

BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 69 (73), Numărul 4, 2023
Secția
CONSTRUCȚII. ARHITECTURĂ
DOI: 10.2478/bipca-2023-0037

AN OVERVIEW OF THE BENEFITS AND DISADVANTAGES ASSOCIATED WITH THE USE OF HEMPCRETE AS A CONSTRUCTION MATERIAL

BY

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Received: May 8, 2023

Accepted for publication: June 10, 2025

Abstract. The building and construction industry has been identified as a major contributor to global energy consumption and greenhouse gas emissions. Therefore, it is imperative to use sustainable building materials. Hempcrete has been recognized as an eco-friendly material that reduces waste and minimizes natural resources and energy use. While it possesses several benefits, including good structural properties, its porous structure limits, its mechanical performance, and water retention, thereby reducing its applicability as a building material. Nevertheless, it can still be used in construction projects where its limitations are not a hindrance. Although, hemp may not provide as much structural strength as previously thought, it exhibits similar properties to fiberglass. This paper provides an overview of the potential opportunities and challenges associated with Hempcrete as a building material based on secondary sources. The paper also identifies areas in Hempcrete research that require further investigation to expand its usage in construction.

Keywords: hempcrete, eco-friendly, sustainable, construction, material.

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1. Introduction

The world is currently facing numerous environmental challenges, including global warming, climate change, and the urban heat island effect. The construction sector is a significant contributor to global energy consumption and greenhouse gas emissions, accounting for 32% and 19% respectively. As a result, the use of eco-friendly building materials is being widely promoted to address these challenges (IPCC, 2014).

Sustainable building materials are gaining popularity due to their positive impact on the environment and human health. Although concrete is the most used building material, its production has a substantial environmental impact. In contrast, plant-based biomaterials like bamboo, flax, and hemp are increasingly being used in the construction industry due to their high insulation and thermal properties. These materials can serve as aggregates for non-structural concrete mixtures (Thakur et al., 2014).

The use of sustainable materials in construction not only reduces costs but also provides long-term benefits for communities. Hempcrete, also known as hemp-based concrete, is a game-changing material in the construction industry that offers various environmental benefits. Hemp absorbs more CO₂ during its lifespan than it produces during its manufacturing, transportation, and construction phases. Studies have shown that hempcrete has exceptional hygric thermal properties and can help reduce environmental impact (Al Ashwal et al., 2015; Ingrao et al., 2016; Pacheco-Torgal & Jalali, 2011).

Hempcrete offers several construction advantages, including fire resistance, robustness, high energy efficiency, and natural resistance to mold, insects, and fire. Consequently, hempcrete has both environmental and constructional benefits that can deliver sustainable solutions (Lye et al., 2020).

This paper provides an overview of the potential of hempcrete as a sustainable building material, including its advantages, disadvantages, and potential applications in the construction sector.

2. Methodology

The literature search was conducted using relevant keywords such as sustainable construction materials, eco-friendly building materials, hemp, and hempcrete. The review included a range of sources, such as peer-reviewed papers published within the last decade, older studies, articles, and journals. The primary objective of the literature review was to provide answers to the following technical questions:

- What exactly is hempcrete and what is its chemical composition?
- What are the unique properties of hempcrete in terms of its thermal, mechanical, and hygric behavior?

- How does hempcrete contribute to eco-friendliness in the construction industry, and what are the environmental benefits of using this material?
- What are the various applications of hempcrete in the construction sector, and how does it compare to traditional building materials in terms of its performance and durability?
- Are there any notable case studies?
- What are the limitations or potential drawbacks of using hempcrete as a building material, and how can these issues be addressed through further research and development?

