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PAIHE  
Stakeholder Engagement Initiative

# Use of Hemp for Building Construction

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# Objective and Outline

- Hemp-based construction materials
- Makeup of hempcrete (ingredients)
- Methods of applying hempcrete (CIP, Spray, Precast/Block)
- Attributes and properties of hempcrete
- Testing related to PA Hemp House
- Hempcrete research to improve mechanical and structural properties & new applications



# What is Industrial Hemp?

## Hemp Plant



- **Hemp is an industrial variant of cannabis that is grown mainly for its fiber, hurd, and seeds.**
- **The growth rate of hemp is fast (about four months)**
- **Does not need much fertilizer or pesticides for growth**
- **The crop can be highly profitable for farmers, IF there are buyers.**



<https://civileats.com/2019/10/21/for-young-farmers-hemp-is-a-gateway-crop/>

<https://kansaslivingmagazine.com/articles/2021/11/17/growing-hemp-in-kansas>

# Materials Made from Hemp Fiber: Rope, Textile, Rugs



<https://mas-service.ro/comments/feed/?s=natural-hemp-rope-the-twisted-monk-mm-xVw5OQSB>

<https://www.amazon.com/Natural-Sporting-Landscaping-Nautical-Gardening/dp/B07KZVZ9QG?th=1>

<https://www.greenmatters.com/p/hemp-fabric-advantages-disadvantages>

<https://www.amazon.co.uk/ZXHKZDX-Decoration-Partition-Ceiling-Outdoor/dp/B0C2Q6P7NY>

<https://fabriclore.com/blogs/fabric-wiki/information-about-hemp-fabric>

# Rugs Made Using Hemp Fiber



<https://tumbleweedanddandelion.com/products/jute-woven-natural-rug>

<https://plushrugs.com/blog/is-hemp-a-good-rug-material/>

# Hemp Insulation Made Using Hemp Fibers



<https://mymaterialwarehouse.com/products/hemp-insulation-hempwool-r20-for-2x6-studs-256-sqft>

<https://www.hempbenchmarks.com/hemp-market-insider/hemp-insulation-for-housing/>

# Roofing Cover Made of Hemp: Shingles, and Tiles

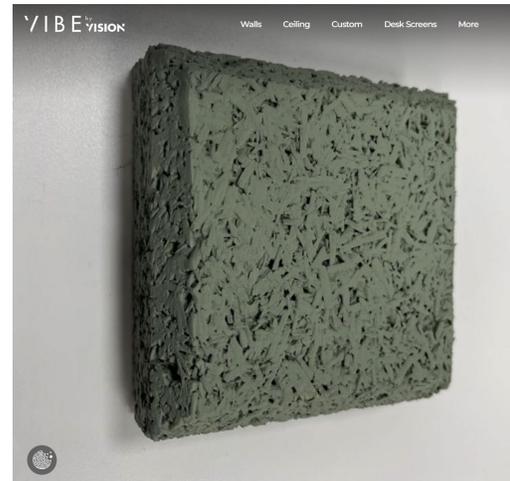
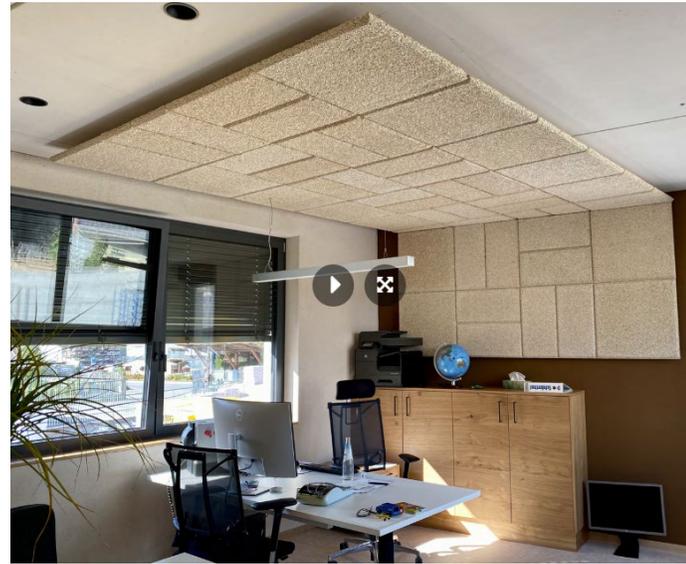


<https://www.suretyshingles.com/>



<https://hemp-green.trusted-roofing.com/roof-tiles.php>

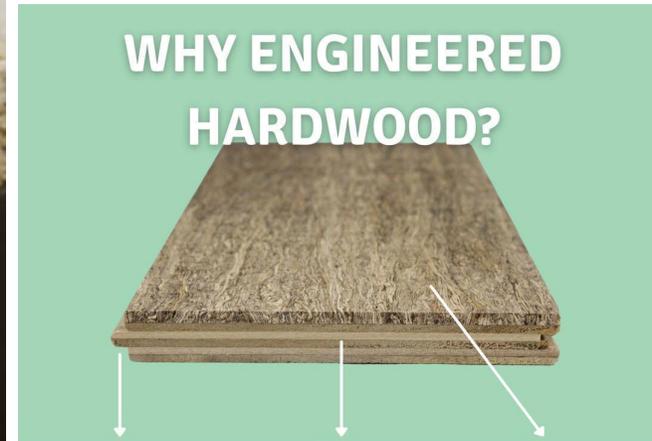
# Hemp Wall Boards, Ceiling Boards



<https://vibebyvision.com/walls/hemp/>

<https://theexplodedview.com/materialbb/hemp-panels/>

# Particleboard and Hardwood Made of Hemp Fibers/Hurd:



<https://hempgazette.com/industrial-hemp/building-construction-hemp/>

<https://hempwood.com/hemp-building-materials/>

# Hemp Fiberboard



<https://bulkhempwarehouse.com/mdf-hemp-fiber-board-sample/>

[https://biofreear.live/product\\_details/112592652.html](https://biofreear.live/product_details/112592652.html)

