amàco

ATELIER MATIÈRES À CONSTRUIRE

WORKSHOP
ACTIVITIES REPORT

Developing and understanding building materials

supported by the Saint Gobain-École des Ponts ParisTech Chair
"Innovating Solutions for a Sustainable Housing"

17th - 21th November 2014
ENPC ParisTech / Champs-sur-Marne, France

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École des Ponts
ParisTech

ATELIER
MATIÈRES À
CONSTRUIRE

amàco

Les grands ateliers

ENSAG

INSA LYON

ESPCI ParisTech

CRAterre

Unité de Recherche
Architecture
Environnement
& Cultures Constructives

INTRODUCTION

The workshop "Developing and understanding building materials" was organized by Ecole des Ponts ParisTech in partnership with **amàco** *(«atelier matières à construire»)*. **amàco** is a project based in France and supported by «Investissements d'Avenir» through the governmental Initiatives for Excellence in Innovative Training program (IDEFI) for a period of eight years, until December, 2019.

amàco teaching method is based on experimentation and hands-on approach. The learning contents use aesthetic and emotion to stimulate the participant's curiosity. We believe that these methods foster open-mindedness and pleasure of learning. We give a priority to teamwork to encourage knowledge exchange, interdisciplinary and collective intelligence. Moreover, we are specialized in developing building techniques using local materials like earth and vegetal fibers. Every workshop is for us an opportunity to put into practice our teaching methods and to experiment with participants coming from various backgrounds.

This workshop was supported by the Saint Gobain-École des Ponts ParisTech Chair "Innovating Solutions for a Sustainable Housing". It took place during the European Week organised in the frame of the ATHENS program, from the 17th to the 21st of november 2014.

Cité Descartes, Champs sur Marne, France

About the site

The Workshop took place at the Cité Descartes, in Champs-sur-Marne, close to Paris. The main part of the activities has been carried out in the new "Coriolis" building of Ecole des Ponts ParisTech.
This innovative building, completed in 2012, is certified by HQE and BBC labels : it is examplary in terms of energetical performance.
In addition to hosting two laboratories and an IDEFI program called "d-school", the building has an important capacity to receive students with a lecture hall, several classrooms and a test hall.


ACCES A4
INCUBATEUR DESCARTES
UNIVERSITÉ PARIS-EST MARNE-LA-VALLÉE
ESIEE PARIS
RESIDENCES ÉTUDIANTES
E D'ARCHITECTURE (EAVT)
CORIOLIS*
ÉCOLE DES PONTS PARISTECH
ESPACE BIENVENÜE**

ATHENS WEEK AN INTERNATIONAL GROUP

About the participants

19 students attended to the workshop. Half of them were part of a master entitled "Material science for sustainable construction", directed by Xavier Chateau and linked to the Mechanics department of Ecole des Ponts ParisTech. The other students came from other universities to participate to the workshop in the frame of the european mobility program called "ATHENS week".

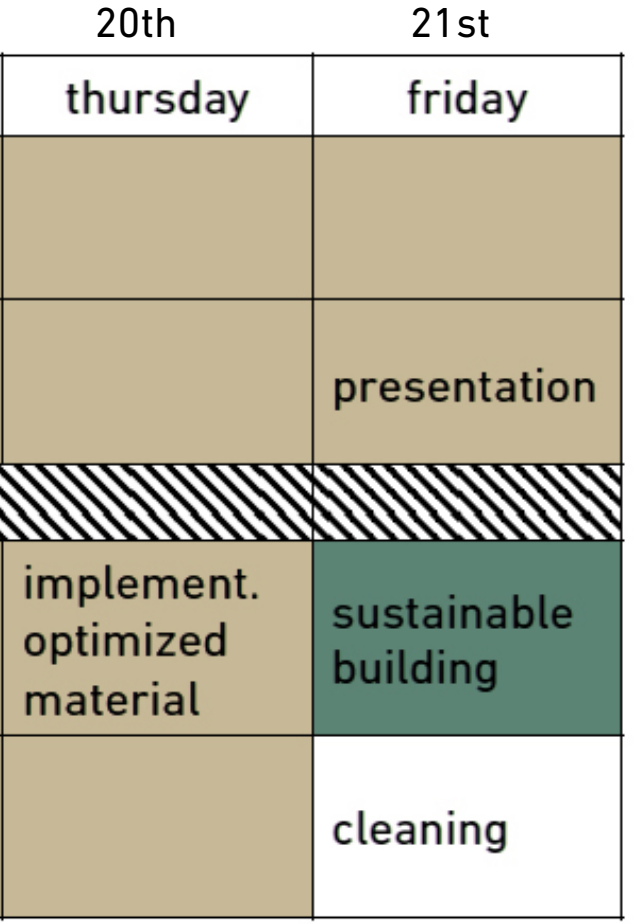
Because of this particular context, many nationalities were represented : iranian, chinese, spanish, italian, moroccan, etc.

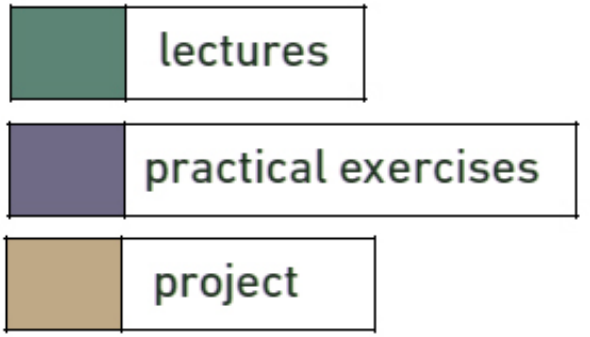
Most of the participants were studying material or civil engineering, some of them were already graduated and had already worked as engineers.

On the first day of the workshop, a short "shaking hand" exercise was organized to facilitate exchanges between the participants. Each student had the opportunity to present shortly his training and professionnal background.

Time schedule

	17th	18th	19th
	monday	tuesday	wednesday
9 am	earth	fibers	
12:30 am	clay concrete	carazas	intermediate presentation
lunch break			
2 pm	instructions	fibers	
5:30 pm	theoretical tools		


20th
21st
thursday
friday
presentation
implement.
optimized
material
sustainable
building
cleaning


lectures
practical exercises
project

magic

earth

emotion

wood

straw

art

sand

etc.

water

creativity

amàco

ATELIER MATIÈRES À CONSTRUIRE

« The *amàco project is an educational resource center that aims to make visible, in sensory and poetic ways, the physic & chemical behavior of the most common natural materials, such as sand, water, earth, wood, straw, etc. The project aims to disseminate knowledge regarding their application in construction, so as to promote the emergence of eco-friendly practices. amàco brings together physicists, engineers, artists and architects, under the same roof. Magic, emotion and creativity are the watchwords of the project.* »

LECTURES & EXERCISES

After a short presentation of the aims, vision and philosophy of the **amàco** project, the lectures focused on two main subjects :
1- «Building with Earth»
2- «Building with Fibers».

