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Is industrial hemp a sustainable construction material?

7th semester elective assignment

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Bachelor of Architectural Technology and Construction Management

IS HEMP A SUSTAINABLE CONSTRUCTION MATERIAL 2012

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NOTE: This report was compiled as a compulsory assignment in the 7th semester Architectural Technology and Construction Management degree course – ***no responsibility is taken for any advice, instruction or conclusion given within!***

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I would like to express my gratitude to my dear friend Stanislav who introduced to me the topic of industrial hemp in the building industry. This report wouldn't be possible without his help.

Abstract

This report was written as an elective study assignment in the 7th semester Constructing architect degree course. My work is a response to the environmental problems we face today and the steps we take to reduce the environmental impact done by the building industry.

This report reflects my investigation weather industrial hemp is a sustainable building material by evaluating its whole life cycle. My report includes a definition of what a sustainable construction material is from environmental perspective. This report does not include financial assessment of hemp production due the lack of established hemp market and due to the irrelevance of the matter from environmental perspective. Another goal of this study is to give advice on how to produce hemp building material more sustainably.

Chapter 2 and 3 contain empirical data gathered by a secondary research. The information concerns hemp production, hemp construction materials such as hempcrete and hemp insulation, and other potential uses of hemp. Investigation on their performance as construction materials is evaluated on the basis of my definition for sustainable material in Chapter 1. Traditional materials with similar purpose to hemp materials are often used for comparison.

I believe that my studies in hemp as a construction material are consistent enough and answer the researched problem questions. I would like to emphasize on the point that my investigation shows that hemp and hemp products are a good way of reducing global carbon emissions and limiting deforestation.

Key words: hemp, fiber, crop, hempcrete, clay, lime, insulation, carbon, sustainable, eco, green, CO_2, building, environment, recycle, breathable

Contents

List of illustrations

Introduction and problem background

This report is written as a 7th semester dissertation for the Bachelor of Architectural Technology and Construction Management education.

Hemp is a controversial bio product with promising performance as a sustainable building material. The fact that hemp is an organic, natural product makes it highly relevant in the present reality of global pollution and struggle for coping with planetary warming. The construction sector is among the leading industries when it comes to energy consumption, release of CO_2 and is responsible for great amounts of waste and pollution. I consider researching and implementation of sustainable building materials a crucial necessity in modern times. The big potential of hemp becoming widely used in the construction industry also hides promising business opportunities in which I as a constructing architect have great interest in.

Hemp or *Cannabis sativa* is well known for its psychoactive effects on humans and has made a strong social and cultural impact over the years. Today hemp production is still facing restrictions in many countries which make its implementation in the building sector difficult. However this report is not interested in Hemp as a drug or its implications as such. With my investigation I will research Hemp from purely technical perspective relying on empirical data, conducted experiments and examples from real life. The purpose of this academic report is to find out if hemp is a sustainable building material or not. I have therefore formulated the following research questions:

1. What is a sustainable construction material?
2. What is hemp and how is it produced?
3. What is the application of hemp as a building material?

The findings in this report are based on a secondary research. Most of the studied and interpreted material is based on quantitative method of research. My methodology of work is mainly gathering information from web sites and reports on the similar topics. Relevant books or other relevant printed materials are currently unavailable. All pieces of information collected are being evaluated, systematized and connected into a fluid and coherent analysis.

Chapter 1: What is a sustainable construction material?

The building industry is one of the most complex industries requiring perfect synchronization between vision, knowledge, resources, funds, institutions etc. Despite the big challenges and the great amount of risks involved in building, the construction sector has always been able to amaze us with astonishing achievements in architecture, construction and work planning. Throughout history the building industry has become a symbol of prosperity and progress by overcoming incredibly complex challenges. Structures like the Hoover dam in the USA, the Bird's nest stadium in China and the Burj Khalifa in Dubai are a proof of that. However, no matter how great these achievements of modern architecture are, we can't neglect the fact that they are not sustainable structures.

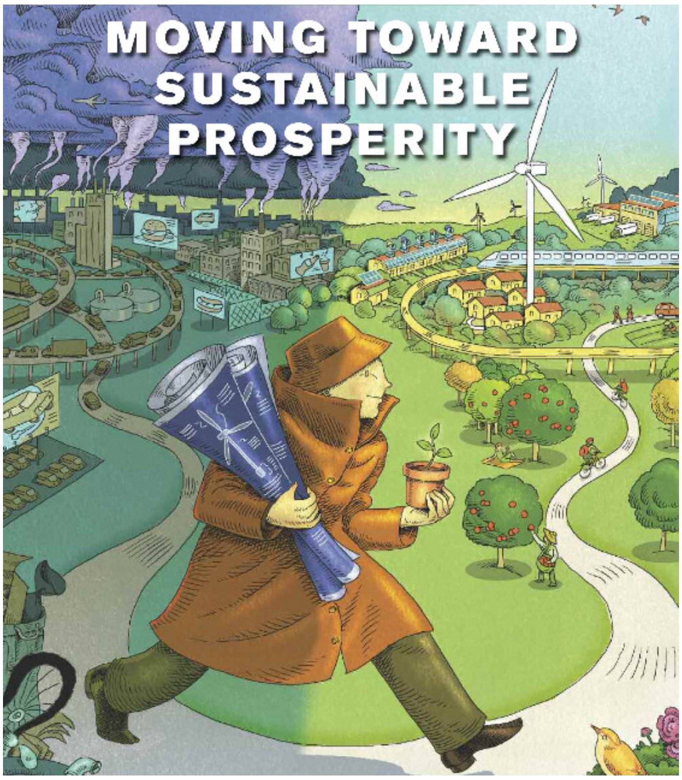


Figure 23: The realized necessity of going 'green'

Today we are entering the global reality of finite resources, growing pollution and increasing population which puts a new even greater challenge for the sector - the challenge of building in a sustainable way. As expected, the building industry is lively reacting to the modern environmental problems by implementing the so called 'green' or sustainable building design which is mainly related to reducing and optimizing the energy usage of a building. Leading countries in sustainable design are taking action by setting higher and higher energy demands for all new buildings. Nowadays we use many different materials to produce complex solutions with outstanding energy performance. Products like insulated foundation blocks, tick cavity walls, triple glazed windows, solar cells and panels, heat recovering ventilation and earth heating are now available. We can now construct houses that use low or zero amount of energy without compromising the occupants' needs. However, we often forget that this good energy performance comes at a big cost. Many of the construction materials in these buildings require huge amounts of energy to be produced at the first place. Others' production is often related to great CO_2 or other greenhouse gases emissions. Third are containing threatening to the human beings substances. Fourth are just scarce. That is why it is very important to evaluate not only the final performance of a material but rather take in consideration it's whole life cycle. This means that we need to investigate in aspects like how the material is being produced, how abundant it is or how it is implemented in order to be able to make an informed decision weather a building material is sustainable or not. So, what are the features making a construction material sustainable?

A sustainable material is an **ecologically friendly** resource or product. This means that all the activities related to its production, transportation and usage are beneficial or non-threatening for us and the environment. There are many ways in which a material can be environmentally non-threatening. Most of the construction materials we use today possess some or a little part of the properties assigned to an eco-friendly material. **A sustainable building material should live up to all of the following criteria** for eco-friendliness:

1. The construction materials should be a **renewable** resource or made out of renewable resources. We can no longer rely on earth's finite mineral resources to solve our infinite needs. Renewable materials are substances derived from living trees, plants, animal or ecosystem which has the ability to regenerate itself. A renewable material can be produced again and again indefinitely. The best example of this is wood, because no matter how many wooden houses we built we can always grow more trees.

2. The second most important feature of a sustainable material is to be **abundant**. It should be easy accessible and not in long distance form the factory or the building site. Even the best performing material is of no use if it's in small quantities or it can be produced in a restricted area. Sand is a perfect example of an abundant construction material.

3. It is important that the materials we use to construct are highly **durable** and require as little maintenance as possible. We need long lasting solutions because it is sustainable to produce as less materials as possible in order to reduce waste. A great example of durable material is the clay brick, which can suite its construction purposes for hundreds of years.

