COMMUNITY INFRASTRUCTURE PROGRAMME

REVIEW OF SUSTAINABLE MATERIALS & DESIGN

LESSONS TO DATE AND RECOMMENDATIONS

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1 INTRODUCTION

Build It International (Build It) has three core principles directing its approach to all its projects: i) sustainable technology and materials; ii) community participation; and iii) vocational training. This report summarises a review that has been conducted of the first core principle (sustainable technology and materials), consisting of the following main components:

a) **Internal review of current approach:** a questionnaire survey of five groups of people (including infrastructure professionals such as architects and surveyors), to determine their attitudes to the use of different building materials and techniques.

b) **External review of infrastructure sector:** a broad sweep through developments in the infrastructure sector worldwide, of relevance to Build It’s work in Zambia, to see how Build It fits into the global movement for sustainability and appropriate technology, and to identify options for future work in Zambia.

c) **Material Choice Guidance:** conclusions and recommendations generated at an internal workshop with further input from advisors. This is primarily to guide material and technology specification for future Build It projects.

Financial considerations were not explored in great detail, but not because they don’t matter. This is because, in selecting technologies for consideration, only those considered ‘affordable’ were chosen. It is important to acknowledge that whilst this work was undertaken primarily for Build It, the discussion and recommendations should be of use to others undertaking community infrastructure projects in Africa, especially south of the Sahara. Indeed, Build It hopes that its experience will be of use to others, especially those whose core business is not construction, but who need low-cost, sustainable buildings for their work. This is further discussed in Section 5.5

2 SUSTAINABILITY IN THE CONSTRUCTION SECTOR

2.1 Lessons on sustainability

A wide-ranging study of published literature and recent developments in the infrastructure sector worldwide was conducted, examining the issues and challenges affecting the development of building technologies and the factors driving the increasing trend for environmental and building assessment ratings (as applied to different building techniques). The findings can be summarised in the form of ten key lessons about sustainability:

**Understanding of sustainability in the construction industry:** To be sustainable, a building programme has to have a holistic approach. Principles from ISO14000 (the international standard for environmental management) and environmental assessment tools (such as the Building Research Establishment Environmental Assessment Method, BREEAM) are usually applied. For developing countries, full application of these tools is an expensive luxury, but Build It should be fully aware of the overall principles and should apply them wherever possible.

**Reducing dependence on carbon:** Stating the obvious, building techniques that approach a carbon-neutral state, and have a good life-cycle assessment rating, use natural materials such as stone, earth and wood, and sometimes other organic products such as straw, bamboo and coconut husks.

**Earth solutions:** For construction of walls, earth-based technologies offer the best solutions for long-term sustainable construction programmes. Rammed-earth and stabilised-soil block (SSB) techniques appear to be the most appropriate, with the added advantage of providing culturally-acceptable solutions in sub-Saharan Africa.

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**Mechanised production:** Mechanised SSB technologies (such as Hydraform) are realistic alternatives to manually-produced blocks on large-scale projects, and can produce a higher-quality manufactured product. However, the technology requires high initial capital input, skilled machines operators, and fuel. Affording the fuel is often an issue for poor communities, raising questions about the sustainability of mechanised block production.

**Acceptance of innovative methods:** Innovative building techniques such as tubular/sausage sand-bag walls with domed roofs (originating from the Nubian Vault system) seem to be too big a leap culturally to be widely adopted in Zambia. Nevertheless, they could have an impact in Zambia under the right conditions; namely, strong community education and awareness-raising (see www.small-earth.com).

**Modern innovation:** Many other technical solutions are available worldwide, promoted by enthusiastic organisations, such as cardboard panels and tubular steel logs. Even though their environmental life-cycle analysis (LCA) ratings are high, it is unlikely that many of these techniques will be culturally acceptable or able to be scaled up.

**High carbon:** Steel-framed buildings are strong and can be erected quickly. However, using large quantities of metal when building on a site remote from the source of the material is not regarded as sustainable (steel in Zambia usually comes from South Africa). In general, the chosen building techniques should limit as much as possible the use of high-carbon materials or activities (cement, steel and long-distance transport).

**SSB options:** Load-bearing walls without the use of intermediate columns (with high cement content) are recommended. This implies a change from dry-jointed interlocking-SSB wall construction. Plain rectangular SSBs offer much more flexibility in creating different layouts. As a modular system, they demand rigorous dimensional discipline, but quarter and half-blocks are easier to use. Where columns are required, they can be built as reinforced piers. Although this approach uses mortar, a 10-mm mortar joint can be lime-based or use only a small percentage of cement, in contrast to standard joints on a concrete-block building.

**Roofing challenge:** Finding sustainable roofing materials is a challenge. The use of corrugated-iron sheeting is almost universal, yet the performance is appalling – thermally, acoustically and aesthetically. Clay or micro-concrete tiles offer a much better alternative, as long as there is good quality control, a maintenance programme and a long-term market support plan. The ultimate zero-carbon technique is vaulted earth.

**Business plans:** Most innovative techniques have only been used in one-off building projects, with no significant scaling up or adoption by the community at large. This is the main challenge to creating affordable and sustainable ‘green’ buildings, and requires a sophisticated business and marketing approach, the resources for which most small organisations appear to lack. An exception is Hydraform, which even advertises on CNN.

A note should be made here that environmental sustainability is not just a function of energy used in construction. The concept of life-time energy cost is increasingly used (though not yet by Build It), and this reinforces the need for naturally-insulated and ventilated structures.

### 2.2 Build It International and sustainability tools

The sustainability of construction technology and materials is increasingly on the international agenda, as demonstrated by the influence of LCA and rating systems like BREEAM. Very few non-governmental organisations (NGOs) have dedicated infrastructure teams, or concentrate on construction, or prioritise sustainable materials. In that sense, Build It is ahead of the pack, and its three pillars of sustainability, community involvement and training form a very firm foundation for
the future. When selecting a technology or material, it is important to take into account environmental costs as well as financial cost, and Build It takes this subject seriously.

Environmental assessment tools such as BREEAM (in the UK) and LEED (Leadership in Energy and Environmental Design, its equivalent in the USA), when fully applied, provide detailed rating or grading systems covering a number of different environmental criteria. Unfortunately (for the purposes of Build It and similar organisations), these systems were designed for conditions in developed economies, and they are expensive and complex to implement and administer in sub-Saharan Africa. Nevertheless, it is vital that the environmental principles behind these tools are understood and applied where possible (which is the case for bioclimatic design, discussed in the next section).

In an effort to find a practicable alternative to formal systems such as BREEAM and LEED, Build It commissioned a study of the carbon footprints of different building techniques. The study was undertaken by Phil Newcombe as an MSc thesis, and the result is a convenient spreadsheet tool that can be used to estimate the embedded energy costs of their current approach. Build It will continue to develop this spreadsheet tool.

The choice of materials will be heavily influenced by what is available locally, following the principle of minimising transport costs. The second key factor is to minimise the use of high-energy materials, such as metal and cement. Newcombe’s spreadsheet then allows quantities to be entered, to generate a CO\textsubscript{2} cost in kg/m\textsuperscript{2} of building.

Build It also has strong links with Shelter Centre, an NGO based in Switzerland that provides technical support to humanitarian operations that are responding to the transitional settlement and reconstruction needs of populations affected by conflicts and natural disasters. This has enabled current trends in environmental assessment, which are being debated in the humanitarian and development sectors, to be taken into account in the preparation of this report. Shelter Centre, with the Norwegian Refugee Council, is developing an interactive reference tool, which is a comprehensive body of knowledge and information on sustainable construction, available as a resource for managers and decision-makers (see http://nrcschumenv.wordpress.com).

In addition, this report draws on the work of Corinna Salzer, who has developed a comprehensive matrix of different building materials (reproduced in Appendix 1). The matrix allocates relative scores to each technology against a wide variety of criteria, such as cost per m\textsuperscript{2}, skills requirements, durability and recycling potential, culminating in a ‘Best practice potential’ score. For the cost per m\textsuperscript{2} criterion (Column D in the table in Appendix 1), in principle, the closer the materials are to natural, sustainable sources, the lower the score.

2.3 Bioclimatic design

There is great potential for improving how a building in sub-Saharan Africa performs when in use, by following the principles of bioclimatic design. This is a method of design and construction that places particular emphasis on the impact of local climate and environmental conditions. Bioclimatic design aims to use natural sources (sun, air, wind, vegetation, water, soil, etc) for heating, cooling and lighting buildings. The general principles of bioclimatic design include the following:

- Heat protection of the buildings in winter as well as in summer, using appropriate techniques that are applied to the external envelope of the building (especially by adequate insulation and air-tightness of the building and its openings).
• Use of solar energy for heating buildings in the winter season and for daytime lighting all year round. This is achieved by the appropriate orientation of the buildings and carefully sizing openings to suit the climatic zone, by the layout of interior spaces according to their heating requirements, and by passive solar systems that collect solar radiation and act as ‘natural’ heating and lighting systems.

• Protection of the buildings from the summer sun, primarily by shading, but also by the appropriate treatment of the building envelope (that is, use of reflective colours and surfaces).

• Removal of the heat that accumulates in the building in summer to the surrounding environment using natural ventilation (passive cooling systems), mostly during the night.

• Adjustment of environmental conditions in the interiors of buildings so that their inhabitants find them comfortable and pleasant (that is, increasing air movement inside spaces, heat storage, or cool storage in walls).

• Making the best use of insolation (combined with solar control) for daytime lighting of buildings, in order to provide sufficient and evenly-distributed light in interior spaces.

• Improvement of the microclimate around buildings, through the bioclimatic design of exterior spaces and in general, of the built environment, adhering to all of the above principles.

Building projects can also cause local environmental degradation. Build It’s policy is to ensure that this is minimised. For example, excavation pits are made safe and used for another purpose if possible. On clearing a new site, as much natural shade as possible is left intact, and sanitation facilities are designed so that they do not cause contamination.
3 REVIEW OF CURRENT APPROACH

3.1 Existing method of construction

The current, standard Build It method of construction can be illustrated as follows:

- **Roof**: Micro-concrete tiles
- **Ring-beam**: reinforced concrete
- **Windows**: steel framed with glass
- **Design**: distinctive (in this case hexagonal)
- **Walls**: interlocking SSBs
- **Columns**: reinforced columns
- **Concrete plinth & spoon drains**
- **Deep foundations & reinforced floor-slab**

Build It already incorporates many of the principles of bioclimatic design into its projects, in particular: aligning the long axis of the building east-west; creating shade by incorporating a 900-mm roof overhang (which is much larger than normal, see photo above); constructing thick walls from earth-based materials (with high thermal mass); preserving existing trees on the site and planting new trees. Other bioclimatic design features (such as split window shutters, which can be opened in different configurations) could be adopted by Build It relatively easily.

