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Prefab Light Clay-Timber Elements for Net Zero Whole-Life Carbon Buildings

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Abstract

"Net zero whole life carbon" is an ambitious climate target that refers to neutralizing and offsetting the entire LCA-based carbon footprint of a building, including both operational and embodied greenhouse gas emissions. Especially in the Northern climate, viable building envelope structures must, therefore, provide good thermal insulation and low embodied emissions. Carbon offset is typically based on excess on-site renewable energy or purchased carbon offsets disconnected from the building and the site. Viable strategies for carbon neutrality start by minimizing material-related and energy-related CO_2e emissions. As a result, new kinds of building envelope structures have been recently introduced in the academic literature and experimental building projects.

Traditional construction materials, such as timber and clay, have been sourced locally and processed manually, providing good results for the embodied emissions in life cycle assessment. Recent studies on clay-based construction materials have concluded that more research on clay as a construction material is needed, in particular considering its environmental performance.

One specific concern in the Northern climate is that the weather conditions limit clay construction outdoors and prevent industrial-scale application of these solutions. The methods of prefabrication can address these issues. This study introduces the critical technical and environmental properties of a new prefabricated wall element based on a combination of light timber frame and light clay. In a hybrid light clay-timber structure, a mixture of clay and hemp shives is cast between the timber studs. On the one hand, the novelty of this wall structure is the prefabrication that enables industrial applications and upscaling without the limitations of weather conditions. On the other hand, the study assesses the climate impact of a light clay-timber wall element : cradle-to-gate emissions, thermal insulation, and the climate benefits outside the system boundary (carbon handprint) reported in the D-module of the LCA framework.

The study also shows that natural materials require a different approach than synthetic materials from industrial processes. There may be variations in the properties of hemp and clay, especially when local sourcing is prioritized for better environmental performance. Moreover, the mixing and installation processes have a significant impact on the final properties and the performance. We show that constructing a light clay wall is a knowledge-intensive process that may result in very different technical properties.

The authors argue that the case study demonstrates a paradigm shift in developing building envelope

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solutions. The future low-carbon building solutions are knowledge-intensive but prioritize local, natural materials and minimize the processing of these materials. The quality control could be based on the grading of natural raw materials, similar to the grading of sawn timber.
In light of the results, we discuss the interpretation of the net zero targets and the viability of accounting for the benefits beyond the system boundary, reported in the LCA framework as module D impacts (also referred to as "carbon handprint") as a carbon offset.
The best specimen of prefabricated light clay-timber elements shows low carbon footprint and good thermal insulation while providing a superb carbon handprint.

Keywords: clay structure; timber structure; carbon footprint; carbon handprint; prefabrication.

Introduction

As the climate crisis continues to escalate, the construction sector seeks more holistic climate targets that would help mitigate the most important life cycle impacts of a building. These targets serve as lighthouses for architects and the developers of new solutions. "Net zero whole life carbon" is an ambitious climate target that refers to neutralizing and offsetting the entire LCA-based carbon footprint of a building (World Green Building Council, 2016) (Carrillo Pineda, 2020), including both operational and embodied greenhouse gas emissions. In the LCA framework, the benefits beyond the system boundary are reported as module D impacts (also referred to as "carbon handprint"). Carbon offset is typically based on excess on-site renewable energy or an investment in a carbon dioxide sequestration project disconnected from the construction process, the building, and the site.

Traditional construction materials, such as timber and clay, have been sourced locally and processed manually, providing good results for the embodied emissions in life cycle assessment (LCA). While the properties of timber are well-known, recent studies have concluded that more research on clay as a construction material is needed, particularly considering its environmental performance (Shubbar, 2019) (Muntari, 2021).

Clay as a construction material has been displaced by industrial building products during the past 100 years and is today often considered a primitive material that requires time-consuming and labour-intensive building techniques. Regarding carbon neutrality, however, clay has again some winning arguments on its side: Clay is widely available all over the World, it is non-combustible, cheap, does not need any extra energy for processing, has no carbon footprint apart from transport, and has an unreachable ability to absorb and transpire humidity, making it one of the most secure building materials in terms of building physics.