These lectures included some live experiments allowing direct visualization and understanding of physical phenomena taking place within the matter. The experiments were presented through video or carried out on live by the lecturer in order to increase the magic and emotion offered by the different scientific experiments.

Practical exercises with earth and fibers have been proposed to involve the participants in a hands-on approach :
1- *Habert test* (Clay concrete parameters)
2- *Carazas test*

« BUILDING WITH EARTH » EXPERIMENTAL LECTURE

The lecture « building with earth - from matter to architecture » is divided into two parts. The first part focuses on presenting an overview of earthen architecture heritage and contemporary examples. The functions that the earth material can fulfill (to carry, to insulate, to cover, to fill, etc.) are presented in relationship with the building techniques associated.

The second part answers the "How does it stand?" question. Scientific experiments are presented to understand the physics of earth as a material composed of grains, air, water and a binder (clay). The lecture offer to go deep in the matter to explain the physico-chemical interactions between these components.

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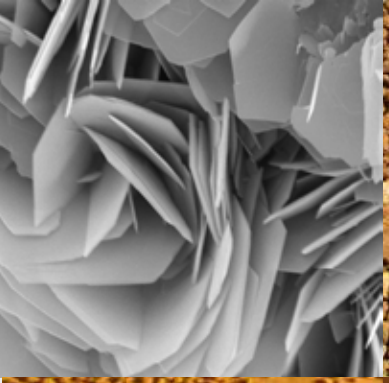
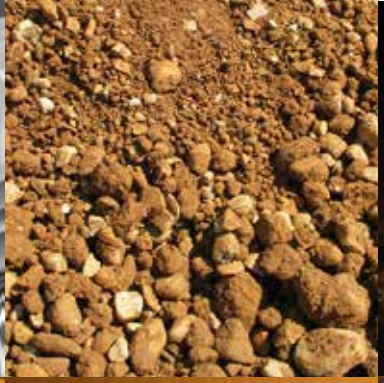
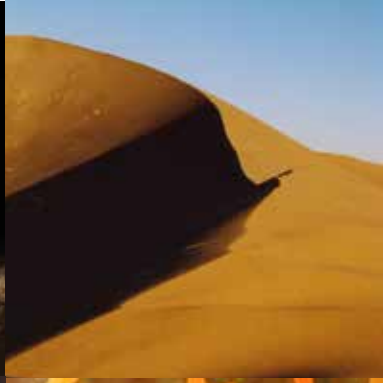
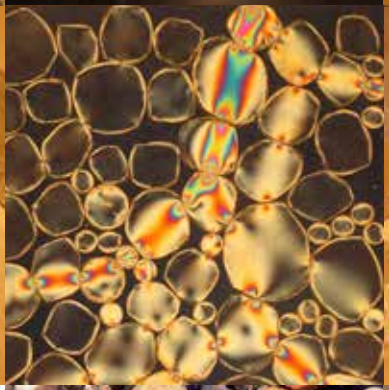
Residence in Schlins – Roger Boltshauser & Martin Rauch, Schlins, Austria © rights reserved



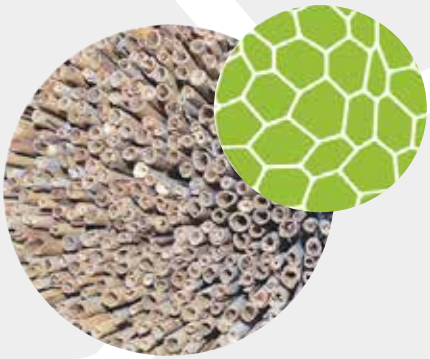










« BUILDING WITH FIBERS » EXPERIMENTAL LECTURE



The lecture « Building with Fibers - from matter to architecture » is also divided into two parts. The first part presents the different ways of using natural fibers in architecture. It explores all possibilities and qualities that can inspire architects, engineers, artists, designers, etc. A short overview of fibers architecture in vernacular and contemporary habitats and some architecture projects linked to the architectural functions that fibers can be used for (filter, insulate, dress, cover, reinforce, etc.) is given.
The second part deals with physics of the fibrous matter. It presents the origin of fibers, their diversity and their inner physico-chemical properties, considering fibers alone or in interaction with other elements (water, grains, binding and soft matter).

Cane construction technics developed by the spanish colective Canya Viva.

Architectural installation in Alsace © Jordi Pimas













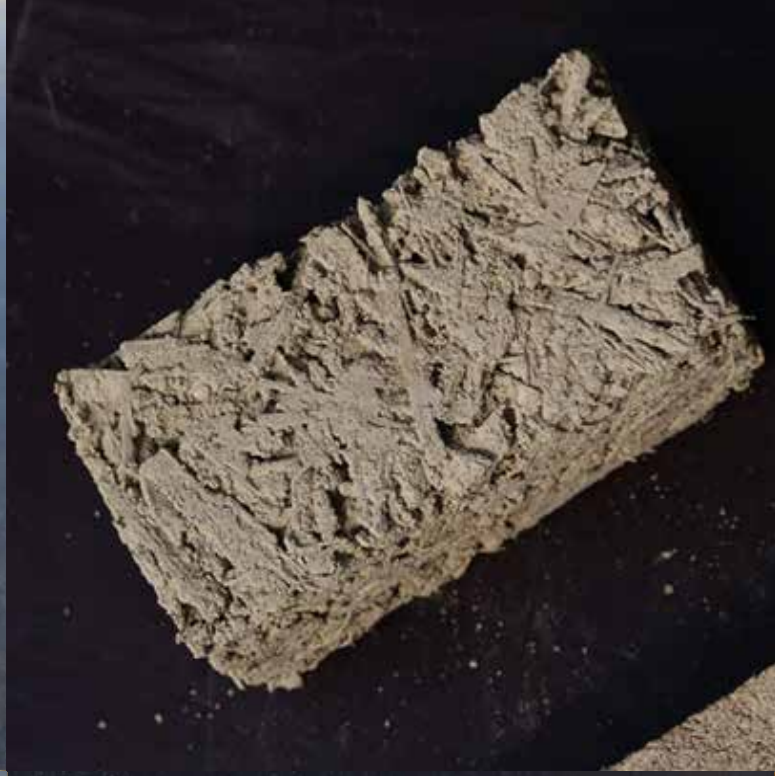



« APPLICATIONS » LECTURE

This short lecture presents the possible implementations of earthen and fibrous matter in the field of innovative materials made of natural and local resources.
Some prototypes developed by amàco-CRAterre in the frame of the "Typha-project", a research program of the United Nations Development Programm (UNDP), are presented. These prototypes are made of two raw materials : clay mud and Typha reed, an invasive plant found in Senegal but also in our European regions. The fabrication process of each material is presented and compared to similar products already existing on the market : reed insulating pannels, OSB panels, etc.
The diversity of materials created with only two natural resources is intented to inspire the participants for their work during the rest of the week.

