POLITECNICO DI TORINO
Master of Science - Architecture Construction and City

BIOCOMPOSITE INSULATION MATERIALS

Analysis and comparison of the composition, application and properties of biocomposite materials such as light earth, straw-lime, hempcrete and olive pit mixes when used as insulation materials for the creation of low carbon footprint, breathable building envelopes. Case study: La Termitière project.

Tutor: Andrea Bocco

Student: Andi Dani

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to my family …

Introduction

The building envelope, consisting of foundation, slab, walls, roof, doors and glazing, is amongst the most substantial elements in a construction because of its direct influence on the users comfort.The presence of an insulation material as an element of the building envelope with performing hygrothermal properties would increase the indoor temperature and humidity levels. The technological solutions mostly consider the thermal and acoustic properties of the insulation materials, being these the principal reasons insulation is applied in buildings. However, other indicators that influence the building occupant's comfort like the indoor air quality and relative humidity levels together with the environmental impact of the materials call for a certain attention. The building construction industry is one of the global major sources of pollution, which is why the building salubrity and the construction materials carbon footprint are becoming more important every day in the construction world. For this reason, a building envelope which has thermal and acoustic insulation properties and is vapour permeable, waterproof and windproof can have an exceptional impact on their inhabitant's comfort. Building envelopes operate as an indoor air quality and humidity regulator and can have good thermal storage qualities.

Today, the building insulation is usually obtained using conventional insulation materials, which are characterized by industrialized processing and low monetary costs. They are well integrated on the global supply chain and they are extensively used without considering the local need changes, while having a low-cost production because of the mass manufacturing. Some of the most common conventional insulation materials are fiberglass, polystyrene, mineral wool, polyurethane, etc.

This thesis focuses on the analysis of the composition, the application techniques and properties of some biocomposite materials which can be used as building insulation and are excellent candidates for the construction of a breathing building envelope.

Biocomposite materials are aggregate materials created by a matrix and a reinforcement of natural fibers. This thesis is focused on the following materials:

- light earth composite, created from a mix of straw and earth
- straw-lime composite, a mixture of straw and lime putty
- hempcrete, produced by mixing hemp shiv and a binder, usually natural hydraulic lime
- crushed and deoiled olive pits mixed with various binders.

Light earth, straw lime and hempcrete were used to build an internal insulation layer to retrofit a former industrial building by La Termitière, a group of students from the Politecnico di Torino I was part of. This gave me the possibility to work closely with these materials. These materials will be compared in terms of performance, availability, environmental impact, flexibility and application possibilities, monetary cost etc. By comparing their characteristics, this thesis aims to define when the use of these materials can be suitable.

Chapter ONE

1. “La Termitière” STUDENT PROJECT

1.1 The birth and the purpose of “La Termitière” student project

“La Termitière” is an informal group of students of the Politecnico di Torino, created during the 2015/2016 academic year. It got financed from the Commission for Contributes and Student Projects for a project that proposed the recovering former industrial buildings near the city centre, by using natural materials like straw, clay and lime. The Commission offers a program that allows students to get financial support for their projects, if they fulfill the required criteria. The deadlines for the presentation of the projects are set five times a year. The applicants can be informal groups of students or associations of the Politecnico di Torino and their activities should last for one term or one full academic year.

“La Termitière” aimed at using this project as an opportunity to learn about the use and the performance of the building materials and techniques on the construction site, applying the “Learning by doing” and “Self-building”principles.

The team’s components are architecture, engineering and industrial design students.

One of the main reasons of this initiative, was the lack of academic programmes that involve the participation of the students in building sites, which is very important for the formation of architects and civil engineers.

Figure 1. Logo and description of "La Termitière"'s activities

The activities were planned by the organisational team which had created a detailed program, as required by the Commission.

According to the initial project, the works were expected to be accomplished within the academic year. In spite of that, during the implementation plan, multiple factors, such as the lack of experience, difficulties in obtaining some materials and bureaucratic documentation, had a negative effect on the timetable, extending their duration. This created the possibility to participate to another call. New members of the team presented an additional project to the Commission, in order to fulfill the tasks which were not yet concluded and.

I joined the team in October 2017. This was the phase when we proposed a project that would allow the works to go further, and we got a second financial support for the "Termitière 2.0" project. As on of the coordinators of this group, my role consisted in designing and developing the project, managing the necessary documentation, finances and student activities, coordinating the works on the site and publishing them, as well as gathering data and information over the materials and techniques used.

One year of active participation in this team gave me the opportunity to work closely with materials like straw, hemp and crushed olive pits, as well as clay, lime putty, natural hydraulic lime, cocciopesto and other binders materials. This allowed me to make further studies on these materials and the ways they can be used in building.

1.2 The Multicultural Hub of Cecchi Point

The project suggested the use of straw-clay, straw-lime and hemp-lime for the thermal insulation of a former-industrial building located in District 7 of Turin, near the city centre. The site is in Cecchi street, inside the Aurora neighbourhood part of a complex of single-storey buildings which used to host the old municipality maintenance workshops. Today, this complex of buildings has been made available to the citizens. This complex is called "Hub Multiculturale Cecchi Point" *and is* part of network known as "neighbourhood houses". The activities that take place in the neighbourhood houses are managed by groups and organisations, like associations, social enterprises, groups of citizens etc.

Cecchi Point is managed by an association called "Campanile". The spaces consist in one building dedicated to education, a building that hosts the offices, two areas dedicated to theatrical shows, a gym, a dancing room, two rehearsal rooms, a bar, a dining room, a bicycle and carpentry workshop called "Officine Creative" and a multifunctional room, called "The Red Room".The Red Room is the space that La Termitière used as a site, based on an agreement letter between the Politecnico di Torino and Cecchi Point.

Figure 2. Bird's eye view of the Multicultural Hub Cecchi Point.
Source: https://scopriportapalazzo.com/

Figure 3. Cecchi Point's courtyard during events.
Source: http://www.cecchipoint.it/

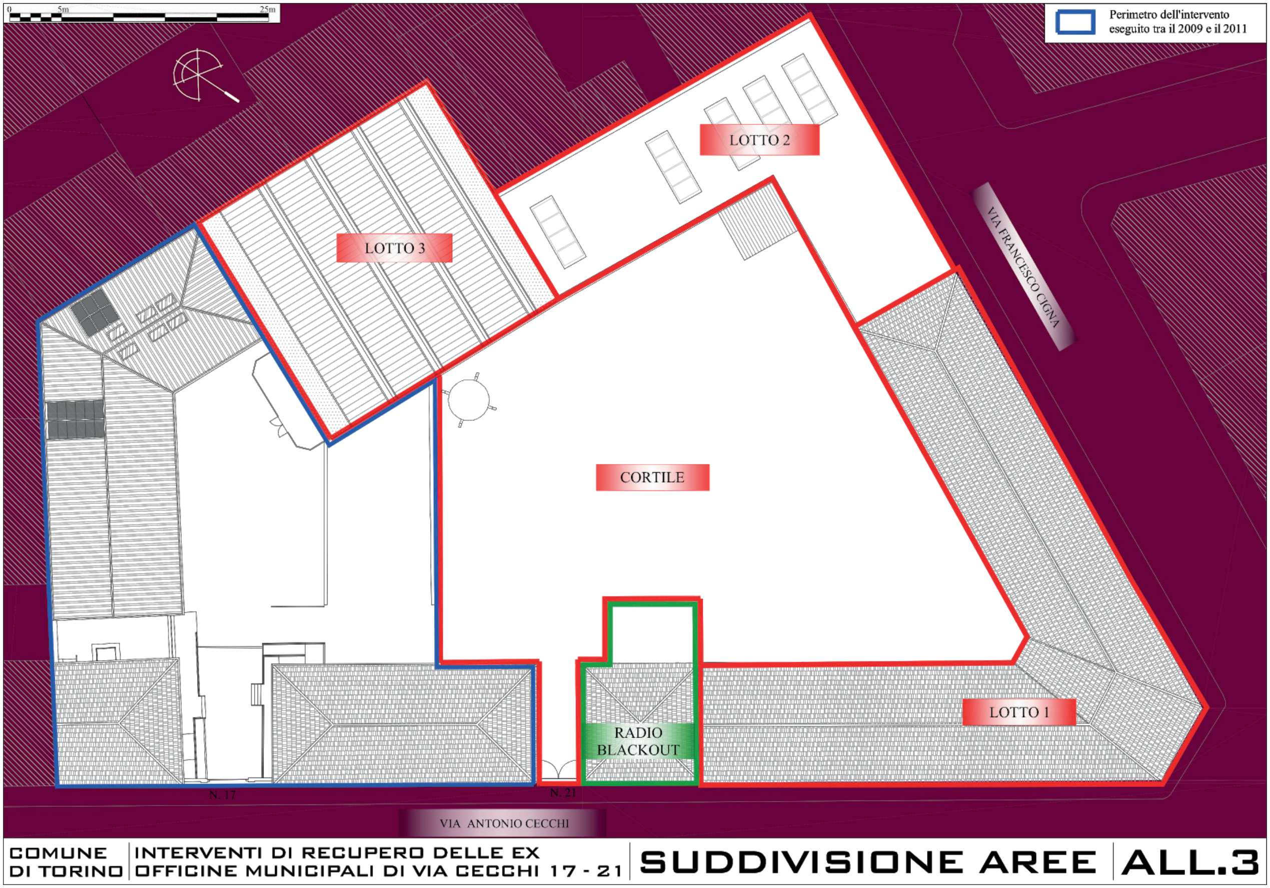


Figure 4. Plan of the covered area over the Cecchi Point complex, divided in sites. The blue area is already retrofitted with the funds of a private foundation in the years 2009-2011, while the red area has not gone through any improvement plan since the time it hosted the Municipal Workshops. The Red Room is found in the Site 2 (Lotto 2).
Source: Progetto di riqualificazione urbanistica - infrastrutturale - dei servizi - ambientale e paesaggistica dell'area urbana quartiere Aurora. http://geoportale.comune.torino.it

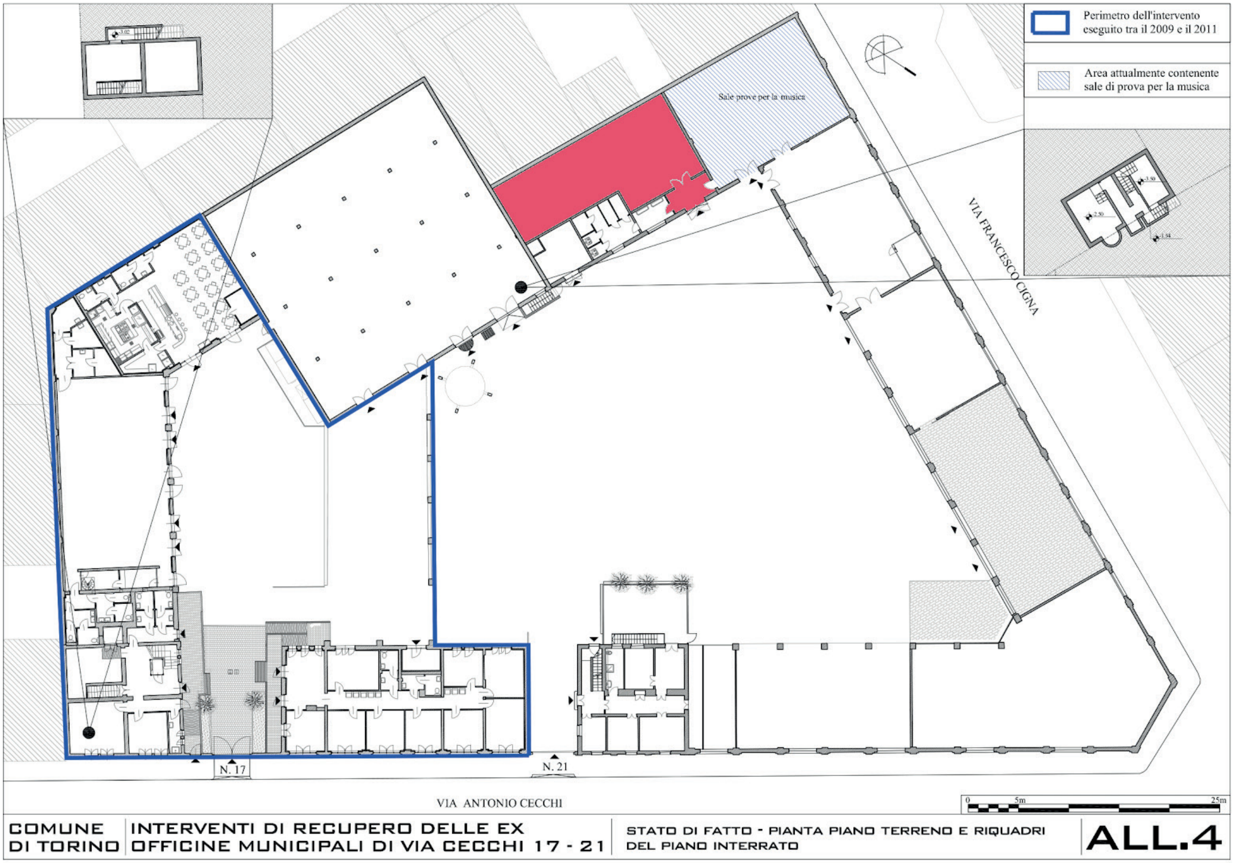


Figure 5.Plan of the Cecchi Point complex, showing the interior distribution of all the buildings belonging to the Neighbourhood House. The Red Room is identified with the red colour.
Source: Progetto di riqualificazione urbanistica - infrastrutturale - dei servizi - ambientale e paesaggistica dell'area urbana quartiere Aurora.
Source: http://geoportale.comune.torino.it

By the time the project was presented to the Commission, some parts of this complex, like the offices, a multifunctional room, the bar and the educational area, were already requalified and put to use.

The nature of the activities that take place in the neighbourhood house and that of the various agents which operate there, gave a big social value to the workshops organised by La Termitière, apart from the student learning.

Figure 6. Students working alongside the other organisations already operating at Cecchi Point inside the Red Room.
Source:https://www.produzionidalbasso.com

1.3 “The Red Room”

The Red Room is a multifunctional hall located in the south-west corner of the Cecchi Point complex. The name derives from the red carpets that used to cover the cement floor. It has a simple rectangular plan with a floor surface of 120 m^2 and a floor to ceiling height that mounts up to 4.8 m. It has no internal walls, except one separating the the room from the restrooms.

The main entrance faces the courtyard and leads to an antechamber. On the left there is the door to the restrooms and straight ahead there is the entry to the room itself. The bordering areas are the “Officine Creative” on the east, a rehearsal room in the west and a courtyard to the front.

The structure is a reinforced concrete skeleton. The columns have a 30x30 cm square section. They are placed every 2.30 m. The beams span 11 m and have a 30x40 mm section. Each beam spans over three columns. The walls have a double layer of solid bricks and cement mortar and they are around one brick thick. They were covered with a cement and sand plaster and paint.

Figure 7. Main entrance of the Red Room from the courtyard.
Photo: Andi Dani

The floor slab has two layers, the first one made of sand, gravel and cement mixture laying on the ground, and a finishing layer made of thin sand and cement, in order to increase the impermeability.

Some parts of the floor had cracked, broken and some parts were missing. There were two weak spots where the damage was enough to create voids, beneath which one could see the ground. The lack of reinforcement appears to be one of the factors that allowed some cracks to transform into 4 m^2 voids.

Figure 8. Internal view of the Red Room before the implementation of the project.
Photo: Arthur Bohn

The roof is flat and is covered with tar roll, heavily degraded in several points where it leaked. The roof slab is made of perforated bricks designed for the construction of ceilings. They are first assembled together with the steel reinforcement, and then concrete is poured, covering the reinforcement bars and filling the channel that the bricks create. The poured concrete, once it dries, creates the secondary beam system, holding the bricks together.

Figure 9 and 10. Double layer of solid bricks wall and the cement and sand plaster.
Photos: Andi Dani

Figure 11. The paint and the plaster have fallen of in the entrance room, revealing roof slab made out of perforated bricks.
Photo: Andi Dani

Figure 12. Degraded plaster and painting in the Red Room.
Photo: Arthur Bohn

Figure 13. The void in the floor was covered with raw earth in order to level it.
Photo: Andi Dani

Figure 14. One of the spots where the floor was unstable and had cracked.
Photo: Andi Dani

The internal ceiling plaster is also made of cement and sand and and has a finishing layer of paint.

In the roof there are two skylights with a rectangular plan. One is close to the entrance door (2.13x5.7 m) and the other one is near the eastern wall (2.13x3.8 m). They are both elevated above the roof level though a brick wall which creates a double pitched covering, where the window frame is fixed. The skylight windows have a steel frame and a semi transparent glass. Foam was applied to fill the holes and imperfections between the wall, the frame and the glass.

Figure 15. Picture showing the wall that divides the Red Room from the “Officine Creative”. The wooden boards at the center of the wall are covering a void where there used to be a door that connected the two areas.
Photo: Arthur Bohn

The partition wall that divides the Red Room from the “Officine Creative” had a door that connected the two areas, but by the time of the intervention. This door had already been removed, creating an opening between the two areas.

The conditions of the Red Room were really bad. Turin has a humid subtropical climate, according to the Köppen climate classification, which means average temperatures in the coldest month between 0 °C (32 °F) (or −3 °C (27 °F)) and 18 °C (64 °F) and mean temperatures in the warmest month 22 °C (72 °F) or higher. The scarce insulation properties of the building envelope resulted in having an almost equal indoor and outdoor temperature. The walls thermal transmittance reached 1.8 W/m^2K where intact and worse where there were flaws.


Figure 16 and 17. The entrance chamber and door before the second phase of the project was implemented.
Photos: Andi Dani

There was air infiltration coming from the entrance doors and the skylights, which along with the roof were a source of water leakage. On the other way, the damaged floor presented the risk of the rising dump process near the internal walls.

These circumstances made the room not suitable for use.

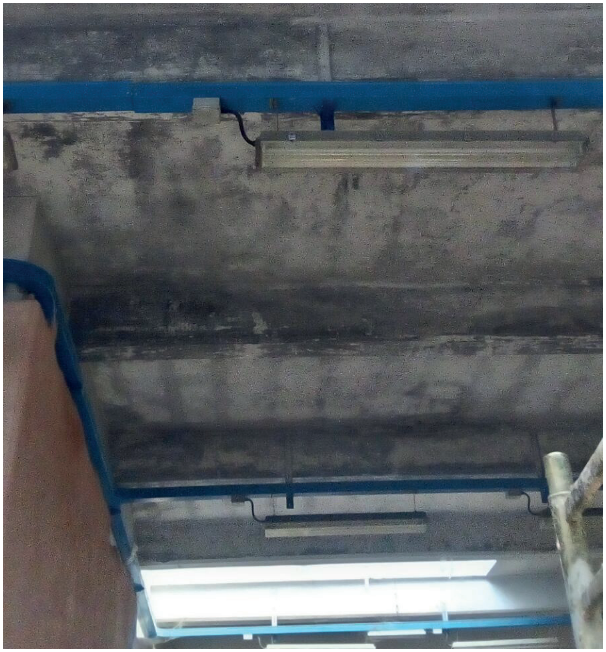
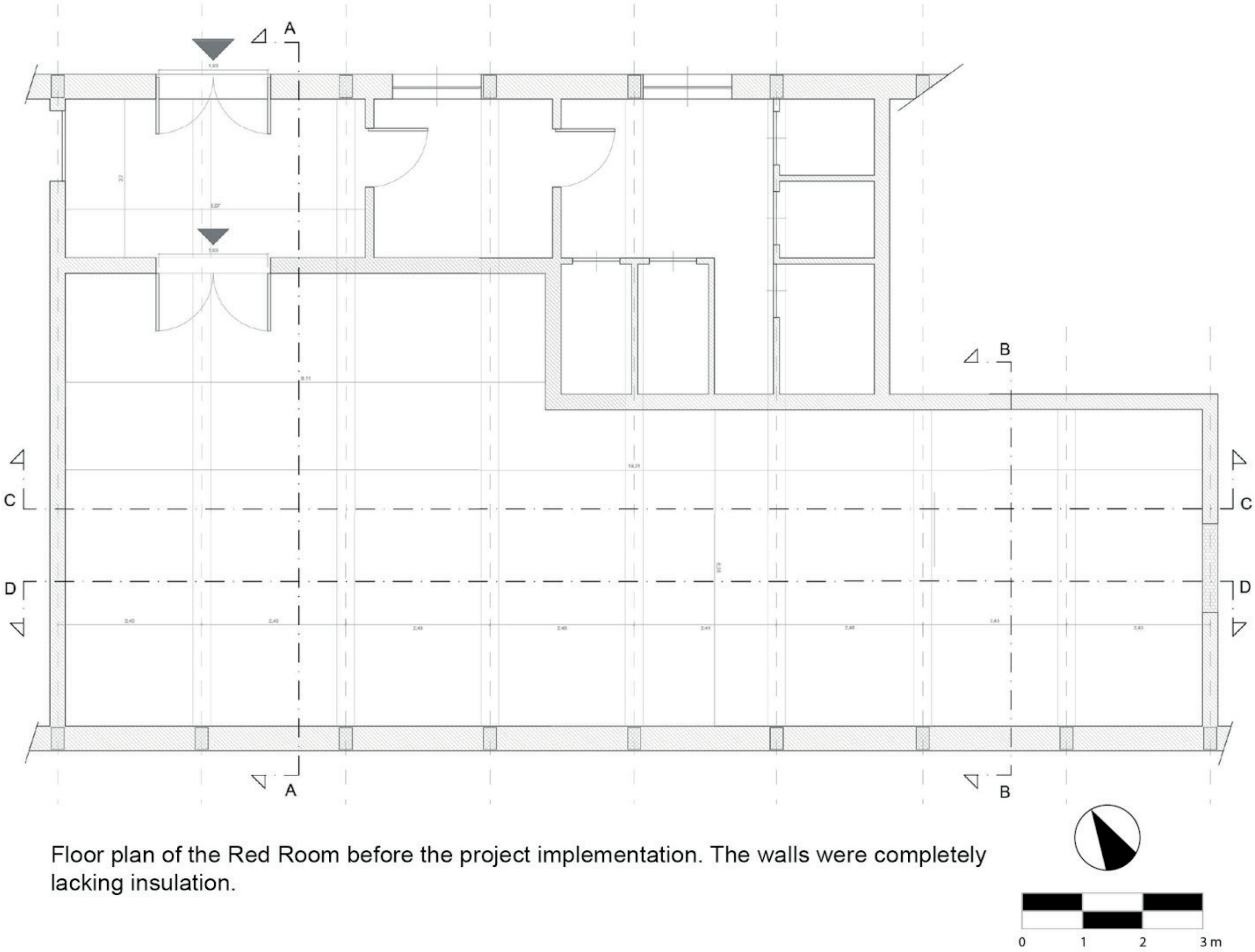
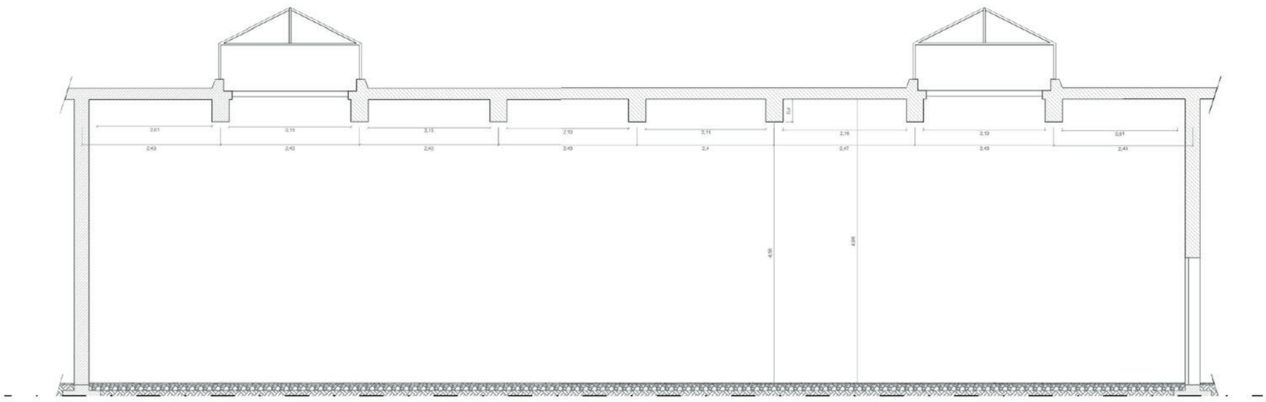


Figure 18. Ceiling of the Red Room.
Photo: Andi Dani

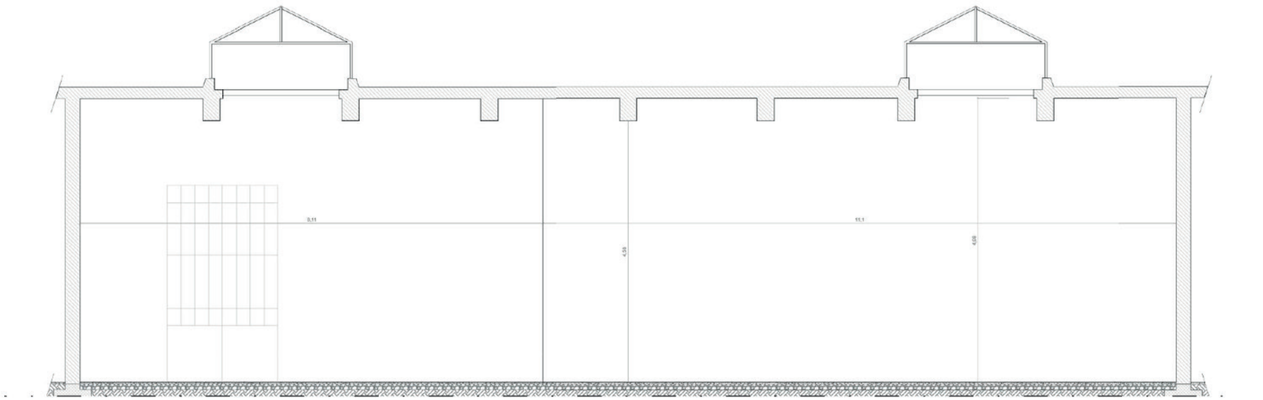


Floor plan of the Red Room before the project implementation. The walls were completely lacking insulation.

Figure 19. Floor plan of the Red Room

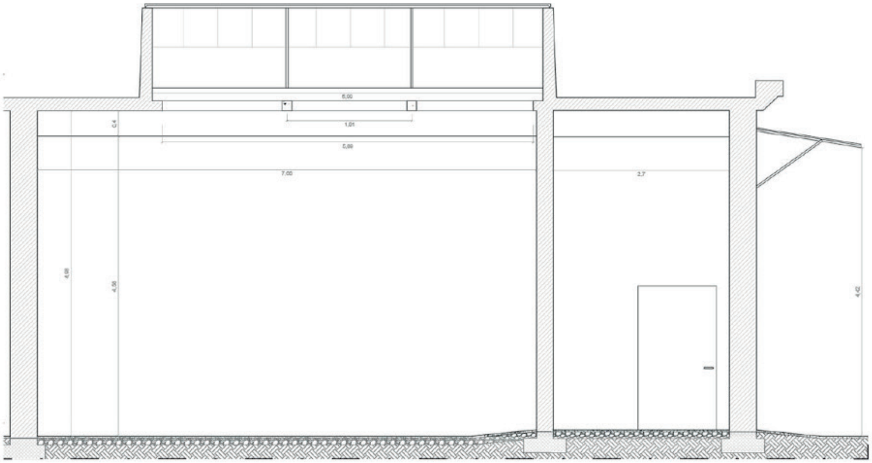


Longitudinal section (D D) of the Red Room

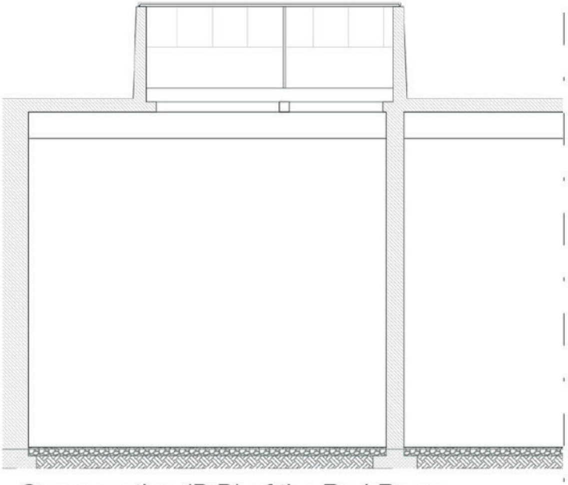


Longitudinal section (C C) of the Red Room

Figure 20 and 21. Longitudinal sections of the Red Room



Cross section (A A) of the Red Room.



Cross section (B B) of the Red Room.

Figure 22 and 23. Cross sections of the Red Room

1.4 “La Termitière 1.0”

The first project got the approval from the Commission for Contributes and Student Projects on the 25th of February, 2016. The proposal was presented by a team of eleven students, three of which, Angelo Iurlaro, Arthur Bohn and Gaia Conti, were the coordinators. The project was was under the supervision of Andrea Bocco, associate professor at the Interuniversity Department of Regional and Urban Studies and Planning. Architects and artisans would assisted the student’s work. University staff were also involved, offering technical and scientific support, like Angela Lacirignola, the professors Mario Grosso, Carlo Caldera, Construction Engineering professor, Daniela Bosia, Architecture Technology didactic area, Manuela Mattone, Restoration didactic area, Paolo Tamborrini and Marco Perino.

Figure 24. “La Termitière” first team.
Source: http://piemonte.checambia.org/

Activities were organised as workshops, to which students could apply and enroll. By participating, they would work with materials like straw, clay and lime. This would help understand the different processes and phases that take place while using these materials in construction, increasing the awareness on the technological solutions a builder can apply. They would also benefit academic credits for taking part in the workshops.

The project was planned to fulfill the following targets:

- Retrofitting a dismissed area, paying attention to the thermic insulation and the salubrity and breathability of the building envelope

- Creating an "academic building site" where students could acquire practical knowledge on some building materials and techniques
- Exchanging information between students of different courses and ages
- Promoting a short supply chain for building materials, choosing low environmental impact and low cost materials, minimising the industrially processed materials
- Analysing the performance of the materials in terms of thermal and acoustic transmittance, and creating a database
- Performing research on the materials and techniques used in this project

During the first phase, the north and west walls and part of the east wall were insulated. These walls were also plastered.

