amàco

ATELIER MATIÈRES À CONSTRUIRE

WORKSHOP

ACTIVITY REPORT

Developing and understanding building materials

École des Ponts ParisTech

supported by the Saint Gobain-École des Ponts ParisTech Chair
"Innovating Solutions for a Sustainaible and Responsible Housing"
and Université Paris Est - MMCD Labex
"Multi-Scale Modelling & Experimentation of Materials for Sustainable Construction"

16th - 20th November 2015
ENPC ParisTech / Champs-sur-Marne, France

CONTENTS

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CONSTRUIRE
amàco

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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" and by Université Paris Est - MMCD Labex "Multi-Scale Modelling & Experimentation of Materials for Sustainable Construction".
It took place during the European Week organised in the frame of the ATHENS program, from the 16th to the 20th of november 2014.

magic

earth

emotion

wood

straw

art

sand

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. »

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**
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About the approach

The first days were devoted to the presentation of **amàco** innovation processes: interdisciplinarity, technology transfer, re-engineering of traditional techniques. Real case studies (research projects and architectural achievements) and educational experiments highlighting physico-chemical phenomena specific to some materials (earth and vegetal fibers) were presented. Then the key issues around construction cycle and supply chain using local products and bio-based material were addressed.

During the week students addressed issues related to the production of building materials, their properties in use and their durability by conducting bibliographic research, implementing models and designing materials.

Students were in small groups (6-7 people) on a particular issue. Each group had to realize a material responding to some specifications, by combining experimental approaches (sample fabrication and characterization) and modeling tools. At the end of the week, the result of this work were presented to the whole group and evaluated by a jury.

About the participants

27 students attended to the workshop. A third of them are 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 others 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 countries were represented: France, China, Germany, Austria, Spain, Italy, Turkey, Morocco, Tunisia and Brasil. Most of the participants are currently studying material or civil engineering. Some of them are already graduated and have already worked as engineers.

Each student had the opportunity to present shortly his training and professionnal background. A brainstorming was made for expressing individual expectations about the workshop.

This "word-cloud"provides an overview of the most frequent keywords mentioned by the participants expressing ther individual expectations of the workshop. →

structures building
sustainable developing Understanding
making Innovative pricing natural
architecture cooperate
constructing life nowadays
uses
water after about materials
understand techniques traditional most Properties
strength study sustainability betwenn Interaction
group
day create Differences able
something chose
expect ways wich science learn Implementing
Discover formulate week approcach
manipulate Practical determine Process
more Way different take
methods connexion earth
order working
Innovation thinking
simple using implemented
theses
experience cases eh
concrete
developping reasonable countries
matters approach international
efficient advantages new
material between every
Structure/application/properties

PROGRAM & TIME SCHEDULE

	monday 16th	tuesday 17th	Wednesday 18th	thursda
9 am	presentation (30')	theoret. tools (1h)		
	carazas test (2h)	sand tower (2h30)		
12:30 am	earth (1h)			
lunch break				
2 pm	project instructions (30')	tower (1h)		implement optimized
5:30 pm	fibers (1h)		sust. build. (1h)	

	lectures
	guided experiment
	project

y 19th	friday 20th
t. material	final presentation (2h)
	cleaning (1h)
	feed backs (30')

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: from matter to architecture.*

2- *Building with fibers*: *from matter to architecture.*

These lectures included some videos of experiments allowing direct visualization and understanding of physical phenomena taking place within the matter.

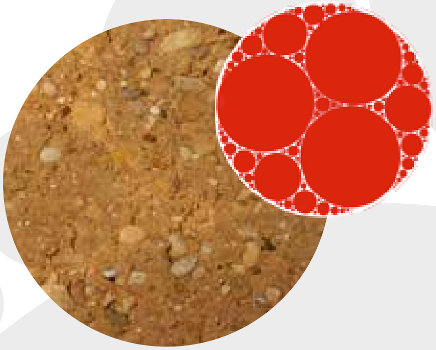
A lecture was given to provide some *Theoretical tools* for modelling the mechanical behaviour of building materials and another to present the general concepts of *Multicriteria analysis for sustainable building*.