3. Literature review

3.1 History of Hemp

Researchers have theorized that hemp may have originated in central Asia and parts of India, including the Himalayan mountains and Kashmir. Hemp has long held religious significance, being considered one of the five most sacred plants according to the Vedas. Hempcrete, a building material made from hemp, has also played a significant role in preserving ancient artwork, such as the Ellora caves in Maharashtra, India. Archaeologist Rajdeo Singh and botanist M.M. Desia discovered that a mix of mud or clay plaster and *Cannabis sativa*, with hemp making up roughly 10% of the mixture, was the reason for the lasting plaster, extending its lifespan to over 1500 years.

This mixture acted as an insulating agent and strengthened the plaster. The Ellora caves, which date back 5 to 10 centuries, are an impressive example of Indian rock-cut architecture, with 34 caves representing Hindu, Buddhist, and Jain beliefs. While studies estimate that hempcrete wall systems in Europe have a lifespan of between 600 and 800 years, the hempcrete used in the Ellora caves has survived for over 1500 years (Joshi, 2017).

Hemp has been used as a construction material for centuries. In the 6th century, a bridge in southern France was constructed using hemp. Modern use of hemp in building materials began in France in the 1990s. The first instance of modern use was for the renovation of historic timber-framed buildings. Lime mixture was cast around the timber frames, and hemp fiber was added to the mixture. Following this, hempcrete was used in residential projects in France and Great Britain (Jones, 2017; Bevan & Wolley, 2008).

3.2. Hempcrete Composition

Hempcrete is a unique bio-composite building material (Figure 1) that is made up of several components. The mixture typically consists of shives, lime binder, and water. Shives are derived from the hemp plant, a fast-growing crop that can reach heights between 1,5 and 4 meters (Figure 2). The plant's

natural fiber is grown mainly for its tensile strength and is found primarily around the woody core of the stem. After harvesting, this fiber is chopped into small pieces measuring between 5 and 25 mm. The shives are then mixed with lime, water, and a small amount of cement to create the final bio-composite mixture known as hempcrete (Manohari et al., 2016; Jones, 2017).



Fig. 1 – Hempcrete bricks produced by blending hemp shives with lime.



Fig. 2 – Hemp and lime blending.

3.3. *Distinctive Properties of Hempcrete*

3.3.1. Density

The density of hempcrete is primarily influenced by the materials used in its composition, the size and porosity of the shivs, and the amount of energy applied during compaction (Klemm *et al.*, 2019). In general, the density of hempcrete used in in-wall applications can range from 400 to 500 kg/m³ when using an on-site pouring method, while the spray method results in a density of 200 to 250 kg/m³, despite using the same amount of shivs. However, by increasing the proportion of binder used in the mixture, it is possible to obtain a higher density of 600 to 1000 kg/m³ (Karus et al., 2017).

Research conducted by Ohmura et al. has found that hempcrete not only exhibits superior strength and density but also demonstrates excellent compaction characteristics. As a result, the density of hempcrete can be customized to suit the specific requirements of different construction projects. These properties make hempcrete a highly versatile material for use in various construction applications (Ohmura et al., 2016).

3.3.2. Thermal conductivity

According to Evrard and Herde, the small amount of moisture drastically affects the thermal performance of the material and slows down the rapid heat flow in a building when the sudden temperature changes, considering a phase change between liquid state to vapor state (Evrard & Herde, 2014). Further, Dhakal et al. also determined that due to its high thermal inertia, hempcrete can heat up in a short period and maintains the temperature for a long time when ambient temperature decreases (Dhakal et al., 2013).

3.3.3. Acoustic properties

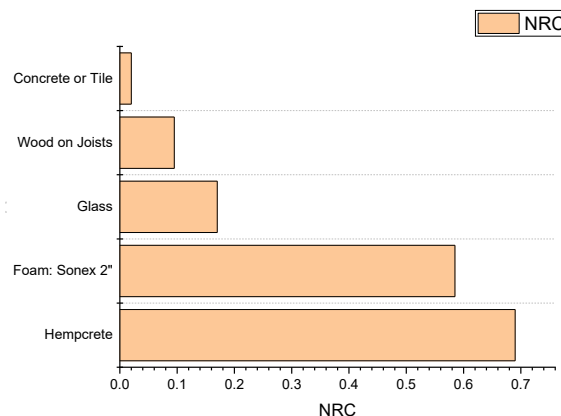


Fig. 3 – Noise reduction coefficient (NRC) of Hempcrete, foam, glass, wood on joists, and concrete or tile (Updike & Felker, 2016).

