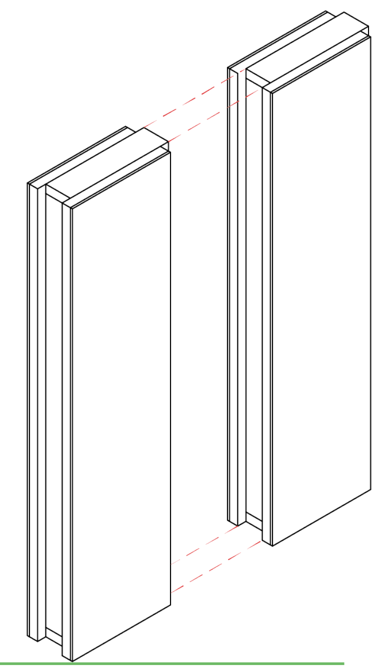


Figure 7.18 Diagram of precast wall system connection.

time for each section of the wall. Once the hemp-lime mixture was poured into the formwork and compacted, 24 hours was required before removing the formwork, where the formwork could then be placed in a higher position to continue constructing the wall. Once an entire wall section was finished, it could take one month, and in some instances up to three months, for the hemp-lime composite to fully cure depending on the exterior climatic conditions. Due to these disadvantages of typical construction, the Nahele i Nāhale Initiative would produce a hemp-lime product in the form of a complete precast structural wall panel system.

A precast structural wall panel system that utilizes a hemp-lime composite would be constructed similar to constructing monolithic walls on site. A precast hemp-lime wall system provides certain advantages that on-site construction does not offer. The first of these advantages of a precast system is that it eliminates the drying and curing time associated with the on-site construction of monolithic walls. The elimination of drying and curing time allows for smoother and better operating logistics of building schedules due to the precast wall systems arriving on-site fully ready for installation. A precast hemp-lime wall system would also eliminate the labor associated with the construction of on-site formwork, cutting down on the overall material cost of the project. Lastly, a

precast hemp-lime wall system can be constructed in a controlled environment, ensuring that each section of the wall possesses the same quality of construction. For the Nahele i Nāhale Initiative, the applications of a precast hemp-lime wall system provide an economical, logistical, and practical building product to the local industry.

7.8 Conclusion

During the first three phases of the Nahele i Nāhale Initiative, the focus is applied to the cultivation, harvesting, and processing of the raw hemp material to produce a precast hemp-lime wall panel system. The critical factors within these three phases are the attention given to the environmental impacts hemp cultivation has on the local ecosystem, ensuring that past introduced and invasive crop cultivation mistakes do not occur with hemp farming. This is accomplished through the simple task of understanding the environment where cultivation takes place and prioritizing farming efforts towards what is beneficial for the health of the soil, perpetuating the traditional caring of the land.

A Hemp-concrete kit was purchased online from a company in Idaho, Hempitecture, that specializes in hemp-concrete construction. The contents of the kit consisted of:

12 ounces of hemp hurds @ 1/4” - 3/8”

12 ounces of a 50/50 mix of hydrated and hydraulic lime binder

6” h x 6” w x 6” d Oriented Strand Board (OSB) form

The instructions indicated that the hurds would need to be dry-mixed with the lime binder ensuring to coat the mixture evenly. Once the hemp hurds were evenly coated with the lime binder half a liter of water was slowly added to the dry mix. Again, this process was done carefully to ensure that there would be no clumping of the lime binder and that the entire mixture of hemp hurd, lime binder, and water was even and consistent.

The hemp-concrete mixture was then poured into the OSB form a layer at a time, damping down the perimeter of the form to ensure even and consistent compaction. Each layer was added approximately an inch at a time until the entire form was filled and compacted. Further instructions indicated that the mixture would be cured enough to remove from the form in three days at which time the hemp-concrete block was removed.

Figure 7.19 Hemp-lime concrete block process images and model

1. Hemp hurd.

2. Hemp hurd & lime binder - dry mix.

3. Hemp hurd, lime binder & water - wet mix.

4. First layer of material.

5. Damping down the edges of each layer.

6. Finished form and awaiting 3 day cure time.

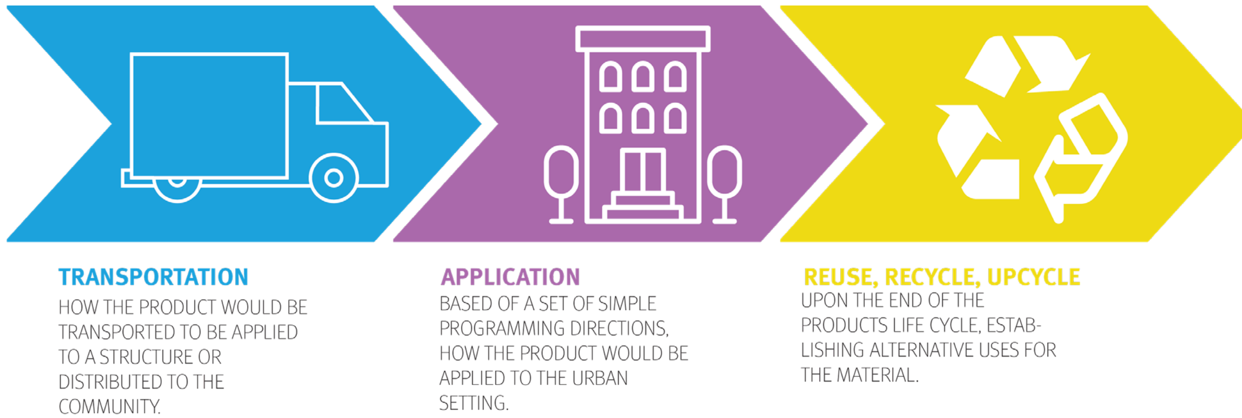


Figure 8.1 Diagram of the remaining stages of the Nahele i Nāhale Initiative.

Chapter 8:

Nahele i Nāhale, Applying the Farm-to-Structure Initiative

For this project to fully embody a farm-to-structure framework, the Nahele i Nāhale Initiative would need to apply the proposed precast hemp-lime wall panel system in an urban setting on O'ahu. Additionally, the Initiative would strive towards maintaining the established practice of preserving proximity that minimizes the transportation of the building product, essentially mitigating its embodied carbon.

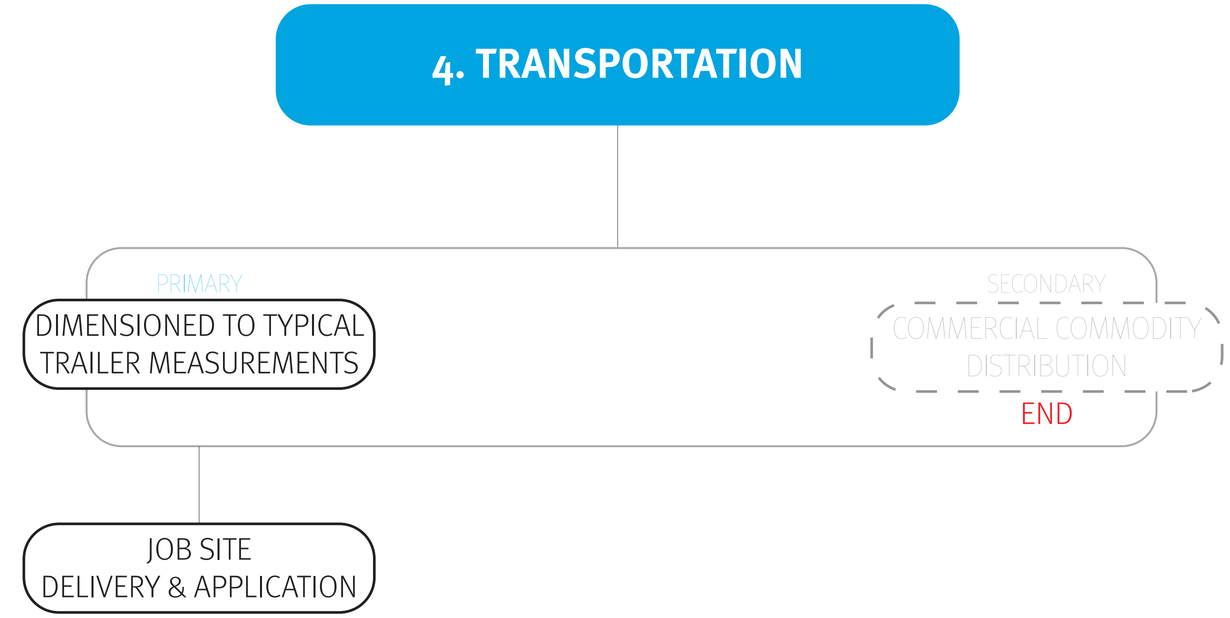


Figure 8.2 Diagram of the transportation of the precast hemp-lime wall system.

8.1 Framework: Transportation of the Precast Hemp-Lime Wall System

Determining the mode in which the precast hemp-lime wall panel system is transported to the project site serves as a beneficial component in maintaining a low environmental impact. For this reason, total efforts towards transportation from farm to project site should not exceed the total carbon sequestration capacity of the hemp plant. With simple arithmetic, the processes involved in the cultivation and production illustrate the potential carbon sequestration qualities during hemp cultivation. Furthermore, the data demonstrate the embodied carbon linked to the cultivation, harvesting, processing, and production phases. This data is critical towards the building industry's responsibility of being better stewards of the environment by ensuring that the entirety of a building product's embodied carbon is considered. All of this data can then be applied to the logistical efforts involving the transportation of the building product, ensuring that the efforts of the Nahele i Nāhale Initiative maintain a zero net carbon footprint. With the health and well-being of the environment at the forefront of each stage of the Nahele i Nāhale Initiative, the building industry begins to foster and perpetuate indigenous cultural concepts like that of mālama 'āina, caring for the land.