<https://bulkhempwarehouse.com/hemp-board-10-things-you-need-to-know-today/>

# Hempcrete Blocks

## **HEMPCRETE**

**HEMP + LIME + WATER  
CARBON NEGATIVE MATERIAL  
DESIGNED TO BUILD**

Non-Toxic

Energy  
Efficient



Incredible  
Insulation

Flame, Water  
& Pest Resistant

Lasts  
Hundreds  
of Years

Strong,  
Lightweight +  
Breathable

# Carbon-negative Construction Material

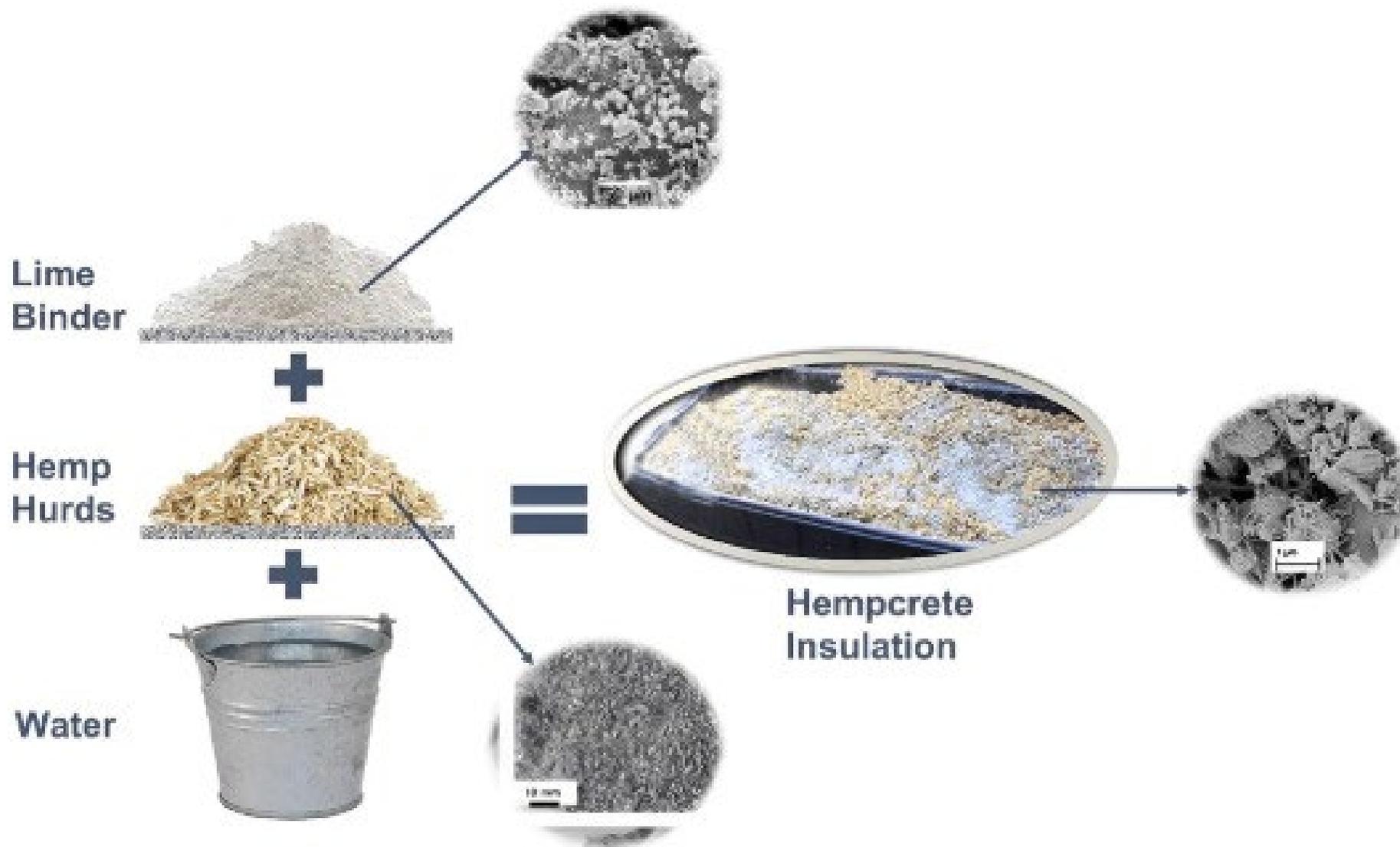


## Hempcrete



- **Hempcrete is a composite material comprising industrial hemp hurd, optionally some fiber, lime-based binder, and water.**
- **Hempcrete can offer numerous environmental benefits.**
- **The carbon-negative aspect of hempcrete stems from the carbon sequestration that transpires during the growth of hemp plants.**

# Raw Materials to Hempcrete Insulation



# Commercially Available Material



Hemp Hurd (Hemp: <https://chanvra.org/pages/hemp-construction-materials-hempcrete>; A bulk sample of Kanabat Building Grade Hemp Hurd that can be used as alternative aggregate of hempcrete.

Lime used for making hempcrete Lime:  
<https://www.lcgfrance.com/mortiers-et-enduits-isolants/>;  
<https://chanvra.org/pages/hemp-construction-materials-hempcrete>

