PLEA 2015
BOLOGNA, ITALY
09 -11 September 2015

USING SCIENCE, SENSES AND EXPERIMENTATION TO TEACH THE IMPORTANCE OF THE CONSTRUCTION CYCLE IN UNIVERSITIES: THE AMÀCO PEDAGOGICAL PROJECT

Fig 1: Students during the exercise of the Sand Tower, a 3 meters-high tower, with load bearing walls only 4 centimetres thick build with nothing else but sand, water and fibres.

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

The construction cycle implies the use, recycling or disposal of local resources and thus the socio-economic and technical habits of a territory in terms of building cultures. Therefore, this cycle can be taken as the basis from which other sustainability concepts in the field of construction can originate from. However, the construction cycle, that includes all the steps of the construction process, from the material extraction, the implementation of the building in a given territory, to the demolition and the treatment of the wastes, is rarely considered in its entirety. Since 2012, the French governmental project "amàco" ("atelier matières à construire"), designs pedagogical methods and contents based on the use of this notion of the construction cycle for architecture and engineering schools teachings. For that purpose, amàco utilizes matter science to help the students understand the behaviour of any raw matter that they can find near or on the construction site. The teaching method is based on simple scientific experiments on five categories of matter science: granular matter, fibrous matter, binding matter, soft matter and liquid matter. From these five categories, the physical and chemical properties of any construction materials such as wood, concrete, earth or straw can be explained. On the other hand, the project tries to give maximum emphasis to the links between physicochemical properties of raw matter and its aesthetics and sensory aspects. With this scientific and sensorial background, the students are invited to participate in experimental and creative workshops and real scale construction exercises. These exercises aim at re-creating a link between students and raw matter and the emotional background that can be associated with social habits of local building cultures. Finally, it aims at facilitating the transfer of knowledge and innovating techniques between new and vernacular construction techniques, back and forth from universities to professionals.

Keywords: matter science, raw matter, construction cycle, learning by doing, pedagogy, experimentation, architecture, sustainable, vernacular, pedagogical innovation.

1. Reconsidering the construction cycle

Sustainability questions in architecture are often discussed exclusively by looking at the mechanical or thermic properties of the materials used for building. In particular, the construction cycle, that includes all the steps of construction from material extraction up to the erection of cities in a given territory and their eventual recycling, is rarely integrated in its entirety. Nonetheless, according to the amàco project's paradigm, this cycle can be considered as the basis from which all sustainability construction concepts should originate from. Indeed, the solution for worldwide sustainability in architecture may not be based on the discovery of synthetic materials with exceptional characteristics, but rather on a rediscovery of the intrinsic qualities of natural materials: the intelligence of simplicity (Fontaine & Anger, 2009).

However, the notion of construction cycle is rarely taught thoroughly in architectural or engineering schools, mainly because the links between territory and matter, and between matter and construction material are missing. The amàco project, which stands for "building matter workshop" in French, proposes to architectural and engineering schools a pedagogical approach to teach matter and material behaviour so as to include them in the construction cycle. For that purpose, the French Ministry for Higher Education and Research has granted the project for a period of eight years up until December 2019. The project is implemented and supported by a consortium of four organizations: Les Grands Ateliers, the Grenoble National School of Architecture (ENSAG) and its CRAterre laboratory, the French Engineering School of Lyon (INSA de Lyon) and a French Engineering School of Paris. It brings together researchers, engineers, architects and artists to develop an interdisciplinary approach of learning for building.

2. From matter to architecture: the general concept of the amàco project

Based on five categories of matter (granular matter, fibre matter, binding matter, soft matter and liquid matter), amàco develops pedagogical experiences to explore the material properties at the scale of a grain of sand, a fibre or a drop of water. The project aims at developing an intuitive understanding of the behaviour of matter by the learners. In this sense, it follows the Strategic Teaching model of Tardif (Tardif, 1992) whereby learning experiences should be structured around three phases:

- Contextualization: a concrete situation or problem is presented, in a simple version, to activate the learners' prior knowledge and interest

- De-contextualization: theoretical elements are presented to equip learners with analytical tools necessary in order to examine the situation or problem with more precision
- Re-contextualization: learners make sense of the situation or problem with the help of these newly acquired analytical tools and can therefore examine it in a more elaborate fashion.