Kallakas et al. (2019) have shown the potential of combining clay and hemp for the fire protection of timber structures. Fire safety is one of the obstacles for large-scale timber construction, and fire protection measures, in general, tend to increase the embodied carbon emissions of buildings.

In the Northern climate, weather conditions limit the use of clay structures. Monolithic light clay structures contain much moisture and need a relatively long time to dry. High moisture content means a very narrow time frame for on-site work in the Northern climate. Furthermore, high moisture content is problematic for the timber structures on building site, and drying prolongs the duration of construction work. This study hypothesizes that these issues can be addressed by prefabrication.

This study introduces the essential technical and environmental properties of a new prefabricated wall element based on a combination of light timber frame and light clay. In a hybrid light clay-timber structure, a mixture of clay and hemp shives is cast in between timber studs. On one hand, the novelty of the wall structure is the prefabrication that enables industrial applications. On the other hand, the study documents the environmental performance considering the most important aspects related to global warming: embodied CO_2e-emissions (cradle-to-gate emissions), thermal performance and the benefits outside the system boundary (carbon handprint) reported in LCA.

The novelty value of the solution presented in this article is the industrial application of the material. Prefabrication addresses several weaknesses of clay building: Whereas light clay construction on the building site is limited to 1–2 summer months in Northern countries, prefabrication can continue year-round in a factory. Avoiding lengthy drying times on the building site enables shorter building processes.

Ideally, the structure featured in this study would deliver the thermal mass, acoustic and moisture performance of a monolithic brick wall, and thermal insulation properties of a contemporary timber element. Protecting timber profiles from fire with clay may enable use of light clay-timber structures in larger buildings.

The section "Materials" presents the design and the construction process of three pre-fabricated wall elements applying the light clay-timber structure. The section "Methods" reviews the analysis methods applied to examine the technical and environmental properties of the wall structures, followed by the results in the next section. In the section "Discussion", we evaluate the prefabrication process and the results gained. We contrast the carbon footprint and the benefits outside the assessment boundary with other wall structures applying a light timber frame. In light of the results, we discuss the definition of whole life zero carbon buildings, in particular, the question of carbon offsets included.

Materials

Three test walls (Table 1) were constructed to research prefabricated hybrid light clay-timber wall structures. Wall element A was designed as an exterior wall. The wall elements were prefabricated horizontally and assembled after the transportation in Tampere, Finland. The specimens were tested at Tampere University. Wall element B was designed as a partition wall and constructed in a vertical position in Tallinn, Estonia. The tests were conducted at Tallinn University of Technology. Wall element C was designed as a partition wall and constructed in a horizontal position.

Table 1

Properties to be evaluated for the wall elements A, B and C

Wall element	Usage	Thickness (mm)	Properties to be evaluated
A	Load-bearing exterior wall	198	Prefabrication in horizontal position, thermal performance, carbon footprint and handprint, U-value, shrinkage, compression strength, density
B	Partition wall	98	Prefabrication in vertical position, shrinkage, density
C	Partition wall	95	Moisture buffering, acoustic properties in an office environment, shrinkage, compression strength, density

In a hybrid light clay-timber structure, a mixture of clay and hemp shives is cast between the timber studs. Hemp shives are added to eliminate the cracking caused by the shrinking of clay. Hemp shives are crushed pieces of the plant stem and a by-product of fibre extraction. The light timber frames were constructed of sawn spruce timber profiles. The solution can be applied to load-bearing exterior and interior walls and partition walls.

The idea of the prototype stems from the observation that clay has considerable potential as a building material in the carbon-neutral era. However, its use is limited and needs industrial production. There are no examples of prefabricated light clay elements, so the prototype project served as a feasibility study for the whole idea.