# Carbon-negative Construction Material



# Three Methods to Apply Hempcrete

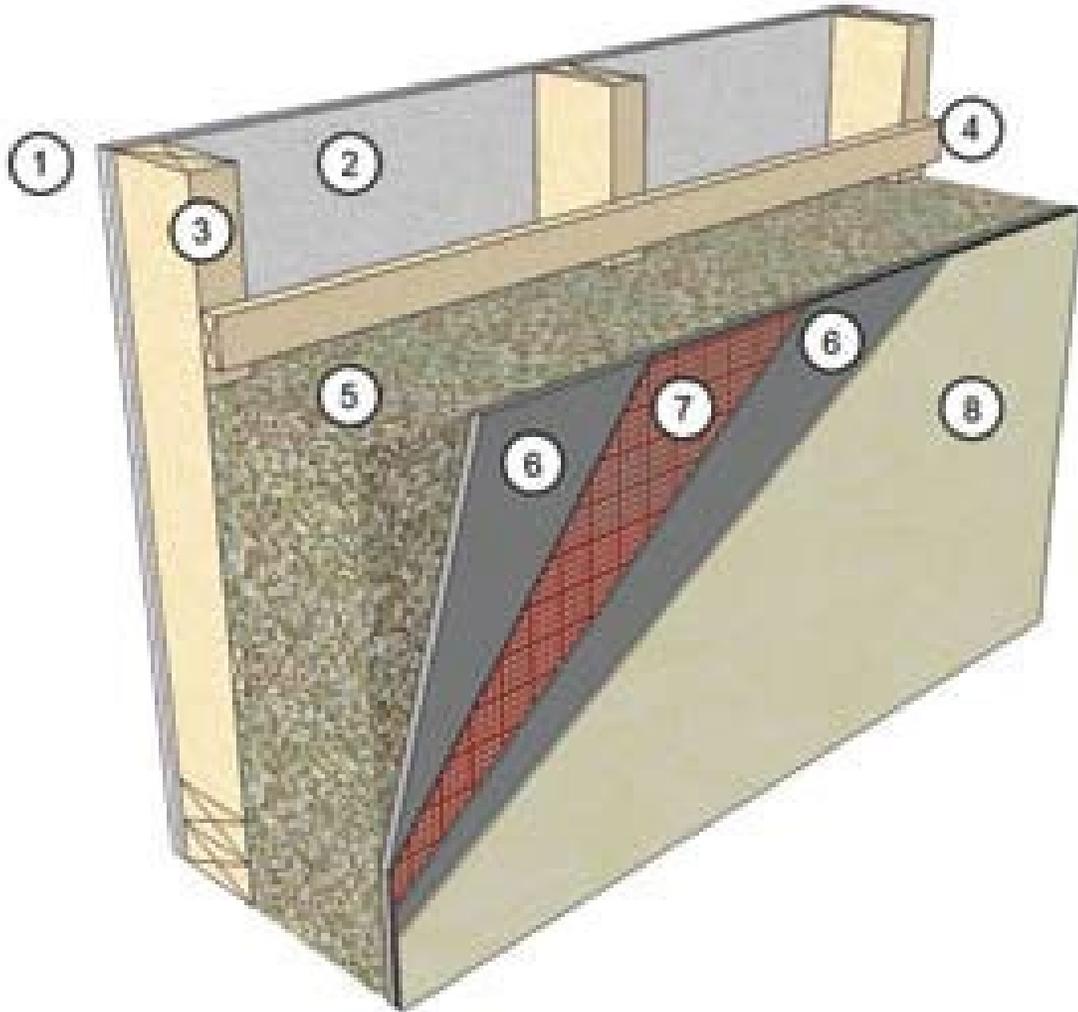


Example cast in place hempcrete wall confining studs (Courtesy of American Lime Technology <http://www.americanlimetechnology.com/tradical-hemcrete/>, and Right, Flahiff 2009: <https://inhabitat.com/hemcrete-carbon-negative-hemp-walls-7x-stronger-than-concrete/> ).

Example spraying hempcrete between studs (<http://rjinsulation.com/nu-wool-premium-cellulose-insulation/>).

Typical example precast Hempcrete Block Building Construction (Courtesy of Wikipedia: <https://en.wikipedia.org/wiki/Hempcrete>; <https://www.iso hemp.com/en/hemp-blocks-buildings-hempro-system>).

# Wall System Detail with Hempcrete Rigid Insulation



- 1) Plaster skim coating**
- 2) Board that includes lime**
- 3) Wood studs**
- 4) Horizontal batten to tie hempcrete insulation to studs**
- 5) Hempcrete insulation**
- 6) Basecoat render**
- 7) Mesh for basecoat**
- 8) Top coat render**

## Cast-In-Place Hempcrete

- ❖ In this method, hempcrete is mixed on-site and poured into formwork to create the walls.
- ❖ It's a versatile method suitable for various wall thicknesses and shapes.
- ❖ It allows for customization and can be used in both load-bearing and non-load-bearing applications.



## Spraying Hempcrete

- ❖ **Spraying hempcrete requires the use of industrial spraying equipment to build a hempcrete wall where the hempcrete is pumped from a mortar mixer through a hose and a spraying nozzle, saving time when compared to hand-packed hempcrete.**



## Precast Hempcrete Block Construction

- ❖ **Hempcrete blocks are pre-made blocks of compressed hempcrete.**
- ❖ **These blocks can be stacked and mortared together to form walls, similar to traditional concrete blocks.**
- ❖ **Hempcrete blocks are convenient and can speed up construction.**



## Hempcrete Panel Systems

- ❖ **Hempcrete panels are pre-fabricated panels made of hempcrete.**
- ❖ **These panels can be used as a complete wall system or as cladding for existing structures.**
- ❖ **They are often used in rapid construction methods.**



## Light Straw-Clay and Hempcrete Hybrid Walls

- ❖ In some cases, hempcrete is combined with light straw-clay construction methods to create hybrid walls.
- ❖ These walls may incorporate straw for additional insulation and structural stability.

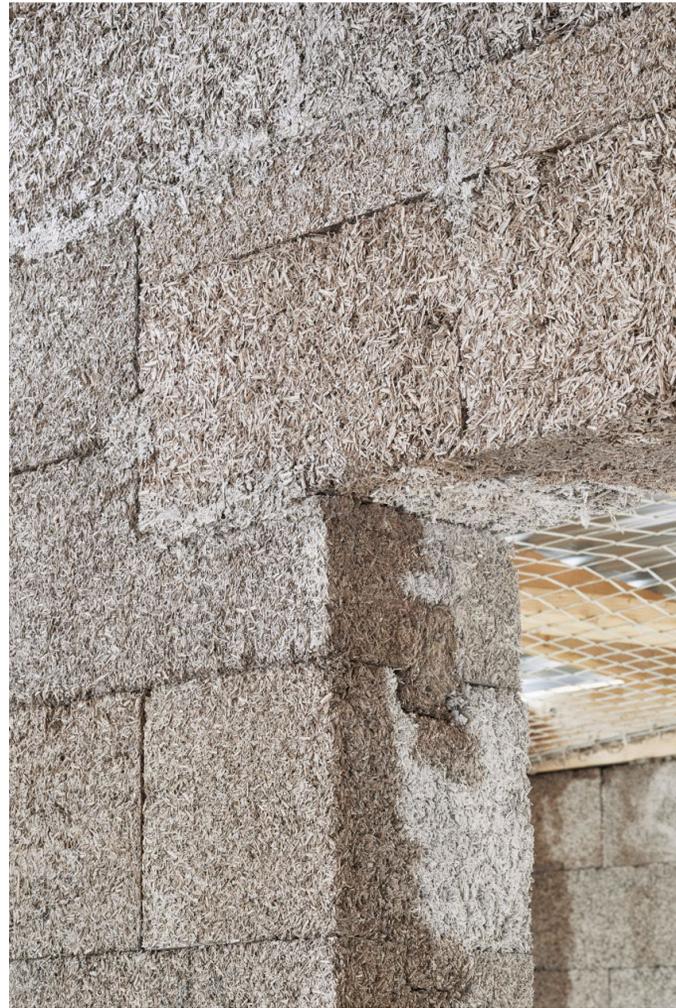


## Reinforced Hempcrete Walls

- ❖ **For load-bearing applications or seismic zones, hempcrete wall can have concrete core reinforced with materials like bamboo, rebar, or metal mesh.**
- ❖ **Reinforcement enhances the structural integrity of the walls.**