Clay mud produced through the washing process of sand and gravels.

Typha plant : all the parts of the plant (stem, leaves and flower) can be turned into materials.



« HOW TO BUILD SUSTAINABLE ? » TOWARD A MULTICRITERIA ANALYSIS

This lecture was presented at the end of the week. The purpose of it was to lead the participants to think about the concept of sustainable construction. Because most of the learning contents of the workshop focused on scientific and technical aspects, it was necessary to bring some elements to a more global reflection.

The lecture started with a presentation of the actual environmental issues (global warming and exhaustion of natural ressources) in which the building sector has a big responsability in terms of greenhouse gases emissions and primary energy required.

In a second part the solutions that have been developped in recent years in response to this alarming situation were presented, such as the French and European labels and norms (RT 2012, HQE, BBC, Minergie, BREAM, etc). Most of these measures lead to an improvement of energetical performance of the buildings. But it didn't take into account the environmental footprint of the whole construction process, in particular the embodied energy of building materials. Moreover, these labels only enable to analyse the quality of architectural project from the environmental point of vue, forgetting the social and economical dimensions, which are the other fundamental pillars of sustainable development.

The third part of the lecture presented briefly some hollistic evaluation methods of sustainable construction. For example, the multicriteria analysis grid proposed by the European « Versus » project is a tool that can be used to evaluate the quality of architectural projects in a more global way.

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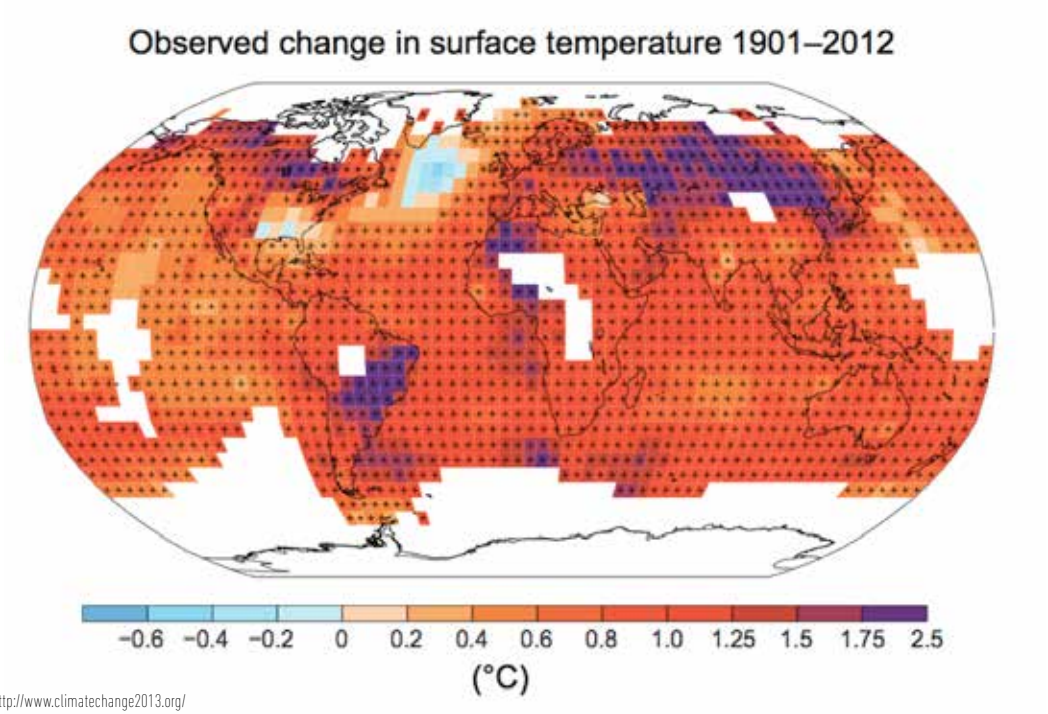
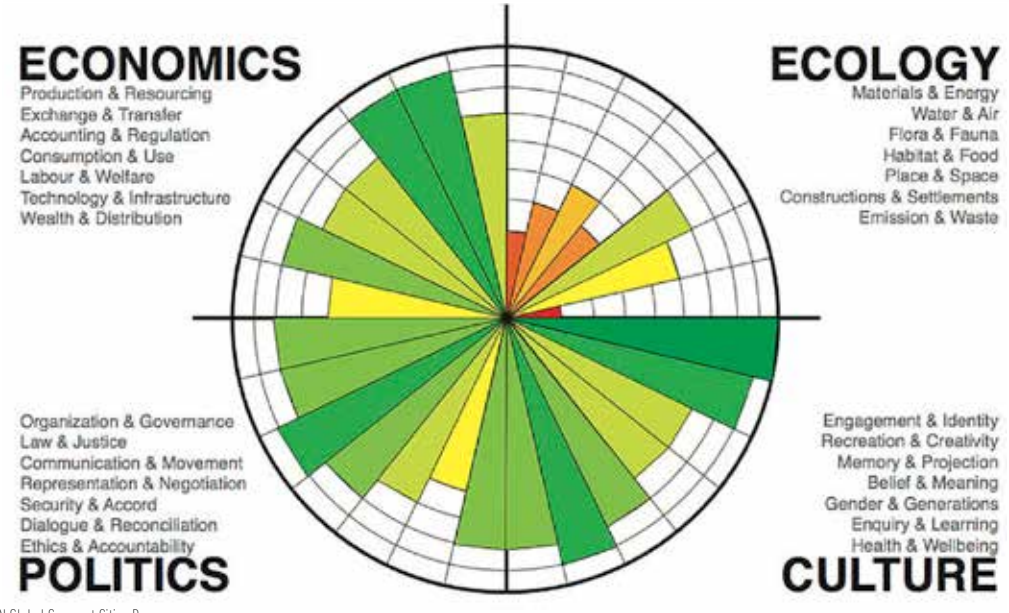