Practical exercises or "guided experiments" have been proposed to involve the participants in a hands-on approach with earth and fibers:

1- *Carazas test*

2- *Sand tower*

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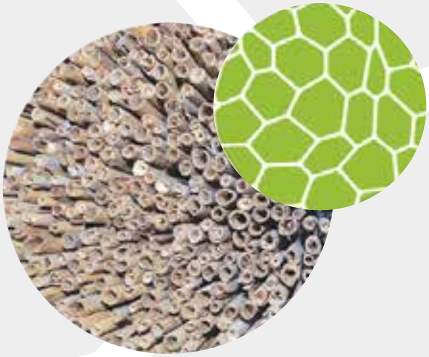
Residence in Schlins – Roger Boltshauser & Martin Rauch, Schlins, Austria © rights reserved

« 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 » LECTURE

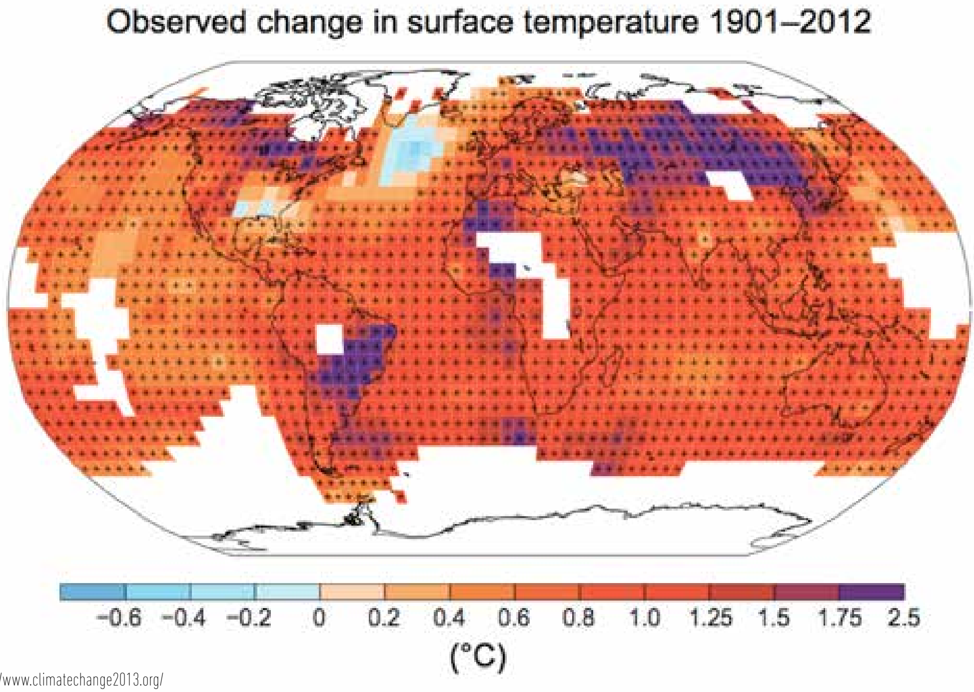
The purpose of this lecture is to lead the participants to think about the concept of sustainable construction. Because most of the learning contents of the workshop focused on scientific and technical aspects, it was necessary to bring some elements to a more global reflection.

The lecture starts 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.

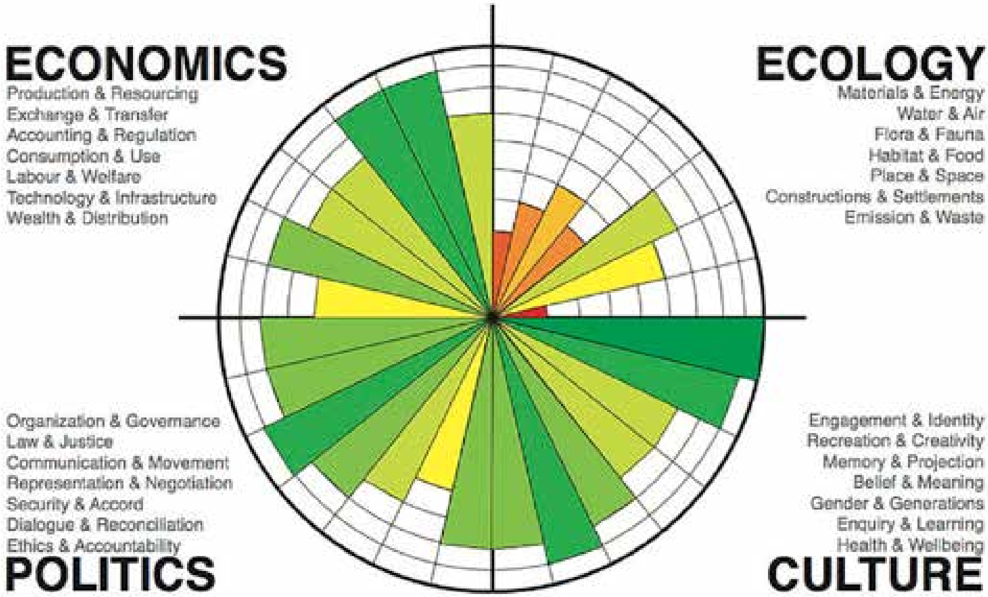
In a second part the solutions that have been developped in recent years in response to this alarming situation are presented, such as the French and European labels and norms (RT 2012, HQE, BBC, Minergie, BREAM, etc). Most of these measures lead to an improvement of energetical performance of the buildings. But they don'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 briefly presents 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.