4. A sustainable material should be **reusable**. No matter how durable a construction is, it can't serve its purpose forever. Therefore all the materials in it should not go to waste after its deconstruction or demolition. There are two ways of eliminating waste: either by recycling the material, or use a biodegradable building material. Biodegradable are organic materials. They decompose easily back into natural elements and by this constitute no waste. On the other hand non-organic materials can't biodegrade (or it takes really long time) but many of them can be recycled.

5. Today we still rely heavily on energy derived from finite resources such as fossil fuels. This is why a sustainable material should require as less energy as possible throughout its whole lifecycle. In other words the material should be **energy 'modest'**. All metals that we use for our roofs or windows usually require a lot of energy to be produced compared to wooden materials which we can use for manufacturing the same elements. It is important to note that production of construction materials should use only energy derived from sustainable resources such as wind, the Sun, tidal power, geo-thermal power etc. These energy sources are practically infinite. Once the global electricity network becomes 100% powered by unlimited energy the 'energy modest' requirement would become simply irrelevant.

6. Recently we have recognized global warming as a real threat to human kind. It is caused by the so called greenhouse effect gases released from our activity as species. Therefore a sustainable building material should be related to zero or minimal CO2 or other greenhouse gas emissions throughout its whole life cycle. Such materials are called **carbon friendly**. Most of the materials used in the building industry today and especially concrete and steel contribute heavily to the global carbon footprint.

7. We as human beings have certain needs when it comes to healthy living environment. Building materials should be **health friendly**. This means that they should not contain any toxic substances or easily lead to injuries during physical contact to us or any other living organism. In order to provide good conditions in our homes we have to use construction materials which are not only safe but also contribute to a healthy indoor climate. This includes proper temperature, humidity, lighting, air flow and noise levels in all habitable structures. There are some materials which perform wonderfully their structural or visual purpose but are destructive to our health. A perfect example of a threatening building material is the carcinogenic asbestos which can still be found in many homes.

8. Last but not least, a sustainable material should have **broad specter of application**. Nowadays we combine so many different materials in order to construct our buildings. It is more sustainable if we could build everything in a construction out of the same eco-friendly material. By producing bigger amounts of the same material we reduce production time and energy waste. Buildings constructed with fewer materials tend to be simpler and cheaper. Wood is probably the best example for a construction material with wide range of usage. However wood require the presence of other non-sustainable materials to be protected from moisture activity.

Bottom line, we can conclude that a sustainable building material and all the activities related to it do not endanger the fragile balance of nature systems. My common knowledge on hemp leads me to the thought that despite of the though requirements, hemp could actually be able to live up to the standard of a sustainable construction material. This is why I consider hemp worthy of deeper investigation.

NOTE: My evaluation of Hemp as sustainable construction material does not include monetary analysis. In a way nature dictates to us that we need to build and live in a sustainable way in order to survive, regardless of money. Therefore I find the financial aspect of the problem irrelevant as it doesn’t have anything to do with how eco-friendly Hemp or any other material is.

Chapter 2: What is hemp and how is it produced?

Hemp's life cycle begins with its production therefore it is crucial to understand what it actually is. Since Hemp is a plant product it is crucial to understand how it's grown, harvested, stored and transported. This part of the report is about hemp's qualities from biological and agricultural point of view. The purpose of this analysis is to give us better understanding of the material and by so identifying the environmental impact related to its nature and cultivation. The goal of this chapter is to compose a sustainable model for fiber Hemp production, if possible.

2.1 Hemp and Marijuana

Hemp is an organic fiber product of variety of the plant *Cannabis Sativa L*. subsp. *sativa* var. *sativa,* which is specially bred to produce strong, fibers and oiled seeds appropriate for industrial purposes. *Cannabis sativa* is an annual wind-pollinated plant, normally dioecious and dimorphic, although sometimes monoecious (mostly in several modern European fiber cultivars). *Staminate* or "male" plants tend to be 10–15% taller and are less robust than the *pistillate* or "female". Special developed hybrids allow the cultivation of mainly female plants for specific purposes.

Figure 24: Cannabis Sativa L: 1. Flowering branch of male plant. 2. Flowering branch of female plant. 3. Seedling. 4. Leaflet. 5. Cluster of male flowers. 6. Female flower, enclosed by perigonal bract. 7. Mature fruit enclosed in perigonal bract. 8. Seed (achene)

Cannabis Sativa L. contains low quantities of tetrahydrocannabinol (THC) which are not enough to make it psychoactive unlike its close cousin *Cannabis sativa* subsp. *Indica* which has poor fiber quality and is produced for recreational and medical purposes. Hemp is often confused with marijuana which is the reason why hemp is illegal to produce in many countries including the United States. All cultivars of marijuana and most cultivars of hemp produce cannabinoids but hemp contains less than 0.3 percent THC. In many countries a maximum amount of 0,2% LHC is agreed as acceptable by the law. If hemp does pollinate any nearby marijuana, genetically, the result will always be lower-THC marijuana, not higher-THC hemp. If hemp is grown outdoors, marijuana will not be grown close by to avoid producing lower-grade marijuana. A trained eye can easy distinguish the difference between the two plants.

2.2 Growing Conditions

Hemp is grown both in the Southern and the Northern hemisphere and basically everywhere where nutrient-rich soil and moist atmosphere is found. Hemp grows in a variety of climates and soil types. The plant responds best to mild climate and drained soil. Cultivation in poorly structured soil or sands requires a lot of additional care which makes the production uneconomical. Hemp requires a lot of moisture especially during flowering time (at least 60-70cm of rainfall per year). Hemp used for fibers (not for seeds) is usually gathered before this stage of development.

During the period of vegetative growth, hemp responds to daytime high temperatures with increased growth and increased water needs. It is said that after the third pair of leaves develops, hemp can survive daily low temperatures as low as -0.5°C for 4-5 days. Steep slopes and high altitudes of more than 400 m above sea level are best avoided. Hemp is relatively insensitive to cold temperatures and can withstand frost down to -5 degrees C. Seeds can germinate down to 1-3 degrees. Seed hemp should not be grown at altitudes higher than 200-250m above sea level. Any higher and there is no guarantee that even early varieties will mature.

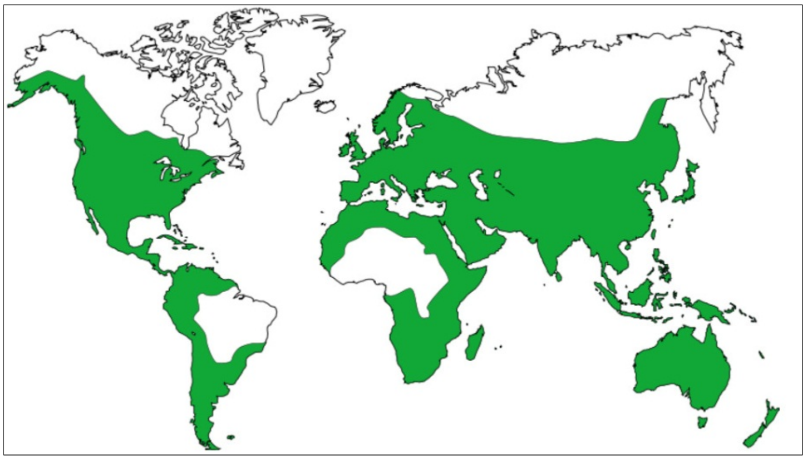


Figure 25: Appropriate climate conditions for growing hemp (in green)

Hemp does not deplete the soil but rather improves it. This makes it possible to grow hemp for many years at the same place without worsening the quality of the fibers. Although Hemp is a very resilient plant and used for crop rotation, it should not be grown in the same location for more than two successive years, otherwise the hemp flea, as well as the hemp moth, multiply rapidly. The deep roots of the plants prevent soil erosion.

2.3 Growth and structure

Cultivated healthy hemp is usually a tall plant reaching 3-5 meters height, depending on the conditions and the genetic construction. The stems are erect, furrowed, and usually branched, with a woody interior, and may be hollow in the internodes. Extensive root systems are the key to the ability of hemp crops to exploit deep supplies of nutrients and water.