For the material, however, there were a few examples. A mixture of clay and hemp shives has been successfully used by the German company Hanffaser as an insulation layer for old buildings, reaching lambda values of 0.068 W/mK (Hanffaser, 2023). This mixture is very light and non-load-bearing, so the load-bearing structure of the element had to be of timber. The prototype development had the following steps:

- Developing the clay-hemp-shive-mixture to work as an element filling and good enough insulation for a house for living;

- Developing the element and the element joints to suit prefabrication, filling with the light clay mixture, transport, and assembly;
- Mixing the light clay mixture and filling the elements with it in a way that makes prefabrication on a large scale feasible;
- Observation and control of the drying-out process;
- Transport and the assembly of the element.

Finding the right mixture was a process of trial and error. To insulate well, the mixture had to be light, and to optimize the dry-out-time, water had to be as low as possible. Also, the order of the steps in the mixing process was important: Traditionally, the clay is first made wet and then mixed with the insulation material. This impacts the ability of clay to glue the insulation particles together. Mixing clay and hemp shives first resulted in a different material strength than mixing clay and water first and only after pouring in the hemp shives.

Wall element A

Prototype element A was dimensioned as an exterior wall element (Fig. 1–2).

The timber frame of a light clay-timber element differs somewhat from an element that is filled with e.g. mineral wool. This prototype had a wall thickness of 198 mm. On the outside, there are load-bearing posts of timber 98x48 mm with a cc 600 mm spacing. Against the interior surface, the posts are 48x48 mm. This leaves a gap between the posts filled with 48x48 mm beams that also tie the outer and the inner posts together. On the one hand, this structure helps to avoid thermal bridges caused by timber, and on the other hand, it creates gaps in the structure that help the clay mixture to get better woven together with the timber structure and to avoid it falling off the structure.

The structure developed worked well, especially the voids in the volume for the light clay mixture, which helped to create "claws" for the material in the timber structure. Of course, they also make it more difficult to fill the element, but in practice, this was no problem. The method to fill the elements also improved during the prototype process. The first elements were still filled by hand, but it was slow and rather hard work. Building a customized vibrating plate made the process not only much faster but also a lot easier for the workers.

Fig. 1
Prefabrication of light clay-timber exterior wall elements (Photo: Juha Päätalo)

Fig. 2
Installation of prefabricated light clay-timber wall elements (Photo: Juha Päätalo)

The elements were filled in a horizontal position, sitting on a drying rack. The drying rack is a custom-built timber frame covered by a tight metal net that keeps the form but allows as much air through as possible. The horizontal position is essential as the materials settle during the dry-out phase. If the elements were drying vertically, there would be a gap on top of each element. This way, the settling will be filled by the plaster covering the wall afterward. (Fig. 3)

Overall, the idea of the drying rack worked well. There can be some improvement, however. On the downside of the elements, some bulges were caused by the metal net that was not tight enough. The solution for the future could be a stiffer net that does not bend at all and is put in first, and then a net with small openings that will not let the light clay mixture through.

With this method, too, there were small gaps of 1–2 mm between the timber frame and the light clay after drying out. Through the 3D geometry of the clay structure, however, they do not exist through the whole structure but only in the depth of the posts. Moreover, they will be filled in any case when the elements are plastered.

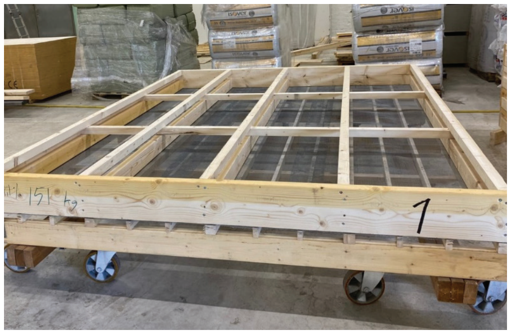


Fig. 3
The element sitting on a drying rack

The biggest surprise in the process was the time needed for drying out. It took months, and the time was made even longer by the fact that the factory building where the elements were made was unused for some of the time, meaning less heating and air exchange shut off. Drying out will undoubtedly be one of the critical parameters for the subsequent development step.