3.2 Internal questionnaire survey

A questionnaire survey was conducted, of five groups of people: a) Users, such as teachers, parents and school children; b) Professionals, such as architects and surveyors; c) Contractors who are familiar with Build It methods; d) Former trainees who have been through the Build It training programme; and e) Clients and donors. The main aims of the survey were to gather feedback on the materials, designs and techniques currently being used by Build It, and to determine the respondents’ general attitudes to the use of different building materials and techniques. The results of the survey were reported in the form of a set of PowerPoint slides, copies of which can be found in Appendix 2. The broad conclusions of the survey can be summarised as follows:

- **Sustainability**: There was a strong consensus that sustainability is important and that Build It should continue to give it priority, alongside community involvement and training.
- **Design**: Build It has developed some innovative and distinctive designs, such as hexagonal classrooms and the ‘cool house’, which are popular with users. Build It should continue to develop creative, replicable designs.
• **Materials:** The promotion of SSBs for walls should be strengthened, although the use of interlocking SSBs needs to be reviewed. Micro-concrete tiles should only be used when the quality of manufacture and installation can be guaranteed.

• **Structural specifications:** The current designs for foundations, floor-slabs, reinforced columns and ring-beams are over-specified structurally. There is considerable scope for simplification and reducing costs (assuming approval of revised specifications by a structural engineer).

• **Advocacy:** Effort needs to be devoted to increasing awareness of sustainable materials and techniques, gaining approval from building inspectors, and achieving inclusion in training syllabuses and examinations.

4 EXTERNAL REVIEW

A review was undertaken of low-cost building materials considered suitable to southern and eastern Africa. Although this is a large region, the prevailing building methods and artisanal skills are similar, as is the level of economic and social development. Obviously, local climatic and soil conditions vary enormously, but the discussion below is relevant for the majority of the region (see also Section 6.2).

4.1 Potential technologies for walls

Apart from traditional wattle-and-daub, the standard technique for constructing walls in sub-Saharan Africa has become concrete blocks (either solid or hollow). It is generally accepted that this is unsustainable, largely due to the high cement content, hence the search for alternatives. Around the world, many other techniques for constructing walls are in use, or have been tried. Some have achieved widespread acceptance, while others are confined to experimental or one-off projects. A broad search was conducted, from literature, the internet, experience and personal contacts. Seven techniques were chosen for further consideration, based on their potential for uptake in sub-Saharan Africa: a) rammed earth; b) confined masonry; c) SSBs; d) natural stone; e) interlocking SSBs; f) adobe; and g) wattle and daub. These techniques are relatively widespread, and considerable experience in their use has accumulated (SSBs and interlocking SSBs are, of course, already being used by Build It). The seven techniques can be summarised as follows:

**Rammed earth**

In this technique, rigid formwork is assembled, and earth layers compacted within, either manually or pneumatically. The formwork is moved upwards as the layers accumulate. The method is slow and inflexible, but community participation is high and cement use very low. Construction must take place during dry weather, but with plenty of water available.

**Confined masonry**

This method is mainly intended for areas prone to earthquakes. Sections of wall are built first, leaving zigzag wall endings and incorporating anchor hooks. Steel-reinforced concrete columns and beams are then poured, tying the wall sections together, to ensure that the wall section does not fall sideways during an earthquake. The wall can use a variety of materials.
SSBs

The familiar soil blocks, moulded in hand-powered or mechanised block-forming machines, in plain rectangular shapes (without frogs, lugs or grooves). Courses are laid using mortar, as in conventional bricklaying. There is complete flexibility in layout for different buildings. If necessary, courses can be strengthened by drilling blocks and reinforcing.

Natural stone

If suitable natural stone is locally available, then rough stones or dressed stone blocks can be used to build attractive, thick, load-bearing walls. Community labour can be used to collect the stones, which can be laid with mortar or a dry-walling technique, and degree of sustainability is similar to using earth. High skill levels are required to achieve a good finish.

Interlocking SSBs

This is the default technique currently used by Build It. SSBs are moulded with tongue-and-groove shapes, so that adjacent blocks and courses interlock. Courses are laid dry, although mortar and reinforcement can be used at intervals for added strength. There is reduced flexibility for layout design.

Adobe

An ancient, traditional method of construction, generally using soil blocks moulded by hand, sometimes reinforced using a binder such as straw, and sun-dried. Blocks are laid using mud-mortar, and the wall finished with a mud render. Annual maintenance is usually required, by plastering a new layer of mud, especially in areas of higher rainfall.

Wattle and daub

Like adobe, an ancient, traditional method of wall construction, in which a woven lattice of wooden strips (wattle) is daubed by hand with a sticky material, usually made of some combination of wet soil, clay, sand, animal dung and straw. A load-bearing wooden frame is usually constructed first, with wattle-and-daub wall panels constructed between the wooden posts.

Further information on the first five of these techniques can be found in Appendix 3. Other techniques that were briefly considered during the external review include the following:

- Straw bales
- Laminated or woven bamboo
- Lightweight tubular steel ‘logs’
- Sausage-bag domes (see photo right)
- Recycled paper or cardboard
- Plastic bottles or tin cans
- Other waste material such as car tyres or oil drums

None of these techniques was considered to be sufficiently practicable, or likely to be culturally acceptable in sub-Saharan Africa, to merit adoption and promotion by Build It.
4.2 Potential technologies for roofing

During the external review, four main roofing materials were considered, all of which are successfully used in Africa, to varying degrees:

Micro-concrete (Parry) tiles are very well known to Build It, and were the subject of polarised opinions in the internal questionnaire survey. They have a poor reputation in some places, due to quality problems in the past, and significant effort is required to restore their reputation. They have many benefits if manufactured and installed properly.

Corrugated iron sheeting

The ubiquitous roofing material in many parts of sub-Saharan Africa, and seen as the aspirational step up from thatch. Sold in small quantities from many retail outlets, even in remote locations, and able to be removed and re-used when someone builds a new house. However, thin-gauge sheets (the most easily available and affordable) are not very good quality.

Improved iron sheeting

Available in a variety of colours and even textured to look like tiles (as in this photo). Also available in long sheet lengths, to minimise joints on the roof pitch. This is a much better quality product (heavier gauge) than standard corrugated iron, and provides a good alternative if micro-concrete tiles are not thought to be appropriate.

Thatch

Thatch is the traditional African roofing material and the ultimate in sustainability. Mostly used on small rural houses, thatch has found a niche market in up-market safari lodges, which should improve its image. However, achieving a durable, waterproof finish is a highly-skilled job. Thatch is unlikely to gain approval from building inspectors for public buildings.

5 DISCUSSION

A workshop was held in Shrewsbury on 20 January 2012. The aims of the workshop were to discuss the draft conclusions from the internal survey and external review, and to draw up provisional recommendations to guide future Build It projects, with respect to achieving Build It’s sustainable building objectives in Zambia and elsewhere. Notes on the workshop discussions now follow.

5.1 Construction methods for walls

The seven main techniques for constructing walls (see Section 4.1) were discussed, and narrowed down to four: rammed earth, plain SSBs, interlocking SSBs and adobe. The common feature of these techniques is that they all use earth as the principal raw material, while minimising the use of cement. The pros and cons of these four techniques were agreed to be as follows:
The final column of the above table allocates a ranking to each technique, with 1 being the most desirable. In other words, it was agreed that load-bearing walls built from SSBs, without columns, should be the default method for Build It projects. The other methods in the table above (or natural stone, which shares the sustainability benefits of earth), can be considered in turn, where they are appropriate for local conditions.

### 5.2 Construction materials for roofing

Similarly, the four roofing techniques described under Section 4.2 were discussed and ranked. Here are the pros and cons:

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammed earth</td>
<td>• Community involvement&lt;br&gt;• Cheap&lt;br&gt;• No cement required&lt;br&gt;• Very good thermal properties&lt;br&gt;• Some design advantages</td>
<td>• Formwork needed&lt;br&gt;• Quality control important&lt;br&gt;• Some design limitations&lt;br&gt;• Maintenance requirements may be greater than other materials</td>
<td>3</td>
</tr>
<tr>
<td>SSBs</td>
<td>• Widely acceptable&lt;br&gt;• Very flexible (building designs)&lt;br&gt;• Teaches bricklaying skills&lt;br&gt;• Long life (25-30 years)&lt;br&gt;• Can drill to reinforce if necessary</td>
<td>• Quality control still an issue&lt;br&gt;• Needs a block press (cost)&lt;br&gt;• Mortar required between courses&lt;br&gt;• Uses some cement in blocks</td>
<td>1</td>
</tr>
<tr>
<td>Interlocking SSBs</td>
<td>• Attractive when done properly&lt;br&gt;• Quick (when laying courses)&lt;br&gt;• Lower skill-level required&lt;br&gt;• Well known and understood</td>
<td>• Quality control still an issue&lt;br&gt;• Needs a block press (cost)&lt;br&gt;• No bricklaying skills gained&lt;br&gt;• Hard to maintain straight courses&lt;br&gt;• Uses some cement in blocks</td>
<td>2</td>
</tr>
<tr>
<td>Adobe</td>
<td>• Community involvement&lt;br&gt;• Cheap&lt;br&gt;• No cement required&lt;br&gt;• Can improve/transfer skills</td>
<td>• Weaker blocks than SSB or ISSB&lt;br&gt;• Questionable life-span&lt;br&gt;• Slow&lt;br&gt;• Frequent maintenance required</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-concrete tiles</td>
<td>• Attractive when installed properly&lt;br&gt;• Good thermal/sound properties&lt;br&gt;• Lower carbon footprint than iron&lt;br&gt;• Community involvement</td>
<td>• Serious quality-control issues&lt;br&gt;• Need a machine to manufacture&lt;br&gt;• Proper installation slow &amp; difficult&lt;br&gt;• Heavy roof structure required&lt;br&gt;• Prone to breakage &amp; leakage</td>
<td>1</td>
</tr>
<tr>
<td>Iron sheet (standard)</td>
<td>• Widely available and trusted&lt;br&gt;• Cheap&lt;br&gt;• Light roof structure&lt;br&gt;• Quick to install&lt;br&gt;• Good for rainwater harvesting</td>
<td>• High carbon footprint&lt;br&gt;• Poor thermal/sound properties&lt;br&gt;• Often poor quality (too thin)&lt;br&gt;• Ugly when old/rusty</td>
<td>4</td>
</tr>
<tr>
<td>Iron sheet (improved)</td>
<td>• Attractive (can mimic tile effect)&lt;br&gt;• No quality issues&lt;br&gt;• Light roof structure&lt;br&gt;• Quick to install&lt;br&gt;• Good for rainwater harvesting</td>
<td>• High carbon footprint&lt;br&gt;• Poor thermal/sound properties&lt;br&gt;• Expensive</td>
<td>2U</td>
</tr>
<tr>
<td>Thatch</td>
<td>• Community involvement&lt;br&gt;• Very low carbon footprint&lt;br&gt;• Good thermal/sound properties&lt;br&gt;• Attractive when done properly</td>
<td>• High skill-level for good thatching&lt;br&gt;• Difficult for large buildings&lt;br&gt;• Often perceived as ‘backward’&lt;br&gt;• Fire risk&lt;br&gt;• Cannot harvest rainwater</td>
<td>2R</td>
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</table>
The rankings in the final column of the above table can be explained as follows:

- Micro-concrete tiles are still the preferred roofing material, despite the problems there have been. However, it is imperative that there is strict quality control during manufacture and installation, so they should only be used on Build It projects where quality can be guaranteed. This will probably involve manufacturing the tiles in dedicated production units.
- If micro-concrete tiles are not thought to be suitable for a particular project, then improved iron sheeting is likely to be the best solution for large buildings or buildings in urban areas.
- In rural areas, thatching should be seriously considered, especially for small buildings such as staff houses. Skilled thatchers should be used (such as those from Western Province, Zambia), to achieve an attractive, durable and waterproof finish.
- If none of these materials is suitable (or cost is a constraint), then standard corrugated iron can be considered.

5.3 Structural components

As already described, the current standard Build It building design uses deep, cast-concrete foundations and reinforced floor-slab, reinforced columns, and a cast, reinforced ring-beam. It is now accepted that this design is significantly over-specified from a structural point of view, and there could be major cost savings from reducing the specifications, especially in favourable ground conditions. Not only would there be cost savings, but the sustainability of the design would be dramatically improved, due to far less cement and steel being required. Coincidentally, a major design study was recently undertaken by McAslan & Partners, in association with Arup, which has addressed these concerns. Build It can benefit from the results of the study.

5.3.1 Foundations and floor slab

The McAslan/Arup study identified over-engineered foundations and high cement content in floor slabs as two of the key issues in a typical existing school design, mirroring Build It’s concerns. In fact, McAslan/Arup estimated that the foundations and floor slab of a typical existing school design together consume 45% of the total budget, as shown here:
It is proposed that Build It adopts or adapts the design developed by McAslan/Arup (see diagram right), described as “Burnt brick strip foundation on bed of tamped sand or lean concrete”, and “Smooth concrete slab over moisture barrier on base course of gravel or crushed stone”. Note that the 100-mm floor slab continues under the wall, which gives very good protection against termites.

With these changes, it may not be necessary to use floor waffles to save cement.

5.3.2 Reinforced columns

With the proposed switch (described earlier) to constructing load-bearing walls using plain SSBs with mortar, reinforced columns become unnecessary structurally. There may still be a place for reinforced columns (or confined masonry) when building in areas prone to earthquakes.

5.3.3 Ring-beam

The current Build It method for casting reinforced ring-beams is costly and time-consuming (taking up to 2 weeks). There are three main alternatives:

- Reduce the specifications of the current design of reinforced concrete, cast using formwork, by using three or even two steel reinforcing bars, instead of four.
- Pre-cast hollow sections (that do away with the need for in-situ formwork), lifted into place (making sure that they are light enough to lift manually), then lightly reinforced and filled with concrete (see sketch diagram right).
- Timber wall-plate, which is likely to be sufficient with a light roof structure (when iron sheeting or thatch is being used).

All these proposed changes to design specifications should be verified by a structural engineer, to make sure that strength and safety are not compromised, and cleared with local building inspectors. No two projects are exactly the same, and local ground conditions, soil strength, availability of materials and skilled labour need to be taken into account when making design decisions. The changes also need to be gradually introduced into the Build It training programme.

5.4 Other design challenges

Other design features were discussed during the workshop. Notes on the discussion are presented in the table below:
<table>
<thead>
<tr>
<th>Design feature</th>
<th>Comments from workshop</th>
</tr>
</thead>
</table>
| **Windows**     | • Introduce treated timber-framed windows (instead of steel-framed) – Borax is an option for local treatment of wood  
                   • No glass necessary for school classrooms  
                   • Manufacture windows in production units, with good quality control  
                   • Shutters are more robust than louvres  
                   • Split shutters allow different configurations depending on temperature |
| **Doors**       | • Introduce treated timber doors  
                   • Frames may still need to be steel (due to termites)  
                   • There is scope for artistic designs incorporated into doors  
                   • Sadolin supply a good range of products in Africa (anti-termite, paint) |
| **Fittings**    | • Avoid using mortice locks (have to break door if lose key)  
                   • Introduce sliding bolts with hasp and padlock |
| **Drainage**    | • Spoon drains tend to deteriorate with ground settlement  
                   • No need for plinth around base of walls (use gravel if necessary)  
                   • Profile land around building to direct run-off away  
                   • Carefully consider habitual walking routes when designing path layouts |
| **Rainwater harvesting** | • Can be included in the right circumstances, but water tanks need strict control, and other sources of water may be more readily (and cheaply) available |

5.5 **Financial cost assessment**

All the options outlined in this paper are considered ‘affordable’ in the context of adoption in most of eastern and southern Africa, including Kenya, Uganda, Zambia and Zimbabwe. However, this document has not looked in detail at the relative cost of the different materials – this is largely a locally-determined factor.

It is important to recognise that, first of all, the lifetime cost of a building includes maintenance and durability. This is just as important as direct build costs, especially in a culture where maintenance costs are a burden.

Secondly, for Build It, we are interested in technologies that are both sustainable and affordable. Our projects must provide opportunities for the men and women we train to develop skills that have a market. If there is any dependence on access to equipment, we must be sure that this is accessible and affordable, otherwise it will not be taken up.

6 **CONCLUSIONS & RECOMMENDATIONS**

6.1 **Summary of conclusions and recommendations**

Pulling together the findings from the internal survey and the external review, the following overall conclusions can be drawn, and recommendations made:
<table>
<thead>
<tr>
<th>Topic</th>
<th>Conclusions</th>
<th>Recommended actions</th>
</tr>
</thead>
</table>
| Sustainability | • Earth remains Build It’s preferred raw material over concrete  
• There is continued strong support for the three pillars of Build It’s approach: sustainable materials, community involvement & training  
• The carbon appraisal study forms a good basis for assessing the carbon footprint of Build It designs  
• Sustainability assessments should cover the full life-cycle of a building, including demolition and disposal or recycling of materials at end-of-life | • Refine the carbon-appraisal spreadsheet tool so it can be used routinely to assess Build It designs and projects  
• Adapt the spreadsheet tool to cover full life-cycle analysis  

| Design   | • Innovative, attractive and user-friendly designs should continue to be developed and promoted by Build It without increasing costs; at the same time, there is considerable scope to develop standard designs to reduce costs  
• There is potential to improve our use of bioclimatic design principles in future projects  
• Designs should be optimised for the materials and methods being used (e.g. minimise splitting blocks or joining roofing sheets)  
• Overall site layout should be considered more carefully, to accommodate circulation patterns, slope and existing shade | • Continue the search for, and promotion of, innovative designs and involve local architects  
• At the same time build up standard designs that can be repeated  
• Further incorporate bioclimatic design principles into the design decision-making process  
• Review and simplify the Build It ‘cool house’ design  
• Include landscaping and vegetation in the overall site design  
• Revise our internal design process with explicit guidelines  
• Catalogue each project to capture our experiences  

| Walls    | • Load-bearing walls built using plain SSBs with mortar between courses should be the default method, promoted as the main Build It technique; this gives trainees more practical experience than with ISSBs, as at present  
• Alternatives (interlocking SSBs, improved adobe, natural stone, rammed earth) should be considered for specific projects if local conditions allow, specific clients or donors are interested, and there are cost/environmental arguments in favour | • Switch from using interlocking SSBs to plain SSBs  
• Investigate setting up a production unit for SSBs in Lusaka and/or Ndola (which could also be mobile) utilising a reliable local source of block machines  
• Obtain a compression rig for on-site testing of blocks  
• Advocate the inclusion of SSBs in building standards/codes and exam syllabuses  
• Actively seek an opportunity to test adobe/rammed earth in a new build |
<table>
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<tr>
<th>Topic</th>
<th>Conclusions</th>
<th>Recommended actions</th>
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</table>
| Roofing             | • Micro-concrete roofing tiles should only be used when quality of manufacture and installation can be guaranteed  
                      • Alternatives can be considered when tiles are not available or appropriate (improved iron sheeting, thatch, standard corrugated iron) | • Investigate in more detail the causes of past problems with micro-concrete tiles - remedy leaks and breakages.  
                      • Investigate setting up a production unit for micro-concrete tiles in Lusaka and/or Ndola (possibly mobile)  
                      • When finishing a project, leave sufficient spare roof tiles and ensure training for maintenance and repairs  
                      • Explore the use of good-quality thatch where appropriate (rural housing); identify skilled thatchers to train some of the new trainees/local thatchers |
| Foundations & floor slab | • Foundations and floor slab are currently over-specified and could be simplified considerably, especially in good ground conditions  
                              • Good alternative designs are available e.g. McAslan/Arup Malawi school  
                              • Continuing the floor slab under the walls offers significant advantages over a floating slab  
                              • Waffles can reduce material costs for a slab but require more labour; if a simpler specification is adopted, the incentive to use waffles reduces | • Obtain specifications and structural calculations behind the McAslan/Arup design  
                              • Develop a ‘menu’ of reduced specifications for foundations/slab that suit different ground conditions and satisfy local regulations  
                              • Take care when siting buildings to select flat sites with good ground conditions  
                              • Continue to perform soil tests for each site at the planning/design stage |
| Columns & ring-beam | • If load-bearing walls are constructed from plain SSBs with mortar, there is no need to use reinforced concrete columns (unless local conditions dictate)  
                              • The current method for in-situ casting of ring-beams is time-consuming and the design is over-specified; alternative methods include pre-cast units & timber | • Commission a structural engineer to review the proposed alternative methods of constructing lighter ring-beams (including timber wall-plates and reduced steel reinforcing)  
                              • Discontinue the use of columns, unless circumstances demand |
| Windows & doors     | • Treated timber-framed windows with shutters (and no glass in the case of school classrooms) are preferable to the current steel-framed windows  
                              • Treated timber doors are the preferred option, although steel door frames may still be necessary | • Finalise the design of timber-framed windows with split shutters that help cool the building  
                              • Finalise a standard timber door design  
                              • Identify a reliable local supplier/craftsman to produce them |
<table>
<thead>
<tr>
<th>Topic</th>
<th>Conclusions</th>
<th>Recommended actions</th>
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</thead>
<tbody>
<tr>
<td>Fittings &amp; finishes</td>
<td>• Mortice locks cause problems; there are better options</td>
<td>• Switch to using bolts with padlocks for all future doors (not mortice locks)</td>
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<td>• Painting, varnishing and other finishes should be done to a high standard</td>
<td>• Investigate a reliable local source (Sadolin?) of products such as anti-termite treatments, waterproof coating for walls, and paints</td>
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<td></td>
<td>• Mortice locks cause problems; there are better options</td>
<td>• Review the inclusion of details such as fascia boards and internal plastering in the design</td>
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<tr>
<td></td>
<td>• Painting, varnishing and other finishes should be done to a high standard</td>
<td>• Promote the decoration of buildings with traditional designs and motifs</td>
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<td>fascia boards and extensive internal cement plastering</td>
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<td>Drainage</td>
<td>• In most cases, there is no need to construct spoon drains or plinths</td>
<td>• Discontinue the use of spoon drains and plinths, unless circumstances demand</td>
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<td>around buildings; the same effect can be achieved by careful siting and</td>
<td>• Carefully consider storm run-off at the planning stage</td>
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<td>landscaping</td>
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<td>Utilities</td>
<td>• The default provision of utilities should be solar-powered lighting,</td>
<td>• Continue to promote the inclusion of solar-powered lighting</td>
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<td>hand-pump or single-tap water supply, and outside VIP latrine sanitation</td>
<td>• Review current practice for sanitation provision and develop a set of standard drawings</td>
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<td>• Consider rainwater harvesting on all new projects, especially in drier areas</td>
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<td>Miscellaneous</td>
<td>• There should be a contract manager or site-agent for every major Build It</td>
<td>• Select a suitable low-risk rural project and introduce the new designs all in one go</td>
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<td>project site, to ensure close supervision</td>
<td>• Make more use of networking opportunities (especially web-based) to share information and ideas and promote the Build It approach</td>
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<td></td>
<td></td>
<td>• Increase advocacy of Build It materials and methods with institutions, architects, government, and standards’ bureaus</td>
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</tbody>
</table>