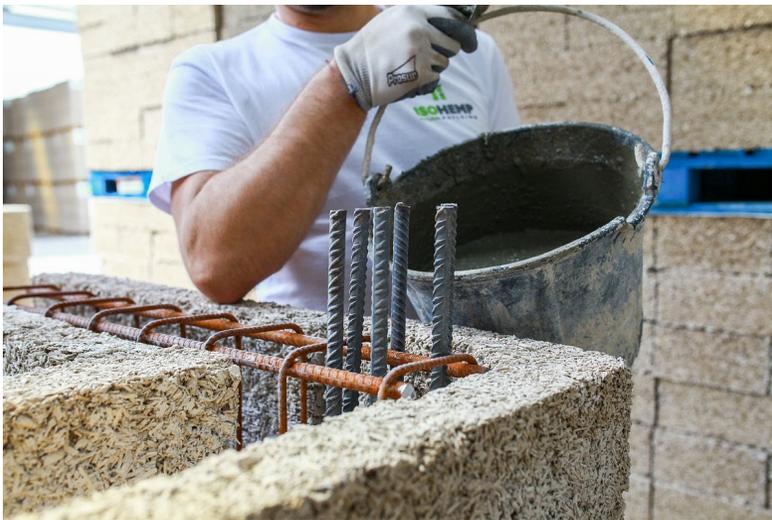


# Hempcrete Block Construction



<https://www.dezeen.com/2021/08/01/hempcrete-pierre-chevet-sports-hall-lemoal-lemoal/>

# Hempcrete Block Construction



# Hemp Block Construction

Multi-story buildings using hempcrete: 12-story building (84 Harrington in Cape Town, South Africa) – tallest in the world; these walls are infill wall, frames take the load.