Figure 25. The north wall after the implementation of light earth and the raw earth plaster
Photo: Arthur Bohn

North and west walls were insulated with a clay and straw mix, while in the east with lime and straw. Different kinds of finishings were applied, with clay, lime, cocciopesto, straw.

The activities were documented by Angelo Iurlaro in his master thesis[1] where he presents his experience and the knowledge he came to acquire while being part of this project and also the data collected.

[1] MSc thesis titled: La Termitière Progetto didattico di riqualificazione al Cecchi Point Edilizia Biologica e Autocostruzione

Figure 26. The Red Room after the first phase of the project was completed
Photo: Angelo Iurlaro

During the planification and realisation of the second phase of the project, the organisational team had the possibility to consult various documentations regarding the materials and the techniques implemented on phase one, and also recreate real life samples of the applied solutions.

The labour was almost completely carried out by the the students, so the final project had to change some of the solutions initially proposed. Some works which couldn't be finalized were the construction of some decorative furnishing elements incorporated in the wall, as well as some hollows that could have been also used as shelves. In spite of that, the initiative was successfully carried out.

Figure 27. The eastern wall after the straw-lime implementation and plaster application
Photo: Angelo Iurlaro

1.5 “La Termitière 2.0”

“La Termitière 2.0” project was submitted on February 2018 to the Commission for Contributes and

Student Projects. This proposal was a continuum of the first project, which started on February 2018. It aimed to finish the works started by “La Termitière 1.0”, while some of the old ex-students would perform the role of tutors by passing the knowledge acquired during the first phase.

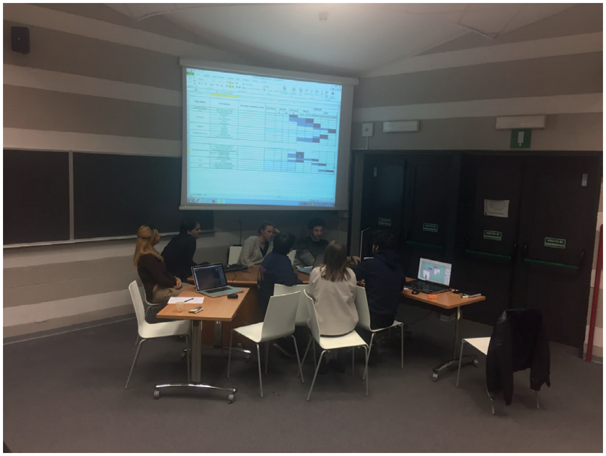


Figure 28. “La Termitière 2.0” organisational team developing the project for the submission.
Photo: Andi Dani

In order to have an organic progress, we ensured that the same academic staff would continue to follow the project. Meanwhile, changes were made in the coordinating team. One of the coordinating students, Arthur Bohn, was also part of the new team. Some other ex-students, followed the works and the evolution of the project as external collaborators, constantly exchanging information and working side by side with the new group.

The new organisational team was formed by students of Architecture, Construction Engineering and Cinema Engineering. The coordinators were four: Arthur Bohn, Louis Chapsal, Ester Carissimi and myself.

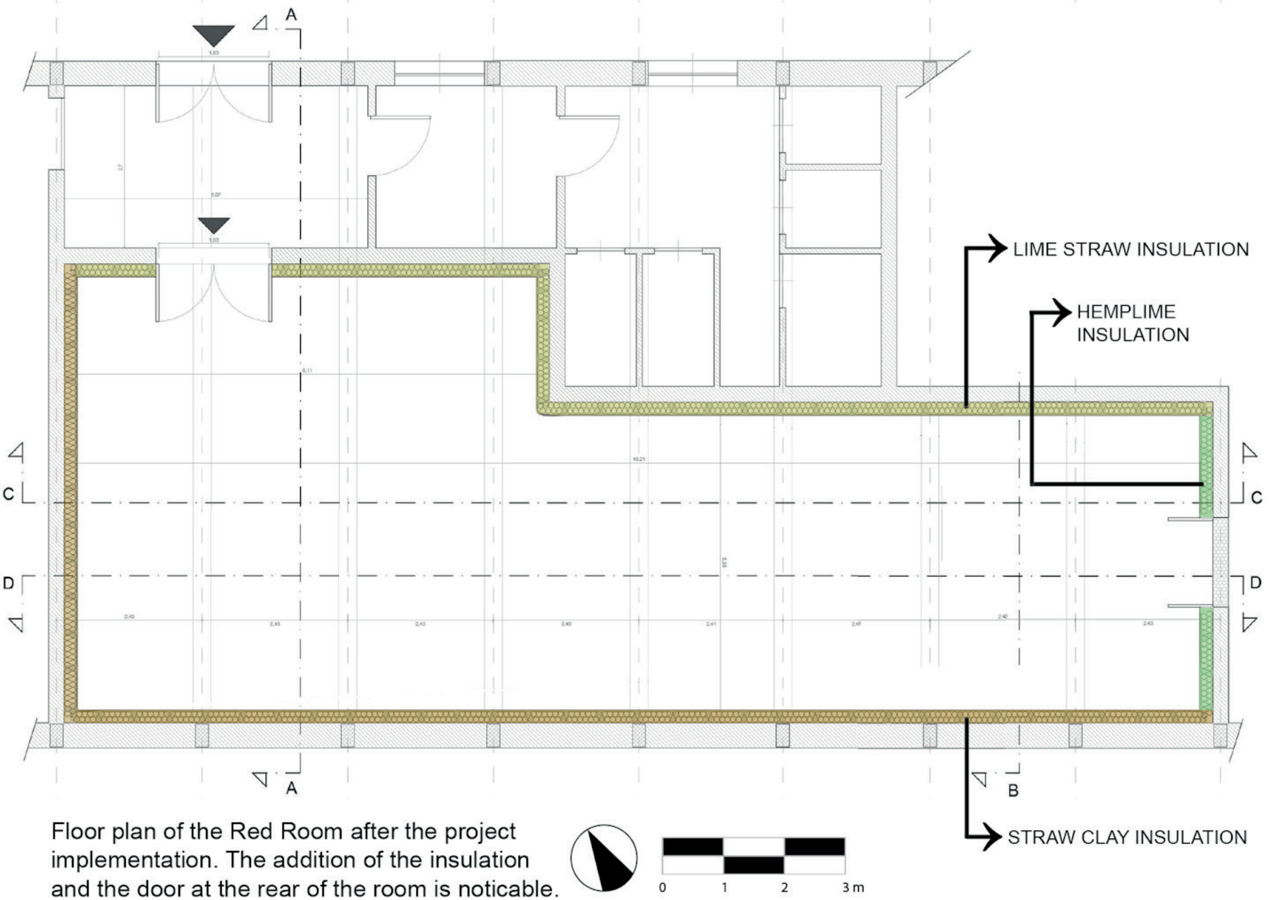
The project that was presented proposed the following activities:

- Complete the insulation of the east wall using prefabricated insulation panels and covering with wooden boards. The lower part of the wall had already been insulated with the lime and straw and plastered in clay
- Insulating the wall which divides the Red Room from the Officine Creative using hempcrete
- Insulating the hole in the wall dividing the Red Room from the Officine Creative using prefabricated insulation panels made of recycled PET plastic

- Building a double door made of prefabricated hemp panels, produced by a company that has patented these panels, that presented high mechanical properties
- Painting the small entrance hall and the entrance doors
- Rendering and painting the outside wall near the entrance
- Rearching an insulation solution for the floor and building a mosaic on the floor of the Red Room. As this process needed more time than expected, it was replaced with a faster solution
- Searching a solution for the insulation and the construction of a countertop on the ceiling
- Finding a solution to intervene and/or insulate the degraded lanterns, choosing between maintaining the old openings and leaving them in the same condition but building two horizontal windows underneath in order to create small insulation greenhouses.

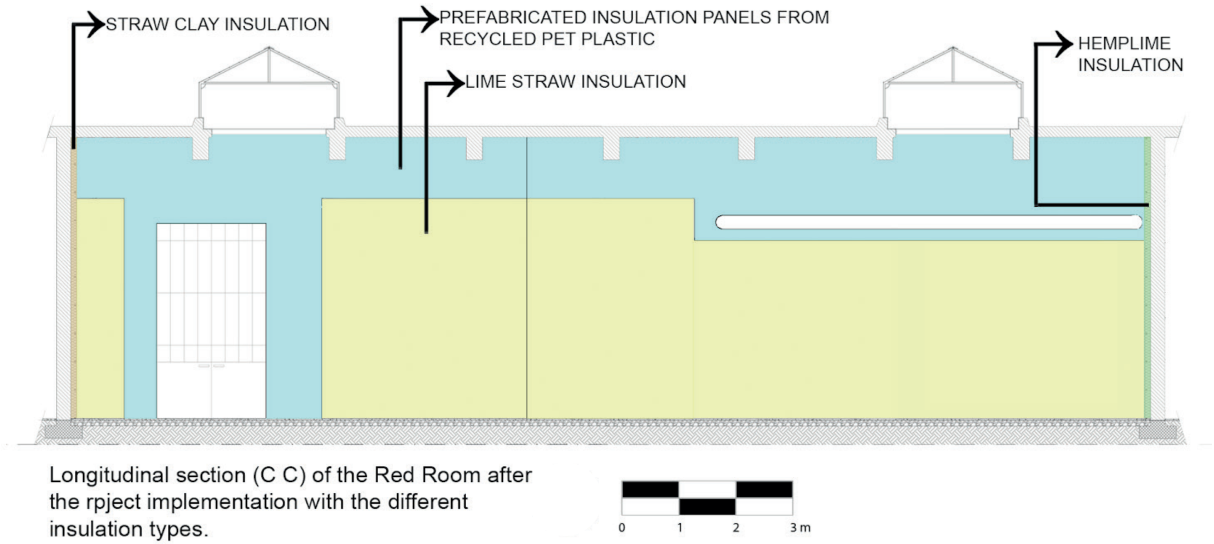
Figure 29 and 30. The entrance door before (left) and after (right) it was rotated and changing the glasing elements. CANAPALITHOS 350 were fixed around the door.
Photos: Andi Dani

Figure 31. The cocciopesto plaster being applied on the facade wall of the Red Room.
Photo: Andi Dani

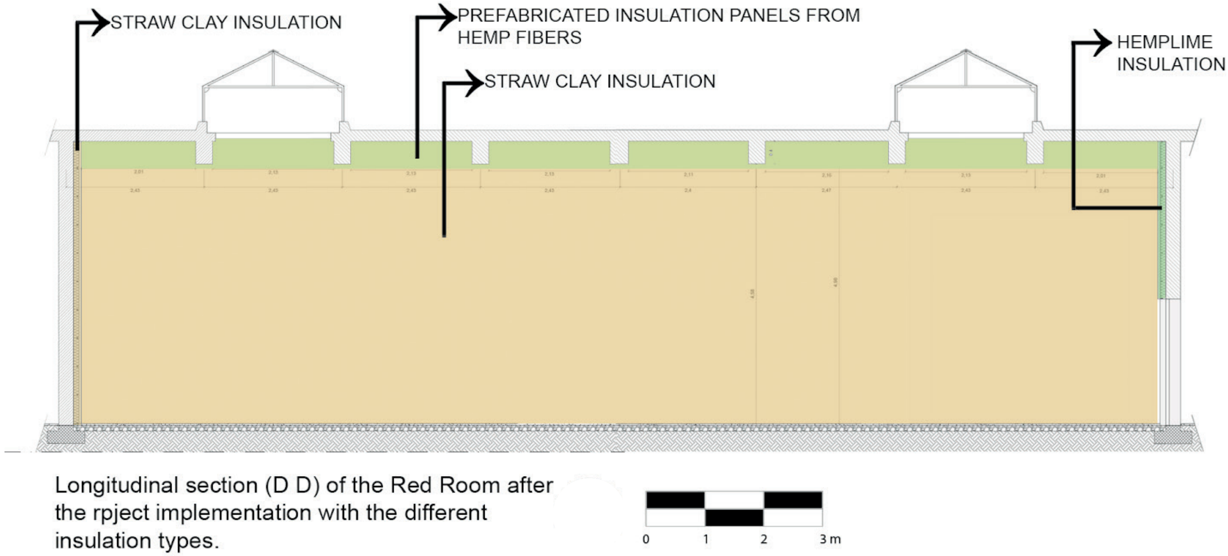


Floor plan of the Red Room after the project implementation. The addition of the insulation and the door at the rear of the room is noticable.

Figure 32. The floor plan of the Red Room showing the different types of insulation materials used.



Longitudinal section (C C) of the Red Room after the rpject implementation with the different insulation types.



Longitudinal section (D D) of the Red Room after the rpject implementation with the different insulation types.

Figure 33 and 34. Longitudinal sections of the Red Room showing the different types of insulation materials used.

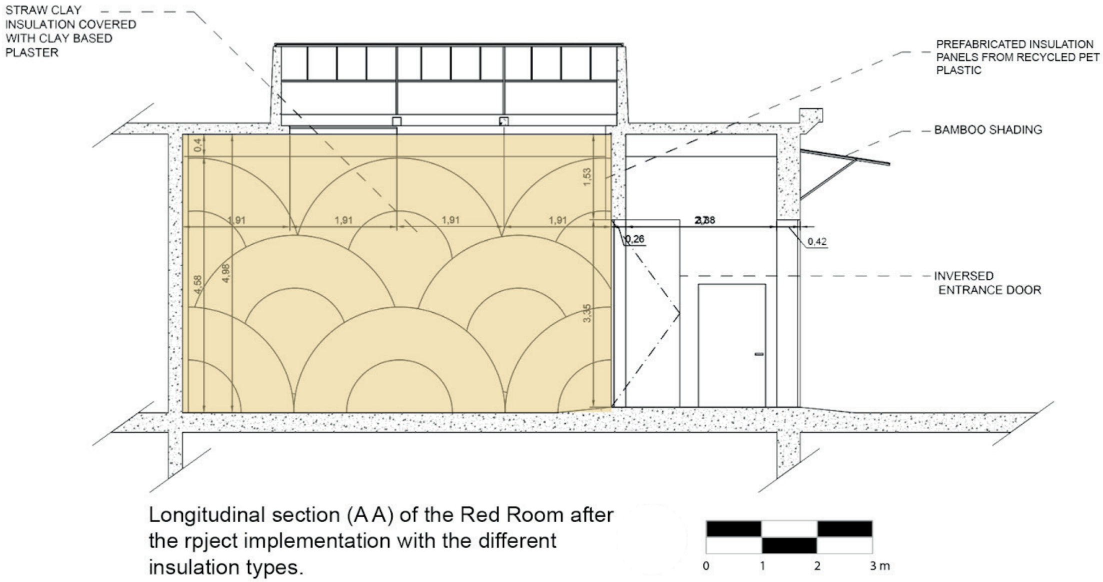


Figure 35. Cross section of the Red Room showing the different types of insulation materials used.

All of the activities mentioned above had to consider an amount of research on old techniques and new solutions. This allowed us to consider different materials and mixtures and experiment with some alternative solutions or materials to apply in the Red Room. The decision in which techniques to use was taken according the environmental impact, efficiency, feasibility, durability and the application easiness. It was of major importance ensuring that these solutions would have a good performance, a guaranty presented from the research of different case studies that had adapted similar solutions. Students would be the primal manpower, so we were lacking constant expert labour.

The first activity was to finish the insulation of the east wall. It was chosen to use dry insulation, because the area of the wall which we needed to insulate was at a height of 3.8 m over the ground level. Continuing with the straw and lime would have not been easy. By applying dry insulation, we could learn a new way of operating, even though we were aware that by using two different kinds of insulation in the same wall, we were creating a linear thermal bridge. The solution was still approved, because the priority is learning how to apply different building solutions, rather than their final performance.

We used insulation panels made of polyester fibers, recovered from the recycle of plastic bottles, with a thickness of 10 cm. This product is named SINTHERM FR, it's produced by a company called Manifattura Maiano and has a thermal conductivity of 0.037 W/mK and good acoustic insulation properties. Wood joists were first fixed on the wall, creating anchors for the panels, which were inserted between them. The next step was fixing of birch plywood forms on the wooden joists, covering the insulation. The plywood was then painted in order to cover the screws and small imperfections. These works were carried out during the workshop that took place from the 5th to the 8th of April, and they were finalised during the workshop of 27-28-29 April, 2018.

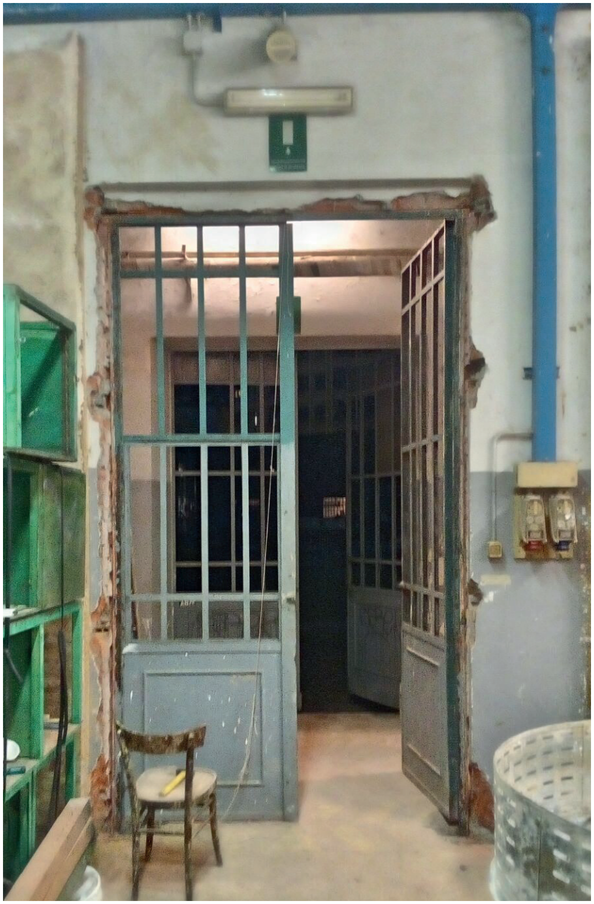


Figure 36. Entrance door from inside the Red Room before the start of phase two.
Photo: Andi Dani

Figure 37. The entrance and part of the east wall after the insulation panels made of recycled plastic were applied, covered with birch wooden boards and painted during the second phase.
Photo: Andi Dani

We then worked on the entrance double doors, made out of steel. The lower parts of the doors were opaque while the upper parts were glazed frames for collage of transparent or semi transparent materials. We unfixed the frame of the inner door and rotating it, changing the direction of the opening. Afterwards we cleaned them, removing the old paint, which had already fallen in different spots, and applying a new rust-proof layer of paint. The glazed parts were fully cleaned from the remaining degraded materials and filled with a 6 mm thick polycarbonate panels, which we attached with silicone. These activities took place during the April workshops as well, having divided the students in work groups.

We went ahead cleaning the entrance from the old paint and plaster where needed, in order to apply new plaster of sand and lime and repaint. The work on the outside wall had the same approach, but in this case, cocciopesto was added to the render. The activities related to the floor were implemented during two workshops, one on 27-28-29 of May, and the other one on the first days of June. They were limited to the stabilising using concrete, in order to reinforce the weak points, and to fill the areas where the floor was literally missing.
The workshops of held on the 14th-15th-16th and 17th of June were concentrated on the insulation of the wall dividing the Red Room from the Officine Creative. We first built a hemp double door which would allow the connection between the two rooms. During this activity, we were helped by the carpenter who operates in the Officine Creative.

Figure 38. The south wall insulated using hempcrete and SNTHERM 40 100 insulation panels.
Photo: Andi Dani

Figure 39, 40 and 41. One of the voids in the Red Room's floor getting filled with a reinforced concrete mix.
Photo: Andi Dani

The door was built using compressed hemp panels, which produced by a company called CMF GreenTech. This company provided different kinds of panels, produced under the brand CANAPALITHOS. The product name is followed by a number, which indicates its density. Different samples were made available to us, allowing the selection of the most suitable panels.

Figure 42. The hemp doors built with the CANAPALITHOS 350, timber and hemp fibers.
Photo: Andi Dani

These panels are made out of hemp shiv and use different binders, all patented by the company. The CANAPALITHOS panels are compressed, a procedure that plays an essential role on their structural properties. We chose the CANAPALITHOS 1000 and CANAPALITHOS 350, the weight of which is respectively 1000 and 350 kg/m^3.

Figure 43. The void on the south wall where the hemp door is to be built viewed from the Officine Creative.
Photo: Andi Dani

Figure 44. The south wall from the Officine Creative after the hemp door was built and fixed.
Photo: Andi Dani

The door was built by assembling a wooden frame, on which to fix the hinges. It was made out of two CANAPALITHOS 350 panels and hemp fibers, adapting a sandwich solution with rigid panels on the exterior concealing the insulating fibers. Birch plywood was then cut and fixed around the angles, in the parts of the door that would submit constant impacts.

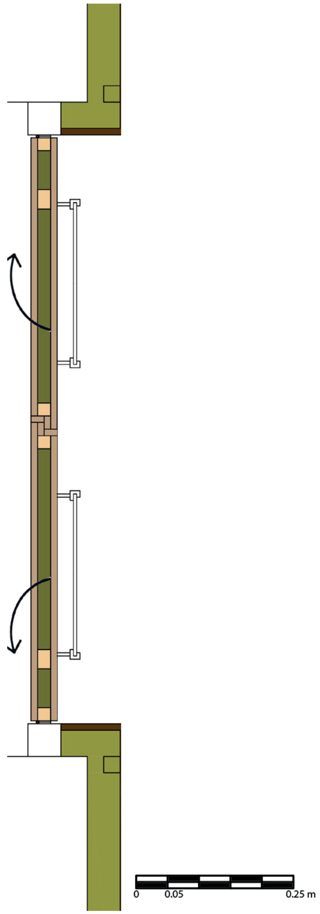


Figure 45. The design of the hemp double door built on the south wall.

Afterwards, a wooden frame was fixed to the wall. This frame would host the subframe, to which the the door would be fixed using metal hinges. The area around the door was insulated using prefabricated insulation panels, with the same technique used on the upper part of the east wall, but this time the insulation was covered with CANAPALITHOS panels instead of birch plywood.

The remaining part of the south wall was insulated using a premixed hemp and lime product purchased from EdilCanapa, a brand created by a company called Metalinea s.r.l.. This activity took place during the workshops of 20-21-22 July and were finalised during the last encounter on 12-13-14 October. After the application of the hemp and lime insulation, a hemp and lime thermal plaster was applied.

All these activities helped us learn different insulation and plastering techniques, their properties and to understand the application time for each activity. This helped us think of building design in a more complex way. The possibility itself, to have a space where young aspiring architects could translate their ideas in a real construction, was a real opportunity for students, most of whom had never been on a building site in their whole training.

Figure 46. The Red Room on the final stages of the second phase of the project. East wall (left) and south wall (front). Picture: Arthur Bohn

Figure 47. The Red Room on the final stages of the second phase of the project. North wall on the front.
Picture: Arthur Bohn

Chapter TWO

2. LIGHT EARTH INSULATION

2.1 Light earth composition

Light earth is a biocomposite material created by mixing straw and clay. It has been used for centuries as an infill material for walls, mostly for timber framed buildings. There are numerous cases across Europe where this mixture has found application, for at least eight centuries (Germany)[2].

Since the 1980s, natural building architects started promoting the use of light clay and straw, while reviving the interest on traditional building techniques and natural materials.[3]

Light earth is a simple method of creating infill material and thermal insulation panels for walls. The ingredients of this aggregate are three: straw, clay and water. Sometimes a small amount of lime putty can be added to the clay and water mix, in order to increase its mechanical properties.

2.1.1 Straw

Straw is an agricultural byproduct, a waste material, which normally makes up almost half of the yield of cereal crops, such as barley, rice, wheat, oats and rye. This means that this material is available in large

[2] There are traces of the usage of this technique as an infill material from the 12th century in Germany. Source: An Introduction to Traditional and Modern German Clay Building

[3] Source: “The art of natural building: design, construction, resources. pp. 165-170.

quantities all over the world. It has been most commonly used as animal feed or bedding, as biomass, as main element for basketry, hat making, packaging, shoemaking, for making ropes, paper, in horticulture and as a construction material.

The straw we used for the construction of the straw and clay insulation consisted in:

- 2 round bales of wheat coming from Chieri with a diameter of 1.2 m and 1.5 m tall. Each round bale weighted 350 kg (700 kg in total)
- 2 jumbo bales coming from Chieri, 1.2x1.0x2.4 m. They weighted 430 kg each (860 kg in total) and their density varied from 180 to 200 kg/m^3.

It is important that the straw is conserved in a dry place before applied. Its humidity level should not be over 15-20%, which is the maximum level acceptable for an adequate straw clay insulation. If the humidity level exceeds the 20%, the use of these fibres is not recommended for any construction process.

Figure 48. The Jumbo straw bale while being inserted in the van that would transport to the building site.
Photo: Arthur Bohn

Figure 49. One of the wheat round bales once arrived inside the Red Room.
Photo: Jasenko Spahic

We conserved the straw in a dry place inside the Red Room, not letting it lay directly on the ground, but lifting it from the ground using a wooden support. Another important feature is the stem dimensions. Traditionally, the harvesting process has been done by hand. This kept stems almost in their full dimensions, and if they were to be used in construction, they had to be cut in smaller pieces. Today, harvesting is a mechanised operation. The machinery cuts the straw from the ground, chips the stems in small pieces (normally their length reaches 10 cm), and presses them together. The output consists in round or rectangular bales. The round bales are normally much more compressed than the rectangular ones, which means that the fibres of these straw bales are more damaged.

2.1.2 Clay

Clay is one of the main components of the soil. The creation of soil itself is a result of rocks which have been physically or chemically crumbled, transported, deposited and precipitated.[4] The mineral composition of soil is formed by different particles, the main of which are:

- Clay (diameter less than 0.002 mm)
- Slit (diameter 0.0039 - 0.05 mm)
- Sand (diameter 0.05 - 2 mm)

Sand and silt are materials which derive from rocks, and are considered rock particles, along with calcite, mica, quartz and feldspar.[5]

Different composition of sand, clay and silt make different kinds of soils. One of presenting the composition is the pyramid chart like the one used by the United States Department of Agriculture (USDA), which is the the U.S. federal department for farming, forestry and food, which has on each side the percentage of the three different particles we mentioned above, in order to identify different types of soil.

[4] USDA 1974, p. 112-113.
[5] Shah & Shroff 2003, p. 22.

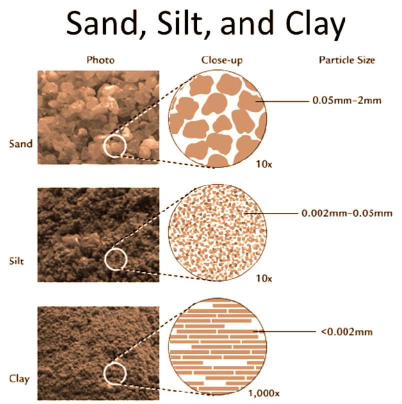


Figure 50. Sand, silt and clay. Their composition and design in microscopic level[6].

In the light earth mix, the clay component performs the role of the binder. The earth should have a 25 to 50% clay content. We had the possibility to use three different types of soils, one of which was obtained from crunching unfired bricks which were discarded before entering the kiln. These bricks were donated by the Carena Furnace. The other two were donated by architect Filippo Caggiano, who allowed us to dig in two different spots in his land, in Coazze.

[6]Source:ording-size-one-method-classifying-soils-mea-q16205151

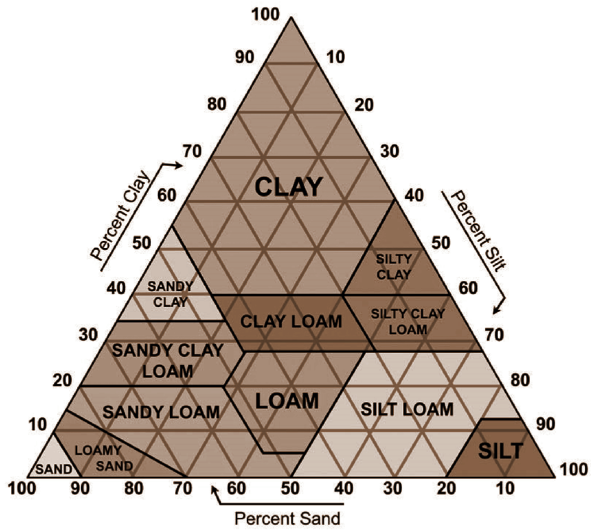


Figure 51. The chart that defines the soil types, as used by the USDA[7].

They were extracted from the subsoil, which is the part of the soil under the first 30-40 cm, where organic matter and roots are formed. One of the soils had a yellow colour and the other one tended to a more brownish colour. The difference in colour is the result of the different ratios of sand, clay and silt.

[7]Source:https://www.chegg.com/homework-help/questions-and-answers/soil-composed-particles-categorized-groups-acc

Figure 52. Crushed bricks used as a binder for the straw clay insulation
Photo: Margherita Pagliari

The sand gives structural and mechanical properties to the soil while the clay is a binder, which, when mixed with sand and silt produces a mixture that's workable and plastic while wet and hard resistant structure when dry. If the mixture has a high clay ratio, after the drying process, it is more likely to present cracks and slits. This process happens due to the structure of the clay which facilitates water absorption, increasing its volume while wet and making the mixture tend to retreat much more after water dries. This is a problem if the soil is used for the production of load bearing elements, like bricks, but a high clay content is preferred when the soil is used as a binder, like the straw clay insulation.

The empirical tests made on the soil during the first Termitière project aimed to analyse the performance and the composition of the three soils that we obtained; the soil obtained from the crunching of unfired bricks, the brown natural soil and the yellow natural soil. The first difference that was noted regarded the composition of the three kinds of earth. The earth obtained from the unfired bricks had a much higher clay content, which made this earth more compact and stickier, while the other two, which were less compact due to the higher sand content. One important experiment to verify this hypothesis was the sedimentation[8] test which would give some results even on the mold resistance of these materials. Samples of each earth were inserted in glass bottles, which were filled with

[8] Sedimentation is the process that shows the tendency of particles in suspension to settle out the fluid in which they are drenched because of their higher density, and come to rest against the bottom barrier.

water. The soil is added first, and the water next to avoid the quick absorption of the water from the soils with a high ratio of clay, which would not allow the earth to get completely wet, a process that could provoke false results. These bottles were shaken at two hours intervals for a whole day, then they were let standing still for eight hours. It was then noted that the first to precipitate were the sand particles, being the heaviest, while the on the top surface the presence of clay was noticed, the smallest particle in the soil mineral composition. It was obvious that the yellow earth had the highest sand ratio, followed by the brown earth, while the earth obtained from the unfired bricks was the most clayey earth. The precipitation of the yellow soil was very uniform. Mold was manifested almost exclusively on the top surface, while the brown soil, being more clayey, showed mold presence signs spreaded over the whole precipitated material. A more chaotic mold presence was noted on the earth obtained from the unfired bricks, due to the moisture entrapment, low permeability and scarce capillarity which causes poor water movement.