Hemp grows tightly spaced (200 to 250 plants per square meter), intercepts 99% of the light and therefore out-competes any weeds, so herbicides are not necessary. It also leaves a weed-free field for a following crop. *Cannabis Sativa* is one of the biggest biomass producers on the planet: 5 tons per hectare in approximately four months. One hectare of hemp is approximately 75 percent cellulose, whereas one hectare of trees is only 60 percent. Hemp matures enough for harvesting in about 100 days and can give two crops per year whereas trees give one crop every 20-30 years.

The plant has naturally course fibers but throughout the history it has been selectively bred to produce finer fibers suitable for manufacturing of wider range of products. The strongest fibers with fine quality are contained in the outer bark of the stem. They are very similar to soft wood fibers and have small lignin content. The core of the stem contains hurds (short fibers) similar to hard wood fibers which find different application. There are many different varieties of hemp which have different amount of fibers or number of seeds depending on the market needs. Hemp fibers are generally longer, 8 times stronger (tensile strength), more absorbent and more mildew-resistant than cotton.

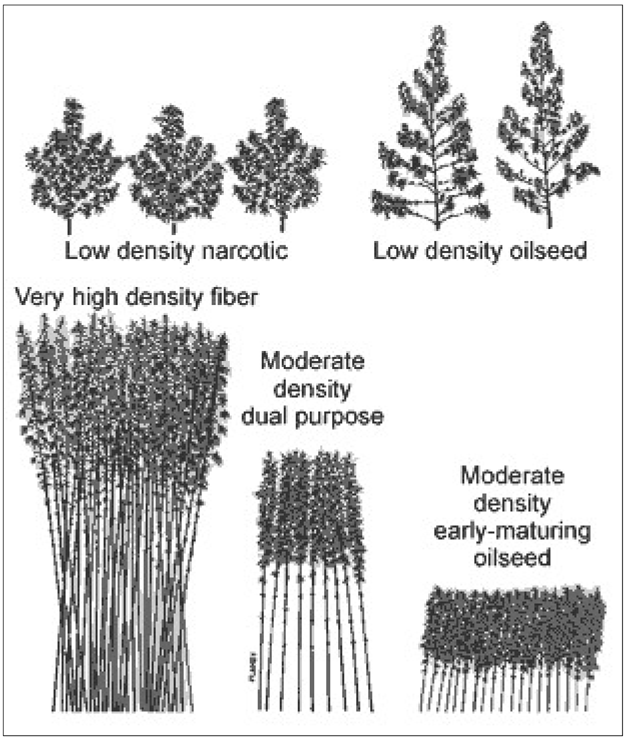


Figure 26: Structure of different types of Cannabis Sativa. Hemp grown for fiber is largest in size and most dense crop

Approximately 1 ton of bast fiber and 2-3 tons of core material can be produced from 3-4 tonnes of good quality, dry retted stalks. These amounts vary depending on the ratio between bast fibers and core fibers in the stalk. The total quantity of fiber depends on the number of stalks per area unit and the quantity of fibers in each plant. The most rich on fiber plants are found in Southern Europe.

Usually Cannabis grown for grain (seeds) is much poorer on fibers therefore the upper mentioned quantities might be much lower. In some countries dual crops are cultivated to produce both seeds and fibers.

2.4 Nitrogen and Hemp

Traditionally, Hemp has been grown in rotation with corn because the nutritive requirements of the two plants are similar. The usage of nitrogen as a fertilizer has always been an environmental concern. Therefore its usage as such has to be kept desirably to 0 or to minimal levels which are not destructive to the soil or the plant. Suggested rates of the three most important nutrients are: 120kg/ha of nitrogen (used in poor soil in Germany); 100 kg/ha of phosphorus; and 160 kg/ha of potassium. However the amounts of nitrogen are different depending on what hemp is grown for. Growing hemp for fiber requires less: 20-60kg/ha (according to the British Springdale farming group). Field trials show that extensive usage of nitrogen can influence badly the quality if the fibers. The stalk becomes larger, the bark section thinner, and the fiber content and strength reduced.

Up to 70% of the nutrients are returned to the soil as leaves fall off stalks during growth. Nutrients are also returned by the trimmings during harvest time, the rotting done on the field (hemp retting) and by leaving the roots in the ground. Reports show that fiber and biomass yields are increased in organic farming rotations where nitrogen is sourced from the preceding crop alone.

2.5 Pests and diseases

Hemp has been promoted as being free of pests and although this isn't the case, hemp is very tolerant of pests and generally pests do seem to prefer other crops. More than 50 different viruses, bacteria, fungi and insect pests are known to affect the hemp crop. However, hemp's rapid growth rate and vigorous nature allow it to overcome the attack of most diseases and pests. The two main diseases on hemp are *Botrytis cinerea* and *Sclerotina sclerotium,* however no significant crop losses are reported yet. There are also no licensed pesticides or fungicides for hemp.

Hemp is a resistant crop and also clears the soil of several pests such as nematodes. Researches show that *Cannabis sativa* can be used as a repellent and botanical pesticide itself. Hemp contains more than 400 chemicals. Its leaf glands contain volatile compounds, such as terpenes, ketones, and esters which produce the characteristic smell of the plant. The limonene and several pinenes which comprise over 75% of volatiles detected in the atmosphere surrounding Cannabis leaves are powerful insect repellents. There is no evidence that the cannabinoids in the plant are playing any role in its performance as pesticide. Hemp has being grown as a companion plant near crops like cotton, wheat, potato and other vegetable fields. All of them suffer less damage by the pests that usually attack these crops when Hemp is not around.

However continuous growth of Hemp as a monoculture would probably allow diseases and pests to adapt to its repellent qualities. Therefore, future necessity of pesticides usage on hemp crops is possible.

Bird damage has been severe in some areas of Ontario and Manitoba. Significant losses in grain yields up to the entire crop have been reported. The stem of the plant is of no interest to birds. Bigger threat to industrial hemp used for construction purposes is the strong wind. Tall plants with bigger leafs can be bent and broken. However most of the broken plants recover. Higher LHC amount could result if harsh weather conditions are present.

2.6 Harvesting for fibers

Hemp is more difficult to harvest compared to cultures like corn and wheat for example. Cannabis plants are tall and strong which makes it difficult for standard machines to harvest properly. In countries like France dual crops of Hemp are cultivated which allows a normal combine to harvest the plant. The fiber from a dual-purpose crop is usually of lower quality and is often used in low-value applications. When industrial hemp is grown for both grain and fiber, it is necessary to re-cut the tall stalks after combining. It is likely that the practice of dual growing will disappear due to greater specialization seeking optimal performance of the end products.

Figure 27: Harvesting hemp with modern machinery

Figure 28: Harvesting hemp by hand

There are also special machines developed for harvesting Hemp which are known for their high prices. Regardless of the price, the machinery used in Hemp production should be kept to minimum. All harvesting and transporting should also be running on clean energy with minimal carbon emissions. Agricultural vehicles running on bio fuels or electricity are now available and could be easily implemented in hemp cultivation.

The most eco-friendly way of harvesting hemp is by hand. This method also reduces losses of fiber and seeds during gathering. China and the smallest hemp producers are using this method, while other big producers in the western countries consider it uneconomical due to high labour costs.

2.7 Hemp retting

Retting is a microbial process that breaks the chemical bonds that hold the stem together and allows separation of the bast fibers and the core fibers (the hurds) from the rest of the stem parts. The two traditional types of retting are field and water retting.

Figure 29: Hemp field retting

Field retting is also called dew retting because it requires the balance between nightly dew and daytime drying conditions. Moisture is needed for the microbial breakdown to occur, but then the weather must be dry enough for the stalks to dry for bailing. Basically, the stems are left lying on the field where they rot under the farmers' supervision. The rotting should be controlled in order to make sure that the qualities if the fibers are not lowered in the process. Field retting has been used extensively for hemp because it is simple, inexpensive and does not require water or any bio threatening treatment. The method is fully mechanized and brings back 40% of the nutrients back to the soil. The disadvantages of dew retting are that it's weather dependent and delays the planting of the next crop.

