SHOULD RAW EARTH BE IMPROVED? AN ENVIRONMENTAL ASSESSMENT

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If there is something on which we probably all agree in this audience it is that raw earth is a wonderful building material. The use of raw earth gave rise to an extraordinary variety of vernacular construction techniques, some of which were illustrated in the previous presentations. It has and it is still providing decent dwellings to a significant fraction of humanity all over the globe, and it is one of the options to consider for facing the affordable housing challenge that the increase of the world population is posing.

When implemented without industrial additives, crude earth is a totally and infinitely recyclable material with a remarkably low environmental impact. In spite of that, raw earth construction is facing serious challenges, many of which stem from its still very limited use in modern construction. It suffers from a – often unjustified – poor image, in social and technical terms, and from the difficulty to pass some durability and mechanical performance tests which were designed for industrial materials, and which are not adapted to raw earth. In addition, earth construction is so far a very labor intensive technique. This leads to a relatively high cost and to time requirements incompatible with current productivity standards.
These are very real challenges, and they have been addressed so far in two ways.

The first one – which is actually not that recent – is the almost systematic "stabilization" of earth with lime, plaster of Paris, Portland cement, or industrial wastes like fly ash or blast furnace slag. This led to the now widespread incorporation - mainly in compressed earth blocks and in rammed earth - of, typically, between 3 and 10% Portland cement. Taking into account the massive character of earthen architecture and the potential number of new dwellings, this represents a substantial volume of cement.

A second – more recent – trend has been to transfer to earth construction the technologies used in concrete construction, in order to lower the labor intensive character. The University of Mokpo in South Korea, ETH Zurich, and CRAterre-Amàco are active places in that field. Thanks to an accurate control of the grain size distribution and the use of clay dispersants, earth-based mixes with a very low water content - of the order of 15% only - can now be cast in place just like ordinary concrete (fig. 1). Some cement-stabilized mixes fluidized with last generation concrete superplasticizer polymers can even be operated like self-compacting or self-leveling concretes, flowing like water right after mixing but gaining strength very rap-

Fig. 1 Poured earth, or better, poured clay concrete

idly once in place, so that formworks can be removed after a few hours only. Dispersion alone, by allowing for a larger final density after drying, has been shown to improve the compression strength as much as stabilization with cement. These are truly amazing developments which make earth construction compatible with modern construction standards. They will be presented later during the week.

As far as the carbon footprint or Global Warming Potential – "GWP" – of earth construction is concerned, this evolution raises a number of questions. Even after stabilization, earth remains a modest construction material. Its compressive strength is relatively small, going from a fraction of MPa to about twenty MPa in the very best cases, with an average around a few MPa. This leads generally to the need of massive walls. Although this has some advantages, in terms of thermal comfort in particular, it has also drawbacks in terms of carbon footprint. Even small relative cement contents may represent large absolute volumes. The same is true for the use of synthetic dispersants, which have in general a carbon footprint larger than that of Portland cement, and the question must be raised whether the environmentally friendly character of earthen construction is still preserved.

Let us make some quantitative evaluation (fig. 2). Rammed earth, for instance, which is very common in this region, has a Global Warming Potential – "GWP" – of the order of 23 gram-eq of CO_2 per kg of rammed earth, which is remarkably small. Among all construction materials, this is only surpassed by raw aggregates, with approximately 5 gram-eq of CO_2 per kg of aggregates including sand, on average. The problem is that one can hardly build with aggregates alone.

Global Warming Potential (GWP)

Rammed earth (RE)	23 g CO_2 per kg
Aggregates	5 g CO_2 per kg
Portland cement (OPC)	830 g CO_2 per kg
Stabilized RE (5 to 10% OPC)	64 to 106 g CO_2 per kg
Ordinary concrete (25 MPa)	130 g CO_2 per kg

Fig. 2 Comparison of global warming potential (GWP) of clay concretes and Portland cement concretes

The picture is changing considerably when stabilization is taken into account. The GWP of modern Portland cement is close to 830 gram-eq CO_2 per kg of cement, about 40 times larger than earth. Thus, even a moderate incorporation of cement – say, 5 to 10% – represents a significant increase in embodied carbon. Simple arithmetics shows that stabilization with 5 to 10% of cement would boost the GWP of rammed earth to values between 64 and 106 gram-eq CO_2 per kg of earth. As a matter of fact, the later value is not far from the GWP of ordinary concrete, which is around 130 gram-eq CO_2 per kg of concrete.

It is interesting to look at the efficiency of stabilization and its environmental cost in relation with the gain in mechanical performance. This can be done by using two indices, the so-called *binder intensity index* on one hand, and the so-called *carbon intensity index* on the other hand. Both were introduced by Damineli and coworkers some years ago. They read as follows (fig. 3) :

$$bi = \frac{b}{s} \qquad and \qquad ci = \frac{c}{s}$$

where b is the total consumption in binder and c is the total CO_2 emitted in obtaining a material of compressive strength s. Thus, the binder intensity index provides an answer to the question: "How much cement do I have to incorporate to obtain 1 MPa of compressive strength?", whereas the carbon intensity index provides an answer to the question: "How much CO_2 do I have to emit to obtain 1 MPa of compressive strength?".

