Original Article

The feasibility of earth block masonry for building sustainable walling in the United Kingdom

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ABSTRACT This article examines the possible use of earth block construction in the United Kingdom. The current and historical trends and distribution patterns of earth building in the United Kingdom and selected overseas countries are reviewed. The rationale for earth building is established, and the unique elements of earth block construction are identified. Economic and technical aspects of building with earth blocks are examined, and the cost of this process is highlighted as one of the major factors that is preventing the wider use of the technique. Methods of reducing the cost of building with earth blocks are examined, and the use of thin bed mortars is advocated as a possible way of reducing the labour cost of building, thereby making earth block building more economically viable. The article examines the structural questions raised by substituting traditional thick joint mortars with earth slurry mortars, and the thermal aspects of earth block walling are discussed. The article supports earth block walling as a sustainable alternative to more traditional walling construction.
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INTRODUCTION

For low-rise construction, unbaked earth is one of the most widely used walling materials worldwide. It has been estimated that a third of all humanity still lives in a home built of earth (Houben and Guillaud, 1994). In India alone, there could be 80 million inhabited earth dwellings, a number that is probably exceeded by China and Africa (Norton, 1997). In developing countries, particularly in rural areas, unbaked earth remains a ubiquitous, cost-effective method of construction for low-rise housing. Economic pressures are, however, bringing about rapid change. In the past 20 years, the growth in global trade has been unprecedented. Countries such as India and China, which until quite recently were overwhelmingly rural with largely subsistence economies in the rural areas, are becoming industrial superpowers. As more and more countries industrialise and their populations move to urban areas, the use of unbaked earth as a construction material is likely to decline. However, in Sri Lanka, it is suggested that compressed stabilised earth masonry would provide an alternative to conventional masonry materials. Owing to the scarcity of these conventional materials, and their associated relatively high embodied energy, Jayasinghe and Mallawaarachchi (2009) have proposed the use of compressed cement-stabilised earth bricks and blocks, and studied the flexural strength of these units when used for walling. These brick and block materials have the disadvantage of using cement, thereby achieving a higher flexural strength, but with higher embodied energy.

This pattern of decline in the face of increased industrialisation was seen across Europe and North America throughout the twentieth century. Before the coming of the railways and motorised transport, materials had to be acquired close to the site of use. With low wages and a surplus of agricultural workers, labour-intensive construction methods needed for earth construction were commercially viable. In its various forms, earth has been used as a construction material throughout large parts of the British Isles. It has been estimated that some half a million inhabited earth buildings still survive; the vast majority of these will have been constructed before the start of the twentieth century (Hurd and Gourley, 2000).

In the United Kingdom, many building techniques have been used to construct earth walls for a variety of building types. The technologies range from the most basic methods such as cob, which is predominantly found in the southwest of England, as illustrated in Figure 1.

Cob walling may be seen as the most unsophisticated method of building in unbaked earth, relying as it does on a wet mix of mud and straw, laid in layers, one on the other, with no support from formwork. The thermal properties of cob walling have been investigated (Goodhew and Griffiths, 2005), and the pathology of the structural failure of cob walls has also been researched, and patterns of failure have been analysed (Keefe, 1998; Keefe *et al*, 2001). Other UK earth building techniques include cleam (similar to cob) in Wales and mud-and-stud in Lincolnshire, a technique that uses a structural timber frame and a thick infill of subsoil. In East Anglia, a more sophisticated technique with earth blocks, known as clay lumps, and shown in Figure 2, were used from just before the beginning of the nineteenth century up to the First World War, with a few later examples.

Clay lump was used extensively for every type of building, from farm buildings and houses to shops, see Figure 3, public houses, schools and windmills (Bouwens, 1990). In the clay lump areas of Norfolk and Suffolk, *it is rare to find any buildings built between 1850 and 1900 which are not of clay lump* (Bouwens, 1990). Earth building reached its nadir in the post-war building boom of the 1960s and 1970s, and it was the determination of a few dedicated enthusiasts that saw earth building emerge from a state of total redundancy in the 1970s to capture a small but growing niche market.