According to Updike & Felker, hempcrete has a mean NRC of 0,69 (Figure 3), where higher NRC signifies greater reduction in noise and hence creates greater comfort for the users of the space or building (Updike & Felker, 2016). Kinnane et al. concluded that hempcrete has better sound absorption properties than conventional materials like concrete, and physical parameters like density and porosity do not impact the acoustic absorption (Kinnane et al., 2016).

Additionally, it has been found that using a lime binder with hempcrete has better acoustic absorption than using hempcrete with Portland cement. In accordance with the current standard for noise reduction coefficients of common building materials, 1 NRC is perfect absorption, while a perfect reflection is signified by 0 NRC (Kinnane et al., 2016, Ingrao et al., 2016).

3.3.4. Hygrothermal behavior

According to Gle et al., the use of hempcrete can regulate indoor temperature, reduce the need for heating and cooling systems, and contribute to greater insulation capacity while maintaining air quality. This is due to the porosity of hempcrete, which allows for the transfer of vapor in the air. The phenomenon occurs during times of high humidity, allowing the vapor to condense back into a liquid state and come to the surface of pores. This process can also be reversed during times of low humidity, acting as a natural humidifier. As the physical states of water alternate between liquid and vapor, they modify the specific heat and thermal conductivity of hempcrete (Gle et al., 2013).

3.3.5. The Environmental Benefits of Using Hempcrete

Hempcrete presents itself as a sustainable building material, boasting a variety of eco-friendly advantages. A noteworthy attribute is its recyclability; waste generated during the construction process can be utilized as a mulch or incorporated into new mixes with additional high-build binder, thereby reducing waste and conserving energy and resources that would otherwise be necessary to manufacture new materials. The hygroscopic nature of hempcrete is conducive to energy conservation in buildings, as it stabilizes the relative humidity and temperature for extended periods. This property contributes to the thermally efficient nature of hempcrete structures, resulting in reduced reliance on artificial heating and cooling systems, thus promoting lower energy costs and decreased carbon emissions (Updike & Felker, 2016; Bevan, 2008).

Additionally, hempcrete acts as a CO₂ sink, as its composition consists of 80-90% shiv, which has the capacity to absorb a significant amount of CO₂ from the environment. Research indicates that each tone of hempcrete can absorb roughly 249 kg of CO₂ over its 100-year lifespan, representing an effective means of mitigating greenhouse gas emissions (Updike & Felker, 2016). Hempcrete's low protein content deters insects and moths, thereby decreasing the necessity for harmful pesticides that can adversely impact the environment and human health. Considering these eco-friendly features, hempcrete is a highly viable option for sustainable construction projects (Bevan, 2008; Bombay Hemp Company, 2014).

3.4. Exploring the Potential of Hempcrete as a Building Material

Hempcrete possesses a range of applications in construction, including as a material for constructing walls, floors, and roofs. Monolithic, sprayed, or precast methods can be used for constructing hempcrete structures, such as hemp bricks or panels. In the case of timber frame infills, hempcrete can be poured between two formwork plates using removable plastic casing. The infill must achieve a density of 400 kg/m^3 and a thermal conductivity of $0,1 \text{ W/mK}$ at $0\% \text{ RH}$, with each layer leveled when the mold is placed around 20 cm in thickness for each addition (Lanos et al., 2013, Madhura & Ayushi, 2022).