Water retting produces better quality fiber but it requires big amounts of fresh water that must be threated before discharged. Despite the fact that it is very labour intensive, this method is considered unsustainable and can't be executed in countries with strict environmental laws. A possible solution to the problem could be converting the waste water into a fertilizer and re-using it.

Mechanical retting is not very popular because it produces only non-woven fibers. This kind of fibers is unusable in the textile industry but have the potential to be involved in construction. The process is energy intensive, so sustainable power and machinery must be implemented in order to make the method sustainable.

Stream retting (STEX) and UV treatments are all techniques that can be considered, however, they require the usage of toxic substances which immediately puts these practices into the graph of unsustainable methods.

Enzyme retting hides big potential but it also requires further greater research. The method uses genetically modified bacteria to detach the fibers form the rest of the stem tissues. Some attempts of combining mechanical and enzyme retting have been done in China.

2.8 Baling and storage

Hemp can be balled by hand or by all common ballers into round or square bales. Sisal or hemp twine must be used to tie bales because polyester or plastic twines could contaminate the later processing of the fibers.

The storage facilities can either be peripheral on the farm, centralized at processing facilities or both. Since hemp is harvested in late summer until October, it has to be able to remain stored for at least a year until the next crop is ready. Bales can be stored both indoors and outdoors. Hemp requires straw moisture content no bigger than 15% when balled and it should continue to dry to about 10%. Moisture content in the stalk is critical in order prevent Hemp form rotting and mold growth.

When stored outside the bales suffer losses of the outer layers due to rain and moist. Sometimes 1/4 of the entire crop is lost due to bad weather conditions. Losses can be reduced to 1-8% if Hemp bales are stored on gravel. Storage under a shelter or in a ventilated structure is prescribed as even better conditions but they are not a must.

Figure 30: Hemp bales storage

2.9 Fiber separation

The tree useful products of *Cannabis sativa* are the fibers, the hurds and the seeds. These three products have to be separated in a processing facility in order to serve their industrial purpose. This happens after the stalks are retted, balled and dried. The process of separation is mechanical and it's called 'breaking'. The method is simple and is very close to traditional techniques for gathering fibers. The stalks are passed between rollers to crush and break the woody core into short pieces (hurds), separating some of it from the bast fibers. The process 'scutching' separates the rest of the hurds and the remaining short fibers from the long fibers. The result after both methods are applied is having two products: tow (hurds and short fibers) and line fiber (fine fibers). The whole process can be executed also by a machine called decorticator. In old times this machine used to be driven by hand but today there are modern more sophisticated versions of this simple device.

It is also possible to process Hemp directly into tow. This is a faster and simpler process as it eliminates 'scutching'. The disadvantage of it is that the line fiber is cut into small pieces making it appropriate for fewer and lower value end products.

Figure 31: Primitive method of breaking dry Hemp stalks

2.10 Hemp, carbon and embodied energy

Hemp is no different than any other plant. It grows by the process of photosynthesis and absorbs CO_2 from the atmosphere. It incorporates the carbon into the structure of the plant, releasing the oxygen. In this way carbon is being removed from the atmosphere, and preserved in the Hemp where it remains until the plant is eaten, burned or it decomposes at which point the carbon is once more released into the atmosphere, most probably in the form of CO_2.

If this CO_2 can be 'locked up' in the fabric of a building then it is removed from the atmosphere for the lifetime of the building or the product it's used for. The amount of carbon in the hurds is about 50% of the total weight of the plant, which is equivalent to removing from the atmosphere 1.83 tons CO_2 per ton of hemp hurds.

Hemp has a low bulk density, which means that storage costs, transport costs and associated CO_2 emissions per ton are high. Local production minimizes transportation and embodied energy of the hurds and is essential if Hemp is to become competitive. Per ton, haulage releases between 7,5kg and 18kg of CO_2 per kilometer. This said, the embodied energy of hemp has been calculated to be around 1.4MJ/t, which is equivalent to 0.14 kg CO_2 per ton. This is negligible compared with the 1.83 tons of CO_2 sequestered per ton of hemp hurds.

2.11 Conclusions on question 2:'What is hemp and how is it produced?'

This conclusion would try to evaluate if hemp and its production is sustainable. It would also try to give advice on how hemp production become eco-friendly, if possible. Based on the research done in Chapter 2, I can now apply my findings to the 8 requirements stated in Chapter 1: 'What is a sustainable construction material?' The requirements for eco-friendly material are as follows:

- **Renewable**: As an organic material derived from the plant *Cannabis Sativa*, Hemp can be classified as renewable material.
- **Abundant**: Despite some specific needs and difference in fiber quality, Cannabis is generally non-pretentious plant that can be grown extensively around the world. As mentioned above, hemp crops are also one of the biggest biomass producers on the planet, far greater than forests. Considering these fact we can classify hempas abundant material. It is unsustainable or impossible to grow hemp in deserts, high altitudes and near the Arctic (Antarctic circles). However emough hemp can be produced to supply easily these areas. Transportation must not be involved with pollution or carbon emissions.

NOTE: Hemp is presently not abundant due to legal restrictions in many countries. However, my investigation on hemp and marijuana shows that these restrictions are more or less absurd. The legal issues surrounding hemp are most likely driven by interest rather than any scientific fact.

- **Durable**: At stage production hemp is highly durable. *Cannabis* is relatively strong plant, highly resilient to pests, diseases and even low temperatures. Hemp can also be stored for a long time with minimum amount of care.
- **Reusable**: At stage production it is impossible to claim that hemp is reusable as it hasn't been involved in any construction yet. However, the production of hemp is or could be

waste free. The entire production of hemp is quite simple and is not wasteful. All parts of the *Cannabis Sativa* which aren't used (leafs, stalk tissues) are left on the field to fertilize the next crop. Unused hemp, as every organic material, is a fully biodegradable.

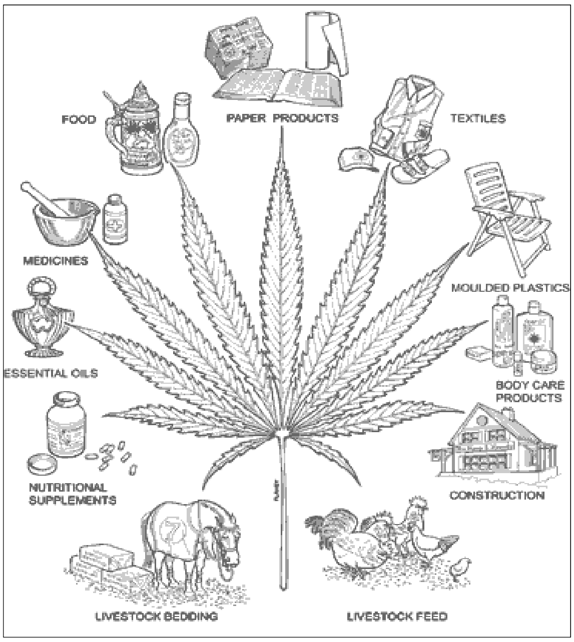
- **Energy modest:** Hemp is a direct product of *Cannabis*, therefore the production of it is not involved with big energy consuming processes such as mining or burning. All the processes described in Chapter one are not complex and can be done by hand or with very primitive machinery and tools. If harvesting machinery is involved it is a must that it runs on electricity or on bio fuels are used (could be even hemp biodiesel).
- **Carbon friendly:** At stage production hemp is carbon negative. However, deeper investigation of the carbon emissions by the machinery involved in Hemp production is suggested.
- **Health friendly:** Hemp is no more dangerous to us or the other species than any other widely used crop. As far THC is concerned, my investigation shows that the quantities contained have no negative impact on organisms. Hemp cultivation contributes positively to the environment as it preserves the nutrients in the soil, prevents erosion, requires no pesticides etc.
- **Broad specter of application:** So far. I haven't researched the uses of industrial Hemp as a construction material therefore it is impossible to make any informed conclusion on the topic at this stage of the report.

Chapter 3: What is the application of hemp as a construction material?

Did you know that Both George Washington and Thomas Jefferson grew hemp on their plantations?

