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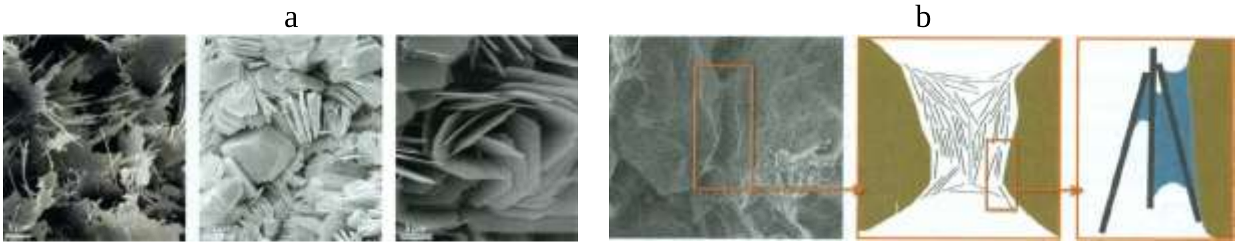
Stabilization revives earthen material in contemporary construction

Today, the need for more comfort, more energy saving and less pollution emission in sustainable built environment is reviving the (re)use of the earthen materials. Earth is a naturally occurring and easily accessible material, traditionally used to provide the shelter to the humankind. More than 30 % of the global population currently live in earth-based buildings. It allows to naturally adjust the fluctuation of temperature and humidity inside the building throughout the day and the night, the summer and the winter; thanks to the moisture in its fine "sheet-like" clay particles. Unfortunately, the earth is mostly not stable in contact with water. Thus, the need for stabilization to improve its performances and competitiveness with other building materials.

Global map showing that the UNESCO patrimonial sites are predominantly located in the regions constructed using earth, CRATerre.org

In the last few decades, many efforts have been made by researchers, builders, and common population to revive the usage of earthen materials in building construction. At material scale, the performances of earth can be improved by addition of granular or fibrous particles, chemical binders, or by compaction of the earth or its mixtures with different additives. At the building scale, the performances of earth-based constructions can be improved by providing adapted foundation and roof to prevent any contact with water. As the saying goes, *earthen buildings should have good boot and good hat!*

Doing so, it allows to maintain the stability/cohesion in the earthen material, mainly the fine, "sheet-like" clay fraction, even in contact with water. Note that earth contain coarse particles of sands and gravels, as well. Some clays are extremely sensible to water: they swell when humid and shrink when dry. This can cause the cracking degradation and instability of earthen structures.



Fine "sheet-like" and porous clay particles controlling the cohesion and other performances of earth: (a) scanning electron micrograph, (b) moisture in capillary bridges, Van Damme 2013

So, what are the techniques for the stabilization of earthen materials?

Looking at the material scale, many techniques have been developed for earth stabilization and the know-how passed through generations over the year. The following three approaches are the commonly used techniques, either alone or in combination.

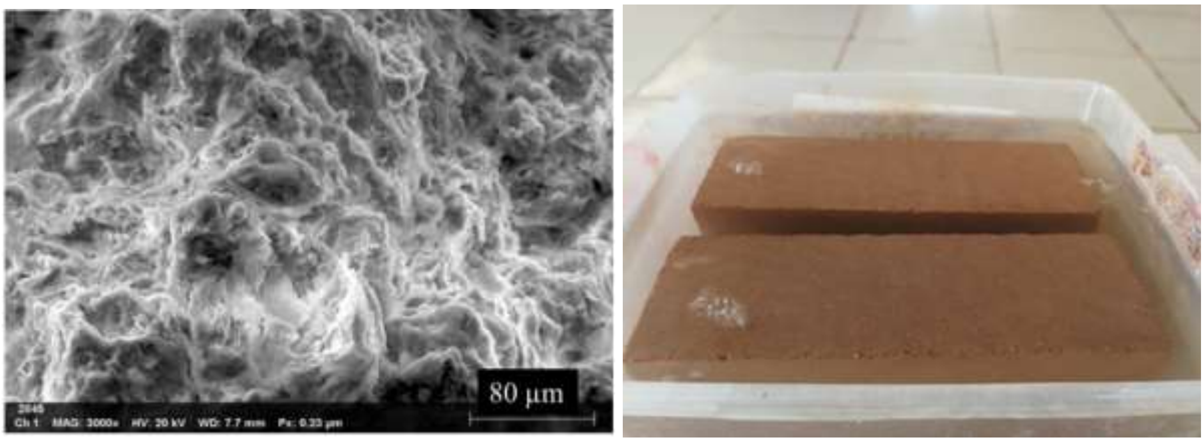
- **Physical stabilization**

As of its name, the physical stabilization consists of physical optimization of the texture and size of the granular particles in the earthen matrix. The optimum and continuous granular distribution allows to fill smaller particles in the holes left by coarser ones. The granular skeleton made of sand, gravel, and naturally bound by the fine clay particles can reach significant stability in dry state. However, it may degrade when it is in contact with water; depending on the type of clay.

The granular particles such as the river sand can also be added to the earth in order to counteract the swelling-shrinkage of the clay. Another technique consists of reinforcing the earthen matrix by incorporation of fiber or aggregates. Among others, one can mention the natural fibers: straw, kenaf and okra bast fibers, banana fibers, sheep wool or synthetic fibers: polystyrene fibers etc. This can also be achieved using the wastes from agriculture, municipal or construction wastes. The incorporation of fibers general reduces the weight and thermal conductivity of earthen materials.

- **Chemical stabilization**

The chemical stabilization consists of the addition of 6-12 % chemical binders: cement and/or lime to the earthen matrix for its modification at the particle or atomic level. In the presence of water, the chemical binders react on their own or with the earth to form "gel-like" cementitious products. This gel further binds the earthen particles to increase their strength. It also assures stability in contact with water by preventing the earthen particles from scattering and keeping that stability over the long term.



Stabilization of the earthen materials using chemical binder densify and improve the cohesion and resistance to water of the matrix of CEBs, Nshimiyimana et al. 2019

- **Mechanical stabilization**

The mechanical stabilization consists of the compaction of the earthen particles or the mixtures with physical or chemical stabilizers. The compaction reduces the void/space between the particles, and therefore the susceptibility to water ingress. Compacted earth is used in modern building construction mainly in two forms: compressed earth blocks (CEBs) and rammed earth (RE). The CEBs are produced by compressing moistened mixture of earthen material in a mold, using either manual, mechanical or hydraulic machine. After maturation and drying, the CEBs are used in masonry work for construction of wall of buildings. By contrast, the RE is directly produced into wall by compaction of moistened earthen material in a formwork, layers by layers.

The physical stabilization by incorporation of fiber or aggregates mainly reduces the shrinkage and improve thermal properties. The stabilization with chemical binders improves the cohesion and the resistance to water degradation. The mechanical stabilization improves the compacity and resistance to mechanical stress. This explains why in most cases, the performances of earthen materials are better improved by combination of at least two of the stabilization techniques.

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