Hempcrete is also suitable for roof insulation applications with a density of $200\text{--}250 \text{ kg/m}^3$ [$\lambda=0,06 \text{ W/mK}$] at $0\% \text{ RH}$, and for floor applications where the density increases to 500 kg/m^3 [$\lambda=0,12 \text{ W/mK}$ at $0\% \text{ RH}$]. For wall and roofing applications, the minimum compressive strength should be greater than $0,2 \text{ MPa}$ and $0,05 \text{ MPa}$, respectively, with an elastic modulus greater than 15 MPa for walls, 3 MPa for roofing applications, and 20 MPa for flooring (Lanos et al., 2013, Madhura & Ayushi, 2022).

Table 1

Comparison between hempcrete and conventional brick [BKS 38] (Gle et al., 2013; Abbot, 2014; Labaran et al., 2021; Leier, 2021)

Properties	Hempcrete	Conventional brick [BKS 38]
<i>Density</i>	<i>240 [kg/m³]</i>	<i>700 [kg/m³]</i>
<i>Thermal conductivity</i>	<i>$\lambda = 0,065 \text{ [W/mK]}$</i>	<i>$\lambda = 0,163 \text{ [W/mK]}$</i>
<i>Construction cost</i>	<i>Low</i>	<i>More than hempcrete</i>
<i>Pest</i>	<i>Pest proof</i>	<i>Pest proof</i>
<i>Workability</i>	<i>Easy and fast</i>	<i>Experience required</i>
<i>Fire resistant</i>	<i>Fireproof due to lime</i>	<i>Externally fireproof</i>
<i>Embodied energy</i>	<i>Low EE</i>	<i>High EE</i>
<i>Carbon footprint</i>	<i>Absorbs CO₂</i>	<i>246 kg CO₂e/m²</i>
<i>Damp and rot</i>	<i>Rot - resistant</i>	<i>Damp - proof</i>
<i>Recycling</i>	<i>Fully recycled</i>	<i>Recycled with high costs</i>

Mix design is a crucial process for ensuring the correct ratio between fluid phases, air and water, and solid phases, such as hemp shiv and binder. For instance, a typical mix design for a wall application would require 100 l of hemp shiv, 22 kg of air lime pre-formulated binder (Tradical PF70 lime), and 30 to 35 kg of water. However, further research on the type of binder that can affect the performance of the material is necessary (Lanos et al., 2013, Madhura & Ayushi, 2022).

Hempcrete structures that have been exposed to outdoor environments for more than two years have shown no signs of mold growth or deterioration.

Therefore, to ensure longevity and climate resistance, it is recommended to use lime render for the external finish. Services can be easily installed by attaching them to the framing or through the frames, and it is advisable to set all services and windows at the roughing stage for ease of construction (Lanos *et al.*, 2013, Madhura & Ayushi, 2022).

3.4.1. Hempcrete implemented in wall construction

Hempcrete, despite its eco-friendly nature, has a poor structural performance, and thus requires a structural wooden frame for support in load-bearing construction. The construction process typically involves building a plinth with a foundation and a damp proof course (D.P.C.) at the base of the wall, followed by the design and construction of a structural frame on the plinth. The frame is usually constructed using simple stud work with a stud, floorplate, and wall plate (Madhura & Ayushi, 2022).



Fig. 4 – Softwood frame centrally embedded within the wall (Stanwix & Sparrow, 2016).

The frame can be cast in various ways, such as central, exposed, or double frames, either internally or externally. A central frame type (Figure 4) is used when the structural timbers are free from moisture and insect attack, providing a stable structural support system as the weight of the hempcrete is evenly distributed around the frames (Updike & Felker, 2016).



Fig. 5 – The internal exposed frame for permanent shuttering, featuring horizontal rails (Zuo, 2021).