3.1 General usage of Hemp before and now

Archeological studies show that Hemp has been used for at least 12,000 years. *Cannabis Sativa* is one of the oldest and most cherished crops cultivated by mankind. Actually the Latin word *Sativa* means *useful* as Hemp finds wide application in almost every industry. In every society where people discovered Cannabis hemp, they often discovered the five uses for hemp which include: *hempen fibers, oil from the seeds, the seeds for food, a medicine, and for its narcotic properties*. Some people refer to Hemp as the plant of 30,000 (25,000 in some websites) uses.



Figur 32: Cannabis uses

Indeed, throughout history Hemp has played an important role in industry as it was used extensively for fabric, paper and oil. From as early as 5 BC to the mid 1800's hemp fibers were used to manufacture 90% of all ships' canvas sails, rigging, nets, and caulk because of its strength and resistance to the destructive effects of salt water. Hemp was also used for making paper, twines, carpet thread, carpet yarns, sailcloth, and for homespun and similar grades of woven goods. From the 500's to the early 1900's, many of the world's greatest painters including Rembrandt, and Van Gogh, created their masterpieces on hemp canvas. In the 1930's Henry Ford constructed an entire automobile body from hemp and presently auto manufacturers such as BMW and Mercedes are beginning to incorporate hemp into car bodies, door panels and dashboards. Hemp paper is used even for printing American dollars. One of the most modern uses of hemp is the production of biofuel. *Cannabis sativa* is extremely unusual in the diversity of products for which it is or can be cultivated. Popular Mechanics magazine (1938) proclaimed hemp as "the new billion dollar crop."

When it comes to construction, Hemp's usage is not something new. French archeologists made an intriguing find when they discovered old bridges that were built with a process that mineralizes hemp stalks into long lasting "cement." This building technique is now rediscovered by architects and builders in France, England and Northern Ireland.

3.2 Hemp-lime Hempcrete

3.2.1 Hemp-lime mixture

Figure 33: Hemp-lime mixture

The product developed in the early 1990's in France is a combination of lime and Hemp hurds which are the short, low value fibers of the plant. The two materials are dry mixed in a big 'pan' mixer or by hand on the building site. A controlled amount of water is added. Through many tests done by hemp builders, four different mixes of Hempcrete have been developed to be used in construction. The different mixes are achieved by varying the ratio of hemp to lime binder, and in some cases (for floor slabs), sand can also be added to the mix in order to increase compressive strength. The four mixes of hempcrete can defined in the following order:

- Lightweight Hempcrete- used primarily as an insulator is weakly bonded and consists of around 10% of binder to hemp;
- Wall Hempcrete, requires some structural capabilities to withstand racking and wind loading, the amount of binder is increased to around 25%;
- Hempcrete floor, requires improved compressive strength, the amount of binder is increased to around 50%;
- Hemp plaster where the binder ratio is increased to around 85-90% in order to achieve workable material properties and water repellent capabilities;

The end substance is quite dry and can be handled even by hand. There are differing opinions about whether hydraulic or air-lime should be used in the hemp-lime mixture. However both types can be used.

3.2.2 Casting hempcrete walls

Figure 34: Casting Hempcrete on sections with plastic shutter forms

Hempcrete is used for no load bearing purposes as it has compressive strength of around $1N/mm^2$. The hemp-lime mixture is put and tamped by hand in shuttering forms around a stud wall. The added pressure during the filling should not be too big in order to preserve air in the structure. The whole process is similar to concrete casting but is simpler and can be done by unskilled workers. Commercially, hemp-lime can also be sprayed which makes construction very fast (though the embodied energy is higher).The shattering can be wooden or made of recycled plastic. It takes longer time to fill the shuttering compared to concrete casting, but less energy is consumed as no pumps are used. The Hemp-lime mixture is much lighter than concrete and that's why It doesn't require strong shuttering. The casting can be done in sections. Each section should be given enough time to dry (around 24 hours) before casting the next, upper section. With time the Hempcrete becomes harder and harder as the hemp petrifies and can last for hundreds of years.

The wooden stud skeleton is smaller in comparison to a regular prefabricated element as it servers only load bearing purpose. In other words we don't need wide studs to accommodate insulation material because Hempcrete is insulation itself. The Hempcrete mixture is casted not only in the cavities between but also around the wooden studs thus eliminating cold bridges. The finished wall is monolithic and self-supporting. One of the biggest advantages of the structure is that it's very simple in comparison with common cavity or wooden external walls. There are no additional layers like insulation, wind board, DPM or gypsum. Hempcrete can also be easily formed up to window and door frames creating air-tight seals preventing unwanted drafts and areas of heat loss. Electricity sockets are usually casted inside the wall structure.

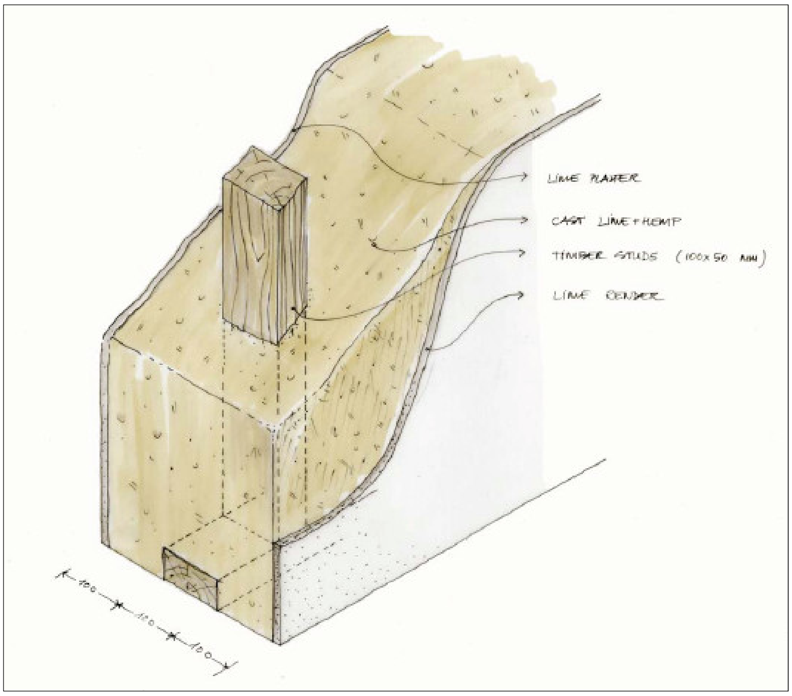


Figure 35: Hempcrete wall structure

3.2.3 Breathability

Traditionally we build cavity walls which we seal tightly. Eventually water finds its way inside this cavity and destroys the insulation. Evacuating the water or ventilating the construction requires a lot materials and precision. Hempcrete walls are different because they are monolithic with only vapour permeable plaster on both external and internal side. This allows the wall to take on the extra humidity in the air inside or outside the building. The water inside the walls is kept until the air humidity drops down and the released back. The alkaline lime wrapped around the hurds and the wood prevents them from rotting. This feature of natural adjusting to air humidity is defined as 'breathability'. Breathable walls control internal humidity reducing condensation and preventing mould growth. This improves the indoor air quality and the health of the building occupants.

3.2.4 Thermal performance and heat loss

As mentioned above, Hempcrete is used to cast monolithic walls without the need of insulation layers. The hemp-lime substance is made of big particles with a lot of small cavities in between. Air is trapped in these cavities, thus performing good thermal insulation. A 300mm Hempcrete wall has a U-value of 0.23 - 0.36 $W/m^2.K$ which meats most of the present building regulation demands. If lower U-values are required, a thicker wall can always be casted. However these are static U-values and buildings are never in a steady state. Unlike mainstream construction methods, the performance of hemp-lime buildings is much better than suggested by the U-value. Experimental building project made with Hempcrete (Adams Brewery, Haverhill house) ended up with great indoor climate, and lower heating bills.

When we talk about heat loss it is crucial to understand the difference between static and dynamic U-values. Static U-values take no account of thermal mass and its ability to retain heat within the structure. Thermal mass provides capacitive insulation. Researches show that the energy lost in the first 24 hours from a hempcrete wall-section with a U-value of 0.29W/m2.K equated to an average heat loss of only 0.11W/m^2.K. This is why hempcrete, unlike traditional construction materials, performs so well in real life conditions where heating is constantly turned on and off. Hemp walls retain the heat from our radiators and release it back when the temperature drops. During the summer the opposite process is observed, as cooler air is preserved. It is observed that the temperature in hempcrete homes during the winter is 2°C higher than houses built with conventional material having the same U-value. Reports form thermographic cameras show that the external temperature of the hempcrete walls is about 5°C lower than the standard construction homes despite the internal temperature being maintained at 20°C.