Review of Sustainable Building Materials & Design 2012
6.2 Applicability to different countries

Although the focus of Build It’s work is currently on Zambia, the approaches covered in this report are applicable to many other countries in sub-Saharan Africa, including Uganda, Zimbabwe and Kenya (countries of particular interest to the Tudor Trust). The writers of this report have good practical experience in all four of these countries. Climatically, Zambia and Zimbabwe fall almost entirely into the zone described as “Tropical with dry seasons” (see map below; source: United Nations). The same climatic zone covers large parts of Uganda and Kenya as well. There are many other similarities, culturally, historically, politically and economically. Of course, there are differences between and within the countries, and the presence in some areas of inappropriate soil types (black-cotton, alluvial or sandy soils) needs to be taken into account. However, it is considered that the sustainable technologies and materials discussed in this report are valid for all four countries; indeed, they are valid for many other African countries, such as Burundi, Rwanda, Malawi, Tanzania, Mozambique and South Africa.

SSBs have been used for construction in Kenya and Uganda for many decades. Makerere University in Kampala, Uganda has a strong record of academic research and practical projects in this field, and Approtech and Makiga in Nairobi, Kenya have been selling block-making machines for over 30 years. A noticeable difference between Uganda and Kenya is the use of brick and stone. Brick is much more common in rural areas of Uganda and stone is not used, except for prestigious buildings. In Kenya, masonry skills are advanced, with widespread use of natural stone, as can be seen in Nairobi and provincial towns such as Nakuru and Kisumu.

The price of cement can vary considerably across East Africa, due to transport distances. For example, prices can range from USD7 per bag near the sources of production (Mombasa in Kenya and Tororo in Uganda), to USD17 per bag in Rwanda and the eastern part of the DR Congo, but it is always expensive. A salutary observation is that in remote parts of the DR Congo, a bag of cement can cost over USD100, but due to its market dominance, there still seems to be little effort by the private sector to search for alternative low-cost solutions.

Zambia and Zimbabwe are both members of the Southern African Development Community (SADC). Within SADC, there is a mechanism whereby regulations and standards (such as building codes) developed and applied by one member state can be adopted relatively easily by other member states. For example, a building standard for rammed earth structures was published in Zimbabwe in 2001, which now provides a good basis for promoting the technique in Zambia. Uganda and Kenya are members of the East African Community (EAC). There are close links between SADC and EAC, so there is good potential for wider dissemination of ideas and standards.
7 FINAL COMMENTS

This study has provided Build It with a critical appraisal of its current approach to selecting the materials it uses on its projects in Zambia with respect to two key considerations:

- Sustainability – in terms of energy/environmental costs
- Applicability – in terms of the potential for trainees to use the skills they learn through us to earn a living

Sometimes, there is a tension between these two factors, and a pragmatic way forward is provided through the detailed recommendations in the tables in Section 6 of this report. This has come out of a robust debate involving key staff and advisors.

This study has been encouraging in its endorsement of our work - we have been asking the right questions and we are heading in the right direction.

As a result we are confident that we have been able to clarify our position in a number of key areas. This allows us to define our starting point for the design and specification of new buildings. Key aspects of this include:

- Bioclimatic design principles
- Minimum (but adequate) foundations and use of reinforced concrete
- Stabilised soil blocks (not-interlocking)
- Micro-concrete roof tiles where quality is available
- Wood, in preference to steel, for fittings
- Basic finishings to a good standard

Even with these clearer points of reference, we still need to accept that every project will be different, as locations and community needs vary. We are also keen to explore other variations in the use of soil-based building materials.

However, we do need to make better use of standard designs and specifications, as this will allow us to improve on material quantity estimation, costings and timescales. Therefore, there needs to be a clear process that we follow to reach the final design and to provide the evidence to justify decisions that are made – including technical issues and community input. This ‘process’, with supporting reference material, could be of use to other organisations involved in community infrastructure projects.

The next step is to work out how best to implement the proposed changes – do we apply them incrementally or all in one go on a new project? How do we avoid confusing our trainees by changing specifications?

Thereafter, we will continue to monitor the performance of our build process and completed buildings. We will also continue to talk to and learn from others and feed all lessons back into the planning cycle for future projects.

As a development organisation, we are driven by the belief that a more sustainable approach to meeting infrastructure requirements remains a critical challenge, because it can make a significant contribution towards meeting wider sustainable development goals.
APPENDIX 1: Comparative ranking matrix for building technologies

Matrix produced by: Corinna Salzer (2010), Affordable Housing Project, ETH Zurich, Switzerland
## Project Work: Affordable Housing

**ETHZ | 2010 | Corinna Elaine Salzer**

### Table of Materials

<table>
<thead>
<tr>
<th>Material Type</th>
<th>A</th>
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<th>C</th>
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<tr>
<td>Waste plastic as replacement for bitumen in stabilized bricks</td>
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<td><strong>Others</strong></td>
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<td>Felt Honeycomb Panels</td>
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<td>Upper Log House</td>
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<td>Corrugated Interlayer</td>
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<td>Corrugated Roof</td>
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<tr>
<td>Rapid Prototyping, Contour Crafting</td>
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APPENDIX 2: Summary report from internal questionnaire survey

Review of experience to date re: sustainable materials & design
Build IT International, November 2011

Introduction
This presentation summarises the results of a survey of attitudes to the use of different building materials and techniques, undertaken as part of a wider study on the comparative advantages of different construction techniques and materials in sub-Saharan Africa. The survey was undertaken during November 2011, using a mixture of email questionnaires and face-to-face interviews, with questions tailored to different categories of respondent. Where relevant, initial conclusions are highlighted in red font.

Responses received from:

<table>
<thead>
<tr>
<th>Ref</th>
<th>Group</th>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Users (teachers, parents, schoolchildren, etc)</td>
<td>Agness, Jennifer, Makangwe (various), Melody</td>
<td>St Agness School, Chainda School, Makangwe School, Mkumbilla School</td>
</tr>
<tr>
<td>B</td>
<td>Professionals (architects and other infrastructure specialists)</td>
<td>Malcolm Alcock, Stephen Chikonde, Rob Fielding, Callistus Kaoma, Jeannette Laramée, Ruhben I Ifika, Joseph McLean, Nick Phiri, Neville Ravensdale, Malcolm Wobby, Evans</td>
<td>Build IT, Habitat Consult (architects), Shelter Centre, Build IT, Ex Building Project Manager (Zambia), Architect and Chair of RII, AKP, Architect used by BII, Architect, HAPPI South Africa, BII trainer</td>
</tr>
<tr>
<td>C</td>
<td>Contractors</td>
<td>Kingston, Mupeta Emerson</td>
<td>Stoneking</td>
</tr>
<tr>
<td>D</td>
<td>Ex-Trainees (trained by Build IT)</td>
<td>Enoch, Makangwe (various), Juliet</td>
<td>n/a</td>
</tr>
<tr>
<td>E</td>
<td>Clients/Donors (familiar with the Build IT approach)</td>
<td>Andrew Jowett, Ric Law, Kevin Lawrence, Harriet Miyato</td>
<td>Build IT, COINS, Shropshire Fiwila Partnership, ZOCS</td>
</tr>
</tbody>
</table>
## Stabilised soil blocks

<table>
<thead>
<tr>
<th>Positive comments</th>
<th>Negative comments</th>
<th>Initial conclusions</th>
</tr>
</thead>
</table>
| *General perception:* better and stronger than concrete blocks and burnt bricks, with no qualms about durability  
*Appearance:* attractive (especially well-laid ISSBs) with no need to use plaster on outside wall; ISSBs are warmer and aesthetically pleasing; can use a variety of finishes  
*Ease of use:* ISSBs good because no mortar between courses; less risk of settlement cracks; unskilled workers can be trained to assist with dry-stacking  
*Cost:* cheaper than most alternatives  
*Sustainability:* minimises use of cement; no need for fuelwood; locally-sourced materials; seen as an environmentally-friendly construction method  
*Manufacture:* community involvement in process (employment and transfer of skills) | *Ease of use:* can be difficult to get even courses (with ISSBs) because no mortar to compensate for small variations in block dimensions  
*Block machines:* not enough block machines available (this is sometimes the main reason for choosing alternatives), and community left without machine for spare blocks; machines have limited mould shapes, so design restricted; Hydraform machines are very expensive  
*Manufacture:* can be slower than just ordering concrete blocks; variable quality; still uses significant cement; not all soils are suitable; suitable soils may be some distance from the site; pits left in the ground afterwards (health & safety hazard when they fill with water) | *Continue and strengthen promotion of ISSBs over alternatives*  
*Review the use of interlocking ISSBs (switch to simpler shapes?)*  
*Consider establishing ISSB production units (with a viable business model)*  
*Get ISSBs included in building standards and exam syllabuses* |

