A Revolution in Sustainable Development: An Analysis on Carbon Footprint and Total Cost of a Residential Home Built Using Conventional Materials, in Comparison to Hemp Biocomposite Materials

By

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A thesis submitted to the University of Colorado at Boulder

in partial fulfillment of the requirements to receive

Honors designation in the Department of Environmental Studies

April 3rd, 2023

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Abstract

The way we are currently developing our building structures is unsustainable, with a large amount of greenhouse gas (GHGs) emissions being a direct result of the production and implementation of the materials used in our buildings.

The purpose of this honors thesis is to better understand the potential and feasibility of hemp biocomposite materials in construction. A case study will be examined, where a house plan will be taken, and utilized in two homes, one being constructed with conventional materials such as lumber, while the other with hemp biocomposites. Because the same house plan is used in both homes, we can objectively quantify the carbon footprint and monetary cost of both dwellings, and directly compare them. This side by side analysis can allow developers, architects, and hemp-based construction material companies to see the difference in cost and carbon footprint associated with switching to hemp biobased materials.

Using professional journals, peer reviewed literature, and interviews with hemp companies, a building product analysis was conducted. This section shows the advantages and potential drawbacks of current building materials, and what are the benefits and drawbacks of transitioning towards hemp biocomposites. Through the building analysis and case study, this thesis is an extensive tool that shows the potential of hemp in future residential home construction.

The carbon sequestered through hemp biocomposites is nearly double its conventional counterparts, and its higher cost can be justified as its benefits could be argued to outweigh the difference in total cost when it comes to the price of the home.

Preface

A passion of mine has always been to study and analyze how nature's diverse plants and ecosystems can provide us humans with amazing technology and services, in ways that are not initially apparent. Hemp historically has been used in thousands of different applications, and its modern adaptations are even more extensive and fascinating. Hemp is a versatile and adaptive plant, which needs to be further explored on how it can aid in many ongoing environmental issues.

Biocomposites are not a silver bullet solution, but can play a vital role in the future of building. Every nation with their unique ecosystems contain some plant material that they can sustainably harvest, and manipulate to aid in their development, whether it be bamboo, straw, or hemp. Hemp is one of the most resilient plants to exist, so its application in all kinds of environments is exciting, but still needs further examination.

Acknowledgements

First off I would like to thank my outside reader and honors committee member, Jay Arehart and Kyungsun Lee. I want to give special thanks to Dale Miller for being my lead advisor, and such a supportive mentor throughout this process. Your extensive knowledge on sustainable homes, and persistence has allowed me to create an amazing honors thesis.

I would like to thank my mother, Iris Ferraz dos Santos, who provided architectural and professional expertise throughout the entirety of this project.

Lastly, I would like to thank my dad who has proofread my essays for as long as I can remember, and my partner Haley for their support throughout this endeavor.

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Introduction

It is no secret that we are currently experiencing a climate crisis, with high amounts of carbon emissions being the major cause. A sector that is often overlooked when it comes to these emissions is our residential home building industry. Large contributors to these emissions are the building materials that the construction industry uses, mainly concrete, and non-rapidly-renewables like lumber. The materials used in homes and its efficiency is a relatively new issue, so we must study how our current building practices are leading to elevated CO_2 levels. In order to lessen the construction industry's carbon footprint as worldwide housing demand rises, it's critical to take into account sustainable alternatives to conventional building materials. Biocomposites are materials made of two or more distinct materials, where at least one of them is naturally derived. Hemp biocomposites, specifically with load-bearing capacity, are beginning to be studied for its potential.

Through a case study, I am comparing and contrasting a typical house constructed of conventional materials (dimensional lumber), with a house constructed using hemp biocomposites (load-bearing hempcrete blocks). The major goal of this study is to assess each house's overall sustainability through its carbon emissions, to better understand monetary costs associated with material transitions, and better understand the advantages and disadvantages when using each home's respective materials. This study intends to shed light on the possible advantages of employing hemp biocomposites in home construction, and to promote the use of more environmentally friendly materials in the residential building sector.

Building Products Comparison

According to an article published regarding energy assessment and sustainability, a staggering 10% of airborne particulates, 25% of landfill waste, and 35% of GHG emissions are a direct result of construction material manufacturing (Sultana et. al., 2022). Firstly, these materials must be produced using a lot of energy, then transported hundreds of miles, and eventually needing extensive energy to construct with.

In order to better understand the transition towards hemp biocomposites, I looked at what building materials are currently being used for building envelopes, and insulation. What are these materials' benefits, and what are their drawbacks? The materials analyzed for building envelopes are dimensional lumber used in stick frame construction, and concrete. Fiberglass insulation, being the most commonly used insulation product, is likewise examined to determine its benefits and drawbacks. These structural and insulating materials are all compared to its hemp biocomposite counterparts.

Benefits of Stick Frame Construction

Nearly 900,000 new stick framed homes were completed in 2021, bringing a total of 92% of homes in the United States being wood framed homes (National Association of Home Builders, 2021). The United States has a long history with lumber in the residential construction industry, and has become attached to it for good reasons. Firstly, this natural material is readily available within the United States. The Forest Service (FS) along with the Bureau of land Management (BLM) conduct lumber sales as an authorized use. These two land management agencies oversee 144.9 million acres and 37.6 million acres of lumber forestry respectively (Congressional Research Service, 2022). A massive 7.5% of the world's forest resides within the

United States, meaning that it is a prevalent and accessible building commodity. (National Association of State Foresters, 2012).

Continuing with lumber's benefits, not only is this material readily available, but lumber is a worthy construction material in regards to health, both for the environment and the homeowner. Lumber, if not processed into other wood type materials, is non-toxic. It is safe to handle and manipulate, sequesters carbon, and releases little chemicals into the environment when being processed (Landmark, 2021). In respect to the homeowner, stick frame construction with air and vapor barriers improves air quality through moderating humidity levels (Beyond Zero Homes, 2021).

What is more fascinating is that wood panels have been studied to have physiological and psychological responses. A study published in the Journal of Wood Science showed that exposure to wood panels significantly decreases blood pressure, while in contrast, being exposed to steel panels makes it rise (Sakuragawa et. al, 2005).

Drawbacks of Stick Frame Construction

While the benefits of constructing with dimensional lumber should not be ignored, it is important to assess how reforestation and management practices can affect how much of this material is available, and the environmental consequences that could subsequently follow. Unfortunately, we can state that not only are current management practices flawed, but the shear volume of trees harvested is monumental. The next few paragraphs will discuss these aforementioned drawbacks of using lumber as a building material, along with other negatives such as its lack of fireproofing, and potential structural failures.

Deforestation is an international environmental issue, and current forest mitigation practices in the United States are only further attributing to this problem. Lumber is a renewable resource, however it is not rapidly-renewable, meaning that the final product is made from an agricultural source that is not harvested within a 10-year or shorter cycle (Green Building Council, 2009). Trees take time to grow, and what used to be a 120 year harvest rotation a few decades ago has been dropped down to 60-80 years, and more recently only a 40 year cycle (Semuels, 2021). This high overturn rate is unsustainable for our ecosystems, and leads to higher amounts of GHGs in the atmosphere as these younger trees sequester less carbon.

