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Hemp-Lime Composites in Architectural Design

Summary

This article concerns the hemp-lime composite (*hempcrete*) – a new, naturally-sourced and ecological material solution and its practical applications in architectural design. The purpose of this publication is to characterise the technology based on a review of global publications, and existing example analysis, thereby bringing awareness to the issue and systemising knowledge which will help provide consistent, comprehensive information about this specific technical solution - particularly for architects. Physical properties, environmental impacts, construction techniques, architectural use and design capabilities and limitations of hempcrete are discussed throughout the chapters of this article.

Key words: hemp–lime composite, *hempcrete*, sustainable architecture.

Introduction

On daily basis we observe the consequences of the omnipresent irreversible human interference in the natural world. The long-term predictions are dire. Humanity faces the challenge of making profound changes in its approach as to how the Earth is being transformed. These changes must include architectural design, as the share of construction in energy consumption, resource depletion, and greenhouse gases emission is significant. There are innumerable projects worldwide whose architects try to reduce the negative impact of the buildings on the environment, but new holistic, innovative, and truly sustainable solutions are still necessary.

The project element which, in many cases, has the most influence on the degree of the building's impact on the environment at all stages of its life-cycle is building materials – a factor, which affects both design capabilities and constraints, and, therefore, the architecture itself.

Hemp–lime composite (*hempcrete*) is a newly discovered construction material which has a much smaller impact on the environment when compared to existing popular materials currently in use. In this publication, the physical properties of the material, related building techniques, and features of architectural structures have been analyzed with focus on its significance regarding form, function, aesthetics, physical issues, and ecological properties of the buildings, indicating the opportunities and limitations associated with the discussed technology.

Material characteristics

Hemp-lime composite is obtained by mixing hemp shiv, lime–based binder, and water (sand is a popular optional ingredient). Hemp shiv (hurd) is the chopped inner core of industrial hemp (*Cannabis Sativa*) stems after fibres have been extracted [it constitutes about 70% of the mass of the hemp stalk (IWNIRZ 2013)]. The binder consists mostly of hydrated lime, but other ingredients are also present in the composition: natural hydraulic lime, pozzolans, cement, and other minor though essential additives. The properties of the material can vary to a great degree depending on the characteristics and proportions of the ingredients, presence of additives, and manufacturing techniques applied. In its most typical variation the material has low mechanical strength [compressive strength of less than 1 Mpa (Benfratello et al. 2013; Elfordy et al. 2008; Walker et al. 2014)]; low thermal conductivity [most often the coefficient of thermal conductivity λ is within the 0,06 – 0,12 W/m^2K range (Benfratello et al. 2013; Elfordy et al. 2008, Walker, Pavia 2014)]; high vapor permeability [the coefficient of water vapor diffusivity μ is about 5 (Evrard & de Herde 2006, Walker & Pavia 2014)]; and a specific heat capacity of around 1300 J/kgK (Walker, Pavia 2014). The material is very water absorbent – it can absorb more than three times its own weight (Walker, Pavia 2012). *Hempcrete* is fire-resistant (a layer of the material protects construction elements from fire as well) (Allin 2012; Bevan, Woolley 2008) and resistant to biological (alkaline environment) and chemical corrosion (Bevan, Woolley 2008; Walker, Pavia 2014). The material also has favourable acoustic properties (Bevan, Woolley 2008).

Life–cycle benefits

The ecological potential of hemp-lime composite is visible in each stage of the life-cycle of a building.

Hemp is cultivated without the use of pesticides (IWNIRZ 2013), it naturally inhibits the growth of weeds and naturally fertilizes the soil (Bosca, Karus 1998; IWNIRZ 2013). Hemp, like every plant, absorbs carbon dioxide from the atmosphere during its lifespan (about 2,5 tons of $CO2$ per one hectare). This, along with other factors, makes it so that negative impact of hemp cultivation on environment and biodiversity is inconsiderable in comparison with other crops (EEA 2007; Montford, Small 1999). Hemp processing is a fully mechanical process – no chemicals are used and no waste remains afterwards. Moreover, hemp shiv has been considered a waste product (used only as a bio-fuel or animal bedding material) in the process of extracting fibers and seeds for other industries. The production of the second component, lime binder, is much more invasive to the environment; the process demands high energy use, causes GHG emissions and landscape degradation. Later, when the lime binds within an erect wall, a portion of the emitted carbon dioxide is sequestered; a process called carbonatation occurs (CO2 is absorbed from the atmosphere), lowering overall emissions. Towards the end of its life-cycle, the material can be grinded down and added into a new mix, used as a fertilizer, or composted. These possibilities makes it a fully recyclable material.