© Versus



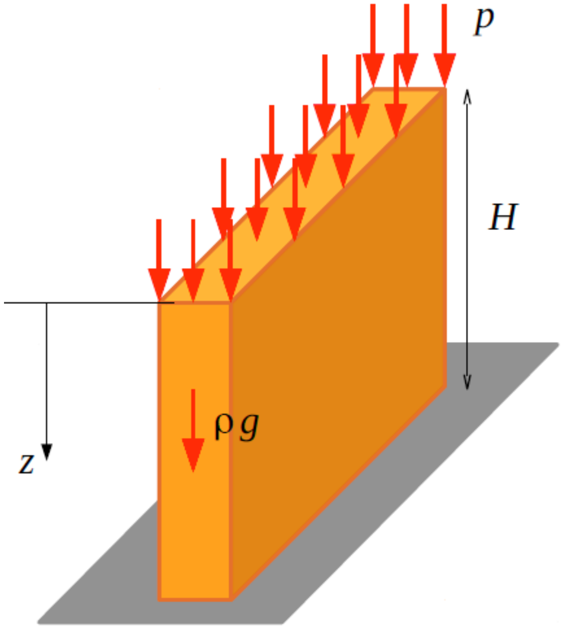
http://www.climatechange2013.org/



UN Global Compact Cities Programme

« THEORETICAL TOOLS FOR MODELLING »

The aim of this lecture was to provide some theoretical tools for modelling the physical 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.
The determination of the strength of the materials was explained. 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.
At the end, the lecture focused on the modelling of thermal behaviour of porous insulating materials.



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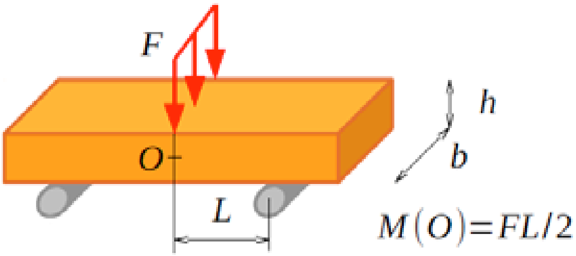

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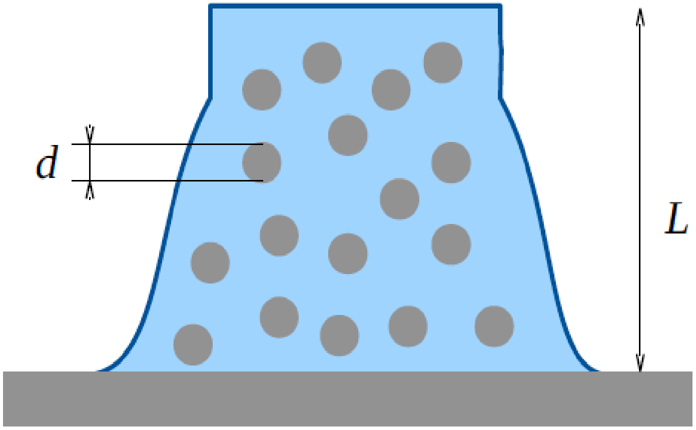
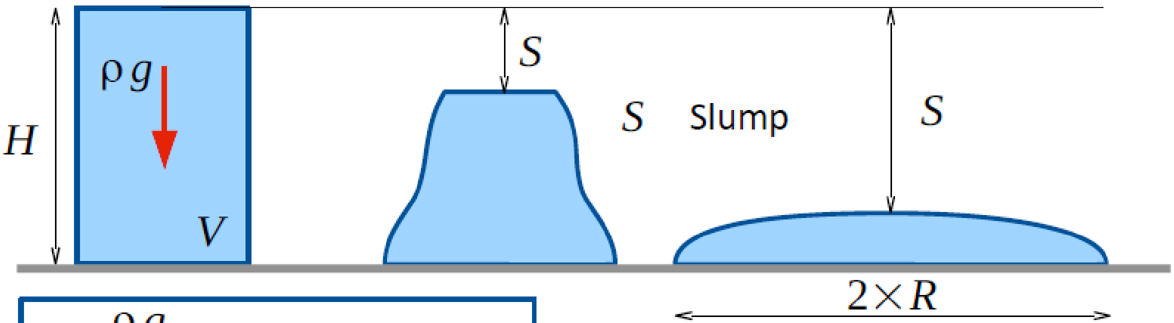