<https://app.2050-materials.com/product/details>



# Hempcrete Floor System



<https://ozhemp.com.au/fields-of-application/>

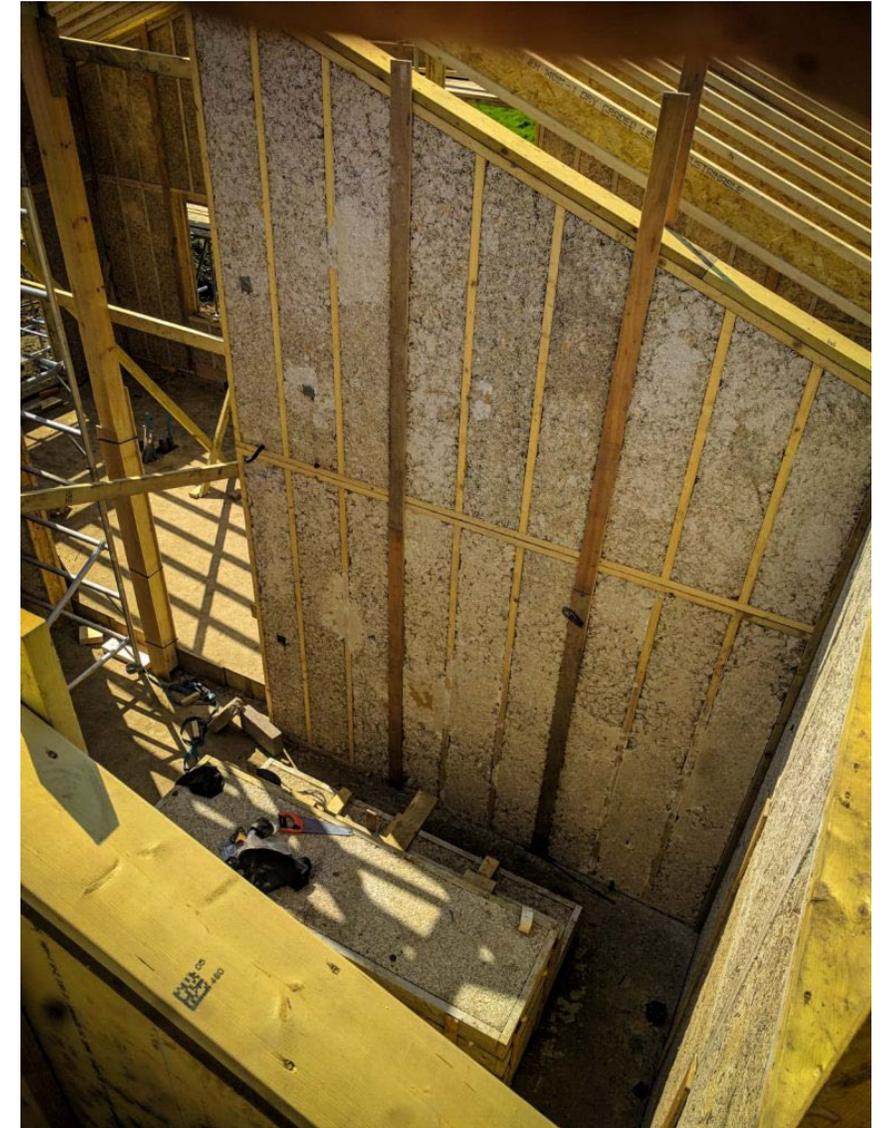
# Hempcrete Roofs



<https://www.fr.weber/en/hempcrete-insulating-roofs>

<https://ozhemp.com.au/fields-of-application/>

# Panelized Systems:



<https://citychangers.org/hemp-fact-file/>

# Why Hempcrete? Attributes of Hempcrete

\* Carbon-negative

\* High insulation

\* Breathable

\* Energy efficient



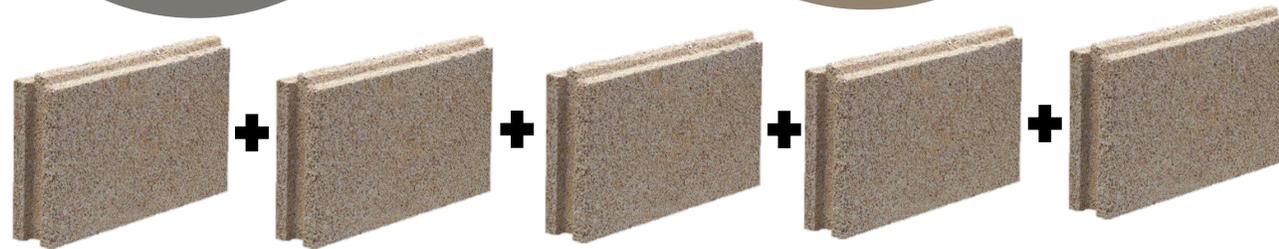
**When 1 Concrete Wall  
Emits 1500 kg CO<sub>2</sub>**



**1500 kg CO<sub>2</sub>  
Emitted  
Per 1 m<sup>3</sup> of  
Portland  
Cement**

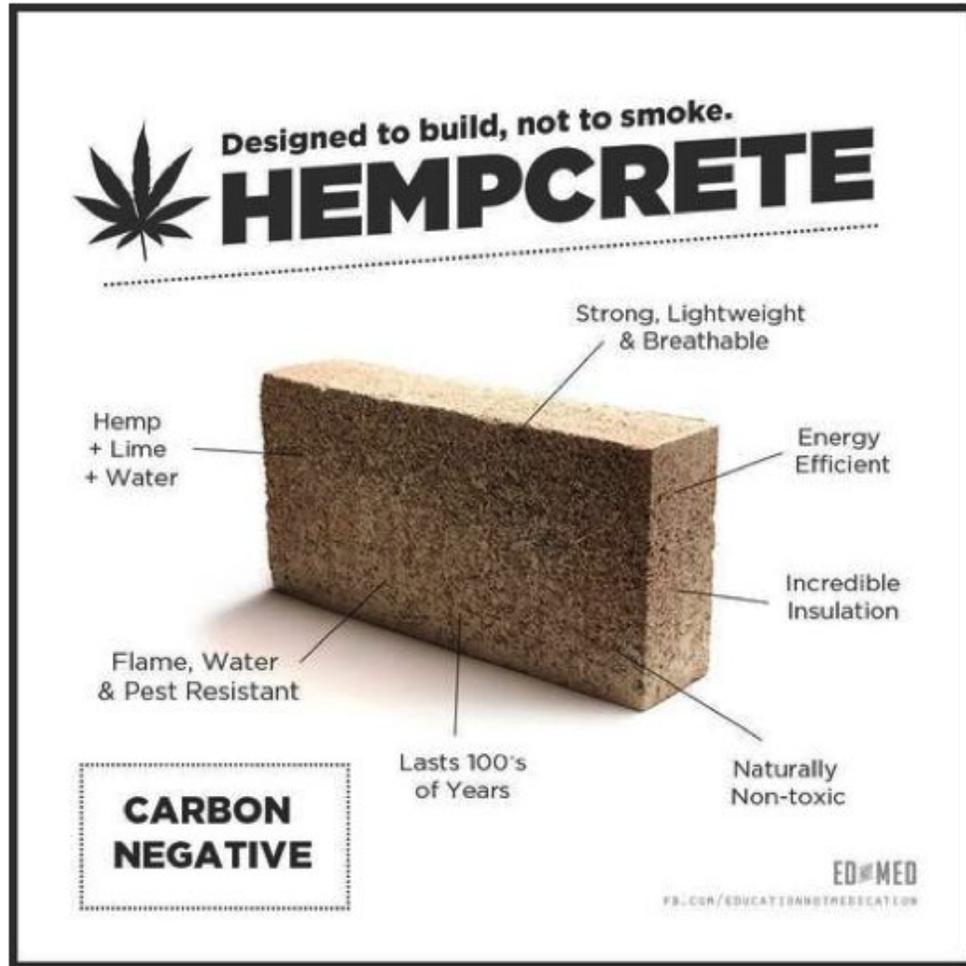


**300 kg CO<sub>2</sub>  
Absorbed  
Per 1 m<sup>3</sup> of  
Hempcrete**



**5 Hempcrete Walls  
Absorb 1500 kg CO<sub>2</sub>**

# Advantage of Industrial Hemp



1. Sustainability
2. Low Environmental Impact
3. Carbon Sequestration
4. High Tensile Strength
5. Lightweight
6. Thermal Insulation
7. Fire Resistance
8. Moisture Regulation
9. Biodegradability
10. Versatility
11. Reduced Energy Consumption
12. Healthier Indoor Air Quality
13. Regulatory Advancements