Fig. 4
A linen felt of 15 mm was installed in the element gaps

One of the reasons for the long drying time is that the element in a dimension of 200 mm and made from insulation material will dry out very slowly in the middle of the element as even the heat hardly gets there. However, in another project where parting walls of 100 mm were built as prototypes, an excessive air flow along the surface of the element made the light clay dry fast, even without extra heat in the process.

It is possible to use sodium bicarbonate or sodium silicate, or both to change the viscosity of the clay milk when mixing light clay. In the project, sodium bicarbonate was used, too, but it hardly showed any effect. In this prototype, an industrial clay powder was used that has been dried by fire (natural gas flame). Later, a test was made using natural clay, and the change in viscosity was evident. This means that the amount of water could be dramatically reduced in future production. According to the literature, the amount of water can be reduced up to 50 percent (Volhard, 2013). Not only would this reduce the time for drying out, but also help to reduce the shrinkage.

The transport and assembly of the elements did not provide any surprises. The elements lasted the transport without any visible damage. There was practically no abraded material during the transport and hardly any during the lifting and settling of the elements. While fixing the elements to each other, the screws were fastened through the light clay material. During this, the material fell off only in the space of the screw. Between the elements, a 15-millimetre linen felt was used to fill the tolerances in the element gaps, allowing tight element joints (Fig. 4).

Wall element B

Wall element B was built by students in a workshop arranged at Taltech University. The mixture of hemp shives and clay was first mixed in a forced action mixer and only after that, water was poured in.

The element was constructed and filled in a vertical position as light clay walls were traditionally built on the building site by pouring the mixture between the timber studs.

The result was disappointing and underlines the importance of quality control both in terms of materials and the procedure of mixing the materials.

The consistency of the material felt strange and porridge-like, and that can be the reason soon after the installation of the infill, some cracks were detected in the element. It is probable that the order should have been the other way around, as mixing clay and water to a clay milk normally gives a more cohesive mixture.

Wall element C

Wall element C is a partition wall that is built of light clay, the idea being that it can serve as a small enough element to make partitions possible that are easy to assemble but also easy to de-assemble and move to a new place. The function of the light clay mixture in the structure is partly of 100 % natural origin, a novelty in the area of partition walls. On the other hand, the partition wall can also help to buffer humidity in an office during the summer months. For this, however, the surface of the walls needs to be in an adequate relation to the volume of the space.

The thickness of the wall is 95 mm. It is filled with a light clay mixture of clay and hemp shives. As inner walls, the density of the material only plays a role in terms of weight. However, the more clay the elements contain, the better is also the moisture buffering capacity.

As these elements, with a dimension of 2270x517x95 mm, are more like interior design elements, the wooden frames were produced by a carpenter to minimize tolerances. The frames were then filled with hemp-clay-mixture.

Methods

The global warming potential for the LCA modules A1-A3 i.e. so-called cradle-to-gate CO_2e emissions of the light clay-timber wall element were estimated following EN 15804+A2:2019 and EN 15978. The assumptions applied in the assessment are presented in Table 2.

Table 2

The assumptions applied in the assessment of global warming potential

Raw material	Share[1]	Carbon footprint		Carbon handprint		Source
	%	$kgCO_2e/kg_{raw\ material}$	$kgCO_2e/kg_{product}$	$kgCO_2e/kg_{raw\ material}$	$kgCO_2e/kg_{product}$	
A1 Raw material extraction						
Clay	51	0.000	0.000		0.00	VTT[2]
Hemp shive	34	0.161	0.055	-1.6	-0.55	Hemka[3]
Wood fibre	3	0.090	0.003	-1.2	-0.03	CO2data.fi
Sawn timber	12	0.069	0.008	-1.6	-0.19	CO2data.fi
Metal connectors	0.1	2.740	0.003			Ruukki Oy
A2 Raw material transportation						
Road transport			0.004			VTT[2]
A3 Production						
Wind electricity			0.000			
Total A1-A3						
$kgCO_2e/kg$			0.073		-0.77	
$kgCO_2e/m^3$			24.513		-259.40	
$kgCO_2e/m^2$	400 mm thickness		9.805		-103.76	

1 Share of dryweight

2 VTT Rakennustekniikka 15.11.2000. Unburnt Clay Building Products, Environmental Impact Report.

3 From planting.

The density and moisture content of specimen were measured at the laboratory of Tampere University (**Fig. 5**).