Not only are the reforestation rates drastically low, but the volume of trees cut down is astronomically high. A staggering 15 billion trees are cut down every year, with a 2015 statistic showing that the global tree count has fallen 46% since the beginning of human civilization (Prestemon et. al, 2015). The United States is responsible for harvesting the largest volume of trees annually, with housing construction being the leading demand for solid wood products. (Prestemon et. al, 2015).

The use of lumber clearly has environmental impacts due to its high amounts of harvesting and poor silviculture practices, but what are its structural flaws? The first and most obvious is that wood is not fireproof. The majority of today's homes have a stick frame build, meaning that if there were to be a wildfire, or simple house fire, then the likelihood of the home keeping its structure is very low. This is important to consider as the United States has some of the highest rates of home fires (Brushlinsky et. al, 2020). A local example in Colorado is the 2020 Marshall fire. A total of 1,084 homes and 7 businesses were destroyed in the Marshall Fire, making it the most destructive fire in terms of buildings damaged in Colorado history (Cook, 2021). An estimated $513,212,589 in damages were reported, and two people lost their lives, all because the fire was able to spread through winds, and were fueled with incendiary building materials.

Stick frame homes also have little resistance towards hurricanes and earthquakes. Large amounts of damage and total home collapse can result from constructing homes from dimensional lumber. This concern is only increasing, as these natural disasters like hurricanes are only becoming more powerful and catastrophic. In 2017, Hurricane Harvey destroyed a total of 200,000 homes and businesses in Texas and Louisiana (Bahney, 2018). Hurricane Ida in 2021 resulted in an estimated $65 billion in damage, and dozens of people lost their lives (Santana, 2021). While the home building material is not entirely to blame, perhaps the damage done would have been minimized if better materials were used.

Continuing with structural flaws, most stick frame construction due to the natural cellular structure of lumber, changes with climatic conditions. The lumber can shrink, twist, and crack over time, leading to potential structural damage. Not only are they subject to climate, but wood is also prone to pests such as termites. Additionally, if the house fails to regulate humidity, then mold and fungi can build up, leading to both structural and health issues (Landmark, 2022).

The drawbacks of using lumber as a construction material could be argued to outweigh the benefits. The environmental impacts are not to be ignored, and the potential safety issues with utilizing the material should be considered. The United States has been using stick frame construction for decades, so it is difficult to admit these flaws, and to transition towards other framing types, analogous to how it is difficult to move away from fossil fuels.

Benefits of Concrete Construction

Concrete, a mixture of cement, water, and aggregate, has only increased in popularity as a potential construction material. Regulations in hurricane building codes, higher demand for reliable structures, and general concerns about safety has caused the number of concrete framed homes built from 2018 to 2019 to rise 46% (Semuels, 2021). The style of framing has double the market share it did in 2009, showing that this framing trend for residential homes will continue to increase (Semuels, 2021).

From a safety standpoint, concrete framed structures pose as an excellent material to resist natural disasters. Massive hurricanes and devastating forest fires have shown the faults of conventional stick framing, and with climate change exacerbating the destructive effects of these events, alternatives like concrete frames have only increased within the conversation of homebuilding (Espejo et al, 2014). The material durability is simply better than its wooden counterpart, and has measurably better resistance to the damages natural disasters can cause (Holmes et. al, 2005).

Concrete's material resistance and durability not only improves safety, but also increases the resilience to invasive pests such as termites. One of the most infamous and ongoing cases of termite damage is the one of the Formosan Termite. In 1998, the U.S. The Department of Agriculture started a $5 million termite-control program named "Operation Full Stop" to reduce the estimated $300 million in structural damage this invasive species causes every year. The Formosan termite thrives inside wooden structures, however it does not stand a chance against concrete framed and precast concrete homes (Holmes et. al, 2005).

Benefits of using concrete for homes goes beyond material durability and resistance, by providing greater architectural expression as well. The Concrete's property of carrying large structural loads reduces the need of internal support walls or columns. As a consequence, homes can have wide open spaces that allow for flexibility in interior design, and more room for creativity. If homeowners were to remodel, the absence of these internal supports allows for easier manipulation of the house as well (Holmes et. al, 2005). In addition to this flexibility in design and layout, homeowners can achieve ceiling heights of 10 ft or more, without any additional costs through precast concrete structures. This is appealing to more modern styles of homes, where cathedral ceilings, great rooms, and more spacious living spaces are increasing in popularity (Holmes et. al, 2005).

Material durability and architectural expression are coupled with lower maintenance costs and retained home value. Concrete frames and precast structures will stand the test of time, and also lower operating costs for the homeowner through energy efficiency (Homes et. al, 2005). These savings and durability retain high resale value over time, again providing more incentives to potential buyers or builders.

Drawbacks of Concrete Construction

Similar to stick frame homes, the benefits of concrete constructed residential homes are numerous. However, there are several drawbacks involved in the use of this material that could be argued to outweigh the potential benefits of concrete homes.

Let's begin with the specialized labor needed to produce these homes. Many contractors and homebuilders know how to build under one method, stick framing. There are several hurdles that contractors need to go through, and lessons to be learned to feel comfortable and proficient with using concrete for structural framing (Gagg, 2014). Special delivery systems through the form of a concrete mixer, are needed due to the viscous nature of wet concrete. Specially inserted reinforced steel bars (rebars) are needed to provide structural support to the final concrete structure. While these transportation hurdles and these specific skills can be overcomed, it poses a challenge and often dissuades homebuilders from adopting this product.

One of the basic materials needed for the synthesis of concrete is sand. According to a paper published by the University of Geneva, between 47 and 59 billion tonnes of sand is mined worldwide (Steinberger et. al, 2010). A particular granular type of sand is needed to create the mix, and it often faces exploitation due to its low quantities throughout the globe. Illegal sand mining poses risks to communities, and the environments around them. The environmental and humanitarian consequences associated with both legal and illegal sand mining range. Extensive coastal erosion, diminished water quality, acid mine drainage, depletion of groundwater, lesser availability of water for industrial agricultural and drinking purposes, destruction of agricultural land, loss of employment to farm workers, threat to livelihoods, human rights violations, and damage to roads and bridges are just some issues. (Saviour et. al, 2012).

Continuing with environmental consequences, the most notable drawback when using concrete is its contribution towards air pollution. Concrete is used in hundreds of applications when it comes to construction and development, making it the second most used material in the world, second only to water (Gagg, 2014). The widespread use of concrete releases large amounts of GHGs and particulate pollutants, with a staggering statistic showing that this material alone accounts for 8% of GHG emissions (Lehne et. al, 2018). Perhaps even more frightening, is that the current trajectory of concrete use is on the rise. Concrete is expected to increase to over 5 billion tonnes a year over the next 30 years, as many regions within Southeast Asia and sub-Saharan Africa are rising in population, and will urgently need new building construction (Lehne et. al, 2018).

Benefits of Fiberglass Insulation

When it comes to insulation, fiberglass is the most commonly used material among its competitors (Energy.gov, 2022). It is budget friendly, making it a first choice for home developers and people who are renovating their homes. It is also easy to install and can be simply manipulated, given that it is lightweight, and can be cut with an x-acto knife (Lewis Insulation, 2023). When insulating your home, depending on both depth of insulation and density, loose fill fiberglass has an R-value of R-2.2 to 2.7 per inch (USDOE, 2023). Its adequate insulation value, cheaper price, and ease of installation all are valid reasons homeowners and contractors choose to adopt this material.