Fig 2: This picture shows the interaction between natural hydrophobic fibres and water.

In a following stage of the learning process, the students are encouraged to implement this intuitive understanding during building material designing exercises. For this purpose, amàco offers creative and experimental workshops, where students can work in collective intelligence and learn by doing (Vygotski, 1978). In fact, learning cooperation is one of amàco's learning hypotheses and relies on the diversity of students to take advantages of their various backgrounds and points of view. In a last step, trough the practical exercises and the implementation of construction projects, students discover the links between the microstructure of the material and the structural issues of a built structure.

3. amàco's pedagogical devices

3.1 To teach matter rather than material

The amàco's five categories of matter correspond to physical states of matter rather than construction material. Indeed, materials such as wood, concrete, earth or straw are apprehended from the same point of view of physics and chemistry. From this point of view, we can show that a concrete, which is a mix of grains agglomerated by a binding material, can be both an artificial material known by all of us (gravels, sands and cement) and a natural material such as earth (gravel, sands, silts and clays) or vegetal grains mixed with a binder (for instance hemp-clay concrete). This approach was chosen to facilitate the transfer of knowledge from a professional sector to another, while bringing together innovating techniques between various construction materials. The five categories are as follow:

- *Granular matter:* Mineral or vegetal grains such as sand, gravels, wood shavings and other granular material found in construction material such as in concrete or earth.
- *Fibrous matter:* matter consisting of vegetal fibres, or fibres added to concrete mixtures such as wood, straw, bamboo, reed, hemp, etc.
- *Binding matter:* matter in the form of mineral pastes capable of hardening and agglomerating grains or fibres such as in Portland cement, plaster, aerial and hydraulic lime, clay, natural cements, roman concrete, geopolymers, etc.
- *Soft matter:* Matter neither liquid nor solid, implemented as a paste, mud, an emulsion or a gel in construction such as fresh cement, lime paste, clay mud, polymers, bitumen, paint, coatings, mortars, etc.
- *Liquid matter:* Interactions between water and building materials (evaporation, capillarity, freezing, thawing, condensation, corrosion, etc.).

3.2 To design counter-intuitive experiments

To clarify the intrinsic nature of matter and its physicochemical properties (internal mechanisms), amàco bases its pedagogy on the development of counterintuitive experiences that have been initiated by a program called "Grains de Bâtisseurs" (Anger & Fontaine, 2005). A counterintuitive experience is an experience that produces an inverse result from the result that was expected intuitively or for which the interpretation goes in the opposite direction of what common sense would predict (Eastes & Pellaud, 2004). The aim of such experiences is to perturb conceptions and increase the desire to learn (Giordan, Girault, & Clément, 1994). Surprise and astonishment are used to acquire, without advanced physical, chemical and mathematical knowledge, a general scientific and technological knowledge of matter for its use in the fields of buildings construction and conservation (Fig. 3, Fig. 4).

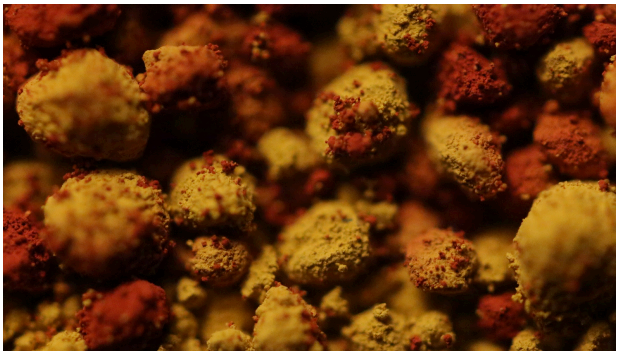

Fig 3: Under specific conditions (temperature, humidity), natural ferrous oxide, responsible for the colour of earth, can change of chemical structure. Here, the experiment shows how goethite, a yellow ferrous oxide, can turn to hematite (reddish ferrous oxide) under a change of temperature.

