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What are the barriers affecting the use of earth as a modern construction material in the context of circular economy?

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Abstract. One path to decrease the impacts of construction is to switch from the current take-make-dispose extractive industrial model, to a circular economy scheme. Building with prime materials and especially with earth (locally available soils containing clay), is a way to foster the circularity of the materials because the unstabilised earth is 100% infinitely reusable. Earth architecture involves different modern and ancient techniques of construction like rammed earth or compressed earth block masonry. However, the development of new earth building is still limited to a niche in spite of its high circularity potential in a modern context. We have performed a review of the barriers that may affect the uptake of the earth as a building material. We have studied journal papers and some findings are based on the experience of the authors as practitioners and researchers. The identified barriers can be classified in Steering mechanisms, Process, Economics, Client understanding and Underpinning knowledge. We have discussed the barriers and reviewed some possible paths to smooth the existing obstacles to the development of earth architecture.

Keywords: barriers, earth building, Circular Economy, sustainable building.

1. Introduction

The modern earth architecture originates from an observation of the great number of existing heritage earth constructions in Europe. This wealth heritage is described for example by [1], as evidence of using vernacular green building materials to deliver a successful and sustainable way of building. Being aware of the quality and quantity of this existing heritage, and using the ideas of past builders who had benefited for thousand years of empirical know-how, some modern architects propose to integrate this vernacular material in the current socio-technical system. To do so, the latest scientific and technological development are used to produce cost-effective earth-based building products. Low energy in the production and circular economy thinking which were obvious in vernacular construction requires now innovation to be implemented in the current built environment.

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The relevance of building with earth in the XXIth century is already shown in some showcase built in Switzerland (by Martin Rauch), France (by Nicolas Meunier) and China (by Lu Wenyu and Wang Shu). The use of local earth as building materials enables to divide the embodied energy of a house by 2, and divide the transportation by 4.5 [2], without increasing the energy consumption during the service life of the building. Moreover, earth architecture delivers high positive impacts on socio-economy [3]. Although there are a growing number of new earth buildings, their prospects of entering mainstream construction as the main structural materials are limited due to different types of barriers that will be studied in this paper.

There are different techniques used to build with earth; however clay is always the main binder whatever the technique. We can distinguish “dry” manufacture process where the earth is compacted, and “wet” manufacture process where the earth is moulded or extruded or stacked [4]. We can also distinguish techniques using small blocks (compressed earth blocks or adobes) implemented with a mortar to build masonry structures, and earth implemented in monolithic walls. In that case we can have rammed earth (Figures 1 and 2) which is a clayey soil (usually less than 20% of clay by dry weight of soil) compacted into formworks with a water content varying with soils, but within the range of 8-20% by dry weight of soil (“dry” process). We also have cob which usually needs soil with a higher content of clay and higher water content of the mixture than rammed earth (“wet” process). Cob sometimes may also contain some kind of fibrous organic material (typically straw) and sometimes lime.

Figure 1. Implementation of prefabricated unstabilised rammed earth walls © Nicolas Meunier.

Figure 2. A completed building of 9.4 metres height with external render and traditional appearance built in 2011. © Nicolas Meunier.

2. Literature review on existing barriers affecting the development of modern earth architecture

Despite the growing interest in engineering issues triggered by the modern implementation of earth as a building material (Figure 3), we have found only one journal paper dealing with the actual barriers affecting the development of modern earth architecture [5].

We have however found some journal papers citing in their introduction some barriers. For example [6] cited the difficulty to understand and to predict the earth architecture long-term behaviour. For [7], the greatest barrier to earth masonry adoption is the durability of the material when subjected to high moisture contents. This idea is consistent with the previous barrier because water is the key parameter variable in the life cycle of the building in the case of unstabilised earth architecture. The authors of [8], dealt with structural challenges facing China's construction industry in moving towards sustainable development, including the improvement of earth buildings. They stated that "outmoded ideas are obviously the major resistance to sustainable construction, which mainly derives from an unreasonable system of indicators. This indicator system concentrates on quantity, or the increment of GNP, alone, and ignores quality, efficiency and environment."