Figure 1: Exposed cob garden wall near Seaton in Devon.

Figure 2: Clay lump exposed for repair in Shipdham, Norfolk.

Today, there are indications that earth building is once again beginning to be taken seriously in the United Kingdom. Morton (2008) has produced a technical guide for the design and construction of earth masonry. The materials used for earth masonry both in new buildings and for damage repair are discussed. Despite the significant drawback of having no dedicated earth building code of practice, investment in research and development and small-scale production is taking place. In Scotland, a small brick company has started to produce unbaked earth bricks, two small producers in the West Country have developed their own mechanised production techniques, and the Ibstock Brick Company has launched an earth brick and block, although currently classed as non-load-bearing. The principal driver in this revival is of concern for the environment. The UN Climate Change Conference, Copenhagen, December 2009, confirmed the need

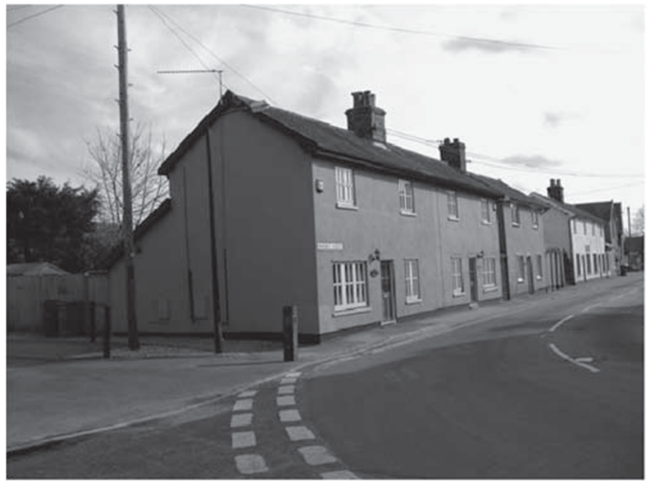

Figure 3: Clay lump cottages in East Harling, Norfolk.

to decrease carbon dioxide (CO_2) emissions by reducing the use of fossil fuels. The need to reduce CO_2 emissions and to find more sustainable construction materials has, for the time being, given earth construction a significant environmental advantage over some forms of conventional masonry.

AIMS

This article has five aims.

1. To outline the reasons for the decline in the use of earth blocks.
2. To establish a case for natural earth block construction.
3. To outline methods of reducing the costs of earth block walling.
4. To consider the flexural strength of natural earth block walling.
5. To consider the thermal aspects of earth block walling.

The last three aims address the three major criticisms of earth walling, namely (i) is it affordable; (ii) will it stand up; and (iii) will it be thermally successful. These three issues support the case for earth block walling as a sustainable method of construction. These five aims will now be discussed in detail.

Reasons for the decline in the use of earth blocks

At the Modern Earth Building 2005 International Conference in Berlin, many delegates spoke of the difficulties they encounter in promoting earth construction in their countries. These range from a lack of national standards, (Spanish and UK delegates), public attitudes that can be sceptical, a lack of knowledge within the construction industry and some resistance from insurance companies and building guarantee providers. However, the one common factor, in developed countries, was the high cost of earth construction compared to more conventional alternatives. This problem was highlighted by Eckhard Beuchela, a specialist in earth construction in Germany, a view that was overwhelmingly endorsed by delegates in an open forum.

In France, the Co-op de Construction responsible for the Salvatierra project reported that despite the success of this project and its popularity with residents, they would not be using earth block construction again as it carried a cost penalty some 10 per cent higher than conventional masonry. In the southwest of the United States, where earth building is still practiced, adobe producers and builders reported that they are unable to compete with conventional timber-framed construction. Periodic surveys of earth block production in New Mexico carried out by the New Mexico Bureau of Mines and Mineral Resources (Smith, 1982; Smith and Austin, 1989; Smith and Austin, 1996) records a 27 per cent reduction in overall production between 1980 and 1995. These surveys record that in 1850, 91 per cent of dwellings built that year were adobe. By 1900, this had declined to 63 per cent, and in 1980 to just 3 per cent. A similar picture can be seen in Germany where despite an increase in earth construction in recent years, the earth building industry is confined to a tiny niche market, owing to the high cost of earth construction. In the United Kingdom too, the few construction projects completed in recent times using earth have all been high-cost developments.