Drawbacks of Fiberglass Insulation

Again, one may argue that the benefits of this cheap insulation are outweighed by its drawbacks. While some insulation companies are forgoing this step, the highly toxic chemical formaldehyde is used in the production of fiberglass to keep the fibers together (Owens Corning, 2023). This chemical can potentially pose health hazards for construction workers, and homeowners. What is more concerning are the environmental impacts associated with fiberglass. The energy-intensive operations necessary to melt glass and create the fibers produce a large amount of GHGs, with a staggering 1,213,287 million metric tons of carbon dioxide equivalents (CO_2e) being reported from only 23 fiberglass insulation plants (EPA, 2019). 7.8 million metric tons of CO_2e in total were released directly from 102 glass manufacturing facilities reporting to the Greenhouse Gas Recording Program (GHGRP) in 2019.

Benefits of Hemp Biocomposites in Construction

Now that we have analyzed current building materials and insulations, let us dive into a potential alternative, hemp biocomposites. The benefits to this material are vast and numerous, and it is a promising and feasible alternative for the residential building sector, given the justifiable difference in cost, and the minor difference methodology wise it has to current home building practices.

While there are multitude of raw materials which can be transformed into potential building mechanisms, there is a reason why people are eyeing hemp. Hemp is an extremely productive and resilient crop, needing little pesticide use and low amounts of water. Therefore, hemp can grow in nearly any natural environment (Hemp Technologies Collective, 2016). Hemp has a low crop turnover rate, being able to be harvested three to four times a year. Each acre of industrial hemp harvested produces up to four times as much raw material, compared to its conventional tree counterpart (Hemp Technologies Collective, 2016). Not only that, hemp is great for crop rotation, as it helps maintain soil fertility through phytoremediation (Hemp Technologies Collective, 2016). The last major benefit of the hemp plant itself is that it is biodegradable. Extensively using this crop will help reduce the large amounts of construction waste (American Lime Technology, 2012).

Now that we understand hemp's benefits as a plant, what are the benefits obtained in a residential home if we were to use it for insulation and load-bearing construction? Hempcrete has originally been used as an insulation material, and for good reason. Its thermal resistance has been measured to R-25 for a 12-inch-thick wall, or up to R 27.4 with inner and outer render applied (HempBlockUSA, 2022). An R-19 to R-21 value is recommended for exterior walls throughout the US, making this an adequate wall insulator no matter where you live in the states

(Johns Manville, 2023). Hemp's porous structure is the key to its low thermal conductivity. This results in comfortable temperatures within the home, so the home will stay cool during the summer, and warm during the winter (Just BioFiber, 2022).

Hemp has impeccable safety ratings when it comes to fire resistance, hurricane resistance, and earthquake resistance. Wooden homes catch fire easily, and even concrete homes with steel framing can deform during intense fires. Hempcrete, due to its lime binder, does not burn. Hempcrete manufacturers have reached an impressive 2-hour fire rating, with a rating of zero smoked development, and zero flame spread (Just BioFiber, 2023). This is important as most fire-related deaths are caused by smoke inhalation (Stanford Medicine, 2023), so building homes out of hempcrete can potentially save many lives from fire related accidents.
Load-bearing hempcrete systems also are advantageous for both earthquakes and hurricanes. Just BioFiber's hempcrete blocks have been tested to have the same compressive strength and shear strength to high performance concrete. Due to its monolithic structure and mortar binding, the structural stress caused by natural disasters are distributed throughout the wall system, rather than into critical points (Just BioFiber, 2023).

Hempcrete also provides a healthy living environment for the homeowners residing in it. Stick frame construction tends to fall to mold and pest infestation, often through improper air gaps leading to moisture build up, or your environment leading to termite infestation. Hempcrete does not have these issues, again due to its lime binder. Lime is naturally pest and mold resistant. It has a high alkaline pH which acts as a fungicide, and is naturally antimicrobial, repelling mold, bugs, and other invasive species in your home (Just BioFiber, 2023).

Lastly, and perhaps most importantly, is the environmental impact associated with hemp biocomposites. We covered how hemp's growing process is good for soil and less damaging to the surrounding environment, but hemp biocomposite building materials are inherently beneficial for our environment as well. The process of constructing hempcrete insulation, or hempcrete blocks, is entirely **carbon negative.** Hemp is extremely efficient at sequestering carbon from the atmosphere during its growth cycle, and lime naturally reabsorbs the carbon that was emitted during its mining through chemical carbonation (Just BioFiber, 2023). While the amount of hemp CO2 sequestration depends on the ratio of binder to hemp (differs depending on the company), consensus shows that the majority of hempcrete compositions result in the overall sequestering of carbon. This is monumental, as there are few building materials on the market with similar carbon sequestering potential, structural benefits, and health benefits. While wood also actively sequesters CO2, hempcrete is much more structurally sound, and does not contain several of the flaws aforementioned. Therefore, we have a biocomposite insulating building product, with load-bearing capacities, increased safety towards natural disasters, and a healthier living environment through pest and mold resistance. The capabilities of hemp in construction is truly impressive.

Drawbacks of Hemp Biocomposites in Construction

No product is ever without flaws, and hemp biocomposites and hempcrete are no exceptions.

One of the largest, and perhaps most detrimental flaws with hempcrete construction is that it cannot work in below grade construction, as the natural product will decompose (Just BioFiber, 2023). While basements are becoming less popular within American single family homes, 24.3 percent of homes built in 2018 still contain below grade basements (National Association of Home Builders, 2019). While some states cannot contain basements at all, other states such as Colorado have high amounts of basements within single family homes. This means that while the majority of the house could be constructed from hemp materials, an alternative needs to be used in below grade levels.

Another drawback of hempcrete is not related to the product itself, but the industry behind it. The construction industry has not seen much change in regards to the methods and materials used within the past decades. While developments and new technologies are underway, dimensional lumber and stick frame construction still encapsulates a massive stake in our residential market. It is difficult to convince architects, contractors, and developers to consider using another material, when they are so comfortable and used to working with lumber. It is necessary to find more progressive developers and contractors, who are willing to take a risk and work with relatively new material. However, it is worth noting that some forms of hempcrete require a much lower learning curve, such as working with large blocks or hemp structural insulating (SIP) panels. Having an easier method of construction can help motivate developers to take this leap and use a new construction material.

Continuing with problems associated with the construction industry, is the subject of price. There are few hemp construction companies within the US, meaning that there is little competition among them. Low amounts of competition, and the fact that working with hemp in construction is such a new idea, means that the price of these products are generally higher than their conventional counterparts. Hence, it is difficult to justify to a developer to use a material which they are not used to working with, that is also more expensive. However, as competition increases, and mass production begins to ensue, this will no longer be an issue.

Lastly, there is a problem of getting hemp biocomposites approved within US residential building code. Building codes can vary from state to state, and even county to county. Current hemp projects have required special approval from their local governments, so to have large amounts of hemp developments will require actual regulations implemented within residential building code. However,there is good news on this front, as the International Code Council (ICC) included hemp + lime construction (hempcrete) into the appendix of the upcoming 2024 International Residential Code (IRC) back in September 2022. This is a primary step in getting hemp into the books, with hempcrete now appearing in “Appendix BA,” applying to one and two family dwellings (Jean Lotus, 2022).