Figure 53. The sedimentation test results.The first bottle contains the earth from the crushed bricks, the second the dark subsoil earth and the third one the yellow subsoil earth.
Photos: Margherita Pagliari

The test results made it easier for us to decide that the earth obtained from the bricks would be the best as a binder for the light straw clay insulation.

2.2 Light earth implementation as insulation in the Red Room

“La Termitière” developed a project to retrofit a former industrial building using natural materials like straw, hemp, earth and lime.It was decided to insulate the room from the inside, using different biocomposite mixtures such as light straw clay, straw and lime and hempcrete.

The first work was the light earth insulation. This mixture was applied against the northern and eastern walls of the Red Room.

The biocomposite had to be be implemented on existing walls, so it was used as insulation, not as an infill material.

2.2.1 The timber skeleton

First, we built a timber skeleton against the walls. This timber structure consisted in 5x10x250 cm studs fixed vertically to the wall with screws. The distance between the stud centers varied from 50 to 70 cm. The short side of the joists (5 cm) goes against the wall. 2x2 cm wooden battens were fixed onto the long side of the studs, in order to create a jointing system. This system is put to work adding other wooden battens horizontally in the distance between the studs, enclosed by the vertical battens and the wall. These elements are placed every 25 to 30 cm during the filling process.

Figure 54. The wooden joists used to build the studs. Initially it was thought to employ 10x10 cm section elements, but this was found to be excessive. The joists were therefore cut in half, reducing them to a 5x10 cm section.
Photo: Jasenko Spahic

The insulation shuttering is made out of uprights, the wall, and plywood boards fixed against the other short side of the uprights. This way, “pockets” are created against the wall, called forms, which are ready to be filled with the light earth mixture.


Figure 55 and 56. Left, the stud fixed against the wall using a steel L-shaped elements and screws, right, the process of fixing the wooden batten along the 10 cm side of the stud.
Photos: Jasenko Spahic

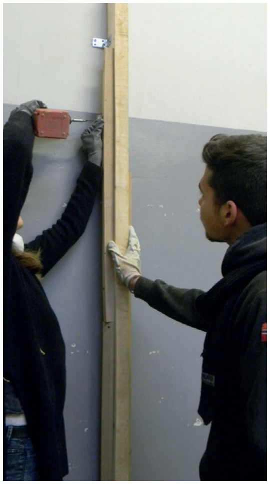



Figure 57 and 58. On the left, one shuttering completely finished and ready to be filled. On the right, two students fixing the wooden batten to the upright.
Photos: Jasenko Spahic

Figure 59. The jointing system between the vertical battens and the horizontal wooden element, if the light earth is used as an infill material in a free-standing wall. In our case there was only one vertical wooden batten, because the wall would serve as a support from the other side.
Photo: Andi Dani

Before applying this insulation layer, the permeability of the floor surface should be checked. In our case, the floor was degraded and lacked any of insulation. To avoid direct contact with the floor, wooden elements were fixed, elevating the insulation at least 10 cm from the ground. The space between floor and light earth mix can can be filled with other materials, like expanded clay or foamed glass, that would drain the rising damp. Both straw and clay absorb moisture, and direct and constant contact with a moist surface would weaken the mechanical performance of the clay binder and the decay of the natural straw fiber.

Figure 60. Expanded clay used to fill the space between floor and the light earth insulation.
Photo: Arthur Bohn

Figure 61. Light earth as applied in the Red Room**.**
Photo: Nicoletta Palama

Figure 62. Light earth insulation applied and wooden board taken off showing a way to detach the insulation from the floor.
Photo: Arthur Bohn

2.2.2 The preparation of the mixture

Just a few ingredients are required make a light earth mix and it is not very hard to prepare. The typical light earth mixture is made out of only pieces of straw stems and clay slip. Nevertheless, a 3 to 5 % in volume of lime putty can be added to the clay and water mix, in order to increase its mechanical properties and repelling the flora and fauna that can find a suitable habitat in the light earth mixture.

We chose to use a simple clay slip and straw mixture.

The earth used for the clay slip was the one we obtained by crushing the unfired bricks and water. The earth was put into buckets, wheelbarrows or barrows that would make the mixing process possible.

Figure 63. Earth and straw exhibited in the Canapissima hemp fair La Termitière participated.
Photo: Andi Dani

The first ingredient to be put is the earth, then water is added gradually while constantly mixing, to maintain a homogenized mix. The water added should be enough to obtain a clay slip that, when poured on a plain surface, spreads around a 15 to 20 cm radius. This means that once a semifluid mix is created it should be checked if the clip it’s ready for application.

Figure 64 and 65. On the left, the process of crushing the unfired bricks, passing them through a sand mix mill. On the right the process of preparing the clay slip from the crushed bricks.
Photos: Arthur Bohn

Figure 66. Testing if the clay slip is ready, pouring it into a flat smooth surface and checking if it spreads in a 15 to 20 cm radius.
Photo: Margherita Pagliari

Figure 67. The clay obtained from crushing the unfired bricks.
Photo: Andi Dani

A light earth aggregate can can be obtained using various kinds of vegetal fibres. The straw stems used in the Red Room derived from wheat and was already chopped in pieces from 2 to 15 cm. The agricultural machinery used for harvesting also gathers and ties the straw into a round bales compresses the stems in order to reduce volume, making it easier to transport and store them. This means the straw should be spread first, an operation done manually, preferably over an impermeable layer. We used waterproof sacks which we laid over wooden pallets. This process allows the compression reduction and increases its workability. This is also the moment that the straw can be cleared of eventual seeds and impurities.The compressed stems sometimes are too damaged to be used. After the straw is spread, the clay slip is gradually poured over it, while simultaneously mixing the materials.

Figure 68. Straw dipping in clay slip. If the straw stems are soaked, they can get more clay binder attached to them and subsequently, they can create a denser composite compared to when clay slip is poured over the straw. This would increase the mechanical properties of the panels, but it would reduce its thermal performance as an insulation material.
Photo: Andi Dani

Figure 69. Light earth insulation life size model that simulates an angle when this material is used as infill material. The mixing process is the same as when light earth mix is used to insulate existing walls.
Photo: Andi Dani

Neither the straw, nor the clay slip are harmful materials for the skin, so this process can be done bare handed (or by using pitchforks, when the working with larger quantities). Anyways, the use of the protection mask is advised because of the dust particles that are released from the straw during this work. The straw-slip proportions should be checked while preparing the mixture.

Figure 70. Straw was initially spread over impermeable bags and then clay slip was gradually poured over it.
Photo: Jasenko Spahic

Figure 70. After the straw was spread over impermeable bags, the process of mixing took place, by gradually pouring clay slip over the straw and mixing it. Photo: Jasenko Spahic

The clay slip should be poured in a homogeneous way over the straw stems while mixing. The mix is covered with an impermeable bag and put over wooden pallets, for not less than 2 hours, and not more than 12. This permits the mix to release the excessive water, while the humidity levels become more homogeneous. During this time the straw fibres also absorb some of the water, becoming softer, increasing their workability. After this process, the light earth mix is ready to be put inside the shutterings.

Pictures 72, 73 and 74. Straw and clay slip getting manually mixed.
Pictures by Arthur Bohn and Andi Dani

2.2.3 Light earth application as insulation against an existing wall

When the wooden upright is fixed and the straw clay mixture is ready, it is time for filling. For this, rigid plywood boards that close the forms are needed to close the shuttering. One side of the board should span from the midpoint of one wooden stud to that of the next one.

Figure 75. After the mixing process is finished, the composite material is left from 2 to 12 hours to rest in a dry spot, covered by an impermeable bags.
Photo: Jasenko Spahic

The plywood boards are then fixed against the studs using screws. Subsequently, the light earth mix is put inside the shuttering by hand. even though this process can be carried out bare handed the use of waterproof gloves is advised to avoid small cuts and constant contact wet materials for a long time.

Figure 76. The filling process done manually, during the which a horizontal wooden batten was added every 25 -30 cm.
Photo: Jasenko Spahic

Figure 77. “The termites” while building the light earth insulation.
Photo: Jasenko Spahic

Figure 78. Straw and clay insulation as applied in the Red Room. The northern wall is in the front view.
Photo: Nicoletta Palama

Figure 79. Straw and clay insulation as applied in the Red Room. View of the eastern wall.
Photo: Nicoletta Palama

The mix is evenly distributed inside the shuttering, and then it is pressed, without excessive force. Pressing ensures that the insulation material fills the whole shuttering without creating big air gaps.

While going up with straw clay cast, every 25 to 30 cm a wooden batten is placed between the long vertical battens previously fixed on the side of the studs. The horizontal battens have to be pulled against the vertical ones, and then they are completely enveloped by the light earth cast. These elements will stay after the mixture dries. Their role is not to allow the horizontal movement of the insulation material which otherwise would not be connected to the wall .

After the first form is filled, the board can be immediately taken off by unscrewing, and the same board can be reused to continue to cast above. The mechanical properties of the light earth mix allow the cast to remain still after it is pressed, allowing an immediate unshuttering. This happens because the length of the straw stems creates a good connection between them. And because the binding properties of the clay slip.

This kind of insulation normally applied going upwards, which means that after the mixture is cast inside the first form, another form is built above it and so on.

Once the insulation is cast against the wall, the shutterings can be removed and it is left to dry. The drying process can go on for months. Mold and vegetation manifestation is normal. Typically, the time that a builder should wait before applying any finishing layer is defined from the dried up and dead sprouts on the surface.

The duration of the drying process is influenced by numerous factors, the most important of which are the related to the atmospheric conditions of the area. Outdoor temperature and humidity levels have a direct impact on the time necessary for the straw clay mix to dry. This period can range from less than one month to more than six.

After the drying process is over, the insulated surface is ready for the application of finishing layers. Natural plasters or thermo-plasters are suggested in order to maintain the breathability of the wall; if desired, the plaster may be painted.

Figure 80. Mold and vegetation manifestation during the drying process of the straw and clay insulation. This phenomenon is normal. Usually the builders know they can start applying finishing layers once the vegetation is all dried up and dead.
Photo: Andi Dani

2.3 Properties

Light earth biocomposite is a sustainable insulation and infill material, with a very good performance and really low carbon emission associated to its production[9]. Its thickness can vary from 8 to 35 cm, and its density from 100 to 800 kg/m^3, sometimes even more. Both straw and clay are materials that regulate the humidity levels of the indoor air, absorbing water vapour when excessive and releasing it back when in deficit.

We applied a 10 cm thick insulation layer. This thickness was decided to be maintained the same for all the insulation types that were to be implemented on the room; light earth, straw-lime and hempcrete, in order to easily compare their similarities and

[9] The quantity of carbon emissioned in nature for these materials can be measured by calculating the energy consumption of the agricultural machinery that gathers the straw and the soil and the transport until they reach the building site. The input energy can be reduced if the builder is already in possess of these goods.

differences related to their implementation and performance.

The density of the dried mix was 210 kg/m^3.

In order to know its properties as an insulation material, two samples of light earth were built and sent to the laboratory of the Department of Energy, one made with the brown subsoil clay binder, and the other one with the clay obtained by the uncooked bricks. These samples were 60x60x10 cm, and they went through Hot Guarded Plate (HGP) test.

Figure 81. The two 60x60x10 cm straw clay samples built for the hot plate test. On the left the sample with subsoil clay binder and on the right the one with unfired brick clay binder
Photo: Angelo Iurlaro

The machinery used for this analysis is called Lasercomp FOX600. This machine has a central plate with a rectangular shape, called “the hot plate”, which is shielded on the sides in order to convey the heat flow to the sample, limiting the radially dispersed heat flux (hence the name “guarded”).

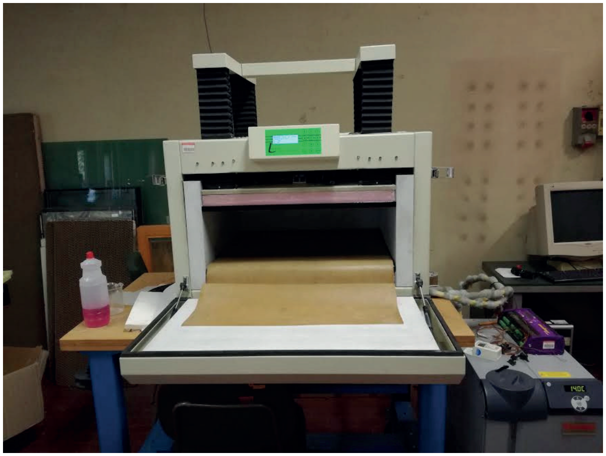


Figure 82. The Lasercomp FOX600 where the hot plate tests are performed.
Photo: Francesco Isaia

The plate is heated by ohmic effect, which is a way of generating heat by passage of electricity through an object which resists the electricity flow. The heat is generated quickly and uniformly in the particulates, so electrical energy is linearly translated to thermal energy. The thermal conductivities of the two samples were 0.098 W/mK for the mix of straw with the earth binder from unfired bricks and 0.090 W/mK for the other sample.

If the insulation material is not fireproof, it should have a certain fire resistance that allows this material to maintain its mechanical resistance and flame seal for an amount of time that would allow the users to get outside the building in case of fire hazards. The fire resistance can be indicated with the REI [10] symbol. The light earth with the density of the one we implemented on the Red Room (210 kg/m^3) has a fire resistance REI 30[11].

One, important characteristic of the straw clay insulation is its application temperature. The temperature range for the preparation of the mix and its application is from 5 to 35 ºC. Lower temperatures can cause the freezing of the mixture during its preparation, reduce it workability and slow down or even stop the drying process. Higher temperatures would present problems during the draining phase of the mix, a period of which the straw stems which are just mixed with the clay slip are supposed to become softer and more workable. The high temperatures may cause excessive drying during this phase.

Clay itself has a good thermal capacity[12](Volumetric heat capacity ranged from 148 to 354 MJ m^3 °C^{-1}), it is capable of filtrating and absorbing odours from the room and it is also vapor permeable, playing an important role on the hygrometric regulation of

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[10] The acronym REI derives from the French words: Resistance Etanchéité Isolement, which means Resistance Ermetic Isolation.
The REI symbol (followed by a number n), identifies a building element that maintains for a given time (n) the mechanical resistance, the flame seal and the hot gas release. The fire resistance classes are: 10, 15, 20, 30, 45, 60, 90, 120, 180, 240 and 360, and the number expresses the time, in minutes, during which the fire resistance must be guaranteed; the rounding up of the time at which the above mentioned criteria fails is defaulted. For example, a wall of insulating panels whose failure is reached at minute 36, will have I = 30.

[11] Source: http://www.gaiagroup.org/assets/pdf/publications/light%20earth%20compressed.pdf

[12] Source: https://www.researchgate.net/

the ambient. This last property of the clay allows it to absorb considerable volumes of water vapour present in the room air and then release it, without compromising the straw that is in contact with. This would also help regulate the rising damp.

Straw, on the other hand, has the capacity to sequester and store carbon. Straw is rich in cellulosic fibres, whose chemical formula is $C_6H_{10}O_5$. This means that approximately 45% of straw is carbon.

According to the Piedmont price lists, straw costs 85 to 170 euros per tonne[13].

Some of the most important properties and requisites for the light earth implementation are shown on the table above, which also confronts the two different light earth mixes we used. The estimated average time for the implementation of the light earth in the Red Room was 1-1.5 h/m^2.[14]

Tab.1. Light earth insulation		
Earth binder	Unfired bricks	Subsoil
Thickness	10 cm	10 cm
Density	210 kg/m^3	154 kg/m^3
Straw stem length	5 - 15 cm	5 - 15 cm
Application temperature	5 - 35 ºC	5 - 35 ºC
Fire resistance	REI 30	REI 30
Thermal conductivity	0.098 W/mK	0.090 W/mK
Implementa tion time	1-1.5 h/m^2	1-1.5 h/m^2
Number of workers	4-6	4-6
Drying time	0.5 to 6 months	0.5 to 6 months

[13]Source: http://www.al.camcom.gov.it/PriceLists/Pub/Item?id_level_2=6

[14] This average time is due to the inexperienced labour force and the initial lack of information over this construction technique. It be reduced to less than 1 hour per m^2 if the works are carried out by experienced workers.

Chapter THREE

3. STRAW-LIME INSULATION

3.1 Straw-lime composition

Straw has been used in building construction for a long time. It has found application not only as a raw material, but also in mixtures, with different binders. The most common binders for straw-based mixtures are clay and lime putty. Straw itself has very good thermal insulation properties. Considering this characteristic, it has been used frequently as an infill material and as insulation panel.

In the second chapter, we described how straw, mixed with a clay binder, can be used to create insulation panels. This chapter is focused on lime-straw insulation, while pointing out their differences and similarities. The binder used for the creation of this mix is lime putty, a material that derives from the processing of the limestone.

3.1.1 Straw

The straw we used for the straw-lime was different from the one used for the light earth insulation. It derived from the rice plant and was obtained from Antignano, near Asti. We employed 16 rectangular 0.35x0.5x0.5~1.2 m straw bales. The total weight was 480 kg (23 to 30 kg for each rectangular bale), while its density ranged between 80 and 120 kg/m^3.

The rice plant is almost in constant contact with moisture. Most varieties of rice ("swamp rice" or "lowland rice") need to be planted in stagnant water and require 200 mm of rainfall per month. This shows that the rice straw is more resistant to humidity and moisture, if compared with other straw types, like the wheat straw. For every kg of harvested rice, 0.7 to 1.4 kg of straw is produced, depending on the varieties.

Figure 83. The rectangular rice straw bales used for the lime straw insulation inside the Red Room.
Photo: Arthur Bohn

Traditionally, the rice straw and husk were considered as waste, and it has been either dumped into rivers or burnt in the field, causing GHG emissions, contamination and pollution. Today, these residues can be used not only in agriculture, as mulch or fertilizer, but also as a biomass or combustible material in the chemistry industry, as well as in the construction sector to produce MDF panels, bricks and insulation panels.

3.1.2 Lime putty

Lime putty is a traditional construction material that has been used for many centuries. It is produced from the processing of limestone.

Limestone contains 80% or more of calcium or magnesium carbonates. Once extracted from mines or quarries, the stones go through a heating process of temperatures from 800 to 1200°C in different kinds of lime kilns and quicklime is produced. The heating process has the following chemical reaction:

Calcium carbonate (100g solid $CaCO_3$) + heat (800-1200°C) = Calcium oxide (56g solid CaO) + Carbon dioxide (44g gaseous CO_2)[15]

Subsequently, the quicklime hydration called lime slaking takes place. The two types of slaking are:

[15] Source: Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide

- dry slaking, which means that the amount of water mixed with the quicklime is just enough to hydrate it and produce a powder called hydrated lime;
- wet slaking, created with the addition of a slight excess of water while hydrating the quicklime, creating the lime putty.

The slaking process is exothermic generating around 1.14 MJ per kg of calcium oxide, so the mixture of quicklime and water reaches boiling temperatures and has the following chemical reaction:

- Calcium oxide (56g solid CaO) + water (18g liquid H_2O) = Calcium hydroxide (74 g solid $Ca(OH)_2$)[16]

Wet slaking has been carried out in a traditional way in different countries, heating the limestone in self-built kilns, and then hydrating the quicklime in appropriate tanks or pools digged in the ground. After the slaking process takes place, the lime putty has to maturate for at least three months before utilisation.

Figure 84. Lime putty ready to be used.
Source: https://www.mikewye.co.uk

Lime putty is white in colour, has a creamy composition and a consistency that can be compared to that of yoghurt. This construction material is harmful to human skin, eyes and respiratory system, so direct contact should be avoided. It is suggested the use of the necessary gear like protective gloves, goggles and

[16] The ratio in mass indicate the proportion for the production of the powdered hydrated lime, while lime putty production needs an excessive amount of water.
Source:Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide

an adequate body suit[17]. For the straw-lime preparation, lime should be diluted.

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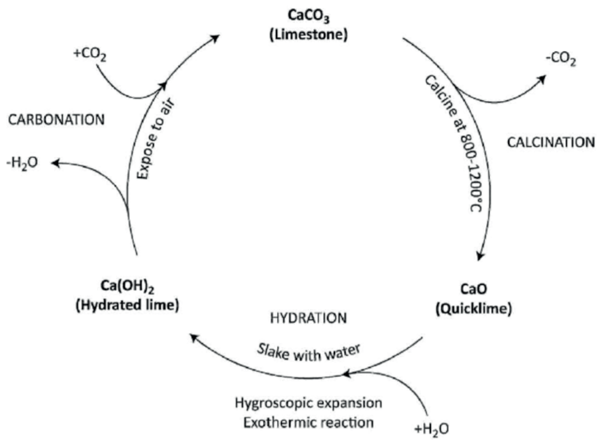

Figure 85. The lime cycle.The limestone goes through a calcination process while a 800 to 1200ºC heat is applied, producing quicklime. After the hydration process takes place, a carbonation process occurs while the hydrated lime is in contact with air and water, returning to limestone once again. Source:https://www.researchgate.net

Lime putty is used as plaster or mortar while mixed with sand, clay or pozzolanic materials, and it can be used as such if applied as finishing paint.

[17] If bodysuits are difficult to obtain, wearing two pairs of long-sleeved shirt is suggested to delay the lime putty from touching the skin in case of accidents during the work.

3.2 Straw-lime implementation as insulation in the Red Room

Lime straw was used for insulation in “La Termitière” project on the surface of the eastern wall. All the walls separate the Red Room from other indoor areas. The eastern wall separates the Red Room from the restrooms, which was the confining indoor area with the worst hygrothermal conditions.

The restrooms situation, with broken glasses on the windows and uninsulated walls, created a nearly direct contact between the eastern wall of the Red Room and the outdoor atmospheric changes. This means that the wall was subjected to high levels of humidity and low temperatures. That is the reason why an insulation solution, with higher resistance to humidity and moisture than light earth was chosen.

Figure 86. Part of the eastern wall after the application of the lime straw insulation.
Photo: Angelo Iurlaro

3.2.1 The timber skeleton

Straw-lime is a biocomposite material the implementation of which is done by casting it inside bedding forms. These forms, called shutterings, were built with the same approach as with the light straw clay insulation.

It consisted in a system of 5x10 cm uprights fixed vertically to the wall, at the sides of which, 2x2 cm wooden battens had been previously fixed in order to create a jointing system for the horizontal battens which are placed during the mix casting.. These short side of the uprights allows the fixing of two consecutive plywood panels with screws. The jostis, the battens and the plywood panels create the shuttering required for the straw-lime insulation.

Figure 87. The lower part of the wooden skeleton with the vertical joists fixed on the eastern wall.
Photo: Lorenzo Torre

Also in this case, it was assured that the mixture would not have touch the floor by adding wooden elements that elevated the bottom of the lowest form at least 10 cm from the ground level.

The choice of a timber skeleton was made taking in consideration the traditional way of building using wood and straw-based mixes and the ease of working with timber. The process of fixing the wooden uprights, drilling the adequate holes in the wall or screwing the wooden elements together in order to create the shutterings does not need qualified manpower.

Figure 88. Expanded clay used to fill the space between floor and the light straw clay insulation in another spot of the room.
Photo: Arthur Bohn

The timber was European silver fir (Abies alba). This kind of softwood is easily found in the Piedmont timber market. Being a softwood, its timber is mostly used for the construction of furniture, plywood and paper manufacture and building non load bearing structures[18].

A timber skeleton is also compatible with the idea of using

[18] Wolf, Heino. "Silver fir - Abies alba". *EUFORGEN "Technical guidelines for genetic conservation and use."*

natural and organic materials for the implementation of this project, in tune with the philosophy of “La Termitière” project.

3.2.2 The preparation of the straw-lime mixture

As explained in the first part of this chapter, lime putty is a kind of hydrated lime (calcium hydroxide), produced from the slaking process of the quicklime (calcium oxide) with water. Both quicklime and lime putty are strongly alkaline, the first more caustic, so it can produce severe burns if it gets in contact with moist skin. Lime putty, on the other hand, can cause skin irritations when the contact with the skin is prolonged, or the people that get in touch with it have particularly sensitive skin or suffer from any dermatological condition. The weather conditions, like hot or humid climate, play an important factor that tend to heighten the caustic effect of hydrated lime on the worker’s skin.

In order to avoid skin burns or irritation, some of the most important recommendations when preparing the lime straw mixture involve the following:

- Wearing long-sleeved shirts, without rolling the sleeves. In cool or humid weather, a second long-sleeved shirt is suggested.
- Wearing boots or high top shoes
- Wearing long pants or trousers tied over the shoe tops. Shorts should not be allowed.
- Wearing leather or impermeable gauntlet gloves.
- Do not wear clothes that would be too tight on neck and wrists, in order to avoid irritations and excessive sweating.
- Wearing safety goggles with side shields all the time while working with lime.
- Wearing face filter masks.
- Always bathe or shower after work in order to clean the body entirely off the lime.

The recommendations listed above were strictly followed while the lime straw mixture was prepared in the Red Room.

Figure 89. The lime putty used for the preparation of the lime straw mixture. It is a 25 kg sack of micronised slaked lime, double aged in tanks in order to reduce the excessive water. It was obtained from the Calce Piasco company. It is specified that this lime putty derives from magnesium limestone.
Photo: Andi Dani

The first operation was the spreading of the straw. The rectangular bales were opened and manually dispersed over some wooden pallets. This process reduces the straw density and increases the straw-lime binder contact surface. It is suggested that impermeable layers are placed under the wooden pallets, so that lime stains on the floor are avoided. After the straw is ready for mixing, the lime putty slip has to be prepared. This operation is similar to the clay slip preparation, but this time, mixing the lime putty with water.

The lime is first put into an adequate tank, then water is gradually added while constantly stirring. In order to obtain the correct density, a test should be done, using a 200 ml jug. The jug is filled with the lime slip and then poured over a smooth surface had been round circles with 20 and 30 cm diameter were previously drawn. If the lime slip uniformly spreads between these two circles, it is ready to be used. The lime we obtained came in 25 kg sacks and was produced by Calce

Piasco. The ratio was around 14 litres of water for a 25 kg sack.

Figure 90. Water being added to the lime putty to prepare the lime slip.
Photo: Josenko Spahic

Figure 91. The lime putty and water being mixed by an electrical mixer in order to get a more homogeneous slip.
Photo: Josenko Spahic

Figure 92. The lime slip density test taken over a smooth wooden board where circles with 20 and 30 cm diameters were previously drawn.
Photo: Josenko Spahic

The lime slip is less dense than the clay slip and may present hazards for the workers health, so, in order to avoid the excessive spreading of the lime, the mixing process proceeded by dipping the straw fibers into the tanks, instead of pouring the slip over the spread straw. The most common tool used for this operation is the digging pitchfork. The straw is grabbed with the pitchfork, dipped in the lime slip tanks and mixed, then dripped and layed over the wooden pallets to drain.

Figure 93. Students at work, mixing the dry straw with the soaked straw.
Photo: Stefano Iurlaro

After getting soaked in the lime slip, the straw quickly reaches a soft squashy state. This allowed to immediately apply the mixture, instead of waiting for it to drain, like with the light earth mix. The quick softening of the straw was driven by the highly alkaline pH of the lime slip, which had caused excessive moistness in the rice straw stems. The problem was solved adding almost the same amount of dry straw to the soaked straw fibres, constantly mixing it with the pitchfork. This way, a lower density mixture was prepared, which was ready to be applied.

Figure 94. Straw being soaked and dripped in tanks filled with the lime putty slip.
Photo: Stefano Iurlaro

Figure 95. The soaking of the rice straw in the lime slip. It can be seen the excessive amount of humid binder around the straw stems, which brought to the decision of mixing the soaked straw with additional dry straw in order to create a mix with an adequate density.
Photo: Jasenko Spahic

Figure 96. Soaked straw laying on wooden pallets is let to drain for a short period of time before being cast in the shutterings.
Photo: Arthur Bohn

3.2.3 Straw-lime application as insulation against an existing wall

The casting process for the straw-lime insulation is pretty similar to light earth casting.

The thickness of the straw-lime insulation implemented in the Red Room was 10 cm, the same as the thickness of light earth. This choice was made in order to make a more adequate comparison between the implementation and performance of the materials.

The operation starts with the construction of the timber skeleton and it proceeds by creating shutterings screwing plywood boards and than casting the straw-lime mix. The straw-lime mix presents higher workability, so the filling process is a little easier than with the light earth. This is due to the soft squashy state of the soaked straw, which made it possible to reach difficult spots and voids inside the forms with ease. The reinforcing horizontal wooden battens were also placed every 25 to 30 cm of poured cast, interlocking this element to the wooden studs previously fixed on the wall. The casting process advances in the same way as with the light earth, going from bottom up and reusing the same wooden boards once the form is completely filled to shutter the next form above it.

Figure 97, 98, 99 and 100. Top, the process of filling, going from bottom up, while using the same wooden board for the shuttering, and bottom, the insulated wall . Pictures extracted from the timelapse of the 26-29 May 2017 workshop

Figure 101. The wooden skeleton fixed to the eastern wall. In the middle of the room, the pallets and tanks are ready for the preparation of the mixture during the workshop of 23 May 2017.
Photo: Angelo Iurlaro

Figure 102. Students preparing of the lime straw mixture during the workshop of 23 May 2017.
Photo: Angelo Iurlaro

Figure 103. The casting process carried out by the students during the workshop of 23 May 2017. The lime straw mixture was initially laid over the wooden pallets for a short draining, and subsequently inserted in the shutterings.
Photo: Angelo Iurlaro

Figure 104. The bottom part of the eastern wall completely insulated. This portion of the insulated wall is 12 m long and 2.5 m high.It took around 6 hours for 20 students to complete this operation. This low productivity (0.25 m^2/h) was due to the lack of experience of the students, and the fact that the total number of the participants was 46 people, and they took turns on the the different processes required for the insulation construction. A faster application time was obtained later by the more experienced students, and it reached 15-20 min/m^2.
Photo: Angelo Iurlaro

3.3 Properties

The straw-lime mix is a material that can efficiently perform the role of an infill material, as well as that of a simple insulation panel. Its composition allows it to have a thickness that can vary from 8 to 35-40 cm, similar to the light earth insulation. The straw-lime we implemented in the Red Room was The cm thick and wall area insulated with this material is 89 m2. The volume of the implemented mix is 8.9 m^3 and has a total weight of 1112.5 kg.