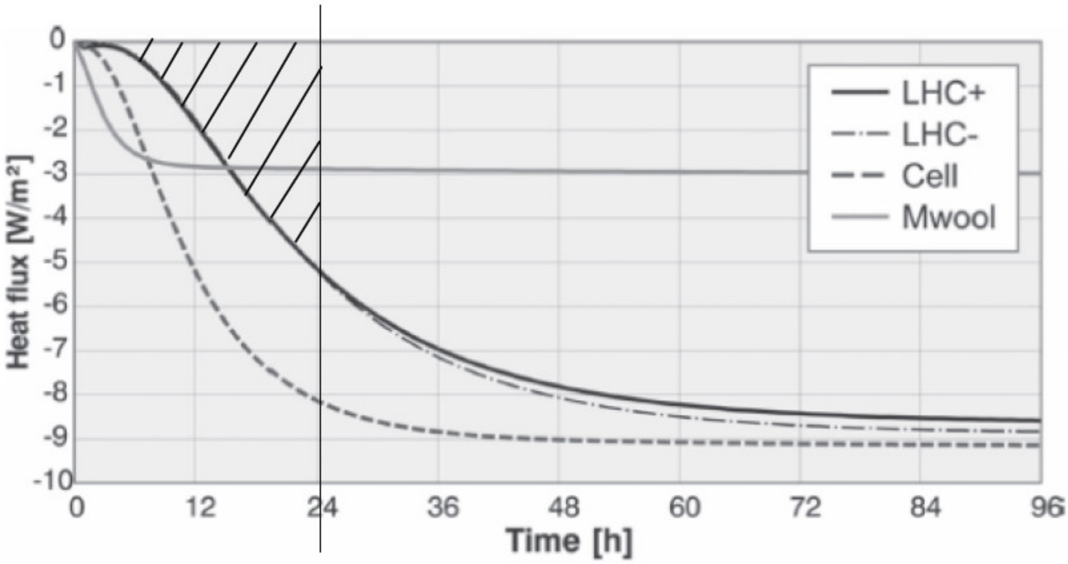


Figure 36: : Performance of different wall sections during sudden drop of outside temperature form 20˚C to ˚0˚C while maintaining 20°C internal temperature. LHC- Lime-hemp concrete; Cell- Cellular concrete; Mwool- mineral wool

The good thermal performance can be explained by the graphic (Fig.14). The area above the curves represents the total heat energy lost from the internal environment, and corresponds to the amount of energy required to maintain the internal temperature. For the first 24 hours this is less for hemp-lime than for both other materials.

The building regulations for heat loss are increasing and hempcrete faces a challenge in order to fulfill them. The thickness of hemp-lime walls will have to be increased to about 500mm or more to live up to the demands. However in countries like Denmark and England we are already seeing walls with similar width. However, as we see here, low static U-value is important but it can also be compensated by the breathing qualities of the materials used. This also puts under question the whole energy policy which western countries are implementing.

When it comes to air tightness, hempcrete looks like a perfect solution. We already discussed that the wooden skeleton is well hidden inside the monolithic wall eliminating cold bridges around the wooden studs. Furthermore, hempcrete can easily be shaped to form precise openings for windows and doors, allowing water tight sealing to be installed (Fig.15).

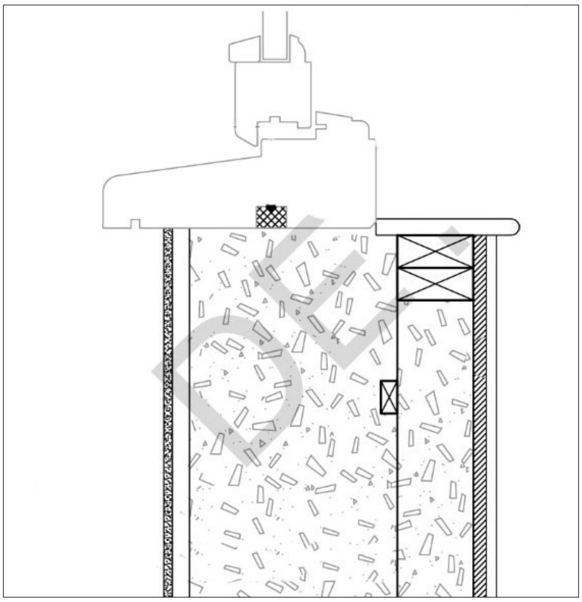


Figure 37: Window bottom frame standing directly on the hempcrete

3.2.5 Acoustics

Reports are showing that traditional wall materials are outperforming hempcrete when it comes to sound insulation. However, hempcrete lives up to the all demands. Houses built with hempcrete are claimed to have excellent sound qualities. I suggest further investigation in this field as no actual amounts for impact and airborne sound absorbation are given.

3.2.6 Fire resistance

Fire testing has been carried out in the UK by BRE and standard wall mix cast material has passed with a Fire Rating of 1hr BS EN 1365-1:1999. An unloaded test sample of 300mm thick standard mix cast Tradical® Hemcrete® survived temperatures of around 1000°C as one wall of a kiln with the outer surface remaining below 70°C for a period in excess of three hours until the test was halted. Other sources state that a 300mm hempcrete wall can perform its structural and thermal purpose for 73minutes.

3.2.7 Carbon emissions

We know that for every ton of hemp produced 500kg of CO^2 is sequestered from the atmosphere. A $1m^2$ section of 300mm tick hempcrete takes around 60kg to construct. This means that about 30-35kg of CO^2 will be locked up in the hemp hurds. The lime used however is accountable for 23 kg of CO^2 emissions per ton. A rough estimation shows that around 2,5kg of CO^2 is released into the atmosphere from the lime inside the hempcrete. Another 2kg are emitted by the plastering (rendering). Bottom line, 300mm hempcrete wall locks up around 25kg of CO^2 per square meter. Traditional cavity walls are estimated to release 100kg-220kg of CO^2 per square meter. We also need to take in consideration that hempcrete walls provide good indoor climate and reduce heat loss which lowers the CO^2 emissions derived from heating or cooling in the building.

3.2.8 Lime in hempcrete

The combination of hemp and lime has obviously excellent performance as a construction material. However, the lime in hempcrete is considered the weak point of the mixture from environmental point of view. Lime is a finite resource that's mined on a large scale. It is associated with biodiversity loss due its mining operations and its contribution to global warming. This material is processed away from the mining site and therefore requires haulage which is highly energy consuming. Lime Kilns use fossil fuels.

Lime is traditionally more difficult to use in comparison with other common binders like cement. Its implementation on the building site is sometimes difficult as Lime is volnurable to harsh weather conditions. Lime is sensitive to frost damage and therefore construction had to wait for the temperature to be above 5°C. This often makes construction with hempcrete impossible during the winter. This leads to a problem as hemp is harvested in September and therefore over-winter storage is necessary.

Figure 38: Limestone mining often involves blasting

Lime is well known for its durability and ability to prevent mold growth. Its presence in hempcrete contributes in keeping termites and other insects away from the construction. However, lime usage should be kept to minimum in order to reduce environmental impact form its production. The carbon dioxide emissions, pollution, waste, haulage requirements and landscape disruption from mining would be vastly reduced if limestone could be mined and burnt locally in efficient Kilns using biomass as fuel (could be Hemp biodiesel).

3.2.9 Recycling

If a hempcrete building needs to be destroyed the walls can be grinded into small pieces and used for new hempcrete mixture. This process would however result in down-cycling the quality of the material deteriorates over time rather than recycling. A way of recycling hempcrete is to be casted in blocks which can late be reused. Lime alone can be re-burned to form hydrated lime or used as aggregate. Lime is also naturally absorbed by the ground without causing poisoning. However, the life expectancy of hempcrete walls is measured by hundreds of years which is far greater than most conventional constructions.