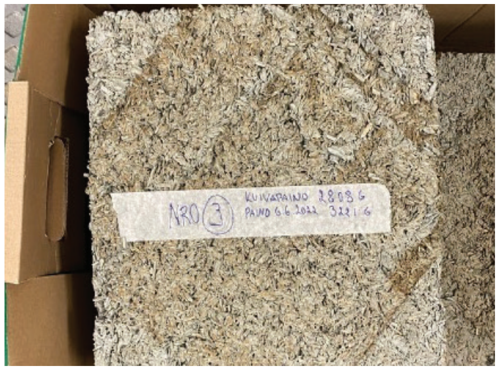
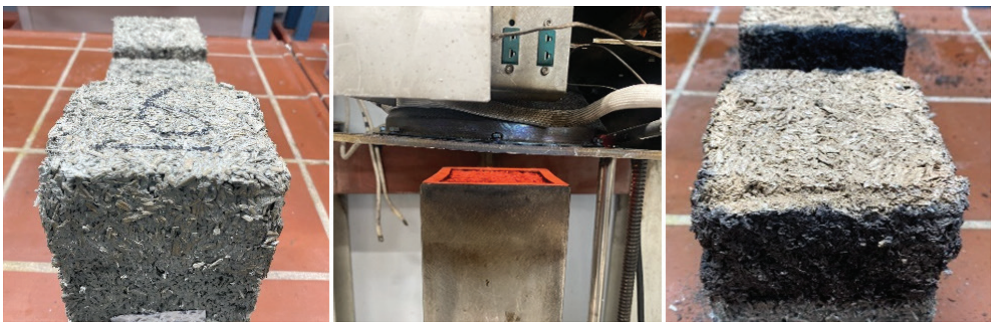


Fig. 5

Material for the insulation property test

For Test element B, tests were conducted at Tallinn University of Technology, Laboratory of Wood Technology. The density of test samples was determined after five days of conditioning at 50 % relative humidity and 23 ± 1°C. The linear dimension of the specimen was determined from 3 points on each side using a laser measuring device for accuracy.

For Wall element B, a fire test was performed based on ISO 5660 to determine the primary protection effect of the hemp/clay brick for timber frames. The test followed the method formerly published by Liblik et al. (2018) and Liblik et al. (2019). The temperature rise ($_{depth}$) was recorded using a k-type thermocouple (**Fig. 6–8**) connected at the interface between the specimen and a timber block (100x100x50 mm). Specimens were exposed at 25 mm to a cone heater of a cone calorimeter with a predetermined radiant heat flux of 50 kW/m^2 at 25 mm for 60 min. Before the test, the specimens were conditioned for five days at 50% RH (Relative Humidity) and 23°C. Four parallels were assessed.



(a) (b) (c)

Fig. 6-8

Cone calorimeter test: (a) Test specimen set-up; (b) exposure to heat flux from cone heater; (c) specimens after test

Results

Wall element A

The drying process was monitored by measuring the weight. At the start, an element of 3000x2400x200 mm weighed 810 kg, and at the end, 400 kg. Thus, in every element of 7.2 m^2, there were more than 400 litres of water. The material tests showed that the amount of water was necessary, too, to make the clay glue the insulation material particles together.

The density of the clay-hemp shive mixture was approximately 320 kg/m^3. The lambda value for the clay-hemp shive mixture in the development was tested at 0.077 W/mK (Tampere University 2022). This can be further optimized, with the target being at 0.070 W/mK. Consequently, with the clay-hemp shive mixture density of 300 kg/m^3 and stud spacing of cc 600 mm, an exterior wall structure with 400 mm dimensioning equals a U-value of 0.17 W/m^{2}K.

Wall element B

Average density of 19 test samples was 474.37 kg/m^3, with a standard deviation of 20.47 (**Table 3**).