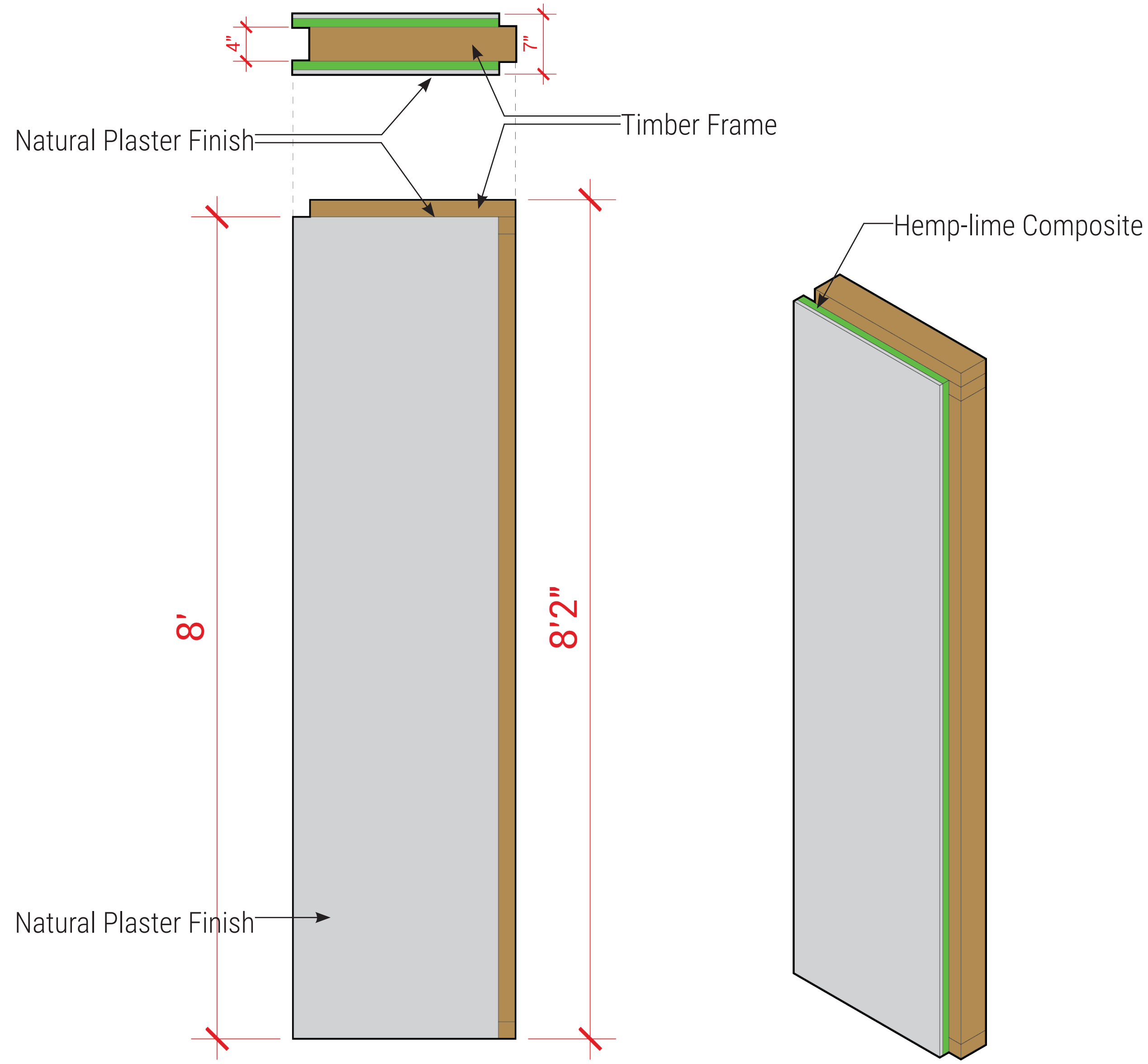


Figure 8.3 Typical dimensions of hemp-lime wall panel.

The first aspect of the logistical operations of transporting the precast hemp-lime wall panel system is ensuring that the dimensions of each wall panel module are within the limits of a typical flatbed trailer. Producing a product that adheres to these standard dimensions allows for the maximum allowable cargo to be transported from the manufacturing to the application or project site. However, standard dimensions are not the only factor to consider while transporting the hemp-lime wall panel system.

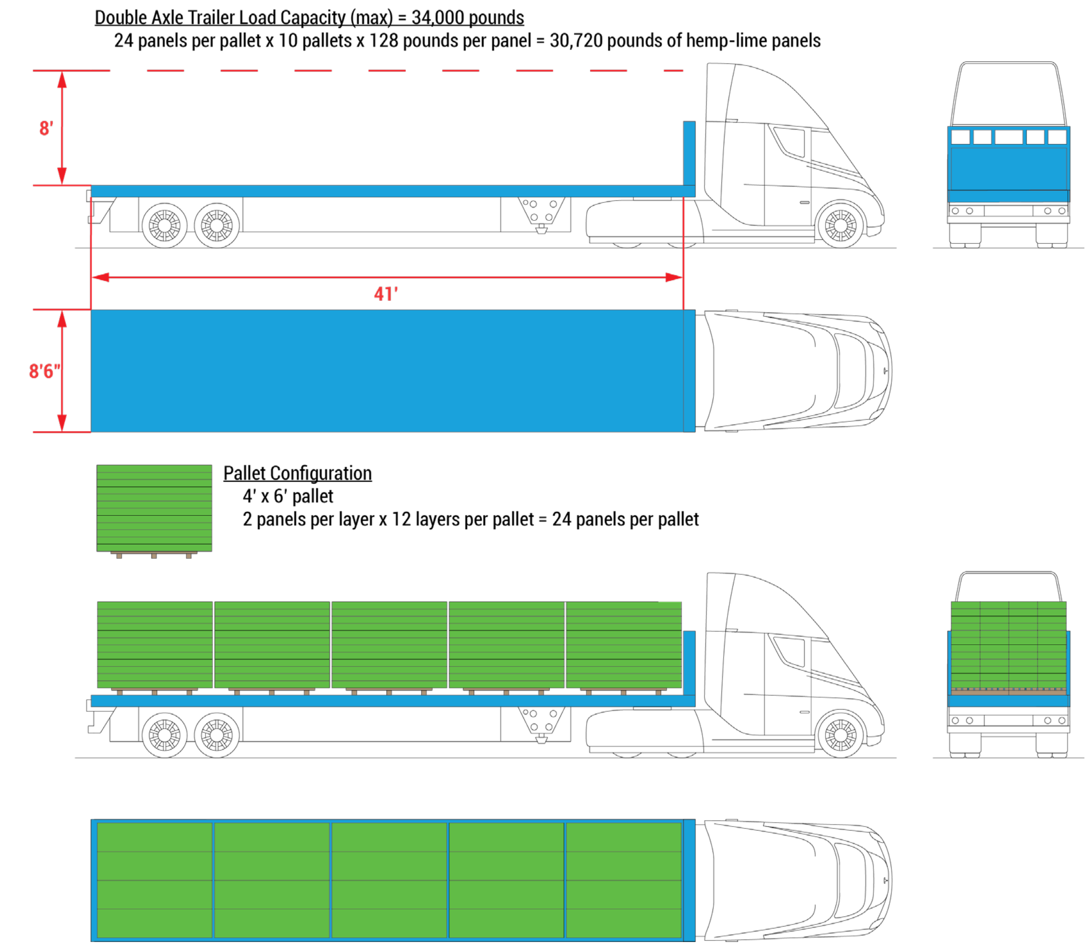
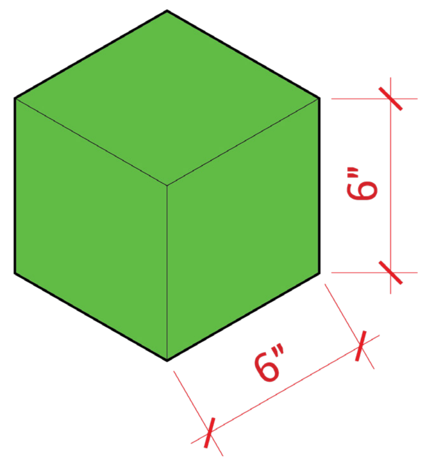


Figure 8.4 Typical dimensions, packing, and load capacity of semi-truck with double axle flat-bed configuration.

The second aspect considered in the transportation of the hemp-lime wall system is the weight of each module. This characteristic has two purposes. The first is the known factor that large semi-trucks used to haul considerable loads have a specified weight limit. The weight limit of a particular shipment is dependent on the semi-truck and its trailer setup. Traditional semi-trucks can weigh anywhere between 15,000 to 25,000 pounds, depending on the type of truck.[33] Adding the weight of the trailer to the truck itself is also considered. By law, semi-trucks with single axles can safely haul a load of 20,000 pounds, while semi-trucks with double axles are allowed to haul loads no more significant than 34,000 pounds.[34] Figure 8.1 is a graphic representation of the typical dimensions,

33 Bryant, Terry. "How Much Does A Semi Truck Weigh? | How Heavy Is A Semi Tractor?" Terry Bryant Accident & Injury Law (blog), April 9, 2020. https://www.terrybryant.com/how-much-does-semi-truck-weigh.

