Draft Report for Milestone 5.

Light Earth Construction
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9.5 Durability Classes and Insured Lives for Light Earth Construction
Preface

This report forms part of the results of a research project carried out for the DETR and later the DTI under the auspices of the Construction Industry Directorate within the 'Partners in Innovation' programme.

The 18 month project has been carried out by Gaia Architects as Lead Partner in partnership with WS Atkins Project Officers and the DETR / DTI Policy Officers as part of a Steering Group which also included Gaia Research and Rebecca Little Contractors.

The overall aim of the project is to initiate and support the development of Light Earth Construction (LEC) in the UK as it is the partners’ opinion that LEC is an exemplar of sustainable construction and offers considerable potential to improve the environmental, social and economic profile of construction in the UK.

The specific project objectives are twofold. The first is to introduce the potential and benefits of Light Earth Construction to the UK industry. The second is to establish the technical viability of this technique in the UK and through this and a set of approved guidelines, to support compliance with building standards and lenders’ / insurers’ requirements.

In this way, the project aims to render the development of the technique on a widespread basis both technically and financially viable.

The three deliverables of the project are a demonstration building constructed and monitored near Melrose in Scotland, a website and this report. The construction of the building near Melrose is described in this report and it’s monitoring regime will be described in a later appendix to this report.

The report also contains the results of a series of tests to establish the technical characteristics of light earth, a number of case studies from around the world, guidance on the construction, maintenance and costs of light earth buildings, noting best practice advice based on the involvement of an Advisory Group of experienced practitioners from around Europe.
Acknowledgements

A wide range of people have made both direct and indirect contributions to this report only a few of which have been paid as partners or sub-contractors.

The development of Light Earth Construction across the globe owes much to the enthusiasm and dedication of certain pioneers. The most significant of these is the German Franz Volhard who wrote the seminal book on the subject. Others across Europe have been involved as part of the Advisory Group and thanks are due to all for their support and helpful advice and feedback.

The Advisory Group also comprised a number of UK individuals and organisations who donated contributions in kind by way of feedback and advice with regard to the financial, technical and other approvals required. Thanks are due to all who kindly gave of their time.

Sandy Halliday of Gaia Research and Rebecca Little of Rebecca Little Construction were invaluable as part of the Steering Group. Particular thanks are also due to Ian Chapman in New Zealand, Dr. Steve Goodhew at Plymouth University, Liam Dewar of Construction Resources, Peter Mayer at Building LifePlans, John Kelly, Barbara Chapman, Elaine Rainey and Linda Aderum at Gaia Architects, also to Iain Frearson, Eva Rut-Lindberg, Sjøp Holst and Päivi Rekula who wrote the Sections on the state of light earth across Europe in Chapter 4, and Jackie Thow - web designer.

Gaia Architects would particularly like to thank Ian Milford and Adam Andrews from WS Atkins for support during the project and to the DTI for the bulk of the financial support of the project.

Special thanks are due to Neil Cockett and Ann Morgan for their courage and trust in investing their money in the Light Earth project at Littlecroft. Thanks are also due to all those who volunteered to help build the walls at Littlecroft as part of the series of workshops held during the summer of 2001.
Glossary of Terms

Additives
Substances added to the base material to improve certain properties. Examples in Light Earth Construction include dung, animal urine or hair or chopped straw in plasters and renders, water glass, plant oils, lime, sawdust and other fibres in the main mix.

Earth
In the context of Earth building, Earth means Soil (normally sub-soil) which has not been fired. Thus it is often referred to as unburnt or unfired earth, and blocks made as unburnt blocks etc.

Earth building
Construction techniques using soil (normally sub-soil) in combination with other natural materials.

Embodied Energy
The energy embodied in a material is equivalent to the total amount of energy used in bringing the material to its present state, that is, the energy used in extracting / harvesting, modifying / manufacturing and transporting the material to site. Many modern building materials have very high amounts of embodied energy.

Hygroscopic
Term used to describe the ability of some materials to absorb and desorb moisture from the surrounding air.

Light Earth
A mix of clay and fibre or other fill material such as straw, woodchip, expanded clay or glass bead forming a solid yet insulative wall within a structural framework.

Mix
Term used informally on light earth building sites, and in this report to describe the clay slip and fibre mix which is ready to be installed into the walls.

Moisture Transusive
Used to describe a material or composite such as a wall or roof etc. which is vapour permeable to a greater or lesser extent, allowing moisture to move from one side to the other and escape.

Monolithic
Within Light Earth Construction this term is used to denote walls made with shuttering which produces a monolithic or continuous mass of light earth, in contrast to block- or panel built walls.

(Clay) Slip
A slurry of clay and water of any consistency from milky to a soft paste, used in Light Earth Construction for coating fibres.

Sustainability
The concept of managing the use of natural resources such that the amount of the resource is not irretrievably depleted. Development taking place in this way is termed ‘sustainable development’ and has been defined as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (ref. 8.3.12).

Sub-soil
Soil that occurs below the organic horizon (top-soil) and above the bedrock.
Waste

Waste is defined in the Control of Pollution Act (1974) as including:

a) Any substance which constitutes ... an effluent or unwanted surplus substance arising from the application of any process

b) Any substance or article, which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled.

The crucial aspect being that the material is perceived to have no further use.
1 Introduction

The purpose of this chapter is to introduce the subject of Light Earth Construction and provide some context within which the rest of the report can be set.

Light Earth Construction is almost unknown in the UK, and the first sub-section is included to give a brief introduction to the technique to enable the reader to appreciate what follows without going into the detail provided in Chapter 3. The three other sub-sections set Light Earth Construction in the contexts most helpful to a good understanding of its potential role in the future of UK construction.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the most pertinent points.

Sub-Contents

1.1 A Typical Light Earth Building
1.2 A History of Light Earth Construction
1.3 The Context of Light Earth within Earth Construction
1.4 Light Earth Construction and Sustainability
   1.3.1 Environmental Issues
   1.3.2 Economic Issues
   1.3.3 Social Issues
Summary

(1.1) Light Earth is the generic name given to a method of construction whereby straw, woodchip, hemp, or some other suitable 'fill' material is coated in clay slip and set within shuttering as simple infill for walls. Light earth is never used in a load bearing capacity but is set within a frame to which both the shuttering, and later services, joinery etc. are fixed. Light Earth is usually made in-situ, but can equally be constructed from blocks / infill panels. The surfaces are normally rendered on both sides, with lime based or earth renders.

(1.2) Light Earth Construction as practised today was only recognised in the middle of the 20th Century as a discrete technique and first documented in Germany in 1933 by Wilhelm Fauth (ref 8.2.4). The technique did not develop widely until the 1980s when, along with a number of 'ecological' or 'neo-traditional' techniques, it was promoted and developed by enthusiasts, particularly in Germany but later across the world.

The seminal book on the subject was written by Franz Volhard in 1983, called "Leichtlehmnbau" ("Light Earth Building") (ref 8.1.2) and this was followed by a small number of minor publications across Europe. Several examples were produced across Europe, particularly Germany but it is only in Germany and New Mexico, US where Light Earth Construction has been recognised within official documentation on building regulations and standards.

(1.3) In comparison with other earth building techniques, Light Earth Construction is perhaps most closely linked to 'wattle and daub' in that it relies on the frame for structural strength and stability and is only an infill material. However, it is also a tamped and shuttered construction akin to 'rammed earth' so holds a peculiar place among the lexicon of techniques. Unlike both of the above, the earth mix is used extremely wet and clayey such that it relies on the shuttering and the fill material for stability until the clay dries. Light Earth, as with conventional earth can be readily used in block form, hand or machine made, compressed or otherwise, and so further eludes neat classification!

(1.4) Light Earth Construction addresses all three criteria of sustainable development, namely environmental, economic and social issues.

Environmentally, resource use overall is reduced by orders of magnitude whilst waste is avoided altogether. Energy efficiency in use and embodied energy of materials are both radically addressed by the technique. Economically, the potential to reduce costs in significant where high labour costs can be reduced to complement the extremely low material costs of the technique. Socially, the health benefits of light earth are considerable.
### 1.1 A Typical Light Earth Building

The purpose of this Section is to introduce the basic and typical composition and characteristics of a light earth building for those not familiar with the technique. This is not to suggest that all light earth buildings are the same, but to provide a basic understanding against which the different materials, techniques and finishes described throughout the report can be appreciated.

1.1.1 Light earth buildings share the same types of foundations as conventional construction and these can be broadly grouped into solid foundations, usually with base walls and low level damp proof courses to raise the light earth elements above the splash level of the ground, or, suspended ground floors on pads, ground beams or similar where the light earth element can begin from the floor level.

1.1.2 The structure of all light earth buildings is formed by a frame which takes all structural loadings. This is usually in wood but can be made of any material such as steel or concrete. The light earth element is only ever infill between this structural framework.

1.1.3 The framework is normally built first and the roof constructed so that all subsequent building works can continue under shelter if necessary.

1.1.4 It is then usual to fill the walls with light earth mix. This is normally made by preparing clay slip from clay and water and adding this to straw, woodchip or other fibrous or fill materials. This wet mix is then placed between shuttering which is fixed to the inner and outer faces of the frame. The shuttering is removed and the mix remains in the wall, dries and sets solid. This is known as ‘monolithic construction’ since the resultant wall is a monolithic or homogeneous mass of light earth with no joints. It is also possible to use permanent shuttering.

1.1.5 Alternatively it is possible to prepare blocks or panels made of light earth and lay
these within or around the frame just like conventional blocks. This technique tends to be quicker on site and avoids the problems that are sometimes associated with the drying out of monolithic walls.

Left, first ‘scratch’ coat on light earth on a brick plinth in the Netherlands, right, finished lime render over light earth block wall in Sweden.

1.1.6 When the walls are dry, they can be plastered internally and rendered externally, or clad with a ventilation gap behind the cladding. The renders and plasters used should enable the wall to ‘breathe’ and so tend to be either lime or clay based. Heavy fixings need to be fixed to the framework but light fixings can be made directly into the light earth itself.

1.1.7 In all other respects, light earth buildings are completed in the same way as conventional buildings. Existing buildings can be refurbished using light earth as infill in place of, say, original brickwork.
1.2 **Brief History of Light Earth Construction**

The purpose of this Section is to provide a brief historical context for the wider consideration of Light Earth Construction developed in this report.

1.2.1 Many of the timber framed buildings constructed before the 20th century contained straw within the earth infill between timbers. In some cases the extent of the straw might lead one to conclude that the result was a sort of prototype or nascent ‘Light’ Earth construction, but there is no evidence of a separate identity for these constructions from what would be understood as wattle and daub or other traditional infill technique.

1.2.2 The History of Light Earth Construction as an identifiable and discrete technique begins in Germany in the 20th Century and the impulses behind its development are closely bound up with that of earth building generally, hence the inclusion of Section 1.4 which provides this context.

1.2.3 In terms of traditional building crafts, the period up to the First World War was similar in Germany to many other European countries. Vernacular crafts and traditions were still practised, but they were increasingly seen as ‘old fashioned’ and were generally phased out in preference to the modern materials and techniques of the time.

1.2.4 As this happened, there was a growing realisation of what was being lost, and a number of people made attempts to document the traditional practices.

1.2.5 The technique of *Strohlehmstanderbau*, or packing straw-clay into shuttered forms similar to those used for rammed earth were described by Wilhelm Fauth in magazine publications issued in Berlin in 1933, and this was followed by the 1948 book, also by Fauth, entitled ‘*Der Praktische Lehmbau*’, from which the following two illustrations are taken.

![Illustration from Fauth's book 'Der Praktische Lehmbau' showing the different stages involved in creating light earth walls.](image-url)
1.2.6 The following thirty years saw a number of experiments and publications, mostly in Germany, but it was not until the 1980s and the growing ecological awareness of the time, that the sustained and widespread interest in traditional building techniques and materials took a foothold.

Illustration from Fauth’s book ‘Der Praktische Lehmbau’ showing a Cross Section of a light earth wall with a central pole structure and outrigger frames for shuttering.

1.2.7 This interest led to a revival of many traditional craft based construction methods. Earth based construction began to be studied as a viable modern construction alternative, particularly in France and Germany, and with the growing confidence of first hand experience, practitioners began to experiment further.

1.2.8 The interest in Light Earth Construction through the eighties remained mostly in Germany, and was due largely to the work of Franz Volhard who subsequently wrote the seminal book, "Leichtlehmbau" ("Light Earth building") on the subject. (ref 8.1.2)

1.2.9 Toward the end of the eighties, the ecological building movement developed more organised communication and the ideas and interest in LEC Germany spread to other European countries as well as the US.

1.2.10 The 1990s saw the inclusion of empirical information about Light Earth being incorporated within German legislation and documentation aimed at formalising and legitimising earth construction, and the State of New Mexico in the US, through it’s Construction Industries Division, published standards for LEC, known as it’s ‘Clay Straw Guidelines’. 
1.3 The Context of Light Earth Construction within the Overall Earth Construction Vocabulary

Having described the historical context of Light Earth Construction in Section 1.2, the purpose of this section is to describe LEC within its modern context, as part of the global re-development of earth building.

1.3.1 Uniquely among earth building techniques, Light Earth Construction has not developed from a recognisable tradition of building. However, as mentioned in Section 1.2, the development of Light Earth Construction shares the same impulses - the revived interest in traditional techniques and the overall interest in sustainable forms of construction - which have led to the development of modern earth building generally.

1.3.2 The position of light earth within the lexicon of earth building techniques is shown below in the diagram created by CRATerre, the French earth building organisation (ref 8.6.2.4).

Earth Building Mandala showing different available techniques grouped into 18 types and 12 generic types.

1.3.3 In the UK at least, one method could be added to the 18 techniques mentioned, that of the use of clay and earth as a mortar within stone, brick or rubble walls. Of these 18, 12 generic types are noted (in the inner ring, and numbered along the outer ring) and of these, 8 are briefly described below.
1.3.4 Adobe (8) is the name for sun baked or dried bricks, more or less hand made, and containing a relatively thick, dry and malleable mud mix to which straw is often added. These are stacked, as per conventional construction, to form load bearing external and internal walls (as well as ceiling vaults etc.) and are usually finished with a earth or lime based plaster or render on both sides. Adobe is usually associated with Central America, Africa and Asian countries, but is equally applicable throughout the world.

1.3.5 Rammed Earth (part 5) as it’s name suggests, involves making a strong formwork, often of metal reinforced plates, and tamping down a fairly dry earth and sand mix to form heavyweight monolithic load bearing walls. The tamping may be by hand, but as with machine moulded adobe, the technique has been significantly developed over the past 25 years, and is now carried out in a largely mechanical site process by experienced and organised construction companies who specialise solely in such buildings.

1.3.6 Compressed Earth Blocks (part 5) are generally larger and more specifically mechanically compressed than adobes. This compression drives out moisture and enables the blocks to take on considerable compressive loads. Both walling and flooring blocks are now available.

1.3.7 Cob (7) is the English term for what is generically known as stacked earth. Stacked earth uses fairly dry mixes, usually with straw for reinforcement, placed or stacked on a wall and trampled or hand tamped into a monolithic wall construction capable of taking considerable loads in compression, but not to such a degree, or to such a calculable extent as the more mechanised procedures. Stacked earth is the most common traditional earth construction method in the UK.

1.3.8 Direct Shaping (6) is perhaps the most basic of earth building techniques. it is thus the most ancient, yet still widespread in many countries. Only the hands of the builder are required to take earth from the ground, mix it with water if necessary for plasticity, and form walls, vaults etc directly into almost any shape. Shrinkage is the principal problem with this technique since there are no obvious lines of weakness to direct the shrinkage associated with drying of the clay mass.

1.3.9 Wattle and Daub (part 12) is the English term for a fairly wet mix applied to a (usually) timber frame as infill. A principal frame is usually fitted with a secondary, smaller scale lattice or series of armatures to which to secure the earth mix. Straw or other fillers / reinforcements are needed to control the shrinkage inevitable in a wet and clayey mix. This and similar techniques were common where timber is an abundant resource, whilst many of the other methods tended to develop in regions without any or significant timber.

1.3.10 Light Earth (11) described as Straw-Clay in the diagram is perhaps most closely linked to wattle and daub in that it relies on the frame for structural strength and stability and is only an infill material. However, it is also a tamped and shuttered construction akin to rammed earth so holds a peculiar place within the whole. Unlike both, the earth mix is used extremely wet and clayey such that the mix
relies on the shuttering and the straw for stability until the clay dries. Light Earth, as with conventional earth can be readily used in block form, hand or machine made, compressed or otherwise, and so further eludes neat classification!

1.3.11 Daubed Earth (part 12) is simply a term for the use of clay in plasters and renders, and this could be onto any suitable substrate. Similarly, earth walls of whatever technique do not have to be covered with earth, or indeed any plasters, so the method is described separately. This report describes the use of certain plaster and render mixes, but it is not the main focus of attention for the above reasons.

1.3.12 Of all of the above, the first three, rammed earth and the various types of block formation, have received huge amounts of interest and hence development in the last 25 years. There is now a wide range of informative documentation and many thousands of modern examples, along with formal and legislative recognition in many countries. The other techniques, such as Cob, Wattle and Daub and Light Earth have received considerably less attention worldwide and yet are perhaps more applicable to the UK situation, being more akin to the traditional examples of the region. Recognition of this is growing, and a number of references are made in this report, but it is hoped that this research can be seen in the light of this attempt to balance the information and interest in earth construction generally toward a more locally useful understanding of the potential to use earth in construction.
**1.4 Light Earth Construction and Sustainability**

The DETR publication ‘Building a Better Quality of Life - A Strategy for more Sustainable Construction’ (ref 8.3.7) stresses that sustainable development “… means achieving social, economic and environmental objectives at the same time.” (p.7).

It is the belief of the partners in this project that the technique of Light Earth Construction simultaneously addresses these three criteria and as such provides an exemplar of sustainable construction which offers numerous benefits to the UK industry stakeholders. These benefits are discussed briefly in this section. Whilst arranged discretely, there are obvious overlaps between the three criteria.

**1.4.1 Environmental Issues**

**1.4.1.1 Resource Use**

One of the principal tenets of environmentally benign construction is the reduction of (finite) resource consumption through efficiencies in use and reduction of the waste stream. Renewable resources are ideal, while those in plentiful supply are preferred over rare or difficult to source materials. Toxic and non-biodegradable elements represent a long term waste problem whilst efficient design and manufacturing techniques can prolong the useful lifespan of each element. Safely biodegradable materials offer the only true zero waste option.

**1.4.1.2 Light earth construction represents the ideal response to these issues. The majority of materials used, by volume, in light earth construction are renewable such as timber (for framing and woodchip infill) and straw. The earth component is extremely plentiful, is not competitive with any other uses and is widely and easily available.**

**1.4.1.3 All materials used are non-toxic and biodegradable so they can be safely composted at the end of their useful life. The earth element simply returns to its original place unchanged while the cellulosic elements decay to form humus. Being renewable this represents a zero waste resource cycle. In addition, Light Earth Construction is a resource efficient technique generating little waste on site as only that which is needed is made and any ‘leftover’ material can be readily reused.**

**1.4.1.4 Energy Efficiency**

Another important issue is energy use which is related to atmospheric pollution and many other environmental problems. Energy use can be reduced both in the operation of buildings, and in the energy used to create the materials from which the buildings are made.

**1.4.1.5 The greatest improvements are to be made in the reduction of energy use to heat and maintain buildings. Light earth elements can be designed to be highly thermally insulative and fit well with a strategy for low energy consumption in buildings. However, they also contain thermal mass, and this quality offers considerable potential to reduce energy use by providing warm internal surfaces which allow for lower air temperatures whilst still achieving good comfort conditions. The balance of insulation and thermal capacity can be adjusted by**
altering the mix of ‘fill’ material and clay and this offers considerable flexibility to
the designer wishing to optimise energy performance in a building.

1.4.1.6
Energy used to extract, manufacture and transport materials is known as
embodied energy and can be very high in some highly processed and imported
materials. By contrast the materials used in light earth require little or no energy to
extract, harvest and manufacture and relatively little to transport, being widely
and easily available.

1.4.2
Economic Issues

1.4.2.1 Cost
The materials used in light earth construction are extremely cheap, and this
is generally true worldwide. As such there is significant potential to reduce the costs
of construction although these low material costs have to be balanced against
generally higher labour costs. In situations and areas where labour costs are also
cheap or not accounted for in the conventional way (such as in some self-build or
government backed employment schemes) the costs of light earth construction
compare favourably with conventional construction types. Even where labour costs
are high, appropriate mechanisation of the build processes renders light earth
construction a competitive form of construction.

1.4.2.2
Because of the ready and widespread availability of materials noted above, and
the simplicity of the manufacturing processes involved, there is potential for the
localised mechanical production of light earth elements to be simple and cost
effective. This has been found to be the case in areas of Europe where such
operations have been developed, though the simple economies of scale have
undermined the relative costs.

1.4.2.3
Where economic assessments are applied which involve Life Cycle Analysis and the
inclusion of externalities often disassociated with the ‘true’ environmental costs of
manufacture and construction, the environmental and other economic benefits of
light earth noted in this section could be expected to further reinforce the economic
case for light earth construction.

1.4.2.4
The potential for light earth construction to contribute to energy efficient building
operation noted above obviously has a direct influence on the financial cost of
building operation and UK competitiveness in its widest sense.

1.4.2.5
Light earth construction benefits from the advantages associated with frame
construction such as speed of construction, the separation of structure and mass
freeing design possibilities and being able to construct the roof early thus enabling
construction to continue with less susceptibility to the weather. The technique fits
into the existing industry preference for, and experience of timber frame
construction so may be more readily adopted than other ‘ecological’ methods. It
also offers the potential to construct ‘masonry look’ buildings - often a condition of
Planning Departments - without the need for an external leaf of concrete
blockwork and associated weight and foundation costs.

1.4.2.6
The technique is extremely flexible on site as all materials are easily adjusted and
machined to suit conditions. No special tools or skills are required and this allows minor and late alterations and improvements to be made without excessive time, safety, or cost implications. In addition, completed light earth buildings remain relatively easy to alter and extend thereby reducing the costs associated with the long term flexibility and responsiveness of these buildings.

1.4.2.7 Durability

Compared to many conventional material and construction combinations, light earth is relatively resistant to damage from fire, albeit not classified as non-combustible, due to the presence of clay. As such it represents a relatively durable and safe construction.

1.4.2.8

The moisture transfusive and hygroscopic nature of light earth construction also protects the structure and fabric intrinsically from damage due to moisture without the need for chemical preservatives and vapour barriers which are susceptible to poor installation and subsequent damage from tradesmen and occupants.

1.4.3 Social Issues

1.4.3.1 Health

The fact that all materials associated with light earth construction are simple to use and entirely non-toxic mean that the technique is easy and safe for all builders.

1.4.3.2

The non-toxic nature of the materials is also of significant health benefit to occupants, particularly when combined with the hygroscopic nature of the construction which tends to balance internal relative humidity and thus reduce many of the potential health risks from swings in humidity in the internal air.

1.4.3.3

The thermal capacity of the light earth wall noted above contributes to a moderation of temperature swings, raises the internal surface temperature of the walls reducing the radiative heat loss of occupants and improves the thermal comfort of the space overall.