$$\boxed{d \ll L}$$

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



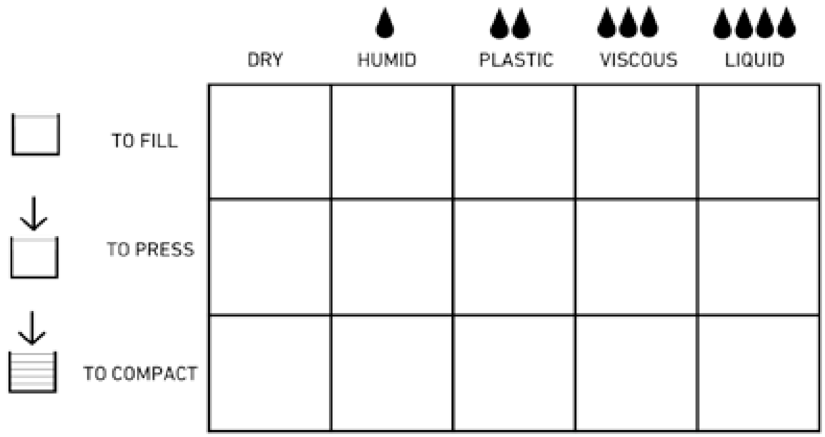
$$\boxed{\tau_c \simeq \frac{\rho g}{\sqrt{3}}(H - S) \qquad S \text{ small}}$$

CARAZAS TEST WITH EARTH AND FIBERS

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). Participants can grasp by handling and observe the impact of some key processing parameters for various soils and fibers: consistancy, water absorption, compactibility, gesture, etc.

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. 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 were compared, highlighting that the result mainly depends on soil composition (granulometry, type of clay, etc).



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, the mechanical action applied on the material varied (to fill, to press or to compact layer by layer). In the other direction, four different mixes were carried out (dry fibers, wet fibers, fibers with clay paste and fibers in a mortar made of clay paste and sand).Four types of raw vegetal fibers were used to observe how their properties (hydrophily, flexibility, absorption capacity, etc) impacts the final result.

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


TO FILL
TO PRESS
TO COMPACT


RISE
SWAG
LIQUID

SAND TOWER BUILD WITH GRAINS, WATER AND FIBERS

Within half a day, a 3 meters high sand tower has been realized. The final weight of the tower was around 400kg with walls having a thickness of only 4cm. The sand in a humid state was compacted layer by layer into formworks that are then removed after piling them up. Plastic grids were put in between the sand layers. Wooden frames were placed at each level of the tower.

The purpose of this exercise is to explore architecture fundamentals (matter, material, element, structure, geometry and space) and to construction cycle concept: learn to build with what is "under our feet", to work with simple materials.

This scale 1 experiment makes the students aware of the importance of the implementation to turn a matter into a construction material (Granular matter: force chains, fibrous matter: reinforcement, liquid matter: capillary bridges)

It makes them conscious that an architectural object is an assembly of different elements, made by assembling different materials (prefabrication, compaction layer by layer, formwork, rammer, reinforcements, ...).

It is also an approach of basic techniques of massonry (level, ringbeam, bracing, inherent stability, mortar, rammed earth).

Each student received a personal learning support to fill during the exercise. A collective restitution discussion is made on the basis of individual observations.

