“ELITH”
Saving embodied energy and thereby reducing emissions: the options for walling

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Embodied energy and embodied emissions in walling

Walling (including its foundations) accounts for about half the mass of a house and around 40% of its ‘embodied’ energy. Because walls are primarily subject to compressive forces rather than tensile ones, they can be made of materials with little tensile strength – such as stone masonry, brickwork and compressed soil.

As ‘soil’ walls are often easily eroded, energy is often used to make soil more durable – by firing it, ‘stabilising’ it with cement or by coating it with more durable materials.

Improving Walling

Walling is a very ancient technology and so there is little scope for real innovation in its design. In recent years in the Tropics, soil-based walling has generally displaced walling made from organic materials such as wood. This reflects the increase in the expected life of housing and the growing scarcity of the more durable forms of organic materials such as hardwood. Thus materials that are 'carbon neutral' over the life-cycle of a building have been replaced by materials whose preparation is energy-intensive and thus emissions-intensive.

Firing, 'Stabilising' & Pressing

Firing of clay into ceramic bricks (and sand into glass) requires high temperature heat from burning fuel, some of which is recoverable in a high-efficiency kiln and some is not.

Manufacturing cement (the most common soil **stabiliser**) similarly requires high temperature heat from burning fuels (40% of GHG emissions) and also directly emits CO_2 (60% of emissions).

Compression requires much less energy but that energy must be in 'work' form. Compression is usually a supplement to stabilisation, so that increasing pressure allows a reduction in stabiliser.

The purposes of walling (i)

Walling serves many purposes which we can divide into: structural , enveloping & aesthetic. in addition we want walling to last intact for many decades:

Structural - walls should

- hold themselves up against vertical and horizontal forces and vibrations
- hold the roof up (and down)
- support any upper floors
- resist penetration by local forces and impacts

The purposes of walling (ii)

Enveloping

Exterior house walling separates the indoor from the outdoor climate, allows a temperature difference to be maintained, provides thermal and acoustic insulation, keeps out rain and insects, permits privacy (and yet by use of openings permits authorised entry, ventilation and day-lighting).

Interior walling can be made to a lower specification than exterior walling.

Plot-boundary walling does not envelop but has to survive harsher environmental conditions

Routes to reducing embodied energy in walls (i)

Make houses smaller (under 8 sq m per person?)

Reduce the area of walling (per unit area of internal floor-space) by:

- Increasing room size
- Sharing walls between adjacent houses
- Providing *unwalled* areas for functions like cooking
- Replacing boundary walls by fencing
- Reducing room height

Saving energy and reducing emissions: the options for walling

Routes to reducing embodied energy in walls (ii)

Change materials from more energy intensive to less energy intensive ones – e.g. mortarless walling

Improve the energy efficiency of building materials production

Make walls thinner

- Use hollow units, cavities & foamed materials
- Compensate for excessive slenderness

Make composite (sandwich) walls, using superior materials only on outside surfaces.

Shelter walls from sun, rain and wind by vegetation

Energy recovery and extending life

Some walling materials can be ‘recovered’ at the end of a building’s life, although this is usually for a lower value application. It is complicated to incorporate this bonus (far in the future) into the energy analysis of new construction.

Extending the life of walling will generally also extend the whole building’s useful life and thereby reduce the need for new construction. However both the associated good maintenance and the periodic adaptation of an old house to new living requirements require some energy.

Changing walling materials (i)

We choose walling materials that are 'fit for purpose', mainly in terms of strength, durability and appearance. The performance requirement of walls depends on their function (e.g. boundary, external, internal).

The properties of soil-based materials are determined by

- choice of soil,
- quantity and type of added stabiliser,
- heat treatment and
- mechanical compaction.

Changing walling materials (ii)

Heat treatment (e.g. brick burning) and stabiliser addition (e.g. cement) are energy intensive, compaction is much less so. Increasing compaction is therefore one route to reducing the energy intensity of walling materials.

In the case of cement-stabilised soil, increasing block-formation pressure from 1 MPa to 10 MPa allows stabiliser content to be reduced by 25%. However such high pressures cannot be achieved with cheap (manual) presses.

Saving energy and reducing emissions: the options for walling

Mortarless construction (i)

For many good reasons, bricks and blocks are traditionally assembled using 'mortar' such as a 5:1 sand:cement mix. This is an energy-intensive material whose removal (implying replacement by more blocks) would save both energy and time.

For example in Uganda mortarless blockwork has a cost and energy density about 15% less than current mortared blockwork.

There has for 15 years therefore been a slow movement towards use of mortarless masonry of stabilised soil, usually in combination with block 'interlocking'. Wall straightness and stiffness depend mainly on the accuracy of the individual blocks – e.g. all critical dimensions are within a tolerance of 1 mm. Suitable presses for producing blocks of sufficient precision are available in both Africa and Asia, but in the field a lack of machine maintenance and operator care often results in lower accuracy.

Mortarless walling using fired brick is rarely attempted.