1.4.3.4 Self build

In combination with its low material costs and flexibility of use, the safe and non-toxic nature of the materials used should endear the technique to self builders and others interested in potentially low cost and healthy construction.

1.4.3.5

Lastly, it should be noted that many of the benefits noted above are less or not applicable to expanded mineral aggregates such as foamed glass balls sometimes used in light earth construction. However, the use of these materials is marginal as yet and the bulk of projects use timber and straw based materials as described.
2

Material Characteristics

The purpose of this chapter is to establish the technical characteristics of Light Earth Construction. This is seen as the first step in gaining the requisite acceptance from bodies related to the Construction Industry. International experience and research has been collated and compared, and UK bodies Plymouth University and Fire Consultants ‘Chiltern International Fire’ (allied to TRADA) have been contracted to undertake additional tests where necessary.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the conclusions to be drawn.

Sub-Contents

2.1 Material Characteristics
2.1.1 Definition
2.1.2 Components of Light Earth

2.2 Structural Characteristics
2.2.1 Resistance to Consolidation and Shrinkage
2.2.2 Strength in relation to fixings

2.3 Durability
2.3.1 The Importance of Maintenance
2.3.2 Corrosion of Metals
2.3.3 Sunlight
2.3.4 Biological Agencies
2.3.5 Water and Frost
2.3.6 Abrasion and Impact

2.4 Thermal Characteristics
2.4.1 Thermal Conductivity
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2.4.3 Application of Thermal Measurements
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2.5 Moisture and Humidity
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2.6 Acoustic Requirements
2.6.1 Sound Insulation
2.6.2 Building Control Requirements

2.7 Behaviour in Regard to Fire
2.7.1 General
2.7.2 Combustibility
2.7.3 Ignitability
2.7.4 Spread of Fire
2.7.5 Fire Resistance
Summary

(2.1) Light Earth Construction is a form of earth construction using a clay slip coating over any suitable fill material. Light Earth is any such mix below a density of 1200 kg/cu.m.

(2.2) Light earth is generally used as infill between a loadbearing frame. It does not have great compressive strength, though certain fill materials have greater consolidation resistance than others. Lighter mixes, particularly straw-clay mixes can suffer from shrinkage upon drying but this can be minimised. Fixings can be made direct into most mixes but heavy loads should be fixed back to the load bearing frame.

(2.3) Well designed, constructed and maintained light earth properties will last indefinitely. The only significant risk to the durability of light earth construction comes from prolonged and excessive wetting which can lead to decay. Otherwise, light earth is not subject to any particular risks of deterioration.

(2.4) The thermal properties of light earth can be adjusted by design and are intimately linked to its density; the lighter the mix the greater its insulative capacity, while the greater the clay content, the greater its ability to store heat (thermal capacity). In practice light earth is both insulative and thermally massive which is a valuable and unusual combination offering both energy efficiency and moderated thermal comfort. The lighter mixes can be effectively used in the UK for external walls being reasonably insulative, but trade-offs may be required under the new regulations.

(2.5) Light earth construction operates as moisture transfusive construction and so is inherently protected against the risk of interstitial condensation because of the vapour permeability and hygroscopicity of the materials used. In addition, the ability of these materials to absorb moisture allows light earth walls, in conjunction with earth based coatings, to moderate internal humidity levels with considerable benefits to the health of occupants. Paint or other finishes must be vapour permeable or microporous for this to remain the case.

(2.6) Acoustic criteria only apply in limited situations but while dense earth performs well in insulating against sound transfer, light earth, having less mass in general, performs less well. Light earth walls can be designed to perform as required but require cavities in much the same way as timber frame walls.

(2.7) Light earth is difficult to ignite but officially combustible due to the presence of combustible fill material (unless mineral fill is used). Even without plaster coatings, its resistance to fire is good but the presence of plaster coatings in use allows it to be used for all situations under the Building Regulations except those requiring non-combustible materials only. Mineral fill mixes can be used in all situations.
2.1 Material Characteristics

2.1.1 Definition

2.1.1.1 The term "Light Earth" derives from the German term "Leichtlehm" which translates literally as "Light Loam". It is a little misleading, as a more accurate term might be "Clay coated Straw, Clay coated Woodchip, or Clay coated Expanded Clay". Clearly “Light Earth” operates as a generic name for which any type of filler can be used, the principle of a non-loadbearing, clay coated insulative mass remaining the same.

2.1.1.2 In Germany, where Light Earth Construction (LEC) is an established form of earth building, the use of the term "Light Earth" differentiates it from denser forms of earth construction, one of which, confusingly, is called "Strohlehm", or "Straw Loam". What the Germans call "Straw Loam" is actually the consistency of what we would term "Cob" or "Mudwall" in the UK, being largely earth with some straw added for reinforcement. In the US, LEC is habitually referred to as "Straw-Clay" which adds to the confusion.

<table>
<thead>
<tr>
<th>Density, kg/cu.m</th>
<th>German Term</th>
<th>Nearest UK Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1200</td>
<td>Leichtlehm</td>
<td>Light Earth</td>
</tr>
<tr>
<td>1200 - 1700</td>
<td>Strohlehm</td>
<td>Cob in England / Mudwall in Scotland</td>
</tr>
<tr>
<td>1700 - 2200</td>
<td>Massivlehm</td>
<td>Rammed Earth, Pressed Adobe or Block</td>
</tr>
</tbody>
</table>

2.1.1.3 Whatever its shortcomings, its as a generic title has persuaded all non US practitioners to stick with the German definitions stated in DIN 18951 which are related to density and are tabled above. A description of the various types of earth construction is found in Chapter 1.

2.1.2 Components of Light Earth

2.1.2.1 Before investigation of Light Earth as a composite material, it is worth mention of the more pertinent characteristics of the individual component materials commonly used. Clay, water and air, described first, are common to all light earth mixes whereas any of the various fill materials may be used, and in any combination.

2.1.2.2 Clay

Earth, excluding the organic humus layer, is a mixture of clay, silt, sand, gravel and rock. In soil science, the definitions are by size of particle and are characterised as shown below. Earth mixes containing a greater proportion of one or the other are known as 'clayey', 'silty', 'sandy' and so on.

<table>
<thead>
<tr>
<th>Particle Size, in mm</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.002</td>
<td>Clay</td>
</tr>
<tr>
<td>0.002 - 0.06</td>
<td>Silt</td>
</tr>
<tr>
<td>0.06 - 2</td>
<td>Sand</td>
</tr>
<tr>
<td>2 - 20</td>
<td>Gravel</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>Pebbles, Stones etc.</td>
</tr>
</tbody>
</table>
2.1.2.3 Although silt, sand and sometimes even gravel will be naturally present in a light earth mix, light earth as a practice concerns itself only with the clay content since this is the only component which can act as a binder. Clay is the common feature and binder in all forms of earth construction.

2.1.2.4 Clay is a result of the specifically chemical erosion of rock, and particularly of silicates such as feldspar, and micas. There are a large range of clay types but the majority are either kaolinites, illites or montmorillonites. A helpful description of earth and clay with reference to earth construction is given in Houben & Guillaud, ref. 8.1.7.

2.1.2.5 Clay acts as a binder because of its cellular and chemical nature while silt and sand are essentially inert and have no binding force of their own. Clay molecules are lamellar in nature, that is, they are formed from minute sheets which join to create wafer-like molecules. These exert a considerable binding force on each other and on adjacent materials. These binding forces are largely electrostatic and related to the presence of water (see paragraph 2.1.2.12 below), but other forces such as cementation, capillarity, electromagnetism and friction play a part.

2.1.2.6 Since cohesion is closely related to surface area, a convenient way of gauging the binding potential of a material is its specific surface measurement. The specific surface of a material is the sum of all particle surfaces and is measured in square metres (or millimetres) per gram. Coarse sand has a specific surface of 230 sq.mm/g, that of silt is around 4,500 sq.mm/g whilst clays range from 100,000 sq.mm/g (kaolinites) to 10,000,000 sq.mm/g (montmorillonites). The figures indicate why clay is the crucial binding element in all earth construction.

2.1.2.7 In solid earth walls, the components are all small and of different sizes so that they fit closely together and the clay is able to exert a considerable binding force on the mix. In light earth construction, there is less adjacency of surfaces and less surface area between which the clay can act as binder. The clay still acts as the principal binder, but while materials like straw-clay also gain their rigidity from the reinforcing nature of the straw, mixes using only expanded clay or glass beads are susceptible to this lack of surface to surface cohesion and appropriate measures need to be taken.

2.1.2.8 Pure clays have a density of around 2500 kg/cu.m. In light earth construction, it is the clay, silt and sand contained in the original earth material which provide the vast majority of the mass of the overall mix. These give the mix its thermal capacity, some of its compressive strength, most of its capacity to absorb sound but reduce its insulative capacity. The presence of the clay also affords some protection against biological decay, most of the mix’s capacity to absorb and regulate moisture and lastly, it is the clay which affords the protection against fire in all but the mineral light earth mixes.

2.1.2.9 Water Water is used at the beginning of the construction process to make the clay slip or slurry necessary to fully coat the fill material. However, the water evaporates over time leaving a relatively dry and solid mix. The presence of so much water in the mix at this early stage poses the principal threat to monolithic light earth from
decay so every effort is made to abet the natural drying process. Some practitioners have used liquids such as water-glass and urine to reduce the water content without loss of performance but there is little conclusive evidence of these materials offering any or significant improvements in this respect.

2.1.2.10 Prefabricated blocks or panels can be made whereby the drying process can be more carefully controlled and over smaller elements. This circumvents the most problematic aspect of monolithic construction and if only for this reason is popular with many practitioners.

2.1.2.11 Once "dry", a significant amount of water remains in the mix in four distinct states. Free Water remains in the mix according to ambient humidity levels and is subject to gravity and capillary action. Condensation is a form of free water. Pore water is that water which is retained within the smaller pores of the materials because the capillarity there is greater than the hydrodynamic forces which effect the free water. Both the above will evaporate under room temperatures, though pore water will require a long time or some kiln drying. These two states of moisture and their movement are discussed in greater detail in Section 2.5.

2.1.2.12 Absorbed water takes the form of a very thin film which covers internal and external surfaces. The electrostatic bond which holds this water is strong and it can only be released by heating up to 200 °C. Structural water, or 'Water of Crystallisation' is chemically bound to the materials forming crystalline networks within the material and can only be released by heating up to 600 °C or so.

2.1.2.13 Even under extremely dry circumstances where all the free water is driven off, a mix will still contain the other three water types, none of which pose any threat of decay. It is only excessive amounts of free water, that cannot be absorbed by the materials in a wall which pose a threat of decay. This is because it is the humidity levels, that is, the 'free-water-in-the-atmosphere' levels that determine fungal and other biological development. Elements with less than 20% relative humidity, however much pore, absorbed and structural water they contain, are essentially 'dry' as far as fungi and insects are concerned.

2.1.2.14 Like the clay, water within light earth walls provides some of its mass and hence thermal and acoustic capacity. It also reduces the insulative characteristics. The water affords no great protection against fire since it is quickly driven off under normal fire situations.

2.1.2.15 Air

It is the air trapped within the mix which affords the element its insulative capacity, as long as the air gaps are not too large. It is the principal function of the fill material to trap this air and whilst the fill materials have an insulative effect of their own, it is the extent to which they trap in within themselves that constitutes the material's insulative capacity. To work best, air pockets should not be larger than 20mm in any direction and it is height which should be avoided most since small, vertically aligned air gaps will set up convection currents - and thus transfer heat - more effectively than horizontally aligned gaps.

2.1.2.16 Straw

Straw is a generic term for the stalks of, usually, cereal crops. These stalks are separated from the seeds at harvesting and baled for storage. They are used for
several agricultural and other purposes, but mostly bedding for animals. The straws of all the common cereal grains are very similar to each other in chemical composition comprising cellulose, hemi-cellulose and lignin in the main.

2.1.2.17

The most common straw types in the UK are barley, wheat, rye, oats and maize. Opinions between practitioners over which type is most effective differ slightly but in practice there is little to choose between those mentioned, with the possible exception of oats which are felt to be softer and therefore more susceptible to consolidation. Other straws that could be used are rice stalks, flax, hemp, reeds and no doubt many more. Reeds are likely to be expensive because they have greater value as thatching material, whilst hemp is of considerable interest having several environmental advantages and being of greater rigidity than the other straws commonly used. Hemp, which should be distinguished from Marijuana, is not yet readily available in the UK, due partly to its misconstrued relationship with its more notorious ‘cousin’. Rice is similarly tough, having a high silica content. In all cases organically grown versions are to be preferred, not only for wider environmental reasons, but because artificially grown straws tend to have enlarged and more ‘spongy’ cell growth and are subsequently softer and more susceptible to decay. Only completely dry straw should ever be used. Even slightly damp, ‘green’ looking or musty smelling straw should be discarded.

2.1.2.18

As the fill material in light earth mixes, straw provides the trapped air which offers insulative properties. In this respect straw is one of the better fill materials. However, straw tends to soften with the addition of the slip and so is more prone to consolidation / shrinkage than most other fill materials. The extent to which it does consolidate also affects its otherwise advantageous thermal performance. It is also more susceptible to decay than the wood-based fill materials. Straw is more susceptible to fire than timber but this difference is largely negated by the presence of the clay.

2.1.2.19

Despite some of its relative disadvantages, straw remains the most popular choice for light earth in most parts of the world. This is partly because it is usually the cheapest fill material, often the most readily available and requiring the least preparation. It is also because if the building is correctly designed, constructed and maintained, its various theoretical disadvantages do not matter because it will work just as well as all the other materials discussed.

2.1.2.20 Hay

It is important to emphasise that hay is not technically a straw and should not be used. Hay is a grass and is normally stored with its seed heads, it is thus more susceptible to decay and insect attack and does not have the same hollow structure and rigidity as straw so would not create a good insulative mix. Straw is a hollow stem with the grains removed and as such offers no ‘food’ for rodents or insects. It is also relatively dry. Hay has been used in (dry) bale construction in the US but is not common as it is more expensive because of its value as an animal feed.

2.1.2.21 Woodchip

The use of woodchip for light earth construction has developed particularly in Germany where its ability to be more easily mechanically mixed has proved popular as it speeds up the preparation time on monolithic construction. It is also preferred in places where straw is not easily or cheaply available and is considered
less prone to fungal decay.

2.1.2.22

Any type of timber can be used, hardwoods and more durable softwood species are sometimes preferred but it is generally held that this will make little difference to the durability of the mix. Ideally bark should not be used, but since it is usually the smaller branches which are chipped - saving the larger section timber for more valuable uses - this can be difficult to avoid. The presence of bark increases the susceptibility to decay, which negates to some extent its advantage over straw.

2.1.2.23

Like straw, timber is largely cellulosic but is denser and so has greater thermal conductivity. However, in practice it does tend to resist consolidation better and so does not always perform as relatively poorly as the figures would suggest. It can be more at risk of crumbling or breakage because it does not have the same reinforcing capacity as straw. Once installed though, fixings are normally firmer than any other fill material as it is both dense and relatively elastic. Its characteristics of moisture hygroscopicity, acoustic performance and combustibility are more or less the same as for straw.

2.1.2.24 Cork

Cork granules can be used as the fill material in light earth. In most respects these are similar to those of woodchip but cork is less dense and so has a correspondingly better thermal insulative value. It is, however, more expensive in general and has less compressive strength making it more susceptible to breakage and crumbling, particularly at corners. For these reasons it is not common, but could be beneficially used in combination with straw, for reinforcement, and other materials.

2.1.2.25 Wood shavings

Wood shavings are occasionally added to light earth mixes. In most respects these are similar to woodchips as described above, the smaller size and shape of shavings can potentially create a texture akin to that of commercially available woodwool slabs. The author is not aware of their use on a monolithic construction and understands that in practice, such lightweight textures are difficult to achieve with shavings alone. This is probably because they compress too easily. This could be avoided by allowing each lift to dry sufficiently before installing the next. Shavings could be beneficially used in combination with other materials to balance different characteristics.

2.1.2.26 Fibres and dust

Small fibres, sawdust and other fine materials such as rye flour have been used in both experimental and commercial block making. The addition of fine particles tends to aid the workability and cohesion of the mix, but requires a greater water content because such materials soak up the water more readily. They also hold onto the moisture more than larger particles and so increase the drying time. Being small, they fill many of the gaps created by larger particles and give a greater surface adjacency which in combination with the clay makes the resultant mass stronger and more resilient to breakage, but also increases the density. For these reasons, they are not commonly used in monolithic construction, where drying time is crucial and insulation desired, but are more valued in block construction where density and drying can be controlled and cohesion and resistance to breakage during transport is important.
2.1.2.27 An exception to the above is the monolithic construction house at Liepe, in Germany, ref. 8.1.13. In this project the light earth mix comprised, clay, water, cherry stones and cow dung. The cherry stones were chosen because of their unusually high thermal capacity combined with low conductivity, along with being natural, hygroscopic and readily available. However, being essentially beads, they are difficult to stick, even with the clay slip coating, so cow dung, also readily available was added to the mix. The cow dung is useful almost entirely because it contains fine fibres - the result of the digestive process - which work well as small reinforcement between the larger cherry stones. The cow dung is also said to be beneficial in that it aids the plasticity of the mix and so reduces the water content required. In Germany the use of cow dung in clay plasters for the above reasons is well known and so the material is relatively available. This is not the case in the UK where straw would probably be the simplest alternative.

2.1.2.28 Mineral Fill Materials The two most common mineral fill materials are expanded clay and expanded glass beads. Pumice and expanded perlite or vermiculite can also be used. The use of mineral fill as opposed to organic fill has a number of advantages. Most importantly, mineral fillers are not susceptible to decay and so the main threat of failure is removed. They are also non-combustible so the mix overall can be classed as non-combustible. In practice this means the elements can be used in any part of a building, even surrounding fire escape routes. In addition, they do not shrink upon drying and so vertical settlement does not present a problem. Vapour diffusion resistance is higher, vapour absorbency is lower and because the fill comes generally in bead or granule format, the light earth is easy to mix mechanically and can even be sprayed or pumped into the formwork.

2.1.2.29 On the other hand, mineral fillers can be expensive if not readily available and this is by and large the state in the UK. In practical terms the beads tend not to have much cohesion and so the percentage of clay for binding requires to be increased. Even so, it is not always possible to satisfactorily reinforce the resultant mass or blocks which remain susceptible to breakage, particularly at corners, and so straw or another reinforcing agent is sometimes added, ref. 7.1.15. The cohesion can be enhanced by choosing carefully differentiated sizes of beads and granules but the author is not aware of this being undertaken.

2.1.2.30 There are some in the light earth movement who believe mineral fillers are the only way ahead for the technique, based largely on the twin advantages of fire and decay resistance. These are compelling advantages but the disadvantages mentioned above, though seemingly insignificant in comparison appear to have affected the uptake of the material. In Germany it is common to use reed mat permanent formwork stapled or nailed to the framework. The mix is simple poured and tamped in and it would appear that this technique would get over the main disadvantage of mineral fill.
2.2 Structural Characteristics

2.2.1 Resistance to Consolidation and Shrinkage

2.2.1.1 One of the two commercially available blocks in the UK - 'Karphosit', imported by Construction Resources and Natural Building Technologies (refs: 8.5.6) is noted as having a density of 925 kg/m$^3$ and a compressive strength of 13.3 N/sq.mm. This compares favourably with Durox 'Supabloc 7 which has a density of 700 kg/m$^3$ and a compressive strength of 7 N/sq.mm so in known and limited situations, it may be possible to design for a nominal loadbearing capacity in accordance with the advice of the manufacturer.

2.2.1.2 Otherwise, light earth in either block or monolithic form is considered an infill material with known loadings taken by a structural frame. This does not mean that the mix has no structural value, but this is discounted for the purposes of assessing the structural properties of the building. The extent to which light earth compresses under load - consolidation - either external or due to self weight, and the extent to which it shrinks with the evaporation of the water are, however, of structural interest to the practitioner.

2.2.1.3 Consolidation

Consolidation tests have been carried out at the University of Helsinki, ref. 8.3.4. and at ETH in Zurich whereby samples were subjected to vertical compression and their consolidation under load measured. These tests provided similar results and those from the Finnish research are shown below. The ‘d’ stands for density and is measured in kg/cu.m while the numbers following each material represent the percentage of that material in the overall make-up of each sample.

Graph showing consolidation (compression) of various light earth samples under vertically applied compressive load.
2.2.1.4 All samples shown above had a moisture content of 3%. The tests show clearly that light earth mixes compress quite readily under load and do not compare with, for example, the commercially available expanded glass block tested at the same time. It is also clear from these tests that consolidation is closely linked to density.

2.2.1.5 In describing the tests, the Finnish observers drew attention to the block of density 399 kg/cu.m and noted that it contained less clay than denser test samples which had compressed more. They surmised that clay has less effect on load bearing capacity than on density. The author would add that this capacity to resist compression is more likely to relate to the increased amount of woodchip in that sample, compared to the others which contained more sawdust.

2.2.1.6 Shrinkage

In practice, the only direct loads normally imposed upon light earth elements are those of self-weight. From the results above we can conclude that a denser mix will resist consolidation better, but will have a greater self weight to resist. Conversely a lighter mix will consolidate more but has less pressure upon it. In reality, resistance to shrinkage and consolidation is likely to depend more on the type of fill material, since all straw mixes will be more susceptible to consolidation than similar density woodchip, expanded clay particle or cork granule mixes, as suggested above.

2.2.1.6 Shrinkage is not an issue for dry, prefabricated blocks or panels, nor for monolithic mineral fill mixes, but it is a practical issue for other types of monolithic light earth construction. On pages 53/54 of Gernot Minke’s book, ref. 8.1.9., he illustrates an example of vertical shrinkage of monolithic straw-clay construction. It should be emphasised that the illustration shows by far the worst case of shrinkage known to the author and well beyond the normal level experienced by most practitioners.

2.2.1.7 In practice, with a reasonable consistency of tamping, the shrinkage of light earth mixes of all or mostly straw-clay tend to shrink by about 15 to 40mm over a storey height however this depends on a number of variables including the rate of the wall raising in relation to its drying and the amount of water in the mix. More is said of this in Section 3.4. For the purposes of this section it is suffice to state that shrinkage is an inevitable function of the drying out of light earth elements but can be minimised with careful workmanship.

2.2.2 Strength in relation to fixings

2.2.2.1 Another structural consideration of light earth walls is their capacity to accept fixings and finishes.

2.2.2.2 Most mixes will be sufficient both to accept applied plaster and to hold reasonably lightweight fixings. What constitutes ‘lightweight’ is clearly ill defined, but light fixures, sockets and pictures, for example, can all be supported by fixings direct into the wall, albeit normally in combination with the plaster itself. This is described in Section 3.5.2.

2.2.2.3 With monolithic construction, it is possible to build a light earth wall which is so light - using so little clay to filler or so lightly compressed - that it is not easy to
apply plaster or render, and into which it is almost impossible to fix anything. This can happen at the top of a wall just beneath the wall or roof plate due to the lack of subsequent compression by layers going on top, and because tamping down can be difficult at this point if the roof is already on.

2.2.2.4 If it is not possible to compress the mix and add more, to bring it up to the requisite density, then it is advisable to apply a mesh, perhaps stapled to adjacent studs. This will enable plaster to be applied. It is also common for lath or battens to be applied, partly to enable plaster application against something suitably firm, but also to enable subsequent fixing to a solid support beneath the plaster.