## Parry roof tiles

<table>
<thead>
<tr>
<th>Positive comments</th>
<th>Negative comments</th>
<th>Initial conclusions</th>
</tr>
</thead>
</table>
| *Appearance:* very attractive when laid properly; aesthetically pleasing; can even use coloured dye  
*Properties:* cool in hot weather, quiet during rain, durable when made properly  
*Sustainability:* can be produced locally with no need for fuelwood; seen as an environmentally-friendly roofing material  
*Manufacture:* community involvement in process, if made locally (employment and transfer of skills) | *General perception:* crack easily if mishandled; prone to leakage in heavy rain or if installed badly; allow entry of dust/ash; strong preference for corrugated iron sheets  
*Manufacture:* serious problems with quality control (bad reputation has spread); need to construct curing tanks (which take a lot of water); difficult to transport without breakages (if not made locally); need to be available at every hardware shop  
*Installation:* slow to install (highly-skilled job); much stronger (& steeper) roof structure required; more difficult to install other fittings such as solar panels and rainwater harvesting systems; really need to install a ceiling as well (tiles produce dust), but ceiling would be spoilt by leakages  
*Tile machines:* not enough tile machines available; machines expensive; not much flexibility with size and shape; community unable to make small numbers of spare tiles for subsequent repairs | *Investigate causes of problems (just quality control, or poor installation, or wind with rain?)*  
*Only use Parry roof tiles when can guarantee quality of manufacture and installation, and when there is access to spare tiles for repairs*  
*Consider establishing roof tile production units (with a viable business model)* |
### Windows, fittings & finishes

<table>
<thead>
<tr>
<th>Item</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Windows | • Preference for opening windows (for ventilation), with glass (for light), iron bars (for security) and insect screens (especially for houses)  
• But standard glass breaks easily and locally-made steel frames are often poor quality  
• Need to test alternatives (wooden shutters, louvres, etc), which incorporate security bars and high-specification mosquito mesh |
| Fittings | • Must be durable, to survive careless usage, although there is a trade-off between quality and cost  
• Fully-treated timber components should be used for doors, windows, etc, with steel elements kept to a minimum for fixings, hinges, kitchen and bathroom fittings |
| Finishes | • Mixed opinions on finishes, including: plaster and paint inside and outside; only plaster inside so can still see blockwork outside; no need for plaster, just render with a cement/laterite wash; must make sure painting is done properly  
• There is more scope for creativity in finishes (especially painting), using traditional motifs and local designs |

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### Foundations

**Comments about design and specifications of foundations**

- Foundations are currently over-specified, and design specifications could be reduced in safe ground conditions
- There would be significant cost savings from reducing the specs for the foundations (and less cement used)
- Performing a structural review for each building may seem expensive, but savings may outweigh the costs
- To avoid having to do structural calculations every time, a ‘menu’ of different foundation designs could be developed and verified by a structural engineer
- Ideally, soil tests would be carried out for each site, and the foundation design adjusted for the local conditions, or a suitable design selected from the ‘menu’
- Need to select flat sites if possible, to minimise the ground preparation and excavation for footings
  - Develop a ‘menu’ of different foundation designs, verified by a structural engineer, to suit different ground conditions
  - Perform soil tests for each site, then select suitable design from the standard ‘menu’
  - If possible, select flatter sites to minimise ground preparation
### Parry columns & ring-beams

<table>
<thead>
<tr>
<th>Item</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parry columns</td>
<td>• This system saves massively on timber shuttering, is quick to build with and is structurally strong and sound; however, moulding equipment is needed and quality control is vital</td>
</tr>
<tr>
<td></td>
<td>• Columns are contentious with regulatory authorities (such as Ministry of Education building inspectors)</td>
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<tr>
<td></td>
<td>• When using Hydraform blocks, columns are an unnecessary cost as we can build without the columns</td>
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<tr>
<td></td>
<td>• Placing of reinforcement outside the column blocks is questionable; it provides little extra reinforcement and is difficult to construct (for the quality of manpower that we use); placing reinforcing bars inside would be much easier</td>
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<tr>
<td></td>
<td>• The nature of rebar is to reinforce from the inside, where it is inherently more structurally sound</td>
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<tr>
<td></td>
<td>• Calculations should be verified by a structural engineer, and the use of Parry columns reconsidered</td>
</tr>
<tr>
<td>Ring-beams</td>
<td>• Structurally, a good ring-beam is sufficient, without using reinforced columns</td>
</tr>
<tr>
<td></td>
<td>• There are cheaper and quicker methods of constructing ring-beams (pre-cast blocks with V-shaped slot, lay reinforcement bars in the slot and fill with concrete)</td>
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<tr>
<td></td>
<td>• Review the method used for casting ring-beams, including new calculations by a structural engineer</td>
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</tbody>
</table>

### Floor slab

<table>
<thead>
<tr>
<th>Item</th>
<th>Comments</th>
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<tbody>
<tr>
<td>General</td>
<td>• Standard Build IT approach is a reinforced concrete floor slab, which is expensive and time-consuming, with high cement consumption, but is VERY strong and durable</td>
</tr>
<tr>
<td></td>
<td>• Review standard floor specs and consider other designs (see below)</td>
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<tr>
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<td>• Perform tests on local soil &amp; tailor slab specs to soil conditions (from a choice of designs)</td>
</tr>
<tr>
<td>Parry pre-cast floor waffles</td>
<td>• Sound technology that saves labour and materials and is popular with builders, but needs equipment and there are the usual quality control issues (but not as serious as with tiles)</td>
</tr>
<tr>
<td></td>
<td>• Good system, saving time and money if applied properly; however, the technique can take a lot longer than casting a standard floor slab; do we really need reinforced floors?</td>
</tr>
<tr>
<td></td>
<td>• There can be general apathy/dislike by materials producers towards making waffles</td>
</tr>
<tr>
<td></td>
<td>• Build IT should focus more on using this technology (cost saving &amp; reduce cement)</td>
</tr>
<tr>
<td>Other designs</td>
<td>• Carbon appraisal study described a system consisting of: substrate of large-dimension aggregate and laterite; 50-mm layer of river sand; polythene damp-proof membrane; 200-mm compacted earth floor; 50-mm lime-soil screed</td>
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</table>
### Attributes of a low-cost house

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Group B (Professionals)</th>
<th>Not at all important</th>
<th>Not very important</th>
<th>Neutral</th>
<th>Quite important</th>
<th>Essential</th>
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</thead>
<tbody>
<tr>
<td>Affordable</td>
<td>X</td>
<td></td>
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<tr>
<td>Strong</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Easy to maintain</td>
<td></td>
<td>xx</td>
<td></td>
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<tr>
<td>Spacious rooms</td>
<td>XXXXXX</td>
<td>xxx</td>
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<tr>
<td>Durable</td>
<td></td>
<td>xxx</td>
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<tr>
<td>Looks attractive</td>
<td></td>
<td>xxx</td>
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<tr>
<td>Secure</td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Comfortable (cool)</td>
<td></td>
<td>X</td>
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<td></td>
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</tr>
<tr>
<td>Not noisy (rain)</td>
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<td>XX</td>
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<tr>
<td>Electricity</td>
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<td>XXXXXX</td>
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<tr>
<td>Water</td>
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<td>XXXXXX</td>
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<tr>
<td>Sanitation</td>
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Respondents were asked to indicate how important they think the above attributes or features are in a low-cost residential house, in order to gain an understanding of their general values about such buildings in sub-Saharan Africa. It’s clear that most people place importance on a house being attractive and comfortable as well as affordable, durable and secure. In other words, **design is still important**.

### Utilities (for low-cost house)

<table>
<thead>
<tr>
<th>Utility</th>
<th>Options</th>
<th>Consensus in responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Continuous mains power intermittent mains power Solar-powered lighting</td>
<td><strong>Overwhelming preference for solar-powered lighting.</strong> A few people mentioned biogas as an alternative power source for cooking and lighting.</td>
</tr>
<tr>
<td>Water</td>
<td>Plumbed-in kitchen/bathroom Piped into house, but just tap Yard tap or shared tap Hand-pump</td>
<td><strong>At least a hand-pump or yard tap, or preferably piped to an inside tap.</strong> Emphasis on availability (with storage?) of clean water; the supply must be secure and affordable. Rainwater harvesting encouraged, even if another source is available.</td>
</tr>
<tr>
<td>Sanitation</td>
<td>Inside flush toilet Outside flush toilet Outside VIP latrine Basic outside latrine</td>
<td><strong>Overwhelming preference for outside VIP latrine.</strong> Some support for flush toilets, but also strong opposition (due to high water requirement and effluent disposal issues).</td>
</tr>
</tbody>
</table>

Of course people would prefer continuous mains power (to run fridges, TVs, etc), a fully-plumbed kitchen and bathroom, and an inside flush toilet, but most responses were commendably realistic. Installation of solar-powered lighting would have many benefits: use of public buildings for evening classes (adult education); facilitating homework (school children); improving health & safety (fire risk, poor eyesight, breathing fumes, etc). Benefits of better water supply and sanitation are well known.
Build IT ‘Cool house’ design

Positives
- Attractive appearance, popular with residents
- Good use of space and nice shady verandah
- Cool in hot conditions because of materials

Negatives
- More expensive than expected (£5,000+)
- Over-complicated roof with weak spots (leaks)
- Complicated design, difficult for local builders

Need to simplify the design for Version 2 and get the cost down to under £3,000 (ZMK 20 million) or even better, under £2,000. Comments and suggestions are invited from those familiar with the design.