http://www.climatechange2013.org/



UN Global Compact Cities Programme

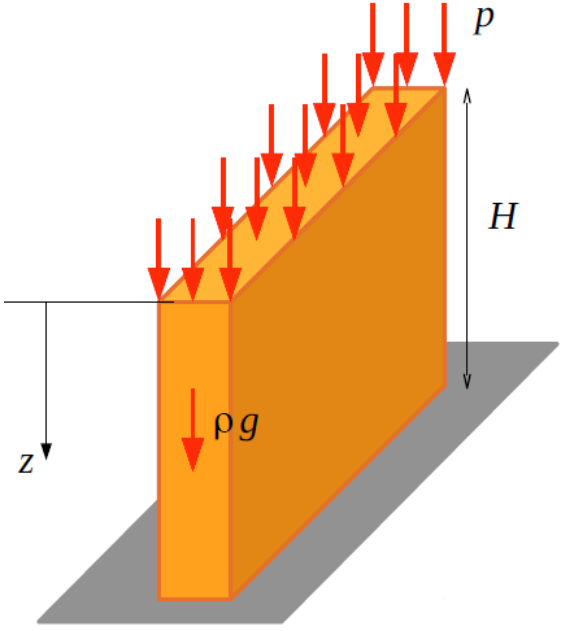
« MECHANICS » THEORETICAL TOOLS FOR MODELLING

The aim of this lecture proposed by Xavier Chateau was to provide some theoretical tools for modelling the mechanical behaviour of building materials.

The concept of stress tensor was explained and applied to describe the stress field in a material loaded in compression or in tension.

The properties of the material at early age were also addressed since the rheology of a mortar is a key parameter to control the implementation of a material (mixing, transport, placing). A model of the slump test was presented.

At the end, the lecture focused on the determination of the strength of the materials. Two criterion commonly used to describe the behaviour of building materials were presented : Von Misès criterion for pure clay, steel, alumium and the Drucker Prager criterion for soils, concrete and foams. Compression and flexural test were described by models.



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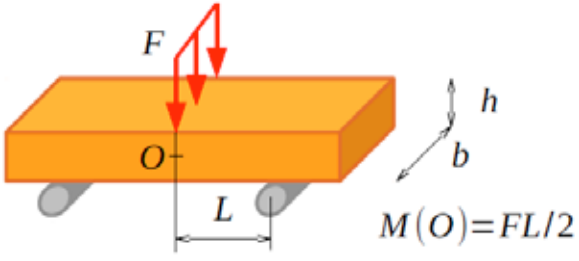

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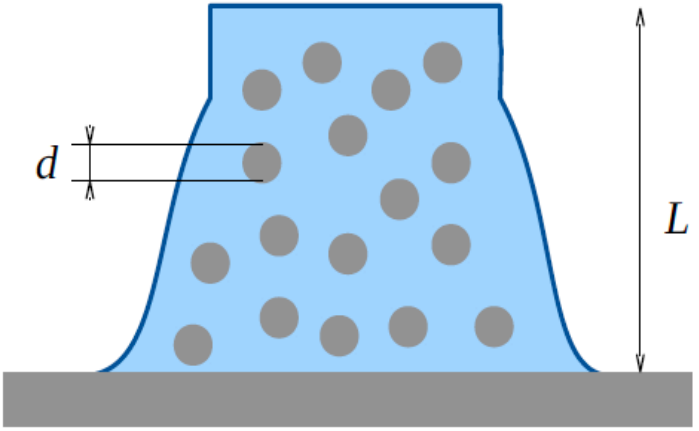
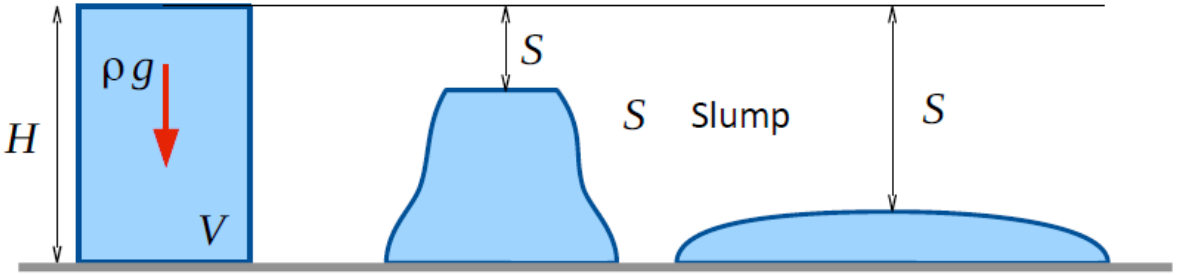


$$d \ll L$$

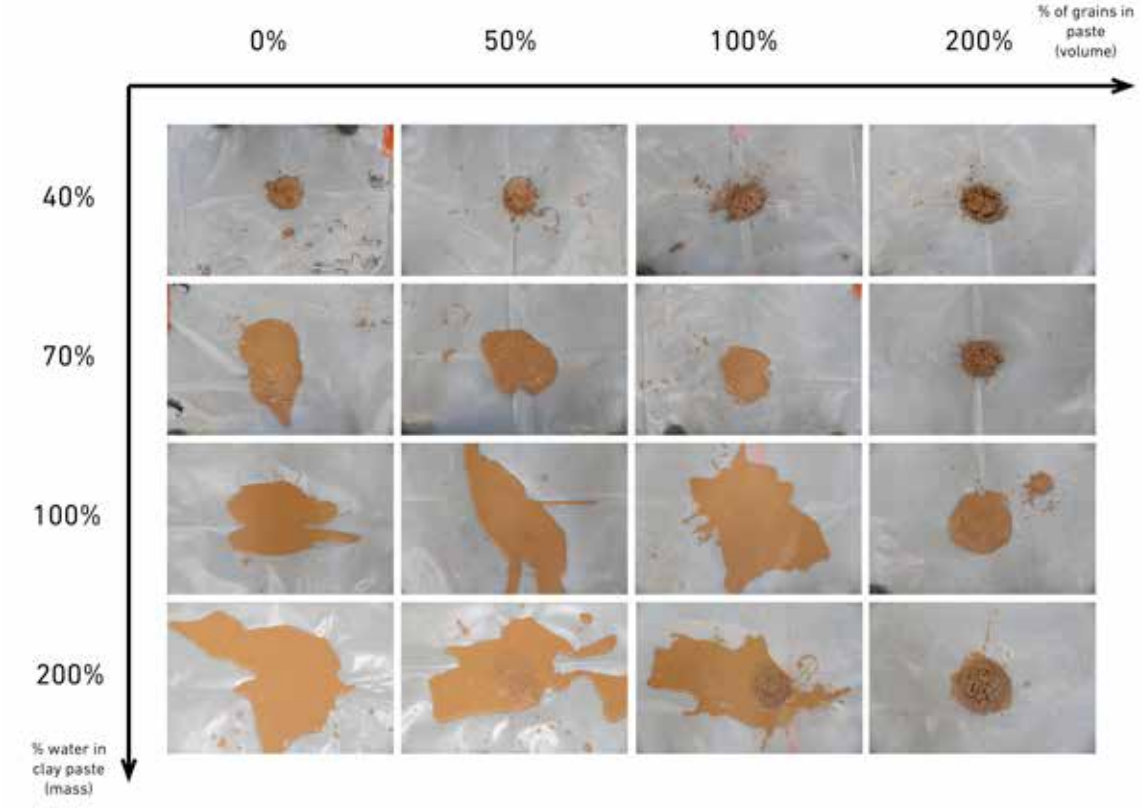
$$(L > 10 \times d) \qquad (d = 10\,cm) \rightarrow (L = 1\,m)$$