2.2.2.5 Where heavy or dangerous loads are anticipated, such as shelving for (lots of) books or high cabinets or units which need to be fixed back at their tops to prevent toppling, it is advisable to allow for these by fixing either back to the adjacent studs or to dwangs or battens fixed between the studs. These battens can be buried beneath the plaster, cut into the mix, or applied afterwards, rather like a picture rail.

2.2.2.6 No tests on "pull out" have been undertaken to the knowledge of the author. It is not an issue for any regulatory body, despite it’s significance in use for builders and clients alike. Subsequently, no testing was carried out for this report and the reader is advised to follow the guidance contained in Section 3.5.
### 2.3 Durability

#### 2.3.1 The Importance of Maintenance

##### 2.3.1.1

A building designed and constructed in accordance with general good practice and the guidelines contained within this report will be inherently durable.

##### 2.3.1.2

The unfinished building near Heeze, in the Netherlands, Section 7.1.7, offers an interesting insight into the durability of light earth walls without coatings, having been left for two years, exposed to the weather. Surrounded by evergreen trees, the walls do not appear to be damaged or altered in any way since they were constructed. There is no evidence or rodent or significant insect colonisation and even the surface removal of the clay coating on the straw which might be expected has not occurred.

##### 2.3.1.3

Similarly, a small shed constructed in 1995 at Kellokoski in Finland has survived without any damage despite being without heating, occupancy or attention and remains in impeccable order. Such examples offer comfort that well constructed light earth buildings are indeed durable even under conditions which would not be considered advantageous.

##### 2.3.1.4

Comforting though these examples may be, it should be emphasised that the most important criteria by far affecting the long term durability of light earth buildings is regular maintenance. This is not to suggest that great amounts of work are necessary, but that regular inspection and prompt action when needed are all that is required. Maintenance of light earth buildings is described in Section 3.5.1.

##### 2.3.1.5

The remainder of this section looks at some of the most common forms or causes of building or material deterioration and comments upon the implications for light earth construction in each case. Many forms of deterioration apply largely to the surface of a material and so are more relevant to the coatings applied than to the mixture itself. Some issues of durability are discussed therefore in Section 3.4 Coatings.

#### 2.3.2 Corrosion of Metals

##### 2.3.2.1

All LEC projects of which the author is aware have been built using a timber frame for the main structure. Whilst this may seem the most ‘natural’ approach it would be quite possible to use a metal frame. Even on timber framed buildings, certain elements such as bracing straps, conduits and pipes may be metallic and located adjacent to or within the light earth mix.

##### 2.3.2.2

Corrosion of ferrous metals tends to occur in moist conditions, where different metals are in electrical contact or in the presence of atmospheric pollution. The latter is not normally expected to pose a significant threat, corrosion risks associated with difference in metals would need to be addressed at the design and specification stage.
2.3.2.3 Corrosion due to moisture is of more interest. Water can condense on cold metallic elements placed on or close to the outer surface of walls. The risk of corrosion is slight due to the hygroscopic nature of the surrounding light earth mass which would tend to draw moisture away from the metal, or, due to being close enough to the surface for evaporation to take effect before any build-up of moisture is evident.

2.3.2.4 There is more experience of using metal in combination with organic materials in US straw bale construction where metal is often used both internally and externally in the form of mesh to stabilise corners and as rods which run from foundation to wall plate to keep the roof construction tied down. Problems have occurred but have been shown to be associated with the use of vapour barriers or dpc’s where moisture collects on one side and is unable to diffuse away. The presence of metal in the bale walls, and particularly on the outer faces does not appear of itself to have caused any problems.

2.3.2.5 Nonetheless the risk is clearly present and it is advisable to avoid metal elements wherever possible and if they are used, to keep them within the heated envelope of the building.

2.3.3 Sunlight

2.3.3.1 Sunlight causes deterioration of certain materials due largely to its ultra-violet component. Certain paints, plastics and rubber bituminous products suffer, certain pigments lose colour and timber will tend to darken and become grey. None of the materials associated with light earth will suffer from sunlight exposure, including timber, and in any event it is the external coatings which bear the brunt of such exposure. In common with any construction type it is assumed that coatings will withstand any such exposure.

2.3.4 Biological Agencies

2.3.4.1 Plants Plants such as creepers left to grow across an external face will tend to cause some damage to any construction because they allow water to collect and remain near to or on the wall surface. Their roots or suckers can penetrate cracks and fissures in the outer coating causing mechanical damage. This can lead to ingress of water into the wall fabric and this is clearly of more concern where the fabric is organic in origin and thus susceptible to decay.

2.3.4.2 It is worth note that the renders advisedly used in LEC are lime and clay based and as such are physically softer than cement based coatings. As such they are easier to break down for roots and suckers and are therefore at greater risk than in conventional construction.

2.3.4.3 Suffice to say that allowing plants to grow across the wall face is not advisable in any construction, but perhaps more so in the case of Light Earth Construction. Where creepers or other plants across the face of the building are desired, it is advised to create a suitable framework for them which is at least 100mm away,
preferably with the possibility of access behind to deter growth onto the wall surface itself.

2.3.4.4 Insects

Insects will attack a material if it is food, if the environmental conditions are right, and if they can gain access. If there are suitable cavities some insects will live in such spaces but not necessarily do any damage. Experience in LEC and similar organic material construction such as straw bale construction has shown that fear of insect attack is wholly unfounded. This is largely because both construction types always involve wet applied plasters to both sides so insects do not gain access to the walls in the first instance. In areas where insects such as termites represent a real threat, LEC and straw bale properties are actually at less risk than conventional timber frame because of this. Care needs to be taken at wall bases, but in such areas termite shields are standard.

2.3.4.5

Even if insects gain access, they will not necessarily do any damage unless the material represents food. Straw appears not to be of any interest to most insects in this regard. Bees in the US have made nests in unplastered straw bale walls and the earliest straw bale houses in Nebraska (c. 1920s), left unplastered, suffered some problems with fleas in a few cases. In one US house termites attacked the timber window and door frames but left the straw bale walls untouched. In other words straw-clay buildings are not at risk, but the plaster coatings which keep any insects out should be maintained for this and other reasons.

2.3.4.6

There is no evidence to suggest that hemp used in lieu of straw in light earth buildings is any different. Hemp is used commercially in a similar way to light earth construction but the binder is lime which is considerably more caustic than clay so no direct comparison is possible. Hemp is much tougher than straw of any type and it may be safe to assume that it may be considered as above.

2.3.4.7

Woodchip-clay construction is slightly different in that insect attack of timber is an established risk. While termites do not live in the UK, the main threats come from four types of beetle: the common furniture beetle, the death watch beetle, the powder post beetle and the house longhorn beetle. In each case, eggs are laid in cracks, these develop into larvae which burrow into the wood. They then form a chamber, develop into a pupa, then beetle and eat their way out to the surface leaving the tell tale exit holes. Other pests include Ambrosia beetles, weevils and wood wasps.

2.3.4.8

As described above these do not represent a serious threat to woodchip-clay construction because the mix is covered in a plaster deterring access in the first place. A possible threat could be where the chips were infested before being placed in a wall, but this is unlikely in practice. Amongst those involved in the research, there have been no known occurrences of insect attack on light earth projects.

2.3.4.9 Fungal decay

In temperate climates such as the UK, it is fungal attack upon the cellulosic materials in light earth construction which presents the most serious hazard risk to this form of construction. If the guidance contained in this report is followed, and care is taken generally there is no likelihood of decay, but it is vital to be aware of
the risks and alert to the conditions which might cause them.

2.3.4.10 Essentially, the risk of decay is due to the fact that most light earth construction uses organic, or more specifically cellulosic material as a major component, and that a relatively large amount of water is used to form the mass. Since such organic material will decay in highly moist conditions, the conditions for decay are present from the beginning. Much of the efforts and concerns of light earth practitioners centre around the need for the mass to dry out as quickly and completely as possible. It should be stressed that in almost every case this is achieved. Nonetheless, a variety of circumstances can lead to the mass being wet for too long and decay thus represents a genuine threat. Prefabricated blocks or panels are clearly not susceptible to any of the risks associated with drying out, but subsequent wetting is of course equally relevant.

2.3.4.11 It should also be stressed that even in the event of decay, all that is normally required is to remove the affected section and replace with sound material in accordance with good practice. There is no other residual risk of decay. The author, in common with most practitioners, is aware of legitimate but largely uninformed prejudice against this and other forms of construction because of the fear of rot, but it is no different from any other construction type in this regard and in fact may be better protected because of the hygroscopicity of the materials used, see Section 2.5. A proper understanding of the risks and causes of decay is crucial for designers and builders alike, but once understood, the risks give little cause for concern.

2.3.4.12 Fungi are simple plants without leaves or flowers which consume ‘ready made’ organic matter and therefore require no chlorophyll or sunlight. The spores (or seeds) are microscopically small but become visible in a mass as an extremely fine powder. They are produced in immense numbers and are dispersed through air or sometimes by insects and animals.

2.3.4.13 Fungi require four essential conditions in order to develop. Described together with the conventional means of avoiding these, they are:

a) suitable ‘food’, i.e. timber.
   In every case the growth of fungi is more vigorous in the sapwood than the heartwood of timbers. To deny growth one can specify heartwood of durable species only, or apply fungicide preservatives.

b) suitable moisture content of timber
   At least 20% moisture content is required for fungi colonisation, though fungi cannot live in saturated conditions. To deny this means simply to maintain a moisture content of less than 20% - or of saturation.

c) suitable temperature
   The optimum temperature for development is about 23°C. Growth at 21°C is twice that at 10°C. Both high temperatures - (few fungi can grow above about 38°C), and low temperatures (growth stops at 0°C) will prevent or reduce growth.

d) oxygen
   Fungi require oxygen for growth. This can be prevented by sealing timber, for example in metal, or by submersion in water.
2.3.4.14 In general practice, there is nothing to be done about access to oxygen and if cellulosic filler is used such as straw or woodchip, then the ‘food’ source is present. It is also difficult to affect suitably high or low temperatures without the aid of considerable - and expensive - technology.

2.3.4.15 There may be some advantages to choosing only durable species or heartwood for chipping. Some practitioners stated specific species chosen for the chips; larch, for example rather than pine, but most maintain that it is not of great importance. Certainly compared to the measures outlined below, such advantages are likely to be marginal.

2.3.4.16 Thus in practical terms, the only method of controlling the risk of fungal decay - apart from not using an organic filler, is to maintain a low moisture content of the mass at all times. Occasional high moisture contents are acceptable but these must only be short lived, hence the importance of drying out the mix quickly and effectively once it has been installed, the use of microporous or ‘breathing’ finishes to allow vapour egress, and the need to maintain regular inspection of the walls to check for cracks, overflowing gutters etc.

2.3.4.17 There are many species of non-destructive fungi such as many common moulds and staining organisms which can form on the surfaces of timber and plaster alike. Moulds tend to indicate excessively damp surfaces, generally in combination with suitable temperatures for fungal growth. Staining fungi feed on the starch and sugar in sapwood cells but not on the cell walls so do not appreciably weaken the timber. Thus while most do not themselves present a risk of decay, they may well suggest that the conditions are suitable for more damaging fungi and so should be taken as a warning. In most cases, these fungi can be simply brushed off when dry, or better vacuum cleaned to prevent spores from spreading.

2.3.4.18 Destructive fungi are of more serious concern but are unlikely ever to colonise a properly designed and constructed light earth building except in the event of, say, a leaking gutter or internal water pipe. The optimum moisture content for the growth of all types of destructive fungi is between 30 and 40% and none can survive for long in moisture contents of less than 20%. Under normal circumstances the walls of a building will not exceed 20% moisture content so there is little to worry about and the focus of concern is on maintenance. It is perhaps worth mention that many of the cases of decay in conventional buildings relate to the ill advised use or placement of vapour barriers or vapour impermeable elements. Thus vapour cannot move freely within the fabric of the building, collects and eventually condenses at the barrier and so creates the conditions suitable for decay. In a light earth building with ‘breathing’ or vapour transmissive construction generally, this risk is removed.

2.3.4.19 Destructive fungi are commonly known as “rots” and lead to softening, discolouration and loss of strength in timber and timber based or other cellulosic materials. The softening can also lead to colonisation by insects which would not otherwise attack the healthy material. In all cases of rot, professional advice should be sought, though guidance is contained in several BRE publications such as
2.3.5 Water and Frost

2.3.5.1 Water
Unless baked, clay remains soluble in water. Clearly it should not be used without some form of protection in situations where it might become wet or excessively damp. The organic fillers to most LE projects suffer in water only if saturated and not allowed to dry out.

2.3.5.2 Having said this, clay is quite easy to protect in a number of ways, the most common being through the addition of linseed oil. With two coats of linseed oil clay or earth walls can be used for splashback areas on sinks and washbasins, and even shower enclosures without damage. (See, for example, rammed earth shower enclosure, ref. 7.1.14). A light earth wall coated in clay plaster could in this way be used as a shower enclosure as long as such a coating was applied, but this would seem somewhat like ‘tempting fate’ and is not advisable.

2.3.5.3 In practical terms and normal circumstances, water is not a concern for light earth construction except in terms of weathering to the outer coating and in this way it is no different to any other form of construction. Where water damage occurs, the consequences are more significant than in a conventional building which again underlines the importance of regular inspection of light earth properties.

2.3.5.4 Frost
Water expands when it freezes. In this way frost can cause damage where water is contained within the (outer) fabric of a wall, for example, expands upon freezing and pushes out or delaminates the material around it.

2.3.5.5 Porous materials are more at risk because they allow more water to remain within their cellular make-up. (Unburnt) clay and lime based coatings are thus indicted but in practice these are rarely affected because their open cellular nature also allows for the expansion of water within their structure, thus preventing ‘push-out’ or similar damage. Frost presents no risk to the light earth mass beneath the dense outer coatings because there is enough space for it to expand without affecting the integrity of the mass.

2.3.6 Abrasion and Impact

2.3.6.1 Light earth mixes are invariably coated with plaster and so impact and abrasion characteristics are not really relevant over the long term. However, when dry and until plastered, the mix is liable to shedding dust when brushed or knocked. This can happen particularly at exposed external corners and the jambs of well used doors during construction. If this happens such that essentially uncoated straw, for example, is left at the surface, it is worth re-coating with clay slip before the plaster is applied.

2.3.6.2 It is common for owners to wish to keep completed light earth walls unplastered as they present a pleasing aesthetic, particularly to those who have worked on
them, and it can seem a shame to cover them up. This needs to be resisted for many reasons, perhaps the least of which is the shedding of dust. Partly because of this desire, “Honesty Windows” are often installed which allow a view of the unplastered wall behind a framed glass pane.

2.3.6.3 During construction and until plastered, and during transportation in the case of prefabricated blocks, light earth mass is relatively fragile. Mixtures without straw or other linear reinforcement in such as those using woodchip, expanded glass or expanded clay only are liable to crumble or break off when knocked and a degree of care needs to be taken. Alternatively, as in the work of Jorg Depta (see 7.1.15) vulnerable corners can be covered in mesh immediately after striking the shuttering.

2.3.6.4 Light earth provides a fairly firm substrate to plaster - much more so, for example, than straw bale, so it protects the plaster to a certain extent, preventing it from ‘caving in’ if it is knocked.

2.3.6.5 The only common area where vibrational impact effects light earth, is at the leading edge of doors and the connection between door frame, sub-frame and the wall itself. As above, constant impact from door closing can cause dusting of the mix adjacent to the frame if it is not sufficiently bound to the frame. Generally speaking this should not cause a problem if the plaster covers the wall sufficiently, and the architrave does the same again. Where either or both of these are wanting, some dust will be visible on the floor at the junction.
2.4 Thermal Characteristics

2.4.1 Thermal Conductivity

2.4.1.1 Thermal conductivity (k) is a measure of the rate of heat transfer through a unit thickness and area of a material from face to face (not adjacent air to air). It is expressed as:

heat units transmitted in unit time through unit thickness of unit area for unit temperature difference between faces
Watts (Joules/second) m m2 degrees K
which gives Wm / m2K i.e. W / m K

2.4.1.2 Thermal conductivity in materials is affected by three interlinked aspects of the material’s make-up. These are, the cellular nature of the material itself, the amount of air (or other gases) trapped within the element, which is related to the compression of the material, and the amount of water or vapour trapped.

2.4.1.3 These three criteria are more or less relevant with different materials. Within any given material, heat moves via radiation between surfaces, convection within the air spaces and conduction along contiguous solid material. At low densities, most of the heat transfer is by radiation and convection since air (or another gas) is a large portion of the material. At high densities, most transfer is by convection. Since light earth is a low density material, changes in the density, or amount of air trapped will have a correspondingly significant effect on the overall heat transfer. Changes in the cellular nature of the filler which would affect mostly the conductive heat transfer will have little thermal effect. The three criteria are discussed below.

2.4.1.4 Materials

The different filler materials which can be used with clay to produce ‘light earth’ are all different in cellular make-up and hence intrinsic thermal conductivity. However, these intrinsic differences are of much less significance than the extent to which these different materials compress and trap air. For example, hemp is more rigid than straws of barley or rye and as such tends to compress less. Similarly, Minke notes, ref. 8.1.9 p.34 that two samples prepared by FEB (ref. 8.6.2.3) with similar densities but different fillers (straw and expanded clay) gave quite dissimilar k figures. These are shown on the graph, paragraph 2.4.2.15.

2.4.1.5 Air

The most significant influence on light earth in terms of thermal conductivity is the amount of air trapped within the mix. It follows that it is the density and compression of the material which is of most significance when establishing the overall thermal conductivity. Note that it is trapped air that is sought for insulative effect not just air gaps. Continuous, large passages of air, especially vertically aligned, can give rise to convective heat losses because of the circulation of the air. The best structure for insulation is to create small and discontinuous gaps. This is worth mention because inexperienced light earth builders will sometimes hardly compress the mix at all in order to achieve “lots of insulation”. This can lead to large and continuous air gaps and is counter-productive.
2.4.1.6 The significance of thermal conductivity and the need to establish a consistent level of compression lead some to conclude that block making is the most appropriate option. In reality however, it is quite easy to attain a fairly consistent level of compression in monolithic construction with practice. This is a problem with volunteer work groups working for one day (as at Littlecroft, for example) but is much less so for teams with even a small amount of experience. The tamping of fill is quite repetitive and it is easier than one might expect in practice to get both a rhythm and a consistent level of pressure.

2.4.1.7 Nonetheless, it is not possible with monolithic construction to establish a completely consistent level of compression. For this reason it is better at the outset to establish degrees of tolerance within which one can confidently work. At Littlecroft, for example, two different densities were entered into the condensation risk analysis with two different 'U' values and condensation risk figures as a result. If the authorities accept the ‘worst case’ and can be convinced that the tolerances are achievable within site practice then all is well.

2.4.1.8 (Air Permeability) Air permeability is the term given to the free passage of air through a material. It’s unit is m²/msPa, where Pa is the pressure difference between faces. It has an effect on the overall thermal conductivity of a material since the higher the permeability, the more heat is transferred simply by the free movement of air through the material.

2.4.1.9 Finnish research, ref. 8.3.4 pp.25-26, looked at the permeability of light earth blocks. Being anisotropic, the properties of light earth blocks sometimes depend of the direction of testing, so air was forced across the blocks in the same direction as their compression across the straw not along it - so that results would relate to the conditions within a completed wall. Many of the samples tested showed readings above the Finnish maximum level of 120 x 10⁻⁶ m²/msPa. Some however, fell beneath this threshold and were tested further to establish readings of around 90 x 10⁻⁶ m²/msPa. Density of these samples were around 350 kg/m³.

2.4.1.10 These are quite high (relatively permeable) and indicate a permeability akin to insulation products such as mineral wool which was also tested on the same apparatus. This is not necessarily a problem but should be noted. Light Earth elements are generally plastered on both sides, thereby more or less reducing to nil the free passage of air through the fabric. However, care needs to be taken accordingly to fill plaster cracks, in the same way that vapour barriers and wind break membranes require attention in conventional frame construction.

2.4.1.11 Water As noted in paragraph 2.1.2.11 there is always water resident in the fabric of the building and this has a significant bearing on the density and conductivity of the fabric and the material elements within. This is because water is itself fairly dense so an amount of water, or vapour within a material will increase it’s overall density and thus conductivity. At a moisture content of 20%, many materials transmit between two and three times more heat as they do when dry. For this reason, stated measurements for density and conductivity are normally subject to given temperatures and moisture contents.
2.4.1.12 To complicate things further, hygroscopic materials, such as all those normally associated with light earth construction (including the timber frame), will tend to absorb and release moisture from the surrounding air and so vary in moisture content with the relative humidity in the atmosphere. This means that the thermal conductivity of the wall is never static. For the purposes of measurement and comparison however, dry densities are normally assumed (sometimes incorrectly) and one is left either to infer the dynamic levels, or, if there is specific interest, to monitor both fabric and surroundings to establish the relationship and equilibrium condition. Monitoring of light earth construction is discussed in Chapter 6.

2.4.2 Measuring Thermal Conductivity

2.4.2.1 Since it’s insulative capacity is one of the main reasons for using light earth in preference to other earth building techniques, it is important to fully understand and quantify this capacity. It is also important for the calculation of ‘U’ values which require to be within certain limits for the purposes of Building Control.

2.4.2.2 The British standard measurement for thermal conductivity is the guarded hot plate test. In this, a section of material 305mm x 305mm by between 25 and 50mm thick is held between two plates, leaving a 200mm by 200mm ‘window’ each side and with all sides completely sealed. A specific temperature can be induced on one side of the material and the temperature on the other surface monitored. The test is extremely accurate and is particularly valued by insulation manufacturers where the differences in their materials are relatively small. Small improvements in these can be accurately depicted using this method.

2.4.2.3 Difficulties

There are however a number of problems with this technique in relation to light earth construction, both of which relate to the thinness of the sample of material required for the test.

2.4.2.4 First, one can be confident that over 300mm, the various inconsistencies and gaps in a light earth block or wall section will even out and you will have a reasonably homogeneous section. The same is not true at 50mm, where a large gap between woodchips, for example, renders the section useless for the purpose of a controlled test.

2.4.2.5 Second, it is physically difficult to produce a block of that thickness which actually relates to a 300mm wall section. There are two ways to produce such a small section. The first is to make a mould or monolithic section to form, say, the 50mm sample. The problem here is that with straw in particular, the edges of the mix are slightly different from the middle areas. Edges are characterised by bent and squashed straw unlike the centre so to individually form a 50mm thick sample would be unrepresentative of the larger wall.

2.4.2.6 A more accurate way to provide the sample is to cut a section from the centre of a larger block. However, this too is difficult without removing or damaging - rather than cleanly cutting - either straw, woodchip or other filler material. Nonetheless this is what was undertaken to provide the sample for testing described below.
2.4.2.7 There is another issue which is that of accuracy. The levels of accuracy possible with this test are not particularly helpful when considering monolithic light earth construction which is relatively variable in nature. What is required is a level of accuracy more akin to the nature of the technique from which can be derived appropriate tolerances for site practice guidelines. Higher levels of accuracy are more relevant for commercial block making, but in both cases another method of measurement is required.