Mortarless construction (ii)

The ELITH partners in Tanzania (NHBRA) and at Warwick have been researching mortarless construction (using ISSBs = interlocking cement-stabilised-soil blocks) for some years – investigating:

- wall straightness & ways to improve it
- wall lateral stiffness (which can be very low) and ways to improve it
- design of the individual blocks for accuracy and wall design flexibility
- speed of assembly
- design of presses and reduction in capital costs

Many ISSB buildings have been constructed by NHBRA

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2 bedroom rural house in Tanzania – built of interlocking mortarless stabilised-soil blocks

Pressed soil blocks

The lowest-energy 'soil' is that containing no stabiliser, is also unfired and preferably was obtained by excavation 'on site' – namely local mud. This widely used rural material, even with the 'modern' addition of compression, has low durability and therefore may need to be 'surfaced' with a more durable material to meet 21st century performance expectations. Despite its lack of flood-resistance, in both developed and under-developed countries this material is slowly returning to favour.

However techniques are required to replace the traditional solutions of

- employing great thickness – e.g. 30cm or more for ground-floor external walls
- applying annual repair.

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Earth construction – 165 year old Norwegian Royal Palace

Modern earth construction In Thailand

Stabilised soil

Soil can be stabilised by addition of cement, lime, fibres and other substances in combination with compaction. The benefits of high compaction point towards use of a masonry approach (assembled pre-formed blocks) rather than adobe or rammed-earth construction.

It takes 6% to 9% addition of opc to get satisfactory crushing strength (e.g. 1 MPa) and surface resistance. This is in combination with architectural measures such as damp-course, roof overhang and reinforcement of corners.

Sometimes it is worth importing 'other' soil from elsewhere to mix with local soil to achieve a mix with the required 10% - 40% fraction of fines.

Energy conservation requires we push the cement content down towards the minimum of about 6%.

Sandwich wall designs

It has long been normal practice to apply internal or external 'finishes' to walls – to give cleaner and smoother indoor surfaces or more weather-resistant external ones. These finishes are generally more energy intensive than is the bulk walling material and so should be applied 'thinly'. However these finishes, even if thin, are generally strong and may possess **tensile** strength lacking in the bulk material. A good attachment of a surface finish to the latter may greatly enhance the overall wall stiffness and resistance to overturning or buckling. This points towards

- taking advantage of the strength of the 'finish' in wall design
- looking for ways to manufacture units that already incorporate the finishes (without however further increasing the capital-intensity of the housing process).

Reducing wall thickness

'Slenderness ratio' *S* (= wall height / thickness) is a common design parameter for wall design. Standards may specify that *S* should not exceed particular limits (e.g. 15 for external brick walling, 10 for adobe) and thereby effectively require wall thickness be 'not too small'. We can therefore save materials and hence energy if we can enhance 'effective thickness' without increasing average material thickness. Ways of doing this include

- buttressing
- having closer-spaced 'returns' (e.g. cross walls)
- using a crenelated (stepped) wall plan
- using curved walls

ELITH has been researching these last two options.

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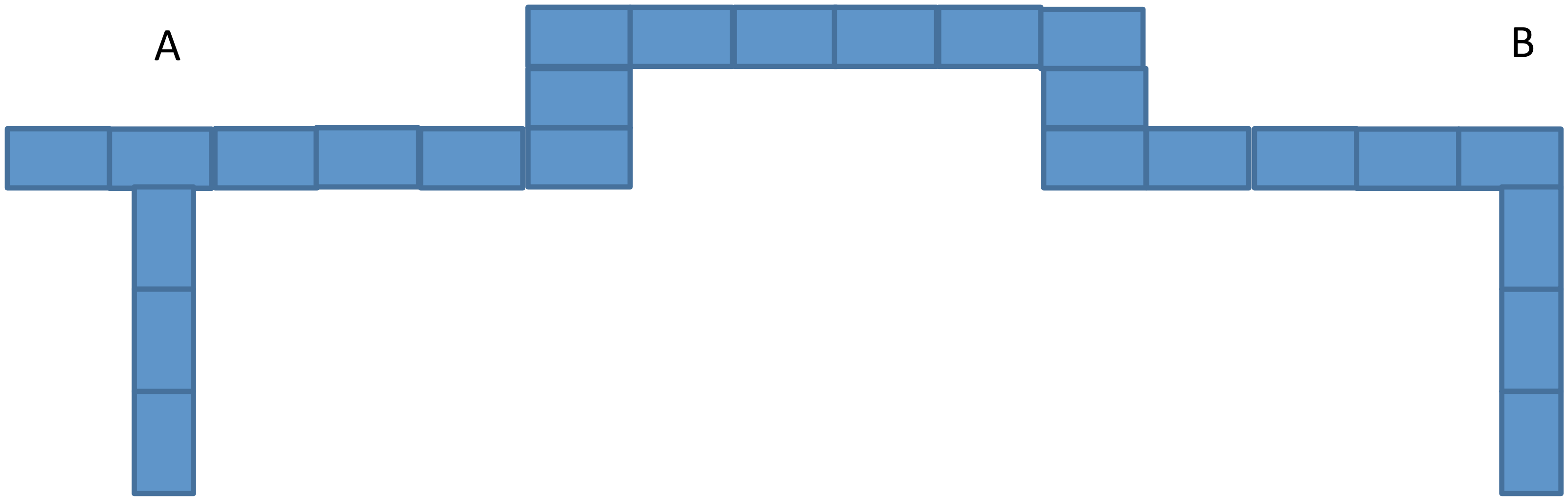
Example: a crenelated wall (A – B) that employs 30% more bricks than a straight wall but if well-bonded is about 5 times more laterally stiff and resistant to buckling.