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:

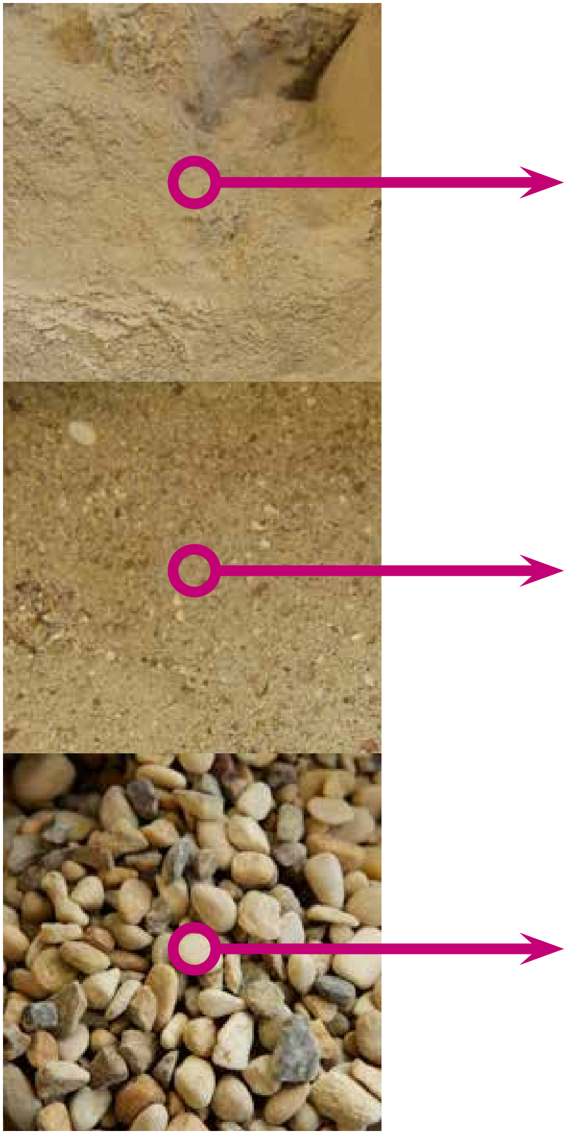
- a self compacting slab
- a wall-facing pannel
- an insulating fibered block
- an insulating foam

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.

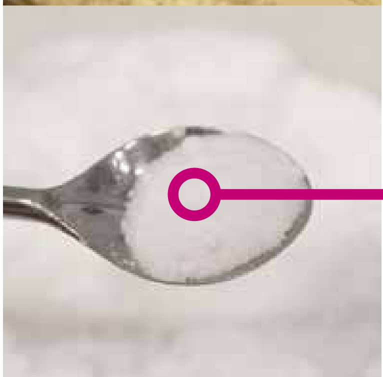
SISAL OAKUM

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

NEWSPAPER

Recycled newpaper is made of cellulose fibers. Mixed with fibers, it can be used as microfibers for reinforcement.



PLASTICIZER

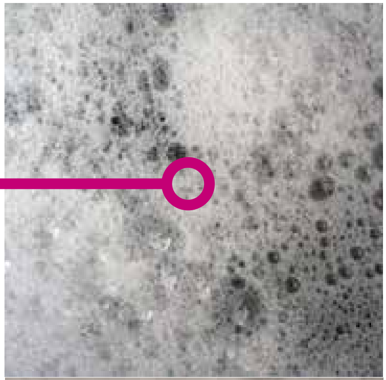
This chemical product (Sodium Hexa-Meta-Phosphate) is used to make easier the mix of clay mud with water. It disperses clay particles and gives the paste a more fluid consistancy with relatively small amounts of water. As it is also used as a food additive, it is considered as non toxic.

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.

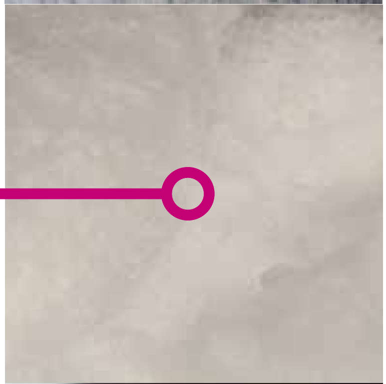
SOAP

Soap is a surfactant: it allows to make bubbles. When it is mixed with water, the air get trapped in it. It can be use to create foams.