2.4.2.8 UK Testing To this end, and as part of this research project, discussions have taken place with Plymouth University, Department of Civil and Structural Engineering, on the use of a transient probe. This involves the use of a larger sample (150mm cube) and, whilst not quite as accurate as the British Standard test, can be used with confidence to produce accurate results by increasing the number of samples and calibration with other materials of known thermal characteristics.

2.4.2.9 Samples The following information is drawn from a contributory report produced by Plymouth University for the purposes of this report. The verbatim report is presented in full in Appendix 9.2.

2.4.2.10 Thermal Conductivity The samples used were of two materials, clay straw, (a mixture of wheat-straw and clay) and clay wood-chip, (a mixture of chips of softwood, with chips varying in size from approximately 50mm x 20mm x 30mm to 20mm x 10mm x 10mm and clay). These were supplied in two sample sizes depending upon the test to be undertaken. 150mm cubes of material were supplied to establish thermal conductivity and thermal capacity measurements. 50mm cubes of material were used to separately establish a thermal capacity measurement to allow corroboration of the results from the other technique. The samples were identical to the material used to construct Littlecroft, and as used for the fire testing described in Section 2.7. The preparation of the woodchip-clay samples is described in Appendix 9.1.

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Thermal Conductivity W/mK</th>
<th>Average Thermal Capacity J/kgK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4 x 150mm cubes</td>
<td>0.07</td>
<td>Inconclusive at Present</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4 x 150mm cubes</td>
<td>0.15</td>
<td>1500</td>
</tr>
</tbody>
</table>

Thermal Probe Measurements of Clay-Straw and Clay-Woodchip Samples.

2.4.2.11 Thermal Capacity The transient probe test also enabled an assessment of the thermal capacity, the values of which are shown in the right hand side column of the table above. These results were then corroborated using a method of mixtures with the 50mm cube samples. In this process, samples are heated to a high temperature over a 24hr
period and rapidly transferred to a known quantity of liquid at a known
temperature held within a heavily insulated container. The results are shown
below. Discussion of these is in Section 2.4.4.

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Thermal Capacity J/kgK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4 x 50mm cubes</td>
<td>1000</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4 x 50mm cubes</td>
<td>1500</td>
</tr>
</tbody>
</table>

Thermal Capacity Measurements of Clay-Straw and Clay-Woodchip Samples.

2.4.2.12 Density

Finally, density values for each sample were measured. The samples exhibited
some variety and the average values are shown below.

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Density kg/cu.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4</td>
<td>145</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4</td>
<td>450</td>
</tr>
</tbody>
</table>

Density Measurements of Clay-Straw and Clay-Woodchip Samples.

2.4.2.13 Discussion

The process of creating the samples, cutting them from larger sections as
described at the beginning of this section, is the most accurate way to achieve
indicative samples. However, the fact that the clay-straw samples are not subject
to the self-weight of the wall above renders them less dense than they would be
in situ. This explains the fairly low average density value for the straw-clay
samples. Woodchip-clay does not compress under load to the same extent and so
the values for these samples can be assumed to be more representative. In
practice, straw-clay is unlikely to be less than 300 kg/cu.m in situ and to an extent
the results of the straw-clay testing are therefore non-representative.

2.4.2.15 Comparison

However, the results are entirely consistent with those produced in other European
studies in that density and thermal conductivity follow a consistent relationship as
shown in the graph below. This is worth emphasis because it is the most significant
aspect of the thermal performance of light earth elements and is reinforced by the
testing undertaken at Plymouth.

2.4.2.16

Of the sources noted in the graph below, values from Volhard and ETH, Zurich can
be found in ref. 8.1.2, those from LRT at ref. 8.3.5. The commercial trade
literature which is a source for the value shown can be found at Construction
Resources, ref. 8.5.6 and those from Minke’s book, ref. 8.1.9.

2.4.2.17 Conclusion

The evidence of the Plymouth tests undertaken for this research, and of the
various European tests is consistent and furthermore supports the assertion that,
within fairly tight tolerances, one can predict the thermal conductivity of a light
earth element, largely regardless of the ‘fill’ constituent, if one can measure the
density.
2.4.3 Application of Thermal Measurements

2.4.3.1 The Building Regulations require buildings to conform to certain overall thermal performance criteria. One of the bases upon which these criteria depend is an assessment of the 'U' values, or thermal transmittance of the walls, floor and ceilings of the building. These measurements describe the rate of heat loss through the various elements of the external fabric and enable both designer and regulator to understand and quantify the building’s likely thermal performance. These 'U' values are derived from the thermal conductivity figures discussed above and this process of derivation is described below.

2.4.3.2 Thermal Resistivity

Thermal resistivity (1/k) is a measure of the resistance to heat flow through a unit thickness and area of material from face to face. It is the reciprocal of conductivity and is expressed as:

\[
\text{thickness (m)} / \text{conductivity (W/mK)} = \text{m K} / \text{W}
\]
2.4.3.3

The table below gives a comparison, based on the CIBSE Guide, of several materials’ density, thermal conductivity and resistivity at normal temperatures and moisture contents.

<table>
<thead>
<tr>
<th>Density kg/ cu.m</th>
<th>Material</th>
<th>Thermal Conductivity (k) W / m K</th>
<th>Thermal Resistivity (1/k) m K / W</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Expanded Polystyrene</td>
<td>0.034</td>
<td>29.4</td>
</tr>
<tr>
<td>48</td>
<td>Mineral Wool</td>
<td>0.038</td>
<td>26.3</td>
</tr>
<tr>
<td>120</td>
<td>Wool Fibre Felt</td>
<td>0.036</td>
<td>27.8</td>
</tr>
<tr>
<td>160</td>
<td>Balsa</td>
<td>0.045</td>
<td>22.2</td>
</tr>
<tr>
<td>240</td>
<td>Insulating Fibre Board</td>
<td>0.053</td>
<td>18.9</td>
</tr>
<tr>
<td>320</td>
<td>Loose Expanded Clay</td>
<td>0.12</td>
<td>8.3</td>
</tr>
<tr>
<td>320</td>
<td>Aerated Concrete</td>
<td>0.084</td>
<td>11.9</td>
</tr>
<tr>
<td>365</td>
<td>Compressed Straw Slab</td>
<td>0.101</td>
<td>9.9</td>
</tr>
<tr>
<td>450</td>
<td>Woodwool Slab</td>
<td>0.093</td>
<td>10.8</td>
</tr>
<tr>
<td>513</td>
<td>Softwood (indicative)</td>
<td>0.124</td>
<td>8.1</td>
</tr>
<tr>
<td>769</td>
<td>Hardwood (indicative)</td>
<td>0.16</td>
<td>6.2</td>
</tr>
<tr>
<td>961</td>
<td>Plasterboard</td>
<td>0.16</td>
<td>6.2</td>
</tr>
<tr>
<td>1142</td>
<td>No Fines Concrete</td>
<td>0.562</td>
<td>1.8</td>
</tr>
<tr>
<td>1442</td>
<td>Plaster, dense</td>
<td>0.48</td>
<td>2.1</td>
</tr>
<tr>
<td>1700</td>
<td>Brickwork</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>2260</td>
<td>Concrete, normal</td>
<td>1.44</td>
<td>0.7</td>
</tr>
<tr>
<td>2520</td>
<td>Glass</td>
<td>1.05</td>
<td>1.0</td>
</tr>
<tr>
<td>7850</td>
<td>Steel</td>
<td>0.57</td>
<td>0.02</td>
</tr>
<tr>
<td>9000</td>
<td>Copper</td>
<td>4.00</td>
<td>0.003</td>
</tr>
<tr>
<td>300</td>
<td>Light Earth</td>
<td>0.1</td>
<td>10.0</td>
</tr>
<tr>
<td>450</td>
<td>Light Earth</td>
<td>0.13</td>
<td>7.7</td>
</tr>
<tr>
<td>600</td>
<td>Light Earth</td>
<td>0.17</td>
<td>5.9</td>
</tr>
<tr>
<td>750</td>
<td>Light Earth</td>
<td>0.2</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Density, Thermal Conductivity and Resistance of Several Common Materials and Light Earth derived from Table on previous page

2.4.3.4 Thermal Resistance

Thermal Resistance is the product of the thermal resistivity and the thickness, m, of the material or element. Thus a woodwool slab of thermal conductivity 0.09 k (W/mK) will have a thermal resistivity of 1/k which is 11.11 mK / W). A 50mm thick slab will have a thermal resistance of (0.05 x 11.11) = 0.55 m² K / W.

2.4.3.5

The thermal resistance of a whole wall, floor or ceiling construction is derived by adding all the separate thermal resistance values. To this sum one must add the thermal resistance of any cavities and of the internal and external surfaces. The thermal resistances of cavities and surfaces are given in CIBSE Guide A3, Thermal Properties of Structures.

2.4.3.6 Thermal Transmittance

The thermal transmittance of a whole wall, floor or ceiling is the reciprocal of the total thermal resistance described above. It measures the overall rate of heat transfer through the construction, from air to air, and is expressed as:

heat (W) / unit area (m²) with temp. difference (K) from air to air = W / m² K.
2.4.3.7

The thermal transmittance is also known as the 'U' value and it is this figure which is used to assess overall building thermal performance under the Building Regulations. The lower the number, the better the insulative value of the construction. The 'U' values of a number of conventional and light earth wall constructions, under normal exposure conditions, are given in the table below for means of comparison and set against the current UK Building Control Maximum.

<table>
<thead>
<tr>
<th>Type of Wall</th>
<th>Details of Construction</th>
<th>U-value W / m² oC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid</td>
<td>220mm brick, 13mm plaster</td>
<td>2.1</td>
</tr>
<tr>
<td>Cavity</td>
<td>110mm brick, 50mm cavity, 100mm insulating block, 13mm hard plaster</td>
<td>1</td>
</tr>
<tr>
<td>As above but with cavity filled with insulation</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>As above but with 75mm insulation</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Timber Frame, Brick Outer Skin</td>
<td>110mm brick, 50mm cavity, 19mm plywood, 100mm frame with 100mm insulation, 13mm plasterboard</td>
<td>0.3</td>
</tr>
<tr>
<td>As above but with 200mm frame and 200mm insulation</td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>Building Control Maximum, 2002 for Walls Only</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Light Earth</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25mm lime plaster, 300mm broken timber frame with infill of LE@ 400 kg/cu.m, 25mm clay plaster</td>
<td>0.37</td>
</tr>
<tr>
<td>As above but with LE @ 600 kg/cu.m</td>
<td></td>
<td>0.51</td>
</tr>
</tbody>
</table>

'U' Values of some Conventional Walls, Light Earth Walls and Building Regulation Standard.

2.4.3.8

The Building Regulations in the UK set maximum limits for 'U' values of a building for all elements of the construction and the simplest way to get approval is to keep within these limits in all cases. However, it is also possible to 'trade' higher values in one part of the building against lower values in another part. This is of particular interest for Light Earth Construction because some limits set are now difficult to achieve using light earth and so the trading options become relevant.

2.4.4

Thermal Capacity

2.4.4.1 Specific Heat

Specific Heat (c) is the term for the amount of heat necessary to warm 1kg of a material through 1 K. Its units are kilojoules per kilogram Kelvin or kJ/kgK.

2.4.4.2 Thermal Capacity

The thermal capacity of a material is the product of the specific heat noted above (kJ/kgK), and the density (kg/m³). Its units are thus kJ/m³ K. It represents the capacity of a material to store heat (or 'coolth') and is sometimes referred to as 'thermal mass'. The thermal capacity of its materials significantly affects both the thermal performance and comfort levels in a building yet it has only recently begun to be investigated and incorporated into environmental design.

2.4.4.3

Materials with a high thermal capacity such as earth, stone, brick and concrete will
absorb heat energy and emit it again when ambient temperatures are lower than their own temperature. They also store ‘coolth’ and so take more energy than other materials to warm up when ambient temperatures rise. Materials with low thermal capacity by comparison get warmer and colder in closer concert with the ambient temperature as they do not ‘hold on’ to warmth or coolth to the same extent.

2.4.4.4 Buildings built largely of materials with a high thermal capacity, for example traditional solid stone or brick buildings - and where that thermal capacity is exposed internally - are known generally as ‘heavyweight’ constructions. When the air becomes warmer they warm up more slowly because they store a portion of the available warmth and so remain relatively cool to the touch. Conversely, when the temperatures drop, they will tend to remain warmer for longer. These materials have the capability to buffer temperature swings and moderate internal temperatures and this capability is now being more thoughtfully exploited in commercial design. In addition, heavyweight construction suits buildings where people use the building for long periods or continuously because once warmed up, they require little energy to keep them warm.

2.4.4.5 Buildings built largely with materials of low thermal capacity are known as ‘lightweight’ and are quick to warm from cold, but equally quick to cool down again. Most modern, timber frame houses fall into the lightweight category, having little more than plasterboard as thermal capacity internally. They suit situations where they are used intermittently or only for short periods because in these situations they take less energy to heat because of their quick ‘response times’.

2.4.4.6 So the choice of heavyweight or lightweight construction should be made primarily in response to known occupancy patterns to optimise energy efficiency. This is true in general but there is a caveat: heavyweight designs have three health benefits over lightweight designs. These are:

1. The thermal buffering effect of heavyweight designs tends also to reduce extremes of relative humidity. Section 2.5.6 describes the advantages of such design but suffice to say here that this reduces several known health risks including viruses, mould and allergy triggers.
2. If maintained warm, heavyweight buildings tend to have warm surfaces which significantly benefits thermal comfort for occupants.
3. Warm surfaces also allows for cooler air temperatures which means reduced heating costs, and reduced heat losses due to infiltration and convection since the heat is stored in the fabric not the air.

2.4.4.7 These benefits tend to push those interested in healthy design toward more heavyweight structures, or at least a better balance than is normally found in modern timber frame and other lightweight construction. Light earth construction is well placed to respond to this since it is essentially a fairly heavyweight option, particularly with its internal plaster, yet it occupies something of a middle ground between the two extremes and can be adjusted to suit varying thermal performance criteria making it a flexible and useful option.
2.5 Moisture and Humidity

2.5.1 Introduction

2.5.1.1 The presence and movement of moisture in all construction types is inevitable due to the continuous ebb and flow of moisture in the atmosphere. Older buildings were generally draughty and built of largely natural materials which were porous, allowing moisture to travel through the walls, and at the same time balancing the humidity of the air inside. Modern buildings are better sealed against unwanted air infiltration and built largely of synthetic or highly modified materials which cannot balance humidity to the same degree and tend to encourage swings in internal humidity. These swings are problematic to occupants’ health and the buildings are more susceptible to condensation risks.

2.5.1.2 On the other hand, the high infiltration levels and lack of thermal insulation in older buildings meant that they were expensive and difficult to keep warm. The development of more energy efficient buildings in the last 30 years has been welcome on many fronts, but a growing awareness of the problems inherent in these buildings has led some to re-think how best to provide for both thermal and humidity comfort.

2.5.1.3 This awareness aims at recapturing the potential health and humidity benefits of older, natural construction without sacrificing any of the thermal benefits of modern buildings. It is founded on an developed understanding of the movement of moisture within buildings, but appears to have developed two slightly distinct aspects. Aside from ventilation aspects, the first is concerned with the movement of moisture through the structure, while another, less developed aspect concerns itself with movement of moisture between the internal air and the structure.

2.5.1.4 The first is commonly termed ‘breathing’ construction but is more correctly termed ‘moisture transfusive’ construction as it concerns itself with vapour movement not air movement as is sometimes thought. The second aspect has been developed partly by those interested in the health giving potential of buildings, and, in particular, earth building. Light earth construction, in common with all earth construction, takes account of both aspects.

2.5.1.5 In order to ensure that light earth construction is free from risks associated with condensation and decay, and to take full advantage of the health benefits offered by the construction, it is important to have an understanding of the moisture characteristics of materials, and of the context within which these materials operate. To this end, Section 2.5.2 to .4 discusses the context and detail of moisture transfusive construction, while Sections 2.5.5 to .6 discusses the context and detail of absorption and humidity balancing.

2.5.2 Humidity, Vapour and Condensation

2.5.2.1 Humidity is the moisture in the atmosphere either in the form of water (liquid) or vapour (gas). Water in the atmosphere exists as cloud, rain, steam and mist.
2.5.2.2 Vapour pressure can increase with increased moisture content until the air is saturated and cannot contain any more vapour. At this point, any further moisture will lead to condensation of the vapour into water. Significantly, vapour pressure is related to temperature so that the warmer the air, the more vapour it can contain. In this way air at a given temperature and vapour pressure can be brought to its saturation point by increasing the moisture content or lowering the temperature.

2.5.2.3 The condensation that results can form on surfaces, like dew on the grass, inside materials, or around dust particles as fog or cloud. In buildings the effects of condensation include misting of windows, beads of water on non-absorbent surfaces and sometimes mould on colder, damp walls. These occur because relatively warm, moist air meets cold air or surfaces that are colder, these cool the air to its dew point such that vapour condenses. This occurs on building surfaces but can also occur unnoticed within the construction when vapour in the fabric reaches the colder parts of the wall. This is called interstitial condensation.

2.5.2.4 Condensation is a problem because it can cause unhealthy conditions, lead to fungal growth, damage to structures, materials and decoration or simply concern to occupants. Factors causing condensation need therefore to be addressed at source and these include consideration of the original moisture sources, heating and insulation of the building, ventilation and the overall use of the building. Of these, ventilation is the most effective way of removing the moisture and subsequently reducing the vapour pressure.

2.5.2.5 Surface Condensation will be relatively easily remedied by a combination of the above. The risk of interstitial condensation will reduce with the above measures, but to try to make sure it does not occur most modern buildings use a vapour barrier located near the inside face of the wall to prevent ingress of moisture. Despite the ubiquity of this approach, it is not a failsafe solution, the membrane is rarely perfectly sealed at all joints and is prone to damage by subsequent contractors. In addition, at certain periods when most moisture ingress is from the outside, warm, wet summers for example, the barrier prevents evaporation to the inside and so can lead to conditions favourable to fungal attack.

2.5.2.6 Avoiding or minimising the risk of interstitial condensation without the use of a vapour barrier requires an understanding of the movement of vapour through the building fabric and an understanding of the vapour diffusion properties of various materials. This is developed below.

2.5.3 Vapour Diffusion

2.5.3.1 Vapour pressure Because the occupants of a building and their activities tend to increase the moisture content of the air inside a building, the vapour pressure of internal air is usually higher than outside. This pressure will tend to force the water vapour through a structure from the inside to the outside. The most effective way to
reduce the risk of condensation is to reduce this pressure by effective ventilation (extract) of the relatively humid air, preferably at source, usually the bathroom or kitchen of a house, for example. In winter particularly, many people tend to reduce the amount of ventilation because of the consequent heat loss and associated heating costs. This is when the risk of condensation is greatest.

2.5.3.2

So, the risk of interstitial condensation occurring depends on the differential between the temperature and humidity of the air on both sides of the structure, as noted above, and also on the resistance of the structure to the passage of heat and vapour, described below. Thermal resistance was discussed in the previous section and vapour passage through the structure can be considered similarly.

2.5.3.3 Vapour diffusivity

As noted above, the flow of vapour through a structure depends on the vapour permeability or diffusivity of the materials used. Vapour diffusivity is the weight of water vapour which passes through unit thickness and area of a material per second under unit water vapour pressure differential and at a given temperature. The higher the figure, the more diffusive or permeable it is. It is expressed as:

\[
\text{Weight (mass) of water vapour} \quad g \\
\text{passing through unit thickness} \quad m \\
\text{of unit area} \quad m^2 \\
\text{per second} \quad s \\
\text{under vapour pressure differential} \quad MN \\
\text{which gives} \quad gm/MNs
\]

2.5.3.4 Vapour resistivity

However, the most common expression of vapour permeability is the reciprocal of vapour diffusivity, known as vapour resistivity. It is a measure of the resistance of the flow of vapour offered by unit thickness of a particular material and is expressed as MN s/g m. Examples of the vapour resistivity of some common materials, along with measured light earth samples are shown in the table below.

2.5.3.5 Vapour resistance

Vapour resistance describes the actual vapour resistance of a material taking into account its thickness. It is a product of the thickness and the vapour resistivity of a material and is expressed as MN s/g. Values are shown in the table on the following page according to the noted thickness. Thin membranes are normally quoted with a vapour resistance only.

2.5.3.6

The table shows values of vapour resistivity and resistance for conventional materials and light earth mixes. Figures for conventional materials have been adapted from BRE Digest 110, ‘Condensation’. The figures for light earth were measured by the FEB, ref. 8.6.2.3 in accordance with the German DIN 52615 Wet Method and are quoted in Minke, ref. 8.1.9.

2.5.3.7

Clearly, all earth based materials are substantially more permeable to vapour than the majority of conventional materials, many of which, like plywood, use glues and binding agents which are highly resistant to vapour. From a light earth practitioner’s perspective, it is interesting to note that mineral fill light earth has a noticeably higher resistance to vapour than straw-clay of the same density.

2.5.3.8

As with thermal considerations, resistivity depends to an extent on the density of
a material, but with vapour, this tendency is much less marked.

<table>
<thead>
<tr>
<th>Material</th>
<th>Vapour resistivity per unit thickness</th>
<th>Typical thickness of material</th>
<th>Vapour Resistance for stated thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MN s/g m</td>
<td>mm</td>
<td>MN s/g</td>
</tr>
<tr>
<td></td>
<td>Numbers for LE are density in kg/cu.m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral wool</td>
<td>5</td>
<td>100</td>
<td>0.5</td>
</tr>
<tr>
<td>Wood wool slab</td>
<td>15 - 40</td>
<td>50</td>
<td>0.7 - 2.0</td>
</tr>
<tr>
<td>Brickwork</td>
<td>25 - 100</td>
<td>100</td>
<td>2.5 - 10</td>
</tr>
<tr>
<td>Timbers</td>
<td>45 - 75</td>
<td>50</td>
<td>2.2 - 3.7</td>
</tr>
<tr>
<td>Gypsum plaster</td>
<td>60</td>
<td>12</td>
<td>0.8</td>
</tr>
<tr>
<td>Hardboard</td>
<td>450 - 750</td>
<td>6</td>
<td>2.3 - 3.8</td>
</tr>
<tr>
<td>Average gloss paint film</td>
<td>-</td>
<td>-</td>
<td>7.5 - 40</td>
</tr>
<tr>
<td>Polythene sheet</td>
<td>-</td>
<td>0.06</td>
<td>110 - 120</td>
</tr>
<tr>
<td>Aluminium foil</td>
<td>-</td>
<td>-</td>
<td>4000.0</td>
</tr>
<tr>
<td>Straw-clay @ 450</td>
<td>2.3</td>
<td>300</td>
<td>0.7</td>
</tr>
<tr>
<td>Straw-clay @ 750</td>
<td>2.9</td>
<td>300</td>
<td>0.9</td>
</tr>
<tr>
<td>Straw-clay @ 1250</td>
<td>4.3</td>
<td>300</td>
<td>1.3</td>
</tr>
<tr>
<td>LE with expanded glass @ 500</td>
<td>7.5</td>
<td>300</td>
<td>2.2</td>
</tr>
<tr>
<td>LE with expanded glass @ 750</td>
<td>7.8</td>
<td>300</td>
<td>2.3</td>
</tr>
<tr>
<td>Silty earth (silt 78%)</td>
<td>6</td>
<td>450</td>
<td>2.7</td>
</tr>
<tr>
<td>Clayey earth (clay 28%)</td>
<td>7.1</td>
<td>450</td>
<td>3.2</td>
</tr>
<tr>
<td>Sandy earth (sand 56%)</td>
<td>7.3</td>
<td>450</td>
<td>3.3</td>
</tr>
<tr>
<td>Clayey earth plaster</td>
<td>8</td>
<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>Lime plaster</td>
<td>11.2</td>
<td>15</td>
<td>0.2</td>
</tr>
<tr>
<td>Lime-linseed oil plaster</td>
<td>15.2</td>
<td>15</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Vapour Resistivities and Resistances for Some Common and Light Earth Materials

2.5.4

**Moisture Transusive Construction**

The risk of interstitial condensation can be reduced by the use of vapour barriers, as noted above, or by 'breathing' or moisture transusive construction. It should be stressed that 'breathing' does not refer to air but to vapour, hence the less misleading, if also less memorable term 'moisture transusive'. Two characteristics underlie the effectiveness of moisture transusive construction. The first is the vapour permeability of the materials. The other is their 'hygroscopicity'. This term describes the ability of materials to absorb and desorb moisture. It plays an important role in both forms of construction but is less widely appreciated.