The main drawback to hemp biocomposites in construction is that it cannot work below grade. While this is a an important limitation, the major issue about hempcrete has to do with the residential construction industry itself, in the form of convincing developers to transition to this material, eventually driving the price down of hemp products, and having building codes out of the appendix and into state and local governments law.

Background of Hemp

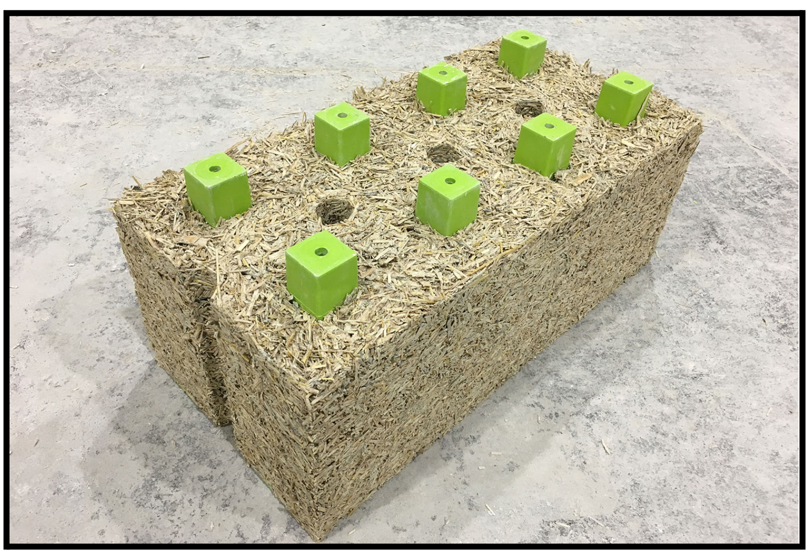
The History of Hemp

Historically, hemp has been one of the most versatile plants that human civilization has used to this day. Its fibers are used for ropes and clothing, oils for candles and medicine, and with Henry Ford making a hemp car, hemp’s versatility is not to be questioned. However, due to racial tensions and prejudice, hemp quickly became the plant of “10,000 uses,” to a demonized drug associated with African Americans and a rising Hispanic population. Criminalized in the 1970 Controlled Substances Act (CSA), cannabis was now outlawed not due to its safety concerns, but rather its association and heavy prejudice associated with minority races (Britanica, 2022).

Cannabis has always been a misunderstood drug, and slowly state by state we are finally starting to recognize its medicinal and industrial uses. However, why is the importance of understanding the history of cannabis relevant to understanding the hemp plant? The Cannabis Sativa L. plant and hemp are the exact same plant, with one key distinction. Hemp is defined as a cannabis plant that contains less than 0.3% tetrahydrocannabinol (THC), the psychoactive cannabinoid. Medical and recreational cannabis can have up to 90% THC, depending on the form in which it is delivered. With hemp's recent legalization in the 2018 Farm Bill, we can now further explore and use this plant to fit our modern needs (Britannica, 2022).

With recent legalization, comes a brand new wave of research and creativity. Innovations like hempcrete need to be heavily researched, and will be further explored in this study (Sannibale, 2021).

The History of Hemp Biocomposites



An Image of Just BioFiber's Load-Bearing Hempcrete Block (Just BioFiber, 2023)

Hempcrete is a type of hemp biocomposite made from the hurd, or woody interior of the hemp plant. It is combined with a binder made of lime to produce a lightweight, insulating substance that can replace building envelope materials and insulation (Britannica, 2022).

Since ancient civilizations in Europe and Asia, hempcrete has been utilized in construction. The prohibition of hemp and the development of synthetic building materials caused it to lose popularity in the 20th century, however the ecological and environmental advantages of hempcrete have led to a rise in attention in recent years (Britannica, 2022).

A number of building projects, including load bearing walls and insulation, can be completed using hemp biocomposites. Due to its many different manners of application, hemp biocomposites are easy to manipulate on a construction site. It can be poured in place, sprayed in-situ, or it can be formed into specific shapes and forms, increasing design versatility (Britannica, 2022).

Hempcrete is already being employed in numerous high-profile construction projects all around the world. France has utilized this material as an insulator for decades, with a modern example being the work of Barrault Pressacco, shown below.

Each floor in the building has three apartments, and is made from wood and hempcrete (Dezeen 2021).

Even more exciting, the world's first load-bearing hempcrete home was built recently in the United Kingdom in 2006. Taking influence from our foreign allies, more hempcrete projects are popping up throughout the states, and several hempcrete companies like Boulder local Rocky Mountain Hemp Build, Hempitecture, and Hempblock USA have been at the forefront of using this material.

Apart from hempcrete, hempwool insulation is another hemp biocomposite material made from the plant's fibers. Hempwool insulation comes in the form of rolls, which can easily be manipulated to fit the form of homes. It can be used to replace fiberglass insulation, and has competitive insulation values, R-3.7 per in., while not being toxic as it lacks formaldehyde (Rocky Mountain Hemp Build, 2022).

Hempwool Insulation (Hempitecture, 2023).

Lastly, the third hemp biobased product we will be analyzing is hemp particleboard. Hemp particleboard is a type of engineered wood product that is made from the woody inner core of the hemp plant, or the hurd. By grinding the hemp hurd into small particles and then compressing them together under heat and pressure, a dense and strong wood alternative board is produced. Hemp particleboard has several advantages over traditional particleboard made from trees. It is a sustainable and renewable resource, as the hemp plant can be grown quickly and in a variety of climates. Hemp particle board is also stronger and more durable than traditional particleboard, making it suitable for a wider range of applications. It is also more resistant to pests, mold, and fire (Just BioFiber, 2023).

Hemp Particleboard (Hemp Wiki, 2023)

Methodology

The research in this thesis is in the form of a case study, which uses carbon calculating software, professional journals, and company data, to better understand the carbon emissions and cost associated with stick framed and hemp biocomposite homes.

Although concrete was analyzed in the building products comparison, a stick frame home will be the framing method for the control group, as it holds a much larger stake in terms of framing materials in residential construction (National Association of Home Builders, 2021). Paired with stick framing is fiberglass insulation, as it similarly is the most popular insulation material for residential homes (USDOE, 2023). With the assistance of Susan Masterman

Architects and associated contractors, a material takeoff will be conducted for the dimensional lumber home. This will provide the amount of materials needed to insulate the home and build the envelope, allowing us to use software to then calculate carbon emissions. Company data from the Home Depot Inc. retail company will be used to estimate these material costs.

For the hemp biocomposite home, the only material analyzed is load-bearing hempcrete. It acts as both an insulator, and building envelope, with the greatest difference in carbon emissions compared to its conventional counterparts. Existing hemp companies like Canada's based Just BioFiber, have research and data sheets regarding their hemp products, which can help us understand both their pricing and overall carbon emissions.

Labor costs will be looked at for both homes as well, as it accounts for a large percentage of cost in residential construction.