34 Ibid



Sample Hemp-lime Block
Dimensions: 6" x 6" x 6"
Volume: 216 cubic inches
Weight: 2.00 pounds

Hemp-lime Panel
Dimensions: 96" x 24" x 6"
Volume: 13,824 cubic inches
Weight: 128 pounds

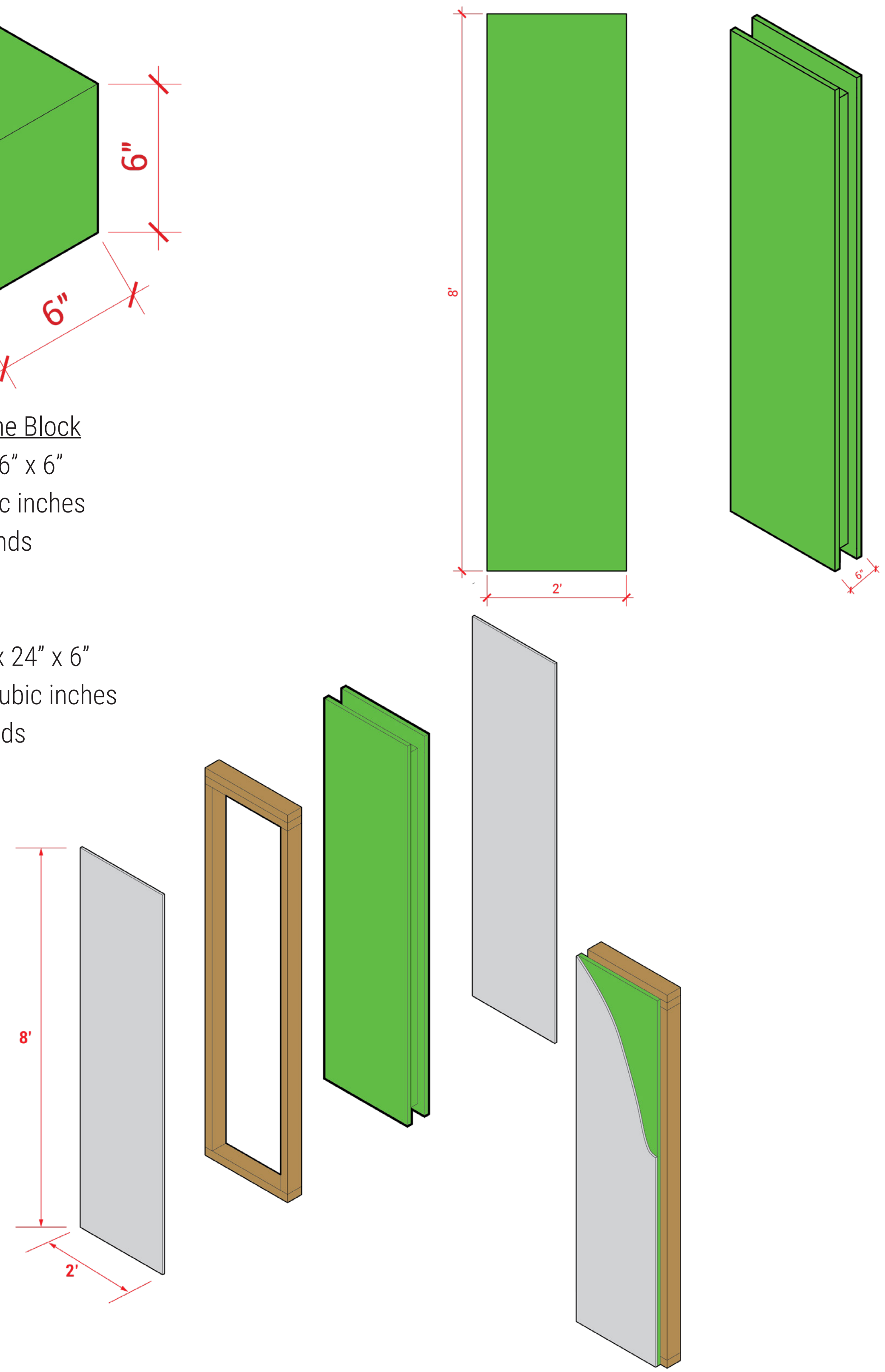


Figure 8.5 Typical dimensions with hemp volume and estimated weight, drawing not to scale.

packing, loading, and weight of a single load of the hemp-lime wall system.

The logic towards establishing a standard weight of each module also plays a part in how a single shipment of hemp-lime wall system panels will be offloaded from its mode of transportation at the project site and installed onto the structure. Traditional prefabricated products utilize concrete and steel as their primary source of building materials. Combining these two building materials in a traditional prefabricated product translates to heavy equipment for the off-loading and installation within a structure. Using secondary heavy equipment like cranes ultimately translates to increased energy and fuel consumption, equating to a larger carbon footprint. The Nahele i Nāhale Initiative proposes that the prefabricated hemp-lime wall panel have dimensions of 96"h x 24"w x 6"d. Figure 8.5 illustrates an exploded axonometric drawing of the construction of each panel with the total volume of hemp-lime composite and the supporting structural members along with an individual panel's total weight. With the illustration and data from Figure 8.5, we can conclude that the proposed dimensions and weight of each prefabricated hemp-lime wall panel would be manageable for a team of workers to transport within the project site.

Transportation logistics are a critical portion of the Nahele i Nāhale Initiative. This phase of the Initiative takes place twice within the entirety of its strategy, once when the raw hemp material is transported to the processing and production phase and subsequently when the building product is transported from the production plant to the project site. The critical factor of the transportation phase is that it is a stage where carbon emissions can negatively impact the environment, thus making it an essential portion of the design intent of the Initiative. Standard hemp-lime module dimensions and weight are considered during the semi-truck setup and size conditions during the transportation phase. The Nahele i Nāhale Initiative would provide a building product that factors the environmental impacts during transit. Additionally, the standardization of the wall panels installation can be accomplished either manually with a team of individuals or by utilizing light or manually operated equipment to quickly assemble the building's envelope.

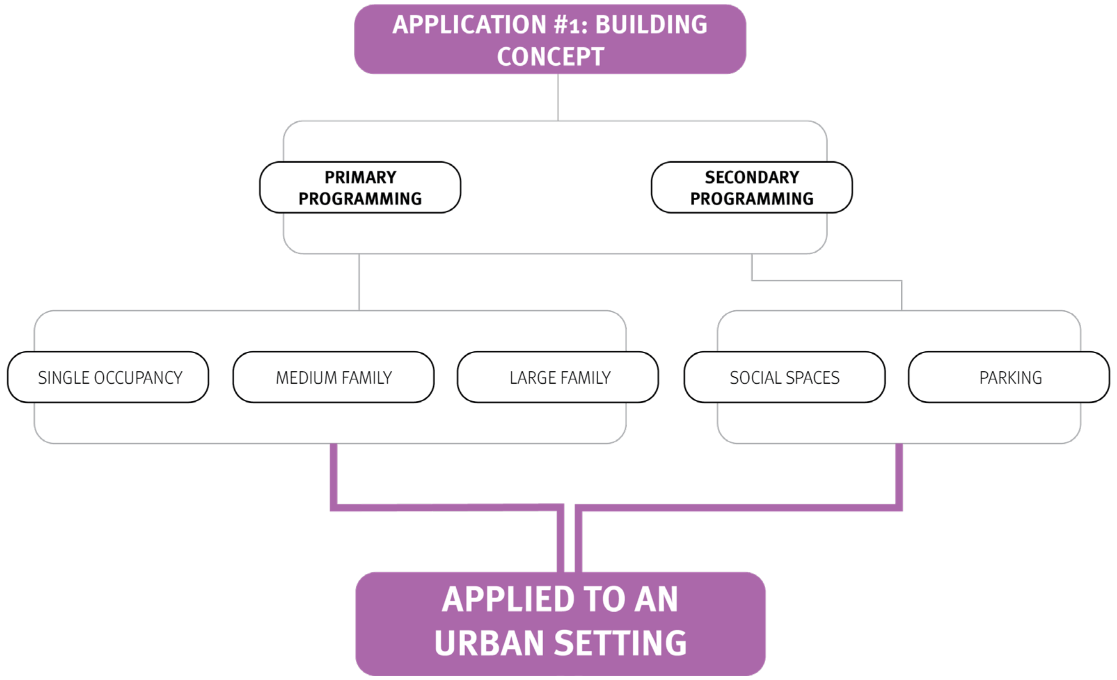


Figure 8.6 Diagram of precast hemp-lime wall system application.

8.2 Framework: Application of the Precast Hemp-Lime Wall System

Over many decades, the urban core of Honolulu, on the island of O'ahu, has grown and spread, encompassing the majority of the island's southern shoreline. The urban sprawl has brought real estate development projects that echo suburban planning practices in the continental United States. With land having both a monetary and quantity premium, this model of constructing large neighborhoods consisting of predominantly single-family homes is being recognized as an inefficient way of providing adequate housing for Hawai'i's residents. Therefore, the speculative design of the proposed Nahele i Nāhale Initiative will focus on providing medium-density housing within the boundaries of the developing cities of Kapolei and Ewa Beach, the latter being referred to as Ewa by residents.

To avoid confusion, the city of Ewa Beach does not share the exact traditional boundaries as the moku of 'Ewa. The city of Ewa Beach rests along the western shoreline of Pu'uloa, or what is commonly referred to as Pearl Harbor, and is the older of the two cities. Sharing a name with the larger moku land district was established in 1907 when Ewa Beach became incorporated with Honolulu County.[35]

35 City Town Info. "Ewa Beach, Hawaii - City Information, Fast Facts, Schools, Colleges, and More." citytowninfo.com. Accessed November 22, 2021. //www.citytowninfo.com/places/hawaii/ewa-beach