Fig 4: In this experiment, the student discovers how water can act as glue between the grains of a pile of sand, thought the capillary action of hydric forces.

3.3 To learn using senses

By touch and observation, builders may consider whether a material is ready to be implemented and used in construction. One of the important objectives of the amàco project is to integrate these "non-academic" information to develop the multiple intelligences of students and to foster affective and/or psychomotor learning (Berthiaume & Daele, 2013).

Through sensory exercises, participants are invited to discover how their five senses allow them to obtain information on the matter. The exercises include kinaesthetic stages where participants, blindfolded, are asked to focus on the sensations given by their other senses: mineral composition, presence of organic matter, salinity, moisture, etc. These exercises intend to bring the student closer to the material to make it more familiar.

3.4 To make the invisible visible

While the students' senses allowed them to "see the heart of matter", a wide variety of shapes, structures and physicochemical phenomena exists inside the matter and way beyond what our perceptions can tell.

On the other hand, the time scales of some chemical and physical processes are too short or too long for the human senses to perceive them. By changing this time scale, unexpected and hidden phenomena governing the behavior of the matter can be seen. Amàco offers the possibility to approach matter at various space and time scales and to make the invisible, visible. For that purpose, the project uses time-laps, slow motion videos, polarized light, to show, for instance, how materials "grow older", how they change in state, etc. (figure 5).

3.5. Use the aesthetic properties of matter

To promote the use of local materials for construction, the general public needs to consider it as appropriate and logical solutions for building. However, raw materials such as earth or straw are considered weak and sometimes archaic and dirty. Amàco proposes to change this image by using the aesthetic properties of natural matter through an artistic approach.

The project takes its inspiration out of the work of renowned artists that work with natural materials. For instance, according to Antoni Tàpies (Tàpies, 1970), a Catalan painter, « to think about straw or manure can be important nowadays. It relates to meditation on primary matter, natural essence, origin and force of life, etc. ». For Koichi Kurita, a Japanese artist, "If people say earth is dirty, the power of art is to change their mind about earth's beauty" (Arlaud, 2007). Within this context, amàco established partnerships with artists such as the artists from the "Colectivo Terrón", that develop theatrical shows based on the use of raw matter such as sand, clay or earth. These shows are directed towards students and the general audience, from the young children to adults, with or without scientific background.

Fig 5: This picture shows a very thin slice of wood, backlighted. The structure of the wood becomes visible and helps to understand the natural properties of this material.

4. From matter to architecture

Fig 6: After the instructions given by the teacher, students are invited to make their own experimentations, to transform matter in material.

"*I never premeditate what I will do, things are done according to the materials available on the site. Stone in the south, wood in Germany, earth in the Lyon region, brick in Paris region. It is also the encounter with a site, a climate and a planning.*"(translation) (Perraudin, 2001, pp. 185–203).

It is with a strong poetic expressiveness that the landscape is revealed through an architecture composed of the less transported and transformed matter, the most available, the one that is simply under our feet and around us. It is on this observation that was settled the relationship between intuitive understanding of the material and its application in the field of architecture, that initiated the amàco project. Indeed, the construction process allows the connection between the microstructure and macrostructure (Anger et al., 2012) : a material is constituted of elements that vary in size, shape and nature and which are found together in various arrangements at several levels such as the level of matter (atoms, grains, platelets, etc.), the level of building material (soil, cement, plaster, etc.) and up to the elements (structure).

4.1 Experiential learning

Once the students have explored the physicochemical properties of matter and its behaviour, amàco proposes to use intuitively this knowledge to transform raw matter in construction materials. Learners reflect upon the various elements they could observe during the experiment. That enables them to draw lessons or generalizations, which constitute new knowledge about matter. Hence, students learn by doing. Results are rather interesting. With no defined guidelines and with access to a broad range of raw matter, the participants develop their own specific recipes and explore their strength, durability and appearance. For instance, the student that wishes to design a natural material containing fibre matter and binding matter, can access to a wide variety of natural raw matter and tools. Practical support is offered to the student regarding implementing technics (Fig. 6).

