

Hemp—A Sustainable Building Material

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Abstract—The manufacturing and construction industries are one of the greatest contributors towards a nation's success. These industries represent a major share of a country's development and economic progress and also create significant employment opportunities. However they are among one of the major source of pollution and climatic imbalance. This is mainly due to their large carbon footprints and an insatiable hunger for cheap source of energy. Manufacturing and extensive use of cement, the 'heat-island effect' due to extensive use of glass and concrete in the urban fabric, transportation of building materials across vast distances and the extensive use of hazardous and non-biodegradable materials, are some of the ways by which the construction industry in a country damages its environmental health. Due to such factors there is a growing need for materials which have low carbon footprint, are economical, multifunctional and environment friendly. Hemp is a natural building material that is fiber based and only requires a lime based binder for its application in the form of walls and flooring. It requires very little processing, has low cultivation cost, is resilient to pests and fungus and most importantly has excellent heat and sound insulation properties. Fibers of this plant have been used in ancient times for making ropes and waterproofing hulls of ships. It has also been used in ancient temple structures for controlling temperature and humidity in the interiors. The purpose of this study therefore is to investigate and put forth evidence regarding the potential uses of hemp in the building & construction industry in India and primarily focusing on its application in creating sustainable, economical and environment friendly architecture.

1. INTRODUCTION

Hemp is one of the most versatile natural material, which has great potential in agriculture and industrial sectors. The research tries to put forth evidence regarding the advantages of using hemp as an architectural material and the impact of Hemp in reducing the carbon footprint. In addition, the study is going to cover the comparative analysis between Hemp and other construction materials, which will help to understand how this versatile material can be used to create sustainable and thermally comfortable houses, which have both aesthetics as well as workability with the vision of elaborating its use as a building material in India.

However, this research will not work on the simulation to calculate carbon footprint.

1.1. Plant Variety

Hemp is the derivative of the Cannabis plant. There are mainly two (pure) varieties of Cannabis plant – Indica and Sativa.

1.1.1. Indica. Indica plants are short and bushy and have wide leaves. These plants typically grow faster and have a higher yield than sativa variety. Medicine produced from this strain have higher CBD and lower THC counts.

1.1.2. Sativa. Sativa strain plants grow tall and thin and have narrow leaves. These plants are lighter in color. This strain takes longer to grow and mature and also requires more light. It has lower CBD and higher THC counts.

2. HEMP

Hemp plant is very similar to the cannabis plant. However a hemp plant is specifically bred for industrial uses. It can attain a height of at least 2 meters and has very little THC content (0.3%). It is one of the oldest domesticated crops known to man. It was used for making paper, textile and cordage for thousands of years. In fact, the oldest relic of human industry ever found was a scrap of hemp fabric dating back to approximately 8,000 BC. It is one of the fastest growing plants and was one of the first plants to be spun around 10,000 years ago. It can be refined into a variety of commercial products such as paper, textile, biodegradable plastics, hemp based paints, thermal insulation, biofuel, food and animal feed. As hemp grows, it also rejuvenates the soil in which it grows.

The *bast* (phloem) *fibers*, also referred to as "Shiv" is the inner bark/ skin surrounding the stems, and can be used to make textiles that are 100 percent hemp, but they are often blended with other organic fibers such as flax, cotton or silk, to make woven fabric for apparel and finishing.

The inner two fibers of the plant are woodier in nature and typically have industrial applications such as mulch, animal bedding, and construction industry and so on. When oxidized, hemp oil from the seeds becomes solid and thus can be used in the manufacturing of oil-based paints, in creams as moisturizing agent, for cooking, and for making plastics, etc.

2.1 Hemp Properties

Hemp fiber, also called “bast”, is one of the most valuable part of the plant, which grows on the outside of the plant’s stalk. Hemp fibers vary between 3ft to 15ft (0.9m to 4.5m) in length and is considered as one of the most durable material in nature.

100% hemp fiber has 62% greater tear strength and 102% greater tensile strength than cotton denim. Hemp can produce 250% more fiber than cotton and 600% more fiber than flax using the same amount of land (Sarich, 2014)

3. ENVIRONMENTAL JUSTIFICATION

There is now a great need to reduce the consumption of oil based products and to minimize the consumption of fossil fuels. Burning of fossil fuels create a negative impact on the environment, and as it is a non-renewable source of energy, there is an ever-present danger that one day we will have no fossil fuel to burn. It is therefore important to innovate and develop materials that are sustainable in their production, application and disposal or reuse.