# PA Hemp House



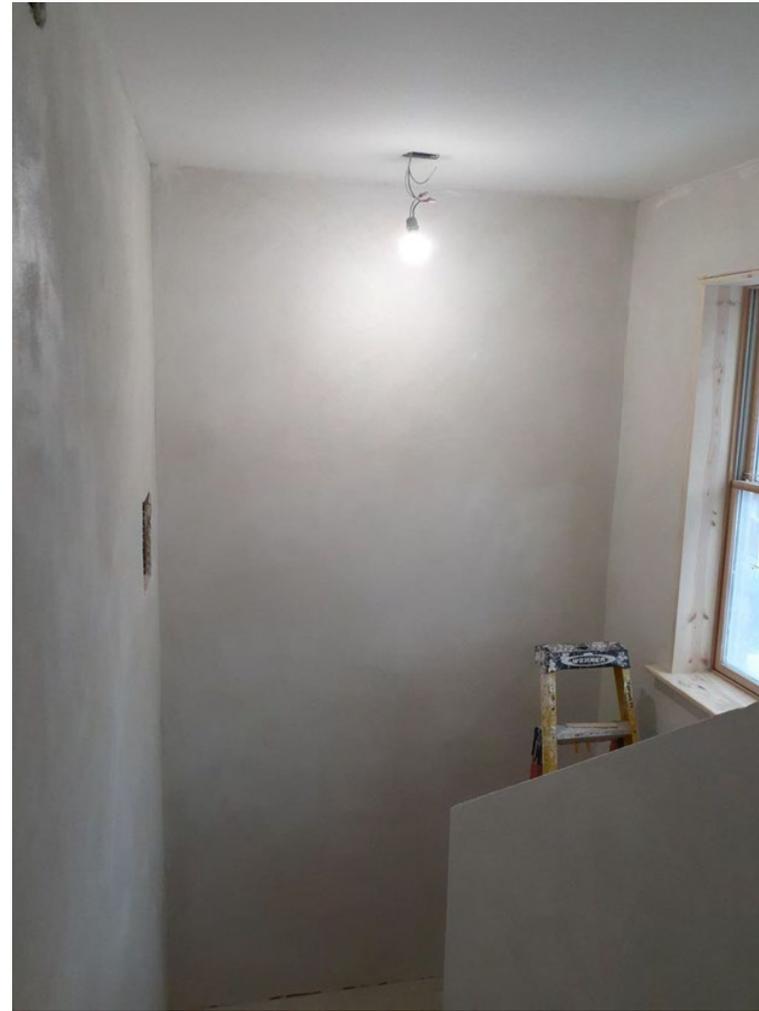
House (on the right) located at 506 Spruce Street New Castle, PA before retrofit, ([https://www.zillow.com/homedetails/506-Spruce-St-New-Castle-PA-16101/86510118\\_zpid/](https://www.zillow.com/homedetails/506-Spruce-St-New-Castle-PA-16101/86510118_zpid/)).



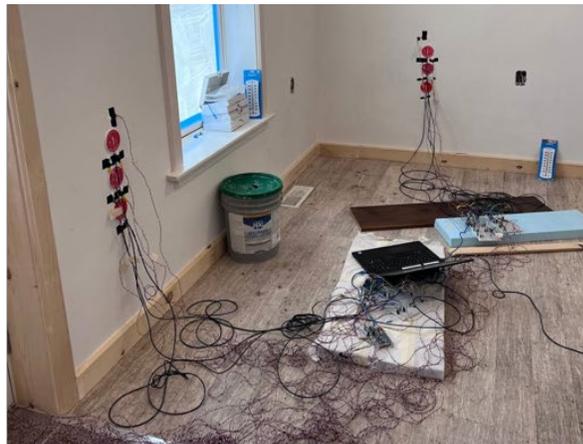
# Hempcrete House Construction



# Hempcrete House Construction



# Hempcrete House Thermal Measurement Study

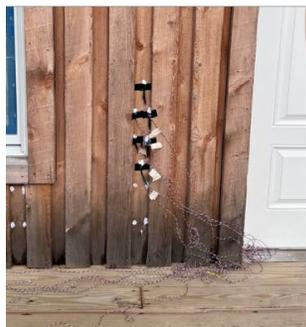
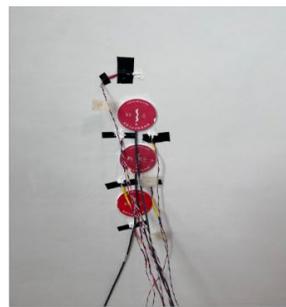
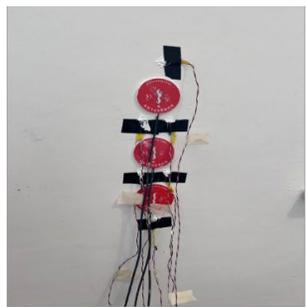


$$q_i = \frac{1}{R} (T_{i, surf, int} - T_{i, surf, ext}) + \sum_{l=1}^p A_l (T_{i-p+l, surf, int} - T_{i-p+l-1, surf, int}) + \sum_{l=1}^p B_l (T_{i-p+l, surf, ext} - T_{i-p+l-1, surf, ext})$$

R-value
Interior temperature

Exterior temperature
➔
R-value

Data from heat flux sensors
Multiple regression Using MATLAB



sensors	H1	H1	H3	Ave.	Total R-value
Sidewall	15.4	16.2	15.7	15.8	16.93
	4	2	3		
Backwall	19.3	18.2	16.5	18.0	
	8	9	3	7	

# Hemp House Test -- Conclusions

- Measured R-value for the whole wall consisting of (interior to exterior)  $\frac{3}{4}$  in. hemp rich plaster, 10 in. thick hempcrete,  $\frac{1}{2}$  in. air space, and  $\frac{1}{2}$  in. thick rough sawn hemlock board siding : **approximately R-17.**
- The BEopt energy modeling results showed an **approximately 75% reduction in total site energy usage** between the pre- and post-retrofit home energy models.
- Despite high outdoor humidity levels during hot summer weeks, the indoor **relative humidity was always less than 60%.**

# Compressive Strength of Hempcrete



- **The average compressive strength for hempcrete can be 0.97 MPa (140 psi) for a 45-day sample and 1.11 MPa (160 psi) for a 60-day sample**
- **Compare with Concrete 20.7 MPa (3000 psi)**