2.5.4.2

In essence, moisture transusive construction allows moisture to pass into the wall from either side and move freely within. Generally there is a higher vapour pressure internally so this tends to drive the moisture from inside to out where it evaporates, though under certain conditions this may be reversed. Because moisture is allowed to move freely it tends not to build up damp conditions conducive to decay, and because the materials used are hygroscopic, they are less at risk from the higher levels of ambient moisture.

2.5.4.3

The potential problem is during cold periods. At these times, the issue is whether the vapour pressure drop from inside to out is greater or less than the temperature drop. If it is greater then all is well, but if it is not, the air will reach its dew point within the wall and may condense. This is shown in the diagram below.
Diagram of Temperature Gradient against Dew Point Gradient to determine Condensation Risk

2.5.4.4

In addressing the risk of interstitial condensation, consideration of moisture transfusive construction divides into two somewhat distinct approaches. The first approach takes the vapour resistivity of the materials to be used and locates them in the wall so as to create a gradient of vapour resistivity across the wall. Materials with a higher resistivity (low permeability) are placed on the inside and materials with lower resistivities on the outside. The theoretical ratio of high: low resistivity is 5:1, but in practice much higher ratios are often built.

2.5.4.5

In this way the passage of vapour through the construction is controlled such that resistance to the vapour is greatest on the inside with a vapour pressure drop across the wall. In other words it is ‘harder’ for the vapour to enter the construction from the inside and ‘easier’ for it to leave on the outside. This approach works well and is advocated by exponents of modern ‘breathing wall’ technology.

2.5.4.6

Exponents of the second approach suggest that this arrangement of resistivities is unnecessary with adequate ventilation and point to the continued survival of traditional buildings which have a more or less constant vapour resistivity through the construction. According to the theory above, they run a greater risk of interstitial condensation but in practice this was rare. Similarly, the condensation that is arrived at by calculation does not pose a great risk, in practice, in earth and light earth buildings which do not necessarily have this vapour resistance gradient. This observation is based on the experience of many practitioners and is noted in Finnish research, para. 2.5.6.12.

2.5.4.7

The main reason for this is effective ventilation. Another is the hygroscopicity of the materials used, combined with their capillarity which tend to draw moisture away so preventing potential damp build-up and decay situations. A third reason is that condensation, if it does form, tends to do so close to the external face of the construction where it tends to simply evaporate if not already dispersed by capillary action and absorption.

2.5.4.8

The distinction between the two approaches, and an understanding of the reasons why traditional and earth based constructions do work in practice is important because most modern appreciation of moisture transfusive construction is of the first type whereas light earth construction relates more closely to the second. Problems in convincing Building Control Officers, Insurers and so on may be encountered because of this.
3

Construction Process and Principles

The purpose of this chapter is to describe the construction processes of Light Earth Construction and to comment on what is generally perceived to be 'Best Practice' amongst the few experienced practitioners.

To this has been added a 'Code of Practice' or set of Draft Guideline Principles which, as a Design, Material Performance, Workmanship and Maintenance Specification, may be followed by the would-be LEC Designer and Contractor to secure the necessary technical and financial support to proceed.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the conclusions to be drawn.

Sub-Contents

3.1 Preparation of Materials
3.1.1 Site layout and arrangements
3.1.2 Preparation of Raw Materials
3.1.3 Preparation of Clay Slip
3.1.4 Preparation of Light Earth Mix

3.2 Monolithic Construction
3.2.1 The Structural Frame
3.2.2 Wall Raising
3.2.3 Mechanised Methods
3.2.4 Drying Out

3.3 Block Construction
3.3.1 Manufacture of Prefabricated Units
3.3.2 Construction Options
3.3.3 Advantages and Disadvantages

3.4 Coatings
3.4.1 Plasters and Renders
3.4.2 Paints
3.4.3 Cladding

3.5 Services and Fixtures
3.5.1 Services
3.5.2 Fixtures

3.6 Maintenance and Repair
3.6.1 Maintenance
3.6.2 Repair

3.7 Renovation
3.7.1 External Insulation
3.7.2 Internal Insulation
3.7.3 Replacement

3.8 Construction Time and Costs
3.8.1 Programme
3.8.2 Timescale and Costs

3.9 Draft Guidance for Design, Construction and Maintenance of LEC Buildings
Summary

(3.1) Site arrangements for light earth are comparable to conventional construction project, though large quantities of ‘loose’ material need to be stored on site before use. Clay is mixed with water to produce ‘slip’, to the correct consistency, and this is mixed - manually or mechanically - with the fill material to provide the light earth mix. This can be installed immediately or allowed to ‘maturate’.

(3.2) Light earth itself is never used as a loadbearing mass. All loads are taken by an engineered structural frame. In monolithic construction, forms or shutters are fixed to the outer faces of the frame and the light earth mix is placed inside and ‘tamped’ down to create a firm solid mass without gaps. Permanent formwork can also be used, but must allow for sufficient ventilation of the mix. The mix can also be installed mechanically. The important thing is to ensure that the mix dries out as quickly and thoroughly as possible, to reduce the risk of decay.

(3.3) With block construction (or panels etc.) prefabricated elements are produced, on- or off-site, and fitted into the wall as dry elements as in conventional construction. Only the mortar needs to dry. This technique removes the risk of decay, and liberates the construction process so that it can take place at any time of the year or in any climate. It is also quicker on site. However, the additional cost of the extra material handling has to be factored in.

(3.4) Lime based and clay based coatings are used almost exclusively on light earth buildings, as these work best with the base material, offering protection whilst allowing moisture vapour to escape. Similarly paints used should be flexible and vapour permeable. Light earth can be clad externally with a ventilation gap.

(3.5) Services and fixtures may be fixed direct to the light earth mass or plaster, but heavy items are best attached to the frame. Items passing through the mass should be ducted.

(3.6) Repair of light earth or associated coatings is straightforward, but should not be necessary if a good maintenance schedule is followed. Regular maintenance is more important than with conventional materials.

(3.7) It is possible to use light earth in renovation projects, and it is often chosen because of its superior thermal performance, but similar movement characteristics, to traditional masonry components. Light earth can also be used to insulate traditional masonry buildings, internally or externally.

(3.8) Monolithic construction requires warm and dry weather for the drying out of the installed mix. In the UK, this means a summer activity. Further restrictions are imposed by the seasonal limitations of the use of lime coating in external conditions. For both reasons, the season for light earth construction is relatively restricted, and the use of block construction, for all or part of the building programme, is a valuable option. Costs of light earth construction are weighted heavily on to labour, with materials costs themselves usually low.
3.1 Preparation of Materials

The following section concerns the preparation of materials for monolithic light earth construction. Block construction is dealt with separately in Section 3.3. Generally the structural frame will be completed before or sometimes during the preparation of materials described below. The structural frame is described however in the following section on monolithic construction.

3.1.1 Site layout and arrangements

3.1.1.1 Site Layout

All building sites require to be arranged according to an understanding of the sequence of processes which will take place there. Issues such as site access, access within the site, storage of materials, necessary protected or inside work areas, outside work areas, site boundaries and restrictions, working at height, power and water supplies, site accommodation, likely plant requirements and so on will all affect the most efficient layout of the site.

3.1.1.2 It is important to know in advance what the relevant stages and processes will be. In addition to other building works, those for LEC are likely to be:

- Take delivery of materials
- Position and store materials as close as possible to place of next use
- Mix clay slip including testing for viscosity
- Mixing of slip and fill material
- Possibly storing of the mix
- Installation of mix into walls, floors etc.

3.1.1.3 Some or even all of the above processes can take place within the building itself. This is particularly useful when mixing the slip and fill material because of course the mix is then very close to where it is intended to be placed. A reasonable amount of space is needed to perform each function but this needs to be balanced against the increased distance for transporting each material between each process which is always time consuming.

3.1.1.4 Tools

Tools required will depend somewhat on the extent of mechanisation of the site. Specific, larger machines are described in their relevant section but those with motors may require 3-phase supply and tend to place a heavy initial load on the system, known as the start-up load. This should be taken into account if the electricity supply is to be the same as for the completed building since it may well not be 3-phase, nor sufficient generally.

3.1.1.5 Assuming no mechanisation at all, though this is unlikely in practice, the tools likely to be required for preparation of materials are:

- Wheelbarrows, buckets and shovels for moving materials about site
  (boards, planks or other can sometimes be useful to form pathways in muddy or otherwise difficult ground conditions)
- Pallets, tarpaulins and rope or heavy blocks for holding down tarps etc. for storage of materials if outside
Light earth construction carried out entirely manually is a time consuming and labour intensive technique. Under certain circumstances this is not a problem and may even be desirable, but generally, practitioners look to speed up the process and mechanise some, if not all, of the tasks.

The most common process to be mechanised is the mixing of the clay slip because this is the hardest work to do manually. In most cases to date, this has been the extent of mechanisation in straw-clay projects though some contraptions have been devised to mechanically mix straw and slip. Most other fill materials can be mixed easily in a cement mixer. Installation and formwork can also be mechanised and/or simplified. These improvements are discussed in the following section.

Building work in general can be untidy and this can be both dangerous and unsightly. It is good practice to keep the site tidy and ordered at all times though this can seem unimportant when involved in the building work itself.

Clients and those not involved in the process do not as a rule appreciate why the almost inevitable mess is necessary and this can lead to difficulties. Conscientious tidying and considerate site practice can prevent this. It is also advisable to establish strict and maintained site boundaries, within the overall site, so that construction mess and materials are contained within specific boundaries. This prevents the spread of materials storage and debris which can overwhelm smaller sites and lead to practical problems of access etc.

All the materials commonly used in light earth are non-toxic and can be safely disposed of on site if necessary. In addition all except the clay and mineral fill materials are also biodegradable and so can be composted on site. It is worth creating a place for discarded, damp or otherwise unwanted material for this purpose so that cleared material has somewhere specific to go and is not left or treated as rubbish. Non-biodegradable material needs to be treated as on any other building site.
3.1.2 Preparation of Raw Materials

3.1.2.1 Clay Testing

A clay rich subsoil may be available on site, which is clearly the most ecologically advantageous option, or it can be imported. In either event, the subsoil chosen needs to achieve certain, fairly basic criteria. If not, it can usually be brought to specification by the use of additives. It should be stressed that no organic matter or humous should be present in the subsoil. This is because the presence of the humous greatly increases the chance of mould in the resultant mix. It also reduces its cohesive characteristics.

3.1.2.2

A subsoil suitable is one with at least 50% clay content by volume, i.e. 'clay-rich'. To ascertain the nature of the subsoil it is possible to obtain a laboratory test for a precise definition of the composition, but for the purposes of monolithic light earth construction this is not necessary; a number of simple 'field tests' will suffice and these are described below.

3.1.2.3

Two very basic tests include the Touch test and Lustre Test. The Touch Test involves removing the largest grains and rubbing the remaining subsoil between the fingers and the palm of the hand. The soil is sandy if a rough sensation is felt and it has no cohesion when moist. It is silty if it is slightly rough and is moderately cohesive when moist. The subsoil is clayey if it contains lumps which resist crushing, is smooth when rubbed and becomes sticky and plastic when moistened. The Lustre Test involves a ball of slightly moist earth which is cut by a knife. If the revealed cut surface is dull, the soil will be predominantly silty whereas if it is shiny, it will be predominantly clayey.

3.1.2.4

Whilst the above are of interest, the following tests give a more accurate picture of the soil composition. The Sedimentation Test offers a preliminary determination of the subsoil composition. A fairly large jar should be filled with 1/3 water and 1/3 subsoil, ensuring that there are no big lumps in the subsoil. This is capped and shaken vigorously until the solids are all in suspension, and then left to settle. The various solids will settle in layers according to their particle sizes, thus gravel will sink first to the bottom, followed by layers of sand, silt and finally clay on top. The clay portion of the mix should occupy 50% of the volume of solids but both clay and silt contents expand slightly due to the presence of water so care should be taken when determining relative quantities.

3.1.2.5

The Ribbon Test is a test for plasticity whereby plasticity roughly relates to stickiness or cohesiveness. An earth of medium plasticity is sought because if it is too pure (too much clay) it will exhibit excessive shrinkage but if it is not plastic enough it will not be as cohesive or as strong. Rolling a moist sample of the subsoil between the fingers to the rough diameter of a pencil, and then bending it at a right angle, will display its relative plasticity. If the sample does not crack at the bend then it is suitable.

3.1.2.6

A more detailed account of both field and laboratory test procedures can be found in Houben & Guillard (ref. 8.1.7)
3.1.7 To be certain that the chosen subsoil will work in practice however, there is no better substitute than to make a small prototype, either in the actual building if it is ready, or on a separate framework of the same proportions.

3.1.8 A material with too little clay is easily remedied by the addition of an appropriate quantity or percentage of clay powder or known clay rich earth. Sand may be added if there is too much clay in the material.

3.1.9 Clay Sourcing

The main practical difficulty with using clay is the fact that in its natural state it is hard and lumpy and thus both difficult to work with and difficult to break down into solution as is required for the creation of the clay slip. Because of this, all efforts are directed toward making the clay easy to dissolve in water.

3.1.10 The simplest possible solution is to purchase a suitable clay, as described above, in powder form. This is the easiest form of the material with which to work and may be available from a local brickworks as clay powder is sometimes collected as a by-product of other brickmaking processes.

3.1.11 A brickworks is perhaps the most straightforward source for clay, particularly for clays of known composition and it may be possible to negotiate the separation of the clay at one of the initial stages of its preparation before being compressed into brick format. The first of these stages is usually crushing of the lumpy source material, followed by ‘crumbling’ of the clay into easily handleable, slightly damp but friable material. Clay will probably also be available in its original condition from a brickworks and an indication of the cost differential between the original clay and the ‘crumbled’ clay is an increase from £12 a tonne to £20 a tonne. A cost difference which is well worth the saving in labour, regardless of the method of mixing for the ‘crumbled’ clay is far easier to move about site than the original source. This was what was done at Littlecroft.

3.1.12 Robert Laporte, in his book ‘MoosePrints’ (ref. 8.1.1) describes another technique in which a layer of clay rich earth is cleared of topsoil and exposed to the weather a year or more in advance of harvesting. The continuous freeze- thaw action will tend to loosen and break down the clay into a powder. This process can be augmented by scraping the surface with a hoe or similar. The resultant clay powder can be collected and stored either in solution, in which case it needs to be stirred occasionally to prevent excessive settlement, or dry, in which case it needs to be sealed and prevented from becoming damp and consolidated.

3.1.13 If some form of modified clay is not available, it is possible to use clay in lump form and simply crush it on site but this is a laborious and time consuming activity. An alternative is to use a fairly powerful machine to break up and dissolve the clay whilst being mixed with the water.

3.1.14 Water

All building sites need a water supply. Even “dry” sites where most of the construction undertaken is timber frame or pre-fabricated still normally require water for site accommodation and tool cleaning etc. The ideal situation is to have an outside tap with surrounding hardstanding and drain, and for this to be reasonably close to the main work area.
3.1.2.15 Water is required for adding to the clay to make slip. For this purpose water can be brought over by buckets but is is clearly preferable to have a hose attachment which can be controlled at the head and fed into the mixing receptacle. Water is also needed for cleaning, principally of tools but also of boots, buckets, hands and children if they are involved!

3.1.2.16 Straw Any type of straw is acceptable, as described in Section 2.1, but it must be completely dry.

3.1.2.17 Straw which is damp or smells musty must be discarded. It is worth having a recognised and separate place for discarded materials, ideally a compost heap so that these materials cannot be mistakenly re-introduced. Occasional tidy-ups are important but a distinction needs to be recognised between ‘mess’ and intentionally discarded material as in workshop situations people can “clear up” other people’s mess and inadvertently re-introduce the damp straw.

3.1.2.18 The straw should not contain seeds, weeds or other green matter. Seeds will tend to sprout in the wall and represent food for rodents and other biological activity while green matter, like hay, is simply more susceptible to decay.

3.1.2.19 If the straw is acquired in traditional rectangular bales, it is easier to move around the site and locate to suit, but it is more common now to find straw stored in the large round bales. In either case, the straw should be stored off the ground, ideally on pallets, to prevent damp from seeping in from the ground. It should also be completely covered with a tarpaulin or similar if it cannot be stored indoors or in some other way under cover.

3.1.2.20 It cannot be emphasised too strongly the need to keep the straw completely dry at all times. Straw which has been damp before it has been mixed into the wall is much more at risk of decay, and of spreading decay to adjacent, healthy straw.

3.1.2.21 Straw stored for long periods can become home to rodents who tend to utilise the ‘channels’ between bales. Whilst it can be satisfying to get in all the materials needed well in advance, it is usually preferable to wait until the straw is needed and arrange delivery. Farmers or whoever is storing the straw will generally be happy to keep it in their barn until it is required.

3.1.2.22 Lastly, while compacted straw is less at risk, loose straw is a potential fire hazard. For this reason straw should not be stored loose (an attractive option when pulling straw from large bales) and it is worth regularly and conscientiously tidying the loose straw which inevitably spreads around the site as work progresses.

3.1.2.23 Woodchip Woodchip is fairly readily acquired in most parts of the UK, but as it is not a common commodity some investigation is normally required. Tree Surgeons, Demolition Contractors, Farmers, Foresters and Sawmills are all potential suppliers of woodchip. Some of these may also be able to arrange delivery. As woodchip use for fuel begins to develop as an industry so too will suppliers and while less common, these will be able to supply chips in bags and dried which is naturally
preferable. A look in the Yellow Pages under ‘Forestry Maintenance Services’ or ‘Tree Work’ should illicit people and companies who can chip timber. This could be done on site with trees from the site, or chips could be delivered from elsewhere.

3.1.2.24 In theory, woodchip without bark and sapwood is preferable because these are less susceptible to decay and infestation. For this reason sawmills, perhaps in combination with others’ chipping machinery may be the best option. However only small branches and twigs are normally chipped while larger timber is more useful as lumber or firewood so most available chips contain bark and sapwood and the established markets for woodchip such as paths and mulches for Garden Centres take no account of this.

3.1.2.25 So, woodchip for light earth mixing is ideally bark-free and of heartwood. It is best dry, thus reducing the moisture which needs to dry out in the mix after installation, and it is best delivered in bags which can be kept dry, and stored off the ground on pallets. The disadvantage of bags is that they can only be dropped off at the closest point to which the lorry can reach. In some cases this can be a considerable distance from the building. Where chips can only be delivered en masse, they will need to be taken by wheelbarrow to a suitable storage area, ideally a hardstanding with back and side boards for containment, or something similar made of plywood boards and kept off the ground to avoid damp seeping through.

3.1.2.26 Mineral Fill

Mineral fill materials suitable for light earth such as expanded clay and vermiculite are more expensive and difficult to come by in the UK. Expanded glass is not available in the UK at the time of writing. The main source for these materials is generally through Garden centres but this is expensive, for example about £7.00 for 25 litres of expanded clay pellets.

3.1.2.27 Materials should be stored so as to remain dry at all times, protected from the weather and damp seepage from the ground.

3.1.3 Preparation of Clay Slip

3.1.3.1 Manual Preparation

The manual preparation of clay slip is arduous, and so preparation is normally abetted by mechanical power of one sort or another. If manual mixing of slip is to be undertaken, it is important to prepare the clay as well as possible. Powdered clay is preferable, and ‘crumbled’ clay is acceptable as described in 3.2.2 above. It can help to store clay in water preceding mixing the slip to loosen and soften it. Mixing stiff clay into a paste with relatively little water before also helps to make the slip mixing easier and reduces the lumps of clay in an easier medium.

3.1.3.2 Traditionally, subsoil was softened and mixed for earth construction by being trammelled by animals by simply being added to a compound. Alternatively the earth was placed in a compound and water added in stages as a heavy wheel or similar was rolled across by horse power. Modern equivalents of these techniques involving tractors are suitable for large amounts of earth such as are used in denser earth construction but they are unnecessary for the relatively small amounts required in light earth construction.
3.1.3.3 At its most basic, all that is required is a drum or barrel, or any suitable receptacle which is both large and strong enough and a mixing stick, preferably a hoe or similar. Old baths and animal feeding troughs have been used which can be easier to mix in, but harder to avoid spillage. A cap or top to the container keeps rain, insects and other debris out of the mix and is advisable. The water is always put first into the barrel and the clay added to it. The clay is mixed in until the right consistency is reached and all the clay is in solution with no lumps at the bottom.

3.1.3.4 If one person carries out this task alone, it is advisable to add the clay in several stages, mixing each in thoroughly before adding the next. If all the clay is added in one go, it will be much more difficult to mix and dislodge from the bottom of the barrel. If two people do this, one can add the clay gradually as the other mixes. It is important to keep the water moving as the clay is added and for this reason two people are to be preferred for the task.

3.1.3.5 Ideally, a ratio of subsoil to water could be given at this point to accurately gauge the mixture. However, this is not possible since the difference in the behaviour of different clays renders such an attempt fruitless. As a rough guide, the amount of clay is likely to be in the region of 8 - 15 shovels / 4 - 7 buckets / 40 - 80 litres to about 60 litres of water.

3.1.3.6 Fingerprint Test

In reality this variability in clays does not matter because the correct consistency is established not by batching, but by two on-site tests. The first is to dip a finger into the mix and draw it out again. The thickness of the mix should be that of thin cream and the clay should just mask the fingerprint. If it is too wet, too little clay, the fingerprint will be evident through the mix and more clay should be added. Clay is added and mixing continues until the fingerprint is covered.

3.1.3.7 Viscosity Test

The second test is known as the Viscosity Test. This may need to be undertaken at a few stages initially as above. This involves pouring 100ml of the slip onto completely level glass from a height of 100mm. The slip should expand to form a puddle between 125mm and 175mm in rough diameter. The ideal is usually about 150mm. If the puddle is too wide, add clay, too small, add water. See below.

![Viscosity Test: 100ml of clay slip poured from 100mm onto level glass.](image-url)
3.1.3.8 Despite the simplicity of the two tests, they provide a consistent and surprisingly accurate gauge of the mix consistency. Once the correct mix ratio has been established the gauging of the mix can be done by measured batching, but the mix should always be tested according to the two tests mentioned before being mixed in with the fill material.