$$\tau_c \simeq \frac{\rho g}{\sqrt{3}}(H - S) \qquad S \text{ small}$$

HABERT TEST CLAY CONCRETE PARAMETERS

Earth can be considered as a "clay concrete", considering that instead of having cement as a binder, clay is the binder. With this new point of view on the material, we can imagine to pour earth into a formwork to make a clay concrete wall. In this case, the mortar has to be in a fluid state to improve the workability of the concrete. How to reach this consistancy?
The purpose of this exercise is to explore two parameters controlling the rheology of a mortar: the amount of water in a paste and the proportion of grains. A clay paste mixed with grains (coarse sand) is used as a model mortar to make slump tests. The results can be observed on a matrix.

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CARAZAS TEST WITH EARTH

Earth is a material composed of matter under three states: liquid (water), solid (clay particles and aggregates) and gas (air and vapour). The relative proportions of these three states determines the intrinsic properties of the material.
The aim of this exercise is to observe the diversity of materials that can be obtained by changing the hydric state of earth (dry, humid, plastic, viscous or liquid) and the mechanical action applied on it (to fill, to press or to compact layer by layer).
Combining some parameters we obtain samples corresponding to particular building techniques (rammed earth, adobe, etc). Some combinations like compacting liquid earth are not so interesting, showing us that the gesture has to be adapted to the hydric state of earth.
Three types of earth are compared, highlighting that the result mainly depends on soil composition (granulometry, type of clay, etc).

CARAZAS TEST WITH FIBERS

A similar exercise, inspired by the original Carazas test, has been developped in order to explore the diversity of materials that can be made with vegetal fibers.
In one direction canvas, the mechanical action applied on the material varies (to fill, to press or to compact layer by layer).
In the other direction, four different mix are carried out (dry fibers, wet fibers, fibers with clay paste and fibers in a mortar made of clay paste and sand).
Four raw vegetal fibers are used to observe how their properties (hydrophily, flexibility, absorption capacity, etc) impacts the final result.

In both exercises, the participants are working in teams to produce the samples. Then, a restitution phase enables the whole group to observe the result of this colective work.

PROJECT « **DESIGN A MATERIAL** »

Through the confrontation of the participants to some issues related to the production of building material (formulation, workability, drying, etc.), the project "Design a material" aims at making operationnal the theoretical knowledge on materials science (rheology, mechanics and thermal properties, etc) taught during the week.

Students work together in teams on a particular issue. By combining experimental (sample fabrication and characterization) and theoretical approach (modelling tools and bibliographic research), each group has to develop a material fulfilling particular specifications :

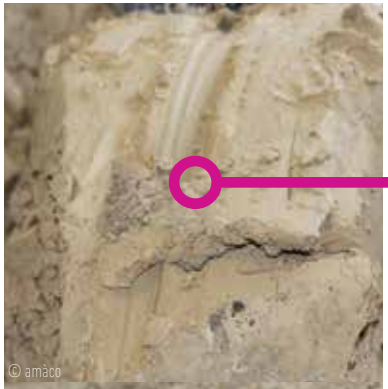
> a load-bearing wall
> a self compacting slab
> an insulating block
> a wall-facing pannel

The challenge is to design this material in just one week and to characterize it in order to convince an eventual customer of the performance of the product.

The result of this work is presented to the whole group and evaluated by a jury.

RAW MATERIALS

GRAINS AND BINDER



CLAY MUD

This clay mud comes from a quarry of CEMEX company located in Montrevel-en-Bresse (01). It is a co-product of the washing process of aggregates destinated to cement concrete fabrication. This waste is produced in huge quantities and can be valorised as a binder. It contains 14% clay (90% smectite) and mostly silts.

SAND

This rolled and washed 0-4mm sand comes from the same quarry. It is an alluvial sand mainly composed of silica and lime.

GRAVELS

This rolled and washed 4-12mm gravel comes from the same quarry. It is an alluvial gravel mainly composed of silica and lime.

FIBERS

HEMPS HURDS

Hemp is a plant commonly available in France. Hemp hurds are broken parts of the core of the stem. It's a porous matter known for its extraordinary capacity of absorbing water.

WHEAT STRAW

This straw is the stem of the wheat, cultivated in our regions for food (cereal). Straw is used as silaged for animals but the production is excedentary. This is why straw can be considered as an agricultural waste.

SISAL OAKUM

Sisal oakum is extracted from sisal plant which is a cactus growing in South & North America. It is very similar to hemp oakum, a fiber commonly used for plaster moldings.

ADDITIONAL PRODUCTS

GYPSUM PLASTER

This hydraulic binder is manufactured as powder. Mixed with water it forms a paste that can be used to accelerate the hardening of a mortar. Because of the very short production time we had during the workshop, plaster was used in some cases to unmold the samples faster.

PLASTICIZER

This chemical product (Sodium Hexa-Meta-Phosphate) is used to make easier the mix of clay mud with water. It disperses clay particles and gives the paste a more fluid consistancy with relatively small amounts of water. As it is also used as a food additive, it is considered as non toxic.

FLAX LINEN

Flax is a plant whose fibers can be transformed into different products, in particular textiles. Flax linen looks like a fine grid. It is coverded by starch to make it more rigid and use it as a reinforcement.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MATERIALS DEVELOPPED

LOAD BEARING WALL

This clay concrete is poured into a formwork to make a wall that can bear the load of a tile roof.