The external walls of a house can account for around 30 per cent of building costs (Anderson and Shiers, 2002). With current production methods and site techniques, earth block construction cannot compete on cost terms with the more conventional, high-energy construction forms using burnt clay, cement and lightweight blocks.

The case for earth block construction in an industrialised world

The case for earth block construction is based on the very low environmental impacts of production, including crucially, very low embodied energy and CO_2 (Morton *et al*, 2005). With greater industrialisation and increasing global trade has come an increase in CO_2 emissions, which, for many societies around the world, could be catastrophic. At Kyoto, the 'developed countries' agreed to reduce their greenhouse gas emissions to 5.2 per cent below 1990 levels over the period 2008–2012. The United Kingdom has agreed that its contribution to this agreement will be a 12.5 per cent reduction over this period. In addition, the United Kingdom has set itself a more ambitious target, which is to achieve a reduction of 20 per cent by 2010 (HM Government, 2006). Currently, very few countries are on target to achieve this. In Britain, CO_2 emissions have increased by approximately 2 per cent since 1997, (Friends of the Earth, 2006).

The building industry is a major contributor to this pollution. Approximately, 10 per cent of total energy consumption arises from the manufacture and transportation of building materials (Anderson and Shiers, 2002). Cement production alone accounts for almost 2 per cent of total UK emissions (British Cement Association, 2006). Furthermore, materials production and construction accounts for an estimated 122 million tonnes of waste or 30 per cent of the total waste arising in the United Kingdom (BMP, BRE, BiE, 1998).

In contrast, earth construction is both low in embodied energy and is recyclable. It can be produced locally with limited technology, thus reducing the environmental impact of transport. It is an ideal material for low-rise buildings and can also be used in multi-storey buildings as, for example, in the EU-sponsored Salvatierra project in France, illustrated in Figure 4, where earth blocks were used on the south-facing facade of a six-storey apartment building to capture solar heat.

In a recent project in Scotland, un-fired bricks produced by the Errol Brick Company Ltd., in Perth, were used as an internal lining in a 'low-cost' house. The authors report that the embodied energy used to produce the bricks was comparable to about 14 per cent

Figure 4: Salvatierra apartment block in Rennes, France.

of the energy used to produce fired bricks, despite the un-fired bricks being artificially dried for 2 days (Morton *et al*, 2005).

The particular advantages of earth blocks over other forms of earth construction lie in their pre-fabrication. This means that the production process is less weather-dependent; the blocks are fully shrunk so that dimensional changes in the completed walls are less severe, and blocks can be pre-tested for strength and durability before their inclusion in the building. This gives greater certainty in design, allowing engineers to predict the compressive and flexural strengths of masonry with greater accuracy than with cob or rammed earth.

Heavyweight construction materials will have an increasing role to play as our climate warms. Research by Arup Research+Development (2006) estimates that timber-framed houses will need air conditioning by the year 2021, if they are to remain comfortable during the summer months. By contrast, homes constructed using heavy masonry construction could remain comfortable without air conditioning until 2061. However, if masonry materials are to continue to be used, the environmental impact of their manufacture and use will need to be reduced.

Methods of reducing costs

The costs involved in earth walling will be addressed under three headings (a) material; (b) production; and (c) construction.

(a) *Material costs*: The clayey sub-soil material for earth blocks is generally acquired for little or no cost. Earth can be excavated on-site from deep foundations, from basements, or as in a recent case in Norfolk from an excavation for a sewage treatment plant. It can also be obtained from existing earth buildings, which are being demolished, where the old earth blocks are recycled into new blocks. Where greater quantities are required, the over-burden from quarry workings is often available at minimal cost. Therefore, the cost of the raw material is not generating the high cost of the finished block product.