Straw-lime insulation has a density of 125 kg/m3, which is almost two times lighter than the light earth previously implemented (210 kg/m3). This is due to the lime putty composition, which typically contains 55 to 70% by weight of solids, while the remaining part is water. The water leaves the mixture during the dying process, influencing its weight.

The information over the thermal insulation properties of this mix were obtained by creating a sample of 60x60x10 cm and sending it to the laboratory of the Department of Energy. This sample, like the light earth samples, went through the Hot Guarded Plate (HGP) test carried out by the same Lasercomp FOX600 machinery.

The straw lime resulted to be slightly more performant than the light earth insulation. Its thermal conductivity was 0.083 W/mK, while the light earth made with the unfired bricks binder had a thermal conductivity of 0.098 W/mK and the one with an earth binder obtained by the subsoil 0.090 W/mK.

A more performing insulation material increases the possibility of condensation. Nevertheless, the lime binder is a material which creates highly breathable mixes, even when used in sand mixes for the production of mortar. This property neutralises the condensation process.

Straw is an organic material of vegetal origin, and if in constant presence of moisture or high humidity levels, there is a high possibility of mold and fungus manifestation. This phenomenon is inevitable in a straw clay mixture, but in the lime straw mix, the alkaline ph of the lime binder prevents almost completely the manifestation and growth of any vegetation. On the other hand, the straw being part of a plant, it has the ability to absorb CO_2 from the atmosphere, retaining the carbon and releasing the oxygen. This phenomenon has a positive impact on the environment and reduces the carbon footprint of this mix.

Italy is the second biggest producer of lime in Europe, after Germany, followed by France and Belgium[19]. The availability of this product makes it a sustainable choice, from the environmental and economic point of view. The price of the lime putty in the Italian market varies from 0.1 to 0.5 €/kg.

The straw-lime insulation material does not necessarily need the presence of a qualified workforce for its implementation. It important though the use of the protective gears form the workers during its implementation. The application time resulted shorter than that needed for the straw clay insulation. This because in this case, there is no need to wait for the fibers to soften after they are mixed with the binder, but it can be directly inserted inside the forms.

[19] In 2004, Germany was ranked the biggest producer of lime amongst the European states with over 6.5 million tonnes per year, followed by Italy with over 3.1 million tonnes per year and France with almost 3 million of tonnes per year. Source: JRC RR - Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide

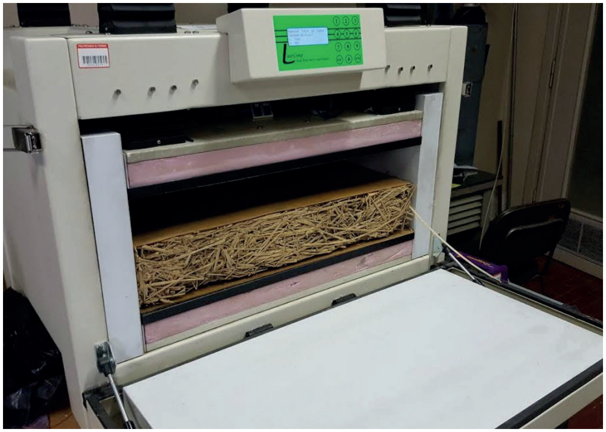

Figure 105. The straw-lime sample inside the Lasercomp FOX600 machinery before the initialization of the analysis.
Photo: Francesco Isaia

Figure 106. The preparation of the straw-lime sample which was sent in the laboratory for the Hot Guarded Plate test.
Photo: Martina Bocci

Figure 107. The 60x60x10 cm straw-lime sample, after the OSB wooden boards were taken off, in order to have a quicker and more efficient drying. A plastic grid was fixed on both sides to help preserve the shape of the sample.
Photo: Martina Bocci

The implementation time is shortened also by the fact that the straw fibres, once mixed with the binder, do not require an excessive pressing process because they easily fill the shutterings, filling the empty spaces between stems with their own weight. One square meter of lime straw with a 10 cm thickness requires 10 to 30 minutes, if carried out from unprofessional workforce, without considering the mixture preparation time.

Tab.2. Straw-lime insulation properties (Lime putty)	
Density	125 kg/m^3
Thickness	10 cm
Granulometry/ fibre length	5 - 15 cm
Application temperature	5 - 35 ºC
Thermal conductivity	0.083 W/mK
Application time	10-30 min/m^2
Drying time	0.5 to 2 months

Chapter FOUR

4. HEMPCRETE

Hempcrete is an aggregate material created by mixing hemp shiv and a binder with water. It is used in construction as an infill material non load-bearing walls and as insulation.

Hemp shiv (shive, hurd, hemp wood) is the woody part of the hemp stem that is broken into pieces and separated from the fibers. Traditionally, hemp has been used for its fibers which were utilised for the production of ropes, textiles, and sail canvas. The shiv is a byproduct created during the process of scutching, and has been used for animal bedding and paper production.

The binder used in this mixture is most commonly natural hydraulic lime, which sets through hydration. Other binders, like Portland cement and natural cement, hydrated lime, pozzolans etc., are used in mixtures with hemp shiv for the creation of hemp bricks, insulating fills or screeds, while synthetic or other suited binders are used for the production of particleboards.

4.1. Hemp shiv

The hemp shiv used for the hempcrete mix can be obtained from almost any type of hemp plant. The criteria for the proper selection regard the physical shape of the shiv, its conservation, the presence of other elements like fines, fibers or dust and the application method. When it is cast manually, the shiv pieces can be coarse, creating a structurally stronger mix and a more breathable matrix.

Figure 108. The hemp shiv in the premixed product obtained from Edilcanapa. This shiv is already mixed with a specific hempcrete binder.
Photo: Andi Dani

Normally, shiv certified for construction is found in a dimensions that vary from 5 to 25 mm, allowing the use of a spraying hose. Bigger pieces can block the hose.

It is important for the hemp shiv to be as clean as possible from impurities, paying attention to the presence of dust. If shiv that contains dust is used, the mechanical properties of the mixture will reduce drastically. The dust particles can mix with the powdered lime binder, reducing its quality, creating a high risk of collapse when the mixture dries. It is suggested to use shiv certified for construction, in order to avoid problems related to an adequate processing and conservation.

In Italy, the use of hemp in construction is not very popular, so the market of adequate hemp shiv for construction is not very wide. Some of the suppliers from which we could have obtained the shiv offered a turn-key contract, which meant they also handled the implementation of the hempcrete product, while other shiv suppliers did not possess any construction certification for their product.

The hempcrete technique was used by La Termitière for the insulation of part of the south wall of the Red Room. We obtained almost 1 m^3 of hemp shiv from Assocanapa, the dimensions of which were not higher than 20 mm. This material wasn't certified for construction and its excessive fiber content was too high, which would create difficulties in the mixing process and would also increase its density. For this reason, this shiv was used only for the creation of some samples and wasn't applied for the wall insulation.

We needed a shiv that contained very little or no fibers nor dust. The utilised hemp shiv was purchased from a company named Edilcanapa, whose product had been certified for construction with a minimum shiv dimension of 6 mm. Edilcanapa offers premixed products, which contain hemp shiv and the adequate binder, already bagged in the right proportion. Finding the hemp shiv and the binder separately in the Italian market was not easy, and this is one of the reasons why a premixed product was purchased. We could have bought it on the French market, where the demand for this product is larger. We chose to give Italian products a priority, and also received a considerable discount from Edilcanapa. By purchasing in Italy, the cost of transport was also lower because of the smaller distance from the supplier to the building site, reducing in this way the total carbon footprint of this mix.

Figure 109. The hemp shiv donated from Assocanapa. The gray colour is due to the presence of dust and excessive fibers.
Photo: Andi Dani

4.2. The binders

The hempcrete composite uses lime as a binder, usually natural hydraulic lime (NHL). There are three different hydraulic natural limes; NHL 5, NHL 3.5 and NHL 2. The number that follows the acronym indicates the compression strength of the binder 28 days after applied. Natural hydraulic lime NHL 5, which is the most used binder for hempcrete, is difficult to be found on the Italian market. It has a compression strength of $5N/mm^2$ 28 days after it has started to set. Anyway, the cases where this binder is used alone, without the addition of other ingredients, are rare. This happens because lime has a slow initial set, so removing the shuttering directly after the mix has been cast might risk a collapse. In order to have a good initial set, which would accelerate the work of the builders, some companies have developed binders that are exclusively used in hempcrete mixes. They use hydrated lime as main ingredient, with the addition of Portland cement and a small amount of other pozzolanic ingredients. The exact components and proportions are confidential. Some of the proprietary binders formulated for the making of hempcrete are Tradical Hempcrete, a product from the UK which uses hydrated lime as the main ingredient, and Batichanvre from France, produced by the world's biggest producer of natural hydraulic lime called Saint-Astier.

Figure 110. The Tradical specific hemp binder produced by Lhoist UK.
Source: www.hemphasis.net

The binder used for the hempcrete insulation against the south wall of the Red Room came already mixed with the hemp, in premixed sacks. The exact composition of this binder is also confidential, but the company claims that their binder contains no cement that they use 100% "natural ingredients" to enhance the initial set.

Basically, the binders used for the creation of hempcrete mixes need vapour permeability to allow the drying of the shiv even after the initial set and provide a full set of the mixture over time. The initial set of the binder is something that builders need in order to have a time efficient construction process, and it is essential for a good drying process, allowing to take down the shutterings within 24 hours.

The construction of an adequate hempcrete mix require specialised manpower who would take responsibility for the quality of the mix.

Even though small hempcrete samples cannot be completely compared to how it would perform when applied in large scale, I tried to see how the hemp shiv would behave if mixed with different binders. No scientific tests were made with these samples, because the aim was observing workability, its ease of application and empirically define the properties of the different binders. Small samples with 16x6x3 cm dimensions were created using the following binders:

- earth obtained from unfired bricks;
- earth obtained from soil;
- lime putty;
- natural hydraulic lime (NHL 5);
- lime putty mixed with NHL 5;
- lime putty mixed with cow milk;
- Portland cement;
- powdered cocciopesto mixed with NHL 5.

The hemp shiv used for these samples was the one donated by Assocanapa. Before being applied in the mixes, it was cleared as much as possible of the excessive fibers it contained.

4.2.1. Sample 1 - Earth from bricks

This binder is the same used for the light earth mix. The proportions of hemp shiv, binder and water vary from the size of the shiv, the type of the binder, the way of mixing and its application (insulation of walls, roof or floor screeds). The common shiv-binder ratios vary from 1:1 by weight for very light density mixes, to 1:3 for high density mixes. For this sample, a 1:2 ratio by weight was used, mixing 220 g of earth and 110 g of hemp shiv.

Figure 111. Saturated earth obtained from unfired bricks and hemp shiv before being mixed.
Photo: Andi Dani

First, earth and water were mixed in a bucket. The hydration process was carried out gradually, until the binder reached a semi-fluid, homogeneous state. This required 160-170 ml of water. Successively, the hemp shiv was added and mixed using a trowel (even though it could have been mixed bare handed). When the composite reached a homogeneous state, the 12x6x3 cm form was filled with it.

Figure 112. Earth from unfired bricks and hemp shiv wet mix.
Photo: Andi Dani

The form was removed after two days after the sample was left to dry. This mixture presented a good workability and it was easy to apply. After it dried completely, it seemed to have good mechanical properties, even though the mix was more morbid and it could be broken and crunched more easily than the common hempcrete mixes.

Figure 113. The sample once cast inside the woodform.
Photo: Andi Dani

A 40x50x10 cm sample with the same binder and the same ratio was also built.

Figure 114. Earth from unfired bricks and hemp shiv 40x50x10 cm sample.
Photo: Andi Dani

4.2.2. Sample 2 - Earth from soil

This sample was created mixing the earth from Coazze with hemp shiv. This time a 1:1.25 ratio by weight was chosen in order to create a lighter mix. 250 g of hemp shiv were mixed with 200 g of earth.

Figure 115. Saturated earth obtained from subsoil and hemp shiv before being mixed.
Photo: Andi Dani

The method is the same as the previous one: earth and water are initially mixed, then hemp shiv is added. The amount of water needed was 150 ml. There were no particular difficulties during the mixing process with a trowel, which means that this type of composite has a good workability as well.

Figure 116. Earth from subsoil and hemp shiv being mixed with a trowel.
Photo: Andi Dani

Once the mixture was ready, it was put in the form next to the first one in order to notice the differences the naked eye can detect.

Figure 117. The two earth-hemp shiv samples, on the left earth from unfired bricks and on the right earth form subsoil
Photo: Andi Dani

It can be noticed that apart from the different densities of two hemp-earth samples, the soil earth is less clayey than the brick earth, making the latter one a better binder.

4.2.3. Sample 3 - Lime putty

The third sample was made from mixing the hemp shiv with lime putty without adding water.

Figure 118. Lime putty and hemp shiv inside a clean bucket before being mixed.
Photo: Andi Dani

Waterproof protective gloves and protective goggles were used during the whole process. The ratio was 1:3 by weight. First, 300 g of lime putty were put in a bucket, then 100 g of hemp shiv was added.

Figure 119. The lime putty-hemp shiv wet mix
Photo: Andi Dani

The mixing seemed to be a little easier than the first two, and the mixture was more fluid.

Figure 120. The cast samples inside the woodform. The third one on the right is the lime putty-hemp shiv mix.
Photo: Andi Dani

If this aggregate had been used for a wall, it would have been impossible to remove the wood shutterings immediately after its application, because of its viscosity, although the casting process would have resulted easier. The dimensions of this sample are the same as the previous two. The dried sample had scarce mechanical properties. It needed very little force to crumble.

4.2.4. Sample 4 - Natural hydraulic lime (NHL 5)

Natural hydraulic lime is the most common binder used for the preparation of hempcrete. NHL 5 is the binder with the highest structural properties amongst the natural hydraulic limes. A 1:1.5 ratio by weight was used for the construction of the hemp shiv-NHL 5 sample. This proportion is used for the construction of low density hempcrete (the 1:1 ratio is applied to get a very light hempcrete mixture). For the preparation of this sample, 100 g of hemp shiv and 150 g of NHL 5 were mixed while both dry.

Figure 121. Natural hydraulic lime NHL 5 and hemp shiv before being mixed while still dry.
Photo: Andi Dani

Once the binder was uniformly spread, water was gradually added while constantly mixing with a trowel. This composite was easily workable, presenting better workability than the mixes with earth binder but similar to the one with the lime putty binder.

Figure 122. The NHL 5-hemp shiv mix after being cast in the woodform.
Photo: Andi Dani

The aggregate was then put to the form, next to the other samples. It presented much better initial set than the lime putty binder. The mechanical properties of the dry sample were worse than the properties that hempcrete made with specific binders. Another reason that this sample did not present very good mechanical properties was the quality of the hemp shiv, which was not certified for construction.

Figure 123. The four created samples. NHL 5 on the far right.
Photo: Andi Dani

4.2.5. Sample 5 - Lime putty and NHL 5

In this sample, lime putty mixed with NHL 5 was used as a binder with the hemp shiv. The ratio was 1:2 by weight, so 115 g of hemp shiv were mixed with 200 g of lime putty and 30 g of NHL 5. All the ingredients were mixed the same time. If this sample would have been larger, the hemp shiv and the NHL 5 would be initially mixed together, and then the lime putty would have been added.

Figure 124. Hemp shiv, lime putty and NHL 5 before being mixed.
Photo: Andi Dani

The necessary protective gear was used during the whole experiment. No significant difference compared with the other two lime-based mixes was noticed in term of aggregate workability, although the NHL 5 increased its initial set, compared to the lime putty sample. Once dry, it showed just slightly better mechanical properties as the third sample, being easily crumbled without using much force.

Figure 125. Hemp shiv, lime putty and NHL 5 after being mixed with a trowel.
Photo: Andi Dani

Figure 126. Hemp shiv, lime putty and NHL 5 mix cast inside the woodform once it had reached a homogenous state.
Photo: Andi Dani

Figure 127. The samples cast next to each other in order to easily observe the difference in their composition and colour.
Photo: Andi Dani

4.2.6. Sample 6 - Lime putty and cow's milk

Cow's milk is rich in proteins, among which casein. This is a conjugated protein which means that it links with other molecules (in the milk, it is bound with phosphorus in the form of esterified phosphoric acid). The phosphoric groups are important not only for the structure of the protein itself, but also for its function, since if charged negatively, these groups of proteins are able to connect with calcium and magnesium ions, a characteristic that gives this protein the function of calcium conveyor.

Figure 128. Hemp shiv and lime putty inside a clean bucket before the addition of milk.
Photo: Andi Dani

There are traditions and practices also used in industry that involve the use of lime and milk to produce not only food products, but also binders and glues. An example is the separating of cream from whole milk: lime water is often added to cream to reduce the acidity before pasteurization when butter is produced.

Figure 129. Milk being added to the lime putty-hemp shiv mixture, while constantly being mixed with a trowel. Photo: Andi Dani

The skimmed milk is subsequently acidified to separate the casein. Casein is mixed with lime and a small amount of sodium fluoride to produce calcium caseinate, a type of glue. The fermentation of the remaining skimmed milk (whey) and the addition of lime form calcium lactate that is marketed as a medicinal product or acidified to produce lactic acid. Casein, in the presence of calcium hydroxide $Ca(OH)_2$, binds with it, producing a glue. This glue increases the structural behavior of the entire mix.

Figure 130. The prepared mix cast inside the form. Photo: Andi Dani

The sample was prepared in a 1:2 ratio by weight of hemp shiv and lime putty, by first putting the putty and then the shiv in the bucket. Then milk is gradually poured while the aggregate is mixed with a trowel. 200 g of lime putty were mixed with 100 g of hemp shiv, while the amount of milk did not superate 100 g.

Figure 131. The created samples inside the woodform. The lime putty and milk mix on top.
Photo: Andi Dani

One more sample was created using these ingredients, but this time, the white part of the egg (albumen) was also added to the mix. This is another material which, when treated with lime, it is used for the production of some glues.

Figure 132. The sample of lime putty, milk and egg white exhibited at the Canapissima hemp fair.
Photo: Andi Dani

This mixture had a good workability as well. The dried sample showed better mechanical properties than the other samples created with lime putty, while the one with albumen offered stronger structural behaviour.

Figure 133. The sample of lime putty, milk and egg white after it was cut with a Japanese saw in order to observe composition of the dry mix.
Photo: Andi Dani

4.2.7. Sample 7 - Portland cement

A hemp shiv and Portland cement sample was also created in order to compare the well known binding properties of this material to the natural binders.

Figure 134. Portland cement and hemp shiv inside a clean bucket before being mixed.
Photo: Andi Dani

The mix had a 1:1 ratio by weight, with 100 g of hemp shiv and 100 g of Portland cement. This ratio is commonly used for very light density hemp mixtures with hydrated lime binders. Hemp shiv and cement were initially mixed together, then water is gradually poured. It resulted very easy to mix, presenting good workability, and also an ease of application.

Figure 135. The Portland cement-hemp shiv sample once cast inside the woodform.
Photo: Andi Dani

Portland cement has a very good initial set, which is why it is often one of the ingredients of specific hempcrete binders. The dried sample was the quickest to dry and had better mechanical behaviour, compared to the other samples.

Figure 136. The samples immediately after they were cast. The Portland cement-hemp shiv sample on the far left.
Photo: Andi Dani

4.2.8. Sample 8 -NHL 5 and cocciopesto

The last sample was created using a mix of NHL 5, cocciopesto and hemp shiv. The proportions of the mix were 1:1:1 by weight (or 1:2 ratio of hemp shiv and binder). 50 g of cocciopesto and 50 g of NHL 5 were mixed with 50 g of hemp shiv. Cocciopesto was used in a powdered state, although during the mixing process it could be felt that its granulometry was coarser than that of NHL 5, which means that it had a negative effect on the composite workability. It also increased the dying time of the mix.

Figure 137. The dry ingredients of the cocciopesto-NHL 5-Hemp shiv sample.
Photo: Andi Dani

The dried sample was the most fragile amongst the eight, and it crumbled almost immediately after the application of a very small.

Figure 138. All the samples next to each other the day they were prepared.
Photo: Andi Dani

4.2.9. Conclusions

The experiments made with the hemp shiv and different binders did not go through any scientific analysing process. The target was that of observing how these mixes differed in their preparation, their initial set and drying time[20], and have a glance over their mechanical behaviour. It resulted that all the mixes had a very good

[20] Even though the times of drying for samples of this scale cannot be considered relevant for big scale applications, they can empirically show the difference from one binder to another.

workability, with the samples made with the earth binder being the "uneasiest" ones. The best initial set and the quickest drying time was showed by the sample made with Portland cement, which was an obvious result, while the samples made with earth, followed by the cocciopesto and then the lime putty with milk were the ones that required more time to dry. From the mechanical point of view, the strongest samples were the ones made with Portland cement, earth, NHL 5 and the one made with lime putty and milk, while the other samples showed a scarce structural behaviour.

The sample made with lime putty, cow milk and albumen resulted to be very interesting regarding its mechanical properties, but it also showed a reduction of the porosity of the mixture matrix. Although the use of this mixture in a large scale would not be possible because of the improper use of these ingredients, the experimentation was compelling for academic research. The difference between a lime putty binder and a lime putty mixed with milk and albumen regarding their structural performance was very obvious even from the naked eye mechanical performance.

Figure 139, 140, 141 (previous page) 142 (above) and 143 (below). Pictures of the drying samples three days after they were created.
Photo: Andi Dani

Tab.3. The empirical results of the hemp samples

Sample no.	Workability	Mechanical performance	Porosity	Drying time (days)	Mortar mixer usage possibility
1	Good	Moderate	Low	10-11	No
2	Very good	Moderate	Moderate	9	No
3	Very good	Bad	Moderate	12-13	No
4	Excellent	Very good	High	7	Yes
5	Good	Moderate	Low	9	No
6	Very good	Very good	Very low	13-14	No
7	Excellent	Very good	High	5	Yes
8	Very good	Very bad	Low	8	Yes

4.3. Hempcrete application as insulation in the Red Room

The hempcrete bio-composite was used to partly insulate the south wall of the Red Room. This wall divides the Red Room from the Officine Creative, both indoor areas, so there is no excessive difference between the temperatures on the two faces of the wall. The decision to insulate only partly with hempcrete was taken because of structural problems in the existing wall regarding a reinforced concrete transom above the void where the hemp door was fixed, and it required further inspection from professionals working on behalf of the municipality. Apparently, a structural intervention was needed on this transom after a short period of time, so we decided to leave the area around it accessible, by using prefabricated insulating panels. This because if we were to apply hempcrete in the areas the inspector needs to analyse, it would have to be torn down by that time.

Figure 144. The 25 kg sack of premixed hempcrete CANAPAMAS 385.
Photo: Andi Dani

The thickness of the applied hempcrete insulation was chosen to be 10 cm, like the other two walls, maintaining a uniform dimension for better comparison.

4.3.1. The timber skeleton

The way the hempcrete aggregate is applied against an existing wall as insulation is similar to the two straw-based bio-composites described in the previous chapters. Even in this case, the construction of a wooden support that would build a shuttering system where the mixture can be cast is required. After the experience with light earth and straw-lime, some small modifications were made to the timber skeleton. 10x5 cm uprights were substituted by 5x5 cm. In order to create the necessary depth that would allow the application of a 10 cm thick hempcrete insulation, 5x5x15 cm wooden elements were screwed on the sides of the timber uprights that would go against the wall. These elements were fixed every 90-100 cm using two screws to avoid rotation. Steel L shaped brackets were subsequently screwed on both sides of 5x5x15 elements through which the uprights were fixed to the wall. This method allowed us to gain volume which would be filled with the hempcrete mix, reducing thermal bridges. The distance between the vertical elements was not more than 1 m. Horizontal wooden battens were also introduced every 25-30 cm during the filling process, although in this case there was no need for the 2x2 cm vertical battens. With this structure the horizontal elements were inserted between the wall and the 5x5 cm upright, pulling it against this element in order to allow the hempcrete composite to go around it, incorporating it inside the mix. These elements would play the role of reinforcement for the dried insulation, keeping it connected to the wall and not allowing possible rotation or collapse.

The timber shutterings are created by the vertical uprights and boards which are fixed against them. The boards were of different types, like compressed bamboo boards, low density fiberboard, MDF and OSB panels. This way, we were able to understand what kind of board would be more suitable for this operation. For instance, the MDF panels had the capacity to absorb humidity from the wet mixture, to the point of manifesting mold, while the fiberboards with an impermeable flat surface would not allow an adequate drying of the mixture during its initial set.

Hemp is a very good moisture absorber, so the timber skeleton includes a support which doesn't allow the mix to be cast directly on the floor, elevating it at least 10 cm from floor level.

Figure 145. The 5x5 cm fir joists fixed against the wall. A 10 cm bedding is created by the addition of 5 cm timber spacers between the wall and the joists. Photo: Andi Dani

Figure 146. The timber frame and the shutterings created by different wooden boards. Photo: Andi Dani

4.3.1. The preparation of the mixture

Hempcrete is a bio-composite material prepared from the mixing of the hemp shiv and hydrated lime based binders. Normally the shiv and the binder come separately and the mixing proportions are prepared at the building site. If so, once the proportions are decided, hemp shiv and binder are mixed. Once a homogeneous state of this dry mix is reached, water is added gradually while the mixing goes on. This mixing process goes on for 1 to 5 minutes, after which the hempcrete is ready to be applied.

Figure 147. The first step:18 litres of water being poured inside a barrel.
Photo: Andi Dani

During the preparation of the mix, the use of adequate protective gear is required. The powdered lime binder, when dry, can produce a certain amount of dust, so breathing masks should be worn. while when working with the wet mix, waterproof gloves and fully covered skin are necessary, being this binder mildly caustic to the skin.

The hempcrete applied to the south wall of the Red Room was obtained in premixed bags of hemp shiv and hempcrete binder, so the proportions were already settled. The lack of professional workforce created a high risk of producing non-uniform mixtures if the shiv and the binder came separately. This risk was avoided by using a premixed product.
The premixed product came in 25 kg sacks. The instructions showed that for the preparation of the mix, 17-18 litres of clean water had to be added for each sack.

Figure 148. The second step: one full sack of premixed hemp shiv and binder (CANAPAMAS 385) is added to the water.
Photo: Andi Dani

Figure 149. The third step: mixing the biocomposite using a drill mixer.
Photo: Andi Dani

The wall area we chose to insulate using hempcrete did was around 20 m^2, so there was no need for large mortar mixers. We used barrels and a drill mixer instead. In this case, the water was the first thing to be poured into the barrel. Then the premixed hemp shiv and binder was added and the mixing process went on for 5-6 minutes, until the composite reached a homogeneous state. During the mixing, the drill should not just make rotatory movements, but it has to be moved vertically as well, bringing the hydrated mix on top and dipping the dry part. Mixing should be done in a rapid and efficient way, avoiding long contact with water of just one part of the premixed product, which would result in excessive water absorption from the wet shiv, not making it available for the remaining dry part.

Adding water first was suggested by the professionals working at Edilcanapa. This is advised when the mixing is done using barrels or wheelbarrows and shovels. This is done in order to allow all of the premixed material to hydrate, something that might not happen if the premix is poured first, which might result on having dry binder stuck in the difficult angles of the barrel.

When the hempcrete mix was ready, it was left to stand for a couple of minutes and then mixed again before it was applied to the wall. This aggregate has to be applied within 45 minutes, after which it starts its initial set, and if it is not yet cast, the properties of the binder would reduce, presenting structural problems in the future.

Figure 150. Hempcrete getting mixed with a drill mixer becoming homogeneously saturated.
Photo: Andi Dani

Figure 151. Waterproof gloves, protective goggles and a face mask are suggested to avoid possible skin irritations or problems the lime dust can cause to the eyes and the respiratory system.
Photo: Andi Dani

4.3.2. Hempcrete application on an existing wall

All the walls of the Red Room have the same composition. They are built with a double layer of solid bricks covered on both sides by a cement and sand plaster and paint.
The hempcrete composite was used as an insulation material for part of the south wall.

Cement plaster and paint have very low vapour permeability, which makes them inadequate materials for the creation of a breathable wall. For this reason, before fixing the timber skeleton, the internal plaster was removed. This process was not carried out when light earth and lime-straw were applied.

Hempcrete was to be applied on exposed bricks on 21-22 July. Because of the hot weather, the brick surface was wetted twice before the cast, once the day before and another time the day of the application. We waited for the water to be absorbed before we proceeded. When the surface was ready, we started the filling process. The mix was instantly prepared, and then it was cast inside the shutterings using small buckets. The preparation of the mix and its application needs to be done at temperatures between +5 and 30°C. The mix was uniformly spread inside the shuttering. Every 5 cm of hempcrete cast, some pressure was applied over it using pieces of wood in order to ensure that all the voids were filled, paying particular attention to the corners. The wood pieces were long enough to reach the bottom and no excessive force was needed while pressing.
The premixed product we obtained is called CANAPAMAS. It came in three distinct confections, which had different densities, and consequently, different thermal insulation properties.

The CANAPAMAS 200 had a density of 200 kg/m^3 and is not suitable for the insulation of walkable areas, while it is suggested for walls and non accessible roofs . CANAPAMAS 330 has a density of 330 kg/m^3, and can be applied even for the insulation of walkable surfaces. CANAPAMAS 385, can be used for the insulation of walls, walkable and carriageable surfaces (garage floor) and has a density of 385 kg/m^3.

Figure 152. The hempcrete mix once cast and pressed inside the shutterings
Photo: Andi Dani

We obtained and used the CANAPAMAS 385 as insulation material [21]. The shutterings were not taken off within 24 hours. A part of the insulation was left inside the forms for several days in order to see how the wet mixture would react during the drying process while using different timber boards for the shuttering.

Figure 153. The shutterings on the left side of the wall were taken off several days after the mix was cast. The colour difference is due to the use of different shuttering boards, MDF panel above and impermeable fiberboards below (still wet).
Photo: Andi Dani

[21] The choice was made considering the availability of the three products and the timetables of the project.

The drying process requires 2 to 6 weeks. The finishing layers are suggested to be applied 30-40 days after the insulation in order to ensure the drying process is completed.

Figure 154. The different boards used for the shutterings on the right side of the wall.
Photo: Andi Dani

Figure 155. Keeping the shutterings for several days after the cast of hempcrete can result in mold manifestation (above) and a very slow drying process (below).
Photo: Andi Dani

Figure 156. The dry hempcrete insulation layer.
Photo: Andi Dani

4.3.3. Properties

Hempcrete is a bio-composite material, which is created by a binding material and a reinforcement of natural fibers. It is used for the insulation of walls, roofs and floor sub-base layer. Its mechanical properties, which depend from the hemp shiv-binder ratio, allow hempcrete to be self-supporting but not load-bearing material. This means that structural components are required when this material is applied, commonly timber frames.