3.1.3.9 Certain practitioners sieve the slip into another storage barrel before the next stage to remove any debris and clay lumps.

3.1.3.10 The slip can be stored more or less indefinitely as the clay will remain in solution, though a thin film of pure water will form at the top of the mix after a day or two and this will increase in depth over the weeks as the clay begins very gradually to re-consolidate. However a quick stir will revive the solution even after several weeks left alone.

3.1.3.11 Mechanised Preparation It is more common to introduce some element of mechanisation into the slip preparation. The simplest and easiest solution is to use a drill with a plasterers’ paddle bit inserted into the mix. Plasterers’ drills are more powerful than a standard drill because of the high motive force needed to turn viscos plaster. Various paddle bits are available but all seem equally effective. Essentially, the person stirring is simply replaced by a person mixing using the drill, otherwise the same principles apply as above.

![Mixing clay slip with a plasterers' paddle drill.](image)

3.1.3.12 This work too is quite arduous and can be hard on the back since one has to lean over the mix and resist the turning of the drill, however, it is much faster and leads in general to a more thoroughly mixed material.

3.1.3.13 Some machines will also allow for a complete mixing of water, clay and fill material in one go. In these situations it is important to build a small section of wall or element before committing to a particular mix ratio so that the agreed mix can be tested properly.
3.1.4 Preparation of Light Earth Mix

3.1.4.1 Straw-Clay

The preparation of straw-clay requires a working platform of approximately 1200mm by 1800mm per person. A sheet of plywood is adequate. This can be used by more than one person working the same mix as shown below, though it is normally more efficient to work singly on separate mixes. Ideally the platform is raised off the ground by as much as 300mm which makes the work easier and less demanding on the back. Some practitioners prefer to have upstand edges on one or more sides, this prevents the loss of mix over the edges but also impedes the work. The platform should be as near as possible to the wall, if it will be installed directly, and / or to its storage location if it is to be allowed to maturate.

3.1.4.2

The ratio of straw to clay slip is discussed below, but the numbers involved are less important than the balance which needs to be learnt in each case. An amount, normally between an eighth and a quarter of a (rectangular) bale per person is spread loose onto the platform. It helps to ensure that the straw is completely loose and teased out as clumps are harder to break up when the slip is added.

3.1.4.3

The slip is then broadcast over the straw. A bucket is fine for this but can be a little uncontrollable, so some practitioners prefer to use a watering can, some add a spreading plate to the nozzle to spread the slip more evenly across the straw as shown below. What is important is to achieve as even a spread as possible in order to speed up the process of mixing. It can help to stack the straw a little so that the slip reaches more straw as it trickles through.

Clay slip is broadcast over loose straw

3.1.4.4 Volhard, ref. 8.1.2, describes another method of mixing whereby a pit or container is filled with clay slip and straw placed into it. The mixture is then trampled underfoot and when thoroughly coated, removed to maturate. This method is suited to denser mixes, for example over 800 kg/cu.m because the amount of clay to straw is excessive for light mixtures, and the straw is crushed which gives it less resilience and hence insulative capacity. For denser mixes, however, this is likely to be a more efficient method for mixing.

3.1.4.5

Once the slip has been added, the mixture is tossed, exactly as a salad, using
pitchforks preferably, but garden forks will suffice. This can be quite hard work for those without experience of heavy manual labour. In these cases smaller amounts of straw and slip make for easier ‘parcels’ of work. Laporte and others describe communal mixing where several people work one large mix at a time. This can be more socialable but tends to be less efficient.

Mixing clay slip with straw with forks on a plywood board, like ‘tossing a salad’

The mixing continues until all the straw is completely, but lightly coated in the slip. It is important that the straw is completely covered, if any yellow-white stalks are visible, more mixing is required. At the same time, because the mixing can take time, it can be tempting to add more slip to speed up the process but this can lead to over-saturation which makes the straw less resilient to over-consolidation in the wall, makes a heavier, less insulating mix, and increases the amount of moisture which must dry out of the mix upon installation. The temptation to add more slip than is necessary is also due to the fact that the correct amount, when added in one go, never looks as if it will be enough, and inexperienced workers will almost always add much too much slip if not shown, and monitored.

Mix ratios are important to establish for the purposes of replicability, but in practice such replicability is difficult to achieve except where the material sources used are the same. Ratios used in different parts of the world are all different yet achieve similar end products. For example, the slip ratios used in New Zealand, when used in Scotland for Littlecroft were wholly inadequate and much thicker slip was required to achieve the same final mix. So the following should be treated with caution and it must be stressed that these ratios are for guidance only. In the same way as mixing the slip, what matters in practice is not that quantities used are the same, but that the end result is of an adequate and consistent quality and this can only really be established through experience.

Partly because of this, few guidelines are given in literature, but also because the eventual density of the mix in the wall depends less on the mix proportions and more on the consolidation of the mix once tamped and built over. The guidelines given range considerably in accuracy and helpfulness. For example, Robert Laporte, in both ‘Mooseprints’ and the later ‘Alternative Construction’ (refs. 8.1.1 and 8.1.5) simply states that one bucket of slip is used to each half bale of straw.
2 buckets to a bale, therefore, or approximately 25 litres to 1 bale. In contrast, the guidelines to which ‘Earthforms’, a light earth specialist contractor in New Zealand worked, were approximately 5 buckets to a bale, or 60 litres per bale.

The following table can be used to provide very rough guidelines as to the quantity of slip added to a bale of straw, in order to achieve the noted densities. This table will be helpful for the low densities noted but cannot be extrapolated for higher densities. A number of assumptions have been made which are stated below.

<table>
<thead>
<tr>
<th>Desired Finished Density of wall, kg/cu.m</th>
<th>Assumed density of compressed fill, kg/cu.m</th>
<th>Additional density to be made up with slip</th>
<th>Litres of slip (@1500 kg/cu.m) required per bale</th>
<th>12 litre buckets per eighth bale mix</th>
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<tr>
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<td>100</td>
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<td>250</td>
<td>167</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Mix ratio Guidelines for Straw-clay

Loose straw has a density of about 70 - 90 kg/cu.m, straw bales have a density of about 400kg/cu.m, that of compressed straw board is about 350 kg/cu.m. The ability in a light earth mix to compress straw increases with the amount of slip and the saturation levels. In a lightweight mix, with lightly tamped straw, it can be assumed that the density of the compressed straw alone is about 200 kg/cu.m. A medium density mix, quite heavily tamped might result in a density of the straw alone of about 300kg/cu.m. Higher densities will be achieved less by greater compression of the straw than by a higher percentage of clay in the overall mix.

Clay slip is assumed to have a density of around 1600 kg/cu.m but this can be altered to suit conditions. At the higher densities of light earth, a higher density of slip, and therefore drier slip mixes, will be required.

Assuming approximately 10 - 15 litres per bucket, full of slip, the number of full buckets per bale can be derived from the table. Further assuming that it is easier in practice for one person to mix an eighth of a bale at a time, the final column gives an indication of buckets (@12 litres) required per eighth of a bale.

Ultimately, the only way to be completely sure of the density and suitability of a particular mix is to make a sample, dry it and weigh a given size. If a number of these are prepared before the start of a project with different, recorded mix ratios, a replicable batch ratio and tolerances can be established from the outset.

Mechanisation

It is possible to mechanically mix straw and slip but there are no ‘off-the-shelf’ machines that are appropriate and some ingenuity and money are needed. The question is whether the money and time needed to create a machine for the job can be offset against savings in the preparation times overall. In general, the larger the job, the more likely it is to be worth the effort.

Because most jobs to date, even in Germany have been more or less one-off
private projects and relatively small, few such machines have been created. One example in New Zealand was a large, approx 2m diameter wheel, with a central axle and a width of about 800mm, rather like a large ‘mouse wheel’ such as is seen in pet cages. Both sides of the wheel and the perimeter were covered in wire mesh with an access door hinged onto one side. 200mm spikes or needles were fitted to the inside of the wheel. Straw was placed in the wheel / cage and a spindle used to turn the mixture while slip was poured, in small amounts, through the top. The spikes caught the straw preventing it from simply staying at the bottom of the turning wheel and as the mix fell, the slip was mixed in. The wheel was adapted from some agricultural machinery but was considered by the builder not to have been worth the effort despite the savings made.

3.1.4.16

Another machine, a 750mm diameter corrugated steel cylinder about 4 metres long was developed by Sjap Holst in the Netherlands and is shown below. It is positioned on a frame which allows the cylinder to be both turned on rollers beneath it, and tilted to adjust the angle of the cylinder. Paddles fixed to the inside of the cylinder prevent the mix simply sliding gradually down the cylinder by catching the straw as they turn. Straw and slip are added to the top and are then mixed as they pass down and through the turning cylinder rather like an elongated washing machine. The speed and thus extent of mixing can be adjusted by the angle of the cylinder. The size of the machine and its transportation problems are the only aspects which offset against the considerable savings in effort and time it affords. The machine was produced as a one-off but on a semi-commercial basis such that subsequent LEC projects could benefit by hiring the machine thus making light earth a more economically viable option in that Country.

Sjap Holst’s light earth mixer in the Netherlands.

3.1.4.17 Woodchip-clay

The significant advantage of woodchip-clay over straw-clay is that it can be readily mechanically mixed, thus saving most of the effort and time associated with manual mixing of straw and slip as described above.

3.1.4.18

Normally, a conventional tip-up concrete mixer is used, but a conventional mortar mixer could also perform the task. In either case it is important to put the slip in first and add the woodchip afterwards, otherwise it does not mix as well and subsequently takes longer to achieve a satisfactory result.

3.1.4.19

In terms of mix ratios, the density of woodchip is generally give as 300 kg/cu., for lighter densities, this can be input into the table above, but unlike straw, woodchip
does not compress much, even when soaked (which is not advisable) so there is little deviation on the densities which can be achieved by tamping alone.

3.1.4.20 Mineral-clay

The preparation of mineral-clay is essentially no different to that described for woodchip-clay. Where straw is added to a mineral-clay mix for greater reinforcement, this will need to be chopped to a maximum of 150mm to be able to be effectively mixed. Straw longer than this tends to stick to the edges of mixers and does not combine effectively with the mineral fill material.

3.1.4.21

Like woodchip, mineral fill will not compress so densities are controlled simply by the addition of more or less clay, a richer or leaner mix of slip, or of other additives. Densities of the mineral can be acquired from the manufacturer.

3.1.4.22 Maturation

There is considerable debate as to whether, once the mix has been prepared, it should be placed immediately in the wall or left to maturate. If newly mixed straw-clay is left to maturate, the moisture of the slip seeps into the straw structure and softens it whilst at the same time beginning to evaporate naturally. Thus maturated straw-clay, left for a few hours or overnight is a much ‘softer’ material, less ‘bouncy’ and, depending on the length of time it has been left, somewhat drier overall. It is also a more homogeneous material. Newly mixed straw-clay looks like yellow straw with brown liquid over it, while maturated mix looks like brown, soft straw and is a more pleasant material to handle.

3.1.4.23

The advantages of using the mix straight away are that it is quicker, although once a system is set up it makes little difference, and there is less handling of the mixture since it goes from the mixing platform direct into the wall. Importantly, as the slip takes some time to seep into the structure of the straw and soften it, placing the mix in immediately avoids the risk of too great a consolidation since the straw remains ‘bouncy’ and thus resilient to compression. In this way the insulative effects of the hollow fibres are maximised.

3.1.4.24

Because at Littlecroft volunteers helped to build much of the wall fabric, the author was concerned about tamping being too ‘enthusiastic’ and the softness of the maturated mix leading to too great a consolidation in the walls, so opted to place the mix in immediately after preparation.

3.1.4.25

The advantages of storing the mix and allowing it to maturate centre around the fact that it has been allowed to dry somewhat before it is placed in the wall. This depends on the looseness with which it has been arranged for maturatation and the ambient conditions but in any event it is drying more effectively than it would be in the wall. For this reason maturation is seen as reducing ‘at source’ the main threat to light earth which is failure to dry out sufficiently in the initial stages.

3.1.4.26

German literature tends to advocate allowing the mix to maturate for at least a few hours after mixing but advises against allowing individual stalks to dry out completely. In practice, the mix is mixed again when moved and installed in the wall so this is not a problem. Where the drying out of the mix is likely to be a particular problem, then maturation should be considered.
3.2 Monolithic Construction

In contrast to block or panel walls, monolithic construction is that which creates monolithic, continuous or seamless walls because the light earth mix is installed wet and sets as a continuous or monolithic mass.

3.2.1 The Structural Frame

3.2.1.1 Light earth itself is never used as a loadbearing mass. All loads are taken by a structural frame which is designed by an engineer to take the known loadings. A light earth wall is likely to be heavier than the equivalent insulated timber frame conventionally used in the UK and, along with the plaster and renders generally used, actually represents a fairly heavy overall load. For this reason it is important to know what the anticipated light earth and coating densities and thicknesses are likely to be to enable the engineer to take account of the loads which will bear upon the foundations. Main posts shouldn’t be further apart than 1.5 m or the mix has too little to which to attach and slumping can occur.

3.2.1.2 Generally, the frame is erected and the roof put on, including coverings, before the light earth installation is started. There are exceptions (see ref. 8.1.5, p 203) but this has the advantages of conventional frame construction whereby work is able to continue under cover and some protection is offered against the weather while the light earth remains unplastered. A frame also allows greater flexibility in subsequent alteration or adjustments to the mixture or wall.

![The double stud type frame at Littlecroft showing the early installation of a weatherproof membrane over the building](image)

3.2.1.3 In common with all earth construction, light earth buildings benefit from a wide overhang on the roof to give protection from the weather. The overhang shown above of just over 600mm is a minimum, many are at least 1m or more and extend to form balconies etc. around the building. An overhang is not necessary if the walls are clad rather than plastered, as is described in Section 3.4.3.

3.2.1.4 External light earth walls across the world have tended to be around 300mm in width. Widths less than this will give insufficient insulation whereas at greater widths, problems may be encountered with insufficient drying of the wall centre, particularly at higher densities.
3.2.1.5 In light earth construction, the frame also has other advantages. The frame is used to fix the formwork but in addition is helpful in fixing other items when the walls are complete such as external cladding or battens, skirting boards, picture rails and other internal fittings. Fixing direct into light earth is possible, but fixing into solid timber is usually preferable.

3.2.1.6 Frame types

The structure may be almost any type at all, but certain arrangements lend themselves to light earth construction. The following six diagrams indicate different ways of creating a suitable structural frame within which LE mix can be placed. All have relative advantages and disadvantages and will tend to suit different conditions. Many hybrids of those shown are also possible and some are indicated in the Case Studies which form the basis of Chapter 7.

3.2.1.7 Coatings or claddings are not shown, nor the location of formwork or shuttering but all could be coated, clad or over-built in any material or system. Each wall is assumed to be 300mm wide. Some traditional German and modern US buildings incorporate stabilising bars which run within the wall and offer increased stability of the mix. These are not shown but each arrangement could be adapted thus. Bracing is not shown but is required if not dealt with elsewhere in the structure.

Diagram 1 shows a main structural frame within the centre of the mass which takes the structural loads. To these main posts are fitted small outriggers to which can be fitted shuttering. This type is also suitable for renovation where the existing posts can be ‘buried’ within an insulating mass with outriggers as shown. This type is common in Germany and its main disadvantage is a relatively large amount of carpentry and joinery with separate timbers for separate jobs.

Diagram 2 shows two completely separate frames offset from each other. Either or both may be structural, but in any case they will be joined at least at top and bottom. One set may be larger than the other, particularly if one is loadbearing. Each frame acts as a facing for shuttering. Because they are not joined otherwise, there is little or no ‘cold bridging’, albeit with timber this is not significant.
3.2.1.9

Diagram 3 shows the two separated frames aligned and joined by a cross piece of timber of particle board. This is in many ways the simplest and most efficient system and is used most around the world. The combined studs act as loadbearing members and can be used to fix formwork to the face of the wall.

3.2.1.10

Diagram 4 shows wide boards used as studs in both a loadbearing and face fixing capacity in perhaps the simplest arrangement. However, because there is no contact between light earth mass on either side of the stud, there is a need to hold the mass and resist being pushed out of the wall. Simple face fixed battens can be used for this as shown or more complex arrangements involving cross pieces running between the major studs. Another solution is to drill large holes in the studs and thread the light earth mix through. There is some ‘cold bridging’ with this arrangement since the timber studs will conduct more heat through than the surrounding mass, if it less than about 700 kg/cu.m. In practice this arrangement is rarely used because of the problems associated with twisting of such wide boards and the lack of reinforcing of the mix ‘through’ the stud.

3.2.1.11

Diagram 5 shows a single line of structural posts wholly encased in light earth with no outriggers, as in diagram 1. The advantage of such a construction is that there is no timber in the face of the wall which then needs to be bridged with skim before plastering. However, most practitioners agree that this is outweighed by the need to construct separate outer frames to which formwork needs to be fixed and the fact that there is no timber to fix to when the wall is complete. An example of this form of construction is Case Study 7.1.7, at Heeze in the Netherlands.
3.2.1.12 Diagram 6 shows a structural frame on the inside with the light earth mass wholly to one side. This form of construction is practised more in the US. It allows the internal framing to be seen and appreciated but it means that shuttering on both sides is more difficult. On the outside, a separate framework needs to be built, while on the inside battens must be fixed to the internal frame and formwork fitted between studs, all of which is more time consuming. One further problem of not having an established timber face to which to fix formwork is that without it, it can be more difficult to keep a true, plumb line and face.

3.2.1.13 When designing the structure, it is worth maintaining an equal distance between studs throughout the building. This has several advantages, but in relation to the process of shuttering it means that the same length of boards can be used for the whole building. If this is not possible, an alternative solution can be to use boards on alternate bays, as discussed in paragraph 3.3.2.7.

3.2.1.14 Bracing is an issue for the engineer, but in conventional timber frame construction is carried out by boards such as plywood fixed to the posts. In light earth buildings these interfere with the natural movement of moisture vapour and may need to be coated against fire spread. Instead of boards, diagonal timber struts or metal straps are used. Metal straps should be placed on the inside of the wall to avoid vapour condensing on them, but these are often preferred because timber bracing tends to interfere with the placing of mix while metal straps can be let into the face of the posts and are relatively unobtrusive.

3.2.1.15 Wall bases In common with any wall type, light earth walls need to be protected not only from above, but from moisture from below. There are essentially two ways of doing this. The image below on the right shows a conventional detail with frame and light earth on a dpc over a concrete foundation wall. The detail on the left shows a suspended timber floor with no dpc and ventilation underneath.
3.2.1.16 The dpc will be required by the Building Control authorities on the example on the right to prevent moisture from the ground rising through capillarity into the floor and wall structure above. This dpc also prevents moisture in the wall from moving downwards. Monitoring of the LEC building in England has shown that moisture levels are consistently higher in the lower parts of the walls and as such, the presence of a dpc, whilst necessary, represents a potential problem since moisture at this point could condense on the colder concrete-backed dpc and has limited movement options. If the external render was cement based or coated with a moisture impermeable paint, this would represent a real threat, but in practice the hygroscopicity of the materials used will mitigate against any such risk.

3.2.1.17 By contrast, the example on the left contains no such potential problems as no dpc is necessary, there are no particularly cold surfaces on which moisture could condense and all accumulated moisture is readily evaporated. While design decisions are taken for a variety of important reasons, it is worth bearing this in mind when designing with light earth.

3.2.2 Wall Raising

3.2.2.1 It is possible to build light earth walls without a framework of any sort, by the use of shuttering that rests upon the mass below, held together by elements which pass through the wall and are extracted when the shuttering is struck. This is the system used for rammed earth which contains no framework and has to be self supporting as it is raised. Several such formwork types are described in Volhard, ref. 8.1.2 pp 68 - 75 but these are not necessary with a structural frame and infer a loadbearing mass which is not intended with light earth in general.

3.2.2.2 Temporary Forms The most common method of shuttering the light earth mix has been to use temporary forms or shutters. Traditionally these were timber planks, but now most practitioners use plywood as it can be used wider and gives a smooth and stable face. These are simply fixed to the structure both sides, ensuring they are level and tight against the timbers and light earth is placed and tamped down within. The forms are struck (removed) and raised for the next lift as shown below.
3.2.2.3 The best board thickness is about 18mm. Thinner boards are easier to handle while thicker boards are needed for longer spans and heavier mixtures which can take some considerable lateral force. Boards are normally cut to 400mm width / height which is readily divided from a 1200mm board and relates to a lift of about 350mm if the need to overlap (usually approx. 50mm) is taken into account.

3.2.2.4 Boards are fixed by strong screws such as hexagonal or square head coach screws. Mechanical assistance to screw and unscrew these speeds up the process considerably. Nails are not used because hammering tends to dislodge the mix. Subsequent to the drying of the mix, it is worth using screw fixing generally to avoid unsettling and dislodging the light earth. Though it is resilient enough to withstand all everyday loads, sudden jarring knocks will be particularly destructive to light earth and should be avoided, for example, in the subsequent fixing of doors, windows, skirtings and architraves etc.

3.2.2.5 It is easy to overlook reveals and external corners. For the average project with 1200mm modules generally, it is worth cutting a few boards to 1500mm to take account of the external corners and using offcuts for the window and door reveals.

3.2.2.6 The number of boards needed should relate to the anticipated wall area coverage that can be prepared in one session, there is no point in cutting any more than can be used. Assuming a light mix of straw-clay, 300mm thick walls, manual mixing and all other conditions normal, an experienced and fit worker can produce very roughly 3 sq.m of wall per day, including mixing and formwork fixing and moving. Inexperienced and unfit workers will produce perhaps less than 1 sq.m. The number of boards needed can be thus derived from the anticipated number of workers consistently on site and adjusted for length of working day, experience etc. Woodchip or mineral-clay will be produced faster and quantities of completed wall might be adjusted to 4 sq.m and 2 sq.m respectively.

3.2.2.7 One problem that can bedevil an inexperienced site is the issue of adequately joining boards end to end, since there is rarely enough face width of timber to make a good connection for both boards. This problem is avoided by fixing formwork to alternate bays, raising the walls in a castellated or "hit and miss" manner. In this way, boards do not have to meet and can be well fixed to each timber as shown below. In many projects, the building is small enough that more mix can be prepared in one day than can be used to fill each raise, and so the boards must be struck and moved mid-way through the process.

Fixing and filling forms on alternate bays, to avoid end to end joints.
In most literature concerning light earth, it is noted that the mix is taken from its place of preparation or storage and placed within the formwork by the use of pitchforks and it is then tamped using a tamping stick. What is not mentioned is that it is often quicker, easier and more effective to do this with the hands.

Mix of any type should be placed loose within the forms no more than about 150mm thick at one time, before it is tamped into position. This is because inconsistencies within loosely positioned mix need to be evened out as the wall is raised to avoid looser areas developing. Inexperienced workers will sometimes be inclined to completely fill the depth of the form with loose mix to save time, then tamp it down and repeat. This leads to poorly consolidated and even completely empty areas exposed when the forms are struck. The advised sequence for one person working is to roughly place about 150mm depth of mix into the forms, tamp this down, then add another loose layer and so on. With two people, one tamping and one ‘feeding’ (usually more than one bay or person), this can be a more or less continuous process. Assuming the forms are filled as described above, with about 150mm of loose mix compressed to about 50 - 75mm each time, the process will need to be repeated between 5 and 8 times before the forms are full.