The carbon footprint of the material is subject to investigation. In (Bevan, Woolley 2008) emission is estimated to be -100 kg/m^3. Other „cradle-to-gate" studies present the values in a range of around minus a few hundred to around plus a few dozen kg/m^3. In a comprehensive „cradle-to-grave" study (Miskin 2010), the overall emission of *hempcrete* (produced, applied, and utilized in a method referred to as „the most probable scenario") was estimated to be -3,5 kg/m^3. The conclusions drawn from all the reviewed studies show that the actual CO_2 emission of the material varies depending on many factors, but generally oscillates around zero.

The material has features which can improve energy performance of buildings during their use-cycles. An experiment (BRE 2002) conducted on two identical houses in Haverhill, UK, revealed interesting results; the house whose walls were made of *hempcrete* (U coefficient of walls = 0,58 W^2/mK) showed less energy demand than the one with walls made of bricks (U coefficient of walls = 0,35 W^2/mK). There are many possible explanations of this phenomenon. First, the single-layer wall where the material was applied in a wet state creates an opportunity to reduce thermal bridging, because the material fills in all the gaps and hard-to-reach places. It is also highly airtight (Shea et al. 2012). Secondly, partitions made of hempcrete (thanks to its not-too-low density and quite high specific heat capacity) have an ability to accumulate extra heat when temperature rises and release it when temperature drops, providing „inertia" against temperature fluctuations. Similarly, when it is too warm outdoors, the partitions help to retain the temperature of the interior at a lower level. Furthermore, a high vapor–permeability of the material, which helps to control the humidity levels indoors, may possibly decrease the user's need for ventilation and contribute to energy savings. Simulations (Evrard, de Herde 2006) prove that a favorable combination of thermal conductivity, density, and specific heat of the material (consequently, a low thermal diffusivity ($\lambda/\rho c$) and not-too-high thermal effusivity ($(\lambda\rho c)^{1\ 2}$) results in a less intensive heat transfer (comparing to selected popular materials) through the partitions in dynamic conditions (when the temperature difference between the interior and exterior changes). There was also a latent heat effect observed (the effect of a moisture phase change within the material), affecting the thermal performance of *hempcrete* partitions.

Construction techniques and applications

The main construction techniques where the use of hempcrete is prevalent include: forming monolithic walls (or vertical insulation layers) directly on a construction site by compacting the mix manually in a formwork (time-consuming method, partitions of medium density, and a relatively long drying time) or spraying the mix onto a one-sided formwork or existing partition (faster method, possible partitions of the lowest density, and a somewhat shorter drying time); bricklaying from precast blocks transported to the site in a dry-state (fast method, partitions rather of the highest density); or using entire prefabricated partitions.

Photo 1. *Hempcrete* techniques: casting monolithic walls, prefabrication of the entire wall elements, spraying, bricklaying

Source: Bevan, Wolley (2008); Hirst (2012).

There are several typical building applications. First, modernization of historical buildings in which the use of cement is inadvisable (for example based on a timber structure), such as filling defects, thermo-modernizations, etc. Key features of the material include plasticity, water vapor permeability, biological and chemical corrosion resistance, self-repairing lime capacity, and a low λ coefficient, all which make it work well with organic and natural materials (also in a damp environment – it does not change after absorbing moisture and drying) (Bevan, Woolley 2008). The main use in new buildings includes filling walls which have independent construction frames (wooden, steel, concrete) – because of its low compressive strength the material, in most cases, has no structural properties and only helps stiffen the construction. The walls may be monolithic (assembled through compaction or spraying methods) or made of bricks, blocks, or panels. Forming monolithic walls with timber frames is popular in smaller buildings, mostly single-family homes, because of the simplicity of the „do-it-yourself" technique. Bricklaying precast *hempcrete* blocks – instead of ceramic, concrete or aerated concrete bricks, hollow bricks, and blocks – is popular in larger buildings of reinforced concrete structures because it allows for a faster build and does not differ much from traditional bricklaying (builders don't need additional specialized skills). Production of horizontal insulation layers for roofs, attics, and floors using a lighter and more loose mix is a solution typically used in buildings where walls are also made using hemp-lime technology, which helps retain the continuum of a single material and facilitates the elimination of thermal bridging. The aforementioned prefabrication of entire partitions is a technique which has significant potential as well – especially because of the increased speed of construction works. There are also hempcrete finishing panels and plasters, which work best with hempcrete walls.