The hempcrete applied on the Red Room has a thickness of 10 cm and a density of 385 kg/m^3.

This hempcrete material is chosen because of the following properties:

- It is a non toxic material which procures a good indoor air quality
- It has good thermal insulating properties and it maintains stable indoor temperatures, having a thermal conductivity that ranges from 0.06 to 0.0788 W/mK
- It is a very performing humidity regulator
- It sequesters carbon reducing its carbon footprint
- It has acoustic insulation properties

- It reduces mold manifestation and condensation due to its high vapor permeability
- It is a fire resistant and durable material with a good compression strength
- It is a parasite, insect and rodent repeller.

The minimal dimension of the utilised hemp siv is 6 mm .

Hempcrete can be applied as a thermal insulation in thicknesses from 6 cm to more than 30 cm.
The premixed product can be easily and quickly prepared and it does not require specialised workforce for its application, while when hemp shiv and binder are obtained separately, specific skills are necessary.

No samples were sent to the laboratory of the Department of Energy for the definition of the thermal conductivity due to the unavailability of the measuring machine in the period October-November 2018. The material itself was supplied on the 19th of July 2018. The values were presented from the company, which had already conducted the necessary analysis on the material. The thermal conductivity of CANAPAMAS 385 implemented on the south wall of the Red Room is 0.0788 W/mK, but it can be 0.06 W/mK in the CANAPAMAS 200 mix which has a smaller binder ratio. The specific heat of this material is 1700 J/kgK.

According to a 2003 study, one tonne of dried hemp stores 325 kg of CO2[22], while the Tradical company, one of the biggest manufacturers of the hempcrete and its specific binders, claims that 1 m^3 of hempcrete sequesters approximately 110 kg of CO_2 every year[23]. This property of hempcrete makes it a material with a very low carbon footprint. Lime on the other hand has a relatively high embodied energy. Anyway, if compared to the Portland cement, it is burnt at a lower temperature. It also has a lower density than cement, reducing the energy required for transportation and it absorbs a certain amount of CO_2 while it sets.

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[22] Pervais, M. 2003, “Carbon storage potential in natural fiber composites,” *Resources, Conservation and Recycling*, vol. 39, no. 4, pp. 325–340

[23] _http://www.tradical.com/pdf/Tradical_Information_Pack.pdf

Hempcrete is a very good humidity regulator, thanks to the porous structure of the hemp shiv, which has the ability to store and release moisture. Dry hempcrete has the capacity to rapidly transfer liquids, it retains high levels of moisture and has a high vapour permeability. These properties make this material avoid condensation and manage the indoor humidity levels retaining comfortable conditions[24]. Its storage capacity are very high, even during hot periods, when the humidity levels are high, it will not be overwhelmed, and it will continue to absorb excessive humidity from the indoor air, releasing it when the air is in deficit of moisture.

The dry composite has a compression strength higher than 1.0 N/mm^2 which is enough to make this material self-supporting.

The insulation panels obtained from CANAPAMAS 385 require 0.8-0.9 liters/kg of premixed material for its preparation and ha a capillary water absorption value of 1.18 $kg/m^2 min^{0.5}$.

Hempcrete is considered non toxic because of the hemp cultivation process, which requires a very small amounts of pesticides and herbicides.

Hempcrete popularity has a direct influence on the availability of the certified for construction hemp shiv and adequate binders for this mix, and thus, on their economic cost. In Italy, the amount of suppliers for this product is very limited, which means that its cost is higher than that of conventional insulation materials. France and United Kingdom for instance make more use of this product and the demand continues to grow, therefore it is easier to find more reasonable prices for this product.

Figure 158. Mold manifestation on drying hempcrete. Photo:Andi Dani

[24] Lawrence, M. et al. (2012) “Hygrothermal performance of an experimental hemp-lime building,” *Key Engineering Materials* 517, pp. 413–421.

Figure 158. The hempcrete after the shutterings were taken off on the right side of the north wall. Photo Andi Dani

Chapter FIVE

5. CRUSHED OLIVE PITS

5.1. Crushed and deoiled olive pits

Crushed olive pits are a waste of the production process of olive oil.

After the olives are gathered, they get cleaned from the leaves and pass through a mill, which crushes the olives and their pit, producing a mix of olive pulp and crushed pits with a non-uniform granulometry which is used to extract the olive oil. The remaining part is called pomace, and is a mixture of olive pits, debris of olive pulp and skin, and pomace of olive oil with the water that was added in the mills. This mix has a moisture content of 50 to 75% and it is used to make a second oil extraction called pomace oil, a process that applies another passage through the mill which makes a further reduction of the crushed olive pits granulometry. The residues of this process are called de-oiled husk. The woody part of the husk is subsequently separated from the rest of the residues and it is most commonly burnt as biomass for heating and sanitary hot water.

The crushed olive pits obtained from biomass pellets confections have a granulometry of 2-3 mm and 3-6% oil still present on the pits. The product I used was supplied by the SUCSA Dr. Giovanni company and it is a certified biomass material used as pellet. This supplier provides crushed olive pits in 25 kg sacks at 0.18 Euro/kg.

Deoiled crushed olive pits can be considered as construction material because of the following reasons:

- The big amount of solid waste produced in the Mediterranean form the olive oil industry, whose disposal can lead to soil and water pollution if adequate life cycle management strategies are not adapted
- Crushed olive pits are a natural material, even though it is obtained through industrialised processes
- Being a woody material with a granulometry of 2-3 mm, it has adequate characteristics a biocomposite material, or it can be mixed with suitable resins for the production of plywood boards

The first consideration was that of using the crushed olive pits as insulation material, which could be poured in previously installed formworks, for floors and roofs, and possibly, even walls.

Figure 159 and 160. Crushed olive pits (human hand as reference).
Photo Andi Dani

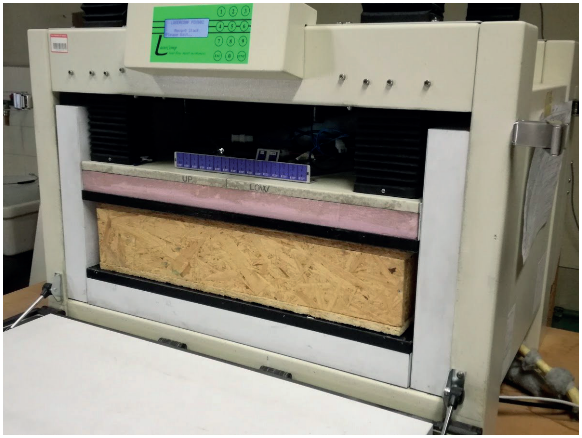
The shape of the crushed pits creates empty spaces between the pieces. One kg of crushed olive pits corresponds to 1.2 to 1.25 litres, which means that its density varies from 800 to 830 kg/m3.

In order to define the thermal conductivity of the raw material,a box with internal dimensions of 600x600x90 mm was made of OSB boards filled with deoiled crushed olive pits. This sample was sent to the Department of Energy laboratory in order to perform a Hot Guarded Plate test. The test was made using the Lasercomp FOX 600 machine with the help of Stefano Fantucci, a research associate at the Industrial and Information Engineering area.

The test showed that raw crushed olive pits were not very performing as thermal insulation. The thermal conductivity resulted 0.147 w/mK, which would require a certain thickness to reach acceptable values for an insulation material, while its thermal resistance (R value) was 0.616 m2K/W for the 90 mm thickness of the analysed olive pits.

The test showed that crushed olive pits if used as an ingredient in a biocomposite, would present a worse performance in terms of thermal insulation compared to when used as such. This doesn’t mean that mixtures of crushed olive pits with different binders can’t be used for the construction of floor screeds or for the production of self-locking paving blocks or floor screeds.

Figure 161 (above), 162, 163, 164 and 165 (next page). The preparation of the crushed olive pits sample which was sent to the laboratory of the Department of Energy of the Politecnico di Torino for the Hot Guarded Test.
Photos: Andi Dani



5.2. Crushed and deoiled olive pits composites

A series of samples were created using the deoiled crushed olive pits mixed with the following binders:

- Earth obtained from crushed bricks (sample 1)
- Subsoil earth coming from Coazze, in the Piedmont region (sample 2)
- Lime putty (sample 3)
- Natural hydraulic lime NHL 5 (sample 4)
- Lime putty and NHL 5 (sample 5)
- Lime putty and milk (sample 6)
- Portland cement (sample 7)
- Cocciopesto and NHL 5 (sample 8)

These samples did not go through any scientific test. The information gathered from the samples regarded the workability of the mixture, the potential use of the mixes based on the binding capacities of the binders, and their ability to absorb the olive odour, the behaviour of the remaining oil when mixed with the binders mentioned above.

5.2.1. Sample 1 - Earth from unfired bricks

Sample 1 is obtained by mixing crushed olive pits with a 6% of incorporated oil with earth obtained by crunching unfired earth bricks. The crushed pits-earth proportions of this mixture in volume are 4:1. This ratio translated in weight is 2.3:1, with 2.3 being the olive pits and 1 of earth binder. This proportion was decided based on some preparation trials. Larger amounts of earth resulted in much denser and less porous samples, while less binder reduced the mechanical properties considerably. The first step was the earth saturation with water. The earth binder was mixed with water, while it was gradually poured and mixed, until it reached a homogeneous and muddy consistency. Then crushed olive pits were added, and mixed with the binder using a trowel. Protection gear is not fundamental during this process, because both ingredients are not harmful to human skin or eyes and no big amounts of dust are released. The mixture is manually worked very easily. The use of mortar mixers for this composite would not be very efficient. On the other hand, the cast was a very easy process, and the viscosity and granulometry of the mix ingredients would allow both manual application and the pouring or spraying through machinery. The composite was used to fill a 15x6x3 cm form and it was left to dry.

Since the binder material was previously used to obtain bricks to build, there is no need for any drying or maturation process, which should be done in case of use of raw earth directly extracted from the subsoil.

Sample 1 was taken out of the form within the next 24 hours for a more efficient drying process, which took around 12 days[25]. It has seemingly good mechanical properties which makes this sample interesting for future experimentations and tests for its application as a floor screed.

The dry sample presents a porous structure, which would allow the creation of a breathable surface if applied. On the other hand, the oil still present in the crushed olive pits reacted with the clay binder, spreading through the whole sample, not manifesting itself on the surface, like it did with some of the other samples. There are some known techniques which use cooked oil from linen, poppy or various nuts for the consolidation of floor areas made with raw earth. This oil is applied on the surface of the dried earthen floor, which reacts with the earth and creates more resistant and impermeable surfaces.

It is important to point out that the earth binder has played a very good role as an odour absorbent, creating an almost odourless sample. The acidic odour of the crushed olive nuts completely fades away in time in earth mix.

Natural fiber addition (straw or hemp) seems fit for this type of composite. Also biochar would positively alter the properties of this

[25] This period is not valid for applications scales larger than those of the sample.

mix, because of the biochar material properties, explained in the following chapter.

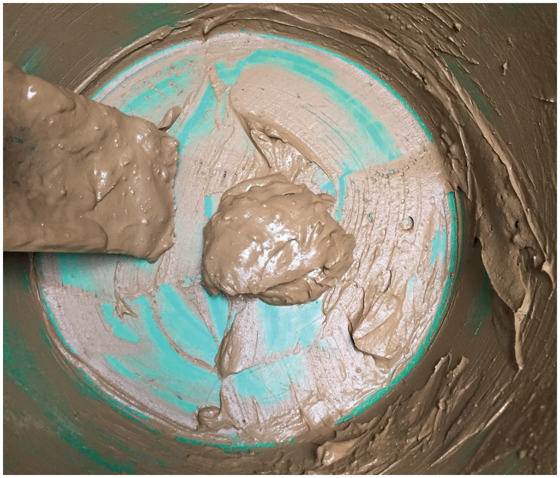


Figure 166, 167 (left) and 168 (above). Preparation and casting of sample 1. First the earth is mixed with water, then the crushed olive pits are added.
Photos: Andi Dani

Figure 169 and 170. Pictures of the dried sample. Almost no oil stains can be noticed.
Photos: Andi Dani

5.2.2. Sample 2 - Earth from subsoil

Sample 2 is prepared by mixing crushed olive pits and earth obtained from subsoil. This earth has lower performing binding properties due to its lower clay ratio and a higher sand consistency, compared to the earth obtained from the unfired bricks. In this case, the crushed olive pits and earth proportions were 1:1 by weight. After its extraction, this earth has been left to maturate outdoors, allowing the washing out of the water soluble salts. Then it has been crushed, reducing it to a pulverised form. When this earth was used to create sample 2, it was in the adequate conditions for use in construction.

220 g of earth and 220 g of crushed olive pits were initially mixed together. This was possible because this earth was in a pulverised state. Once the mix was homogeneous, water was added gradually while continuously mixing, until the aggregate reaches the saturation point, which means it does not accept more water. The mixing

process was done manually while using a small trowel, even though the granulometry of the crushed olive pits and the pulverised state of the earth can allow this composite to efficiently mix in various cement mixers. Anyway, this composite was easily mixed, showing good workability. The mixture was then put inside a 15x6x3 wood form next to sample 1.
Sample 2 was taken out of the wood form within 24 hours. After 10 days it was dry and observations could be made. This sample showed higher porosity than sample 1, which is mostly due to the lower pits:earth binder ratio and the different sand:clay ratio of the two earths. The oil residue in the crushed olive pits is distributed in the whole mixture also in sample 2, although there are small oil stains on the surface. This might indicate that the oil reacts much more with a clayey composition, increasing its binding properties and its impermeability. The acidic odour of the olive was almost completely gone, showing the capacity of the earth to absorb odours. From the mechanical point of view, sample 1 resulted stronger than sample 2.

Nevertheless, this biocomposite shows that its application as a floor screed could show interesting results. The addition of other ingredients which would increase its structural properties, like lime, or the addition of a certain amount of natural fibers, might be considered.

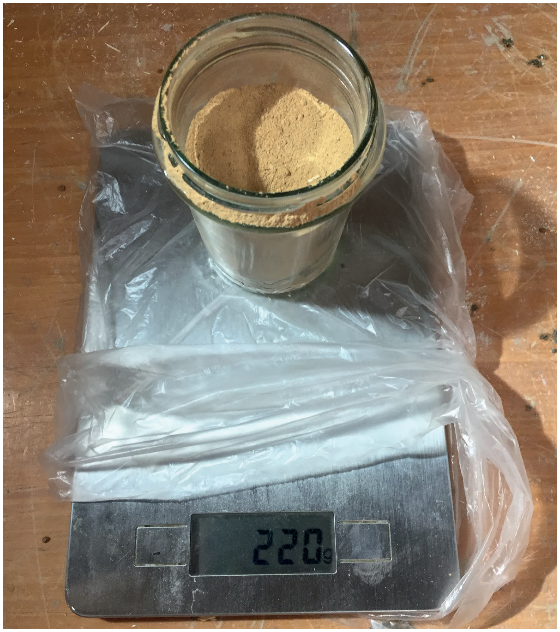


Figure 171. Earth binder from subsoil in a powdered state.
Photos: Andi Dani

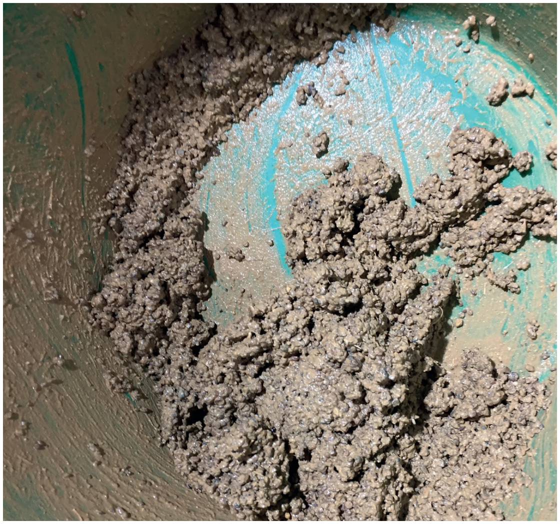


Figure 172, 173 (left) and 174 (above). Sample 2 getting mixed and cast in the wood form next to sample 1.
Photos: Andi Dani

Figure 174 and 175. Dried sample 2. Very few oil stains can be seen.
Photos: Andi Dani

5.2.3. Sample 3 - Lime putty

Sample 3 was created by mixing crushed olive pits and lime putty. The proportions were 2:1 by volume (2 for the crushed olive pits and 1 for the lime putty). The mixture was prepared by first putting in a bucket the lime putty, then the crushed olive pits, even though there is no suggested order on the ingredient addition. Then both ingredients were mixed using a trowel. The crushed olive pits and lime putty composite was viscous enough to show very good workability properties. During the preparation of the mix, the necessary protective gear was used (waterproof gloves, protective goggles and face mask). When a homogeneous mixture was reached, it was inserted in the 15x6x3 wood form, maintaining the same dimensions for all the samples.

Sample 3 required almost two weeks to dry. The dry sample was completely lacking the olive odour, while the remaining olive oil present in the crushed pits had found its way to the top surface. It resulted in a more compact and less porous sample compared to sample 1 and 2. Regarding the mechanical performance, sample 3 could be crumbled without applying too much force, resulting weaker than the previous two. A composite made out of crushed olive pits and lime putty only doesn't seem suitable for floor screeds or insulation panels. Nevertheless, this composite might be used in construction if other ingredients are added to the mixture.

Figure 176 (left), 177 and 178 (above). Preparation and casting of sample 3.
Photos: Andi Dani

Figure 179. Sample 1, 2 and 3 right after they were cast.
Photo: Andi Dani

Figure 180. Picture of the dried sample 3..
Photo: Andi Dani

5.2.4. Sample 4 - NHL 5

Sample 4 is prepared from a mix between crushed olive pits and NHL 5 in a 1:1 ratio by weight. 150 g of crushed olive pits and 150 g of NHL 5 are first mixed together, then water is added gradually, while continuing to mix with a trowel. For the preparation of this sample it is also necessary to use of protective gear like waterproof gloves, face mask and protective goggles. The crushed olive pits and NHL 5 mix can be prepared using mortar mixers. The manual mixing did not present difficulties, showing that this mix has a good workability. Once the mix was homogeneous, it was cast in a wood form next to the other samples.

Sample 4 was taken out of the woodform within 24 hours, and it was left outside to complete the drying process, which required less than 8 days. The natural hydraulic lime played a very good role in eliminating the acidic odour of the crushed olive pits.

Figure 181 and 182. Sample 4 being prepared (abve) and while cast (below).
Photos: Andi Dani

Its mechanical properties were better than sample 3, although the edges were fragile and could be easily crumbled. The remaining oil mostly manifested on the top of the sample creating stains and an impermeable and smooth surface, and was partly distributed inside the mix. Sample 4 was also almost completely lacking porosity in the millimetric level.

Figure 183. Picture of the wet samples next to each other. Sample 4 at the far right.
Photo: Andi Dani

A crushed olive pits and NHL 5 mix has a potential for the creation of building blocks or bricks and floor screed. However, in this case the addition of other ingredients like a natural fiber reinforcement or sand would be suggested in order to create stronger and more resistant composites more suitable for construction.

Figure 184. The dry sample 4. The edges were crumbled without excessive force.
Photo: Andi Dani

Figure 184. The dry sample 4. The brown stains on the top surface derive from the remaining oil in the olive pits.
Photo: Andi Dani

5.2.5. Sample 5 - Lime putty and NHL 5

Sample 5 was created by pouring in a bucket the three ingredients: crushed olive pits, lime putty and natural hydraulic lime. The proportions between the olive pits and the lime binder was 1:1.5, mixing 200 g pits with 200 g lime putty and 100 g NHL 5. They were initially mixed together, then a small quantity of water was added. The composite was easily workable and was manually mixed, using a trowel, while the waterproof gloves, protective goggles and face mask were worn during the whole experiment. The mix was then inserted in the wood form next to the other samples.

Figure 185. Sample 5 before getting mixed.
Photo: Andi Dani

Sample 5 was taken out of the wood form within the next 24 hours after preparation. It was completely dry after 10 days, more than the 8 days required for sample 4 and less than the two weeks necessary for sample 3. In this sample also the odour of the olive pits was not noticed once dried. Less oil stains were present in the surface, compared to sample 3 and 4. The dry composite resulted very fragile, crumbling very easily.

Figure 186. Sample 5 after it was cast in the wood form.
Photo: Andi Dani

Figure 187 and 188. The dry sample was easily broken and crumbled. The oil is seen on the surface where it has created brownish stains.
Photo: Andi Dani

5.2.6. Sample 6 - Lime putty and milk

This sample, just like the one made with the same binder and hemp shiv, had the purpose of observing how the milk, which contains casein, reacts when used as binder together with lime putty. The proportion between crushed olive pits and lime putty was 1:1. First 250 g of lime putty and 250 g of olive pits were mixed using a trowel. Once these two ingredients created a homogeneous mix, cow milk was added gradually, until a saturated mix was created. The amount of milk for the preparation of sample 6 was approximately 30 g. When the composite was ready and completely mixed, it was cast in the 16x6x3 wood form, near the other samples.

Sample 6 required a 15-16 days to dry completely. This sample reduced the olive smell, but the milk presence created an odour which was similar to rotten dairy products (this smell was not strong, but noticeable). The olive oil which the olive pits still carried manifested on the top surface of this sample more than all the other samples previously created. The top side of the sample was covered by a brownish continuous stain which created a very smooth and impermeable surface.

Figure 189. Preparation of sample 6.
Photo: Andi Dani

The mechanical properties were the worst of all the other previous olive pits samples. The lack of porosity was another characteristic of the dried mixture. This sample, together with the other samples which used a lime putty binder, showed that the lime putty might not be the best binding solution in a composite that uses crushed olive pits as an aggregate for the creation of construction materials.

Figure 190 and 191. Sample 6 after it was cast in the woodform.
Photo: Andi Dani

Figure 192, 193 (left) and 194 (above). Dried sample 6 showing a very fragile behaviour and olive stains, mostly on the top surface.
Photo: Andi Dani

5.2.7. Sample 7 - Portland cement

This sample is created as a means of comparison between the various binders taken in consideration. The sample 7 proportions were 1:1 by weight. 200 g of each ingredient were first mixed, then water was gradually added while constantly mixing. The use of mortar mixers for the preparation of the mix is possible, but this process was carried out manually using a trowel, because the dimensions of this sample required a very small amount of material. The protective gloves, goggles and face mask were used also during this experiment. The mix was very easy to prepare, in terms of workability. Once a homogeneous and fully saturated mix was obtained, it was poured in the wood form with the same dimensions as the previous samples.

The sample was taken out of the woodform the day after its preparation. This sample was the quickest to dry, requiring less than 5 days to complete this process. The olive odour was completely absent, while the remaining oil manifested around the external surfaces of the sample, with the larger amount of stains in the top surface. The surfaces where the oil stains were present, were very smooth and seemingly impermeable.

This sample was the strongest, in terms of mechanical properties, showing at the same time a high level of porosity.

This sample shows that the use of crushed olive pits in a mix with Portland cement can be considered for the creation of construction bricks, self-locking pavement blocks, floor screeds while promising a much better mechanical performance compared to the other samples. The addition of sand and/or natural fibres might be taken in consideration. The portland cement can be also an additional ingredient in mixes crushed olive pits and earth, NHL 5 or cocciopesto, increasing their structural properties and reducing the setting time.

Figure 196. Preparation of sample 7. Portland cement and crushed olive pits are first mixed while dry, then water is added.
Photo: Andi Dani

Figure 197. Sample 7 on the far left together with the other samples once cast in the woodform.
Photo: Andi Dani

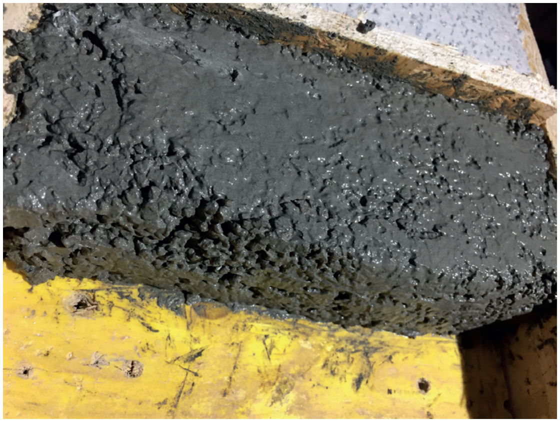


Figure 196. Casting of sample 7 in the woodfrom.
Photo: Andi Dani

Figure 198. Sample 7 once dried. Oil stains can be noticed on the surface.
Photo: Andi Dani

Figure 199. Oil manifestation on the top surface of dried sample no. 7.
Photo: Andi Dani

5.2.8. Sample 8 - Cocciopesto and NHL 5

The last experiment involved the use of powdered cocciopesto and NHL 5. The ingredients of sample 8 were in a 1:1:1 ratio by weight. 150 g of each material were put in a bucket and mixed while dry. The addition of water was done gradually while continuously mixing, until a saturated homogeneous mixture was obtained. The composite was mixed manually using a trowel and showed good workability. All the adequate protective gear was worn for this experiment; waterproof gloves, goggles and face mask, because of the hazards that the lime can cause if in contact with skin or eyes, and because of the dust particles released during the mixing process. The characteristics of this material make the mixing process suitable to be carried out with various mortar mixing machines for the production of large quantities of this mix. Once saturated, sample 8 was also poured and compacted in the wood form very easily and with a minimum effort.

The sample was taken out of the wood form within 24 hours from its preparation, and 12-13 days were needed for it to completely dry. The acidic odour was almost completely removed by the application of the binder. The air gaps between the crushed olive pits were completely filled by the binder material, making this sample non-porous. The top side of the sample showed some oil stains, creating a smooth and impermeable surface, although the oil manifestation was moderate compared to the samples made with cement or lime binders. It showed quite good mechanical properties, with some fragile performance on the edges of the sample. The substitution of NHL 5 with Portland cement might increase its mechanical performance, making such a composite adequate for use in construction blocks and floor screed.

Figure 200. Preparation of the mix for the creation of sample 8
Photo: Andi Dani

Figure 201. Sample no. 8 cast in the woodform.
Photo: Andi Dani

Figure 202. All the samples in the inside the woodform the day of their preparation.
Photo: Andi Dani

Figure 203 and 204. Pictures of dried sample 8. No noticeable oil stains are shown
Photo: Andi Dani

5.3. Conclusions

The experiments done with the deoiled crushed olive pits had had the target of identifying a way to use this material in construction. The experiment results showed promising potentiality for this material. The most efficient way of using this material is that of applying it as an inert material in various composites for the creation of the following construction products:

- Construction bricks
- Self-locking pavement blocks
- Various composites applied as floor screed during the construction of the floor slabs

This material can find other applications in the construction sector, for example it can be used for the creation of insulation layers in horizontal surfaces (even though its thermal performance is not exceptional, it can reach acceptable values for big thicknesses) or for the creation of rigid compressed boards if adequate glues and production processes are applied

Tab. 4. Empirical results of the crushed olive pits samples

Sample no.	Workability	Mechanical performance	Odour capture	Drying time (days)	Porosity	Oil miscibility	Mortar mixer (possible) usage	Potential use
1	Good	Very good	Very good	12	High	High	No	Floor screed
2	Very good	Good	Very good	10	High	High	Yes	Floor screed
3	Very good	Very bad	Good	14-15	Low	Very low	No	-
4	Excellent	Very good	Good	8	Low	Low	Yes	Construction blocks, floor screed
5	Good	Bad	Good	10	Low	Very low	No	-
6	Very good	Very bad	Moderate	15-16	Low	Low	No	-
7	Excellent	Excellent	Very good	5	High	Very low	Yes	Construction blocks, floor screed
8	Very good	Very good	Excellent	12-13	Moderate	Moderate	Yes	Construction blocks, floor screed

Chapter SIX

6.BIOCHAR

6.1. Production

Biochar is a type of char produced through a pyrolysis process of biomass matter. Pyrolysis provokes thermal degradation of a material while burning it in absence of oxygen in a temperature range from 300°C to 800°C with traditional stoves or kilns. The biochar produced in industrialised kilns can reach burning temperatures of 1200°C, but the higher the temperature, the less biochar matter is obtained and the lower its quality.

The biomass that goes through through the pyrolysis process can have an animal origin (e.g. animal bones) , or vegetal origin[26] (e.g. like pruning, corn or wheat stubble, rice husk almond husk, olive pits, dry foliage, plant stems, wood etc.). Traditionally, biochar has been a waste from the home biomass stoves, or the burning of the dry crop residues. In many places, like the Amazon, India, Pakistan, Thailand etc. the biochar production is part of their local culture, using it as a fertiliser. They also have traditionally built kiln which would allow the biochar to be burnt in the right temperature in order to produce more biochar material. When the pyrolysis is done between 300°C and 800°C, the biochar matter produced can reach 16% to 25% of the biomass used as fuel by weight.

It is worth mentioning the tradition of Terra preta (Black Earth in Portuguese), a methodology of mixing the earth with organic or carbonized waste, based on raw earth or terra cotta. This process had the effect that an amendment would have on acid and alkaline soils. Biochar works in the agricultural field in the same way, converting infertile soils into

[26] Source:Pellegrino Conte, Hans-Peter Schmidt e Giulia Cimò, *Research and Application of Biochar in Europe*, in *Agricultural and Environmental Applications of Biochar: Advances and Barriers*, 1º aprile 2016, pp. 409–422

agricultural land. Pretty rich literature on this material and its properties and uses is available today.

6.2. Application in construction

The characteristics that have made biochar widely and wisely used in agriculture, has also drawn attention for its use in building construction. Amongst its properties, the ones which can make its use as construction material interesting are the following[27]:

- Carbon sequestration
- Earth temperature regulation
- Earth density reduction
- Moisture retainer
- Humidity regulator
- Thermal insulation
- Anti-bacterial and fungicide reaction
- Termite repellent
- Air and water purification
- Electromagnetic radiation protection
- Toxine repeller
- Odour sequestration
- Etc.

Documentation that shows different possible mixtures made using biochar as an ingredient for plasters or insulation[28]. It has the ability to absorb water up to 6 times its weight because of its very porous structure in the microscopic and nanoscopic levels.

6.2.1. Biochar plasters

Biochar plasters are made by mixing biochar with sand, clay, lime or even Portland cement. The proportions are 50% biochar, 30% sand and 20% clay [29]. Biochar can be used in a powdered state or in pieces with a suggested diameter around 25 mm, in order to reduce cracking risks. It has very rapid drying time and depending on the

[27] The following properties were extracted by consulting publications, some of which are listed in the following site: http://www.e2bebis.eu/?page_id=34

[28] Source: http://www.ithaka-journal.net

[29] Source: http://www.ithaka-journal.net
Hans-Peter Schmidt “The use of biochar as building material - cities as carbon sinks”

desired thickness, a second layer can be applied above the the base plaster in the next 12-24 hours. Biochar plasters can have a thickness of 10-20 mm when used biochar in a powdered state or when the pieces are smaller than 10 mm.