SELF-COMPACTING SLAB

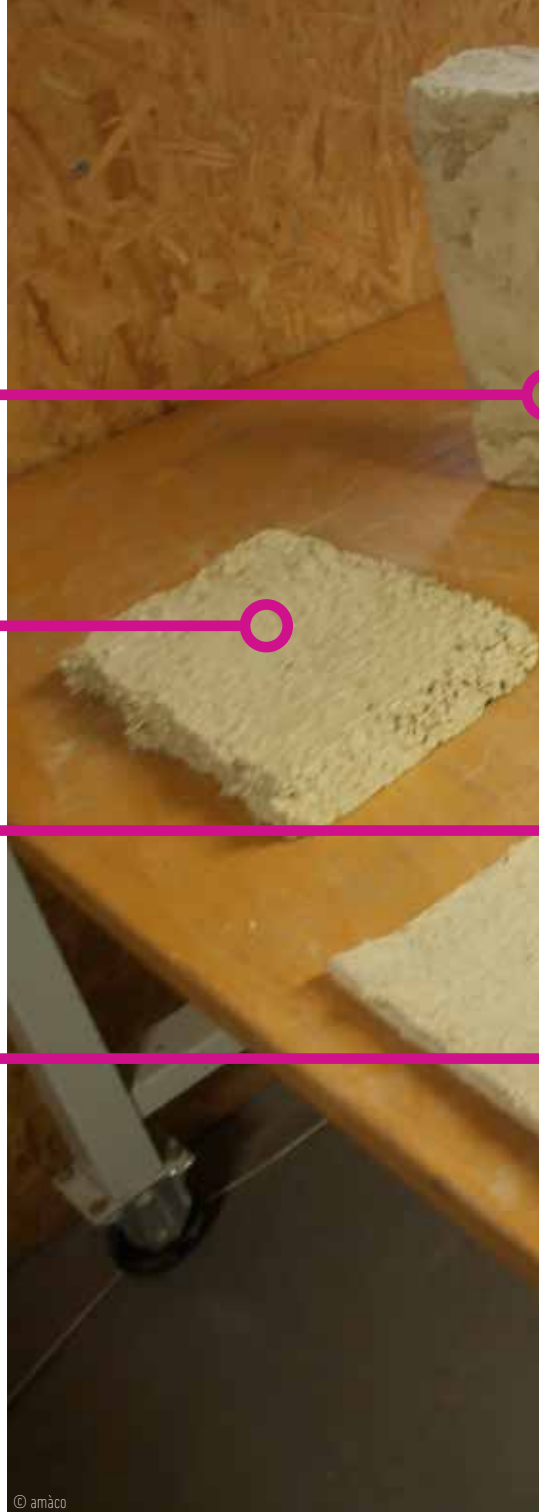
This very fluid clay concrete allows to make self-compacting slab.

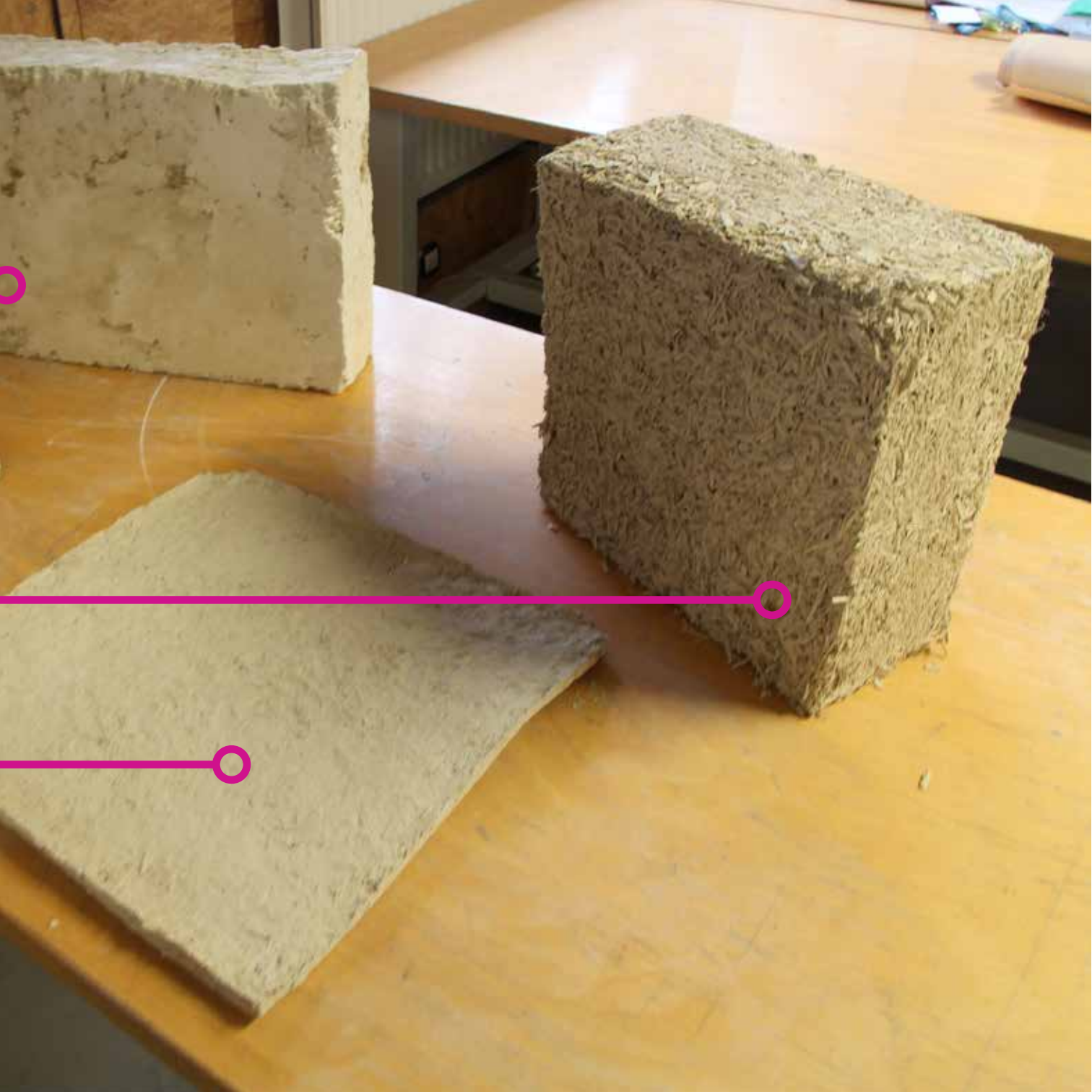
INSULATING BLOCK

This insulating block can be used to fill-in a structure.

WALL FACING PANNEL

This interior wall facing pannel can be screwed on a structure.



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LOAD BEARING WALL

This clay concrete is designed to make a load bearing wall of dimension 3m high and 30cm thick. It is able to support the weight of a clay tile roof, equivalent to a load of 500kg/m^2.

The mortar is constituted of:
> 50% gravels
> 30% sand
> 20% clay mud*
(volumic proportions)

Thanks to tests on cylindric 11/22cm samples, the compressive strength of the material has been measured and evaluated at 1,1MPa.

Slump tests have been performed to check the workability of the mix at fresh state. The mortar was fluid enough to be poured into a formwork using a vibrating tool.

