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## **Some observations about the paper “Earth construction: Lessons from the past for future eco-efficient construction” by F. Pacheco-Torgal and S. Jalali**

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As the starting point of this discussion, we would like to congratulate the authors for this interesting review [1], which defends the use of earth as a building material. Indeed, while this is one of the oldest building materials in the world, it is also one of the less studied by the scientific community, and thus, one of the less understood. However, as stated by the two authors of this review, the number of scientific studies on this subject has increased dramatically in recent years.

There searches on earth as a building material are mainly motivated by the growing demand of masons and construction companies for scientific data and evidence to evaluate and improve the wealth, the hygrothermal comfort and the seismic resistance of earth construction.

First of all, we share the approach proposed by the author that consists of connecting the past and present (and even the future). This point is well illustrated by the first paragraph of the paper and its attractive title. Indeed, we think that the comparisons between the characteristics of modern earthen material and existing ones, which have proven their effectiveness over the decades, is a major key to improve our understanding of this multi-scale composite material. The authors wish here to compare their views with those of Pacheco-Torgal and Jalali and highlight the following three main points of disagreement that justify this discussion.

### **1. The present and the future of unstabilised earth constructions**

Throughout the article, the authors seem to postulate that the stabilisation technique (e.g., addition of hydraulic binders) is a compulsory step for earth construction. This leads to quite surprising conclusions about the cost and environmental impacts and their assumed direct link with the nature and amount of the binder used.

These conclusions become even stranger if we consider cement stabilisation, which could be irrelevant from environmental, economic and technical perspectives. Indeed, if this stabilisation is efficient in the case of kaolinic clay materials containing appreciable amount

of sand [2], the same is not necessarily the case for raw clay materials rich in montmorillonite [3-5].

From this partial point of view on the stabilisation, we can strongly question the consistency displayed by the authors to link traditional earth constructions to the modern use of soil as a building material. Indeed, this former is mostly constituted by structures made of unstabilised earth, even for areas subject to heavy rains (Northern Europe).

As a consequence, while it is true that in some countries, the temptation to accelerate the strengthening of the material by the addition of hydraulic binders can be justified for industrial production rates [6] or for maintenance purposes [2, 7-8], an understanding review should not overshadow the research that is ongoing on un-stabilised earth constructions.

An illustration of the significant importance of taking into consideration both stabilised and unstabilised materials is given in Germany, which is regularly used as a reference by the authors in their review. Indeed, after updating their professional rules, the Dachverband Lehm wrote a draft standard on earth-based bricks considering only un-stabilised bricks (except plant fibres that can be considered as a stabiliser in some cases).

Based on this premise that un-stabilised earth constructions were only useful in the past, the majority of this review loses its relevance and contradicts the title that suggests that we can build the future using knowledge from the past.

This contradiction becomes particularly annoying during the discussions on economic and environmental impacts. The unstabilised earth is solely able to be returned to its initial state (as a soil) without any “waste” of energy, by simply wetting. Moreover, it is possible to reuse the material with the same embodied energy to build again. This is the only material with drystone masonry to be able to do that. Using cement or lime stabilisation increases the embodied energy of the material.

The authors are not at all against the stabilisation, particularly if it is done with the real three dimensions of sustainable building, when for example it enables to use local materials and develop local skills and employment but they are just aware that using earth is not sufficient to be sustainable.

## **2. Material properties**

The presentation of the material properties of the soil used for earth construction is interesting but definitely lacks a discussion on the compressive strength. This feature has been extensively studied by various researchers since the 1980s, see for examples [9-29].

Indeed, this characteristic is currently a feature required by all parties involved in construction as a proof of durability. However, there is a paradox between this parameter and the observation of existing earth constructions that have long shown sufficient durability. Thus, despite years of research, there is still no consensus on how to measure this characteristic [27]. As an example, similarly to what it is observed for other building materials, such as concrete, Anglo-Saxon culture advocates the measurement of the “confined” resistance, whereas in French culture, we continue to be attached to the “unconfined” measurements.

Many discussions about the extent and relevance of this feature continue to animate the scientific debate within the community working on this subject.

Moreover, as is rightly stated by the authors, the compressive strength will depend on the sample shape (and this is where the main problem with the compression test lies). However, to echo the previous discussion, it is important to underline here that the stabilisation will also significantly affect the fracture behaviour of the test sample.

Actually, stabilisation created by rigidifying the material will induce a commonly observed behaviour in brittle materials as concrete or stone. In contrast, the un-stabilised material is likely to be closer to conventional behaviour of soils. In this case, the soil behaviour elasto-plastic models are a priori better suited to earthen materials [30-31].

Thus, any comparison between the compressive strengths of stabilised and unstabilised earth samples should be made with care.

### **3. Hygrothermal properties**

Finally, a similar discussion can be undertaken on the hygrothermal properties of earthen materials and their impact on comfort and indoor air quality. One of the main assets that is used to promote earth constructions is their role in controlling moisture and indoor air quality. To our knowledge, there are also few studies that demonstrate what the influence of stabilisation on the hygroscopic behaviour might be. It is well known since [23] that, for materials of the same soils manufactured at the optimum water content, stabilisation increases the volume fraction porosity of the material. The consequence is that the sorptivity of the cement stabilised samples is higher than the unstabilised sample [32]. But recent studies in the moisture buffering in buildings, clearly stated that the vapour transfer were reduced by the stabilisation with lime or cement [33-34]. However, the prediction of this phenomenon through the integration of the measured physical properties of moisture and the heat transfer coupled models is extremely rare [35-37] and should also be completed in further studies.

### **4. Conclusions**

We believe that it is necessary to continue discussions among scientists on the use of this material in modern “green buildings”. Moreover, it is quite relevant, as suggested by Pacheco-Torgal and Jalali, to study existing earth constructions for, at least, the transmission of cultural know-how. However, the existence of these structures is, by itself, evidence of the durability of these types of constructions, which have remained intact for decades. It will be necessary to increase our knowledge of this material to renovate it properly (including from the energy point of view, for example, in the countries of Northern Europe).

Finally, the question remains open on stabilisation. While it is entirely appropriate for some applications (low-cost buildings in India subjected to the monsoon to avoid having to rebuild every year for example), its routine use in industrialised countries can be questioned. Some local soils are known to exhibit sufficient mechanical characteristics without amendment.

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