It is important that the corners and edges of the mix are sufficiently well tamped before working the central areas. This ensures that the mix properly fills the edges and corners which are easily missed and that the exposed edges are sufficiently firm and complete. Sloppy tamping is always exposed when the forms are struck!

Tamping is simply the act of jabbing down and pressing the mix into place. Short, fairly sharp jabs are particularly effective on straw-clay whereas more restrained and gentle tamping is more effective for woodchip and most other mixes. It is important not to tamp too firmly, unless trying to create a much denser mix, because much of the consolidation is achieved by the addition of subsequent lifts. The extent of this consolidation depends also on how soon the next lift is put on and the relative rigidity of the lift underneath.

Tamping straw-clay, left, at an easy low level, and, right, as the wall gets higher
3.2.2.132 It is not necessary to exert much pressure while tamping, most workers instinctively tamp too hard. This is probably because the mix in its wet state appears too insubstantial to really work as part of a building, but once dry, the straw and clay is transformed into a solid and more convincing structure!

3.2.2.13 Tamping sticks can be of anything suitable, but are generally fashioned from 50x50mm timbers, about 400 - 500mm long with one slightly tapered end for more awkward gaps, corners and around pipes, bracing etc.

3.2.2.14 Once the formwork is full, it may be struck. Certain practitioners advise against the immediate removal of the forms, and certain light or wet mixes do need some time to set before the forms can be struck, but generally it is possible to do so immediately, and this starts the drying out as soon as possible.

3.2.2.15 To remove the forms, screws must be removed while the board is kept tight against the wall. It is important both that the board is kept tight, and that when it is removed, it is done so with a sliding movement, not simply pulled away. This is because the mix is likely to have stuck slightly to the board. Pulling it away, or letting it come away from the frame as you loosen the screws can sometimes lead to the mix pulling away from itself as it sticks to the boards.

3.2.2.16 Once the boards are removed they can be re-fixed elsewhere, leaving a 50mm overlap with the layer beneath to avoid mix spilling out beneath the bottom edge.

![Left, lift lines clearly visible at the early stages of installation at Littlecroft and, right, at later stages at Dairy Flat, New Zealand.](image)

3.2.2.17 The work becomes more time consuming as the working platform is raised. It is particularly helpful to have at least two people working each area at this stage to avoid the need to get up and down regularly from the raised access level.

3.2.2.18 Unless there is direct access to the top of the wall from above which is unusual, it can be difficult to adequately tamp the last 200mm or so of the wall. Formwork is fixed as normal on one side, while on the working side, it is most common to use smaller width planks to more gradually build up the height for the last bit. It is useful to work back from the top in terms of plan width so that the last, top plank
fits accurately when needed. At the top, it is advisable to work sideways, putting the top plank a certain distance across the face of the wall and filling the gap from beyond the end of the plank. Whilst an accurate face is more difficult to maintain at this point, it can usually be hidden within the depth of the subsequent plaster.

3.3.2.19 Permanent Formwork

Temporary formwork fixing, striking, moving and re-fixing actually comprises a considerable percentage of the time taken in most light earth projects. One way to reduce this is to use permanent shuttering. The main advantage is that it need be fixed only once. The main disadvantage is that it does not allow the mix to dry. To overcome this, permanent shuttering needs to offer a strong and resilient surface to resist lateral force and support the wall, yet allow sufficient ventilation to enable the mix to dry out. In addition it needs to behave in a similar fashion to the rest of the wall and frame in terms of moisture and thermal movement and provide an adequate substrate for plastering.

3.3.2.20

Two techniques have developed to fulfil this role. One is timber lath and the other is reed matting. The use of timber lath, shown below, is more time consuming since each lath is individually fixed to each post after being cut to length.

Timber lath applied to the outside face of a light earth building in the US, see ref.8.1.5.

3.3.2.21

The other option, which has become popular in Germany and other European countries in the last two decades, is the use of reed matting. Reeds are cut to length and connected using twisted wires. The mats can be bought and fixed directly to the walls using staple guns. These are available in the UK through Construction Resources and NBT, ref. 8.5.6.

Reed mats as permanent shuttering. These are rolled up and fixed to the wall as it is filled, two completed wall sections are shown on the right.
3.2.3 Mechanised Methods

3.2.3.1 Alternative partly mechanised methods have been used for creating light earth walls and other construction elements. Whilst each affords some advantage over standard monolithic construction, usually speed of construction, most entail complications which mean that none have yet developed into viable commercial operations, nor popular alternatives to standard monolithic or block construction.

3.2.3.2 The most common alternative form of mechanised light earth construction involves the use of pumped material injected between shuttering or sprayed between posts and against rear formwork. The shuttering can be temporary or permanent. The image below shows a light earth mix being sprayed into an internal wall.

![Light earth pump and spray](image)

3.2.3.3 Pumped and sprayed light earth involves the bulk mixing of large quantities of light earth material which can be undertaken in a factory and delivered to site and pumped into position in a relatively short space of time. The depth of wall that can be built up depends on the skill of the applicator, the cohesion of the mix and the drying out period. Injecting light earth between formwork removes the need for skillful operation and considerable improves the inevitable mess left on site by one sided spraying operations such as shown in the image above.

3.2.3.4 Light earth can also be simply poured between shuttering and allowed to settle and dry without the use of tamping or pressured application. This is sometimes done with mineral fill light earth mixes since these cannot be compressed in any case. Such mixes can be prepared in large quantities and, as above, completion of the light earth element can be achieved in a matter of hours rather than weeks.

3.2.3.5 Minke, ref. 8.1.10 mentions the use of light earth as an infill between hollow blocks or other preformed elements in lieu of more conventional fill materials. He also describes the use of cotton hoses filled with light earth which can be laid on top of each other to produce largely self supporting internal walls. The hoses are filled by mechanical pumps with the hoses attached to small diameter outlets through which the mechanically prepared mix is extruded.
3.2.4  

**Drying Out**

3.2.4.1  **Drying**

In monolithic construction the greatest risk to the process is that the mix will not dry sufficiently once installed and will begin to decay. Though this is not likely if good practice is observed, it remains a risk to which all practitioners must remain vigilant. Mineral fill may be used in which case the risk of decay is not present, and block construction avoids the issue through using pre-dried elements. However even with monolithic construction using organic fill materials, a number of techniques can be used to augment the drying process and reduce the risk of decay. Some of these have been mentioned elsewhere in the report but are noted below as a checklist of points which may be useful in this regard.

3.2.4.2

The guidelines for mixing slip are described in Section 3.1.3. To reduce the drying out time of the mix, it is possible to reduce the water content which is used. This means either increasing the relative clay content of the slip - using a thicker slip mix than described - or reducing the amount of slip used when coating the fill material, or both. It is possible to reduce slightly the amount of slip used by simply increasing the mixing time but it must be emphasised that the fill material should be completely covered with slip before installation.

3.2.4.3

It is also possible to use additives to the slip mix which will result in less water being required. Adding sand to the mix reduces the relative clay content and thus both shrinkage and absorption of water overall, however, it also reduces the cohesion of the mix and the hygroscopicity. Water glass, casein, animal urine and several other materials have been used to increase plasticity and reduce water content so reducing drying times. Lime has been added to the slip or light earth mix to ‘burn off’ some of the moisture through a minor slaking action whilst increasing strength. However, the evidence for the efficacy of these additives is largely anecdotal and few properly conducted tests have indicated anything other than nominal or marginal improvements in performance which could not be explained in other ways. Minke, ref. 8.1.10 describes the results of some of these tests and Westermarck, ref. 8.1.3 / 8.3.8 describes the effects of certain additives in blockmaking experimentation.

3.2.4.4

In most cases, the most effective method of reducing drying times once installed is to allow the mix to maturate before installation. The looser the mix is left to maturate, the more effectively it will dry. It is commonplace for the mix to be simply stacked but this means that only the outer 100mm or so begins to dry much whereas spreading the mix out and leaving overnight allows all of the material to dry to a certain extent. Some stalks will completely dry and these should be mixed a little before installation to ensure sufficient cohesion of the installed mix.

3.2.4.5

Depending on the required density, it is often possible to reduce the intensity or compressive strength of the tamping of the material within the formwork. Only a very light compression is required. In addition, certain practitioners advise to only tamp the edges and corners of the mix, leaving the centre of the wall to compress only through the subsequent weight of additional layers. This has the effect of
leaving more air and less mix in the centre of the wall and hence an enhanced drying out process.

3.2.4.6 In most cases it is possible to strike (remove) the shuttering immediately after filling the mix within. In certain light mixes with materials of little cohesion this may not be possible. This enables the mix to begin to dry immediately and is to be preferred.

3.2.4.7 It is air movement which has the greatest effect on the drying of the mix, along with the ambient temperature and humidity. There is little to be done about the latter, but it is possible to maximise the benefits of air movement. To this end, it is useful to organise the wall raising so that prevailing winds are not blocked by the earlier raised wall sections and thus not effective for latter sections. It is important to leave the site clear so as to reduce as little as possible the disturbance of air movement across the site. Similarly, windows and doors should not usually be installed before the mix is dry. This can be an issue because on conventional sites external windows and doors are normally installed as soon as the surrounding walls are built, or soon after so as to create a weatherproof shell within which to begin internal works. The same is not true on light earth projects where it is usually advisable to leave the completed walls without external doors and windows for at east four weeks. This has implications for the site programme.

3.2.4.8 Alternatively windows and doors can be installed as, or even before, the light earth is built up, if the heating system can be turned on once the walls are complete. This will tend to dry out the interior and so dry out the walls. This may be advantageous for other site and programmatic reasons but is difficult to organise since the heating is likely to be out of sequence, and the air movement described above is more effective at drying out the mix.

3.2.4.9 Another option, which has not been tried to the knowledge of the author is to place pre-dried elements within the centre of the mix. Since it is the centre of the mix which takes longest to dry, and is the most at risk, this approach would reduce the risk of decay at the most vulnerable place, and reduces the overall quantity of moisture in the wall. However, it does require the manufacture of elements before other light earth operations and may reduce the structural integrity and cohesiveness of the wall overall.

3.2.4.10 Shrinkage Shrinkage is the inevitable process which results from the evaporation of moisture and the gradual compression or consolidation of the mix over time. It is most pronounced with straw-clay walls and denser mixes with higher concentrations of clay. This is discussed briefly in paragraphs 2.2.1.6 and .7. Shrinkage takes place throughout the wall but only tends to be a problem at the head of the wall or beneath horizontal noggins or dwangs where gaps of as much as 30mm can develop. Cracks can appear where differential settlement occurs as shown in the image below.

3.2.4.11 Two problems result from shrinkage. One is that it necessitates additional work in filling those areas which need it. The other is that, if not detailed to take account of shrinkage or subsequently infilled, it can create air gaps in the construction
which can lead to infiltration and heat loss. A number of methods can be used to reduce the likelihood and extent of shrinkage, apart from using mineral fill materials or pre-dried elements.

Shrinkage in a dense woodchip-clay wall has led to cracking of the mix around the double protruding double stud connecting piece which has been chamfered to reduce this problem.

3.2.4.12 Most of the techniques described above to reduce moisture content in the wall and drying out times will also reduce shrinkage. In addition it may be possible to extend the period of light earth installation, leaving longer periods between lifts. This means that each lift is drier and more rigid before the subsequent lift is placed on top and so reduces the overall consolidation of the wall.

3.2.4.13 However, this is not usually practicable on sites. Another method is to leave the last lift perhaps two weeks before infilling at the head of the wall. This should ensure that all likely shrinkage has taken place and that what little shrinkage will take place in the last 200mm or so will not be noticeable or problematic. Some practitioners make blocks for the last section which negates the shrinkage associated with drying out, and makes the last bit of the wall easier to fill.

3.2.4.14 It is also possible to install a compressible / expandable strip between the top edge of light earth and the bottom edge of a horizontal noggin or wall plate which expands to fill the gap left by the shrinkage of the mix. However, this is a rather fiddly option and it is usually easier to simply infill the area after any shrinkage has taken place. Alternatively, the wall head area or cill can be detailed to make subsequent filling easy, or allow insulation resting directly above the mix to simply move down as the mix settles. Allowing the ceiling insulation and light earth wall to be directly adjacent, rather than separated by wall head beams etc enables this to take place so no gaps appear and the insulation of the overall building fabric is not compromised.
3.3 Block Construction

This Section discusses the use of prefabricated units of light earth, the vast majority of which are created in a block form, hence the title of the Section. However, two other prefabricated types of light earth have been manufactured, namely boards and panels, and these are also discussed briefly in this Section.

3.3.1 Manufacture of Prefabricated Units

3.3.1.1 The manufacture of prefabricated units splits clearly between a consideration of hand made, or manual production, and commercial, mechanised production. Manual production of blocks involves the use of moulds, while mechanised production may be based on moulds or extrusion. In either case the mixing of clay, water and fill materials is based on the principles outlined in the previous sections, though commercial manufacturers place more emphasis on the need for blocks to withstand transport and handling and adjust their mixes accordingly.

3.3.1.2 Manual Production

The main reason for opting for manual, rather than commercial or bought blocks is likely to be cost. In situations where costs need to be kept low, and time, labour and enthusiasm are available, cheap or free, hand made blocks can be the most economic option. However, if the manufacture of blocks has to be paid for, or factored into self-build time/cost analyses, then it is likely to work out more expensive due to the inevitable financial advantage of economies of scale offered by the commercial blockmaker.

3.3.1.3 Manually produced blocks have other advantages. They can be produced from locally sourced subsoil, perhaps even from site excavations, and may incur little or no embodied energy costs from transportation, unlike commercially available blocks, which, in the UK at present, are all imported from Germany. For these reasons, they appeal to those wishing to seriously address environmental issues.

3.3.1.4 If hand made blocks are to be made on site it is necessary to ensure adequate space, not only for the advantageous arrangement of materials, but of the manufacturing process, and most significantly, of suitable storage space for air drying of the blocks.

3.3.1.5 The first step is to decide on the size and shape of the block. Some of the issues to be considered for this are discussed in the next section on construction options. A mould must then be made which is strong enough and enables easy removal of the mould from the block. Metal and wood are both commonly used for moulds. Simple shapes work best but are not always suitable for their intended end use because of the need to interlock with the frame. The size of the mould needs to take into account the finished wall dimensions, the ease of handling of the finished blocks and the the drying time of the blocks (thinner / smaller blocks dry faster).

3.3.1.6 Compression may be by hand or foot, by use of a tamper or more commonly by the use of an offset pivoted lever, as shown in the diagram and photograph below.
3.3.1.7

The operation is simple, repetitive and time consuming and most practitioners attempt to speed it up by basic mass production involving multiplication of the units produced in each operation. In this way moulds are made not of one block but, for example, eight in a row which in one operation can be compressed, and, if all resting on one board, can then be moved and stored in a single operation.

3.3.1.8

Once compressed, the blocks are moved to a suitable stack for storage and air drying. Ideally, this is under complete cover, but with as much ventilation as possible. Open ended polythene ‘Cloche’ type greenhouses are ideal because in addition to shelter from rain and open ends for ventilation, they are translucent and so allow the sunshine to augment the drying process. The image below, left, shows blocks air drying in Germany in barely adequate shelter.

3.3.1.9

Another method by which the labour associated with manual production of blocks can be reduced is simply to produce much larger blocks. These have the disadvantage of being more difficult to handle, and, depending on the smallest
dimension, will take longer to dry, however, they reduce the manufacturing and wall building times. In Minke, ref. 8.1.10, the work of German Architect Sylvester Dufter is described. He uses blocks of 300 x 500 x 600mm, laid flat to produce a 500mm wall thickness. The blocks are made of a light mix of straw-clay (they need to be light to dry sufficiently in such large blocks) and weigh 26 kg each. The production and installation of these blocks is shown below.

![Image of large, lightweight straw-clay blocks developed by German Architect Sylvester Dufter.](image)

Left, manufacture, and right, installation of large, lightweight straw-clay blocks developed by German Architect Sylvester Dufter, from Minke, ref. 8.1.10, p. 77.

3.3.1.10 The blocks described above, laid to form a 500mm wall thickness give a 'U' value of 0.3 W/sq.mK. Dufter used the blocks for several self-build groups. In one case, an owner builder family was able to produce 1500 such blocks in five weeks, sufficient for a very large family home.

3.3.1.11 Commercial Products A number of commercially available light earth block products are available across Europe, though the only country with a significant market spread so far is Germany. Each block has its own advantages and disadvantages, some are large while some are brick sized. They are of different densities, but most incorporate additional smaller fill materials such as sawdust or washed cow dung to increase cohesiveness and density.

3.3.1.12 There are two light earth blocks commercially available in the UK. At the time of writing both are available from Construction Resources in London, ref. 8.5.6.1 while ‘Karphosit’ blocks are also available from Natural Building Technologies (NBT), ref. 8.5.6.2. Images of both are shown on the next page.

3.3.1.13 ‘Karphosit’ blocks are 100mm wide, 250mm high and 500mm long made of clay and straw. They have an interlocking tongue and groove and are additionally bonded by a thin cellulose based adhesive which makes for a fast and easy method of building non-loadbearing partition walls with a sound reduction of 45 dB if a skim plaster coat is applied both sides. They offer 90 minutes fire resistance and have a density of about 925 kg/cu.m. They will take nails and screws and can support heavily loaded shelves.

3.3.1.14 Construction Resources also import straw-clay blocks made by 'Claytec' - a large earth building material manufacturer in Germany. Theses simple blocks are
113mm high by 115mm wide and 240mm long. They have a density of 700kg/cu.m and are aimed at restoration projects though they could be used in any number of situations. Being more insulative than 'Karphosit' blocks, they are recommended for use in external walls while other dense earth blocks are also imported and are recommended for thermal capacity and moisture balancing internal partitions. Light clay mortar can be purchased for use with the blocks.

![Left, 'Karphosit' Blocks, right, Construction Resources‘ Light NF Clay Bricks taken from Construction Resources trade literature.](image)

3.3.1.15

Construction Resources also import Clay board which is marketed as an alternative to plasterboard. It is made of clay, reeds and hessian and is 500 kg/cu.m in density. The boards are available in lengths of 1500mm, 625mm wide and 25mm thick. Their thermal conductivity is 0.14W/mK. They can be cut using a jigsaw blade and fixed with standard countersunk screws. Boards have a hessian finish over which it is recommended to plaster with a clay based finish.

![Clay, reed and hessian faced wall board taken from Construction Resources trade literature.](image)

3.3.1.16

Though not available commercially in the UK, it is possible in Germany to purchase ready made storey height timber panels, infilled with earth and light earth. These are simply craned into position and located tight against each other, with joints filled normally with wool felt for air tightness. Minke, ref. 8.1.10, notes the 1m by 3m high panels produced by HDB Weissinger. These are filled with mineral based light earth mixtures. A similar product, yet to be released commercially is under
development near Berlin and involves a number of partners, including earth building specialist Jorg Depta, ref. 8.3.1. The panels are also 3m by 1m, 300mm thick with a surrounding timber frame, internal diagonal frame and small section ‘ladder’ studs as shown in the pictures below. These skeletons are filled with a mix of expanded glass and straw with clay to form a mix of 600 kg/cu.m. The panels are delivered dry to site, installed, and plastered once scrim has been applied over the exposed timber faces.

3.3.1.17

The partners to the project include an architect who has devised a complete house building system to suit the panels and plans a prototype is in development with a view to establishing costs and then marketing the system as a whole.

![Images of Prefabricated light earth panel and derived house type produced by Arbeitsgemeinschaft Jaklin-Depta](image)

3.3.2

Construction Options

3.3.2.1

Essentially block construction is as flexible as monolithic construction in terms of what options are available. As with any block construction, they can be located anywhere that suits the construction generally as long as basic thermal, vapour, structural, fire, durability and other considerations are acceptable.

3.3.2.2

In some situations, blocks can be more readily used to fit within structural frames without the need for complex shuttering and subsequent shrinkage. Where access is only available from one side, blocks can be used where a wet mix would not be able to dry on the other side, such as with certain refurbishment works.

3.3.2.3

Blocks can be placed within the structural frame as simple infill. Ideally, both are designed so that an exact fit is possible and no cutting of blocks in necessary. This is quite straightforward in new build situations, as shown below, but in refurbishment projects blocks may need to be specially made, cut to suit and in many cases, cut to fit around bracing and other elements within the wall. Clearly, the less working of the blocks, the quicker and more efficient the installation.
Use of mechanised manufacture straw-clay blocks at Raisio, Section 7.1.8, placed within a frame designed to fit exactly around the block dimensions.

3.3.2.4

It is also important to establish the means by which the blocks are held within the frame and prevented from being dislodged or ‘pushed out’ of the wall, inwards or out. This also needs to be considered when planning a new build project with blockwork, along with size co-ordination.

3.3.2.5

The diagram below shows two common options for both locating and stabilising blocks within both a 100mm wide, single stud internal wall, above, and a 300mm wide, double stud wall, below. In each case a protrusion locks into a receptive gap or indentation and this can be created either way around as shown. In many cases, particularly with thin blocks laid vertically, there is also an interlocking shape cast into the top and bottom of the block for additional vertical stability, as can be seen in the ‘Karphosit’ blocks illustrated in paragraph 3.3.1.14.

Interlocking shapes of blocks within a frame.

3.3.2.6

It is also possible to use simpler block shapes and to use the mortar to cohere block to block and block to frame. This was done at Littlecroft to simplify the blockmaking process. Instead of a protrusion to each block, the blocks were simple rectangles in plan and the mortar, with woodchip in it to minimise differential movement, was used to fill the gap between blocks and in between the two post sections. This mortar bonded with the standard mortar courses and provided resistance and cohesiveness without the need for complicated moulds.

3.3.2.7

The advantage of placing blocks within the frame is simplicity of wall construction and the most effective use of space, optimising the width of the wall. The disadvantage of placing blocks within the frame is that, where the blocks and frame are not co-ordinated, it can be a time consuming and ineffective method of
filling a wall involving a good deal of cutting, filling and sometimes individual block making. In such situations, another approach is to lay the blocks adjacent to the frame so that they do not have to coincide in any modular way. In these situations the block wall can be laid quickly with relatively little waste due to cutting of blocks.

3.3.2.8

In most cases the blocks will need to be tied together to the frame, and there are many proprietary systems which can be used for this purpose.

3.3.2.9

These walls have the advantage of an unbroken run of light earth face on one side which can be quickly plastered without the need for scrim to bridge the timber faces of exposed posts. However, the side adjacent to the posts has to be more carefully plastered, and detailed in general, to achieve a satisfactory connection in practical and aesthetic terms. For example, where there is differential movement between the frame and block wall, it is difficult to mask because it is not possible to scrim over the exposed frame edges.

3.3.2.10

A solution which is perhaps midway between these two options was developed by a thesis student at the University of Technology at Helsinki, ref. 8.1.3 / 8.3.8. It is shown in the drawing below. The blocks are moulded to include two ‘cut-ins’ to accept the posts whilst presenting an unbroken surface to the inside for plastering. The blocks are held in place by mortar and spiked board fixers which are themselves fixed back to the frame.

![Diagram of light earth wall](image)

Finnish designed system for light earth blocks being adjacent and partially set within the structural frame. Taken from Westermarck, ’Luonnonmukaiset Rakennusaineet’, ref. 8.1.3.