# Tensile Strength of Hempcrete

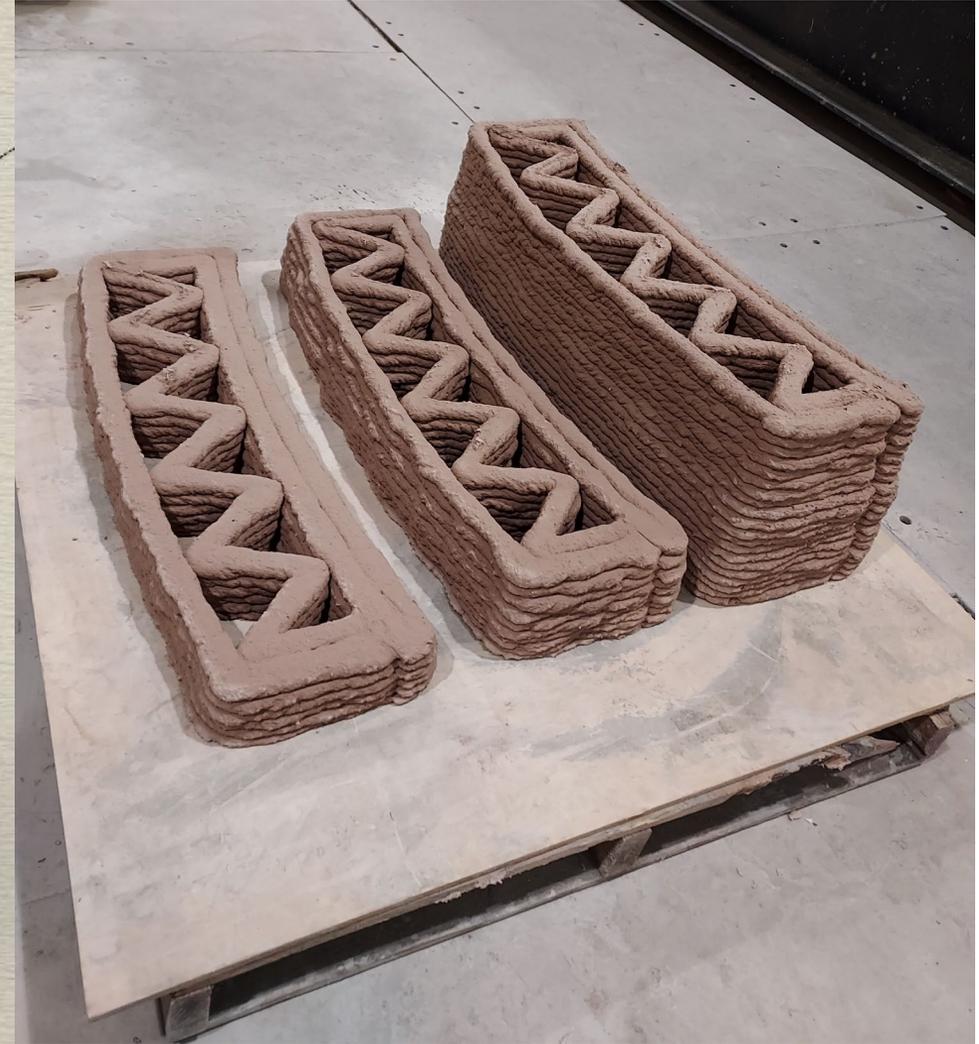
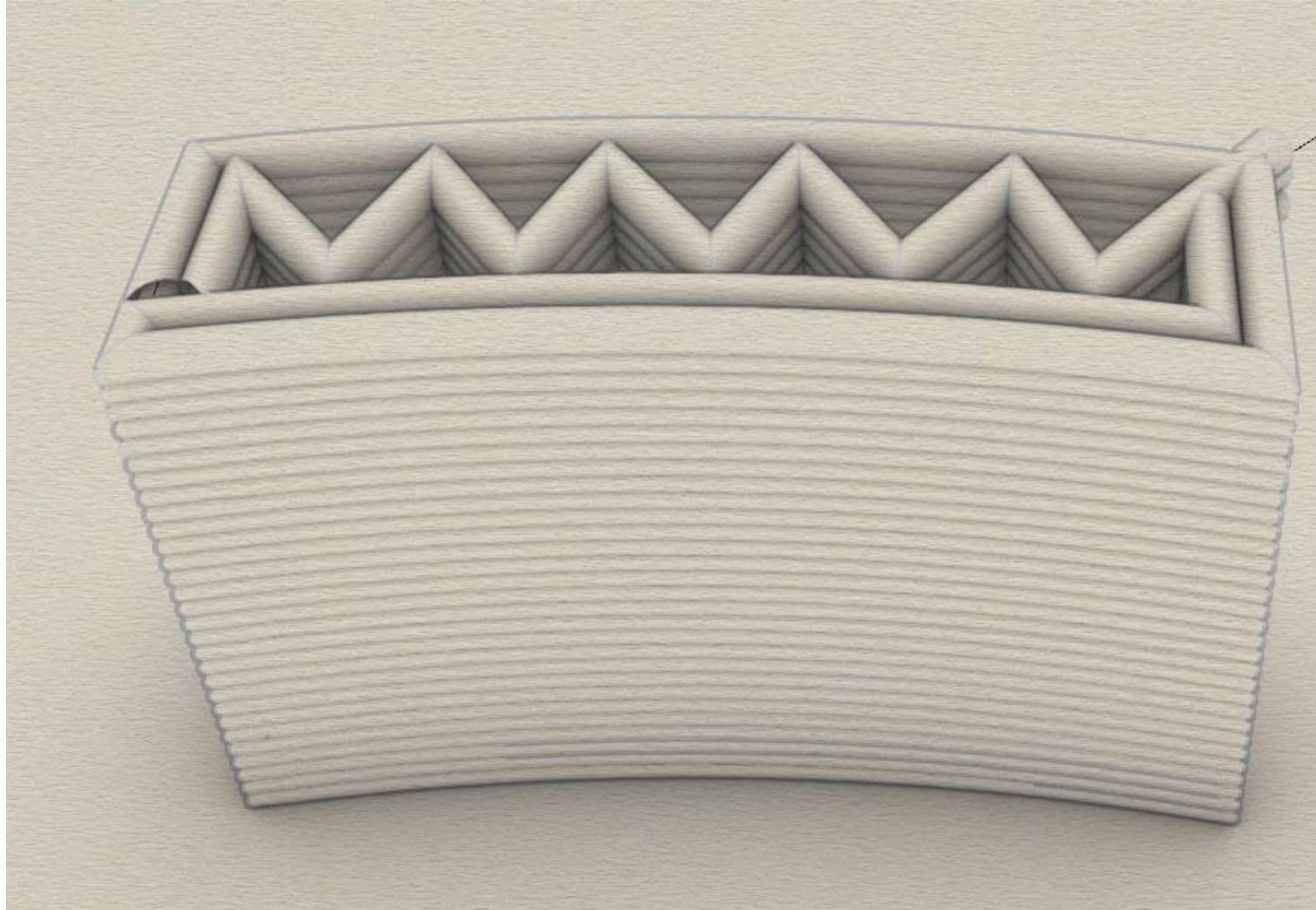