Design

Miscellaneous comments on design issues
- Good feedback from users about BI ‘cool house’ design, including the round end and shady verandah
- The steeper roof pitch required for Parry tiles mirrors more closely the proportions of traditional buildings
- Hexagonal classroom creates a good learning environment, with children gathered around the teacher, but it’s more difficult and more expensive to construct
- Building design should be optimised for the materials being used (for example, width of building designed to allow single sheet of corrugated iron for each roof pitch)
- Design approach should be flexible, responding to local conditions (such as soil quality) and availability of certain materials
- New building methods or materials should be tested first, to gain confidence that they will work well and be durable (risk of wasting the benefactor’s money, and bringing a bad name to the technology)
- With thought in the design phase, a building can still be quick and cheap to construct, while also being comfortable and high quality; there is no reason why good design should be ignored, just because it is for a low-cost building; we need to get rid of the box mentality and be creative with design and layout
- Many buildings exhibit good design qualities but use inappropriate materials, or appropriate materials but atrocious designs (uneconomical use of space, poor aesthetics)
- Only a good design can make the spaces inside a building pleasant to work or live in; environmental factors can of course affect the spaces, but appropriate materials can help to overcome the environmental factors
- There is a strong consensus that BI should continue promoting good design and an innovative approach to both layout and materials, rather than being tempted into churning out standard boxes
Sustainability

Carbon appraisal

- Study carried out jointly by the Centre for Alternative Technology and the University of East London
- Compared the total carbon intensity of a standard government building (cement blocks and corrugated-iron roof), a Build IT design (ISSBs and Parry tiles) and a Ram Cast school (rammed-earth walls, green roof)
- Results: standard method 220 kgCO\(_2\)/m\(^2\); Build IT method 121 kgCO\(_2\)/m\(^2\); Ram Cast method 37 kgCO\(_2\)/m\(^2\)
- Potential to reduce the Build IT figure significantly, in particular by reviewing the specifications of foundations and floor slabs, and making more use of lime instead of cement

Comments on sustainability and environmental impact of materials & techniques

This is definitely an important issue, but there is limited technical capacity among regulators and construction professionals; a massive education programme is needed to highlight the negative impacts of high-energy materials like concrete blocks and corrugated-iron sheets

Environmental impact analysis is not enough; there should be full Life-Cycle Analysis of building materials and the whole construction process, including transportation, energy use, waste disposal & decommissioning

Wherever possible, materials should be sourced locally or produced on site, but we need to be practical and realistic, because we are talking ‘affordable’ housing

- Strong consensus that sustainability is important, and Build IT should continue to give it priority
- Several mentions of bio-climatic design (passive solar heating/cooling, correct building orientation)

Introducing new technology

The challenge

Concrete blocks and corrugated-iron roofing seem to be the materials of choice, not just for small houses but for large institutions such as schools and hospitals. Respondents were asked for their opinion on obstacles to the introduction of new technology:

- Large institutions are working on tight budgets as well; metal sheets and concrete blocks are often the cheapest, relatively-durable materials available
- Construction techniques using these materials are simple and well known; their strength and lifespan are also well known and predictable
- Larger buildings can make use of long metal roof sheets laid to a low pitch, with a relatively light roof structure compared to most other roofing materials
- Policy and legal obstacles – building standards, building codes, exam syllabuses for vocational training
- Lack of widespread availability of alternatives such as ISSBs, plus concerns about quality and consistency
- Tradition, habit, propaganda, brain-washing, inertia, aversion to risk, ignorance, lack of education
- Governments are not promoting the use of alternative materials, and there is little or no state-sponsored research on sustainable building materials
- Cultural reluctance, with these materials seen as ‘modern’, and wood, thatch, soil, etc., seen as ‘backward’

Some solutions:

- Increase awareness of ISSBs, etc., by using them on highly-visible public buildings; introduce strict quality control
- Advocacy with key bodies such as Zambia Bureau of Standards, National Housing Authority, Zambia Institute of Architects; inclusion in exam syllabuses & design standards
- Establish production units for high-quality ISSBs, etc., so that the blocks are available off-the-shelf
APPENDIX 3: Fact sheets on technologies for walls

RAMMED EARTH

Country of Practice
Applied in several rural areas of the world

A Description

Picture source: www.iagram.com

Picture source – Rob Fielding
Traditional rammed earth - Bhutan

Company Institution Source
GTZ, BASIN Network; German Appropriate Technology Exchange GATE; email: gate-basin@gtz.de
SKAT www.skat.ch

Construction Type
Load-bearing massive earth walls

Building Category
Heavy weight

Size and Dimension
One to two stories. Floor area limitless. Room dimensions may need alternative structural supporting elements to create large spans.

Construction Components
Locally-available soil (optimal mix 50-75% gravel and sand, 15-30% silt, 10-20% clay). Formwork- rigid formwork required, as pressure during process is high, erection and dismantling process are keys for optimization, reduction of moves needed, flexible for changing wall thicknesses, minimum wall thickness 30 cm, better ramming comfort if wall is 40 cm, climbing formwork developed by University of Kassel (Prof Minke), length between 150-300 cm, height between 50-100 cm. Rammer - manual or pneumatic, heavy wood or metal, high initial cost for pneumatic - economy of scale, alternatively small vibrating plate can be used (University of
Kassel) which does not need human guidance once established in the formwork. Foundation on conventional stone, brick or concrete bed up to the first 30 cm above ground, damp proof between footing and walls in humid areas.

**Cost per m²**
The rammed earth construction as well as the wattle-and-daub method, adding structural parts to the clay, belong to the cheapest building technologies available. The cost remains below 40 $/m².

**Building Process**
Wall construction should be started at a corner. Earth is filled into formwork in layers of up to 10 cm and thoroughly compacted to a thickness of 6-7 cm with a ramming tool. The person stands on the edges of the formwork or in the case of Bhutan, the walls are wide enough to use people as part of the ramming process. When the formwork is full, it is dismantled and horizontally moved to the next position fixing it over a previously completed row. Gradual progress, layer by layer, row by row. Time and labour intensive. Skill requirement in earth work. No surface treatment required, broken edges, cracks and holes have to be filled immediately after formwork removal (“wet in wet”), as wet in dry does not stick anymore. Formwork has a decisive influence on cost, quality and speed. Stabilizing agents should be avoided as they complicate the procedure (only possible with good soil conditions and well-designed buildings). With some systems, openings have to be planned carefully, as they have to correspond to the end of one formwork.

**Time Schedule**
Slow progress, the construction of one unit requires more than two weeks for completion.

**Economy of Scale to Mass Production**
No economy of scale effect beside reuse of formwork.

**Durability**
High-quality house last for hundreds of years, resistance against earthquakes is only low to medium, hurricane good, rain medium, insects medium. The ideal climate is hot and dry, upland climates.

**Maintenance Requirements**
Frequent maintenance for closure of cracks has to be carried out. A good quality of construction reduces the frequency; harsh environmental conditions increase the requirements.

**Modularization to Flexibility**
Flexibility only in the beginning, after construction, only small cuttings possible but no structural changes (walls are load bearing).

**Potential for recycling - demolition**
100% if no stabilizing agent was used in the soil. Energy requirement is only a fragment of the amount compared to other technologies. No wastage, no pollution, 100% natural material. Soils without stabilizer can be reused easily.

**Local Value Creation**
The use of purely local materials and unskilled labour contributes highly positively to the local environment. However, the short durability lacks in the creation of enduring values.

**Social Acceptance**
It is accepted as a traditional building method; however, it often remains behind the acceptance of concrete structures. Rammed earth walls are seen as “cheap method for the poor”.

**B Why selected – benefits**
Low carbon, natural product
Excellent thermal and bioclimatic properties
Cheap
Involves community participation
Low maintenance cost
C  Adaption potential

Track record
The method has been used for centuries in various parts of the world, also named with the French word “pisé”. Bhutan – rammed earth. UK – Cob.

Transfer Potential
Traditionally spread over rural areas with good soil properties (see world map of earth construction in the Book of the Literature List “Planning and Housing in the Rapidly Urbanizing World”).

Interface for Housing Techniques and Infrastructure
Complicated, houses contain only low proportions of housing techniques.

Possible Limitations - Chances - Improvement Options
Some equipment exists for improving the ramming process. The time schedule remains time intensive. The rammed earth construction method is not suitable for highly-compacted urban centers, very seldom it is recorded to be used in multi-storey housing, however no track record exist to these projects.

D  Limitations and risks - Zambia suitability

Given the right soil conditions, combined with good quality timber formwork which is readily available this, technology is extremely suitable in Zambian situation. Community participation is important and even though it is not a fast building method then it has a lot of potential. Construction needs to take place in a dry period during the year but where water is available.

E  Further information

Credit: Corinna Salzer – ref LCA sheets

Julien Rowland Keable – Earth Structures – Guide to Good Practice

Peter Walker (Author), R. Keable (Author), J. Marton (Author), V. Maniatidis (Author) Rammed Earth: Design and Construction Guidelines

Johan van Lengen - Barefoot Architect –
http://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Dstripbooks&field-keywords=Barefoot+architect&x=18&y=15
CONFINED MASONRY

Country of Practice
Technique that has been commonly used throughout the world but has gained increasing recognition as an effective method to be used in high seismic areas. It has been used throughout the world in both urban and rural settings.

This approach is contrary to common practice for reinforced concrete structures; www.confinedmasonry.org

A Description

The Confined Masonry Initiative

International Disaster and Risk Conference, Davos, Switzerland, May 30 – June 3, 2010

In contrast to conventional reinforced concrete, where columns are built first, followed by walls (left-hand diagram below), in the confined masonry technique, sections of wall are built first, with columns added later (right-hand diagram):

Every bit of wall is enclosed (i.e. confined) and anchored by reinforced concrete columns and beams (also called ‘ties’). The walls are raised first, and the steel reinforced concrete elements are poured in afterwards.
The reinforced concrete ties hold the wall together like a string around a parcel, to ensure that the wall doesn’t fall out sideways during an earthquake.

Bricks are anchored to the columns through zigzag wall endings and through anchor hooks.

The end result looks similar to reinforced concrete (RC)-frames with brick in-fills, but the mechanics are very different: with confined masonry it’s the solid walls that take the efforts of the quake, with RC frames it’s the (often badly done) concrete columns and beams.

**Construction Type**
Integrated, combined, confined, masonry or SSB walls by reinforced concrete beams and columns.

**Building Category**
Heavy weight

**Size and Dimension**
Multi-storey. Floor area limitless. For more complete seismic resistance, the introduction of shear walls in both X and Y directions are highly recommended.

**Cost per m²**
Similar to standard concrete/brick reinforced framed structures but with improved structural qualities. $100/m².
Building Process
Setting out of columns and the main framework is critical. The walls are built first from suitable block or masonry elements. Jagged or staggered coursing is left exposed ready for steel reinforcing to be completed. Depending on level of seismic design that is required, horizontal tie bars can easily be included in the coursing and linked into the column reinforcement. Shuttering is then required to enable the columns to be cast in one lift or in several lifts. The amount of shuttering required is considerably less than a convention RC moment structure.