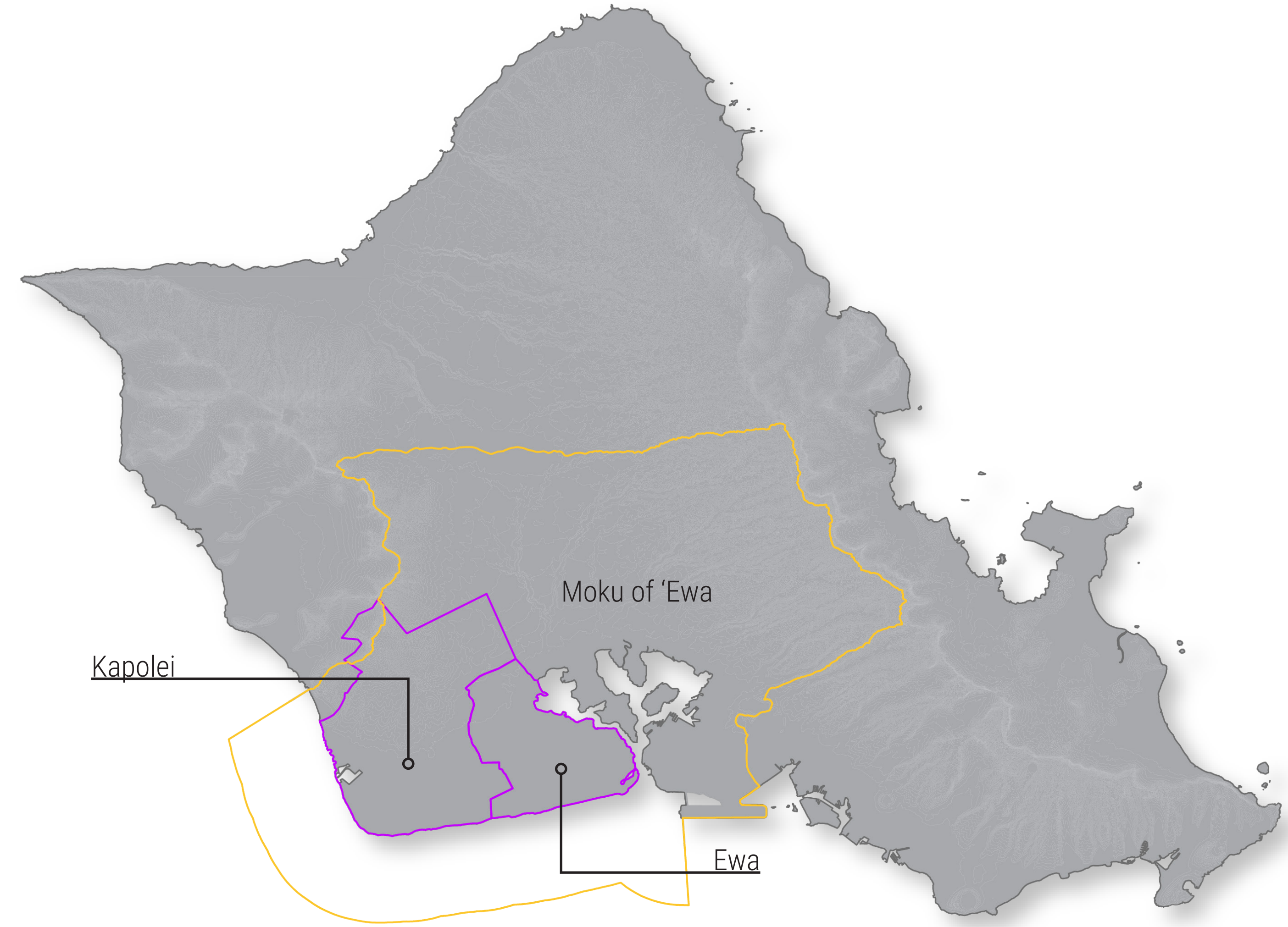


Figure 8.7 Diagram of the municipalities of Kapolei and 'Ewa within the traditional moku of 'Ewa.

Figure 8.7 illustrates the boundaries of both cities within the more extensive traditional land division, the moku.

These two cities were chosen as speculative locations because of the continued growth and urban sprawl of the densely inhabited City of Honolulu. Although individual cities, Kapolei and Ewa fall under the municipality of the City and County of Honolulu. This area of O'ahu has seen enormous growth with the planning of many new communities, businesses, schools, and infrastructure. Once an area utilized to cultivate sugar, the region that the two cities now occupy displays tiny remnants of the historical impacts of the old sugar plantations. According to the 2020 United States Census, the

Figure 8.8 Historical image of the ʻEwa Plain, the eventual locations of Kapolei and Ewa Beach. Image Source: https://memoirsofgrowingupinparadise.wordpress.com/2013/09/17/ewa4ewa/

Figure 8.9 Current aerial image of the ʻEwa Plain with single-family typologies to accommodate urban sprawl. Image Source: HomeQuest, http://homequesthawaii.com/communities/ewa-plain/

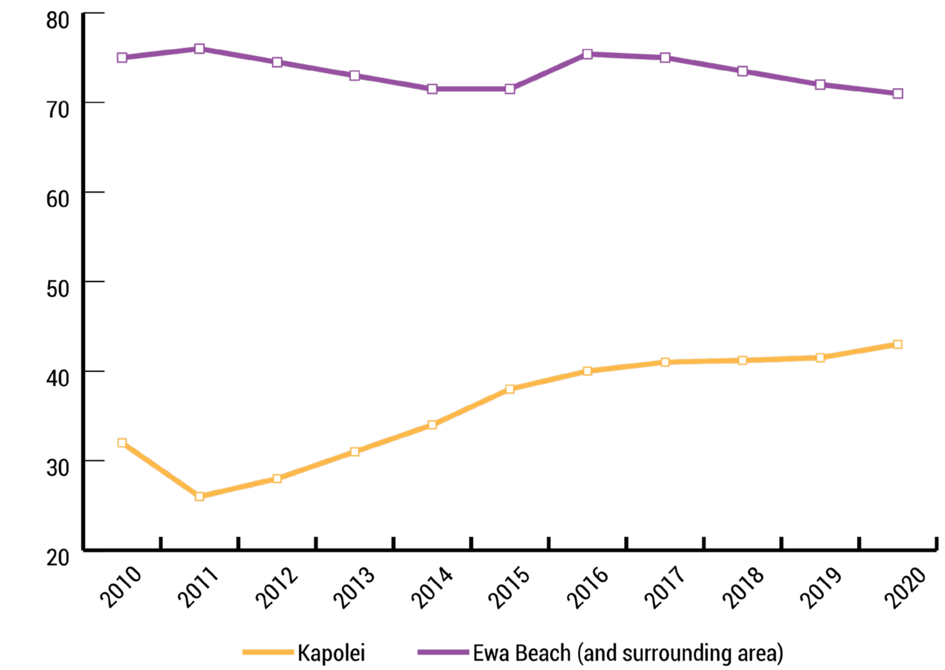


Figure 8.10 Population growth graph of Kapolei and Ewa Beach. Data Source: U.S. Census Bureau

population of the Ewa Beach area is 70,435, with the Kapolei area having a population of 41,288.[36] Over the last few decades, this area of Oʻahu has seen significant growth and development to the extent where the city of Kapolei is commonly referred to as the "second city" of Oʻahu with Honolulu. Both cities possess building typologies mentioned in the previous chapter where large communities have been planned and developed for single-family dwellings. However, as seen in Figure 8.1, where these two city boundaries meet, an opportunity for the development of medium-density housing which utilizes a precast hemp-lime wall system exists on lands managed by the University of Hawaiʻi, West Oʻahu campus.

36 U.S. Census. "U.S. Census Bureau QuickFacts: Kapolei CDP, Hawaii; Ewa Villages CDP, Hawaii; Ewa Beach CDP, Hawaii; Ewa Gentry CDP, Hawaii." Accessed November 22, 2021. https://www.census.gov/quickfacts/fact/table/kapoleicdphawaii,ewavillagescdphawaii,ewabeachcdphawaii,ewagentrycdphawaii/PST045219.

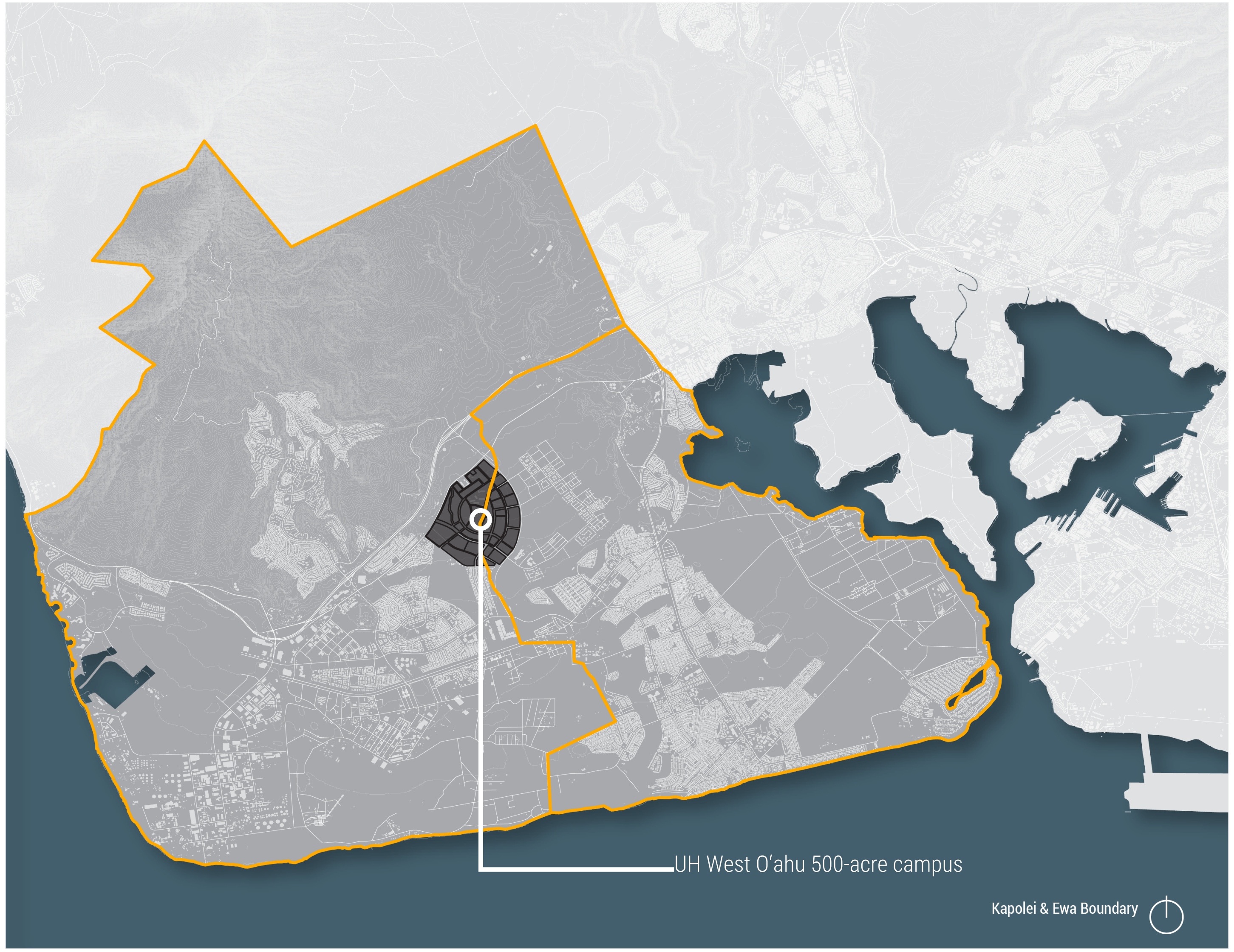


Figure 8.11 The University of Hawai'i, West O'ahu Campus intersection with Kapolei and Ewa Beach.