A demonstrative wall of dimensions 38x45x10cm has been realized. A proportion by mass of gypsum plaster corresponding to 10% of total dry matter content has been added, to make sure that the formwork could be removed after less than 24hrs.

Density of dry material is around 2000kg/m^3.

* The clay mud contains 30% of dry matter and 70% of water (proportions by mass). Plasticizer has been added (0,1% of dry matter content).


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SELF-COMPACTING SLAB

This clay concrete enables the fabrication of slab floors.

The mortar is constituted by:
> 50% gravels
> 25% sand
> 25% clay mud
(volumic proportions)

Hemp hurds have been added (half of clay mud volume) to prevent cracking. The material presents 0,45% of shrinkage when drying.

More plasticizer has been added to obtain a really fluid consistancy. Slump tests have been performed to ensure that the mortar was fluid enough to make a self-compacting slab.

A demonstrative slab of dimensions 26x42x5cm was produced. It did not crack when drying.

* The clay mud contains 30% of dry matter and 70% water (proportions by mass). Plasticizer has been added (0,1% of dry matter content).

WALL FACING PANNEL

This pannel is designed for interior wall facing.
A demonstrative pannel of dimensions 45cmx45cmx6mm has been realized with:
> clay mud reinforced with recycled newspapers (“paper-clay”)
> hemp hurds
> flax linen
An optimal volumic ratio of (hemp+paper): clay of 2:1 has been determined.

The structure of the material has been optimized to reinforce its flexural strength: two grids of flax linen have been placed on each side of the pannel.

The weight of the “real” material (dimensions 3mx1,2mx6mm) would be less than 25kg so as to be transportable by two people. A simple 3 points flexural test was performed to ensure that the material would not break when manipulated. The test made on rectangular samples of dimensions 11x22cmx6mm showed that they resist to a load until 12kg.

The samples have also been screwed in order to demonstrate that the material is ductile enough to be used with this kind of fixing system without cracking.

* The clay mud contains 30% of dry matter and 70% water (proportions by mass). Plasticizer has been added (0,1% of dry matter content)


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INSULATING BLOCK

Those blocks are easy-to-use masonry bricks made with:
> 20% hemp hurds
> 80% clay mud*
(proportions by mass)

A demonstrative material of dimensions 30x30x10cm has been realized. The "real" material would be slightly thicker (15cm) than the demonstrator. With a dry density of 520kg/m^3, each block would have a weight of 7kg. Moreover, a good balance between binder and fibers makes the material cohesive enough to be manipulated and assembled.

Tests have been performed on samples of dimensions 10x10x20cm to ensure that a 3 meters high wall would resist to its own weight, equivalent to a 15kPa load. The compressive strength is 144kPa.

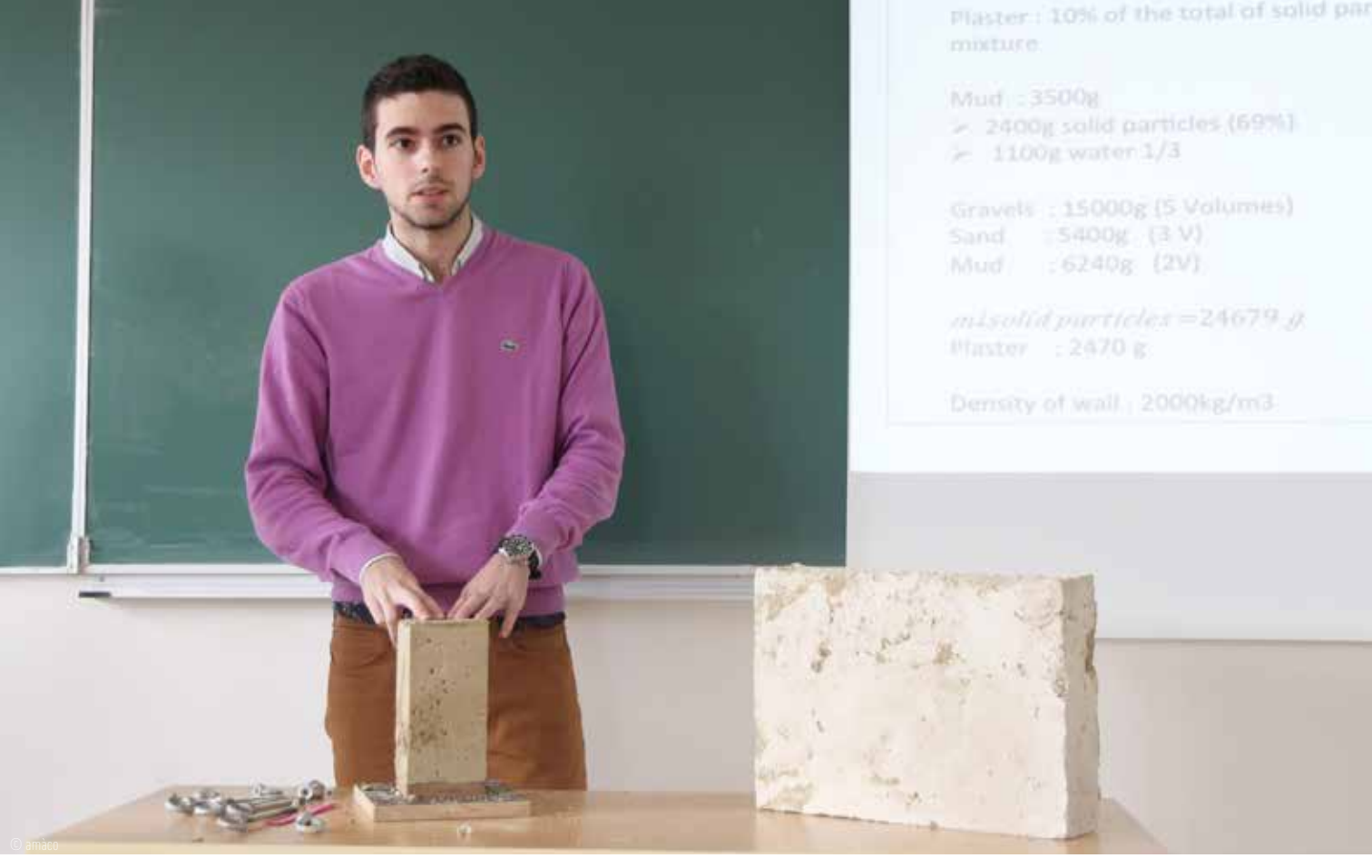
Knowing the density of the material, the thermal conductivity is estimated to be 0.16 W/mK. For a wall 45cm thick (3 blocks together**), it could be possible to reach a thermal resistance R=2,8Km^2/W, slightly above the RT2005 normative (2,5Km^2/W).