In the case of an exposed frame (Figure 5), the structural frame is usually flush with either the external or internal face of the wall, and additional horizontal rails are added to provide good lateral resistance to the hempcrete wall as the weight of the hempcrete is not evenly distributed. These additional horizontal rails are typically fixed to the stud that faces the interior side of the wall and cover the whole length of it at 600 mm vertical centers (Zuo, 2021; Updike & Felker, 2016).

A double frame type is typically used when both internal and external cladding are permanent. It consists of an exposed frame flush with an internal face that acts as a structural frame on which permanent shuttering is constructed, along with a non-load bearing frame flush that contains an external face, which provides a fix for cladding (Stanwix & Sparrow, 2014; Zuo, 2021).

3.4.2. Pre-fabricated Hempcrete Panels

Prefabricated hempcrete panels are typically utilized in large-scale commercial and residential construction, particularly in areas where oak wood is readily available. These panels consist of a timber framework, an integrated insulation layer, and a breathable vapor control layer. They are manufactured off-site, typically dried prior to delivery to the construction site, and can be customized to meet specific U-value requirements. The panels undergo air-drying through forced air circulation during the manufacturing process, resulting in significant time savings during construction (Lanos et al., 2013; Stanwix & Sparrow, 2016).

3.4.3. Hempcrete-based blocks

Hempcrete blocks offer ease of use and are easily customizable with a hand saw to fit within a structural frame. The primary advantage of using hempcrete blocks lies in their ability to expedite construction processes while minimizing site waste. However, due to their limited compressive strength, these blocks cannot withstand the load of a roof or upper structure independently and require additional support.

Hempcrete blocks (Figure 6) are suitable for internal wall construction or where superior acoustic performance is a priority, given their higher density than other comparable materials. Despite their advantages, hempcrete blocks have certain drawbacks, such as their high cost compared to conventional materials such as concrete or burnt bricks, and potentially higher embodied energy. Consequently, cast-in-situ methods are favored when utilizing hempcrete as a building material (Madhura & Ayushi, 2022).



Fig. 6 – Hempcrete blocks (Evo hemp, 2022).

3.4.4. Application of Hempcrete in Flooring

Hempcrete exhibits insulating properties that make it a suitable material for flooring applications (Figure 7). Its eco-friendliness, sustainability, cost-effectiveness, and energy-saving attributes have made it increasingly popular in construction projects. Unlike traditional concrete floors, hempcrete flooring requires less depth due to its insulation capabilities. The main structural layer and subbase comprise insulating materials, leading to reduced excavation requirements (Madhura & Ayushi, 2022).



Fig. 7 – Hempcrete walls and flooring (Madhura & Ayushi, 2022).

3.4.5. Applications of Hempcrete in Roofing

Hempcrete is a suitable construction material for roofing applications (Figure 8), particularly in areas where a one-inch breathable space can be maintained between the sheeting material and the top side of hempcrete. The sheeting material used can be either plywood or hemp board. Hempcrete roofs have numerous benefits, such as being highly durable, capable of withstanding harsh weather conditions without requiring a layer of stucco finish or plaster, energy-efficient, cost-effective, and resistant to fire. It is essential to ensure that the thickness of the hempcrete is nearly equal to the depth of rafters and not excessive, as it may result in issues such as an increase in roof height and additional weight on the original structure.



Fig. 8 – Hempcrete roofing (Tradical, 2017).

In the experiments conducted at the Faculty of Civil Engineering and Building Services from the “Gheorghe Asachi” Technical University of Iași, various ways of using hemp concrete were analyzed, as well as the specific

parameters of the material for its application in the construction field. Among these studies, notable experiments include the technology of making hemp concrete, the technology of executing walls in the formwork casting version or in the prefabricated version of masonry blocks, as well as studies conducted on the resulting materials to determine their characteristics as materials usable in the resistance structure or as thermal insulation materials (Adam & Isopescu, 2022). These characteristics include density, mechanical resistance to various stresses, (mainly compression and bending stresses), thermal conductivity coefficient and thermal capacity.