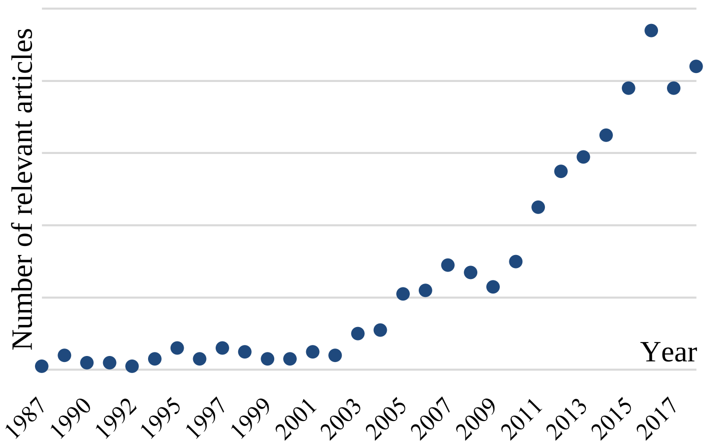

Figure 3. Journal papers related to earth architecture published every year, from Scopus.

Tom Woolley explains in his book [9] that the barriers for using natural building materials (including earth) in the mainstream construction industry are: the lack of scientific data to quantify their true performance and lack of experience by the mainstream construction industry in using these materials.

The only extensive study published in a journal paper is given by [5], where data is provided by questionnaires sent to professionals affiliated to ICOMOS (International Council on Monuments and Sites). Even if the article aims to assess critical parameters on earth buildings as "sustainable architecture", the sampling is limited to people interested in earth as a material in the cultural heritage. The questionnaire was sent in 2012 to ICOMOS members from six countries (USA, UK, Iran, India, Australia, Malaysia). The major bias of this study is that modern earth architecture is dedicated to buildings like factories, single and multi-family houses or schools etc., with different stakes compared to cultural heritage monuments which are unique. Whereas most of the new buildings will be deconstructed or demolished at their end of life, the cultural heritage has to be preserved. The authors [5] have identified nine barriers: Perceived higher upfront costs, Lack of education, Lack of awareness, No fiscal incentive, Different accounting methods, No coordination, Politics, Payback periods, Education of 'non-sustainable' people.

3. Discussion

The discussion will be made in the European context. Most of the barriers identified in the literature are not specific to earth buildings but are related to the implementation of a new sustainable building technique. In fact, earth architecture is included in this concept. So that we can rely on the extensive study made by [10], on sustainable buildings in general, in the Finnish context. Similarly to [10], we can classify the barriers to earth architecture into categories (Table 1).

Table 1. Barriers to the development of earth architecture.

	barriers	Reference
Steering mechanisms	No fiscal incentive	[5]
	Politics	[5]
Process	Different accounting methods	[5]
Economics	Perceived higher upfront costs	[5]
	Payback periods	[5]
Client understanding	Lack of awareness	[5,8]
	Resistance to innovation	[8]
Underpinning knowledge	Lack of education	[5,8]
	Lack of experience	[5,8]
	No coordination	[5]
	Education of 'non-sustainable' people	[5]
	Durability of unstabilised earth	[6,7]
	Lack of useful scientific data	[9]

3.1. Steering mechanisms
We can distinguish two kind of steering mechanisms: normative and fiscal instruments [10]. On the fiscal strand, there is not yet fiscal incentive specifically for earth architecture. However, an appropriate earth architecture will benefit from all incentives related to energy savings (from embodied and in use energy), sustainability (e.g. LEEDS in the US [11], Minergie in Switzerland [12] and BREEAM [13] in the UK) and circular economy.

On the normative strand, there are existing useful standards, however with limited impact, either due to the scope (only a specific technique or geographic area is addressed) or due to the status of the normative text. For example, the French Standard [14] scope is limited to Compressed Earth Blocks and to the geographic area excluding freezing weather (which exclude most of the French metropolitan territory). Another example is [15] which addresses all earth architecture but in the status of Handbook, the lowest status of Standards Australia.

To facilitate the development of appropriate standards, the "274-TCE" RILEM Technical Committee [16] is currently developing pre-Standard testing procedures, on testing and characterization of earth-based building materials and elements.

3.2. Processes
Regarding processes, [10] has detailed that it was dealing with procurement and tendering, timing, cooperation and networking. We think that there is not only the issue of different accounting methods (Table 1) but also a lack of collaboration in the whole life cycle of the asset. To make earth architecture affordable and to gain the mainstream of constructions, all the stakeholders should be involved in the design phase. This may be supported by the digital revolution currently in process in the AEC industry with the development of BIM (Building Information Modelling). As stated by [10], the use of BIM and BIM-based tools may have an important role in the sustainable management of buildings in the future.