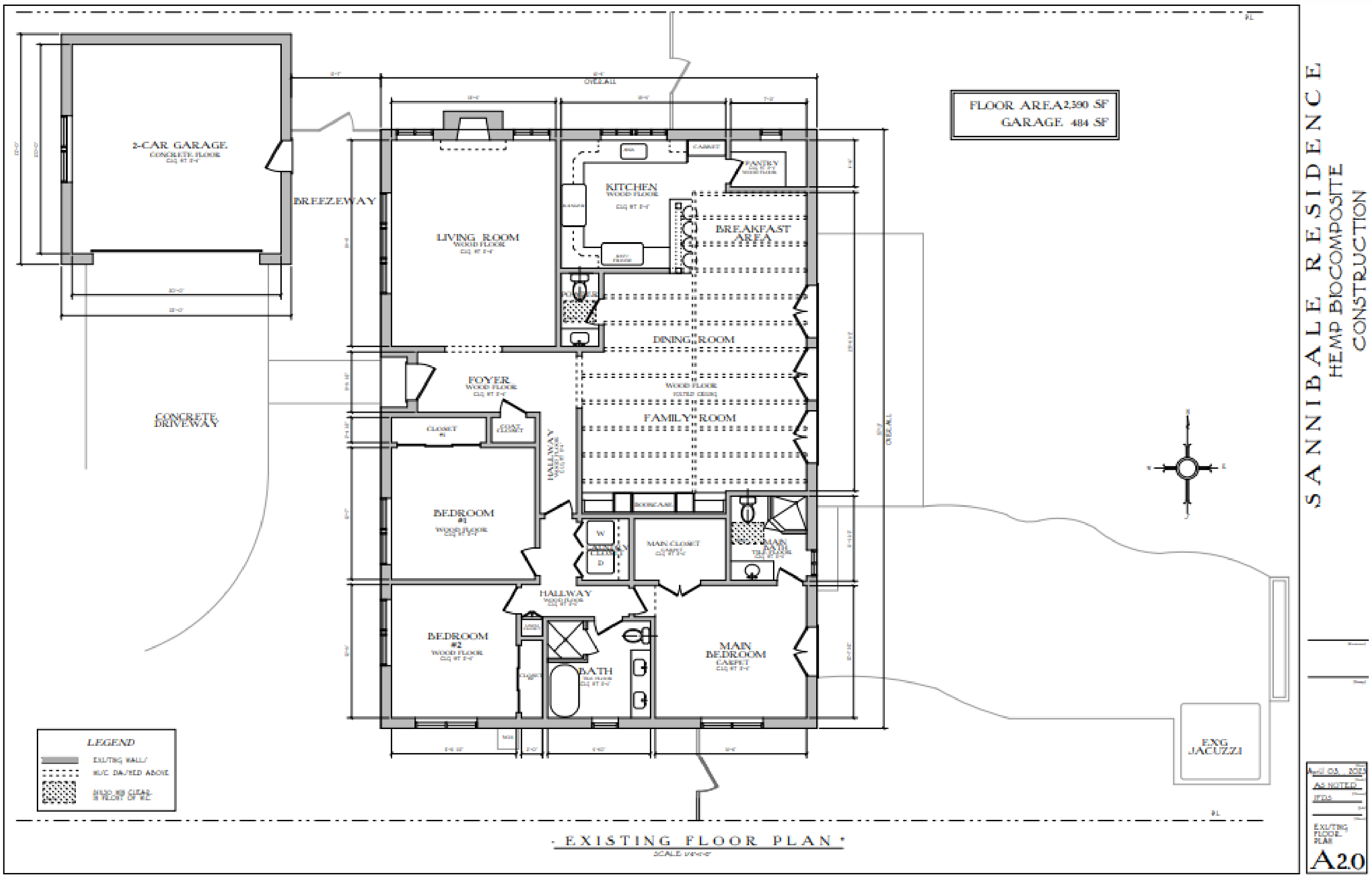
The same house plan is utilized for both the home made with conventional materials and hemp biocomposites, removing any variability due to design or difference in square footage. The total carbon footprint and cost will be analyzed for each home using the aforementioned methods. This will give us a clear cut understanding of what the difference is in carbon emissions when building with hemp, and how much more or less expensive it will be to construct.

Case Study

Breakdown of House Plan

The house plan used is a modern 2,300 sq. foot home, with an attached 484 sq. ft garage. This three bedroom home contains two bathrooms, a dining room, family room, and kitchen. The plan has been simplified from an already existing home in California to have four walls in a rectangular form to simplify calculations of carbon and cost. The plan has been provided by Iris Ferraz dos Santos, with Susan Masterman Architects, a licensed California and Texas architect studio.

The two parts of the home that will be compared are the exterior load-bearing walls, and insulation within these walls. While hemp biocomposites can be used in other applications such as flooring, the most impactful form hemp biocomposites can take place in is through a hempcrete load-bearing wall system. Because these blocks are thicker in width and are naturally insulating, insulation in both the hempcrete and stick frame home will be taken into account as well.



House plan provided by Iris Ferraz dos Santos (Susan Masterman Architects, 2023).

Conventional Materials Home Overview

The data regarding the amount of materials and costs associated with lumber has been quantified and examined by myself, with the support of architects and contractors with Susan Masterman Architects. While concrete as a framing material was examined in the previous background section, as I mentioned before, I am putting emphasis towards stick frame construction and fiberglass insulation as they are much commonly used in residential homes.

Breakdown of Stick Frame Home: Monetary Analysis

Sannibale Residence - Hemp Biocomposite

April 2023

	WOOD CALCULATION				
House Linear Feet 206.5'	**Calculation**	**Total LF**	**Total CuF**	**Material Quantity**	**Costs**
Studs 2"x6"x8' every foot +1@each corner	2"x6"x([207+12]x8')	1,752'	146 CuF	219	
TOP Plate (2"x6"x16')x5	206.5':16'	1,040'	87 CuF	65	
Tread Lumber (bottom) (2"x6"x16')x1	206.5':16'	208'	17 CuF	13	
Sub Total 2"x6"x linear		3,000'	250 CuF		
Header (4"x6"x12') **A. 4"x6"x linear** **B. 4"x8"x linear** **C. 4"x12"x linear**	 4"x6"x43' 4"x8"x27' 4"x12"x10'	 43' 27' 10'	 7 CuF 6CuF 4CuF	 _______4 _______2 _______1	
Sub Total 4"x(varies)"x linear		80'	17 CuF		
Plywood 4'x8'x1/2"	206.5':4'	52'	416 SFor 18 CuF	52	
Insulation R-19 (39.2') 8'x(linear)	206.5'x8'	207'	1,652 SF	6 Rolls	
Garage Linear Feet 88'	**Calculation**	**Total LF**	**Total CuF**	**Material Quantity**	**Costs**
Studs 2"x6"x8' every foot +1@each corner	2"x6"x([88+4]x8')	736'	62 CuF	92	
TOP Plate (2"x6"x16')x5	88':16'	480'	40 CuF	30	
Tread Lumber (bottom) (2"x6"x16')x1	88':16'	96'	8 CuF	6	
Sub Total 2"x6"x linear		1,312'	110 CuF		
Header (4"x8"x12') **A. 4"x6"x linear** **B. 4"x8"x linear** **C. 4"x12"x linear**	 4"x6"x4' 4"x8"x7' 4"x12"x17'	 12' 12' 18'	 6 CuF 6 CuF 4CuF	 _______1 _______1 _______1	
Sub Total 4"x(varies)"x linear		42'	16 CuF		