In addition, a series of studies have been conducted on the possibilities of using hemp concrete in construction, which represents a viable solution for improving the ecological performance of the built environment, reducing resource consumption and increasing energy efficiency. Through this research, an innovative solution was proposed for the use of hemp chips in the production of lightweight concrete, in combination with perlite (Adam *et al.*, 2023), the resulting hemp concrete being an efficient solution, both mechanically and thermally.

Other significant studies have focused on the use of hemp concrete for the production of floors (Adam *et al.*, 2023). The studies conducted have led to the following conclusions regarding the advantages of using hemp concrete:

- reducing the weight of structural elements and implicitly of the construction as a whole;
- reducing the amount of cement used with positive influences on environmental protection, resulting from the lower emissions of CO₂ into the atmosphere;
- improving thermal and sound insulation, contributing to the thermal efficiency of buildings and increasing the overall level of human comfort.

3.5. Disadvantages in using hempcrete as a building material

3.5.1. Limitations in mechanical properties

One of the main drawbacks of hempcrete is its poor mechanical performance (Figure 9), making it unsuitable for load-bearing construction. Arnaud and Gourlay have reported that hempcrete's high porosity results in poor adhesion to the lime binder, leading to elastic-like behavior. However, this material can be useful in situations such as earthquakes, where its ability to bend without cracking can be advantageous (Arnaud & Gourlay, 2012). To address this issue, Lu and Korman conducted a study that showed that a composite consisting of 40% hemp fiber and 60% recycled high-density polyethylene (rHDPE) volume resulted in an ultimate tensile strength of 60.2 MPa. This suggests that incorporating other materials into hempcrete could

enhance its mechanical properties and make it suitable for a wider range of construction applications (Lu & Korman, 2013; Bourdot et al., 2017).

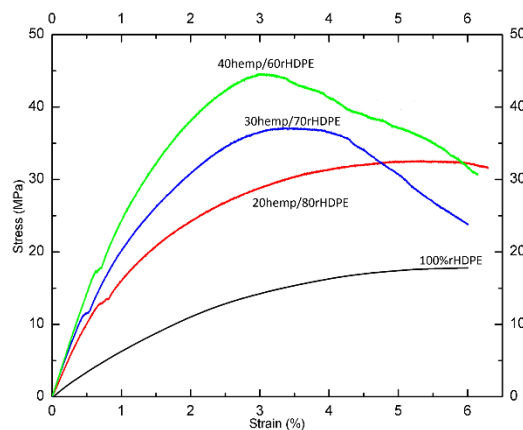


Fig. 9 – Flexural stress of hemp/rHDPE composite and pure rHDPE (Lu & Korman, 2013).

3.5.2. Capacity of Hempcrete to Retain Water

Hempcrete has a notable water retention capacity and can absorb a significant amount of water, up to 300-400 times its weight. Inadequate ventilation during the absorption process can lead to several issues, such as bio-decay, freezing and thawing, and salt crystal formation, which can reduce the material's durability. Researchers such as Arizzi et al. (2015) have found that the type of lime binder used can also affect the drying rate of hempcrete. The use of natural hydraulic lime (NHL3.5) as a binder can enable better vapor exchange with the surrounding air, which, in turn, decreases the amount of water absorbed by hempcrete when immersed. This binder reduces the tendency of bio-decay in comparison to aerated limes, thereby improving the durability of hempcrete (Arizzi et al., 2015; Zuo, 2021).

4. Discussion

Hemp concrete is a sustainable building material that offers many opportunities for the built environment due to its thermal insulation efficiency, its CO₂ absorption property and its resistance to fire and phytopathogenic agents.