3.3. Economics
The cost of modern earth architecture in Europe is a real obstacle. To decrease the cost, some stakeholders are currently developing the automation of the manufacture of earth walls. For example for

the unstabilised rammed earth, an automated process on site was developed by Nicolas Meunier (Figure 1). The other strategy to decrease the cost is to industrialise the manufacturing process like any other current construction materials (concrete, steel, timber…). In that case, the walls or blocks are manufactured by an automated process in a factory (prefabrication) with an earth from a given source (quarry). We don't believe in this strategy because it is not possible to use local soils as close as possible to the construction site. If you don't use local soil earth architecture cannot be seen as sustainable [2] since earth architecture needs thick heavy walls, therefore expensive when transported. An output of this optimisation process is that the composition of materials must be standard, which is not compatible with using local soils.

3.4. Client understanding
Barriers linked to client understanding are thoroughly discussed in [10] where the governmental and local authority organizations that own and develop public buildings may affect the development of sustainable buildings significantly. For example, we can cite the project of "Domaine de la terre" in France, an experimental building programme of 63 residences initiated in 1982 and backed by the local government [17].

3.5. Underpinning knowledge
Concerning processes, [10] has detailed that it was dealing with knowledge and common language, availability of methods and tools, innovation.

We believe that the predominant barriers are not related to engineering limitation of the material because modern engineers and architects can benefit from tools of the current science (see the growing scientific data published, Figure 3), whereas, in the past, vernacular builders could not, but manage to construct sustainable earth architecture anyway.

However, limitation of building with earth is discussed here because there is a tendency to try to improve the mechanical characteristics or the resistance to water of earth by adding stabilizers (cement or lime are the most popular). This strategy should not replace the other strategy of trying to cope with the limitation of the material by adapting the architecture. Firstly, by stabilising earth with additives, the empirical knowledge of vernacular architecture cannot be used anymore, because the stabilised earth is a different material. For example, adding cement enhances the resistance to water but may weaken the material when freezing and thawing cycle are occurring in cold climates of Europe (although no publications were found on this topic). Secondly, in the context of a circular economy, by adding polymers or hydraulic binders to earth, the material's circularity is decreased, and the environmental impact is increased. Moreover, adding cement to earth will never manage to get higher mechanical characteristics or resistance to water than concrete, which is a material optimised by years of engineering researches.

The other tendency of using earth as non-bearing walls to avoid engineering validation can be criticised. Once again, this option should be avoided when possible, because adding another load-bearing structure in parallel of the earthen walls will increase the cost and the impact of the whole building. Moreover, the mechanical compatibility of materials as different, in term of stiffness, like steel and earth, makes it a challenge to design the interface. To increase the height of load-bearing unstabilised rammed earth building, a floor can be added leading to a maximum height of four floors (3 rammed earth floors and for the top floor: timber frame and light walls). The four-floor building represents 70% of the new multi-family residential buildings for 2006-2013 in France [18], and 84% in Switzerland in 2011-2016, [19].

As we said previously, using earth implies to use a local soil as close as possible to the construction site. In that case, the low impact on the environment is secured. In this context, the availability of suitable soil for earth construction may be an issue, especially in dense urban areas. The suitability of earth is a hot topic, and since decades the stakeholders are trying to set up guidance on this subject. We believe that the performance of the material and architecture should drive the choice of a given earth, but not its composition. For the specific challenge of suitable earth availability, it is possible to develop tools to help to quantify the resource [19]. In the paper [19], the authors have developed a new methodology based on the cross-referencing of spatialized pedological and heritage data to identify and quantify soil resources available for earth construction. The study shows the huge potential of the resource for new buildings in the region of Britany (France), with 137 inhabitants/km^2.

4. Conclusion

Unstabilised earth as a building material is not new material and has actually benefited of thousands of years of empirical validation which should give confidence to all the stakeholders to adopt unstabilised earth architecture for appropriate constructions less than four storey height. What is new is the socio-cultural context of the building industry, so that it is very important to be aware of the barriers and limitations of the material to successfully design and build earth architecture in Europe.

This paper has discussed the current barriers to earth architecture, related to Steering mechanisms, Processes, Economics, Client understanding and Underpinning knowledge. As far are the current barriers are tackled, the earth architecture will ensure a sustainable building. In the case of unstabilised earth, sourced from a local public work site or from the excavation of the building site itself, the circularity index developed by The Ellen McArthur Foundation [20], is 100%. This takes into account that the source of the materials is a waste, and that it can be infinitely reused by only adding water and mixing.

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