Today buildings are created by incorporating several layers of material where each material serves a specific individual purpose. The processing of these material involves a large amount of time, labor and transportation cost which in the end leaves heavy carbon footprint on the environment. Hemp on the other hand is a carbon negative material which absorbs carbon dioxide from the air, making it cleaner. It is also one of the most economic natural material which has applications in architecture, food, plastics, textile and other such industries. Hemp yields four times more fibers per acres than trees do and thus while being a crop that is easy to cultivate in almost any climate in the northern hemisphere, it could provide a source of material that can be cultivated more effectively and abundantly.

Hemp’s capability of heat and sound insulation is also one of the key factors for using this material in the construction industry, as it would reduce the energy demands significantly.

4. HISTORY

In the past, hemp was used in the form of ropes and as a fibrous agent for strengthening mud and concrete structures in many parts of the world such as France, Britain and India. In parts of the world such as Spain, after wood, hemp was becoming the best material for shipbuilding as it made the ship structure water tight. It was used for making ship sails, ropes and hulls. Thus extraordinary qualities of this material became more and more apparent with time.

A recent study however suggests that hemp fibers may in fact were being used since thousands of years before the French. A recent study revealed that the rock cut temples of India’s Ellora Caves have been preserved so magnificently, in part because of the special properties of clay plaster covering the

interior of the shrines. The researchers discovered that the mixture contained at least 10% hemp fibers which made it bind better, make it insect resistant and also helped to regulate humidity inside the cave. (Lorenzi, 2016)

5. HEMPCRETE

The mixture of lime based binder and hemp shiv with the addition of water produces a bio-composite material often called lime-hemp. Similar to the use of hemp fibers with concrete, in lime-hemp, lime acts as the binder and shiv acts as the better substitute for aggregate. The mixture helps in achieving high levels of thermal insulation and vapor permeability while remaining rigid, lightweight and durable.

Hemp fiberboards have a high potential for heat and sound insulation, while being highly economical.

6. COMPARATIVE ANALYSIS

Type of Mixture (lime-based binder made of 75% of hydrated lime (98% CaO), 15 % of hydraulic binder and 10 % of pozzolanic binder)	Hemp/ Binder mass ratio (Florence Collet, 2014)
Sprayed hempcrete – wall	0.5
prayed Hempcrete - floor	0.4
Sprayed Hempcrete - roof	1
Pre-cast hempcrete - wall	0.65

Attributes	Hempcrete	Concrete	Brick
Density	275Kg/m ³ 260kg/ m ³ for roof to 460 kg/m ³ for floor (Florence Collet, 2014)	2240- 2400Kg/m ³	1900-2100 Kg/m ³ (Concrete Brick)

NOTE: The value stated here for concrete, hempcrete, is the density of 1 m³ volume of a cube created using a mixture of various components traditionally used in that particular building material.

Thermal Conductivity (The rate of heat transfer in an object/solid)	0.06 - 0.07W/m.K	0.1 - 1.8W/m.K	0.6 - 1.31W/m.K
Heat Capacity (The amount heat required to raise the temperature of the solid)	1500-1700J/Kg	1000 J/Kg	800 J/Kg
Mean Sound Absorption Coefficient (Ability of a material/ solid to absorb sound)	0.69NRC	0.05 - 0.07 NRC	0.02 - 0.05NRC

NOTE: The ability of a material to absorb sound also depends upon:
 1. The thickness of the structure in which it has been used
 2. The frequency of the incidental sound, and
 3. Other factors such as levels of moisture in the material, other materials added to the structure, etc.