The results are not in line with the densities specified for Wall element A, and imply that the desired properties in thermal performance were not achieved. After two weeks of drying, the clay-hemp shive infill had severe cracks caused by shrinking.

Table 3
The densities of sample pieces

Sample ID	Density
	kg/m³
8	459.74
23	497.58
21	476.43
24	500.35
14	511.81
5	521.87
13	503.36
16	542.05

The fire test gave promising implications. Compared to the results published by Liblik et al. (2021), the low temperature rise (**Fig. 9**) indicates the better fire protection ability of the hemp/clay brick; besides, none of the replicates reached these critical values. Typically, the critical temperature values of 270 and 300°C, corresponding to the protection temperature and start of char temperature for timber, are of key focus. It should be mentioned, however, that in that study, reported results are for 20 mm specimens examined for 40 min. The hemp-clay bricks exhibited a consistent average mass loss of 15.7 ± 1.4 g. The time to ignition appeared to be consistent for 3 of the hemp/clay brick specimens (17 ± 2 s), but one of the specimens did not ignite. This may be due to adequate embedment of the hemp shives in the clay matrix. Regardless, in the case of ignition, this was followed almost immediately by smoldering after 60 s for another 2 min before total removal of visible flaming.

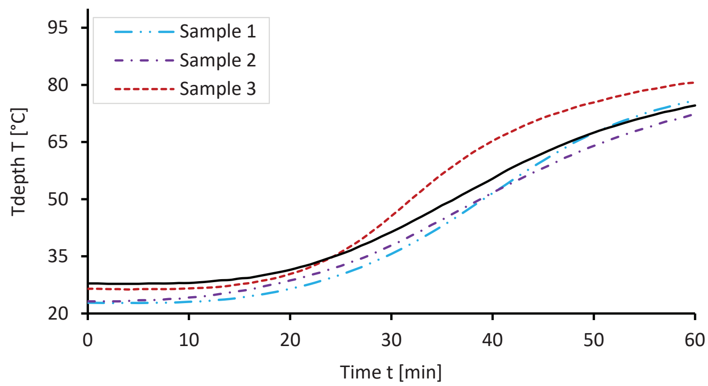


Fig. 9
Temperature rise was measured between the hemp-clay brick and the timber block

Wall element C

As the wall elements A needed a long time to dry out, a new method was tried out: The elements were stacked on top of each other, the drying racks allowed 100 mm air between them, and a lot of air was blown through a tunnel formed by a plastic sheet (**Fig. 11–12**). The workshop had a moderate temperature of ca. 15 °C. This way, drying out of the elements took about 10 days.

The dry out process produced pleasing results. The mixture showed no cracks. There were minor shrinking issues, however, causing some mm gaps between the frame and the clay filling (**Fig. 12**).

(a) (b) (c)

Fig. 10-12
A drying tunnel for the elements (a, b), shrinking gaps after drying (c)

That shouldn't be a problem because of the frame structure. There is a 25x25 mm wooden filling piece in the middle of the frame, avoiding the gap reaching through the element (Fig. 13). This is important for the acoustic performance of the elements as these elements are not plastered but covered by felt.