Of course straight walls are more convenient for arranging furniture etc but there is always architectural interest in alternatives to purely rectangular floor plans.

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90m ‘wavy wall’ under construction in a seismic area of Uganda. Wall thickness = 100mm So slenderness ratio *S* exceeds 20. Brick count is only 70% that of a standard 200mm wall

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Ancient 'crinkle crankle' boundary wall in UK

Hollowness

The central zone of a wall contributes little to wall strength or stiffness and might therefore be removed (i.e. replaced by a void). This would save material and hence energy. However sufficient material connecting the front and back wall faces must be retained to ensure the wall behaves as a single unit. (Traditional European 'cavity walls', designed to limit moisture penetration, did not satisfy this condition and have now largely gone out of fashion.)

Hollowness generally improves heat insulation, reduces the mass of upper floor walling – desirable in seismic areas, and simplifies the threading of electrical services.

Various sorts of hollow block or brick are manufactured in different countries but 'best practice' seems not to travel readily from one country to another.

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Raising the energy efficiency of brick-making

There are long-established designs for brick kilns that feature heat recovery (from the cooling, just-fired bricks). These designs, fired by powdered coal, sawdust or crop wastes, are however generally large-scale and capital intensive. In consequence they are little used in Africa where bricks are mostly made in 'clamps' of around 10,000 per firing. These 'country bricks' may even be made on site. They are cheap but require large supplies of firewood to form and rather large amounts of cement mortar to lay.

The long-term future of the 'country brick' is insecure, but for a decade or two to come there is extensive scope for emissions saving by increasing brick quality/reducing wastage, partially substituting crop wastes for wood and minor improvements to kilns.

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New requirements on tropical walling (i)

So far this presentation has focussed on means of reducing the carbon footprint of tropical walling – in the context of a steady change from short-life 'informal' materials to longer-life 'formal ones'. No attention has so far been given to the impact of wall design on the lifetime **operational** carbon footprint of housing, itself often dominated by mechanical cooling..

In arid zones walls have traditionally been made high mass to aid thermal comfort. In more humid zones enhancing ventilation, reducing solar gain (especially that via glazing) and increasing thermal insulation are more relevant to improving comfort and thereby reducing energy use for indoor cooling. As resistance to unwanted heat transfer is roughly proportional to wall thickness, the thinner walling advocated earlier is not helpful.

Organic Materials for Walling (i)

Most vernacular walling made major use of organic materials such as poles and matting. In other continents but less in Africa, sawn timber was and is used for flooring, roofing and columns in walling. Organic products such as plywood and fibreboards are used for internal walls as well as for ceilings.

There is a revival of interest in use of softwood in construction and a growing range of materials containing other organics (for example hemp-clay panels in Germany) have appeared on the market. Greater use of crop-wastes and of farm-grown fibres in construction could benefit householders (lower costs), farmers (extra income) and the world (less GHG emissions).

Organic Materials for Walling (ii)

Combinations of sand cement and mineral fibres (glass, rockwool but no longer asbestos) are well established. We may expect a similar expansion in the use of soil-based materials 'improved' by the inclusion of *organic* fibres.

The key to the long survival of organic materials in buildings is to keep them dry by appropriate architectural detailing. The use of poisonous preservatives is declining in popularity as understanding of 'sick buildings', and general safety standards, improves.

New requirements on tropical walling (ii)

So proper architectural use of shading, vegetation and thin layers of highly insulating materials need to accompany measures to minimise the **embodied** energy in walling.

Urbanisation continues in the tropics, with urban housing needs outpacing rural ones. The inevitable high urban land prices point towards the replacement of almost all single-storey housing by multi-storey – a process well advanced in Asia but not yet in Africa. This transition does not have much impact on the required *area* of walling per unit of floor-space, but does impinge upon walling quality (e.g. strength).

Finally we may safely assume that the slow process of transferring building from site-work to in-factory manufacturing will continue and affect walling.

Summary

Cement manufacture and brick-burning using fossil fuels (or un-replaced biomass) are significant contributors to GHG emissions which can be reduced by better process technology, better wall design and more skilled assembly.

Two rival improvement strategies are on offer:

- Use of less material (e.g. thinner walls) but in more complex configurations
- Use of very-low-energy 'weak' materials, often in high thickness (e.g. surface-protected unstabilised soil).

On behalf of the ELITH Programme, thank you for your attention

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