4.2 From construction material to structure

In a last stage, amàco designs real scale exercises where raw matter is implemented for building purposes and for the design of architectural spaces (Fig. 7). The project suggests to the students to draw their inspiration from vernacular techniques and to adapt them to other uses, locations, needs or materials for contemporary projects. The exercise of the "tower of sand" is a good example of what such an exercise can be (Anger, 2011), (Fig. 1). In this exercise, students build a 3 meter high tower of sand, with walls only 4 centimetre thick. To avoid destabilization in the tower of sand, the students fit horizontal reinforcements (woven fibres) at regular intervals between the compacted sand layers to reduce the horizontal stresses that could cause the collapse of the tower. Although the weight of the tower reaches 400 kg, the tower stands up nevertheless the slenderness of the walls. This exercise is related to an example of vernacular architecture. Indeed, Chinese architects had to design the Great wall with materials they found in their direct environment. In the desert, they only had sand. So they built portions of the Great Wall following this construction system (superposition of layers of sand and reed layers).


Fig 7: Once the physical, mechanical and chemical properties of the building material produced are understood, the next step is to implement it for architectural needs.

5. Future implementation

Given the youth of the project, it remains difficult at this stage to assess on the long term the feedbacks of the project regarding the relatively limited number of participant that have been actually implementing their teachings in their professional exercise. Nevertheless, the educational team currently works on the continuous improvement of its training offer and develops teachings directed toward different levels from undergraduate schools to master and professionals.

One other challenge that the project faces is related to its large-scale dissemination and its role as demonstrator. Indeed, the team is not presently able to respond fully to requests for collaborations in France and abroad. For wider distribution and thus the success of the project, the project now seek teachers that would be willing to be trained by the team and act as a dissemination vector in their institutions.

A quality system was set up in 2014 to ensure continuous improvement of our training activities. It covers the entire process, from design to evaluation of trainings. At each step, specific documents allow to capitalise on the team's training experience and to document the project monitoring indicators. A collective drafting process of educational matrix (targets, contents, methods, learning assessment) and a training scenario are developed in the design step. Learning assessment is made at the stage of execution. During the assessment of training steps, an evaluation questionnaire is distributed to the participants at the end of the training (satisfaction, strong points, weak points, ideas for improvements…). The trainers also fill an evaluation questionnaire. Supervising team meets to make a collective balance sheet on the basis of the previous evaluations results. Then, post-training questionnaires are sent to the participants 4-6 months after (reuse of the apprenticeships, future of the participants…). For dissemination, an illustrated summary balance sheet of the training is sent to the participants and a web page is posted. The complete analysis will begin in September. For now, the satisfaction rate is 94%, on a sample of 610 students who completed satisfaction questionnaires.

6. Conclusions

The goal of the amàco project (2012) is to give to future building industry professionals the tools to design and produce construction materials from any raw materials that they can find locally. This learning strategy has received very good feedback from students and teachers. Since 2012, amàco has developed its teaching methodology and tested its educational strategy within its associated institutions (INSA de Lyon, Ecole Nationale Supérieure d'Architecture de Grenoble, ESPCI ParisTech) but also in other French institutions (Ecoles Nationales Supérieures d'Architecture of Lyon, Clermont-Ferrand, Saint-Etienne, Nantes, Strasbourg, Paris-Belleville, Lille, Ecole Nationale des Ponts et Chaussées ParisTech) and foreign institutions (Stuttgart School of Architecture, University of Lima (Peru), University of Linz in (Austria), University of Lomé (Togo), University of Yazd (Iran), The Swiss Federal Institute of Technology in Zurich, etc.). Nearly 3500 students were trained.
Moreover, amàco care to remain up to date with the latest research on materials and architecture, so that construction from raw or minimally processed materials can be considered viable, and fully meet the challenges of sustainable construction.

7. Acknowledgments

The authors thank Denis Berthiaume for their support and participation in the writing of this communication

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