3.3 Hemp-clay Hempcrete

The eco-credentials of hemp and its ability to sequester carbon are reviewed and are found to be convincing. However the high embodied energy and carbon dioxide emissions associated with lime limit the potential of the method for carbon sequestration. Using lime in Hempcrete proves to increase the environmental impact of the material. Using cement as a binder has even more damaging performance. This is why the usage of these binders should be avoided if we want Hempcrete to be a fully sustainable material.

3.3.1 Properties of clay

Clay is not a renewable material when it's used in human terms. This is because it takes very long time for clay to be produced by natural processes and we use it too rapidly. However, clay is globally abundant and widely locally available. It is often a waste product from foundation construction and is fully recyclable (is it's not mixed with cement or lime). The main reason why clay could be a better binder for hemp hurd is that it has very low embodied energy and carbon in itself. Clay used for hempcrete is raw and isn't undergoing any thermal treatment unlike clay bricks. It has high thermal mass and is highly hygroscopic. It transfers and stores both heat and moisture, which makes it perfect for regulating temperature and humidity. Clay is plastic when moist, and relatively impermeable to water. It absorbs pollutants, and helps maintain a healthy environment.

By using clay we enter the realm of earth building which has proven its sustainable nature over the centuries. Earth requires minimal amount of processing as it does not need to be dried or fired before use. No distant processing or haulage is involved as clay can be dug directly from the ground on the building site. In many cases earth is mixed to lime or cement to improve performance under pressure, moisture or cracking. However, clay stabilization can be achieved through compaction or by adding bitumen, aggregate and most importantly-fiber.

3.3.2 Hemp-clay mixture

This building method hasn't been implemented on a big scale and is yet to be developed. However tests have been done in order to give us initial measurement of hemp-lime hempcrete. First, clay slip is being made by mixing water and clay into a cream like liquid. The process can be done by hand, with paddle mixer for plaster or in a bigger industrial size mixer, depending on the quantity needed. Hemp hurds are added and mixed until all clumps of dry hemp are eliminated. The final substance can be mixed in a large drum mixer and is similar to hemp-lime mix in consistency. The clay slip-hemp ratio should be 1:2 for mould growth is occurring in mix with more clay. Tests are being done on hemp-clay brick casted in wooden frames. However the actual construction of a wall would be similar to hemp-lime practice. It is advised that the shuttering is removed as fast as possible in order to speed up the drying process.

Figure 40: Clay Slip

Figure 39: Hemp-clay bricks casting

3.3.3 Clay hempcrete performance

Hemp-clay is relatively lightweight, completely safe to handle. A clay hempcrete structure has similar performance to lime hempcrete analogue.

Initial investigations of the basic thermal parameters of hemp and clay monolithic walls show that these are similar to their hemp-lime equivalent with U-values ranging in between 0,08-0,13W/m.K.

The breathability of the structure is preserved or even improved. The hygroscopic nature of the materials contributes to thermal comfort thereby permitting smaller heating systems. The walls will absorb and store heat and moisture, buffering against temperature and humidity fluctuations.

When it comes to strength, clay hempcrete is slightly weaker than lime hempcrete, which is not crucial as hempcrete is non-load bearing.

It appears that a main disadvantage of non-stabilized earth is that it's volnurable to rain. It is advised that limewash or lime rendering is applied in combination with bigger overhang to protect the external structure.

Clay hemp is 100% reusable as it can be re-hydrated and reused after demolishing. Any waste from the construction process or after demolishing constitutes no waste. The clay slip is naturally accepted by the soil whereas hemp biodegrades.

Some of the test clay-hemp block used for research have developed surface mold which could occur in actual wall structure. A further investigation in this field is advised.

Benefit / Property	Lime-binder	Clay-binder	Winner?
Hygroscopic	Not really	Highly	Clay
Capillary open	Good	Better	Clay
Vapour permeable	Yes	Yes	Neither
Humidity buffering capacity	Questionable	Excellent	Clay
Embodied energy	High	Low	Clay
Associated CO_2 emissions	High	Low	Clay
Carbon sequestration	Neutral to good	Very good	Clay
Cohesive/Binding force	Good	Good	?
Compressive strength of composite material	Poor	Possibly less good?	Lime?
Preservative – of timber and hemp	Yes (probably [91])	Yes	Neither?
Stability	Good	Less good	Lime
Recyclability	Questionable	Good	Clay
Reusability	Doubtful unless in block/panel form	Good	Clay?
Commercial potential	Good	Possibly less good?	Lime?
Use as infill	Yes	Yes	Neither
Use as blocks	Yes	Yes	Neither
Use for spray application	Yes	Probably	Neither?
Locally available	Yes – probably	Yes – probably	Neither?
toxicity/handling risk	Caustic in construction	Good	Clay

Figure 41: Comparison of lime and clay binders for hempcrete

The table above shows a comparison between clay and lime hempcrete properties after the initial research of Ruth Busbridge, Jan 2009. It is obvious that hemp-clay is at least as good if not better than hemp-lime.

3.4 Hemp fiber insulation

3.4.1 Energy demands and traditional insulation products

Presently we are seeing growing demands for energy efficiency of our buildings, especially in Europe. At this moment it makes a great deal of sense to save as much energy as possible as energy is produced mainly from finite fossil fuels. This accounts for huge amount of pollution and carbon emissions in the air. The best way to improve house energy performance is by adding more insulation and by this reducing heat loss of a structure. And yes, the energy efficiency policies in Europe and other countries with strict environmental laws are giving promising results.

Today there are insulation materials and special solutions providing continuous, high performance insulation around the whole structure of a building. The traditional soft insulation materials are man-made mineral fibers made from natural or synthetic minerals or metal oxides. Materials such as fiberglass, ceramic fibers and stone fibers (stone wool) are the most used ones today. The large energy saving achieved with insulation means that the embodied energy of insulation products is of low importance as the energy is paid back in 2-5 years and only accounts for ~10% of the total energy consumed by a house throughout its life time. Despite the great performance of most of these insulation materials they are not completely environmentally friendly. Fiberglass manufacturers regularly use products that are hazardous or dangerous to workers and the environment which is in contradiction with the requirement for **health friendliness**. The insulations used in construction are made from finite resources, conducts waste and have high embodied energy. With the increasing energy demand more insulation is used and by this the embodied energy of the whole building is increased. Keeping the embodied energy of insulation to a minimum therefore without compromising performance seems a reasonable approach.

3.4.2 Hemp insulation batts

Hemp insulation batts are made from woven hemp fibers. The fibers should be with consistent length, clean and well retted so they can divide easily. The finer fibers used the better performance of the insulation. When over-retted hemp's bast fiber yield is higher, the fibers are more easily separated from the hurds and are fine although their color is inconsistent and strength falls. The color and the strength are irrelevant in this case. This means that fibers of a suitable quality can easily be obtained as normally retted and over-retted are suitable.

Figure 42: Hemp fiber batts

Hemp batts are easy to handle and are absolutely save during physical contact unlike fiberglass for example. The product is biodegradable and recyclable. Hemp batts are suitable for use in external walls in timber and steel frame buildings, and for all internal applications including walls, suspended floors, lofts and roofs. They come in standard sizes and can be used in both new build and renovation. Most manufacturers of hemp batts produce insulation with λ value of ~0.039 W/m.K which is equivalent to a high performance traditional insulation. Hemp insulation is hygroscopic material which regulates the moisture and performs perfectly in case of damp. That is why hemp batts are best used in breathable constructions.

Hemp insulation batts look like a good substitute for traditional insulations such as rockwool. Naturally grown hemp fiber has embodied energy of 1,5MJ/kg whereas rockwool has 30MJ/kg. Almost all producers of hemp insulation add polyester and borax to improve the fire qualities of the batts. Polyester is made of petro-chemicals and has higher embodied energy of 53,7MJ/kg. Its presence is usually around 15% which means that the total amount of embodied energy of hemp batts is 9MJ/kg which is still three times lower than rockwool (also considered for the most energy modest traditional insulation on the market). Estimations show that every kilogram of rockwool replaced with hemp insulation saved 1,4kg of CO_2 which reduces further the environmental impact.