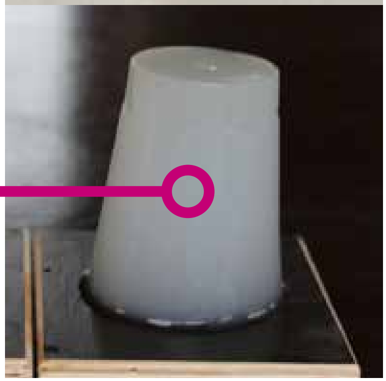
EGG WHITE

Egg white can also be used to make foams. Mainly constitued by water (90% in mass), it contains a protein called "ovalbumin" that is both hydrophilic and hydrophobic (like soap).



AGAR AGAR GEL

Agar-agar is a powder obtained from algae. Mixed with boiling water in given proportions, it forms a gel after cooling. It has a good interaction with clay and can help to reinforced it.



MATERIALS DEVELOPPED

INSULATING CLAY FOAM

light masonry bricks to build a 3m high wall, having a thermal resistance of an insulating material, able to resist the charge of the wall itself.

Prototype dimensions: 10cmx5cm

INSULATING FIBERED BLOCK

light masonry blocks to build a 3m high wall, having a thermal resistance of an insulating material, able to resist the charge of the wall itself and the charge of a clay tiles roof.

Prototype dimensions: 45x45x15cm

SELF-COMPACTING SLAB

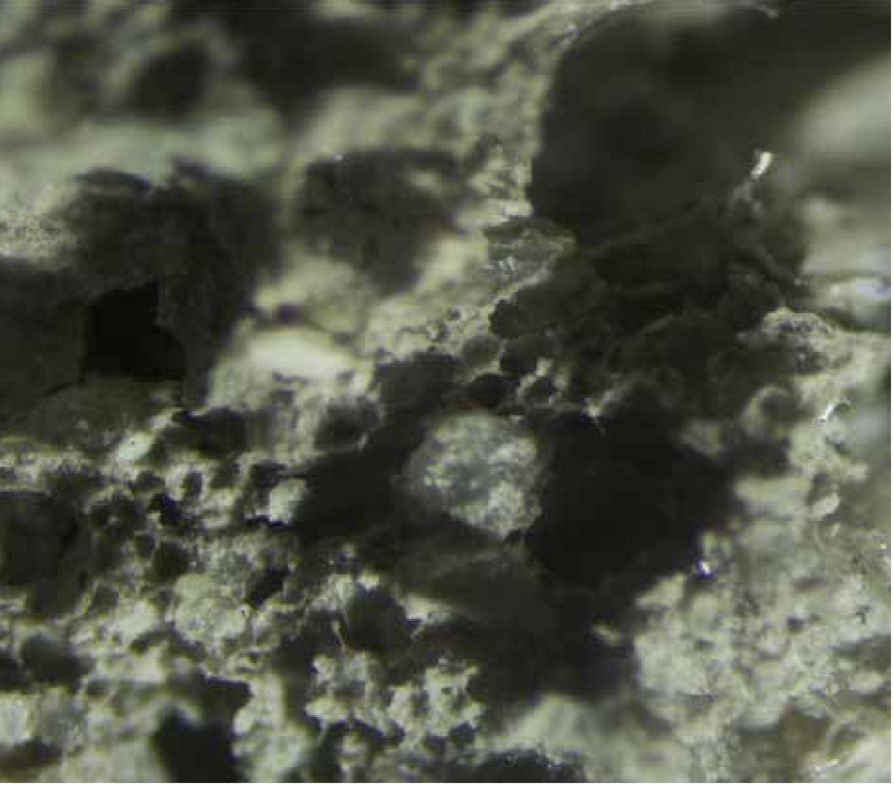
A very fluid clay concrete allowing the realization of 3mx3m slabs without cracks.

Prototype dimensions: 26x42x5cm

WALL FACING PANNEL

An interior pannel of dimensions 3x1,2m that can be transported by to people and screwed on a structure.

Prototype dimensions: 45x45x1,4cm



INSULATING CLAY FOAM

Density of dry earth mortar is approximately 1700kg/m^3. By inserting bubbles in the mix of earth and water, it is possible to obtain a clay foam, that could be used to make insulating bricks.

Tests were made with two different surfactants to make this foam: either egg whites or soap. Agar agar was used in order to cause the gelification of the mortar and facilitate the release from the mould.