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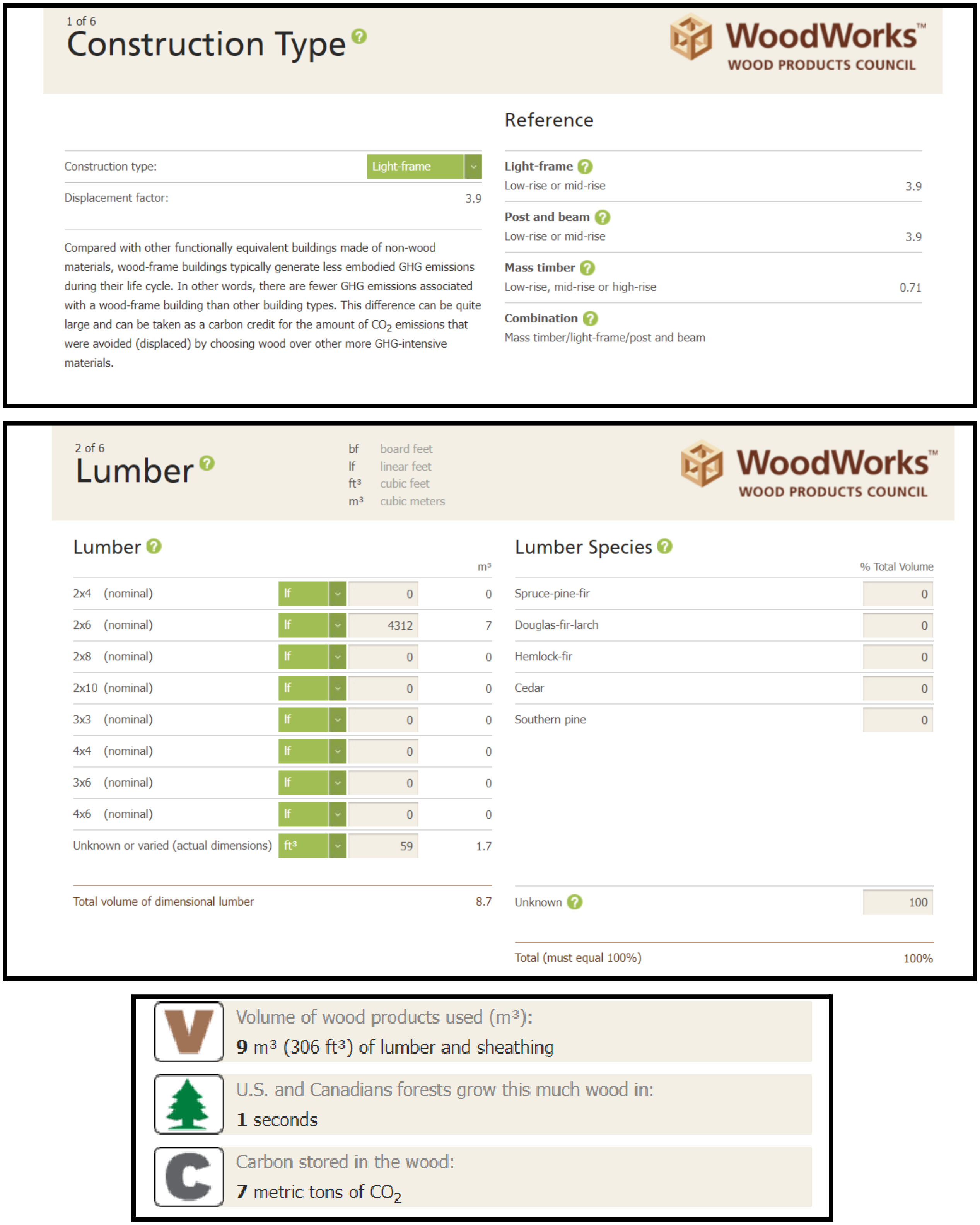
	WOOD CALCULATION				
House Linear Feet 206.5'	**Calculation**	**Total LF**	**Total CuF**	**Material Quantity**	**Costs**
Plywood 4'x8'x1/2"	88':4'	22'	176 SF or 8 CuF	22	
Total costs framing					$7,420.00
Total costs Insulation					$6,653.00
Total costs Labor					$13,145.00
TOTAL costs material & labor					**$27,218.00**
TOTAL Linear Feet & Cubic Feet		4,434 LF	1,081 CubF		

Material Takeoff for Stick Frame Home (Susan Masterman Architects, 2023)

Through the material takeoff above, the amount of **$7,420** comes from framing of the house and garage, **$6,653** from insulating the house, and the majority of the cost comes from labor, reaching **$13,145.** This brings the total cost of the conventional home to a total of **$27,218.**

Breakdown of Stick Frame Home: Carbon Analysis

As the conversation about carbon emissions from building materials grows, so do the tools that can help us calculate these carbon emissions. The Wood Products Council, partnered with the U.S. Forest Service has developed a web based software called the WoodWorks calculator. This tool calculates the amount of carbon sequestered in wood products based on the quantity and dimensions of the wood product. Using this tool, and the material takeoff listed above, we can calculate that the total amount of CO_2 sequestered is **7 metric tons, or 15,432.4 lbs.**



1 of 6
Construction Type

WoodWorks™ WOOD PRODUCTS COUNCIL

Construction type:	Light-frame
Displacement factor:	3.9

Compared with other functionally equivalent buildings made of non-wood materials, wood-frame buildings typically generate less embodied GHG emissions during their life cycle. In other words, there are fewer GHG emissions associated with a wood-frame building than other building types. This difference can be quite large and can be taken as a carbon credit for the amount of CO_2 emissions that were avoided (displaced) by choosing wood over other more GHG-intensive materials.

Reference

Light-frame Low-rise or mid-rise	3.9
Post and beam Low-rise or mid-rise	3.9
Mass timber Low-rise, mid-rise or high-rise	0.71
Combination Mass timber/light-frame/post and beam	

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Lumber

bf board feet
lf linear feet
ft³ cubic feet
m³ cubic meters

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Lumber

	Unit	Quantity	m³
2x4 (nominal)	lf	0	0
2x6 (nominal)	lf	4312	7
2x8 (nominal)	lf	0	0
2x10 (nominal)	lf	0	0
3x3 (nominal)	lf	0	0
4x4 (nominal)	lf	0	0
3x6 (nominal)	lf	0	0
4x6 (nominal)	lf	0	0
Unknown or varied (actual dimensions)	ft³	59	1.7
Total volume of dimensional lumber			8.7

Lumber Species

	% Total Volume
Spruce-pine-fir	0
Douglas-fir-larch	0
Hemlock-fir	0
Cedar	0
Southern pine	0
Unknown	100
Total (must equal 100%)	100%

Volume of wood products used (m³):
9 m³ (306 ft³) of lumber and sheathing

U.S. and Canadians forests grow this much wood in:
1 seconds

Carbon stored in the wood:
7 metric tons of CO_2

Software used to calculate carbon sequestration of stick frame home (WoodWorks, 2023).

While the amount of carbon sequestered through the wood is impressive, light framed lumber is not naturally insulating, unlike its hempcrete counterpart. Therefore the carbon emissions of fiberglass must be accounted for.. The figure below published in the Journal of Building Sciences shows the embodied carbon of several insulators, with fiberglass insulation at a R-28 value emitting 17.6 kgCO2e per 4′ x 8′ section of wall.

Table showing embodied carbon of common insulations (Green Builder, 2016).