(b) *Production costs*: Earth block production is almost invariably small-scale and local. From an environmental viewpoint this is the best option, minimising the need for transport. The disadvantage is that small-scale production will almost invariably mean high unit costs. In the southwest of England, two small producers of earth

Figure 5: Laying compressed earth blocks with slurry mortar in Southern Colorado.

blocks charge approximately £32 per m^2. In Cambridgeshire, a small producer of hand-made earth blocks charges £64 per m^2. In Scotland, the Errol Brick Company can produce extruded earth bricks for around £18 per m^2. These bricks are produced on a much larger scale than the previous examples, and come close to the cost of conventional masonry. As a comparison, dense concrete blocks can be obtained for £15 per m^2. With greater demand, the unit cost of production will reduce. The examples given above are based on wall thicknesses of approximately 225 mm and exclude transport costs.

(c) *Construction costs*: In the United Kingdom, the majority of masonry units, including earth blocks, are laid using thick joint mortars. Thick joint mortars require skilled operatives and result in high site labour costs. In an attempt to reduce these costs, at least two manufacturers of aerated blocks have produced proprietary thin joint mortar systems. Both companies claim the use of thin joint mortar can double the rate of block-laying compared to thick joint mortars, see Howes (2001) and Langdon (2007). In the United States, earth slurry mortars, stabilised with small quantities of cement, are often used with compressed earth blocks to reduce labour costs and construction time, as illustrated in Figure 5.

Flexural strength of earth block walling

As far as the authors are aware, earth slurry mortars have not so far been used commercially in any large-scale operation in the United Kingdom. If earth slurry jointing can be proven to be structurally sound, large potential cost savings through reductions in labour costs and increased speed of construction may be possible.

However, there is a second important advantage beyond cost efficiencies available with earth slurry mortar, and this relates to its potential for achieving higher flexural strengths than are generally possible with thick joint mortars. Masonry walls, including earth block walls, will usually have adequate compressive strength to resist vertical loads. The thickness of the external walls will normally be determined by their lateral strength; that is, their ability to resist wind load. With cob construction, wall thicknesses of 600 mm or more are common and wind loading is unlikely to become a critical design factor. The mass of the structure and the section modulus of the wall will provide adequate lateral strength for single and two-storey buildings. However, walls of this thickness are expensive to construct. They will also be expensive in terms of the space they occupy, an important consideration as sites become smaller.

Conventional thick joint earth mortars, including those stabilised with cement, offer very little flexural strength (Walker, 1999). As an aside, it is important to underline that Walker made artificial earth mixtures for the blocks and mortars, in order to have complete control over the composition and quality of the earth-cement materials in his study. The present work and Williams *et al* (forthcoming) concerns natural earth samples with no cement stabilisation. When determining the ability of earth block walls to resist horizontal loads, it has been normal to disregard the flexural strength of the masonry. In a series of tests of flexural strength carried out by Walker (1999) on cement stabilised thick joint earth mortars he concluded that: *unless confirmed by in situ testing it is recommended that characteristic flexural bond strength be ignored in design*. For earth block masonry, this approach will typically result in wall thicknesses of between 400 and 500 mm. The critical masonry panels being those subject to the least vertical load, typically gable end walls. Owing to the stronger bond developed between an earth mortar and an earth block comprising the same material, as demonstrated by Williams *et al* (forthcoming), earth slurry mortars offer the possibility of increasing the flexural strength of the masonry. Williams *et al* showed that a flexural strength of sufficient magnitude and consistency can be established, and therefore it should be possible to reduce the overall thickness of earth block walls. For example, if the thickness of earth block walling could be reduced from 400 to 300 mm, a potential cost reduction of 25 per cent would be available both in terms of production and construction costs. Moreover, this would result in a more practical wall thickness. However, these cost reductions are dependent on the ability to adequately join earth blocks of lower than normally used thicknesses. Further discussion concerning the thickness of earth block walling is given in the next section on the thermal properties of these walls.