Figure 205. Biochar plaster applied with a spraying hose in the wine cellar of the Ithaka Institute, Switzerland.
Source: http://www.ithaka-journal.net

Such plater would significantly improve a rooms climate and air quality, and it can also reach a thickness of 10 to 20 cm, where insulation and humidity problems are present. A 10 cm plaster was used in the wine cellar underneath the Ithaka Institute in canton of Valais, Switzerland.

Figure 206. The Ithaka Institute wine cellar after the biochar plaster was applied and dried.
Source: http://www.ithaka-journal.net

The plaster had a 50%-30%-20% biochar-sand-clay ratio, while the biochar amount was reduced as much as 15%-20% in the areas where a lighter colour was desired. Humidity levels below 40% can cause dry mucous of the users and levels above 70% could result in mould manifestation in closed spaces [30].

[30] Source: http://www.ithaka-journal.net
Hans-Peter Schmidt “Biochar as Building Material for Optimal Indoor Climate”

The air humidity levels after the application of this plaster on the wine cellar walls have remained constant at 65-75%.

Other Ithaka Institute building indoor areas like offices, meeting rooms etc. also used the biochar plaster on their walls with a 2 to 3 cm thickness on the inside and reaching up to 20 cm on the outside. Plaster was applied using a spraying hose, but traditional plaster application techniques can be easily applied as well. There is no need for excessive protection gear, because none of the ingredients is harmful for the skin, if not beneficial.

Biochar plasters can accept paint layers (limewash is suggested in order to maintain the breathability of the wall).

This plaster would have numerous benefits for the building inhabitants. It has the ability to absorb odours and toxins, which would make it very useful for places that are frequented by big groups of people like schools, universities, study rooms, libraries, or places where strong odours or fumes are present, like hospitals, kitchens or smoker's houses.

Figure 207 and 208. Different ratios of biochar, sand and clay create plasters with different colours. Pictures of the Ithaka Institute wine cellar.
Source: http://www.ithaka-journal.net

Figure 209. The biochar plaster applied on the walls of the indoor areas on the Ithaka Institute.
Source: http://www.ithaka-journal.net

While a member of La Termitière team, I had the possibility to create some samples of plaster, in a mix with sand, clay and carbon char. At the time the samples were built, had no biochar material, so a carbon char with very similar properties was used instead. The information over the proportions were given by one of the artisans who worked with the biochar material for the plastering of the Ithaka Institute building, Martin Steiger, and the process was followed by architect Filippo Caggiano on the site. The carbon char content in our samples varied between 10% and 50%.

Figure 210. One of the samples of charcoal plaster where the char consisted in 40% of the mix. Photo: Andi Dani

Figure 211. The charcoal plaster sample where the char consisted in 20% of the mixtures weight. The smaller the quantity of char (biochar) added to the mix, the lighter the plaster colour and the slower the drying time. Photo: Andi Dani

Figure 212. The charcoal plaster samples. On top on the left the plaster with 10% of char consistency. On top on the right a sample with no char addition for comparison.
Photo: Andi Dani

6.2.2. Bricks

Biochar can also used for the production of bricks mixing it with Portland cement.

Some trials were made and published on the Ithaka Journal blog by Andreas Wittman and Alexander Arns. They used wet biochar bulk with a density of 1-1.2 g/cm^3[31], mixed with cement, lime or mud. They stated that when using cement and lime, the sand could be completely replaced with biochar, reducing by five the weight of the brick, while having a compression strength of 20 N/mm^2.

In India, a local company produces biochar bricks under the name GEO Biochar Bricks. They make three kinds of bricks using rice husk biochar saturated with water, with the following proportions[32]:

- Rice husk biochar 6 kg / Portland cement 3 kg
- Sand 14 kg / Rice husk biochar 1 kg / Portland cement 2 kg
- Sand 14 kg / Rice husk biochar 1 kg / Portland cement 1 kg

[31] This density is created because the biochar material is initially soaked in water before being mixed with the other ingredients, increasing its density.
[32] Source: Biocharculture: Biochar for Environment and Development" by Sai Bhaskar N. Reddy

Figure 213, 2014 and 2015. Biochar bricks floating on water.
Photos: Andreas Wittman and Alexander Arns

Figure 216. For the production of biochar bricks, the biochar material is first saturated, being the quickest ingredient to absorb water. The wet biochar is then mixed with sand, and the last ingredient to be added is the cement.
Source:http://e-biocharbricks.blogspot.com/

Figure 217. The sand used for the production of the biochar bricks.
Source:http://e-biocharbricks.blogspot.com/

Figure 218 and 219. After wet biochar is mixed with sand, Portland cement is subsequently added (above). Once the ingredients are mixed and a homogenous composite is obtained, they are inserted in a form which gives the biochar brick its shape (below).
Source:http://e-biocharbricks.blogspot.com/

Figure 220 and 221. The composite produced by mixing biochar, sand and cement is poured gradually in the form, while constantly pressing the mix in order to obtain a compressed brick.
Source:http://e-biocharbricks.blogspot.com/

Figure 222. The dry biochar brick produced in a mix with 50% biochar by weight.
Source:http://e-biocharbricks.blogspot.com/

Figure 223. Biochar bricks produced with different biochar proportions.
Source:http://e-biocharbricks.blogspot.com/

Figure 224. Biochar bricks produced by GEO Biochar Bricks, India.
Source:http://e-biocharbricks.blogspot.com/

Similar experiments and tests are done with the rice ash husk, which can also used as biofuel for the biochar production. Rice husk burnt in temperatures below 700°C produces an ash which has a very high silica content (85-96%) and it is used as a pozzolanic material to improve the microstructure of the interfacial transition zone between the cement paste and the aggregate in a self-compacting concrete[33].

6.2.3. Mixtures for insulation

An experiment was made using carbon char[34] as an ingredient for the creation of an insulation panel, mixing it with hemp shiv and NHL 5 by me and my colleges of La Termitère. The idea was that of creating a lighter and more performing insulation material than the traditional hempcrete.

For the creation of this sample, we first passed the carbon char through a crushing mill, obtaining a powdered product. The char could have been used in this mix even by applying 10-25 mm pieces instead of the powderised material. Coarse char pieces instead of the powder would offer a better structural performance.

[33] Source: Nonconventional and Vernacular Construction Materials, Characterisation, Properties and Applications, dited by K.A. Harries, B. Sharma

[34] In the time the sample was created, we were not in possession of any biochar material, so common char was used instead.

For the construction of the hemp shiv-NHL 5-carbon char mix a 60%:34%:6% ratio by weight was adopted.

Figure 225. Charcoal being pulverised through a crushing mill.
Photo: Andi Dani

The sample was 40x50x10 cm, and required less time to dry, compared to a normal hempcrete mix (1.5-2 times quicker). It was feared that the powdered char would drastically reduce the mechanical properties of the sample, by influencing the performance of the binder. The dry sample was indeed a more fragile and more crumbles of hemp shiv and dust were released on its breaking point, compared typical hempcrete mixes compared to hempcrete.

Figure 226. The mixing process was done with a rotating mill.
Photo: Andi Dani

Nevertheless, the mechanical properties were promising, so tests that can define the variation of the compressive strength while changing the ingredients proportions while conducting tests on its thermal performance are necessary to define the most efficient proportions.

Figure 226. The sample produced by mixing hemp shiv, NHL 5 and charcoal.
Photo: Andi Dani

Chapter SEVEN

7.PROJECT PROPOSAL

The experiments made with the crushed olive pits and the knowledge acquired about the biochar material and its use in construction have given a promising feedback. A pilot project which can be carried out from students can be requested to the Politecnico di Torino through the Commission for Contributes and Student Projects programmes for the a life scale application of these materials. This project can be realised taking in consideration a real case study where these materials can be applied.

This chapter will be focusing on presenting a series of mixtures for the construction of a floor screed using the crushed olive pits in a mixture with a binding material, the application of a biocomposite insulation layer with the addition of the biochar material as an ingredient and a biochar finishing plaster, proposing what resulted to be the most suitable proportions.

There is no accessible documentation regarding the use of the crushed olive pits in the construction sector, so its use in a mix with a binding material as suggested in this project is based on the experiment results carried out by the author, choosing the most promising samples and proposing further testing before their application.

The biochar on the other hand has been used as a construction material by some artisans from Switzerland, one of which has shared the way they applied this material for the creation of a composite used as plaster. Other applications of biochar as a construction material was found during an research on the web. Some artisans and small companies, mostly in India, used this material as an ingredient for the production of biochar bricks, creating mixes with different ratios of cement, sand and biochar.

This project suggest a number of experiments and tests in order to identify suitable and performing combinations and proportions between the different ingredients of the proposed mixtures.

The most performing mixes would make interesting case studies if applied in life scale in real buildings, creating the possibility to analyse their long term behaviour. Good candidates for their application would be buildings which present bad hygrothermal conditions, like old or dismissed buildings. The crushed olive pits floor screed could be applied in the Red Rooms floor, while the insulation mixes and plasters can be implemented as internal coating inside another ambient that might present the same conditions as the Red Room before the project implementation. This way there would be a possibility to retrofit another building and putting it to use again while continuing to gather information over these materials, their application and their properties.

7.1. The floor screed

The proposed material for the construction of the floor screed is a mix between deoiled crushed olive pits and one or more binders. The target is that of creating a biocomposite material with a lower embodied energy and carbon footprint than the conventional cement sand mixes, while having a better hygrothermal performance and a lower density. For this reason, the use of Portland cement as a binder is not taken in consideration, even though it has a good initial set and strong binding properties when it dries. The mixes which show the the greatest potential as performing materials for the construction of floor screeds are the following:

- Crushed olive pits and unfired earth
- Crushed olive pits, unfired earth and lime putty
- Crushed olive pits, unfired earth, sand and lime putty

7.1.1. Crushed olive pits and unfired earth

The mix between the crushed olive pits and unfired earth would be the simplest way of creating a performing material which can be used as floor screed. The earth used as a binder should have a high clay consistency, with the clay being the element that adds binding properties to the earth. The ratios of crushed olive pits and the binder might vary from the type of the earth used. The cement and sand based screeds typically use a cement-sand ratio by weight that varies from 1:2 to 1:5. For the crushed olive pits and earth mix, the proposed ratios by weight of these ingredients would vary from 1:2 to 2:1. The same 1:2 ratio as in the cement mix is proposed because the crushed olive pit inert has a bigger granulometry than the sharp sand (2-3 mm compared to 0.06-2 mm) which would increase the mechanical behavior of the mix.

Tab. 5. Crushed olive pits and earth mixture for the construction of the floor screed

Sample no.	Crushed olive pits ratio by weight (%)	Earth ratio by weight (%)
1.	30	70
2.	40	60
3.	50	50
4.	60	40
5.	70	30

The 1:5 ratio frequently adapted for the creation of the sand-cement mixes is not applied in this mix because of the binding properties of the cement and earth differ. In this case, the testing of a 1:1 and 2:1 ratios in weight are proposed instead, in order to compare their properties with those of a sample with a 1:2 earth:olive pits ratio.

This composite has the potential to create a vapour permeable and insulative screed, bettering the temperature and humidity conditions of an indoor area.

7.1.2. Crushed olive pits, unfired earth and lime putty

The second proposed mix for the construction of a floor screed is made with crushed olive pits, unfired earth and an addition of lime putty.

The addition of lime putty is considered, aiming the increase the mechanical properties of the mix and to shorten is setting time by creating a stronger binder. Lime putty would also increase the mixtures resistance to bacteria, fungus, insects or microflora which tend to manifest in earthen mixes.

The creation of six different samples with these ingredients are suggested, in order to observe which promises a better performance.

The chosen sample has to go through tests that would identify its mechanical and thermal properties.

Tab. 6. Crushed olive pits, earth and lime mixture for the construction of the floor screed

Sample no.	Crushed olive pits ratio by weight (%)	Earth ratio by weight (%)	Lime putty ratio by weight (%)
1.	50	30	20
2.	50	40	10
3.	45	45	10
4.	40	30	30
5.	40	40	20
6.	30	50	20

7.1.3. Crushed olive pits, unfired earth, sand and lime putty

The third hypothesis for the creation of a material which can be used for floor screeding proposes a mix between crushed olive pits , unfired earth and the addition of lime putty and sand.

The sand is thought to increase the mechanical properties of the mix. The addition of sand to the mix would result denser and less porous composite, and subsequently, it would present a worse thermal performance.

Tab. 7. Crushed olive pits, earth, sand and lime mixture for the construction of the floor screed

Sample no.	Crushed olive pits ratio by weight (%)	Earth ratio by weight (%)	Sand ratio by weight (%)	Lime putty ratio by weight (%)
1.	50	30	10	10
2.	40	30	20	10
3.	40	30	10	20
4.	40	30	15	15
5.	30	30	30	10
6.	30	40	20	10

Nevertheless, being the mechanical properties important for a material used for the construction of floor screeds, it is interesting to test how the sand addition would influence the mixture performance. Six different proportions of the four ingredients are proposed for the creation of samples which would require further testing, where the crushed olive pits ratio by weight does not go under 30% of the mixture and the sand ratio by weight does not go over 30%.

7.2. The insulation composite

7.2.1. Light earth insulation and biochar

Light earth is a biocomposite which, when used as an insulation material, has good hygrothermal properties. Its ingredients have very low embodied energy, low carbon footprint during their life cycle and are also available in large quantities in a global scale. Nevertheless, its hygrothermal performance is not exceptional and the mix requires a long time to dry. The addition of the biochar material to the mixture is considered in order to increase its efficiency as an insulation material and humidity regulator and also to accelerate this composite's setting process. The ability of biochar to absorb humidity and release it when the surrounding ambient is in deficit would help the straw fibres in presence of excessive humidity levels, lowering the fiber decay risk. It would also work as an anti-bacterial and as a repellent for fungus, microflora and insects.

Two different approaches can be made while adding biochar to the light earth mix:

- By adding powdered biochar in the clay slip mix
- By adding biochar pieces in the straw-clay mix

Tab. 8. Earth - powdered biochar proportions by weight for the preparation of the clay slip

Sample no.	Earth proportion by weight (%)	Powdered biochar proportion by weight (%)
1.	90	10
2.	85	15
3.	80	20

For the creation of the light earth and powdered biochar mix, the biochar material should be added during the preparation of the clay slip after it is transformed in a powdered state. The proposed biochar-earth proportions by weight are between 10%-80% and 20%-80%, where the biochar ingredient occupies 10-20% of the aggregate material required for the creation of the clay slip. In order to prepare an adequate slip, it would be better to mix earth and water first, allowing the water to be homogeneously absorbed by the earth binder, and then proceed with the addition of the biochar. This way the absorption of water from the biochar material which might be on obstruction for the homogeneous saturation of the clay is avoided.

It is suggested the construction of at least one 60x60x10 cm sample for each combination, in order to have the possibility to test their thermal performance through the hot guarded plate test, being these the dimensions required by the Lasercomp FOX600 machine in the Energy Department of Politecnico di Torino.

The scenario where biochar pieces are added to the light earth mix, foresees this process happening not during the preparation of the clay slip, but during the mixing of the straw with the slip.

Tab. 9. Straw- biochar pieces proportions by weight

Sample no.	Straw proportion by weight (%)	Biochar pieces proportion by weight (%)
1.	90	10
2.	80	20
3.	70	30

The biochar pieces should should be between 20-30 mm, avoiding this way excessive biochar material in specific spots of the mix, while also playing the role of an inert material and increasing the structural performance of the mixture. The proposed quantity of the biochar pieces is regulated by the straw-biochar ratio by weight, which varies from 90% straw and 10% biochar to 70% straw and 30% biochar.

7.2.2. Straw-lime insulation and biochar

The second scenario proposes the addition of biochar in the straw-lime mixture. Straw lime is a biocomposite, the thermal performance of which is slightly better than light clay.

Tab. 10. Lime putty - powdered biochar proportions by weight for the preparation of the clay slip		
Sample no.	Lime putty proportion by weight (%)	Powdered biochar proportion by weight (%)
1.	90	10
2.	85	15
3.	80	20

This material also requires long drying times and presents a rick of straw fiber decay in presence of constant high humidity levels. Also in this case, the biochar addition can be applied in two ways:

- By adding powdered biochar to the lime slip
- By using the biochar pieces.

Tab. 11. Straw- biochar pieces proportions by weight		
Sample no.	Straw ratio by weight (%)	Biochar pieces ratio by weight (%)
1.	90	10
2.	80	20
3.	70	30

The preparation of the mix in both cases is the same as the ones suggested for the biochar addition in the light earth mix explained in paragraph 7.1. The proposed biochar-lime putty or the biochar-straw ratios by weight are also analogue to the ones used for the light clay. This way the differences and similarities between the two biocomposites with the addition of biochar can be compared more easily.

7.2.3. Hempcrete insulation and biochar

The hempcrete mix is also considered for the creation of samples in order to identify the influence that the biochar addition creates while applied as a powder and in 20-30 mm pieces.

Tab. 12. Hempcrete binder - powdered biochar proportions by weight

Sample no.	Hempcrete binder proportion by weight (%)	Powdered biochar proportion by weight (%)
1.	90	10
2.	85	15
3.	80	20

The expected variation of the properties are related to this biocomposite hygrothermal properties, mechanical performance, density and setting time.

Tab. 13. Hemp shiv - biochar pieces proportions by weight

Sample no.	Hemp shiv proportion by weight (%)	Biochar pieces proportion by weight (%)
1.	90	10
2.	80	20
3.	70	30

Amongst the proposed proportions which foresee the use of powdered biochar, the sample number two which uses a 15% biochar by weight and a 85% natural hydraulic lime NHL5 was already built, and it showed promising results. In order to observe the variation of the composite performance while changing the ingredients proportions, other two ratios are suggested to be tried.

In this case, the hemp shiv, the hempcrete binder and the powdered biochar or the biochar pieces can be first mixed together, than water is added (or they are added into a barrow or mortar mixer where the right amount of water is previously inserted).

7.3. The biochar plaster

The biochar plaster is the one technological solution which has already been implemented in a real life scale for the plastering of the indoor ambients of the Ithaka Institute in Switzerland. The same ingredients with the same proportions are also suggested for this project, although it is suggested the testing of other ratios as well. Using the 50%-30%-20% biochar-sand-earth ratio by weight in order to create a plastering material, will result in a very vapour permeable surface. The lower the biochar ratio and the higher the earth binder ratio the less permeable the created surface. Nevertheless, big quantities of biochar addition to this mix would reduce the drying time considerably. The biochar plasters can have thicknesses that can vary from a couple of millimeters (samples of 2-3 mm biochar plasters were created during the experience on La Termitière) to 20 cm. A 20 cm thickness is excessive for a plaster, but it has been applied in Switzerland inside the Ithaka Institute, in an underground area where the humidity levels were very high and this plaster was used to make up for the lack of any insulation material. The biochar plaster cannot be created only by using powdered biochar.

Tab. 14. Biochar, sand and earth plaster

Sample no.	Biochar proportion by weight (%)	Sand proportion by weight (%)	Earth proportion by weight (%)
1.	50	30	20
2.	40	30	30
3.	30	30	40

Biochar pieces with dimensions 15-25 mm can be used for the construction of plasters also, although this would require the construction of a thermo-plaster layer, the thickness of which should be more than 25 mm. In both cases, the quantities of biochar don’t have to change.

Tab. 15. Biochar, sand, earth and lime putty plaster

Sample no.	Biochar proportion by weight (%)	Sand proportion by weight (%)	Earth proportion by weight (%)	Lime putty proportion by weight (%)
1.	50	30	10	10
2.	50	20	10	20
3.	40	20	20	20
4.	40	20	30	10
5.	40	20	10	30
6.	30	20	20	30
7.	30	20	30	20

The difference between powdered biochar and biochar pieces would be shown in the mechanical properties of the plaster, which is supposed to be more performant when pieces of biochar are used.

The proposed mixtures for the creation of biochar plasters suggest the use of biochar, sand and earth for one type of mix, and the same ingredients with the addition of lime putty for the creation of another variant mix. The lime putty is added in order to increase the mechanical properties of these plasters, which are most performing when applied in thicknesses of more than 15 mm.

7.3. Application

This proposal foresees the organisation of the activities in two phases:

- experimental phase, during the which the samples are created and tested in order to choose which material to implement

- the implementation phase, during the which the chosen mixtures are applied in a real building

The way it can be applied can be the same as the other activities previously organised by La Termitière team. This would result in "La Termitière 3.0" project and would require the creation of a new organisational team. It is necessary for the activities to have an annual span to make make space for both phases, which require long times for their fulfillment. After the development of a project based on the architectonic features of a suitable case study, it is required to take in consideration the following processes in order to adequately plan the activities:

- the construction of the samples, which can be carried out during one or two workshop activities (depending on the number of participants) workshops of 3-4 days each in a 2-3 week span
- the drying of the samples, which might require more than 1 month for the slowest drying sample
- the sample testing in laboratories, which if properly organised in advance, can require approximately 1-2 months.
- the material supply, 1 week to 1 month
- the application time, which can require 1 to 4 months

This scenario would be in case all three composites are to be applied (floor screed, insulation and plaster). In case only one or two of them are chosen to be applied, the time required to complete this project would shorten. For instance, if only the biochar plaster is to be applied, the samples can be done by creating a matrix with the different ratios, wait for them to dry and then choose the most performing one. This process would require only a few days and no machinised tests, while tests like the plasters water absorption can be carried out in site.

Chapter EIGHT

8.CONCLUSIONS

Light earth, straw-lime and hempcrete are bio-aggregates, created by mixing earth or lime binders with natural reinforcing fibers like straw stems or hemp shiv.

All three of them have found large application in construction and create breathable building envelopes. Although their properties and application techniques are very similar, they differ in thermal performance, economical feasibility, workability, carbon footprint etc. The information which I was unable to personally acquire during the implementation of La Termitière project due to the lack of time or experience, was filled out by consulting literature. Nevertheless, most of the information over these materials and their use has been gathered by me and my colleges of La Termitière by creating samples, conducting tests using the facilities of the Politecnico di Torino and applying them in a real case study.

The comparison between these biocomposites has the purpose to point out the differences and similarities between these materials, in order to make it easier for a builder to choose which would be the most suitable solution

8.1. Implementation feasibility

If a builder is to choose one of the three biocomposites for the insulation of the whole building envelop, the following factors should be taken in consideration:

- Structural frame
- Implementation time
- The labour force qualification
- Thermal conductivity

- Structural properties
- Building site

8.1.1. Structural frame

Light earth, straw-lime and hempcrete are applied as infill insulation material. All of them require a structural frame, preferably made out of timber. The structural frame for these biocomposite materials can be exactly the same.

From this point of view, any of the three composites can be freely chosen to be implemented.

8.1.2. Application time

Application time is an important factor when working with composite materials. The time needed for the construction of an insulation layer using light earth, straw-lime or hempcrete can be divided in:

a. time required for the construction of the structural frame
b. time required for the preparation of the mixture
c. time required for the application of the mixture
d. time necessary for the composite to dry.

a. The time required for the construction of the structural frame can be the same for the three bio-aggregates.
b. Hempcrete is the fastest composite to prepare. One of the main reasons is the possibility of using various mortar mixers (preferably vertical shaft mixers) and its ability to be directly cast once its prepared. This reduces the preparation times drastically. Straw-lime is the second fastest composite. The straw-lime mix requires traditional manual work for its preparation, which means it needs more time than hempcrete, but once the mix is ready, it can be immediately placed the shutterings.
Light earth requires the most time to get ready for application. It cannot be prepared by using

any type of machinery because of the size of the straw stems, so the process can only be carried out through manual work. Then, the wet mix needs to be left to drain before being applied. This time varies from 2 to 12 hours.

c. Hempcrete is the quickest to apply. This is due to the hemp shiv dimensions which allow the use of machinery like spraying hoses. Even when this process is carried out manually, the composition and the dimensions of the shiv make it easier and faster to fill the shutterings, and it does not require excessive pressing after the composite is cast. The second fastest biocomposite is straw-lime. This is due to the high alkaline ph of the lime putty, which allows the straw stems to reach a morbid state very fast, increasing their workability and making it very easy for the mixture to be placed and compacted with minimum effort. Light earth on the other hand is a little harder to cast, compared with the other two, and requires more effort during the pressing process once the composite is cast inside the shutterings.

d. The time necessary for the drying of a 10 cm layer are the following:

- Light earth → 0.5 to more than 6 months (more in cold temperatures and humid weather)
- Straw-lime → 0.5 to 2 months (more in cold temperatures and humid weather)
- Hempcrete → 2 to 6 weeks (sometimes 8 weeks in cases of moist atmospheric conditions, low temperatures or very wet mix ratios)

8.1.3. Labour force qualification

The labour force required for the correct application of these biocomposites doesn’t always need to be qualified, even though an experienced and skilled workforce would considerably increase the quality

of the works and reduce their application time. The preparation and application of light earth not only does not require any qualification from the workforce, but it does not require any protective gear or specific instruments. Straw-lime, on the other hand, does not need any specific qualification from the workforce, but does require the use of protective gear like gloves, protective goggles, face masks, boots, long sleeved clothes or adequate suit, and instruments like barrels and pitchforks. Hempcrete is the only material which requires skilled and experienced manpower, or at least a learned construction supervisor on site. If the biocomposite material is supplied in premixed confections, or the proportions of the specific shiv and binder are already pre stabilised, the manpower can be amateur, even though supervision is always suggested in order to avoid problems with the performance of the wall.
For an efficient preparation and application of these biocomposites, an adequate number of workers is 2-3 people.

8.2. Thermal insulation

Light earth, straw-lime and hempcrete are biocomposites used as insulation materials because of their good thermal performance. Even though their thermal conductivity is acceptable, lots of the conventional insulation materials found on the market are frequently more performing in terms of thermal resistance. The thermal performance depends from their density, the natural fiber:binder ratio and the way they are applied. The biocomposties we have applied in the Red Room have the following densities and thermal conductivities:

- Light earth obtained binder from unfired bricks (210 kg/m^3) → 0.098 W/mK
- Light earth obtained binder from subsoil (154 kg/m^3) → 0.090 W/mK
- Straw-lime (125 kg/m^3) → 0.083 W/mK
- Hempcrete (385 kg/m^3) → 0.0788 W/mK (its thermal conductivity is 0.06 W/mK when its density is 200 kg/m^3)

The values of the thermal performance of light earth and straw-lime are obtained by the members of La Termitière after they are tested in the laboratory of the Department of Energy, while the thermal conductivity of hempcrete is given by the supplying company. The thermal conductivity values and the materials density are in tune with those literature shows[35].

The light earth with the same or lower density as hempcrete shows a worse thermal conductivity. Straw-lime, even though it is lighter, has also a higher thermal conductivity than a dense hempcrete mix. This shows that in terms of thermal conductivity, hempcrete is the best performing material out of the three mixes, followed by straw lime, with the last being light earth.

8.3. Building envelope

8.3.1. Walls

[35] Franz Volhard: Light earth building

The construction of an insulation layer against the walls of an existing building or the construction of free-standing walls using infill material can be efficiently carried out by using all three of the biocomposites taken in consideration in this chapter. Apart from the differences pointed out in the previous paragraphs, it is important to say that in order to have the same thermal performance from the three materials, the thickness of the insulation layer will need to vary.

The light earth is the least performing material, with a thermal conductivity of 0.098 W/mK for a mix with a density of 210 kg/m^3. This means a thicker insulation layer is necessary in order to obtain the same U-value. The thinnest insulation layer is obtained from the hempcrete material.

This means that a balance has to be seeked between the area sacrificed for the addition of the insulation layer, the application time and economical feasibility.

8.3.2. Roof

To choose an insulating biocomposite for the roof, the following factors should be taken in account:

- the thickness of the layer
- the density, which influences the weight the structural frame has to bear. The heavier the weight, the strongest the structural frame, the higher the amount of material for its construction. Light earth, being at the same time the densest material and the one that requires the thickest layer, would be the heaviest solution of the three. The second heaviest solution would be the straw-lime, while the lightest one the hempcrete aggregate. Hempcrete can be produced in densities that can reach down to 120 kg/m^3 when applied in roof insulation, while maintaining or improving its thermal performance.
- the application ease is also an important factor. Having to deal with horizontal wood forms which need to be filled for the roof insulation, the dimensions of the straw stems make it difficult to apply light earth and also straw-lime, influencing negatively on the application time. The hempcrete mix on the other hand, using an aggregate material (hemp shiv) with smaller dimensions, is far more easier to be cast in this case.

8.3.3. Sub slab

To build a sub slab insulation, the following factors should be considered:

- the thickness of the insulation layer
- the application feasibility
- the mechanical properties of the mix. Today, the use of hempcrete for sub slab insulation has been applied in numerous cases. An important characteristic of this material when used for floor insulation, is that it does not need a structural frame. This

material is directly cast on the floor, if with a high binder ratio in order to reach densities between 350 and 500 kg/m^3. Once this mix is dried, a flooring layer can be directly applied.

The other two materials can also be used for the sub slab insulation, but they will require additional structural elements, like timber joists, creating woodforms which are filled with the biocomposites. The loads applied over the floor, preferably made of wooden boards, would set down on the timber joists, not the biocomposite. The compressive strength of light earth and straw-lime is not high enough for them to carry the loads which can be applied over a floor.

8.4. Structural properties

The three biocomposites have self-bearing mechanical properties. They are not used as load-bearing elements is not applied, although David Lea has been performing tests on the use of the hempcrete as a load-bearing material in the Cardiff University in United Kingdom.

The mechanical properties of light earth, straw-lime and hempcrete are strictly connected to the natural fiber:binder ratio and the mix compression at application. The compressive strength of these biocomposites is increased if a higher binder ratio is used and also if the mix is pressed more than necessary. The increasing mechanical performance will result in a worse thermal performance, because denser and less porous mixtures are created.

From the mechanical point of view the best performing biocomposite is the hempcrete, whose compressive strength is slightly above 1N/mm^2 value at densities between 350 and 500 kg/m^3, while the compressive strength of light earth and straw-lime is very unlikely to exceed 1N/mm^2.

8.5. Embodied energy

The three biocomposites have lower embodied energy and carbon if compared to conventional insulation materials. However, there are differences between them.

Straw has a very low embodied energy (0.24 MJ/kg)[36], essentially made up of energy consumption from the agricultural machinery used for harvesting and for transportation to the building site. The closest the supplier, the lower the embodied energy of the material.