Material	Embodied carbon by weight*	Embodied carbon for 4x8 foot wall @ R-28**	Carbon footprint after sequestration
Straw bales	0.063 $kgCO_2e/kg$[5]	8 $kgCO_2e$	-42.8 kg per panel
Mineral wool batt	1.28 $kgCO_2e/kg$	21.75 $kgCO_2e$	21.75 kg per panel
Fiberglass batt	1.35 $kgCO_2e/kg$	17.6 $kgCO_2e$	17.6 kg per panel
Denim batt	1.5 $kgCO_2e/kg$	22.45 $kgCO_2e$	15.45 kg per panel
Dense packed cellulose	0.63 $kgCO_2e/kg$	41.3 $kgCO_2e$	10.3 kg per panel
Extruded polystyrene foam	3.42 $kgCO_2e/kg$	38.5 $kgCO_2e$	38.5 kg per panel
Expanded polystyrene foam	3.29 $kgCO_2e/kg$	37.25 $kgCO_2e$	37.25 kg per panel
	* figures from Inventory of Carbon and Energy (ICE) 2.0	**material densities from *Making Better Buildings*	

With this amount in mind, we can calculate the amount of CO2e emitted for the lumber home. The wall area of the home is 1584 sq ft [(57.25 ft length* 8 ft height * 2 walls) + (41.75 ft length * 8 ft height * 2 walls)]. Knowing the carbon emissions of the fiberglass, we can calculate that the total emission from fiberglass to insulate the home will be **871.2 kg of CO2e or 1920.7 lbs** [[(57.25 ft length* 8 ft height) / (4 ft length*8 ft height) * 2 walls) + (41.75 ft length * 8 ft height) / (4 ft length * 8 ft height) * 2 walls)] * 17.6 kg CO2].

Now that we know the carbon sequestered in the wood and emitted from the fiberglass, we can finally calculate the total amount of carbon being sequestered to be **13,511.7 lbs** (15432.4 lbs sequestered - 1920.7 lbs emitted).

Hemp Biocomposite Home Overview

As aforementioned, the main hemp biocomposite material I will examine is hempcrete, to use in both the home's load-bearing walls, and insulation. While there are a few load-bearing hempcrete systems available, I decided to use Canadian based Just BioFiber hempcrete blocks. Their product is a mixture of hemp hurd (the plant's woody core), water, and a proprietary lime mixture that hardens when CO2 is added and moisture is removed. It also utilizes a revolutionary composite structural frame that interlocks when stacked inside each block, giving the blocks its load-bearing capacity (Just BioFiber, 2023). The reason why this company's product was chosen over others, is that they have completed several projects throughout Canadian territories, and also have copious amounts of data regarding the carbon footprint of their product. Their hempcrete blocks are also simpler to work with, lessening the learning curve towards adopting this new material.

Hempcrete will be used in both the exterior walls of the home, and the garage. A simple 8 step guide on how to build with their material is pasted below from their website.

1. The Bottom Strip (composite) is laid down and tied into the foundation
2. Flax-Lime Mortar is applied to the bottom strip to reduce thermal transfer
3. Glue is applied to the Bottom Strip to lock onto the blocks
4. Blocks are placed onto the Bottom Strip

5. Flax-Lime Mortar and Glue are applied to each block
6. Blocks are placed onto each other in an interlocking pattern
7. When all courses (rows) of the wall are assembled, the top interlocking caps are cut off
8. The Top Strip is laid over the block wall and tied into the wall using bolts

(Just BioFiber, 2023).

Breakdown of Hemp Home: Monetary Analysis

Representatives from Just BioFiber gave me a formula to estimate the cost of materials for building a home out of their hempcrete blocks. I need to multiply $25 by the walls´ square footage. To find the wall square footage of the home itself, I will multiply each face of the wall times the standard height of 8 ft, to get 1,584 sq ft. [(57.25 ft length * 8 ft height * 2 walls) + (41.75 ft length * 8 ft height * 2 walls)]. Multiplied by $25 per sq ft of wall area, we get a total of **$39,600 for the home in material cost** (1,584 sq ft * $25).

A similar calculation is done for the garage. Assuming a standard double garage length of 16 ft, we get a total of 576 wall sq. ft for the garage [(22 ft length * 8 ft height * 3 walls) + (6 ft length * 8 ft height)]. Multiplying this figure by $25 per sq ft of wall, we get a total of **$14,400 for garage material cost** (576 sq ft * $25)**.**

While the material cost is much higher for hempcrete, there are savings in terms of labor. Due to shorter construction times, Just BioFiber states that labor costs can be half the cost of a traditional stick frame build. Using the labor cost for the stick frame home above, we can assume the **costs in labor for this home will be $6,753** ($13,145 labor costs / 2).

Using the materials cost for the home and garage, plus labor costs, we can estimate that this home will cost around **$60,573** ($39,600 house cost + $14,400 garage cost + $6,753 labor cost).

Breakdown of Hemp Home: Carbon Analysis

Given that the blocks have a dimension of 21.332 x 10.666 x 8.000″ (541.83 x 270.92 x 203.20mm^3) (Just BioFiber 2023), we can calculate the amount of blocks needed for the exterior of the walls for the home and garage. To simplify the calculation and allow for a buffer of potential extra needed materials typical when constructing a residential home, I will not be removing blocks for the doors and windows of the home, or subtract blocks due to the interlocking pattern. After finding the amount of blocks needed to build each face of the home, I will multiply it by the carbon sequestration amount per block, to determine the total amount of carbon sequestered through the materials of the home.

Let us start with finding how many blocks are needed to complete the longer side of the home. The length of the home is 57′-3″ long. Giving the home a standard height of 8′, we can then calculate the amount of blocks needed for this face. The length of the wall is first converted to millimeters (mm) for ease of calculation , and is divided by the length of the block in mm [(57.25 ft *12 in * 25.4 mm) / 541.83 mm], giving us a total of 32.21 blocks needed to complete the length of the home. The height of the wall is again converted to mm, and then divided by the height of the block in mm [(8 ft * 12 in * 25.4 mm) / 203.20 mm] giving us a total of 12 blocks needed to achieve a height of 8 ft. With both the amount of blocks needed to complete the length and height of the home, we can then multiply to find the total number of blocks needed to complete the face, (12 blocks for height * 32.21 blocks for length), bringing us to a total of 386.5

blocks needed to complete the longer face of the house. Multiplying this by 2 grants us the amount of blocks for the other wall bringing us to a total rounded total of **773 blocks** for the longer faces of the home (386.5 blocks * 2 wall faces).

A similar calculation will be done for the shorter side of the home. The length of this side is 41′-9″, and again the height is 8′. This length is converted to mm and then divided by the length of the block [(41.75 ft *12 in *25.4 mm) / 541.83 mm], to give us a total of 23.5 blocks needed to complete the shorter length of the home. Because the height is the same on this face, we multiply by the 12 block height, to get a total of 282 blocks needed to complete the shorter face of the home (23.5 block length * 12 block height). We multiply these numbers of blocks by 2 to get the total amount of blocks needed for both shorter faces of the wall, bringing us to a total of **564 blocks** for these sides of the home (282 blocks * 2 wall faces) .