8.3 Site Selection: The University of Hawai'i, West O'ahu Campus

The University of Hawai'i West O'ahu (UHWO) campus presents a unique opportunity to implement the speculative design applications of a building design that utilizes a precast hemp-lime wall system. The UHWO campus is one of ten campuses in the more extensive state-wide UH system. With its newly developed campus in the 'Ewa plain, the UHWO plans to expand its land holdings beyond educational purposes.

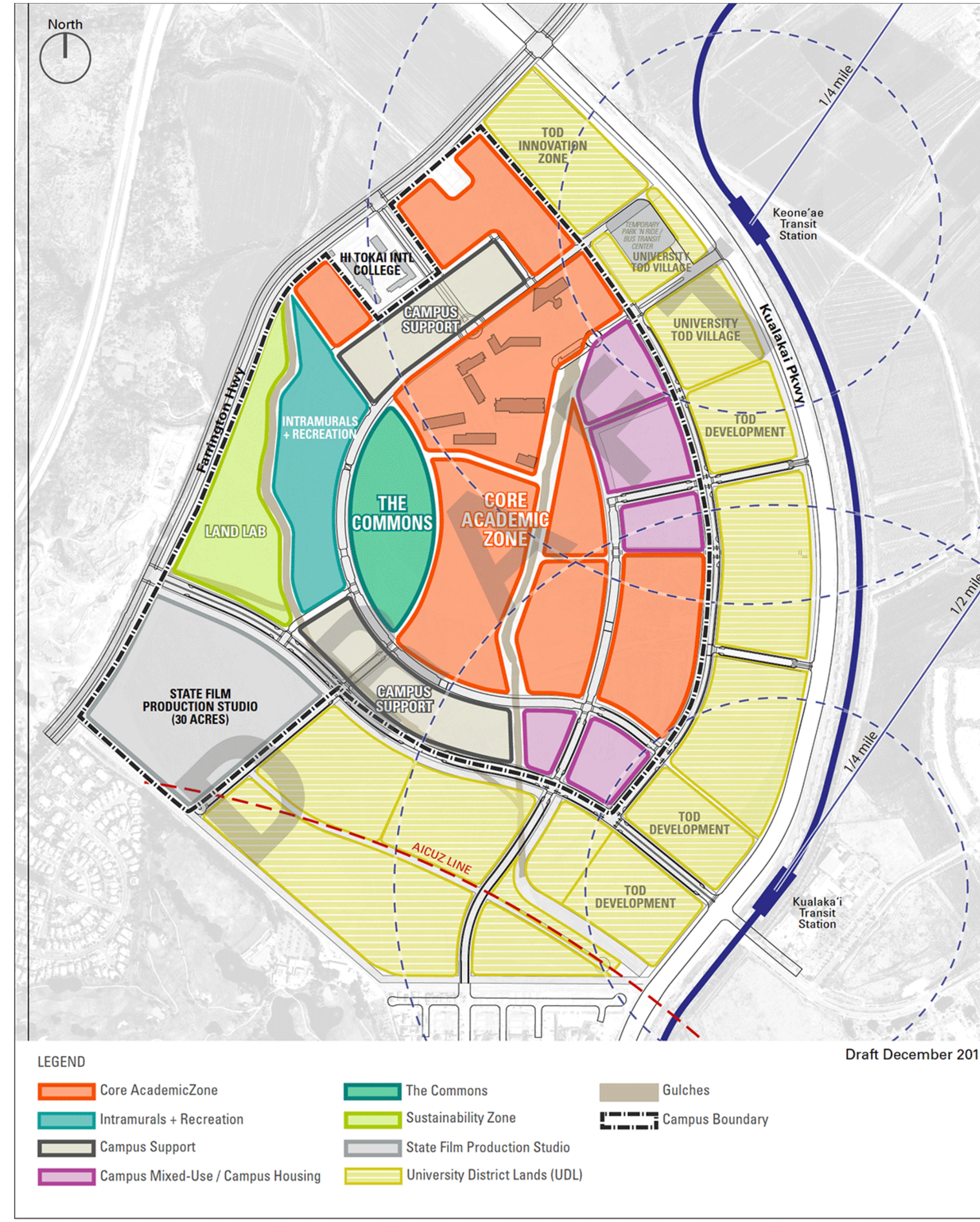


Figure 8.12 University of Hawai'i West O'ahu Master Plan, 2018. Image Source: University of Hawai'i West O'ahu.

In 1999 the University petitioned the state for approximately 500 acres of property within the ʻEwa plain. This land had previously carried a zone designation of AG-1 Restricted Agricultural District. In "November 2008, the UHWO completed a zone change for the property. . .to BMX-3 Community Business Mixed Use District, A-2 Medium Density Apartment District, R-3.5 Residential District, R-5 Residential District, and P-2 General Preservation District under Ordinance 08-30."[37] This land acquisition allowed the UHWO to transport its faculty and programs from its temporary campus at the Leeward Community College campus to its campus, which opened in 2012.

The UHWO established a conceptual long-range development plan that provided a framework for the future development of what a 2015 Annual Report designates as University District Lands (UDL). Incorporated into this conceptual long-range plan are conditions for using both the University's campus and the University District Lands. These UDL portions occupy "approximately 168 acres allocated for mixed-use."[38] The State Land Use Commission implemented a series of twenty-six conditions.

This annual report provided a structure for developing a speculative building design that utilizes a prefabricated hemp-lime wall system. Identifying that with the UHWO's acquisition of the 500 acres and the conditions set forth by the state, the first condition provided the framework for selecting a 17.5-acre site within the UHWO's district lands. Condition 1 states:

> Petitioner [UHWO], its successors, and assigns shall provide affordable housing opportunities for residents of the State of Hawaiʻi by applicable affordable housing requirements of the City and County. The location and distribution of the affordable housing or other provisions for affordable housing shall be under such terms as may be mutually agreeable between Petitioner, its successors, and assigns, and the City and County. [39]

In the last few years since the opening of the UHWO campus, little development has occurred within the University District Lands. However, the lands adjacent to the University District Lands have seen significant development from other state entities like the Department of Hawaiian Homelands

37 Ibid U.S. Census. "U.S. Census Bureau QuickFacts: Kapolei CDP, Hawaii; Ewa Villages CDP, Hawaii; Ewa Beach CDP, Hawaii; Ewa Gentry CDP, Hawaii." Accessed November 22, 2021. https://www.census.gov/quickfacts/fact/table/kapoleicdphawaii,ewavillagescdphawaii,ewabeachcdphawaii,ewagentrycdphawaii/PST045219.
38 Ibid
39 Ibid

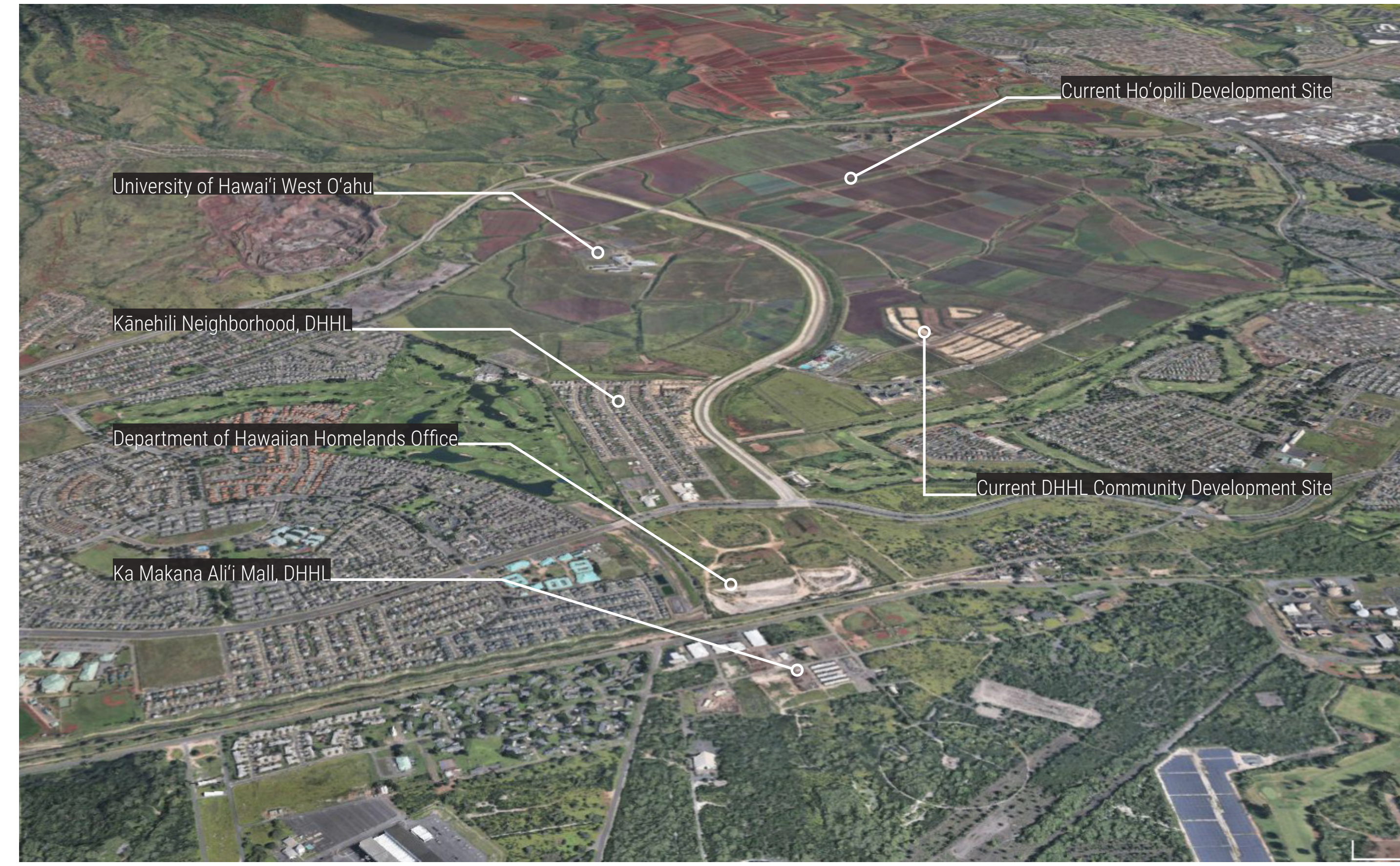


Figure 8.13 Google Earth image of UHWO campus and surrounding neighborhood.