* The clay mud contains 30% of dry matter and 70% water (proportions by mass). Plasticizer has been added (0,1% of dry matter content)
** According to a paper (T. Behzad, M. Sain , Measurement and Prediction of Thermal Conductivity for Hemp Fiber Reinforced Composites, POLYMER ENGINEERING AND SCIENCE, 2007) it would be more efficient to use the blocks in a way that the main orientation of fibers would be perpedicular to the main direction of heat transfer.

GROUP PRESENTATIONS

During a 15min presentation, each group had to answer to the following questions :

> Present the final product, its characteristics, how to implement it and how it can be used
> Present the optimization process of the material
> What remains to do in order to improve your product ?



The evaluation was structured around 5 criteria :
> GOAL : The request of the customer was correctly understood and translated into key parameters for optimization.
> OPTIMIZATION PROCESS : The experimental & theoretical process was clearly explained. The analysis was based on scientific concepts and guided by a rational approach
> RESULTS : The final product fulfilled the customer's request.
> CONCLUSION : The group was able to take a step back : the strong points were highlighted and potential sources of improvement were identified.
> COMMUNICATION : The oral expression and the information presented was clear and relevant. The group was able to prepare a strategy to present the work and answer to the questions in a coordinated way.









EVALUATION OF THE WORKSHOP

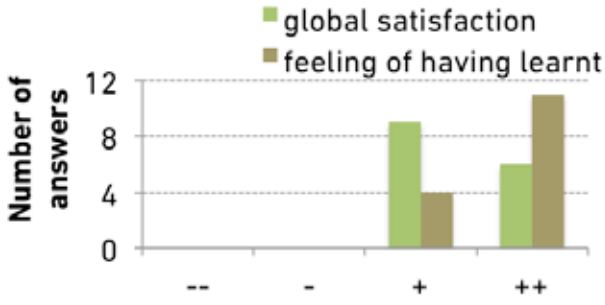
At the end of the week, the students completed anonymous individual assessment forms.

They have been asked about:
- their global satisfaction level
- their feeling about having learnt something
- the skills they have developped
- the things they wish they could have learnt more
- the usefulness of this training workshop
- the strong points of the workshop
- their ideas of improvements.

The trainers also evaluated the workshop by answering the same questions. A debriefing meeting allowed to complete these opinions with new ideas of improvement.

The next pages present a synthesis of these evaluations.

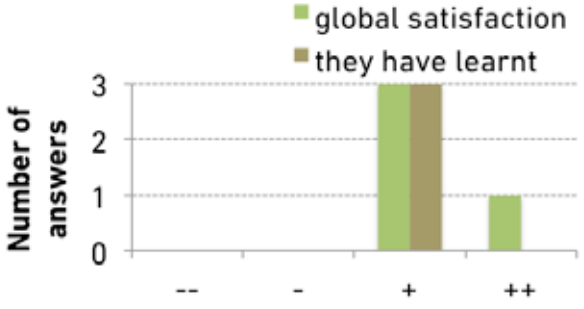
EVALUATION BY THE STUDENTS



The students especially liked to work in the project. Team working, experimental approach, right to make mistakes, using specific skills to answer a realistic challenge have been pointed out as strong positive points of the workshop. They also appreciated the quality of the experimental lectures.

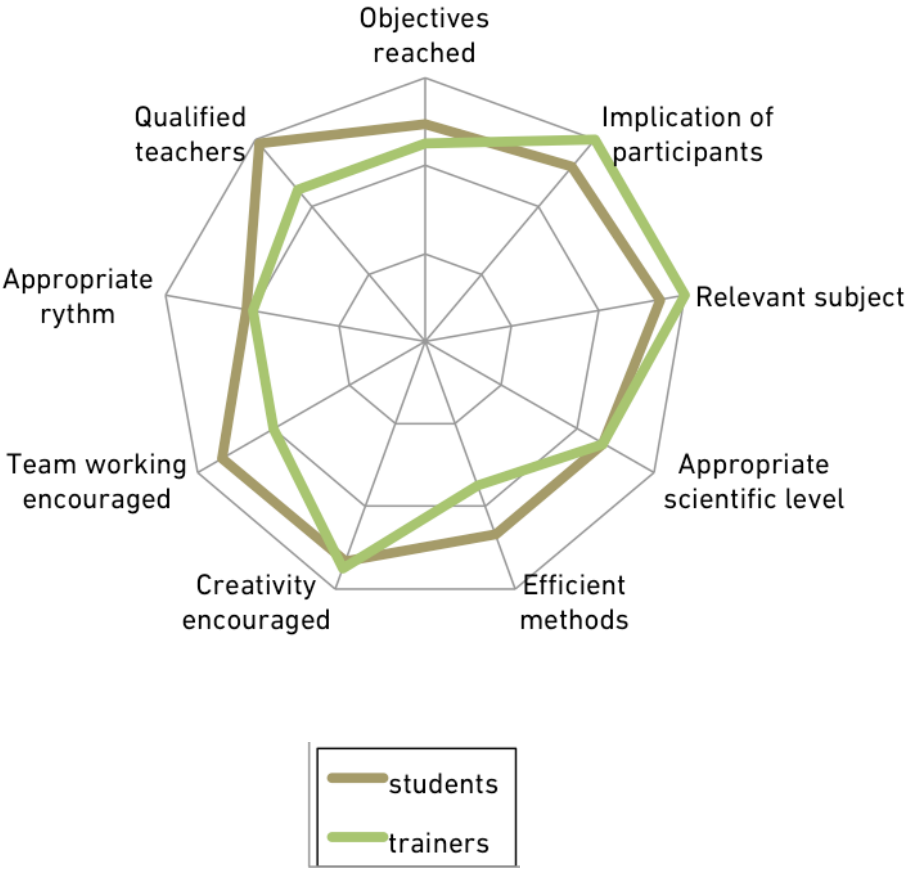
They suggest to dedicate more time and equipments to the project. They also suggest to produce and analyze classical materials before creating innovative ones.

EVALUATION BY THE TRAINERS



The trainers are very satisfied with the involvement of each student during the project time. The proposed approach was stimulative and encouraged creativity. The association of scientific theoretical models with the experimental approach is very promising.

The supervision during the project should guide the students towards a more efficient use of the data and tools given during the lectures and exercises. It is suggested to make available for the students a collection of usual building materials as benchmarks. An additional exercise about traditional fabrication techniques would be useful.


Objectives reached
Implication of participants
Relevant subject
Appropriate scientific level
Efficient methods
Creativity encouraged
Team working encouraged
Appropriate rythm
Qualified teachers
students
trainers

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