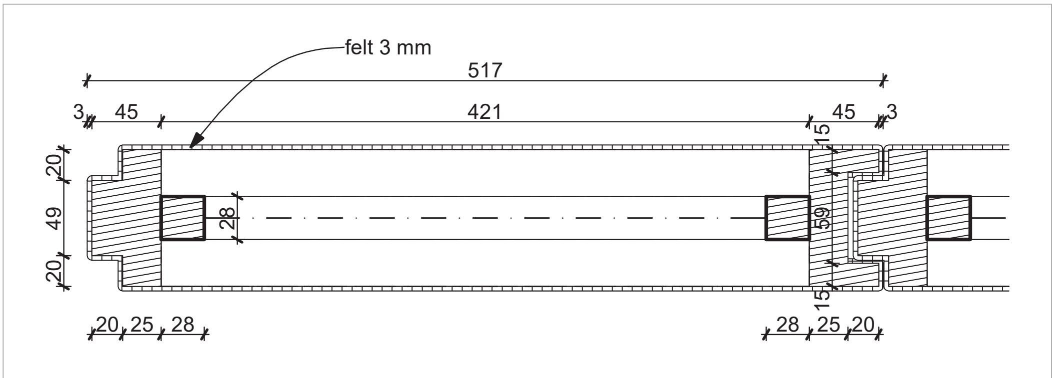


Fig. 13
Frame of wall element C, horizontal section

At the time of writing, these elements are ready and have survived the transport very well. They are yet to be installed in the offices of the customer. The same applies to measured data from the moisture buffering and acoustic performance of the elements.

During the process, 10 samples in the dimension of 100x100x100 mm were taken from the material mix of wall element C. The density of the samples was 404 kg/m^3 which was somewhat higher than in the wall elements A. The results of the compressive strength of the samples are shown in the Table 4.

Table 4
The compressive strength of sample pieces

Sample ID	Density	Fmax	Compressive strength
	kg/m^3	N	N/mm^2
5	407.38	4989.331	0.46
6	412.06	5321.156	0.51
9	433.14	5496.163	0.55
2	394.70	5714.899	0.53
3	388.59	4870.887	0.46
8	400.68	4754.778	0.45
7	409.15	5911.378	0.54
1	395.52	5084.544	0.48

Discussion

The assessment of climate impact shows promising results in environmental performance. A comparison of alternative solutions reveals significant benefits in environmental performance (Table 5). Prefabricated light clay-timber element seems to outperform most of the other light timber frame solutions in carbon footprint and provides a superb carbon handprint (benefits beyond the system boundary, reported as module D).

Table 5
Carbon footprint and the environmental benefits beyond the system boundary (Carbon handprint) for various types of exterior wall structures (kgCO_2e/m^2 of wall surface area). Source: Mikael Westermarck, Tampere University

Exterior wall structure	Carbon footprint	Carbon handprint
	kgCO_2e/m^2	kgCO_2e/m^2
Light clay-timber wall with wood exterior cladding	14,4	-107
Light timber frame with wood shavings insulation	12,5	-85
Light timber frame wall with straw insulation	15,2	-66
Light timber frame wall with mineral wool thermal insulation	16,1	-33
Concrete element with brick cladding	120	0

For this comparison, the light clay-timber element was assumed to have ventilated wood cladding without finishes on both sides. The claddings on both sides of the structure have increased the carbon footprint and had a minor impact on the carbon handprint. Also, on the outer side of the element in this comparison, every element has a 30 mm mineral wool board. With the clay-timber wall, this could be replaced by clay or lime plaster, resulting in a smaller carbon footprint.

The hybrid clay-timber wall needs no vapour barrier and can be constructed without additional chemicals. The only non-renewable material in the test wall structure is the nail connectors. The lambda value for the clay-hemp shive mixture in the development was 0.077 W/mK (Tampere University 2022). This value can be further developed by using hemp shives with longer stems, letting more air in the wall filling. Consequently, with the clay-hemp shive mixture density of 300 kg/m^3 and stud spacing of cc 600 mm, an exterior wall structure with 400 mm dimensioning can equal a U-value of 0.17 W/m^2.

The results for wall element A imply that the hemp shive is enough to tackle the shrinking of clay as it dries out. Any gap between the wall studs and the light-clay infill would harm thermal performance.

The results on environmental performance for Wall element A were promising in terms of embodied emissions, thermal performance, and the module D impacts. However, accounting for module D benefits in the net carbon balance remains debatable. According to standard EN15804, module D cannot be included in the carbon footprint, but the definitions for carbon neutrality and carbon offsetting are not based on standards but rather agreements on compensative measures. The interpretation of the net zero target should emphasize front-load CO_2e emission reduction and be cautious in applying carbon dioxide removal measures (Fankhauser, et al., 2022). The solution presented in this study is well-aligned with these attributes. It is also important to note that the embedded carbon of hemp in the structure will renew in a one-year period. That is elementally different to the carbon embedded in timber during a growth period of 80-120 years.