The usage of polyester as a base is the main drawback of hemp insulation batts. However polyester can be successfully replaced with natural materials such as potato starch. The presence of borax as fire retardant and repellent is a must. So far no better substitutes for borax are found.

3.5 Other potential uses of hemp in construction

3.5.1 Fiberboard

Hemp medium density fiberboard (MDF) is a very promising material. Test productions have been done in Washington's State University. The production process uses the short hemp fibers which are additionally shortened to fulfill all size and geometric demands. Broken machinery has been reported due to the high strength of hemp fibers. After the fiber is ready, it is dropped into a horizontally spinning drum. As the fiber floats in the spinning drum a binder (glue) is sprayed on it. The fluffed up fiber, now with a binder, is put into a hot press, under tons of pressure. The resulting fiberboard is said to outperform by far all other wood analogues when it comes to strength.

Figure 43: Experimental hemp MDF

Even though hemp MDF is not on the market yet, it hides a great potential. MDF boards are used extensively in the building industry. Replacing wooden fiberboards with hemp could be one more way to limiting forest depletion.

3.5.2 Hemp plastic

Hemp plastic was developed in Europe in a period of 15 years. It is not a new discovery as it has been used by Henry Ford for his famous hemp car series in the 40s'. Hemp plastic is a composite material made of hemp fiber. It's a perfect substitute for oil-based plastics because it's very strong for a plastic. Hemp plastic is fully biodegradable and is resistant to higher temperatures compared to other plastics. Today China is the biggest producer of the product.

Figure 44: Chair made of hemp plastic

Plastics also find wide application in the building industry. Hemp plastic can be used in construction everywhere where normal plastic is used: reinforcement fixators, floor supports, curtain walls framing, windows, piping, fixed furniture etc. All plastic tools used on the building site like buckets, trays, containers, helmets etc. can be replaced with hemp plastic analogues.

3.6 Conclusions on question 3: 'What is the application of hemp as a construction material?'

This conclusion will try to evaluate if hemp construction materials are sustainable according to the 8 requirements in chapter 1: '*What is a sustainable construction material?*' The products *hempcrete* (both lime and clay based) and *hemp insulation batts* will be considered in this evaluation. The rest of the mentioned products and their performance as construction materials are not studied well enough, so an educated statement can't be given.

- **Renewable:** Hempcrete made with lime and clay does not live up this demand as the two binder materials are finite resources. Clay's renewability is neglected in this case because of the long period that it requires for the process. In order for hempcrete to fulfill this requirement, a new binder (probably organic) made of renewable source would have to be found.

  Hemp insulation batts, on the other hand, can be considered as fulfilling the requirement for renewability. This is because hemp insulation is a direct product of hemp fiber, which is a renewable material itself (discussed in Chapter: 2). Hemp batts are usually produced with a small amount of non-renewable additives in order to make it more resistant vermin and fire. However hemp insulation can be made even if these materials are not present.

- **Abundant:** Hempcrete is indeed an abundant material as both binders are vastly available. However, clay is 'more' abundant than lime, as it's found almost everywhere on Earth. Clay is easily accessible and often present on the building site. Clay can be classified as pone of the most abundant construction materials available today.

- **Durable:** Hempcrete based on both lime and clay is a highly durable material. As discussed hemp has the ability of fossilizing in the walls and is considered to last for hundreds of years. Hempcrete is naturally resistant to moisture due the hygroscopic nature of the hemp fiber. Hempcrete also proven to satisfy modern requirements for resistance to fire.

  Hemp insulation batts are also a resistant material. Hemp fiber insulation can perform well even in the presence of damp which is considered a big problem when it comes to traditional insulation materials.

- **Reusable:** Both types of hempcrete are reusable materials as they can be recycled and used in a construction again. Hempcrete can't be recycled many times as the quality of the mixture worsens. However, hempcrete would not cause any waste as hemp is biodegradable and both lime and clay are naturally absorbed by the soil.

  Hemp fiber insulation is both recyclable and biodegradable product and therefore it's not accountable for any waste.

- **Energy modest:** Both hempcrete and hemp fiber insulation are energy modest materials in comparison with many of the traditional construction solutions with similar purpose.

- **Carbon friendly:** Hempcrete is a carbon friendly material. Even though lime is accountable for a substantial amount of CO_2, lime hempcrete is, in the worst case, at least carbon neutral. Clay hempcrete is completely carbon negative.

  Hemp fiber insulation is carbon negative material.

- **Health friendly**: Both types of hempcrete do not contain any life threatening substances and are health friendly. The breathable nature of hempcrete walls improves the indoor climate and contributes to human healthy life. However, it is important to note that production of lime could be engaged with heavy mining which is destructive to the natural systems.

  Hemp fiber insulation is health friendly material. However polyester and chemical must not be used in the production process.

- **Broad specter of application:** The research in Chapter 3 proves that hemp grown for fiber has a broad application as a construction material. Other products such as paint from hemp seeds, hemp fiber ropes, hemp paper, hemp bio-diesel could also be involved in the entire building process.

Conclusion

The investigation on this report managed to answer all research questions and by this allowing an educated conclusion. My method of work provided enough data to be able to evaluate the properties of hemp as a construction material following its whole life cycle. Personally, this investigation and my attempt to define a sustainable construction material broadened my view and understanding of sustainability. I believe this report could be very useful for providing basic knowledge for hemp to other students or even professionals interested in this topic. My investigation can also be used against the unreasonable restrictions on hemp production worldwide.

On stage production industrial hemp for fiber is sustainable. The organic nature of hemp, its resilience, abundance, large biomass, fast growth, carbon negativity, simplicity of handling and other qualities mentioned in Chapter 1, elevate hemp up to all criteria for sustainable, eco-friendly material. It is important to note that cultivation of hemp could easily become non-sustainable if executed in an unsustainable way. Based on my knowledge about hemp production I can make the following recommendations for a sustainable hemp production model:

- Hemp should be cultivated only in areas where climate and soil conditions allow the natural growth of the plant.
- All soil nutrients should be natural or acquired by the process of on-field rotting of hemp stalks.
- Hemp should be grown and processed as close to the building site as possible.
- Hemp should be harvested by hand or with machines running on bio fuels.
- Only field retting should be performed.
- Retted hemp stalks should be processed as close to the crop as possible.
- Fiber separation should be done by hand or with decorticator running on sustainable energy.
- Hemp should be stored under a shelter.

My investigation on hemp materials usable in a building construction allows evaluation of hempcrete and hemp fiber insulation. The rest of the mentioned products or potential applications of hemp are not studied well enough to be included in this conclusion. The questions regarding the environmental impact of these materials remains open and further investigation is advices.

Both lime hempcrete and clay hempcrete are not sustainable constructing materials because both binders are non-renewable resources. However, hempcrete fulfills all other points for eco-friendliness and hides great potential in the attempt of reducing carbon emissions. Hempcrete is not the ultimate sustainable material but it's very, very close. Hempcrete is certainly performing much better than many of the traditional solutions with similar application and therefore is advised to be implemented as much as possible. Hemp-clay hempcrete can be considered as sustainable when used locally. Further research of this material should be performed in order to find a good substitute for the finite clay and lime. These are some recommendations of how to use hempcrete more sustainably:

- Clay hempcrete should be used as clay is more sustainable than lime.
- Hempcrete mixture should be prepared on site by hand or with a mixer running on sustainable energy source.
- Hempcrete should be tamped by hand in wooden or recycled plastic shuttering.
- Natural, breathable rendering and plaster should be applied to hempcrete walls.

Hemp fiber insulation is a sustainable material for insulating wall and roof constructions. This material lives up all demands for a sustainable product. The product is not only eco-friendly but also outperforms traditional insulation materials when it comes to moisture resilience. Hemp insulation batts are strongly advised for implementation in the building sector. There are a few conditions regarding production that must be followed in order for hemp insulation to be sustainable:

- The energy used for production should be from sustainable sources.
- No borax should be added to the insulation.
- Traditionally used synthetic additives should be replaces with natural products such as potato starch.

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Enclosures

1. Title page- *IS HEMP A SUSTAINABLE CONSTRUCTION MATERIAL 2012*

–page 1