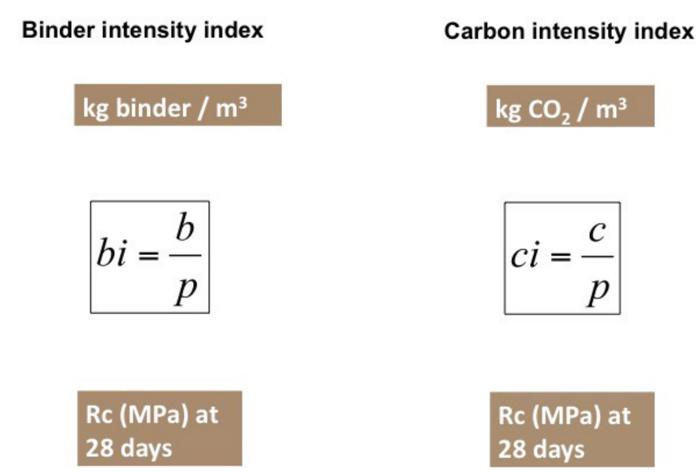

Fig. 3 Binder intensity index and carbon intensity index, concepts introduced by Damineli et al.

The cloud of small data points on this graph (fig. 4) represents the values of the binder intensity index for about one thousand different concrete mixes made with Portland cement. In such a graph, the good values for the index are the small values. In spite of the very large scatter of the data, the trend is clear. The most efficient way to use cement is to use it in a high performance concrete, with a compact matrix of aggregates and compressive strength larger than 60 MPa. The spots representing stabilized adobe, rammed earth, and self-compacting clay concrete, are all on the low strength side of the graph, which is not a surprise. But they are also high in the graph, which shows that stabilizing adobe and rammed earth with cement is a very inefficient way to use cement. The only moderately

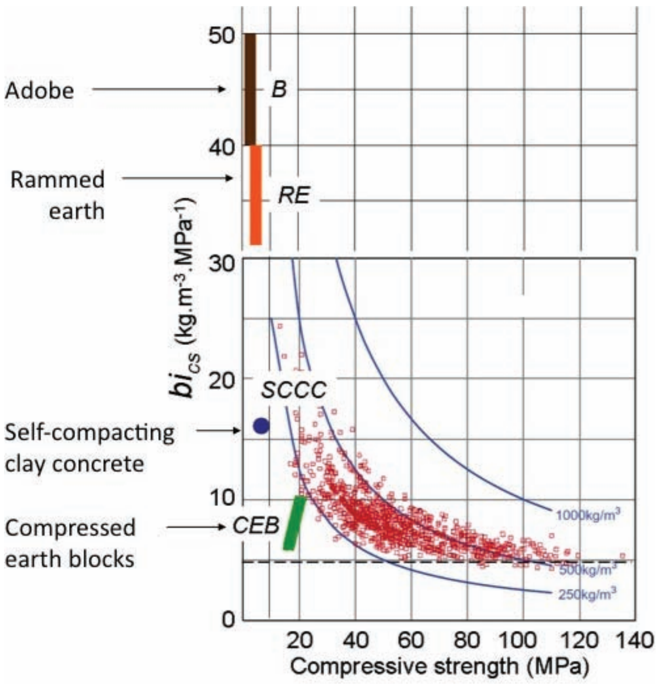

Fig. 4 Binder intensity index comparison chart. (After Damineli et al.)

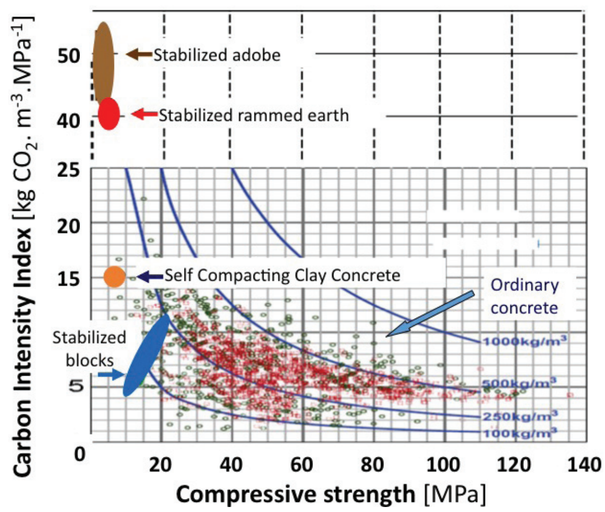

Fig. 5 Carbon intensity index comparison chart. (After Damineli et al.)

acceptable case is that of compressed earth blocks. Their index values are comparable to those of the average value for concrete, but their strength is much lower.

The analysis becomes even more disturbing when the environmental cost of stabilization is considered (fig. 5). Like in the previous graph, the good values are the low lying data points and spots. Compressed earth blocks behave like a concrete of moderately poor environmental and mechanical performance. Self-compacting clay concrete is close to the worst - in environmental terms - ordinary concrete formulations. Stabilized rammed earth and mud bricks have extremely poor environmental performances, with a CO_2 intensity index about ten times worse than the average concrete values.

The conclusion of this analysis is clear. Stabilization of raw earth with Portland cement is not advisable, neither in mechanical nor in environmental terms. It provides very moderate benefits while using large volume of binders.

We do not have the time here to perform a similar analysis for earth fluidized with inorganic or organic dispersants, but the conclusion would have been similar. Without a careful choice of the compounds to be used, the carbon footprint of dispersants may considerably degrade the environmentally friendly character of earth construction. Conversely, provided low-impact and low-cost dispersants can be identified, dispersion could be a very promising alternative to stabilization with cement.

Our conclusions do not call earthen construction into question. Provided some simple architectural rules often inscribed in the local constructive culture are followed, construction with unstabilized earth is a durable technology that has a role to play in the formidable challenge awaiting us in the coming decades. Climate change may possibly modify the architectural rules to be followed, but rather than massively transforming earth into a low quality concrete, it would be more appropriate to adapt the architectural practice and to look for new ways to improve strength and durability.

Thank you for your attention. Earth has a bright future!