The best sample obtained had a density of 560 kg/m^3. It was made of (massic proportions):

- 16% of egg white foam
- 39% of grey earth
- 26% of sand
- 18% of water with 3% agar agar
- 1% of superplasticizer

In a dry state, it was slightly cracked and brittle, but still had cohesion.
Some compressive test were made on small samples with simple 2kg weight, showing that they could resist to a 20kg mass (corresponding to a 200 Newtons load).

An image realized with a microscope brought to light the porous and "bubbly" structure of the material.




SELF-COMPACTING SLAB

A self-compacting concrete has the ability to compact itself only by means of its own weight without the requirement of vibration. The mortars must be fluid and homogeneous (low yield stress and high deformability).

This type of concrete enables the fabrication, onsite or prefabricated, of slabs, but also stairs, pannels, etc. It is adapted to complex shapes and geometries.

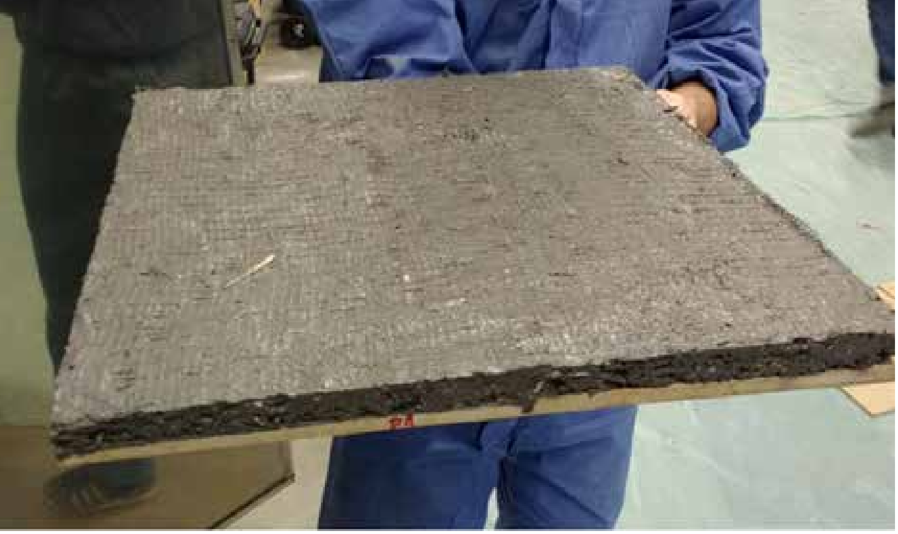
The mortar is constituted by (volumic proportions):

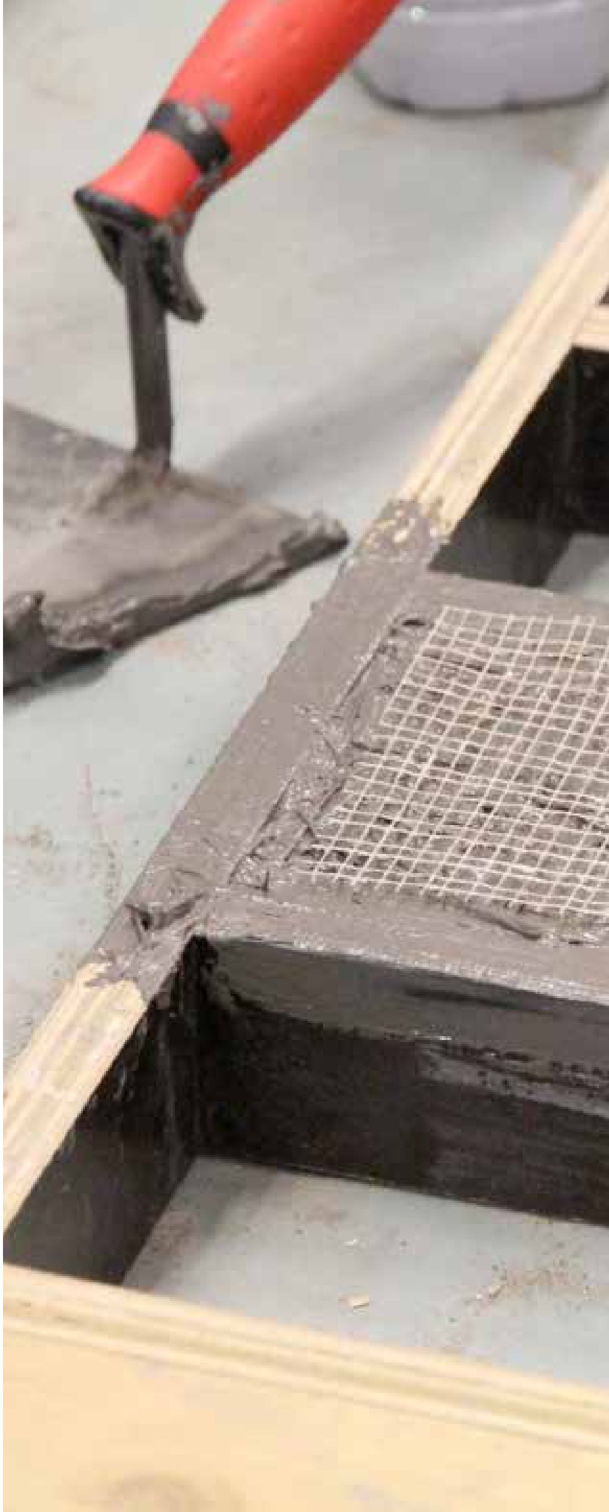
- 33% gravels
- 16% sand
- 51% grey earth
- water: 2/3 (from the grey earth's mass)
- 2% superplasticizer (from the grey earth's mass)