Hemp shiv on the other hand, requires processing in order to be suitable for its use in construction, such as reducing the shivs to adequate dimensions and cleaning them from dust and fibers. This increases its embodied energy little, if compared to straw. Hemp itself has an embodied energy of 1.4 MJ/tonne[37] while the embodied energy value of the hemp shiv is difficult to obtain.

Unfired earth is one of the construction materials with the lowest embodied energy. It essentially consists in the energy consumption of the excavating machine, if used at all, and the energy necessary for transport to the building site. Its estimated embodied energy has a mean value of 0.45 MJ/kg[38].

Lime putty needs to go through a kiln for its production, which burns in temperatures between 800 and 1200°C. This gives it a much higher embodied energy. The estimated embodied energy of lime is 5.3 MJ/kg[39].

The natural hydraulic lime production requires a burning in kilns that reaches temperatures between 1000 and 1300°C. The addition of Portland cement to the specific hempcrete binders increases the embodied energy of the mix. Portland cement goes through a production process that reaches burning temperatures of 1500°C and has an average embodied energy of 5.2 MJ/kg[40].

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[36] Source: Hammond and Jones 2011
[37] Source:BRE 2001, Pervaiz 2003

[38] Source: Inventory of Carbon and Energy database V2.0
[39] Source: Inventory of Carbon and Energy database V2.0
[40] Source: Inventory of Carbon and Energy database V2.0

This shows that light earth is the composite which contains the lowest embodied energy, followed by straw-lime and hempcrete.

8.6. Carbon footprint

Straw and hemp are vegetal materials, which means they derive from plants that have the ability to absorb the carbon dioxide releasing O_2 back to the atmosphere. These materials have the ability to sequester CO_2 after they are harvested, and subsequently, even when they are used in construction (e.g. 1 m^3 of hempcrete sequesters approximately 110 kg of CO_2 every year[41])

On the other hand, CO_2 is released by the machinery used for harvesting, processing, transport and application of these materials.

The carbon footprint of wheat straw varies from 125 $kgCO_2$/tonne if it goes through an organic treatment to 368 $kgCO_2$/tonne when it goes through a conventional treatment[42].

The carbon footprint of hemp fibre production[43] varies from 682 to 835 $kgCO_2$/tonne[44], depending mostly on the use of fertilization.

The earth binder has a nearly zero carbon footprint, which makes it one of the most sustainable building materials.

Lime putty and natural hydraulic lime on the other hand have a considerable carbon footprint due to their production process, which includes quarrying, transportation to the kilns, a burning process which reaches temperatures as high as 1300°C, packaging and transport to the building

41-http://www.tradical.com/pdf/Tradical_Information_Pack.pdf

42 Source:https://www1.agric.gov.ab.ca/ Jennifer Fix and Sean Tynan, HB Lanarc Consultants Vancouver, BC: "*Carbon Footprint Analysis for Wood & Agricultural Residue Sources of Pulp*"

43 With hemp shiv being a byproduct, it is difficult to obtain information on its carbon footprint, so that of the hemp fibre production is considered instead.

44 Source: http://eiha.org Martha Barth, Michael Carus (nova-Institute): "*Carbon Footprint and Sustainability of Different Natural Fibres for Biocomposites and Insulation Material*"

site. The lime production has an estimated carbon footprint of 740 kgCO_2/tonne[45]. Even though these materials derive from processing of stone, their embodied energy affects their carbon footprint. It is important to point out that the lime putty binder sets through carbonation, which means it absorbs back some CO_2 during its hardening process.

To sum up, the biocomposite with the highest carbon footprint is hempcrete mix, followed by straw-lime and light earth.

8.7. Economical feasibility

Light earth, straw-lime and hempcrete can allow the construction of low cost insulation layers or free standing wall infilling. The cost of the ingredients of these biocomposites can vary based on their availability. Anyway, straw, hemp shiv and earth (sometimes even lime putty, in places where its production continues to be made in traditional ways) can be obtained at almost no cost.

Straw is a much easier material to obtain compared to hemp shiv, due to its larger availability in a global scale, and therefore its cost is lower. The cheapest is earth, followed by lime putty. Specific hempcrete binders can be found almost exclusively where the use of this material has gained popularity. The price of this binder is also higher than earth and lime putty.

This means that the cheapest material is of the three is the light earth, followed by the straw-lime while the most expensive of the three is the hempcrete material.

The average price of straw in northern Italy is 120 euros per tonne, while that of the hemp shiv is 330-340 euros per tonne[46], if bought from farmers which claim their product can be applied in construction (which means adequate dimensions of the hemp shiv pieces and dust and fibers have been removed). Hemp shiv is not

[45] https://www.winnipeg.ca

[46] Source: http://canapalifestyle.com/home/bio-edilizia/canapulo/canapulo-depolverato-per-bio-edilizia-detail

only more expensive, but also harder to find than straw.

The cost of binders differ as well. The earth binder, if bought in confections, would have a very high cost as it is usually sold for plasters and finishing works. The traditional and most cost efficient way of obtaining an earth binder is extracting it from the subsoil. This would have a very low cost, which which does not appear in regional or national price lists for the construction materials. Such earth needs to go through some processes (drying and the elimination of the microorganisms, which require time and a storage place) before it can be used in construction.

Lime putty is the second cheapest and can be easily found. Its price in northern Italy can range between 0.1 and 1.3 euro per kg (100-1300 Euro per ton) depending from its ageing[47].

The hempcrete binder, if prepared in site, would require at least one qualified person constantly present. This binder is mostly made of natural hydraulic lime (typically around 70-80%) the price of which varies from 0.35-1 Euro per kg (350-1000 euro per tonne)[48] in Italy, making it the most expensive binder.

So, in terms of economical feasibility, the cheapest solution would be the light earth, followed by the straw-lime and hempcrete.

The cost of hempcrete ranges between 400 and 700 euro per m^3, that of straw-lime, that of straw-lime between 100 and 200 euro per m^3 and the average cost of light earth is around 100 euro per m^3.

8.8. New construction

Light earth, straw-lime and hempcrete can be used both in new construction and existing buildings. If one of these aggregates is to be chosen

[47] Source: www.regione.piemonte.it/oopp/prezzario/dwd/sez03.xls

[48] Source: www.regione.piemonte.it/oopp/prezzario/dwd/sez03.xls

as an infill material for the construction of a new building with a thermal performance as required by the present regulation, the differences would be the following:

- The thickness of the walls will differ because of the different thermal conductivity of the mixes. Light earth has the highest thermal conductivity of the three, making it the less insulative. This means thicker infilling layers are required and therefore, a thicker wall.
- The indoor area is influenced by the wall thickness. If there is a limit on the built area, it should be taken in consideration that these materials were to have the same U value (e.g. the u value of the F climatic zone in the Italian regulation for the years 2019-2021 is set to 0.2 W/m^{2}K for walls) thy would have the following thickness ranking:
    - 49 cm of light earth with a density of 210 kg/m^3
    - 45 cm of light earth with a density of 154 kg/m^3
    - 41 cm of straw-lime
    - 39 cm of hempcrete from CANAPAMAS 385 (385 kg/m^3)
    - 30 cm of hempcrete CANAPAMAS 200 (200 kg/m^3)
- Different amounts of material for structural frames are required because of the different thicknesses and densities of the infill. The composite which requires a stronger structural frame, and therefore more time and material for its application is the light earth, followed by the straw-lime and hempcrete.
- The implementation time also differs. Light earth is the material that requires more time for application, followed by straw-lime hempcrete. The factors influencing on the application time are stated in paragraph 8.1.2..

8.9. Conclusions

Light earth, straw-lime and hempcrete are materials which can be used for the construction of vapour permeable and insulative building envelope. The advantages of using these materials are not related only to the users comfort, but also to the environmental impact. What mostly characterises these biocomposites are the following features:

- Thermal conductivity
- Humidity regulation
- CO_2 sequestration
- Acoustic insulation
- Ease of application
- Low embodied energy and carbon footprint
- Low monetary costs
- Non-toxic building materials
- Etc..

These materials have shown that when applied in construction, they have the potential to perform better than conventional materials. Nevertheless, these biocomposites could not replace the conventional insulation material in every scenario. The use of light earth, straw-lime and hempcrete should mostly be seeked when the aim of a construction process is that of obtaining a construction or an intervention on an existing building with a low cost, embodied energy and carbon footprint, while offering an adequate indoor air quality and temperature.

Attachments

Canapalithos® 350

CANAPAlithos® is the precursor of a new generation of biomaterials, created from the synthesis between a hemp biomass and our "Pappa Reale" (Royal Jelly) binder which is in no way connected to the petroleum industry; it is free from formaldehyde - a substance considered carcinogenic.

CANAPAlithos® 350

CANAPAlithos® 350 is the lighter version, made with a greater particle component to limit its density. It is an excellent heat insulator for sustainable constructions thanks to its heat resistance properties.
It also boasts a high sound proofing performance so is perfect as false ceiling panels in installations made to guarantee reduced noise.

USE
It lends itself for external and internal claddings, internal and external double walls, as an internal partition wall filler, roofing and floors.

APPLICATIONS
All those that mainly require heat and sound performance.

SPECIFICATIONS
Hemp is an excellent heat and sound proofing material, resistant to insects, rodents and mould. Durable over time.
This product has been designed to be used mainly for roofing, claddings, spaces between walls and double walls. It cannot be used as a structural and/or collaborative panel. This material boasts an extremely low environmental impact; it is completely formaldehyde free, oil free, green friendly, resource is renewable, water proof and wood tools. The maximum size of the panel is 2010x3980 mm, with a density of $350 kg/m^3$, thermal conductivity 0.09W/mK and permeability to steam $\mu=6,6$. Tolerance on bulk density is ±10%, panel dimensional tolerance is ±2 mm.

CMF greentech

SIZE		
mm		
600	x	1200
600	x	1800
660	x	1320
660	x	1980
1200	x	1800
1890	x	3780
2010	x	3980

THICKNESS
mm
25
30
40
50
60

COMPOSITION **CANAPAlithos® 350**		
		standard
NOMINAL DRY DENSITY	350 Kg/m³	
RESIDUAL HUMIDITY CONTENT	9-11%	
SURFACE FINISH OF THE BOARD	Unpolished *	
THICKNESS TOLERANCE	±2 mm	
DIMENSIONAL TOLERANCES	Length / Width ±2 mm, Diagonal < 3 mm	
FIRE BEHAVIOUR CATEGORY	C, s1 - d0	EN 13501-1
SOUND INSULATION	insulation classes**	
WATER VAPOUR DIFFUSION RESISTANCE VALUE	μ = 6,6	EN 12572
ABSORPTION AFTER 24 HOURS OF WATER IMMERSION	100,00%	EN 12087
SWELLING AFTER 24 HOURS OF WATER IMMERSION	< 5% (2,7%)	EN 317
THERMAL CONDUCTIVITY	λ = 0,09 W/mK	EN 12667
THERMAL EXPANSION COEFFICIENT	$-66\ 10^{-6}\ K^{-1}$	ASTM E228
LEVEL FORMALDEHYDE	FREE FORMALDEHYDE	
STANDARD COLOURS	Beige - natural colour	

MECHANICAL PROPERTY		
	N/mm²	*standard*
STRESS PERPENDICULAR TO THE PLANE OF THE BOARD		
Bending strenght	1,1	EN 310
Compression up to crushing	1,4	EN 826
Flexural modulus	292	EN 310

RESISTANCE TO SCREW EXTRACTION		
Perpendicular to faces [N]	337	EN 320

Attachment 1. Description and properties of the CANAPALITHOS 350, supplied by CMF GreenTech. Source: http://www.cmfgreentech.com

Canapalithos® **1000**

CANAPAlithos® is the precursor of a new generation of biomaterials, created from the synthesis between a hemp biomass and our "Pappa Reale" (Royal Jelly) binder which is in no way connected to the petroleum industry; it is free from formaldehyde - a substance considered carcinogenic.

CANAPAlithos® 1000

CANAPAlithos® 1000 is a panel that adds mechanical characteristics and decidedly higher resistance to water and fire to the already great heat and sound proofing properties of versions 500 and 700. Thanks to its dimensional stability frame bearing structure sections can also be reduced quite considerably.

FIRE PROOF · WATER PROOF · 100% FORMALDEHYDE FREE · OIL FREE · RENEWABLE RESOURCES · GREEN FRIENDLY · HEMP · MADE IN MODENA

USE
It lends itself for bracing, internal and external double walls, roofing, floors.

APPLICATIONS
All those that mainly require heat and sound performance and as a collaborative element.

SPECIFICATIONS
Hemp is an excellent heat and sound proofing material, resistant to insects, rodents and mould. Durable over time.
This product has been designed to be used mainly for roofing and floors, as an excellent substitute for other wood panels or panels of different origins, double walls. It cannot be used as a structural panel but as a collaborative panel. This material boasts an extremely low environmental impact; it is completely formaldehyde free, oil free, green friendly, resource is renewable, water proof and wood tools. The maximum size of the panel is 2010x3980 mm, with a density of 1000kg/m3, thermal conductivity 0.165W/mK and permeability to steam μ=23,3. Tolerance on bulk density is ±5%, panel dimensional tolerance is ±2 mm.

SIZE mm		
600	x	1200
600	x	1800
660	x	1320
660	x	1980
1200	x	1800
1890	x	3780
2010	x	3980

THICKNESS mm
10
12,5
15
20

CMF greentech

COMPOSITION **CANAPAlithos® 1000**		
		standard
NOMINAL DRY DENSITY	1000 Kg/m^3	
RESIDUAL HUMIDITY CONTENT	9-11%	
SURFACE FINISH OF THE BOARD	Unpolished *	
THICKNESS TOLERANCE	±2 mm	
DIMENSIONAL TOLERANCES	Length / Width ±2 mm, Diagonal < 3 mm	
FIRE BEHAVIOUR CATEGORY	B, s1 - d0	EN 13501-1
SOUND INSULATION	insulation classes**	
WATER VAPOUR DIFFUSION RESISTANCE VALUE	μ = 23,3	EN 12572
ABSORPTION AFTER 24 HOURS OF WATER IMMERSION	24,80%	EN 12087
SWELLING AFTER 24 HOURS OF WATER IMMERSION	< 5% (2,9%)	EN 317
THERMAL CONDUCTIVITY	λ = 0,165 W/mK	EN 12667
THERMAL EXPANSION COEFFICIENT	-37 10^{-6} K^{-1}	ASTM E228
LEVEL FORMALDEHYDE	FREE FORMALDEHYDE	
STANDARD COLOURS	Beige - natural colour	

MECHANICAL PROPERTY		
	N/mm^2	*standard*
STRESS PERPENDICULAR TO THE PLANE OF THE BOARD		
Bending strenght	10,4	EN 310
Compression up to crushing < 10%*	6,9	EN 826
Flexural modulus	2455	EN 310
RESISTANCE TO SCREW EXTRACTION		
Perpendicular to faces [N]	1059	EN 320

Attachment 2. Description and properties of the CANAPALITHOS 1000, supplied by CMF GreenTech. Source: http://www.cmfgreentech.com

TECHNICAL SPECIFICATIONS

CHEMICAL COMPOSITION	90% hemp - 10% polyester

PARAMETER	STANDARD	RESULT	DENSITY AND REFERENCE THICKNESS
Thermal conductivity	UNI EN ISO 12667	λ= 0,038 W/mk λ= 0,040 W/mk	50 kg/m³ 30 kg/m³
Specific Heat	---	c= 1700 J/KgK	
Water vapour resistance factor	UNI EN 12086	μ = 1-2	
Recyclability	---	100%	

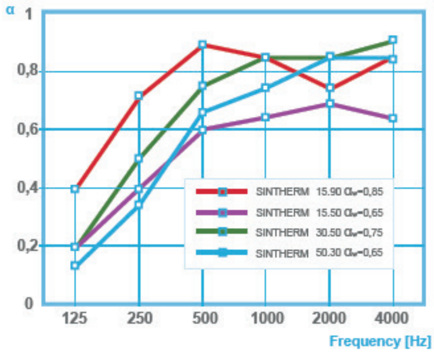
SIZE AND PACKAGES

PRODUCT NAME	density kg/mc	thickness mm	panels cm x cm	thermal resistance R	sq. m. per pack	panels per pack	sq. m. on pallet	recommended applications
NATURTHERM-CA 30.40	30	40	120 x 60	1,00	10,80	15	86,40	walls and roofs
NATURTHERM-CA 30.60	30	60	120 x 60	1,50	7,20	10	57,60	walls and roofs
NATURTHERM-CA 30.80	30	80	120 x 60	2,00	5,04	7	40,30	walls and roofs
NATURTHERM-CA 30.100	30	100	120 x 60	2,50	4,32	6	34,56	walls and roofs
NATURTHERM-CA 30.120	30	120	120 x 60	3,00	3,60	5	28,80	walls and roofs
NATURTHERM-CA 50.40	50	40	120 x 60	1,05	10,80	15	86,40	walls and roofs
NATURTHERM-CA 50.60	50	60	120 x 60	1,58	7,20	10	57,60	walls and roofs
NATURTHERM-CA 50.80	50	80	120 x 60	2,11	5,04	7	40,30	walls and roofs
NATURTHERM-CA 50.100	50	100	120 x 60	2,63	4,32	6	34,56	walls and roofs
NATURTHERM-CA 50.120	50	120	120 x 60	3,16	3,60	5	28,28	walls and roofs

Attachment 3..Tables with types and characteristics of the prefabricated insulation panels made out of hemp fibres called NATURTHERM CA supplied by Manifattura Maiano. We obtained the NATURTHERM CA 30.60 and the NATURTHERM CA 30.100.
Souce: http://www.maiano.it

Measurement of sound absorption in a reverberation room (UNI EN ISO 354)

	15.90 α_w=0,85	15.50 α_w=0,65	30.50 α_w=0,75	50.30 α_w=0,65
[Hz]	α	α	α	α
125	0,40	0,20	0,20	0,15
250	0,70	0,40	0,50	0,35
500	0,90	0,60	0,75	0,65
1000	0,85	0,65	0,85	0,75
2000	0,75	0,70	0,85	0,85
4000	0,85	0,65	0,90	0,85



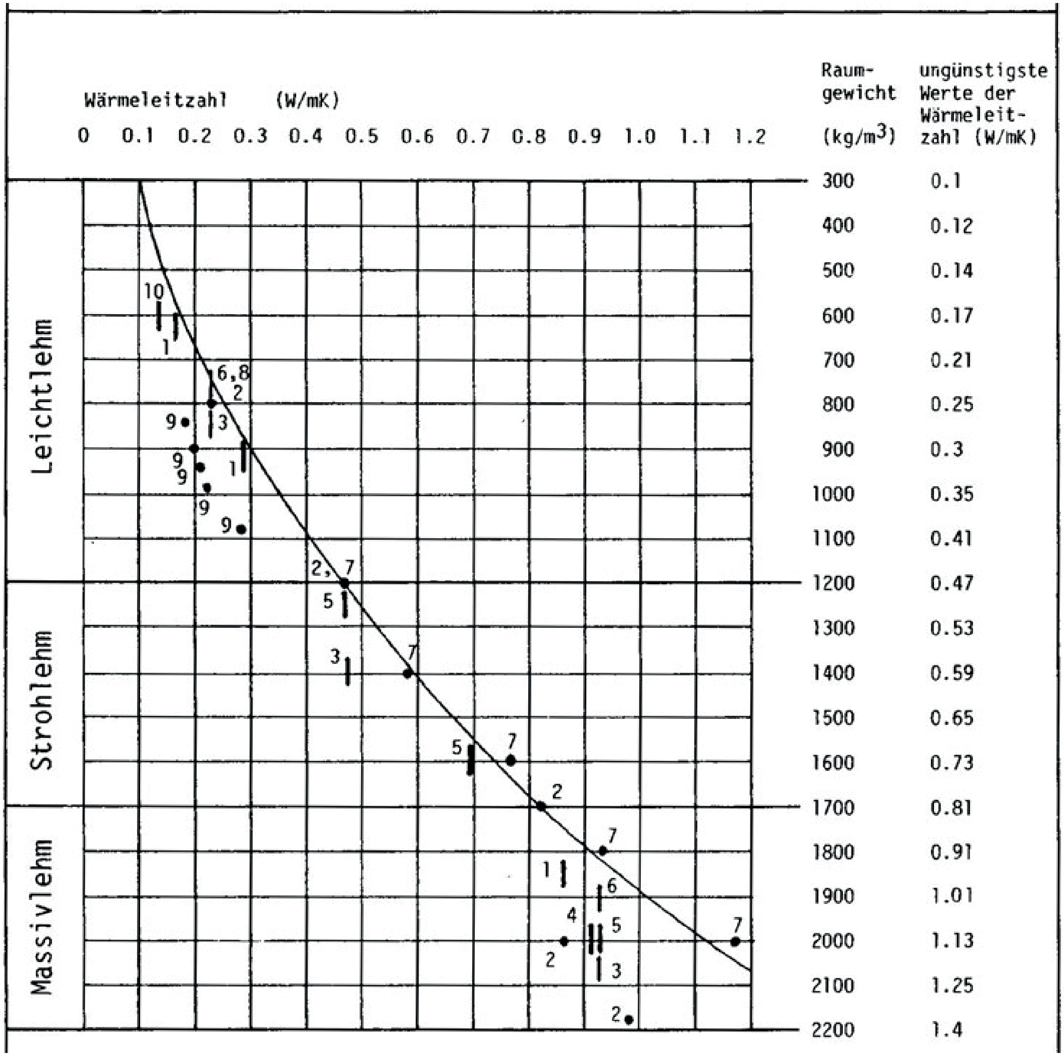
CHEMICAL COMPOSITION	100% polyester (85% of the fiber is regenerated from PET)

PARAMETER	STANDARD	RESULT	DENSITY AND REFERENCE THICKNESS	
Rating of sound absorption	UNI EN ISO 11654	α_w =0,65 α_w =0,75	50 kg/m³ 30 kg/m³	30 mm 50 mm
Sound-insulation	UNI EN ISO 140-4	R'$_w$ = 53 dB	Partition wall with metal framework and double plasterboard cladding, 12.5 and 15 mm, on both sides. Double slab of Sintherm FR 60.40 in cavity. (Various Certificates in place available on request)	
Dynamic Stiffness	UNI EN 29052	S'$_t$ =15 MN/m³ S'$_t$ =1,8 MN/m³	100 kg/m³ 50 kg/m³	8 mm 30 mm
Deformation under load 1 kPa	UNI EN 12431	3%	100 kg/m³	8 mm
Thermal conductivity	UNI EN 12667	λ= 0,034 W/mk λ= 0,036 W/mk λ= 0,037 W/mk λ= 0,042 W/mk λ= 0,048 W/mk	60 kg/m³ 50 kg/m³ 40 kg/m³ 30 kg/m³ 20 kg/m³	
Reaction to fire - Classification	UNI EN13501-1	B s2, d0		
	UNI 9177	CLASS 1		
Optical density of smoke and gas toxicity	ATS 1000.001-issue 4	limits satisfied		
Specific heat	---	c= 1200J/KgK		
Ecological and toxicological certificate	Certified product Oeko Tex standard 100	Class I RDP 1208054.O		
Recyclability	---	100%		
Temperature of application	---	- 40°C + 110°C		

DIMENSIONI E CONFEZIONI

NOME PRODOTTO	Densità kg/mc	spessore mm	Resistenza termica R	pannelli cm x cm	mq per pacco	pannelli per pacco	mq a pallet	pacchi x pallet
SINTHERM FR 15.50	15	50	1,00	120X60	8,64	12	69,12	8
SINTHERM FR 20.40	20	40	1,02	120X60	10,8	15	86,4	8
SINTHERM FR 30.40	30	40	1,05	120X60	10,8	15	86,4	8
SINTHERM FR 30.50	30	50	1,31	120X60	8,64	12	69,12	8
SINTHERM FR 30.100	30	100	2,63	120X60	4,32	6	34,56	8
SINTHERM FR 40.20	40	20	0,54	120X60	21,6	30	172,8	8
SINTHERM FR 40.30	40	30	0,81	120X60	14,40	20	115,20	8
SINTHERM FR 40.40	40	40	1,08	120X60	10,8	15	86,4	8
SINTHERM FR 40.50	40	50	1,35	120X60	8,64	12	69,12	8
SINTHERM FR 40.60	40	60	1,62	120X60	7,2	10	57,6	8
SINTHERM FR 40.80	40	80	2,16	120X60	5,04	7	40,30	8
SINTHERM FR 40.100	40	100	2,70	120X60	4,32	6	34.56	8
SINTHERM FR 50.30	50	30	0,83	120X60	14,4	20	115,2	8
SINTHERM FR 50.40	50	40	1,11	120X60	10,8	15	86,4	8
SINTHERM FR 50.50	50	50	1,39	120X60	8,64	12	69,12	8
SINTHERM FR 50.60	50	60	1,67	120X60	7,2	10	57,6	8
SINTHERM FR 60.40	60	40	1,18	120X60	10,8	15	86,4	8
SINTHERM FR 100.8	100	8	In pannelli 180x100 cm - In rotoli 1,50x20 mtl					9

Attachment 4..Tables with the characteristics and the types the prefabricated insulation panels made out of recycled PET plastic denominated SINTHERM FR supplied by Manifattura Maiano. We obtained and applied the SINTHERM FR 40.100, which have a density of 40 kg/mc,a thickness of 100 mm and a thermal resistance of 2.70 K/W. The panels came in 120c60 cm dimensions, and were manually cut in order to fit the necessary are they needed to cover.
Source: http://www.maiano.it

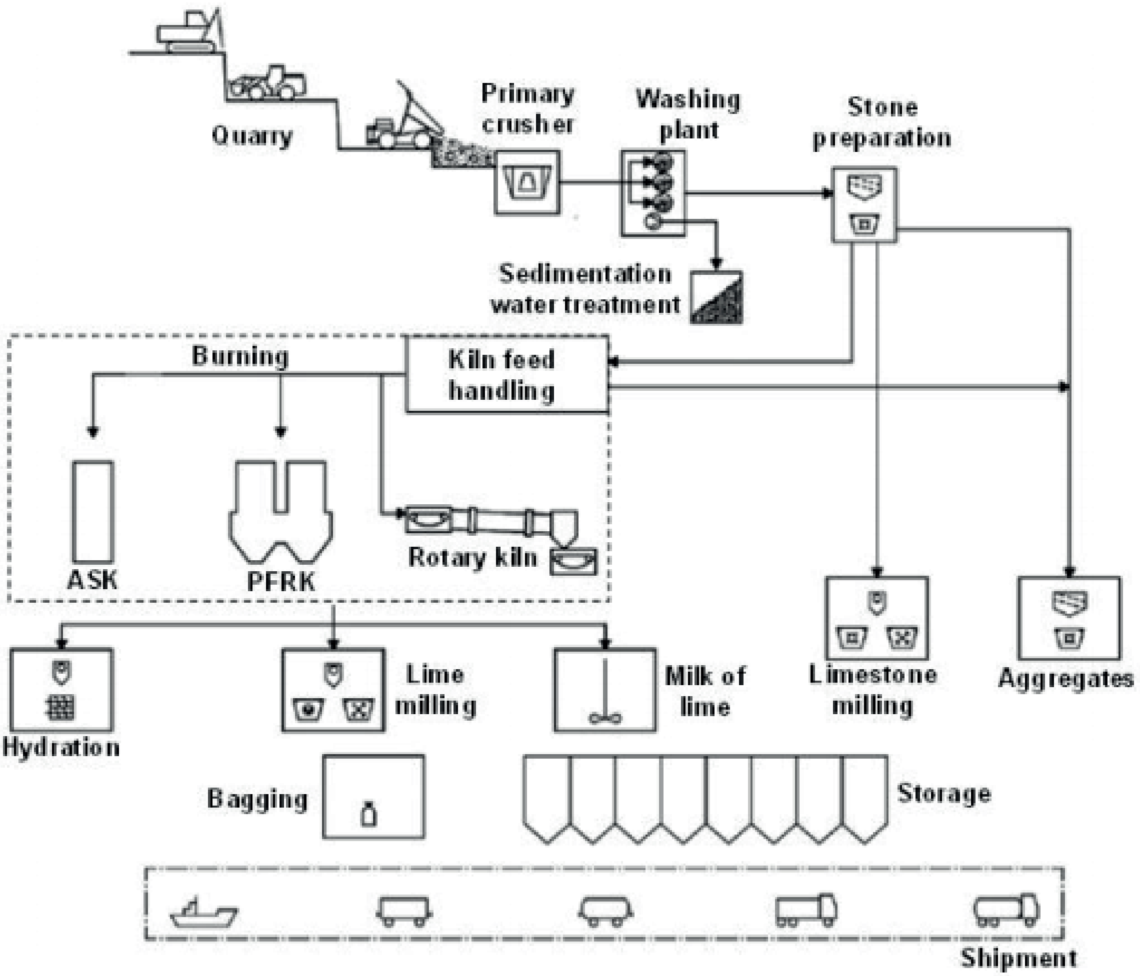


Attachment 5. Chart showing thermal performance versus density from Franz Volhard's book on leichtlehm construction. The red oval indicates the density and thermal range for very-light straw-clay."Leichtlehm" translates as "light loam", or "light clay".