Time Schedule
Reuse of formwork. Should be faster than a traditional RC frame.

Durability
As standard RC blocks and concrete frames. Proven higher seismic performance particularly if good quality assurance through site supervision to ensure that reinforcement is carried out correctly.

Maintenance Requirements
Low maintenance.

Modularization to Flexibility
New openings can be added but knowledge of where the reinforcement was placed will make this practical, otherwise a lot of steel cutting is needed. This may have the problem of compromising the structural integrity.

Potential for recycling – demolition
As with other RC type construction. Limited recycling.

Local Value Creation
Need skilled labour but principles should easily be transferrable to enable communities to adapt and use the technology.

Social Acceptance
It is accepted as a traditional building method; however it often remains behind the acceptance of concrete structures.

B Why selected – benefits
Higher structural quality than standard RC framed construction. Need to consider the principles in high risk seismic zones. Low maintenance cost.

C Adaption potential
Once the principles are understood then the layouts are adaptable.

D Limitations and risks - Zambia suitability
Check out local building regulations. The use of RC framed structures seems to be standard even for simple single-storey buildings. This gives a stronger solution.

E Further information
Contact: Tom Schacher - Swiss Agency for Development and Cooperation, Switzerland
See also: www.confinedmasonry.org
# STABILISED SOIL BLOCKS (SSBs)

## Country of Practice
Widely spread in Africa, South America and Asia

## A Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-quality, low-cost SSB construction used as an example by Corinna Salzer (Masters’ Thesis)</td>
<td><img src="https://www.mnlconsulting.com" alt="Image" /></td>
</tr>
<tr>
<td>Affordable housing using simple SSBs, rectangular profile.</td>
<td><img src="https://www.mnlconsulting.com" alt="Image" /></td>
</tr>
<tr>
<td>Many different machines on the market:</td>
<td><img src="https://www.mnlconsulting.com" alt="Image" /></td>
</tr>
<tr>
<td>- Fully manual</td>
<td>Picture Source: <a href="http://www.mnlconsulting.com">www.mnlconsulting.com</a></td>
</tr>
<tr>
<td>- Manual with hand hydraulic press to increase compression ratio</td>
<td></td>
</tr>
<tr>
<td>- Fully mechanical</td>
<td></td>
</tr>
<tr>
<td>Standard SSBs</td>
<td><img src="https://www.mnlconsulting.com" alt="Image" /></td>
</tr>
<tr>
<td>Higher ratio cement for plinth and first soldier course.</td>
<td></td>
</tr>
<tr>
<td>Note: no RC columns. Shear walls projecting which also improves wall shading.</td>
<td></td>
</tr>
<tr>
<td>(Dormitories in Malawi)</td>
<td></td>
</tr>
</tbody>
</table>
Simple on-site mobile testing rig gives reassurance as to the block quality, and saves having to transport blocks to distant testing labs.

Gives local assurance and interest to those watching!

(Malawi)

Different type of soil. Low clay content.

Note: no RC columns used.

For houses with small spans and intermediate walls this works very well.

(Kenya)

Easy to cut to half or quarter blocks as needed.

12/16-mm hole drilled to allow for rebar to be used as a tie to fix the wall plate at the top of the wall, with or without RC ring beam (see below).

(Kenya)

Note:

- Shuttering for RC concrete ring and tie beam across main structural walls.
- Quarter blocks added half way along wall. Bonding pattern clearly thought out at the setting out stage.
- Holding down rebars already caste in ring beam ready to take timber wall plate.
Combination of timber frame and SSB construction.

(Kenya)

Picture Source: Rob Fielding

Company - Institution - Source
Multiple international and multilateral organizations as well as NGOs support this technology.
Selected data sources are: CRATerre, BASIN | GTZ, Practical Action, SKAT
Private Sector Example: MNL Consulting, LLC, Los Angeles, California 90047 USA, www.mnlconsulting.com

Construction Type
Load-bearing massive block walls

Building Category
Heavy weight

Size | Dimension
Mostly one and two-storey buildings, CRATerre mentions building up to three stories.
Various floor plans possible e.g. sample unit 34.6 m² (MNL Sample Unit).

Settlement Environment
Rural, Semi-Urban, partially Urban

Construction Components
For the general history of construction with soil, refer to Fact Sheet 1_04 (by Corinna Salzer, see below)
The new components of the technologies presented in here are:

- usage of an cement stabilizer (1_07),
- usage of special enzymes for stabilization (1_08),
- integration of fibres for stabilization (1_09)

Stabilization of blocks is useful, when the material is going to be exposed due to bad design, failing to take account of the fundamental principles of building with earth, or location environmental conditions. The advantage of stabilized blocks compared to other earth construction technologies are that a greater water resistance and higher strength can be achieved. The load bearing capacity of stabilized blocks is significantly higher than that of pure adobe blocks (Fact Sheet 1_04). The compressive strength of soil blocks is according to a research of RICS 178. Due to the use of fibres, this can be increased to 189. The use of 5% cement increases it above the requirement of 300 psi, averaging 343 psi. Further advantages are that the blocks can be moved and stacked up to 5 layers immediately after construction, a lower breakage rate after drying, a higher height to thickness ratio and no external rendering is required. All this leads to a saving in material and time, lowers the cost for production and energy input than for equivalent volume of burned clay bricks or concrete blocks. However, beside the process optimization, the use of the stabilizer itself causes a price increase compared to non-stabilized blocks. Fibres are naturally the cheapest form of stabilization; cement is the most commonly used one.
Block construction has been promoted since the beginning of self-help projects (see development of conceptual viewpoints). Much has been improved in the equipment sector since then. Modern equipment for large volume mass production exists, which still fulfills the requirement of being simple in handling and maintenance. Both portable on site production facilities and fixed plants are possible. However, for small rural communities, the capital expenditure outlay is high. A specialist technician is required on a regular basis for maintenance. If the project is dependent on one machine which has a mechanical failure, it may take days or even weeks to get replacement parts, if the machines are too sophisticated. Ref: Hydraform.

<table>
<thead>
<tr>
<th>Press Type</th>
<th>Theoretical Output (blocks per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>300 -1,500</td>
</tr>
<tr>
<td>Motor-driven</td>
<td>1,000 – 5,000</td>
</tr>
<tr>
<td>Mobile Production Unit</td>
<td>1,500 – 4,000</td>
</tr>
<tr>
<td>Fixed Production Unit</td>
<td>2,000 – 10,000</td>
</tr>
</tbody>
</table>

Beside the press, a mixer, a crusher, a screening device and an automated transport facility might be used depending on the production line assembly. Labour for one production line is around 9. The productivity is dramatically dependent on the amount of investment.

**Cost per m²**
The costs involved with stabilized earth blocks belong to the medium category. Soil blocks without stabilization are cheaper, the screening of several project evaluations has averaged a price to be around 120 - 140 $/m². Several factors influence the price, such as the type of production line (see components above), the units produced and the local conditions of land and worker prices. A detailed analysis can be found in the key literature of CRATerre. Source: “Compressed Earth Blocks” Rigassi, CRATerre.

**Building Process**
The production of compressed earth blocks can be regarded as similar to that of fired earth blocks produced by compaction, except that there is no firing stage. Production will be differently organized, depending on whether it is a small scale unit or in the context of a semi-industrial or industrial unit.

Beside the basic development steps of extraction, compression, curing and stocking, the processes of preparation (including drying, pulverizing and screening) as well as mixing (including dry and wet mixing) have to be carried out in order to integrate the stabilizing component into the block mass.

Cement is the most common choice of stabilizer with around 5% cement in the dry mixture. It is recommended to add an exterior weatherproof finish. Alternatively a small amount of organic enzyme/polymer is added as a soil stabilizer, acting as water repellent by raising the block density so that no external coating is required anymore. The durability with the use of enzymes has been increased significantly. Furthermore there is no curing time needed with the enzyme and the blocks can be used right out of the machine, leading to an increase in construction speed. Fibres are the cheapest stabilization material. An overview about the variety of fibre materials is described in Fact Sheet 3_05. (source: Corinna Salzer).

In the production it is as well the most complex one, as the effect of clumping and clustering are threatening the blocks. An effective quality control is an important element especially in case of fibre use. Out of the three stabilizing options (cement, enzyme, fibre), cement is by far the most often used method. Most of the machines can be set up in a few minutes and use any of the described stabilizers. The capacity building of unskilled locals is generally possible within few hours. However, for high-quality blocks with which houses with three levels can be realized, also earth construction requires the skills of workers.

**Time Schedule/Prefabrication**
Drying period depends on the stabilizer added. 5 days with bitumen, 15 days with cement and 25 days with lime. Cement and lime blocks must be kept moist for the first 5 days. The enzyme addition is here of large advantage, as no curing time is required. There has not been any data of how fibres increase the curing time.

**Economy of Scale/Mass production**
There is only minor price reduction possible through mass production. Certainly the brick production can be improved however the labour-intensive construction remains time intensive.
Potential for Recycling/Demolition
As it is a natural building material, the inert material can be demolished or reused. The stabilizer, however, increases the effort of demolishing the blocks into pulverized shape.

Durability
The stability of the blocks has been increased significantly compared to non-stabilized blocks. The enzyme usage improves the durability according to the producing company. Compared to concrete or burnt bricks, however, the blocks are still by far more attacked due to insects and humidity over the time. There has not been any possibility to improve the earthquake resistance. This development has been achieved through the use of hollow blocks (1_12) and interlocking blocks (1_13).

Maintenance Requirements
The maintenance requirements have been reduced in comparison to the non-stabilized blocks. However, frequent maintenance is still important in order to close cracks, repair damages or attacked blocks. An average rating has been given.

Modularization/Flexibility
Low potential, even though advanced systems with different block modules were implemented, difficulties in realization remain. “As simple as possible” has been proven as less critical in implementation.

Local Value Creation- local materials, local labour
High, a significant improvement in performance can be realized due to the addition of a stabilizing material like cement, fibres or enzymes. Described and promoted on the one side as “unique humanitarian real estate approach”, a lack of suitability remains in the high density urban application. No real business model appears to exist where this technology has been brought to a real commercial scale of operations.

Interface for Housing Techniques and Infrastructure
An integration of housing techniques or pipe interfaces requires additional effort for chasing or external installation.

General Remarks
As per today Compressed Earth Blocks are promoted worldwide as a key technology for the massive world demand for low cost housing. This considers the fact that many multilateral initiatives or international organizations work in rural areas where space is available for horizontal growth.