Carbon Capture	22 tonnes of Co2 per Hectare (2.47 Acres) (James Vosper BSCHons, 2011)	-	-
Environmental Impact In Kg eq. CO2 per year	-0.5Kg carbon/year	+0.5kg carbon/year	+1 - 1.5Kg carbon/year
Durable to Fungus, Mold and Rodent	Yes	No	No
Hemp has been used in various ancient buildings such as the Ellora caves of India and the ancient Egyptian pyramids where it acts as fungus, mold and rodent resistant while controlling the interior humidity and temperature levels			
Recyclability	Hempcrete is made out of Hemp fibers, water and a binder. Whenever a hempcrete building is to be demolished, all the material can be used again with some extra binding agent to create new structures.	Recycling of concrete is difficult and expensive which also reduces its strength and speed up the decay	Old and used bricks are reusable and recyclable.
Hygroscopic Material (Ability of a material to absorb or adsorb water readily from its environment)	Hempcrete is Hygroscopic in nature, which means that when moisture is high in air, it absorbs it and releases when the moisture levels in the air around drop.	Concrete absorbs water from the ground and traps it inside for longer durations	Brick also acts like concrete

Impact on Environment	Reasons why Hempcrete has positive impact on the environment: <ul style="list-style-type: none"> • Reduced cost of production • Reduces the building functioning cost being a thermal insulator. • One of the fastest growing crop • Every part of the plant has numerous construction and industrial applications 	Concrete makes up the largest proportions of construction and demolition waste, and represents about 1/3 rd of all landfill sites	Because of the use of coal in heat treatment of bricks, brick manufacturing is one of the major contributors to CO2 emissions along with contributing in the excessive use of a nonrenewable source of energy in its production process.
Cement manufacturing creates nearly 5% of the Global CO2 emissions. (Cement Industry Federation)			
Fire Resistance	Fire tests on 300mm thick hempcrete wall gave 73 minutes of structural adequacy/ insulative capacity. The charring will happen on the surface	Concrete is also a fire resistant material and hence cannot be burnt	Brick is a fire resistant material
The aesthetic appeal utilizing material appearance is subjective to creative and technical exploration of material, either singularly or in combination with additive/ other materials.			
Life-span of the Material	Over 200 years (As its use is only started in the last few decades, so it is not possible to predict accurately)	50 - 100 years	100 - 300 years
NOTE: The lifespan of a material depends upon: 1. Type of material mixture 2. Quality of materials used 3. Maintenance of the structure, 4. Exposure to weathering, etc.			

Earthquake Resistance	Being lightweight and less brittle than mortar, concrete and bricks, Hempcrete can assist in resisting seismic loads.	Concrete by itself is not earthquake resistant	Bricks by themselves are not earthquake resistant
NOTE: The material's ability to resist seismic waves/ energy largely depends upon the kind of reinforcement it has, and its ability to cope with such forces.			
Passive self-regulation of temperature and humidity	Yes Hempcrete can absorb heat (and humidity) and releases it when the temperature levels in the surroundings drop.	No	No

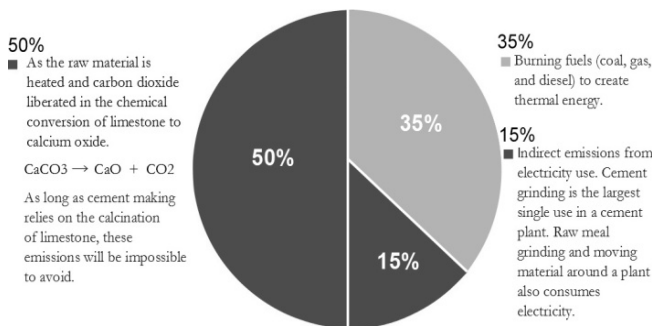


Figure 1: Source of greenhouse gas emission in a cement plant. (Cement Industry Federation)

7. HEMPCRETE HOUSE IN FLORIDA - CASE STUDY

The site is near the Sponge Docks and Riverwalk tourist area, a block away from Pinellas Trail. (*A Hempcrete House for Tarpon Springs, FL., n.d.*)

The project was conceived in the summers of the year 2012 to be one of the first Hempcrete House in America. The architects and builders anticipated a cost of about 225 dollars per sq. ft.

7.1 Site Conditions

- Size of the plot was 50ft. x 100ft.
- It would be 1560 sq. ft. house with 3 bedrooms, two baths, a kitchen and a 2-car garage.
- The site was located at the center of the town, hence making it urban.

- It was near the sponge docks and Riverwalk tourist area, a block from Pinellas Trail, a 40-mile bicycle trail that circumnavigates the county. A short walk downtown to shops and restaurants. One could live at such a place without a car or use an electric vehicle with no range anxiety.

7.2 Climatic Conditions

- Pinellas County experiences hurricanes (Tarpon springs received a direct hit from category 3 hurricane on October 25, 1921, bringing 115 mph winds).
- The site is also under the flood zone A.
- Sometimes the site would experience a 2” of rain in 20 minutes which would cause localized flooding.