Table 1

Specimen	Density (#/ ft^3)	Density (kg/m^3)	Conductivity (W/m*K)	delta temp. (deg. C)	temp_median (deg. C)	R/inch (hr*F*ft^2/BTU/inch)
Low Dens. I	10.2	164	0.08	4.54	23.21	1.80
Low Dens. II	13.0	209	0.09	approx 4.5	approx 23	1.69
So. Dakota I	15.8	254	0.09	4.51	23.40	1.55
So. Dakota II	13.3	213	0.09	4.54	23.39	1.67
Reg I	13.3	213	0.08	4.55	21.30	1.72
Reg II	13.7	220	0.09	4.54	23.59	1.66
NM I	38.1	612	0.13	4.58	23.21	1.11
NM II	43.9	705	0.16	4.19	23.40	0.90

Attachment 6. Table showing the variation of the light earth thermal conductivity with the variation on its density and earth type. Source:http://www.designcoalition.org/StrawClay/research/rvalue.htm



Attachment 7. The basic steps involved in the overall lime manufacturing process listed as follows: 1.Quarrying/winning of raw material from limestone properties; 2.Limestone storage and preparation; 3.Storage and preparation of different kinds of fuel; 4.Calcination of limestone; 5.Quicklime hydration and slaking; 6.Quicklime processing; 7.Other processing of lime; 8.Storage, handling and transport. These processes show that this material has a considerable embodied energy.
Source: [44, EuLA, 2006], [168, TWG CLM, 2007], [177, EULA, 2008]

Material Profile: Soil

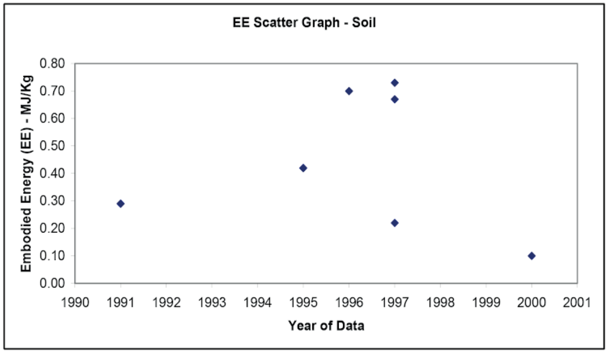
Embodied Energy (EE) ICE-Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Soil	7	0,45	0,26	0,10	0,73	None
Soil, General	7	0,45	0,26	0,10	0,73	
Unspecified	7	0,45	0,26	0,10	0,73	

Selected Embodied Energy & Carbon Coefficients and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2e/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General (Rammed) Soil	0,45	0,024	Cradle to Site	0,15	0,73	-
Cement stabilised soil @ 5%	0,68	0,061		(+/- 30%)		Assumed 5% cement content
Cement stabilised soil @ 8%	0,83	0,084				Assumed 8% stabiliser contents (6% cement and 2% lime)
GGBS stabilised soil	0,65	0,047				Assumed 8% stabiliser contents (8% GGBS and 2% lime)
Fly ash stabilised soil	0,56	0,041				Assumed 10% stabiliser contents (8% fly ash and 2% lime)
Comments	Data was limited for soil. Soil stabilised data was estimated from the stabiliser contents and the ICE data.					

Attachment 8. The soil material profile regarding the embodied energy and carbon.
Source: Inventory of Carbon and Energy database V2.0

Material Scatter Graph	Embodied Energy & Embodied Carbon Split
	No fuel split or embodied carbon breakdown was available.

Material Properties (CIBSE Data)

Material	Condition	Thermal conductivity (W-m-1 K-1)	Density (kg m -3)	Specific heat (J kg-1 K-1)	Thermal Diffusivity (M^2 S-1)
earth, common		1,28	1460	880	9,96264E-07
earth, gravel-based		0,52	2050	180	1,40921E-06

Attachment 9. The soil material profile regarding the embodied energy and carbon.
Source: Inventory of Carbon and Energy database V2.0

Material Profile: Lime

Embodied Energy (EE) ICE-Database Statistics - MJ/Kg

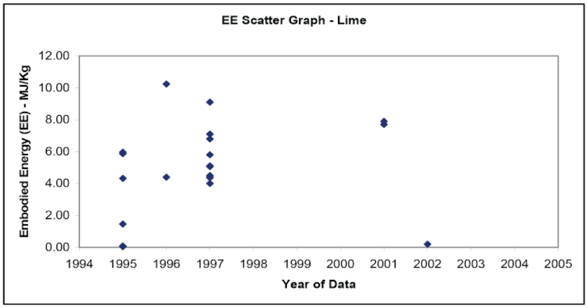
Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Lime	39	4,57	2,79	0,04	10,24	None
Lime, General	39	4,57	2,79	0,04	10,24	
Unspecified	4	6,51	4,36	0,20	10,24	
Virgin	35	4,24	2,40	0,04	9,10	

Selected Embodied Energy & Carbon Coefficients and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2e/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General Lime	5,3	0,78	Cradle to Gate	4	9,1	Wide range, dependent upon manufacturing technology. Although the embodied energy was higher than for cement the UK lime industry mix of fuels were cleaner thank cement, as such its embodied carbon was lower.
Comments	Lime is often chosen as an environmentally friendly material. It was therefore surprising to learn that the embodied energy of lime was slightly higher than for cement. This was observed from the respectable sample size of 39 data records. Lime is fired in the kiln to a lower temperature than cement, which is often misconceived as proof for a lower embodied energy. The present authors suggest that yield, density, and time in the kiln are all vital parameters to total energy consumption and that firing temperature may not be used as a proxy for embodied energy. This is presented as a possibility for its higher embodied energy. It should be noted that embodied energy is, in itself, not evidence to discredit limes environmental credentials. Due to a more favourable fuel mix and slightly lower process related carbon dioxide emissions lime has a lower embodied carbon than cement. An additional benefit of using lime based mortar includes the increased ability for deconstruction, rather than demolition. The re-carbonation that occurs over the lifetimes of both cement and lime based mortars (when exposed to air) will reduce the embodied carbon impact of the materials. Its understood that this process is not undesirable for lime (unlike cement). Examination of lime's full carbon cycle, cradle-to-grave, is therefore necessary.					

Attachment 10. The lime material profile regarding the embodied energy and carbon.
Source: Inventory of Carbon and Energy database V2.0

Material Scatter Graph



Embodied Energy & Embodied Carbon Split

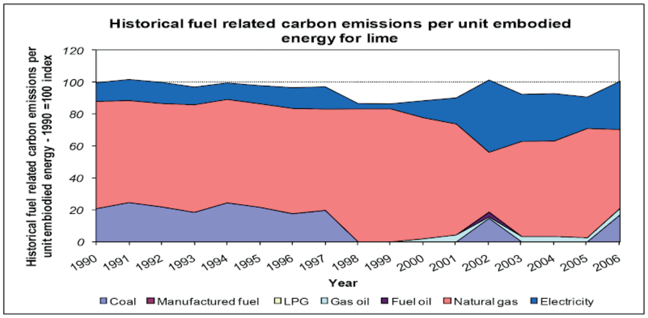
Energy source	% of Embodied Energy from energy source	% of embodied carbon from energy source
Coal	10,8%	6,2%
LPG	0,0%	0,0%
Oil	3,4%	1,5%
Natural gas	56,4%	18,1%
Electricity	29,4%	11,1%
Other	0,0%	63,1%
Total	**100,0%**	**100,0%**

Comments:

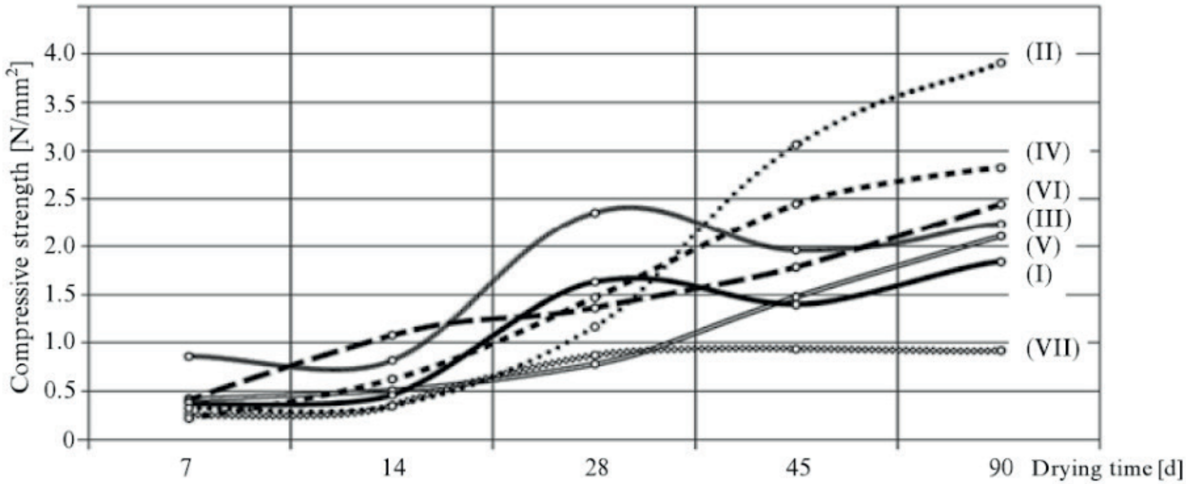
The fuel split was taken from the typical UK fuel use in UK lime industry. Lime releases approximately 0.48 kg CO2/kg lime produced. This is a process related emission and is additional to the fuel related CO2.

Note Space

Historical embodied carbon per unit fuel use



Attachment 11. The lime material profile regarding the embodied energy and carbon.
Source: Inventory of Carbon and Energy database V2.0



(I) loess soil, natural, $w \sim w_{pr}$
(II) loess soil, natural, $w > w_{pr}$
(III) rammed earth with coarse aggregate, $w \sim w_{pr}$
(IV) rammed earth with coarse aggregate, $w > w_{pr}$
(V) rammed earth with coarse aggregate+ straw fibers, $w \sim w_{pr}$
(VI) rammed earth with coarse aggregate+ straw fibers, $w > w_{pr}$
(VII) rammed earth with coarse aggregate+ straw fibers, $w < w_{pr}$

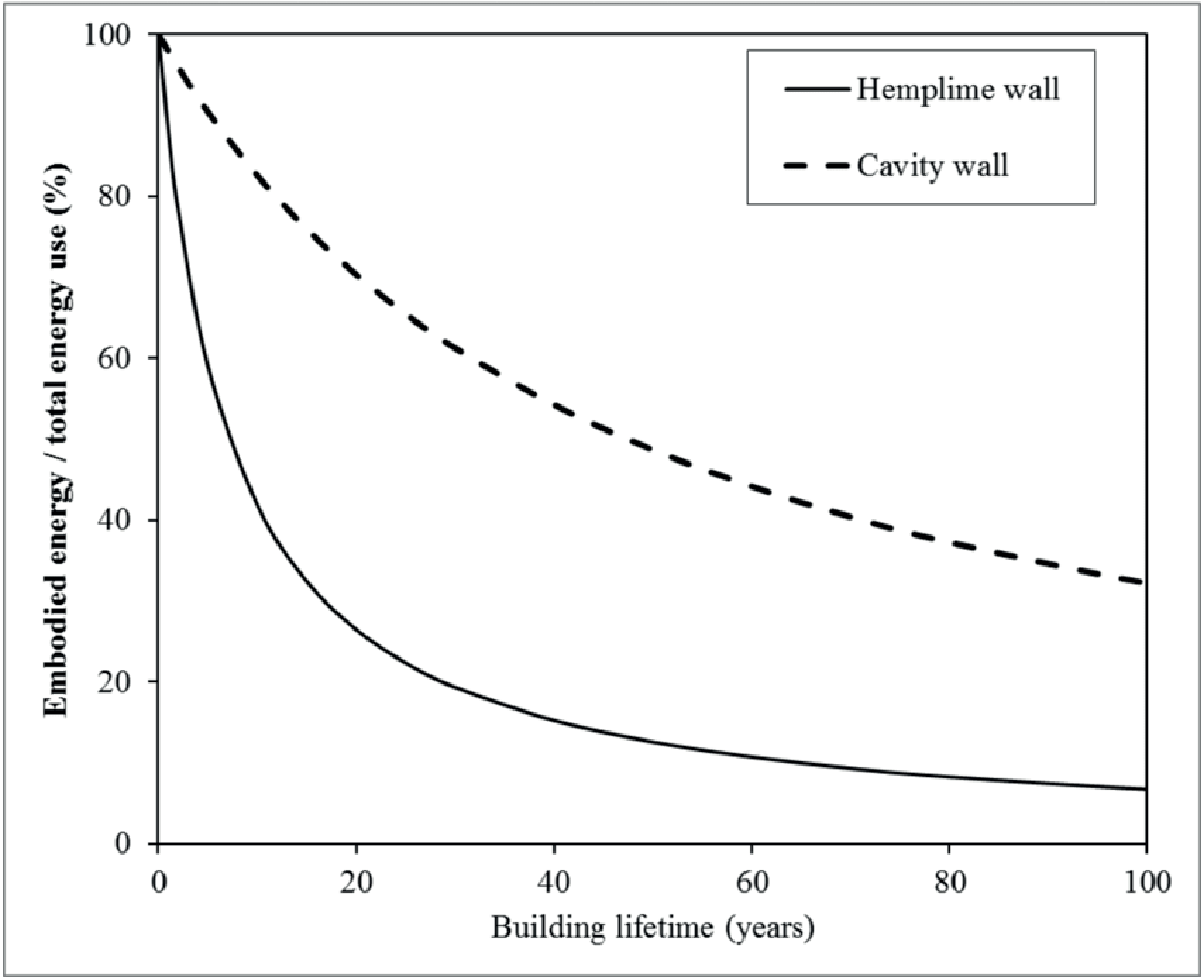
Attachment 12. The variation of the compressive strength of different earth mixtures depending from the drying time.
Source: https://link.springer.com/chapter/10.1007/978-3-319-19491-2_3

Material	Embodied carbon by weight*	Embodied carbon for 4x8 foot wall @ R-28**	Carbon footprint after sequestration
Hempcrete	-2.73 $kgCO_2e/kg$ for 300 kg/m^3 mix	-121.4 $kgCO_2e$	-121.4 kg per 4x8 wall area
Mineral wool batt	1.28 $kgCO_2e/kg$	21.75 $kgCO_2e$	21.75 kg per 4x8 wall area
Fiberglass batt	1.35 $kgCO_2e/kg$	17.6 $kgCO_2e$	17.6 kg per 4x8 wall area
Denim batt	1.28 $kgCO_2e/kg$	22.45 $kgCO_2e$	-1.5 kg per 4x8 wall area
Dense packed cellulose	0.63 $kgCO_2e/kg$	35.3 $kgCO_2e$	-41.3 kg per 4x8 wall area
Extruded polystyrene foam	3.42 $kgCO_2e/kg$	38.5 $kgCO_2e$	38.5 kg per 4x8 wall area
Expanded polystyrene foam	3.29 $kgCO_2e/kg$	37.25 $kgCO_2e$	37.25 kg per 4x8 wall area
	* figures from Inventory of Carbon and Energy (ICE) 2.0	**material densities from *Making Better Buildings*	

Attachment 13. Hempcrete embodied carbon by weight.
Source: Hempcrete construction, the complete step-by-step guide

Treatment	Removable Straw Yield (kg straw/ha) [16]	Total CO_2 (Straw) (kg CO_2/tonne straw)[17]	Total CO_2 (Straw required for one tonne pulp)[18] (kg CO_2/tonne pulp)
Conventional	983	154	**368**
Organic	961[19]	52	**125**

Attachment 14. Carbon footprint of wheat straw production.
Source: https://www1.agric.gov.ab.ca



Attachment 15. Embodied energy of a hempcrete wall during the building lifetime.
Source: https://www.researchgate.net/

Totale: 320 mm

Ordine	DESCRIZIONE DELLO STRATO (dall'interno all'esterno)	s (mm)	C (W/m^2K)	M.V. (Kg/m^3)	$Px10^{12}$ (Kg/msPa)	R (m^2K/W)
	Adduttanza interna		7.7			0.13
1	Intonaco di gesso puro	20	0.3500	1200	18.00	0.057
2	Mattoni pieni in laterizio	280	0.8000	1800	20.57	0.35
3	Malta di cemento	20	1.4000	2000	8.50	0.014
	Adduttanza esterna		25.0			0.04

s = Spessore dello strato; C = Conduttività termica del materiale; M.S. = Massa superficiale; P = Permeabilità al vapore; R = Resistenza termica

Trasmittanza (W/m^2K): **1.691 > 0.3** (Valore di legge)

Massa superficiale (Kg/m^2): **568**

Resistenza termica (m^2K/W): **0.591**

Spessore totale (mm): **320**

Il valore della trasmittanza (1.691) oltrepassa i termini di legge (0.3)

Comune di **Torino**

Zona Climatica: **E**, Gradi Giorno **2617**

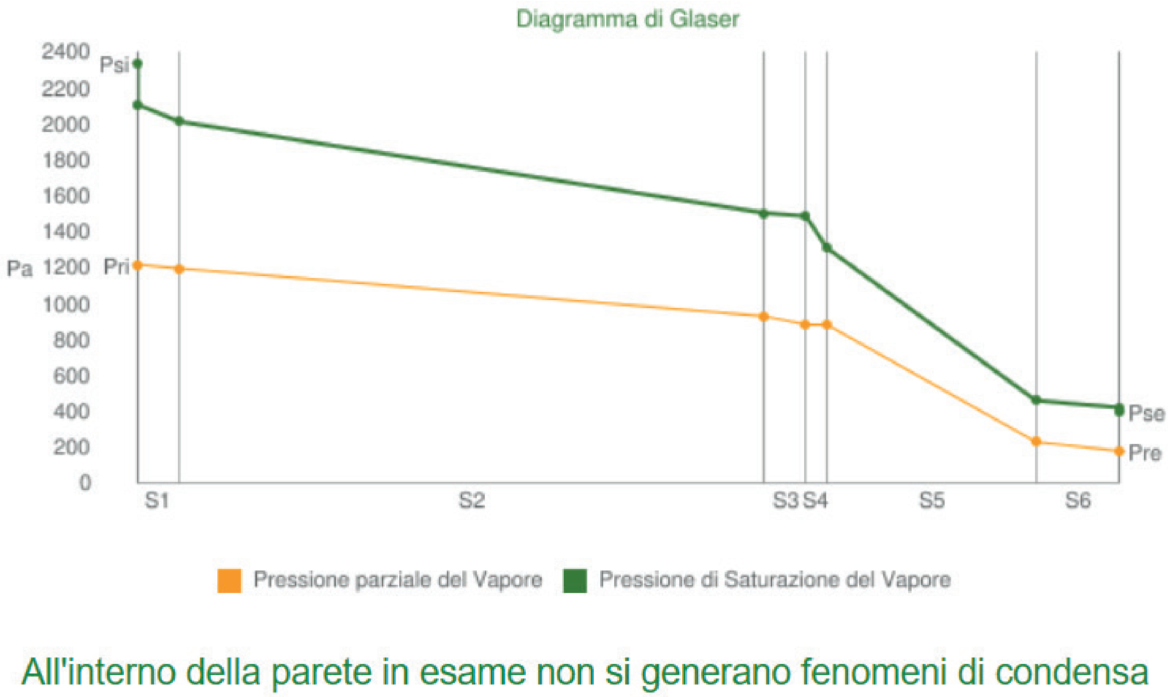
T interna (°C): **20.0**

T esterna (°C): **-8.0**

U interna (%): **52.0**

U esterna (%): **44.4**

Attachment 16. U value of the wall in absence of insulation.



Attachment 17. Glaser's diagram for the wall in absence of insulation.

Totale: 470 mm

Ordine	DESCRIZIONE DELLO STRATO (dall'interno all'esterno)	s (mm)	C (W/m^{2}K)	M.V. (Kg/m^3)	Px10^{12} (Kg/msPa)	R (m^{2}K/W)
	Adduttanza interna		7.7			0.13
1	Intonaco di gesso puro	20	0.3500	1200	18.00	0.057
2	Mattoni pieni in laterizio	280	0.8000	1800	20.57	0.35
3	Malta di cemento	20	1.4000	2000	8.50	0.014
4	Strato d aria verticale (spessore tra 1 cm e 1,5 cm)	10	0.0670	1	193.00	0.149
5	Isolante personalizzato (valori imposti dall'utente)	100	0.0980	210	3.00	1.02
6	Intonaco in argilla	40	0.4900	1200	15.38	0.082
	Adduttanza esterna		25.0			0.04

s = Spessore dello strato; C = Conduttività termica del materiale; M.S. = Massa superficiale; P = Permeabilità al vapore; R = Resistenza termica

Trasmittanza (W/m^{2}K): **0.543 > 0.3** (Valore di legge)

Massa superficiale (Kg/m^2): **637**

Resistenza termica (m^{2}K/W): **1.843**

Spessore totale (mm): **470**

Il valore della trasmittanza (0.543) oltrepassa i termini di legge (0.3)

Comune di **Torino**

Zona Climatica: **E**, Gradi Giorno **2617**

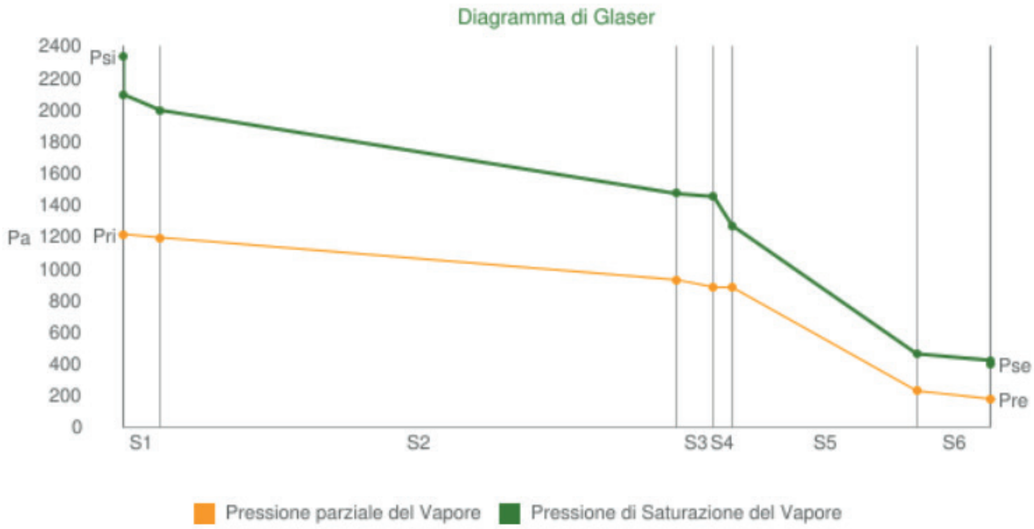
T interna (°C): **20.0**

T esterna (°C): **-8.0**

U interna (%): **52.0**

U esterna (%): **44.4**

Attachment 18. U value of the wall insulated with light earth from unfired bricks.



All'interno della parete in esame non si generano fenomeni di condensa

Attachment 19. Glaser’s diagram for the wall after insulated with the light earth from unfired bricks.

Totale: 470 mm

Ordine	DESCRIZIONE DELLO STRATO (dall'interno all'esterno)	s (mm)	C (W/m²K)	M.V. (Kg/m³)	Px10¹² (Kg/msPa)	R (m²K/W)
	Adduttanza interna		7.7			0.13
1	Intonaco di gesso puro	20	0.3500	1200	18.00	0.057
2	Mattoni pieni in laterizio	280	0.8000	1800	20.57	0.35
3	Malta di cemento	20	1.4000	2000	8.50	0.014
4	Strato d aria verticale (spessore tra 1 cm e 1,5 cm)	10	0.0670	1	193.00	0.149
5	Isolante personalizzato (valori imposti dall'utente)	100	0.0900	154	3.00	1.111
6	Intonaco in argilla	40	0.4900	1200	15.38	0.082
	Adduttanza esterna		25.0			0.04

s = Spessore dello strato; C = Conduttività termica del materiale; M.S. = Massa superficiale; P = Permeabilità al vapore; R = Resistenza termica

Trasmittanza (W/m²K): **0.517 > 0.3** (Valore di legge)

Massa superficiale (Kg/m²): **631**

Resistenza termica (m²K/W): **1.933**

Spessore totale (mm): **470**

Il valore della trasmittanza (0.517) oltrepassa i termini di legge (0.3)

Comune di **Torino**

Zona Climatica: **E**, Gradi Giorno **2617**

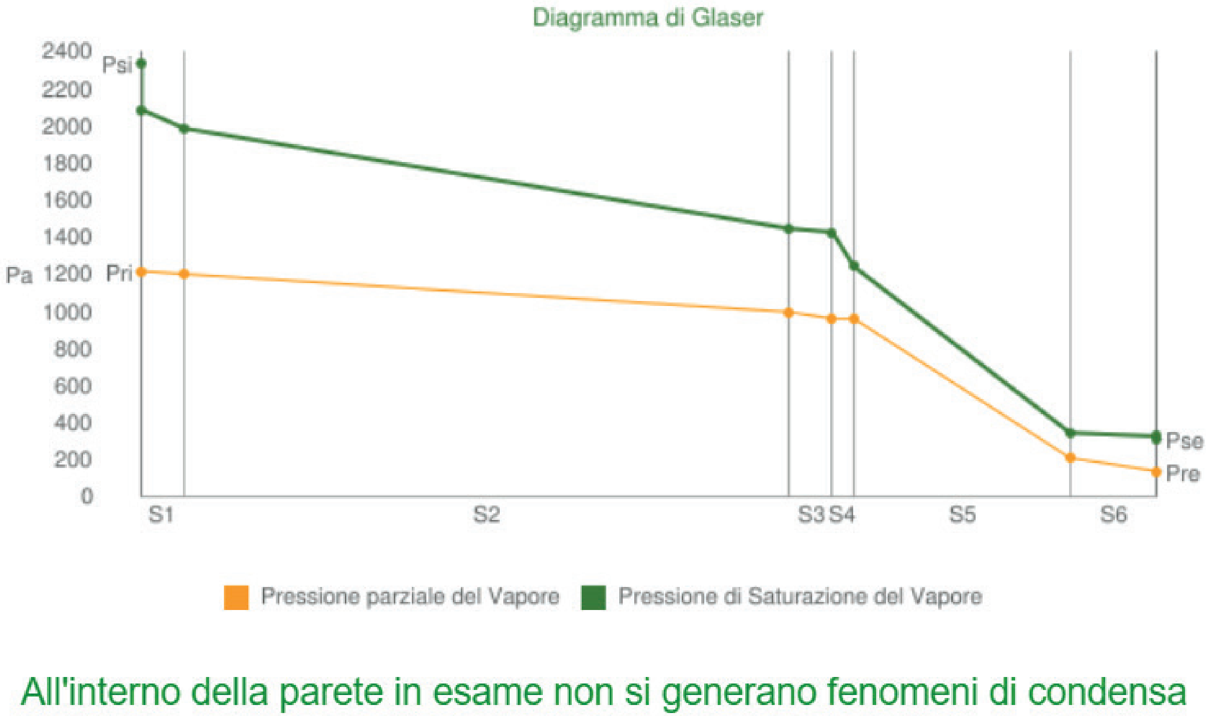
T interna (°C): **20.0**

T esterna (°C): **-5.0**

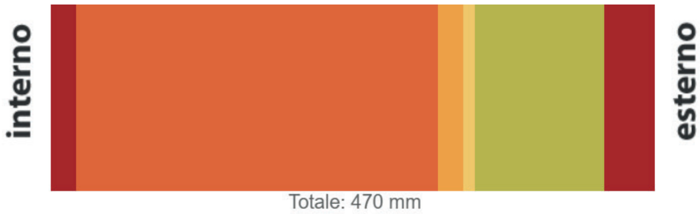
U interna (%): **52.0**

U esterna (%): **44.4**

Attachment 20. U value of the wall if insulated with light earth from subsoil.



Attachment 21. Glaser's diagram for the wall if insulated with light earth from subsoil.



Ordine	DESCRIZIONE DELLO STRATO (dall'interno all'esterno)	s (mm)	C (W/m²K)	M.V. (Kg/m³)	Px10¹² (Kg/msPa)	R (m²K/W)
	Adduttanza interna		7.7			0.13
1	Intonaco di gesso puro	20	0.3500	1200	18.00	0.057
2	Mattoni pieni in laterizio	280	0.8000	1800	20.57	0.35
3	Malta di cemento	20	1.4000	2000	8.50	0.014
4	Strato d aria verticale (spessore tra 1 cm e 1,5 cm)	10	0.0670	1	193.00	0.149
5	Isolante personalizzato (valori imposti dall'utente)	100	0.0830	125	2.00	1.205
6	Malta di calce o di calce di cemento	40	0.9000	1800	8.50	0.044
	Adduttanza esterna		25.0			0.04

s = Spessore dello strato; C = Conduttività termica del materiale; M.S. = Massa superficiale; P = Permeabilità al vapore; R = Resistenza termica

Trasmittanza (W/m²K): **0.503 > 0.3** (Valore di legge)

Massa superficiale (Kg/m²): **653**

Resistenza termica (m²K/W): **1.99**

Spessore totale (mm): **470**

OH NO Il valore della trasmittanza (0.503) oltrepassa i termini di legge (0.3)

Comune di **Torino**

Zona Climatica: **E**, Gradi Giorno **2617**

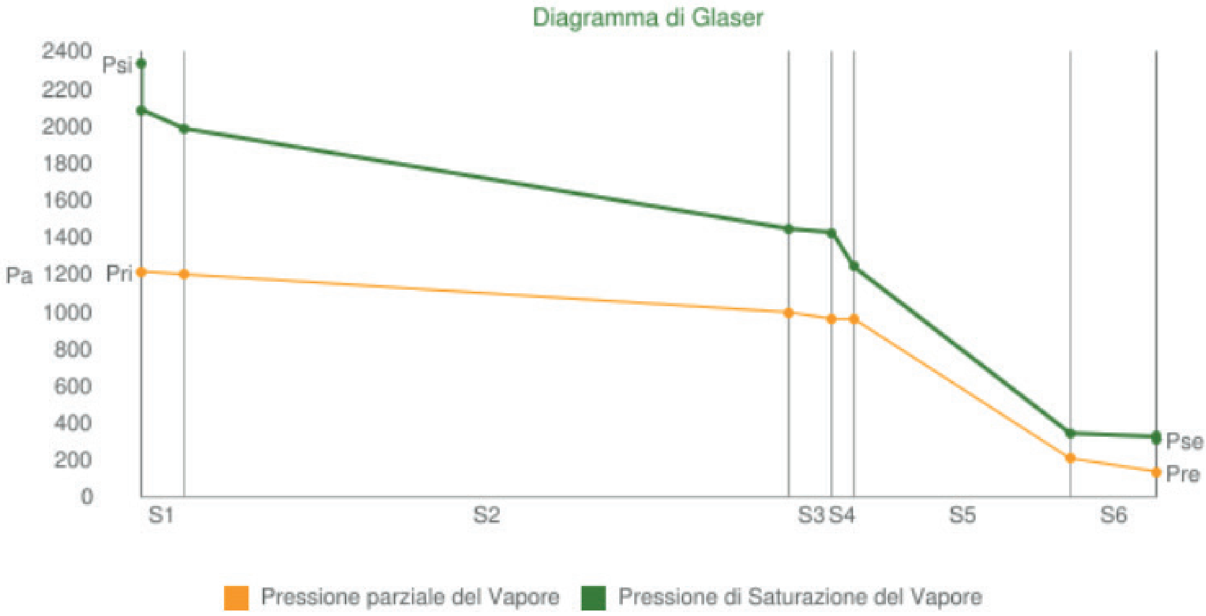
T interna (°C): **20.0**

T esterna (°C): **-8.0**

U interna (%): **52.0**

U esterna (%): **44.4**

Attachment 22. U value of the wall once insulated using straw-lime.



All'interno della parete in esame non si generano fenomeni di condensa

Attachment 23. Glaser's diagram of the wall once insulated with the straw-lime material.

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