(DHHL) and the Honolulu Authority for Rapid Transportation (HART) with the construction of the rail guideway and transit stations. The development from the previous two entities, partnered with the University's obligation to provide affordable housing, makes a case for proposing a scenario where the UHWO develops medium-density mixed-use housing. The UDL provides an opportunity for the logical implementation of this project's speculative building design furthering the Nahele i Nāhale Initiative towards the application phase.

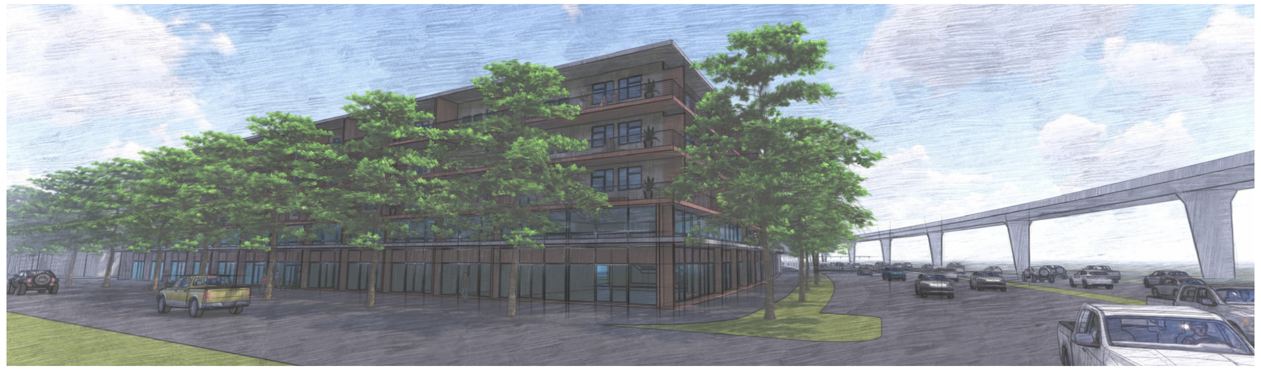


Figure 8.14 Speculative Building Design.

8.4 Framework: Speculative Building Design and Application

The application phase of the Nahele i Nāhale Initiative is no more important than any of the other proceeding phases. However, the application phase is where the proposal of a prefabricated hemp-lime wall system begins to emerge independently from the typical construction typologies established in Chapter 6. Although a prefabricated wall panel system typology exists in today's building industry, where this project looks to expand upon the architecture and design profession and how architects utilize hemp as a future building material, is its application into a building typology not previously accomplished.

As stated in Chapter 6, hemp-lime composites are typically utilized in single-family building typologies, with monolithic infill being the dominant construction typology. These building and construction typologies work well in areas where high land value and density are not an issue. For the island of O'ahu, the scarcity of developable land influences policy implementation and changes that look toward providing housing typologies at varying densities, factoring out single-family zoning. These housing typologies can be categorized into three general classes, low-density, medium-density, and high-density.

Defining density for this project is as important as defining what constitutes a sustainable material. However, because this project explores applying a prefabricated wall system on a medium-density housing typology, defining this typology will be accomplished in detail. The low-density housing typology would typically include single-family residential units. However, to exclude single-family units from being constructed in areas where housing density is at a premium, low-density housing typology could be defined as housing units with two to four units clustered together. This typology would primarily consist of townhomes that are arranged in either a duplex or a quadplex design. For this project and its location, the definition of a high-density housing typology would be a structure that is six or more stories in height with 100 plus units. As previously stated, the housing typology that this project looks to apply the prefabricated hemp-lime wall system to is medium-density. Medium-density housing consists of a structure not exceeding five stories and between 40-100 units. This housing typology would also exclude particular building attributes typical of multi-story housing, such as elevators. As elevators are needed per the Americans with Disabilities Act (ADA) for individuals to have the ability to access units on the upper floors of a building, this project will accommodate individuals with disabilities by providing ADA-accessible units at ground level. A medium-density housing typology would be considered a walk-up.

The selected site within the UHWO's district lands is approximately 17.5 acres in area. Proposing a single structure on a site of this size would be a disservice to applying a prefabricated hemp-lime wall system. Therefore, proposing the design of a single medium-density housing typology showcases the speculative construction methods and techniques used to apply the prefabricated wall system. This structure may only inhabit between 1.5 – 2 acres of area within the proposed 17.5-acre site. Therefore, the proposed design will provide a massing of different building typologies, creating a context for the neighborhood and its amenities. The programming of the remainder of the site will also include businesses, parking, pedestrian circulation, and social spaces. These aspects are all essential towards establishing densification and a thriving community. For this mixed-use and mix-typology community to flourish, specific amenities should be near the site. These amenities include but are not limited to employment, education, healthcare, and transportation. As the two cities of Kapolei and Ewa continue to grow, these amenities will also become more defined.

This speculative design aims to provide a viable site plan and programming of the 17.5 acres ensuring the hypothetical zoning of mixed-use residential within the project site provides varying housing typologies. The intention of the speculative building design consists of four design characteristics to establish hemp as a viable building material.

Speculating a building design begins with site selection and site analysis. How the Nahele i Nāhale Initiative impacts the local neighborhood context while also examining what a structure that utilizes the prefabricated hemp-lime wall panel system would look like within the community.

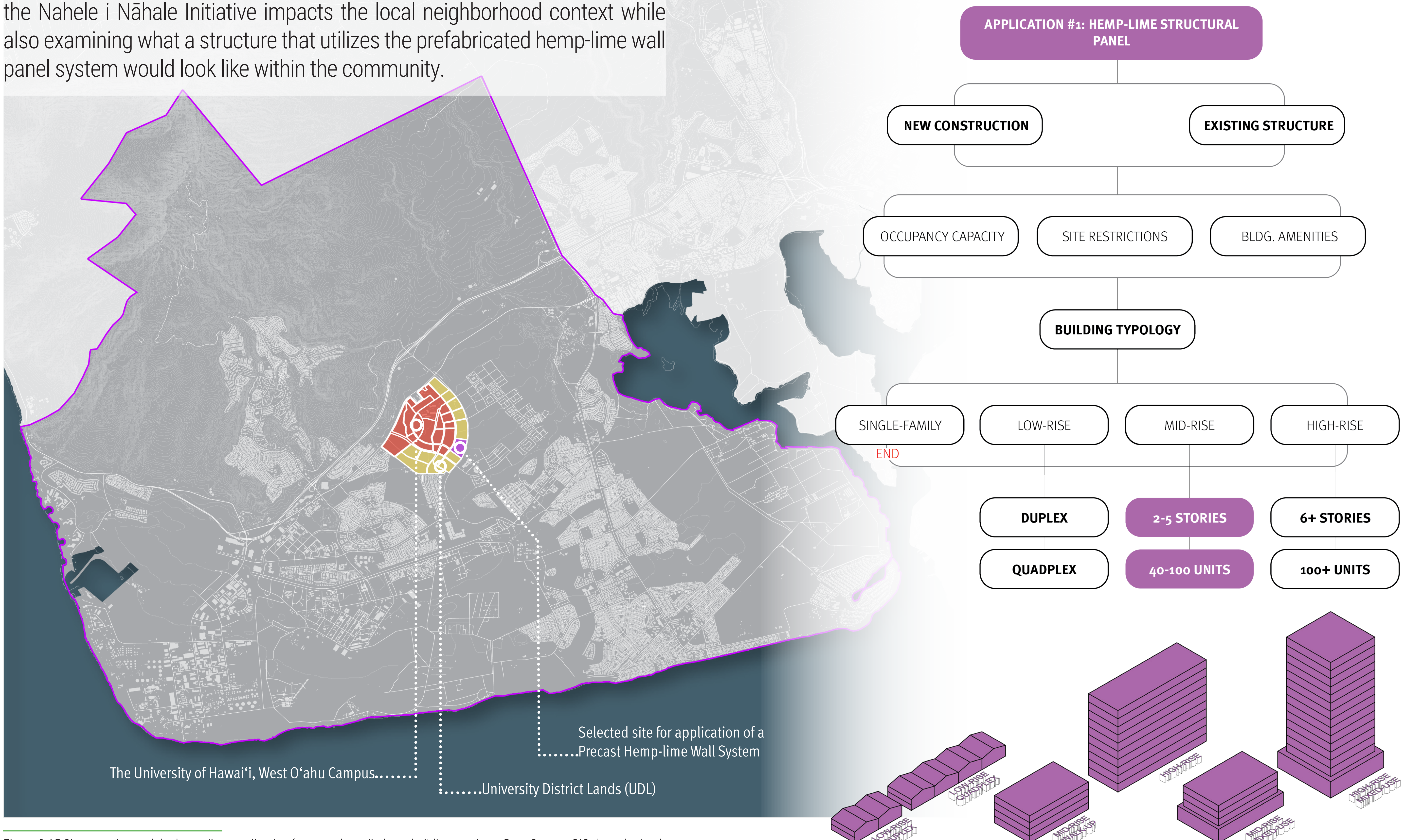


Figure 8.15 Site selection and the hemp-lime application framework applied to a building typology. Data Source: GIS data obtained from Hawai'i State Office of Planning, Hawai'i Statewide GIS Program, Geospatial Data Portal. Open source material.