As voluntary benchmarks may become significant drivers for the he construction sector, there is still a need for discussion about the definition for the types of carbon offsets that can be included and accounted for when striving towards whole-life net zero buildings. As the LCA module D reports positive climate impacts that would not exist without the construction process and the use of the building, they may be considered more elementary parts of the life of the building than the purchased offsets that are typically totally disconnected from the process, and for which the reliable climate impact is also much more challenging to verify. Recently, Taylor et al. have proposed including carbon storage in mass timber construction in offset measures (Taylor, Gu, Nepal, & Bergman, 2023).

As processing tends to increase the carbon footprint of construction materials and often reduce recyclability, we argue that the solution presented demonstrates a paradigm shift for the construction industry: the added value for future construction solutions is based on the use of natural and locally available raw materials and processes that have low energy intensity but high knowledge-intensity; they may apply prefabrication but only a limited number of preferably local materials without additional chemicals.

Moreover, recent studies have implied that the fire safety of timber structures could be addressed with clay (Kallakas, et al., 2019) (Liblik, Küppers, Just, Zehfuß & Ziegert, 2018) (Liblik, Küppers, Just, Maaten & Pajusaar, 2019) (Liblik, Küppers, Maaten, & Just, 2021). This may be an untapped potential for the next generation of timber structures.

However, it should be noted that this study is based on a limited number of test walls, and the long-term performance of the light clay-timber combinations requires further research. Industrial-scale applications would still require further testing to optimize the prefabrication process while maintaining the opportunity of using local, even on-site materials, such as on-site clay.

The use of these hemp-clay elements in fire-restrictive environments is possible when using additional materials e.g. plaster on top of the elements. It is known from similar light timber elements (Ecococon straw elements) that with clay plastering of 25 mm, a classification of REI120 is possible. Similar test is yet to be performed for the hemp-clay elements. It is worth mentioning, however, that in terms of carbon footprint, clay plaster has further potential. Any other timber frame elements, like the nominally better solution with wood shavings as insulation material, need gypsum boards or mineral wool for fire protection. With the hemp-clay element, clay plaster does the job with far less carbon emissions.

The fire classification of these hemp-clay elements requires further study anyway because the cone heater test is primarily used for product development and quality control, and it may not fully assess the fire performance of these elements in real-world scenarios.

For the mixture, further testing and development work is needed. For using local clay, the test method for cohesive force according to DIN V 18952 Bl 2[1] can be used to find a clay that best suits the light clay mixture. In the development of a light clay mixture, the highest possible cohesive force is the best as it glues the insulation particles together with the least amount of clay, resulting in a robust yet light and well-insulating structure.

Also, with a local producer for the hemp shives, tests with different particle sizes can determine the best mixture regarding sturdiness and insulation properties. In the first prototypes, a commercial product with a standard (and rather small) particle size was used. Using a larger particle size, the insulation properties should improve as the structure has more air.

Conclusions

In the course of this study, we have undertaken a comprehensive examination of the technical performance and the global warming potential associated with a prefabricated light clay-timber wall structure composed of hemp shives and clay installed in a load-bearing softwood stud frame. Our findings, encompassing the assessment of embodied emissions, thermal performance, and the consequential climate benefits beyond the assessment boundary, yield promising outcomes.

Industrial application through prefabrication appeared feasible, although the wide variation in the technical properties of specimens emphasized that special attention needs to be paid to quality control. Utilization of local resources and natural materials requires a different kind of approach than industrial processes, where the quality can be controlled by adjusting the processes. If the positive climate impact reported in the LCA module D qualifies as a carbon offset, whole-life net zero carbon construction may become a significant driver for the utilization of local, natural construction materials.

Carbon sequestration reported in the LCA module D is an integral part of a building project and therefore a more pivotal impact to address than the investments in carbon sequestration elsewhere.

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1 The method is well described e.g. in Volhard 2012, pp. 46–47.

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