<https://www.civilengineeringforum.me/splitting-tensile-strength/>

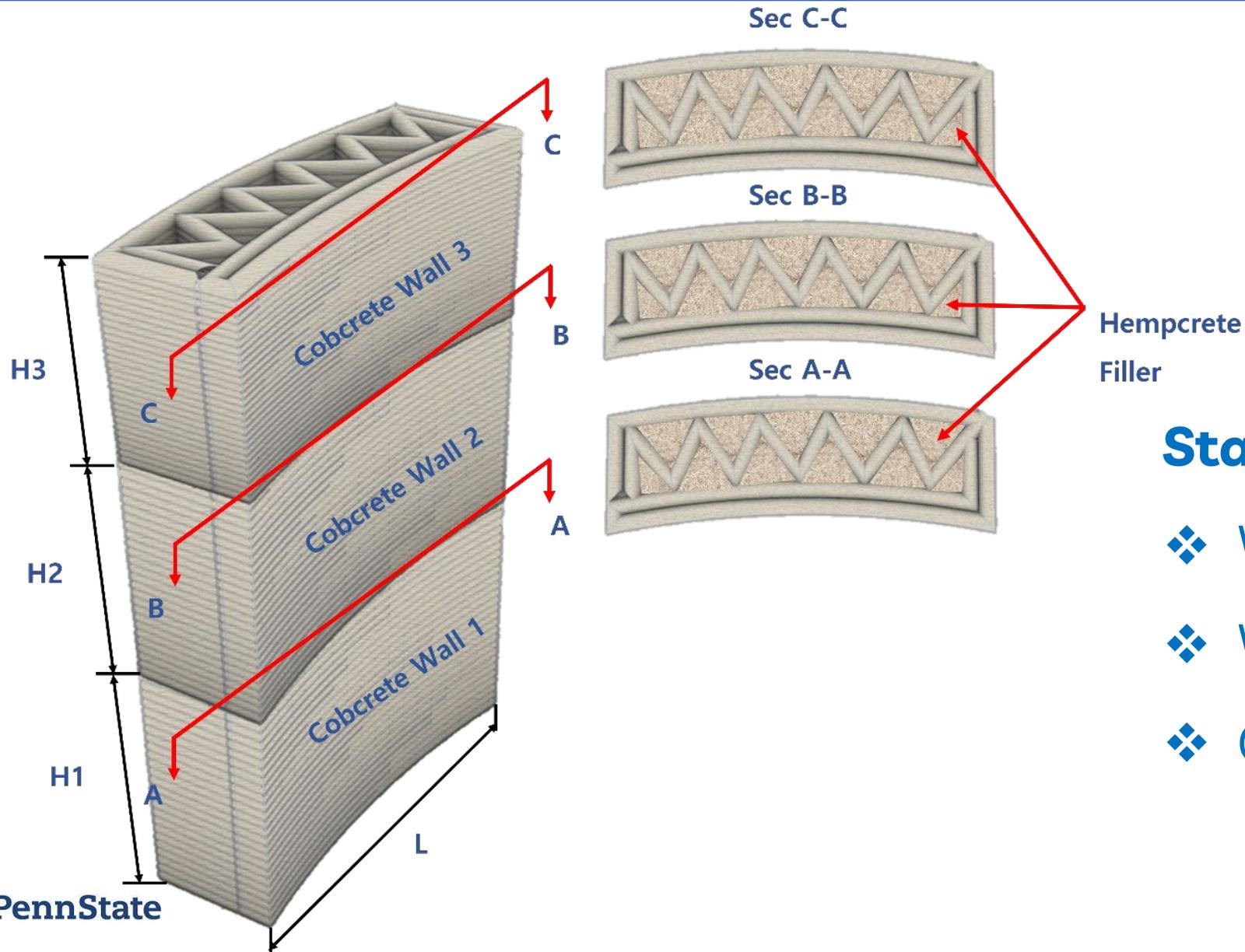


- **The tensile strength of hempcrete can be determined from the splitting cylinder test.**
- **The average split cylinder tensile strength of hempcrete is about 0.22 MPa (32 psi) and 0.268 MPa (39 psi) for 45 days and 60 days, respectively.**

# Successfully 3D Printed a Clay-Hemp based Wall



# Future Work – 3D printing “cobcrete” wall with hempcrete filler



**Stabilizing equation using:**

- ❖ Wall height
- ❖ Wall length
- ❖ Optimal time

# Acknowledgement

Contributions of my students and assistants including Nadia Mirzai, Eden Binega, Mahsa Hashemi, Bahareh Tayebani in their testing and the content of some of the slides is acknowledged.

# References

1. Asghari, N. and Memari, A. M., (2024). “State of the Art Review of Attributes and Mechanical Properties of Hempcrete,” MDPI Buildings, Special Issue on Innovative Systems for Biomass Crop Production and Use, published 02/02/24, Vol. 4, No. 1, pp. 65-91, <https://doi.org/10.3390/biomass4010004>.
2. Zuabi, W. and Memari, A. M., (2021). “Review of Hempcrete as a Sustainable Building Material,” *International Journal of Architecture, Engineering and Construction*, published January 2021; Vol. 10, No. 1, pp. 1-17, <http://dx.doi.org/10.7492/IJAEC.2021.004>.
3. Yi, H., Griffin, C., and Memari, A. M., (2022). “Critical Review of the Characterization of Environmental and Mechanical Properties of Hemp Hurd and Hempcrete,” *Proceedings of the 6<sup>th</sup> Residential Building Design and Construction Conference*, Virtual, Penn State University, University Park, PA, May 11-12, 2022, pp. 208-216. ISBN 978-1-62307-009-0.
4. Yi, H., Griffin, C., Memari, A., Lanning, D., Dooley, J. H., (2020). “Hempcrete for as Residential Construction Material: State-of-the-art and Challenges,” *Proceedings of the 5<sup>th</sup> Residential Building Design and Construction Conference*, Penn State University, University Park, PA, March 4-6, 2020, 10p, ISBN 978-1-62307-007-6.
5. Memari, A., Griffin, C., Yi, H., Lowe, S., Mirzai, N., and Hashemi, M., (2022). *Thermal, Energy, and Indoor Environment Quality Performance of the PA Hemp House*, Report Submitted to DON Services, Inc., The Pennsylvania Housing Research Center, Penn State University, 66p.