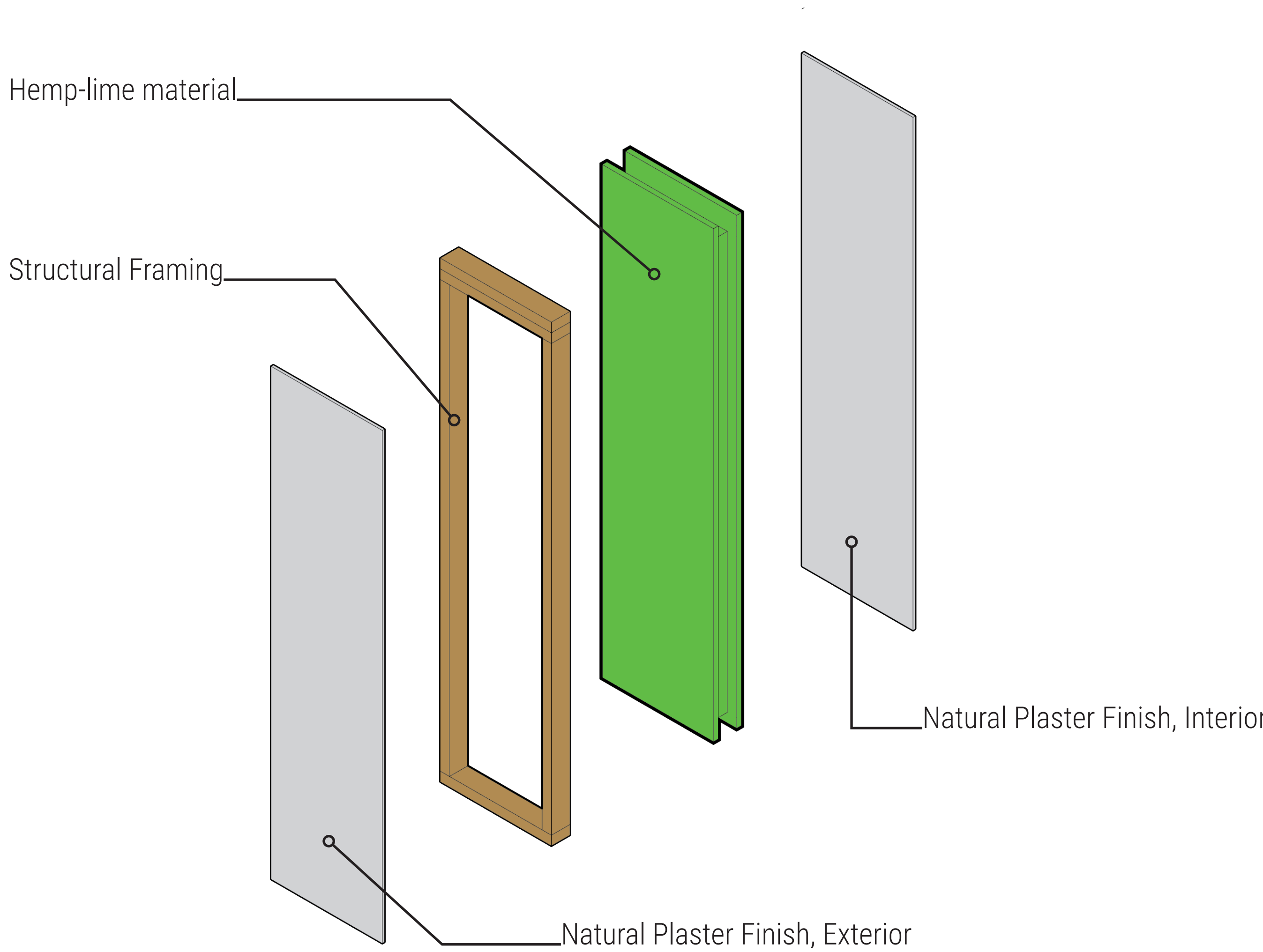


Figure 8.16 Diagram of a typical panel assembly.

These four characteristics are:

1. The prefabricated wall systems are applied to buildings of higher density where the wall system maintains a level of structural integrity suitable for its application as the building's envelope.
2. The medium-density structure's orientation considers the site's climatic conditions to ensure the beneficial characteristics of a hemp-based building product for the health of the building and its occupants.
3. The use of a hemp-based prefabricated wall system provides a feasible alternative as a substitute for typical building products used in constructing traditional walls.
4. Lastly, at the end of its current use as a prefabricated wall system, the hemp-based product

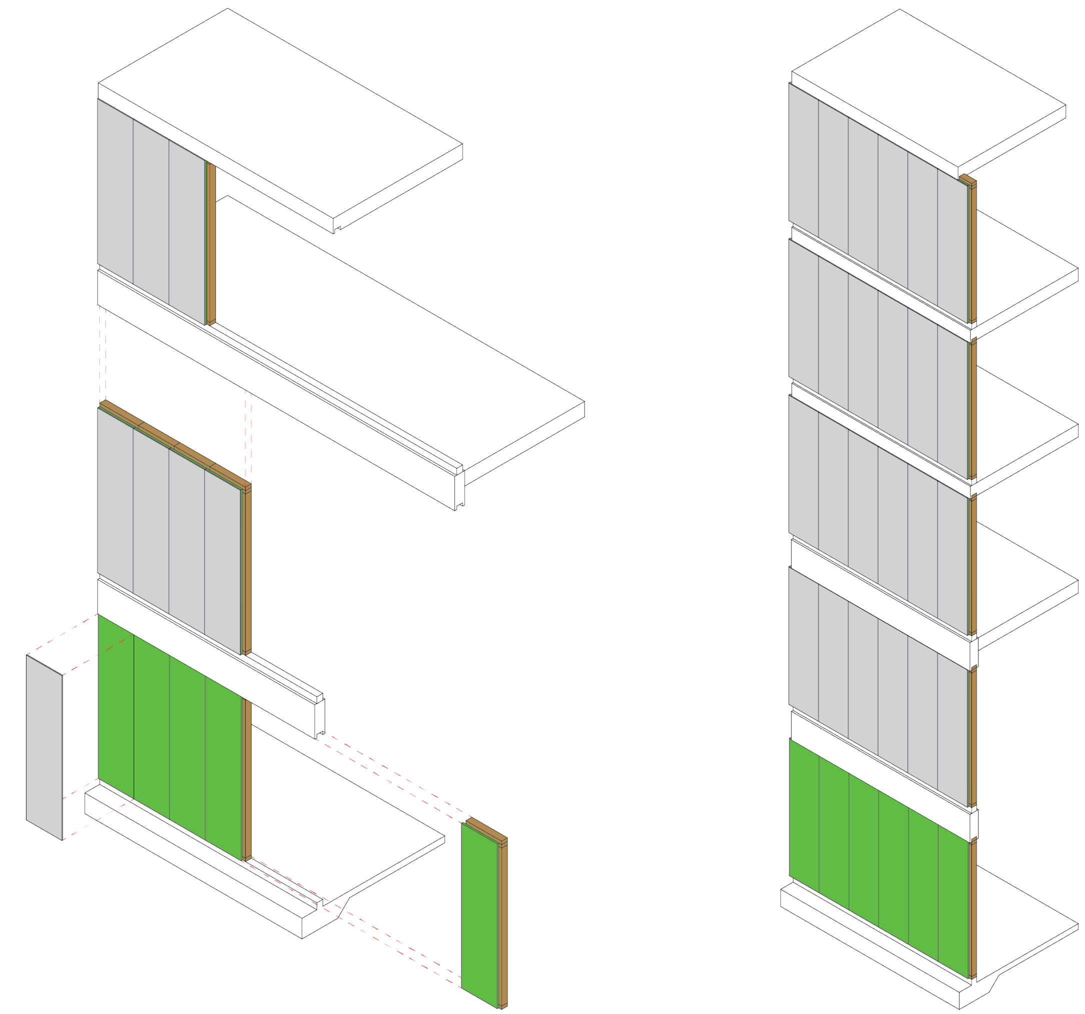


Figure 8.17 Diagram of a typical wall, exploded axonometric and assembled.

continues to be utilized through the process of reuse, recycling, and upcycle.

The proposed building design consists of a structure composed of responsibly sourced mass timber structural members. The use of mass timber products is meant to complement the building health qualities associated with hemp. As mass timber is also a natural material, its use aids in the health of the occupants of the building. Additionally, mass timber provides an added layer of fire protection due to its high fire rating. However, due to the current status of locally grown construction grade timber, the mass timber structural members will require sourcing from external manufacturers, meaning that these structural members would need to be imported. To ensure a net-zero carbon footprint, the entirety of the processes to produce and deliver the mass timber structural members to the site would need to be accounted for during the cultivation and inherent carbon sequestration

Figure 8.18 Site Plan of speculative 17.5 acre lot.

Figure 8.19 Rendering of speculative 17.5 acre lot.

phase of the Initiative. This process could equate to cultivating more hemp to offset the carbon footprint of the mass timber system. A more significant cultivation phase would benefit building projects as the raw hemp can be stored for future use.

The site's climatic conditions allow the building's orientation to capture the prevailing winds from the north, northeast portion of the site. The building's exposure to the prevailing winds ensures that the prefabricated hemp-lime walls maintain low moisture content with hemp's porous nature, eliminating the possibility of mold growth. Designed penetrations of the prefabricated hemp-lime wall system allow installing windows and doors, allowing each unit to be passively cooled. Creating comfortable interior spaces through passive cooling is essential at this site location because the Ewa Plain is known for sustaining temperatures in the high 80's to low 90's. Another aspect of ensuring occupant comfort is the building's exposure to the sun. Hemp-lime composites possess excellent thermal properties. The thermal properties of hemp are due to the hurds high porosity making it an

Figure 8.20 Facade rendering showing the hemp-lime building envelope with mass timber members

exceedingly good thermal insulator. Research has shown that hemp possesses a thermal conductivity coefficient ranging from 0.038-0.055 (W/m*K).[40] Hemp's thermal conductivity coefficient means that heat absorption happens at a much lower rate equating to the product radiating stored energy at a rate significantly less than traditional building materials such as concrete. The moisture and heat absorption factors present the prefabricated hemp-lime wall system as superior to typical building materials. Using a hemp-lime composite as a prefabricated wall system provides thermal comfort greater than typical building products eliminating the use of batt insulation, fiberglass insulation, spray foam insulation, moisture barriers, and gypsum boards.