The thermal properties of earth block walls

Table 1 gives three examples of wall constructions for comparison, and to support a discussion of the thermal merits of various wall options.

Wall 1 is an example of a traditional block and brick construction taken from CIBSE (2006), and is the only masonry wall with a U-value less than 0.35 W/m^{2}K described.

Table 1: Physical properties of some walls

Wall	*Description*	*Thickness mm*	*U-Value W/m^{2}K*	*Admittance W/m^{2}K*	*Decrement lag time Hour*	*Decrement factor*
1	105 mm brick, 100 mm blown fibre insulation, 100 mm lightweight aggregate concrete block, 13 mm dense plaster	318	0.33	3.05	9.2	0.39
2	105 mm brick, 50 mm airspace, 19 mm plywood sheathing, 140 mm studding with 140 mm mineral wool between studs, 13 mm plasterboard	327	0.29	0.74	6.5	0.57
3	400 mm earth block wall, 50 mm ventilated cavity 19 mm plywood sheathing, 100 mm studding with 100 mm paper insulation, 13 mm plasterboard	582	0.26	0.94	18.2	0.03

This wall has a medium length lag time at about 9 hours and a relatively high decrement factor at 0.39. This wall allows a substantial fraction of the incident solar radiation to penetrate and traverse the wall.

Wall 2, again taken from CIBSE (2006), is a typical timber frame construction with an acceptable U-value at 0.29 W/m^2K, but has a relatively short time lag for absorbed solar energy to reach the interior of the wall and a higher decrement factor, suggesting a higher solar gain via this wall compared with wall 1. Recent remarks by fire professionals, Anon CFOA (2009), following the Peckham, London, building site fire on 26 November 2009, suggests that timber-framed buildings under construction have a higher potential fire hazard, or risk. This fire risk together with the anticipated climate change, where solar gain in timber-framed buildings found in the southeast of England, (Arup Research+Development, 2006), is likely to lead to cooling problems, making timber frame construction unattractive.

Wall 3 is constructed from 400 mm earth blocks, with 100 mm of paper insulation Goodhew and Griffiths (2005). This wall is sustainable, although relatively thick by modern standards. Comparing this wall thickness of 582 mm, it is nearly twice the thickness of wall 1. This would lead to an unprofitable use of land. For example, a dwelling with an interior floor area 6 m by 8 m would require 57.3 m^2 of land with wall 1, but 65.7 m^2 with an earth block wall like wall 3 above with thickness 582 mm. This represents a 15 per cent increase in land for the building owing to the increased wall thickness, and is about equal to the floor area of a small garage or large shed.

Wall 3 has an acceptable U-value at 0.26 W/m^2K, a long lag time of 18 hours and a small decrement factor at 0.03, suggesting a much smaller internal solar gain compared with the timber frame wall. Wall 3 would not have the fire risk when under construction, and would be able to cope with increased environmental temperatures associated with climate change.

CONCLUSIONS

The five aims specified earlier have been addressed. The reasons for the decline in the utilisation of earth blocks for constructing buildings have been reviewed, aim 1. The decline arises mainly because earth block construction cannot compete with conventional high-energy constructions using burnt clay, cement and lightweight blocks. A case for earth block construction has been established, aim 2. For example, heavyweight construction will play an increasing role as the climate warms, by allowing greater damping of diurnal temperature swings. The use of earth blocks for walling has the advantage of allowing pre-testing for strength before construction. The economics of earth block construction has been explored briefly to meet aim 3. The sustainable nature of earth block walling, using similar and appropriate earth mortars, has been suggested. The last two aims, aims 4 and 5, conclude that the structural and thermal aspects of earth block walling meet current UK Building Regulation requirements for wall strength and thermal performance.

This work assumes that simple real earth mixtures are used to manufacture earth blocks employed with earth slurries or mortars to form walling. If these materials were adopted, thereby avoiding the use of cement stabilisation, a more sustainable building method would be achieved.

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