Different fibers have been tested to prevent cracking (samples of dimensions 25cmx25cm in silicone molds). It was decided to put com grids of flax linen in between layers of mortar.

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 by drying.





WALL FACING PANNEL

This pannel is designed for interior wall facing. It can be used as an input of thermal inertia and regulation of ambiant air humidity. It can be easily screwed and plastered.

A demonstrative pannel of dimensions 45cmx45cmx14mm has been realized with:

- grey earth
- hemp hurds
- flax linen grids (on both sides to reinforce flexural strength)

An optimal volumic ratio of (hemp+earth): clay of 1:1 has been determined.

Dry density of the final material is 1,10g/cm^3. A “real” pannel of dimensions 3mx1,2mx14mm would have a weight of 78kg, similar to a Fermacell board (57kg). The weight should be improved to be less than 30kg 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 tests performed on rectangular samples of dimensions 11x22cmx14mm showed that they resist to a load until 20kg without breaking. The material showed a ductile behaviour.

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.

INSULATING FIBERED BLOCKS

Those blocks are easy-to-use masonry blocks made of (volumic proportions):

- 40% hemps hurds
- 24% grey earth
- 16% sand
- 4% sisal oakum
- 16% water

A demonstrative material of dimensions 45x45x15cm has been realized. With a dry density of 1280kg/m^3, this block has a weight of approximately 40kg. 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 and to the charge of a clay tile roof. The compressive strength has to be higher than 0,31MPa. The formulation chosen for the prototype gives a strength of 0,62MPa, complying with this requirement with a safety factor of 2.

Knowing the density of the material, the thermal conductivity is estimated to be 0.39 W/mK. For a 45cm thick wall (3 blocks together), it could be possible to reach a thermal resistance R=1,2Km^2/W, approaching the RT2005 normative (2,5Km^2/W).

GROUP PRESENTATIONS

During the project, the participants try to combine experimental approach (sample fabrication and characterization, observation of physico-chemical phenomena) and theoretical approach (modeling tools). They use some bibliographic researches for a deeper understanding of thematics treated in the lectures.

During a 10min presentation, each group was invited to present the work realized, by answering to the following questions:

- Presentation of the prototype
    - What is this material for ? What can be its function in a building ?
    - What are its characteristics (composition, dimensions, physical properties)?
    - How to implement it ?

- Optimisation process of the material
    - Which key parameters did you try to optimize ?
    - Which tests did you perform ? What where the results ?

- From prototype to final product
    - What could be done in order to turn your prototype into a final product ?
    additional tests, improvement of the design...
    - How could it be processed at a large scale for a building site ?
    production tools needed, technical problems to solve
    - What are the benefits and the disadvantages of your product ?
    compare it to similar products already existing on the market

The evaluation was structured around 5 criteria:

- GOAL: The product specifications were 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.

TEACHING, COORDINATION AND JURY MEMBERS
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