A building's attributes are an essential aspect of its design. How the materials are used and how those materials create spaces within the building provide the functionality to its occupants. Another, perhaps more critical, aspect to a building design's success is how it fits into the neighborhood

40 Pochwała, Sławomir, Damian Makiola, Stanisław Anweiler, and Michał Böhm. "The Heat Conductivity Properties of Hemp–Lime Composite Material Used in Single-Family Buildings." Materials 13, no. 4 (February 24, 2020): 1011. https://doi.org/10.3390/ma13041011.

Figure 8.21 View of courtyard with ADA units

and its surrounding landscape. For this project, working with a clean slate could be a negative or a favorable condition. Being able to design a building and the surrounding context is something that most are not afforded. This is perhaps the best part of design school. In any case, the project site is not entirely void of the surrounding context. Within a two-mile radius of the project site, there are many amenities that prospective residents may find appealing. Amenities like a brand new school, a new public rail system, shopping centers, and businesses invite prospective occupants to reside in a building made from a locally sourced material that provides all of the climatic comfort mentioned in the preceding paragraph and offers healthy indoor environments. Despite all of the amenities throughout the community, perhaps that most significant advantage is its proximity to the resources that provided the material to construct the speculative building.

Figure 8.22 Birds-eye view of east facade, surrounding building context and future rail.

8.5 Framework: End-of-Life Cycle of the Precast Hemp-Lime Wall System

Sustainability has many levels, and as established in the definition of sustainable building material, one of these levels ensures that a sustainable building product possesses the potential and subsequent use through reuse, recycling, or upcycling. A building product reused for its intended purposes, recycled into another sustainable product of similar use, or upcycled into an entirely different product establishes the final phase of the Nahele i Nāhale Initiative and are all factors taken into consideration. As resources become more and more scarce, constructing new buildings will become more and more difficult. Additionally, the demolition of older buildings translates to landfills being occupied by discarded building materials. In thinking about the entire life cycle of the prefabricated hemp-lime wall system, understanding what to do with the wall module develops into tangent speculative design applications. However, because this project's foundational reaction was to identify a solution to the building industry's environmental impacts, a few scaled design applications are considered for the prefabricated hemp-lime wall system.

The first two purposes of this end-of-life cycle phase become self-explanatory. Reusing and recycling the prefabricated wall system is considered at the early stages of the product's design. With the absence of adhesives and the use of reusable fasteners, each module has the potential to be deconstructed, packed, and transported to another site for further use. However, should a module become unusable for its intended purpose, the hemp-lime composite can be separated from the internal structural components of the individual module, broken up, and recycled as aggregate into another hemp-lime composite application. The recycling of hemp hurds is essential to consider should crop outputs slow, and the availability of raw hemp hurds becomes unavailable. The last aspect of the end-of-life cycle for a prefabricated hemp-lime wall system is envisioning how the product can be upcycled or transformed into a material or product unlike its original. One possible outcome is separating the hemp-lime composite core of the wall system from its structural members and cutting the inner hemp core into boards to be used as shading devices on existing buildings or as materials for furniture. The objective of this phase of the Nahele i Nāhale Initiative is to examine further and implement strategies to use hemp-lime composites.

8.6 Conclusion

From transportation to its continued use, the prefabricated hemp-lime wall system possesses many desirable design qualities when applied to the built environment. As a prefabricated wall system, it eliminates the use of potentially harmful building products that affect the overall health of the occupants of our buildings. These typical building products are made with toxic chemicals that alter our buildings' interior environments, linking health issues to what has been termed sick building syndrome. Hemp-lime composites hold the potential of eliminating those toxic products from our buildings and, in exchange providing cleaner, healthier interior spaces.

This idea of providing healthier buildings through healthier building products is a foundational element of the Nahele i Nāhale Initiative. Through the Initiative, the application of the prefabricated hemp-lime wall system can be implemented in medium-density housing, testing its potential for its application in high-density housing designs. This strategic design implementation at the UHWO district lands can set a precedent for further testing and use in other O'ahu regions and throughout Hawai'i. Hemp-lime composites could hold the potential of being retrofitted to existing buildings so that established structures can share beneficial qualities. Lastly, designing, building, and rebuilding with a hemp-based product isn't restricted to Hawai'i. With hemp being a hardy plant to cultivate, the Nahele i Nāhale Initiative can be implemented worldwide.

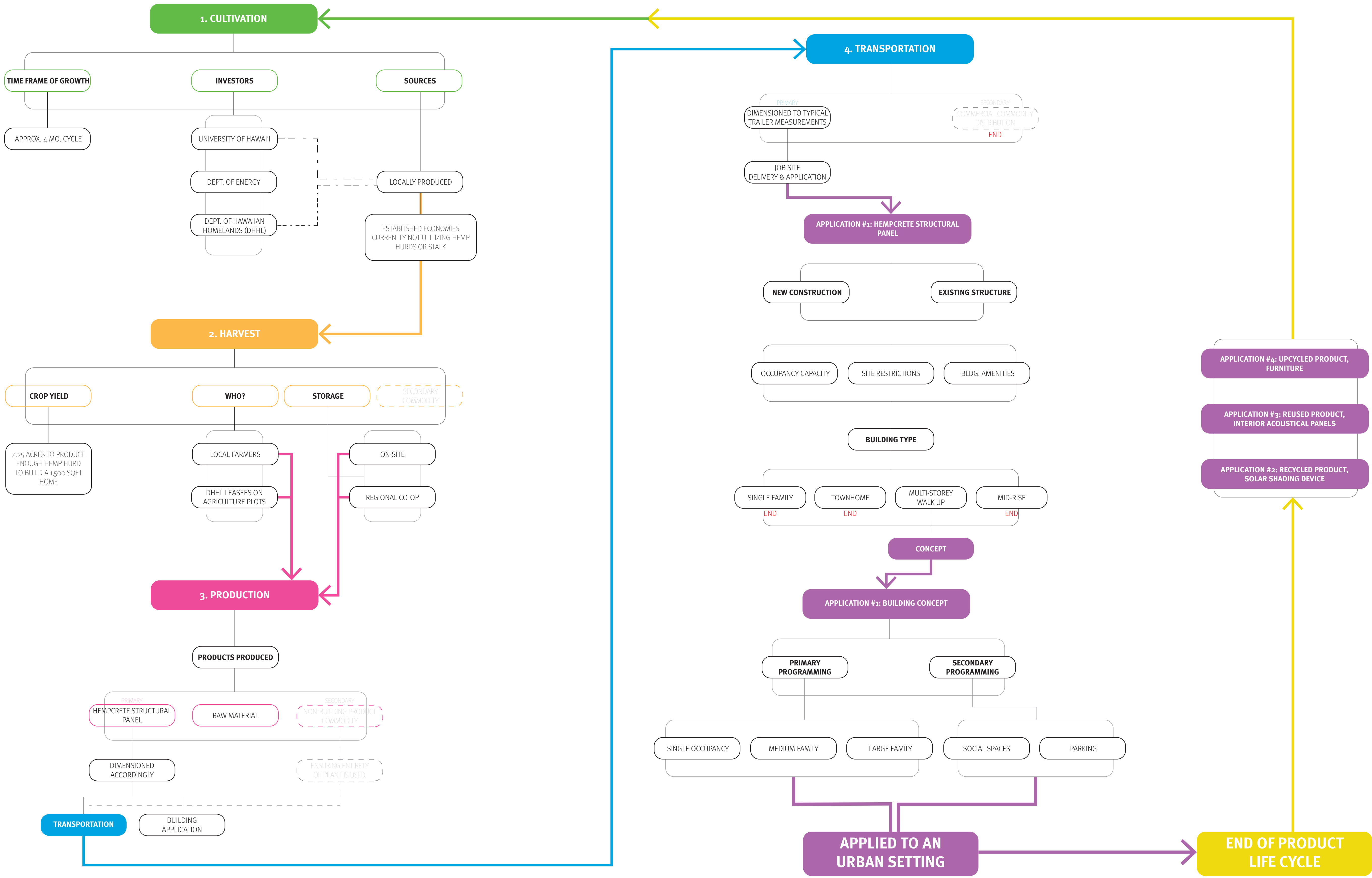


Figure 8.23 Diagram of entire Nahele i Nāhale Initiative.

Chapter 9:
Project Conclusion

This project began as an inspiration from external sources. Many of those sources came from the beginning stages of my academic journey. Those sources of inspiration may have started as the ignition point to take a journey along a path that some may have thought silly, but with the constant encouragement, what I imagine for myself in the future with this project can only continue to blossom as I cultivate and collaborate with others. As a plant, hemp possesses exceptional qualities that students, practitioners, and professionals expand upon daily. The products and uses that stem from these individuals begin in the same way this research project has—identifying a problem and finding a solution that has the potential to keep growing.

I began this project to explore how a hemp-based product could be applied to the built environment. The initial thoughts and ideas broadened into an initiative like Nahele i Nāhale, proposing a way to look at the entire lifecycle rather than just the end product. With initiatives like Nahele i Nāhale, we can apply similar tasks and responsibilities through multiple stages of the building industry. Understanding that our resources to construct dwellings, offices, schools, and institutions are finite should only exacerbate the need for alternative sustainable building materials. Perhaps what is needed is to take a step back and seek inspiration from those who have done, those who are doing, and those who will be our realm's future designers.

Mālama Pono,

B. Keolamaika'i Annino

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