However, for urban demand for permanent, dense settlement this solution has clear limitations as long as it is produced with low qualities. Building with stabilized earth does require skills. The technology is capable for multi-storey purposes (up to level 2-3), but skills and quality control are important. Lack of expertise brings out poor constructions, which damages the local value chain. However, with guidance, local unskilled labour can learn to construct with earth. The technology actively creates local value as natural materials are used and labour can be engaged. The potential for process optimization of a block construction is there, but limited (see Fact Sheet BIIT 05 - for Interlocking Blocks).

Reference
FACT SHEET │ TECHNOLOGY 1_07 – 09 (Corinna Salzer – ref LCA sheets)
# NATURAL STONE

**Country of Practice**
Natural stone along with wood is one of the oldest used building materials. Stone structures or basic enclosures can be found in all parts of the world. In this post-modern era of technology the status of stone appears to have changed considerably. It is now often perceived as a luxury material for high-quality finishes or decoration associated with high-end buildings.

## A Description

There are many different ways of using stone. The technical methods depend on the type of material and in what form it is available. There is a large spectrum within this category from using unprocessed river stone to highly-machined panels quarried from specialist sites involving a complex industrial process. For the purposes of this fact sheet the different stone techniques can be described as:

- Random rubble
- Dry stone
- Semi-dressed
- Gabion walls

<table>
<thead>
<tr>
<th>Choice:</th>
<th><img src="image1.jpg" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally fired brick or stone.</td>
<td></td>
</tr>
<tr>
<td>Stone was plentiful in this location (eastern district of Uganda).</td>
<td></td>
</tr>
<tr>
<td>Capacity building and training was needed</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Community participation:</th>
<th><img src="image2.jpg" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to get the community involved.</td>
<td></td>
</tr>
<tr>
<td>- Clearing fields of stones</td>
<td></td>
</tr>
<tr>
<td>- River stone</td>
<td></td>
</tr>
<tr>
<td>- Source from old landslides</td>
<td></td>
</tr>
<tr>
<td>- No quarrying needed</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foundations:</th>
<th><img src="image3.jpg" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal for strip foundations</td>
<td></td>
</tr>
<tr>
<td>Building Material</td>
<td>Location</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Random rubble walls</td>
<td>Uganda</td>
</tr>
<tr>
<td>Semi-dressed stone:</td>
<td>Uganda</td>
</tr>
<tr>
<td>Community lodge:</td>
<td>Namibia</td>
</tr>
<tr>
<td>Gabion wall structure:</td>
<td>Namibia</td>
</tr>
</tbody>
</table>

Photo Source: Rob Fielding
**Construction Type**
Load-bearing walls or structural piers.

**Building Category**
Heavy weight

**Size and Dimension**
Multi-storey. Limitless floor plans.

**Construction Components**
Stone and binding cementicious material, even mud mortar.

**Cost per m²**
Difficult to estimate. Depends on the source of the material and the amount of preparation work and energy that is required before it can be used.

**Building Process**
Often considered to require specialist skills only achieved after a long apprenticeship. Whilst this may be necessary for some high end quality work, for basic wall construction on single-storey small structures, good quality work can be achieved with short periods of training.

**Time Schedule**
Often considered to be a slow process, but where labour is plentiful or it is a community project then material collection can be a very positive contribution assisting also improving the sense of ownership.

**Durability**
Depends on the type of material. Most stonework will last hundreds of years. Some stones such as sandstone and limestone have working surfaces that can erode quickly once exposed to wind and rain but careful detailing and a good understanding of the material makes stone one of the most durable building materials available.

**Maintenance Requirements**
Usually low maintenance

**Modularization to Flexibility**
Flexibility only in the beginning, after construction only small cuttings possible but no structural changes (walls are load bearing)

**Potential for recycling – demolition**
100% recyclable. In developed countries, new stone is at the high end of the market and is often unaffordable. Reclaimed stone is very desirable.

**Local Value Creation**
The use of purely local materials and unskilled labour contributes highly positive to the local environment.

**Social Acceptance**
Often considered to be high status. A material that is often overlooked. For example, an example from a remote part of Uganda. Due to a poor road network Kapchorwa, on the eastern side of Uganda on the slopes of Mount Elgon considered that they were poor because they had limited access to markets. They thought they could not build without cement or steel. Yet, locally they had limitless availability of stone and sustainable timber. Skilled labourers were needed to train locals on how to use the indigenous materials.

**Why selected – benefits**
Low carbon, natural product
Excellent thermal and bioclimatic properties
Cheap, with low maintenance cost
Involves community participation
C Adaption potential

Track record
The method has been used for centuries in various parts of the world where stone is readily available.

Transfer Potential
Depends on local stone availability.

Possible Limitations - Chances - Improvement Options
Some specialist equipment and skills are needed. Transport costs may be high. Often sources of the material are in remote hills and are difficult to access.

D Limitations and risks - Zambia suitability

Has to be geographically specific where good quality river or quarried stone is available within a close range of probably less than 5 km.

E Further information

Example of how stone is being used in different ways in high end lodges and houses but gives an idea of what can be done:

Home Lodges and Dwellings, Stone Age Construction, 35b Van Riebeeckstreet, Barrydale 6750 ZA
Cell: 082 4669933 (John de Jager); Tel: 028 572 1508 (Office)
Email: john.dejager@yahoo.com; http://www.stoneagecon.co.za/

Nina Maritz Architect, P.O.Box 11944, Windhoek, Namibia
Tel: +264-61-220 752; Fax: +264-61-232 139
E-Mail: nina@mweb.com.na; www.architectureweek.com/architects/Nina_Maritz-01.html
INTERLOCKING SSBs

Country of Practice
Applied in several countries, widely spread in Africa, Asia and South America

Company  Institution  Source
Mr. Gyanendra R. Sthapit, Habitech Center, Asian Institute of Technology AIT, Pathumthani-12120, Thailand
Tel: (66-2) 524 5621; Email: sthapit@ait.ac.th; http://www.habitech-international.com

For the sake of this particular phase of this study, limited illustrations have been used. Build it International has a good and proven understanding of this technology. However, there are different profiles and systems which warrant further investigation and study.

A Description

Large range of ISSB profiles available

Hydraform range of products:

Sophisticated profile block making manual press
Construction Type
Load-bearing interlocking soil-cement block walls

Building Category
Heavy weight

Size | Dimension
Mostly one and two stories, however multi-storey buildings possible G3+. Various floor plans possible, on average around 40 m².

Settlement Environment
Rural, Semi-Urban, Urban

Construction Components
High quality, while low complexity offers real potential for improvement. For construction with soil it is referred to 1_04, for details about cement stabilized blocks the Fact Sheet 1_07 gives implications. The new component of this technology is the interlocking shape of the stabilized soil-cement blocks. These can be assembled without mortar, but they require sophisticated moulds and a high compressive force.

Initial Construction Cost per m²
A wide range of different projects and costs has been documented (www.habitech-international.com). The cost analysis of soil blocks has shown that non-stabilized blocks belong to the cheapest ones. However, they have significantly less good properties and durability. The stabilization with fibres, cement or enzymes causes an increase in skills and costs. The interlocking blocks can decrease the cost by keeping the quality but reducing the process requirements. Most of the projects range in between 40 - 80 $/m². In average a reduction compared to the conventional system stabilized block system of 30-50 % due to speed, skill level and mortar saving.

Building Process
Variation of the standard stabilized soil block: LOK BRIK System by AIT (Mr. Etherington), greater accuracy, speed and less skill required. Production made with a modified brick-making machine, which has two parallel upward trust pistons for a more accurate dimension and a system of positive and negative frogs to form recesses or protruding arts. No mortar is needed for bricklaying, in the vertical holes grout is poured and vertical steel reinforcement can be inserted for improved earthquake resistance. Apart from cost saving in material and labor, the uniformity and accuracy gives an appealing finish, so that no rendering is needed.

The building materials used in their construction can be fabricated in micro or small-scale production units when the total quantity of houses to be built is relatively small. Typical small-scale production facility can deliver the equivalent of 50 to 100 houses per year depending on their size and the equipment configuration of the facility. When the project involves the construction of many houses over a number of years then medium-scale production units can be set-up by contractors or housing cooperatives to supply construction activities. A typical mid-size production unit can supply the construction of 250 to 500 housing units per year.

Time Schedule
The mortar-less block can be laid up to five times faster than the conventional block, a five-man crew can erect and finish one unit within not more than 1 week. The placement of interlocking bricks is a dry process; wall construction is much faster than when using wet mortar. Furthermore there is no need for columns and beams as the walls are reinforced horizontally and vertically with steel using the cavities of the interlocking bricks. There is no need to prepare formwork for reinforced beams and columns. There is no need to cut other elements of the building system to put them in place as they already have the right dimensions based on the same module.

Economy of Scale | Mass Production
The new block shape required new pressing machines that allow the required precision of the bricks. A decisive price reduction through large scale production can be achieved. The production in a large scale approach is of advantage for the price. The reduction of costs through the increased construction speed multiplies itself within a large project.
Durability
The stability of the blocks has been increased significantly compared to non-stabilized blocks. Compared to concrete or burnt bricks, however, the blocks are still by far more attacked due to insects and humidity over the time. Due to the integration of reinforcement in the holes of the blocks, a significant improvement in the earthquake resistance has been achieved.

Maintenance Requirements
The maintenance requirements have been reduced in comparison to the non-stabilized blocks. However, frequent maintenance is still important in order to close cracks, repair damages or attacked blocks. An average rating has been given.

Modularization | Flexibility
Low potential. Even though advanced systems with different block modules were implemented, difficulties in realization remained.

Potential for recycling | demolition
As it is a natural building material, the inert material can be demolished or reused. The stabilizer, however, increases the effort of demolish the blocks into pulverized shape.

Local Value Creation
The interlocking blocks reduce the skill requirement of workers significantly. Due to the ease of construction, employment options in the spot are created. Labour unskilled during construction, higher precision required during production of the blocks. Affordable houses for this group are often built under self-help or mutual aid techniques whereby family members can participate either in the fabrication of the building materials or in the construction of the houses or in both activities.

References

Credit: FACT SHEET | TECHNOLOGY 1_13 1 (Corinna Salzer)
Pictures: FACT SHEET | TECHNOLOGY 1_13 2

Picture Source:
http://www.habitech-international.com and “Building with Earth”, CRATerre

http://sheltercentre.org/sites/default/files/2736_alt.pdf
This is a link to a very comprehensive document published by UN-Habitat in cooperation with GET. (Good Earth Trust). Interlocking Stabilised Soil Blocks – Uganda ISBN: 978–92–1–132150–0.