Research conducted by the team from the Faculty of Civil Engineering and Building Services from the “Gheorghe Asachi” Technical University of Iași has shown that, for eco-sustainable hemp concrete, density can be considered a determining factor in achieving the desired values for its characteristic

properties: mechanical resistance values are in a proportional relationship with density values, while thermal resistance values are in an inversely proportional relationship with density values. The treatment of hemp fibers and the type of product used for this process can influence the properties of eco-sustainable concrete. The study demonstrated that the use of pre-treatment with sodium hydroxide improves the compressive strength of the compositions (Adam et al., 2022, 2023).

Life cycle analyses for hemp concrete were also conducted, confirming the advantages of using hemp-based eco-concrete to achieve climate neutrality. The analyses contributed to understanding the impact of using this renewable resource in terms of global warming potential as CO₂ input from fossil sources, biogenic sources or land transformation and occupation.

Despite the advantages of hempcrete, it has some major drawbacks. Firstly, it is not readily available in the market or in every possible area like other contemporary building materials such as concrete or steel. Secondly, it requires skillful labor to work with hempcrete and frame structure. Finally, it requires regular maintenance and repairs. Nevertheless, hempcrete remains a great material concerning sustainability and outperforms traditional materials in some parameters, making it an intriguing option for civil engineers and builders.

5. Conclusions

In recent years, conventional building materials like concrete and steel have been associated with environmental problems such as global warming, urban heat island effect, and climate change. Therefore, it is advisable to consider sustainable materials such as hemp in construction. Hempcrete is a lightweight, high-density plant-based biomaterial that can be grown in smaller site areas with minimal pesticide requirements. It is fire-resistant, robust, recyclable, energy-efficient, non-toxic, and insect-resistant. Hempcrete can be used in constructing walls, floors, and roofs, and is available in the form of blocks and panels that reduce construction time and costs. It is typically used in large-scale commercial and public buildings.

Minimizing the carbon footprint that the production of hemp concrete building materials can generate is achieved in two ways: directly by optimizing the consumption of resources highlighted when designing hemp concrete performances based on knowing the influence of the composition on variations in the thermal conductivity coefficient and compressive strength; and indirectly by reducing pollution during the transportation of materials, by adopting a circular economy model in which the production chain can be carried out locally.

Despite its many advantages, hempcrete has some drawbacks, including poor mechanical performance that renders it unsuitable for load-bearing construction and a high capacity to absorb and retain water that decreases its

durability. Therefore, further research is needed to understand the mechanical and chemical properties of hempcrete.

Acknowledgements. This paper was realized with the support of project EFECON – Eco-innovative products and technologies for energy efficiency in construction, POC/71/1/4 - Knowledge Transfer Partnership, Cod MySMIS: 105524, ID: P_40_295, Project co-financed by the European Regional Development Fund.

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ANALIZĂ DE ANSAMBLU A AVANTAJELOR ȘI DEZAVANTAJELOR UTILIZĂRII HEMPCRETE-ULUI CA MATERIAL DE CONSTRUCȚIE

În industria construcțiilor se constată o contribuție semnificativă la consumul global de energie și emisiile de gaze cu efect de seră. Prin urmare, utilizarea materialelor de construcție durabile este esențială. Hempcrete a fost recunoscut ca un material ecologic care reduce pierderile și minimizează utilizarea resurselor naturale și a energiei. Deși are mai multe beneficii, inclusiv proprietăți structurale bune, structura sa poroasă limitează performanța mecanică și retenția de apă, ceea ce reduce aplicabilitatea sa ca material de construcție. Cu toate acestea, acesta poate fi utilizat în proiecte de construcție unde limitările sale nu sunt un obstacol. Chiar dacă cânepa nu oferă o

rezistență structurală la fel de mare precum s-a crezut anterior, aceasta prezintă proprietăți similare cu cele ale fibrei de sticlă. Acest articol oferă o perspectivă asupra oportunităților și provocărilor asociate cu utilizarea de hempcrete ca material de construcție, bazat pe surse secundare. De asemenea, articolul identifică domeniile de cercetare în ale hempcrete care necesită investigații suplimentare pentru a extinde utilizarea sa în construcții.