This brings us to a total of **1,337** blocks needed to envelope the entirety of the home (564 blocks + 773 blocks)

Now taking the garage into account, it is a 22′ square with a height of 8′. Given the standard double garage size, there is a 16 foot section missing on one face of the wall. Again converting the ft into mm for ease of calculation, we can divide this figure by the length of the block in mm. This brings us to a total of 12.4 blocks needed to complete the length of a face for the garage [(22 ft * 12 in * 25.4 mm) / 541.83 mm]. We then take this figure and multiply it by the 12 block height needed, to bring us to a total of 148.5 blocks needed to complete one singular face of the garage (12.7 block length * 12 block height). We then multiply this figure by 3 to get the total amount needed to cover 3 faces of the garage, bringing us to 446 blocks (148.5 blocks per face * 3 faces). With only 6 linear ft to cover for the side with the garage door, we only need a total of 3.4 blocks to complete the length [(6 ft * 12 in * 25.4 mm) / 541.83 mm]. Multiply this by a height of 12 blocks you need a total of 41 blocks to cover the garage door face.

Adding the 4 faces together, we need a total of **487** blocks to envelope the entire garage (446 blocks + 41 blocks).

We have now found both the amount of blocks needed to envelope both the home and garage, bringing us to a grand total of **1,823** blocks needed. The sustainable construction system Just BioFiber utilizes accounts for all of the emissions produced during raw material extraction, transportation, processing, installation, and usage, bringing us to a figure of **6.5 kg of CO2 sequestered per block** (Just BioFiber, 2023). With a total of 1,823 blocks being used, we can estimate that this home and garage will sequester a staggering **11,850 kg, or 26,2019 lbs of CO2** (1,823 blocks * 6.5 kg CO2 sequestered per block). This is on par with their claim that a standard home of 2,000 sq can sequester up to 10 metric tons of CO2 (Just BioFiber, 2023).

Case Study Results

	Stick-Frame Home	**Hemp Biocomposite Home**
Cost:	$27,218.00 for envelope and insulation	$60,573 for envelope and insulation
Carbon Footprint:	13,511.7 lbs CO2 sequestered	26,2019 lbs of CO2 sequestered

Monetary Analysis

After thorough calculations through a material takeoff for the lumber home, and a strong estimate of the hemp home using figures from the same company whose material I am using, the differences in price between the two are quite drastic.

The cost of the lumber home came out to a total of **$27,218**, after $7,420 coming from framing the home and garage, $6,653 from insulating the home, and $13,145 from labor costs.

The cost of the hemp home totalled to **$60,573**. $54,000 came from material costs for both framing the home and insulating the home, and costs in labor for this home is $6,753.

The hemp home costs about 2.2 times more than the conventional stick framing and fiberglass insulation build. This drastic difference in price is due to the small number of companies working with hemp builds, and the smaller market size of hemp homes in general. However, it is worth noting that the labor costs are much less for the hemp home. When mass production of hempcrete ensues, prices can compete with stick frame builds, or perhaps even be cheaper.

Carbon Analysis

More important in this thesis are the carbon emissions associated with the home. Using tools such as the WoodWorks calculator, professional journals, and carbon emissions statistics from Just BioFiber, I was able to calculate the rough carbon footprint for both the stick frame home and hemp home.

Looking at the stick frame and fiberglass home first, I found that a total of **13,512lbs of CO_2 will be sequestered by the home.** About 15,432 lbs is sequestered through the wood, while about 1,920 lbs is emitted from the fiberglass.

The hemp home with its estimated 1,823 blocks needed, sequesters and impressive **26,2019 lbs of CO_2**, on par with the statements that Just BioFiber makes.

Based on these calculations, the hemp home sequesters about 12,615.6 lbs, or 5.7 metric tons of CO_2 more than the stick frame build.

Limitations of Research

It is important to stress that there are some limitations within this paper. The first worth mentioning is that only the house envelope and insulation is covered. When it comes to the impact of the whole home, home emissions or sequestration could be even greater, depending on the materials used. An extensive cost and carbon analysis of an entire home, and all materials used could provide a more profound picture when it comes to total home construction emissions.

Another important limitation are the estimates used in this thesis. If the house plan were to be evaluated by Just BioFiber's team, a more accurate assessment could be generated on the cost of the project. Continuing, the carbon footprint analysis is likely smaller than what is estimated, as the interlocking pattern was not considered, along with gaps and spaces for the windows and doors. However, the idea still remains, that the cost of hemp biocomposites for building envelopes and insulation is higher, but results in a greater amount of carbon sequestered.

Conclusion

My calculations clearly show that building the exterior walls out of hempcrete is pricier than traditional builds. However, although it is more expensive, it has a much larger carbon sequestration potential.

The material cost for hempcrete is substantially higher than the lumber cost, however it is interesting to see that the labor cost for the hempcrete home is cheaper. Another interesting fact is that you do not need to pay for insulation for the hemp home, as these exterior walls made out of hempcrete are naturally insulating and pose a high R-value.

These findings are extremely important to contractors, developers, and architects, as they now know that hemp biocomposites can actually play a pivotal role in reducing the embodied carbon within buildings. If one hemp house can sequester over 20,000 lbs of carbon, imagine the potential of creating an entire residential community out of this material. Not only will all these homes actively aid our climate crisis, but there are clear cut advantages when it comes to structural stability and home health.

Recommendations

The importance of this research is not only the validation of hempcrete's use in building envelopes and insulation, but to validate this material as a more sustainable alternative to its commonly used counterparts. With concrete's high contributions towards air pollution, and the several flaws associated with stick frame construction, hempcrete truly holds value as a future construction material.

We have seen time and time again that stick frame homes are not sturdy enough, are too flammable, and have potential for pests and rot. We know that concrete is a more sturdy construction material, however it accounts for enormous amounts of air pollution and carbon emissions. We also know that fiberglass is not the best insulative material out there, and it too results in large amounts of embodied carbon. Hempcrete, seems like an all inclusive solution to these issues, with a heftier price.

However, when looking at the grand scheme of a home, a $30,000 dollar difference can be justified. The average price of constructing a home in 2022 is $300,000 (Forbes, 2022), which means that fortifying your building envelope with a high sequestering material, high insulating, and safer material, is only a 10% increase. Many developers can use this as a major selling point to their contractors, and potential homebuyers. I recommend that developers take advantage of their superior material, even if it accounts for a 10% increase in home construction cost.

The potential of hempcrete is just being scratched within this study. With proper development, the expanse this material can reach is enormous. There can be potential in the commercial space, and we can already see its ability when it comes to building affordable housing communities. The Advanced Research Projects Agency-Energy (ARPA-E) Harnessing

Emissions into Structures Taking Inputs from the Atmosphere (HESTIA), awarded Texas A&M University $3.47 million to develop affordable housing utilizing hemp materials (Davis, 2022).

While the potential of hemp biocomposites like hempcrete are very appealing, it still needs to be further researched. Comparisons against other building materials like concrete homes should be analyzed, and more extensive testing regarding the savings in heating and cooling should be examined as well. Other styles of hempcrete construction should be closely scrutinized, as there are a handful of companies who are emerging in the load-bearing hempcrete market. Researchers should compare these alternatives to each other, to either further validate the potential of hempcrete, or perhaps find more flaws.

As aforementioned in the introduction, our climate crisis will not solve itself. While initiatives to become more sustainable can happen on levels large and small, one problem I would like are the flaws in residential home building materials, and I think hemp biocomposites certainly will play a role in that solution.

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