Architectural use

There are historical examples of the use of similar materials made of a mix of lime binder and organic infill, though in modern times the hemp-lime mix was used for the first time in the late 1980's in France. The renovation of the *Maison de la Turquie*, a historical wattle and daub building, was most-likely-its first practical application. After the second world war there were many other buildings in similar catastrophic technical conditions in the *Champagne* region. Attempts to use cement in restoration works only worsened the situation (leading to a retention of moisture in timber due to low vapor permeability). After experimenting with a variety of binders and shiv from different plants (jute, flax, cotton, silk), a hemp–lime mixture suggested by Charles Rasetti proved to be a perfect solution. Use of hemp for many industries in Asia and Europe has a long history, but development of hempcrete technology in the end of XX century was inhibited in many countries because of legal regulations – hemp crops were illegal because of the inaccurate association with psychoactive substances which *Cannabis Indica* contains. Recent legislation changes, and increased market demand for naturally – sourced materials enabled the popularization and improvement of the technology. Nowadays, the material is used for new buildings; mostly single-family homes but also multi-family and public buildings, warehouses, and other structures. Most of these are built in France and Great Britain, but there are projects all around the world exploiting the technique as well. Currently, research is still ongoing, while practical innovations are underway and academic discussion on the subject continues.

Photo 2. *Maison d' Adam*, Angers, France – renovation in 1994

Source: Wikipedia.

Capabilities and limitations: form, function, aesthetics, physics

Hempcrete, like all materials, carries its own specific capabilities and limitations as a component of architectural design, though in this case effects of the practical use of the material are more so „invisible" physical issues rather than the element's significant impact on so-called architectural expression.

The material's impact on the form of the building is minute. As hempcrete (in most cases) does not carry any load with the exception of its own weight (which may be significant, especially immediately after production when the wall is still wet), the limit of the height of the building depends on its structural elements. When considering monolithic walls with frames, the limited capacity of the material to carry its own weight can be overlooked by additional structural elements within the wall transferring the weight of the material to the pillars. The shape of the plan of the walls does not have to be rectangular; curves are possible if contoured formwork is used. Theoretically, a specific shape of the structure of a construction frame may allow forming irregular wall shapes in all dimensions. Research on using construction frames made of hemp stalks instead of timber was undertaken (Bell 2012).

Photo 3. 3d view of WISE Building, CAT, Machynlleth, Great Britain, 2010 – building constructed with hemp-lime and rammed earth walls

Source: Bevan, Wolley (2008).

Functional solutions and elevation design may be slightly limited in the case of monolithic *hempcrete* walls with a structural frame. Typically, wooden pillars in construction walls of single-family homes are spaced about 1 meter apart, which may limit the range of freedom of design of the openings: doors, windows (especially horizontal), but then again, this problem can be bypassed as well. Some interior design possibilities may also be limited because heavy objects cannot be fixed directly to the material, and should instead be attached to the frame, which is (often) located deeper within the wall. Therefore, additional supports must be devised for heavier elements, such as kitchen cabinets.

As the composite is sensitive to water, it must be protected from direct water action. Typical finishes on both sides are appropriate, unless they limit water vapor diffusion; they can be lime- or clay–based plasters or other breathable finishes. If any non-vapor-permeable elevation materials are used, a ventilated air gap must be incorporated into the design. There are some examples of unplastered interior walls which show the material's texture. It is possible to achieve the same effect on the external side; there are examples of the use of transparent and breathable external finishing layers, even in very unfavorable climates.

The main architectural capability of *hempcrete* is its natural ability to create a favourable microclimate of the interiors. As mentioned before, certain properties of the compound help regulate indoor humidity and keep it at a comfortable level. Hemp-lime partitions stabilize interior temperatures, but they do not produce the unpleasant feeling of cold surfaces, like heavy materials do. The aforementioned possibility of energy savings which helps users economize costs is also an important attribute of *hempcrete* use.

Conclusions

Hempcrete, the material discussed in this paper has significant potential for aiding in advances in the development of sustainable architecture. Its properties help create a healthy and comfortable indoor microclimate and lead to high potential energy savings. In its most typical applications, the use of the material does not cause significant limitations to architectural design. Though the material may not appear very attractive to architects because of its lack of extravagant artistic effects and possibilities, its „invisible advantages" are multitudinal and valuable.

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Kompozyty konopno-wapienne w projektach architektonicznych

Streszczenie

Tematyka artykułu dotyczy kompozytów konopno-wapiennych (betonu konopnego) – nowego, naturalnego i ekologicznego materiału budowlanego, i jego praktycznych zastosowań w projektach architektonicznych. Celem publikacji jest charakterystyka technologii oparta na wielu międzynarodowych artykułach i istniejących analizach przykładów, zwiększających i systematyzujących wiedzę o tym zagadnieniu, która pomoże w zdobyciu spójnych i wyczerpujących informacji na temat tego konkretnego rozwiązania technicznego – zwłaszcza architektom. W artykule w poszczególnych rozdziałach omówiono właściwości fizyczne, wpływ na środowisko, techniki budowlane, zastosowanie w architekturze, potencjał projektowy i ograniczenia betonu konopnego.

Słowa kluczowe: kompozyty konopno-wapienne, beton konopny, architektura zrównoważona.

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