7.3 Design Goals

- The wall was made 300mm or 12” Thick (for R30 insulation)
- The ceiling was insulated with 300 mm thermal hemp insulation.

(Hempcrete needs 45 days to cure and it needs to be shielded from the rain for the first 10 days while it cures. This was a challenge as Florida has a 6-month rainy season.)

- 130 mph rated windows for walls and roofs would be used.
- Hempcrete does not likes to sit in water, so the house is made to sit on a slab 2’ above the ground.

Hempcrete is believed to reduce the racking action in houses with wooden frames, which in turn makes it good for areas with considerable seismic and hurricane activity. So even though hempcrete is non-load bearing material, it still contributes to the building’s structural strength and thus a hempcrete house will be stronger than the conventional houses that are built in the area.

Hempcrete is also very effective in preventing structural cracking. (Marrero, 2014)

8. LIMITATIONS OF HEMP

The few of the disadvantages of Hemp are:

1. Due to the low structural strength of the material, Hempcrete blocks and other hempcrete structures become incapable of handling greater loads. Thus limits the numbers of floors up to which a structure could be built, even when using reinforced hempcrete for construction. Hempcrete houses are generally built to up to 2 floors.
2. Second disadvantage lies in cannabis being a taboo and exploitative uses of marijuana in substance-abuse, thus being illegal and class A drug in most of the developed and developing countries such as America, India, etc.

3. Due to this the agriculture and research of Hemp is nearly impossible.
4. Setting and curing period of hempcrete structures can also be considered as negative factor amidst its so many benefits as it nearly takes a month and a half to let it dry before doing any further activity upon it. Although this duration highly depends upon the surrounding climate, temperature and humidity levels along with the access of sunlight.



Figure 1: Bob Clayton crafted a 1,640-square-foot house of hempcrete — the hemp plant's woody core and a lime-based binder. Photos by JOHN PENDYGRAFT | Times-Hempcrete house in Florida

9. HEMP FOR INDIA

India is a rapidly growing market, but it is not only this market that is growing at an enormous rate. India's population is booming from the past decade and this has resulted in the shortages of affordable quality housing especially for the urban and rural poor.

It's not only the availability of living space, which is an issue, it is the affordability of those living spaces. Many residential projects across India have been a failure due to this unaffordability, giving rise to the problem of slums. People still don't have a decent place to live, while on the other side there are several residential units that are kept vacant because the poor cannot afford them.

This is not only bad for the people but also for the economy. Large sums of money that were spent to create those residential structures have turned into ashes, as there is no return from it.

This problem can be solved by the application of sustainable and ecofriendly materials like hempcrete to create residential units that are not only economic to construct, but also are ecofriendly and reduce the energy consumption and thus the reducing cost of running the unit for the poor.

Hempcrete can be used in place of the traditional materials to create sustainable affordable housing units thereby replacing slums. If only the poor is educated enough and are provided with a source for acquiring the right resources, our government might not have to spend crores of rupees on slum rehabilitation projects.

The need of the hour is thus to replace our traditional building materials that are a burden upon us as well as on the planet with materials like industrial hemp which not only provides us with food, Textile, fuel and most importantly Hempcrete.

10. CONCLUSION

It is apparent from the comparative analysis that hempcrete and other hemp based construction materials and products can greatly improve the living conditions for the economically weaker sections of our society, living in slums by providing economical building material and free microclimate control. Hemp, if not directly, can be used in combination with other building material to improve the overall quality and functionality of a living space.

If the cultivation of this plant is controlled properly, it can not only provide cheap products (such as biofuel, fiber for textile, food, paper, etc.), but it can also improve the condition of Indian farmers and also the agriculture industry. Due to the plants ability to grow easily, its applications in various industries like construction, textile, agriculture, etc., and the plant's ability to resist any fungus or virus/ bacterial attacks. Hemp has large potential as a prime material in the building and construction industry.

The cultivation of Hemp requires little to no use of pesticides, which is one of the main source of water pollution caused by farming activities.

Hemp is a versatile crop, which if used properly, can become a crucial contributor for a nation's success, while preserving its environmental health.

- A suggestive solution to overcome longer setting time of hempcrete is to develop a system of prefabricated modules

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