3.3.2.11

Lastly, it is possible to mix the use of LE blocks and wet mix, as shown below. Here the blocks are used in lieu of a timber frame to provide a flat and stable surface in front of an old stone wall. The irregular gap between the blocks and stone wall has been filled with a wet woodchip-clay mix. A clay plaster has been applied to the block face. This combination avoids the use of a frame to create a true internal face, but has the disadvantage of placing wet mix ‘behind’ dry materials thus increasing the drying out period required.
Use of blocks and wet mix in an insulation upgrade and refurbishment of an old stone wall. Image taken from Construction Resources trade literature, ref. 8.5.6.1.

### 3.3.3 Advantages and Disadvantages

#### 3.3.3.1 Advantages

Monolithic light earth construction has two principal disadvantages when compared with most construction methods. The first is that it is relatively labour intensive, although this can be ameliorated, and the second is the imperative for the mix to dry quickly and sufficiently once installed to avoid decay. In both cases, the use of prefabricated units would appear to negate these disadvantages and so has attracted the attention of many practitioners keen to optimise the competitiveness and minimise the risks of the technique.

#### 3.3.3.2

It is clear that blocks or prefabricated units of any type are not liable to insufficient drying out since they are ‘pre-dried’ before arrival on site. Blocks are normally built into the wall using a wet clay and sand mortar, but this relatively small amount of moisture is quickly dissipated and either absorbed or evaporated.

#### 3.3.3.3

Where there is likely to be a particular problem with drying out, for example if the building programme has been delayed and light earth installation is anticipated to be undertaken in the shoulder or winter months, this advantage of block construction outweighs all other considerations and in some cases, is the only option available to the light earth practitioner. The use of non-organic fill materials is also an option, but lengthy drying out times can also affect the timber frame embedded in the mix and have a disruptive effect on other building trades and the construction programme. For example, it is not advisable to plaster light earth walls before they are completely dry, and the high local humidity caused by the drying of light earth walls can adversely affect other items such as thin boards or panels which can warp. By contract, the use of blocks allows plastering to continue relatively soon after installation and there are no adverse effects on other materials or the building programme due to moisture levels.

#### 3.3.3.4

The notion of blocks reducing the necessary labour is something of a misconception because in reality more labour is required to make them. However, if
prefabricated blocks are bought in, the labour required on site to make the wall is greatly reduced. The mixing has been done, the shuttering is not required (it has essentially been transferred to the mould making process) and all that is required is to mix mortar and lay the blocks as normal. This can be a huge advantage, particularly where speed of site works is important and monolithic construction would render light earth construction otherwise unsuitable.

3.3.3.5 There are other advantages to using blocks. The fact that blocks can be laid without prejudice at any time of the year has an effect on the economic and practical viability of light earth as a technique overall. Conventional construction programmes take little account of the time of the year, albeit concrete curing times, lime rendering and road surfacing etc. have to be integrated within the overall programme. Monolithic construction can only take place when ambient temperatures are quite high, and moisture levels quite low, i.e. late spring, summer and early autumn. To restrict construction programmes to suit light earth could seriously harm its uptake and popularity on a wide scale and for this reason alone, prefabricated light earth construction will always be of relevance and value.

3.3.3.6 It is also possible to make blocks or panels at almost any time, as long as a suitable drying regime can be organised, blocks can also be stored indefinitely and so the processes of manufacture and installation can be split, adding flexibility to the overall programme.

3.3.3.7 Block sizes can be adjusted to suit any number of variations in the wall construction. Where handmade blocks are produced on site, one-offs can be readily incorporated, and all blocks are easily sawn or broken into smaller blocks if need be. Broken blocks can be crumbled and re-hydrated without loss of performance because clay does not cure like cement and so can be indefinitely re-used. In this way, a light earth project can approach zero waste generation if carefully managed. The same is true of monolithic light earth, but not of all other block materials.

3.3.3.8 Because blocks are pre-dried, there is no shrinkage of walls once installed, this saves the labour, albeit normally not a great deal, associated with filling areas of excessive settlement or shrinkage in monolithic construction.

3.3.3.9 Lastly, the use of blocks on site reduces the amount of mess which is made, and which needs to be tidied at regular intervals. Though rarely mentioned, this has a noticeable effect on progress.

3.3.3.9 Disadvantages The principal disadvantage of prefabricated construction is that in reality, it involves more handling and processing of the material than monolithic construction where the raw materials are installed directly into the wall. If the blocks or panels are bought in, that is, made by someone else, then the element of manufacturing labour has been transferred and is simply paid for. If the blocks are made on site and / or by the same workers, then this additional labour is tangible. It is difficult to quantify this additional labour because of the variable factors affecting timescales, however, the manufacture of blocks itself involves more labour than installation of mix into walls because of the larger number of operations involving
smaller amounts of mix to be handled, tamped, checked, removed, stored and so on. To this must then be added the labour of installing the blocks. The two processes together comprise more, rather than less work and so blockmaking has remained less popular than monolithic construction.

3.3.3.10 Another reason why blockmaking has remained less popular, though it is not a disadvantage as such, is that despite the emphasis in this report on the risks associated with insufficient drying out of light earth mix, if good practice is observed, problems of decay rarely occur. In other words, if good practice is observed, it is not normally necessary to go to the trouble of making blocks.

3.3.3.11 Because blocks require to be handled and often transported, it is necessary to make them more resistant to knocks, jarring and rough handling. This usually means the addition of clay or of some reinforcing material which can then mitigate against other characteristics required of the material. This is particularly an issue where high insulation rates are required since the addition of clay simply to transport the blocks directly increases the thermal conductivity of the wall. This problem was encountered during the production of blocks for Littlecroft, as noted in Appendix 9.1, paragraph 6.3 where a ratio of clay to woodchip was adjusted to be denser to overcome fragility during transportation. With denser blocks this is unlikely to be an important issue but should be noted by those wishing to produce walls of density less than 450kg/cu.m.

3.3.3.12 Where it has been decided to produce blocks of a density less than 450kg/cu.m, it may be advisable to consider material additives or adjusted fill material to avoid the need to add clay. For example straw will tend to reinforce a woodchip or mineral bead mix, smaller fibres such as animal hairs, wood shavings or similar will tend to reinforce and add cohesion, while the addition of small particulate materials such as sawdust or hemp hurd will add cohesion and thus strength to the block, but will also slow down the drying out process.

3.3.3.13 Whilst blockmaking can add flexibility to the time frame within which wall building can take place, the blockmaking itself needs to carried out either when it is possible for the blocks to air dry, or where it is possible to induce forced ventilation within a suitable space such as a drying shed. If this is carried out at cold times of the year, some heating may be needed to augment the drying out process.

3.3.3.14 Once dried, blocks need to be kept dry. This is perhaps obvious but can be overlooked on crowded, busy sites. Blocks should be protected from rain, kept off the ground while stored, and ideally sealed against excessive atmospheric moisture ingress. The blocks delivered to Littlecroft were wrapped in commercial grade and width ‘cling film’ and firmly fixed to pallets. They were immediately stacked inside and under cover and built into the wall within a few days.
3.4 Coatings

The purpose of this Section is not to offer a definitive account of the coatings which may be applied to light earth walls, but to highlight some of the pertinent issues which arise from their use on light earth and to give some indication of the types of coatings which have been used. Wider and more detailed information on all the coatings described below is available from noted sources.

3.4.1 Plasters and Renders

3.4.1.1 Light earth walls are usually, but not exclusively plastered on both sides. The plaster coating performs a number of functions, including:
- A sound, stable finish which can be decorative, or decorated, does not shed dust and is strong enough to withstand everyday wear and tear.
- A maintainable surface
- Prevention of insect or rodent ingress into the light earth mix
- Increased acoustic absorbent mass
- Increased fire resistance
- For external renders, a weatherproof finish
- For internal plasters,
  Additional thermal capacity immediately adjacent to the internal air
  Additional hygroscopic material immediately adjacent to the internal air

These functions have been discussed elsewhere in the study.

3.4.1.2 Suitable Plasters

Clay and Lime based coatings are used on all light earth buildings. Gypsum can only be used as an internal coating because it is water soluble, but because gypsum is relatively impermeable to vapour and does not readily either absorb or desorb moisture, it tends to hinder the beneficial functioning of the wall as a moisture balancing mass.

3.4.1.3 Cement is relatively strong and inflexible and so does not move, either in relation to moisture or structural movement, in a comparable manner to the clay based substrate. This can cause it to crack and, if used externally, allows moisture in which can be ruinous to the light earth within, particularly because this moisture will not readily permeate out again through the cement based finish.

3.4.1.4 For these reasons gypsum and cement are not advised for use with light earth.

Clay based and lime based plasters have similar movement and vapour permeable characteristics to the light earth mass within and so are exclusively chosen by light earth practitioners.

3.4.1.5 Clay based plasters, unless substantially altered by additives are not weatherproof and so are rarely used as the finish external coating, whereas lime plasters may be used in both internal and external applications. Clay based plasters may be used externally but usually need to be finished with a lime based top coat, or a suitably altered clay based topcoat. There is little experience of such suitably altered clay plasters in the UK, but knowledge and awareness of modified external clay plasters on the continent is greater and will inevitably filter through to the UK.
Detailed information on the preparation of clay based plasters is available from resources such as Laporte, ref. 8.1.1, Volhard, ref. 8.1.2, Elizabeth and Adams, ref. 8.1.5, Minke, 8.1.10 and particularly Westermanck, ref. 8.1.3. A number of commercially available clay based plasters can be sourced in the UK, from either Construction Resources in London or NBT in High Wycombe, refs. 8.6.5.1 and 8.6.5.2. These are generally imported from Germany which increases their embodied energy and cost, but the materials are of high quality.

The surfaces of most light earth mixes are ideal substrates for the application of plaster being firm and deeply textured. No chemical bond takes place with earth or lime plasters so the physical bond is all important. Where timber stud faces are exposed, scrim should be applied to bridge between light earth surfaces, and where large expanses of smooth material are exposed, it is advisable to use mesh or lath, fixed firmly, to ensure a good bond between the substrate and plaster. Loose material should be removed before plaster is applied.

Importantly substrates must be completely dry before plaster is applied otherwise they may shrink and pull away from the plaster so losing the key. In apparent contrast, the substrate is given a light spray of water directly before application of the plaster to increase adhesion, even out the porosity between old and new material and prevent the plaster from drying too quickly and cracking.

Because of the movement of clay, and to a lesser extent lime plasters, it is advisable to avoid sharp arrisses, such as the external corners of many light earth buildings. Exposed frame corners should be ‘rounded off’ with a spokeshave, while light earth corners can be simply ‘hacked’ into a rough rounded form. This prevent cracks forming in the final clay coatings which can allow moisture ingress.

Plaster can be applied by trowel, smeared by hand or thrown (hurled - ‘harled’). It can also be pumped and sprayed on under mechanical pressure.

Generally, clay plasters comprise clay, silt, sand and water. Circumstances and individual materials vary so greatly that it is unwise to try to establish a certain type of plaster in any generic sense. However, too great a clay content will lead to shrinkage and cracking, yet too little will mean the mix does not sufficiently cohere to itself or to the substrate. It is always best to make different mixes with the materials to hand and establish the most suitable mix ratio and application sequence before mixing large batches. Alternatively, seek the advice of a plasterer experienced in the quite different behaviour of clay and lime plasters which usually means they have experience of conservation projects.

The most common additive to clay plasters are reinforcement materials such as chopped straw, animal hair and any other fibre which will help to bulk out the plaster and control movement and cracking. This is particularly important in the first coat which can act as a ‘bridging’ coat, in terms of movement, between the light earth substrate and more dense final coat.

Clay plasters are normally applied in two coats. The first coat, or base coat is the...
thickest and provides the bulk of the overall coating. It should contain reinforcement, as noted above and should be left quite roughly surfaced, to better act as a key for the final coat. Drying should not be too quick because this will lead to excessive shrinkage cracks, so the finish should not be exposed to the sun while drying. However, it does not matter too greatly about the inevitable cracks which will occur as these will be filled in by the subsequent coat(s).

3.4.1.14 A simple formula used by some, for first coat plaster is, by volume, 1 part thick clay slip (consistency of thick cream) to 1/3 of fibre, to 2 of aggregate such as sand. For the finish coat use 1 part slip, as before, to 2 parts fine sand. Fine fibre such as animal hair or hemp hurd may be added for reinforcement and control of shrinkage, but note that it will affect the finish texture, colour and strength of the finish. Laporte, ref 8.1.1, adds 1% oil in the final coat for water repellency but European practitioners avoid this because it reduces vapour permeability.

3.4.1.15 The finish coat tends to be thinner, around 5mm thick and with fine fibres or none at all. Aggregates are kept small, such as fine sand and the overall appearance should be relatively smooth. Surface hardness and water repellency can be improved by adding lime, casein, fat-free quark, cow dung and other materials in preference to oil or tallow. Application and drying is as per the first coat.

3.4.1.16 Lime plasters Unlike clay, lime has a reasonably involved chemical cycle which determines many of the practical aspects of working with it and which is best understood before attempting to use the material for the first time. There is a distinct body of knowledge associated with lime work in general and it is worth taking the advice of specialist applicators. Two good sources of expertise are the Lime Centre near Stroud, and the Scottish Lime Centre in Charleston, Fife, ref. 8.6.1.3. Specialist suppliers of lime products may be accessed through the AECB, ref. 8.6.1.4.

3.4.1.17 Lime can only be worked externally under certain temperature conditions with a season of approximately April to September inclusive. This may have an effect on other work operations and should be borne in mind at the design stage.

3.4.2 Paints

3.4.2.1 The application of paints in light earth construction is the same as with any other construction but the choice of paints must be made with care because the vapour diffusion of a light earth wall needs to be understood and the paint finishes must take account of this.

3.4.2.2 If, for example, a water repellent and vapour impermeable masonry paint was applied to the outer face of a lime plastered light earth wall, it could be ruinous for the building. Such a coating would provide a vapour barrier on the outer face so moisture travelling through the wall would not be able to evaporate from the outer surface. It would collect, condense and begin to saturate the outer areas of the wall, while gradually seeping down to the base area of the wall where decay would soon begin. The hygroscopic nature of the wall material would mitigate against this but if normal amounts of moisture were generated inside the building, the hygroscopicity of the wall alone would not be sufficient to avoid considerable
problems in the medium, and possibly short term.

3.4.2.3 Choosing the correct paint is not easy if choosing between conventional paint suppliers because few give details of vapour diffusivity and most are largely vapour impermeable in any case. For this reason a completely different choice of paint options is required.

3.4.2.4 This different range of paints are marketed either as ‘conservation’ paints or as ‘ecological’ but have in common the use of largely natural materials. These paints not only diffuse vapour but tend not to form ‘films’ of paint so much as to deposit solid materials onto the base surface.

3.4.2.5 Such paints tend to be based on lime, clay, silicates, and other minerals such as borax and chalk, casein, natural waxes, pigments and oils. Because these paints are not widely known about or available, suppliers are listed in Section 8.6.5.

3.4.2.6 It should be noted that where paints will be used, it is important to establish their relative vapour diffusivity and ensure that the paint intended for use on the external side has a vapour diffusivity higher - more permeable - than that chosen for the inside. This is to ensure that vapour in the wall is more able to evaporate from the outside of the wall thus reducing the risk of interstitial condensation.

3.4.2.7 Paint finishes to be used internally will usually need to be wipeable and this should be checked since many are not. Similarly, paints used externally need to be adequately resistant to the weather and again it is important to check paints are suitable for their intended application.

3.4.3 Cladding

3.4.3.1 Internal cladding

Internal cladding of light earth walls is less common than direct applied plaster. Claddings such as timber boards, gypsum plasterboard, clay boards and others may be fixed direct to the exposed stud faces, and in most cases will be quicker to apply. However, unless there is a substantial area of contact between such boards and the light earth, there will be a break in the thermal and, to a lesser extent, moisture buffering capacity of the wall due to the air gap between them.

3.4.3.2 If cladding boards are to be used internally, it is important to ensure that the light earth wall beneath is adequately protected from insect ingress and is adequately detailed in regard to fire spread, ignition and resistance overall. A thin coat of plaster is recommended in most cases, even if a cladding is to be applied for the reasons above, but an alternative may be the application of a membrane of suitable vapour permeability.

3.4.3.3 External cladding

External cladding of light earth buildings is also less common than rendering, but the specific advantages of cladding merit consideration, particularly in areas with persistently wet and windy weather.

3.4.3.4 Where cladding is applied, it is important that moisture in the wall is allowed to escape to the outside and for this reason it is essential to maintain a ventilated
cavity behind the cladding.

3.4.3.5 In areas like the UK, Canada, Scandinavia and others, ventilated rainscreen cladding affords two significant advantages over directly applied external plaster coatings. The first is that the rain and other elemental moisture does not reach the light earth so it never runs the risk of becoming saturated. The second is that the light earth can be allowed to be much more freely ventilated on the external face - behind the cladding - so more effectively dispersing moisture from within.

3.4.3.6 In some cases, including the example shown below, the light earth has been left unplastered. This is not advisable due to the increased potential for insect and rodent ingress, and the reduced overall resistance to fire.

3.4.3.7 The image below shows a light earth house extension designed by Lou Host-Jablonski in the US (ref. 8.1.5, p. 305). The horizontal timber cladding serves to protect the light earth from the elements whilst also appearing consistent with the prevailing architectural language of that region.

Light Earth House extension in Wisconsin, US featuring horizontal timber board cladding on vertical battens direct over unplastered light earth walls.

3.4.3.8 Another advantage of ventilated cladding over directly applied plaster is that in cold, wet and windy conditions, a significant proportion of the heat lost by a solid walled building is through evaporation. A similar solid walled building with ventilated cladding avoids all such losses since the moisture reaches only the cladding while the solid wall beneath remains dry.
3.5 Services and Fixtures

The location of services and likely fixtures requires consideration at the design stage in order to ensure that unsatisfactory compromises need not be made and time consumed at later stages. The following section describes many of the issues which will need to be addressed in most light earth projects.

3.5.1 Services

3.5.1.1 Electrics

The simplest and cheapest place to run cables is attached to the surface of the completed light earth mass wall, clipped to the exposed post faces, before the first coats of plaster are applied. However, the problems with this approach are that if the cables are not properly sized, they can overheat, that it is not possible to alter or re-wire as it is embedded in the plaster, and that if it is hidden, subsequent DIY could result in the cables being penetrated by nails or screws with disastrous consequences.

3.5.1.2

Thus it is advisable either to surface run the cables (or hide them behind skirting boards or bulkheads) or conduit the cables if they require to be embedded within a wall. This ventilates and protects them while also allowing for re-wiring. Most areas of run can be mounted behind skirting boards in practice, which also enables easy access, but light and other high level switches, and runs to upper level appliances generally such as wall lights need to be run within conduit fixed, normally to the side of posts as part of the first fix electrics before the light earth is installed.

3.5.1.3

Socket outlets, switch plates and other items are usually fixed to the face of posts, or slightly checked in to allow for the depth of plaster to be applied subsequently, see below. Where only a thin skim of plaster is to be applied, they can equally be fixed to the sides of posts or specially fitted noggins / dwang, as per fixings discussed below.

3.5.1.4 Plumbing

Whilst it is possible to run water and waste pipes within the frame or plaster depth in general this is not advisable. Cold water pipes and those which run to the
outside will tend to be colder in the heating season than the light earth or plaster mass and, particularly toward the outer edge of the wall, will therefore provide a potential source of condensation as warmer, moist air cools on contact with them.

3.5.1.5

Another reason for not placing pipes within the body of the wall is that should leaks occur, they can continue for some time before any sign of them is discovered, by which time tremendous damage can have been done. When such a leak is discovered, it is also difficult to locate the source of the leak since moisture will spread fairly freely within a light earth mass.

3.5.1.6

A third reason is that pipes buried within the body of the building are likely to be more difficult to access, adjust and maintain should the need arise. Lastly, as with electric cables, an unprotected pipe is more liable to accidental damage from subsequent building or maintenance works.

3.5.1.7

For the four reasons above, it is advisable to ensure all runs are surface mounted, hidden within bulkheads, service runs or behind skirtings. In this way condensation and accidental damage are prevented and leaks and access less of a problem.

3.5.1.8

In practice however, it is not always easy to avoid at least some buried pipework and in these cases it is advisable to encase pipes in conduit which also avoids any of the four potential problems noted above.

3.5.1.9

Where service pipes have to penetrate external walls, they should do so within large diameter conduits carefully insulated within and sealed at both ends to minimise both heat loss and air infiltration. The conduit also allows for adjustment or replacement at a later date. Where possible, it is preferable to locate fabric penetrations in the floor since less heat will be lost this way, but practical issues normally take precedence and access can be more difficult.

3.5.1.10

Sanitary and other plumbed fittings are dealt with under the following section.

3.5.2

*Fixtures*

3.5.2.1

Small pictures and other light objects can be supported by a simple screw or screwed plug into the depth of the plaster and light earth behind. Depending on the depth of the plaster, this will take most of the weight. Wider screws will provide a greater key and support than narrow gauge screws. Nails do not work well, mainly because the hammer action tends to crack the plaster. This and the following four options are illustrated in the diagram on the next page.

3.5.2.2

For greater weight, such as larger pictures, wall lights etc. it is possible to simply extend the principle above by inserting, for example, two long screws at different angles through the plaster and into the wall mix. Two screws of 75mm or 100mm each, at different angles provide a surprisingly secure fixing. In general, the denser the mix, the more effectively it will support the fixing.

3.5.2.3

An improvement on this, noted in Volhard, ref. 8.1.2, and other literature, is to insert a wedge shaped wooden block, smaller end facing outward, into the mix,
with one face exposed and into which screws can be fixed. The wedge is generally assumed to be positioned after the installation of the mix and bedded in mortar / plaster mix on all non exposed sides.

Four options for fixing into light earth walls: 1, simple screw into plaster; 2, two screws at an angle to provide a greater anchor resistance; 3, wood block inserted and mortared into the wall; 4, horizontal noggin or dwang fixed between posts.

3.5.2.4

In practice it is simpler and certainly stronger to fit a noggin or dwang in between two vertical posts. This is used where a known weight will be taken or when secure fixing back to the wall is required, in exactly the same way as is common in conventional timber frame construction.

3.5.2.5

Alternatively, it is of course possible to fix items direct to the posts themselves if their position is able to be identified after the application of plaster coats, and suits the intended fixing.

3.5.2.6

If it is not possible or desirable to ‘bury’ a noggin or dwang into the wall, it is equally possible to fix a timber piece to the finished surface of the wall to much the same effect. This can act rather like a traditional picture rail, for example. Where a greater choice or flexibility is required, an entire panel of timber boards or plywood can be affixed in this way. This can either be on the surface or concealed beneath plaster as before, though note the need in this case for the application of mesh or lath for adequate cohesion of the plaster to the board or boards. Such an approach might be relevant for bathroom areas where bath, basin and toilet all require a variety of structural fixings, plumbing fixings and so on which cannot be entirely foreseen.

3.5.2.7

Lastly, it is often possible, where a wall hung item might be generally used, to substitute this with a floor mounted alternative, thus avoiding the issue rather than having to solve it. The use of bulkheads is helpful in this regard and can also aid the accessible positioning of attendant service runs.
3.6  Maintenance and Repair

Owners of light earth properties should expect to undertake a little more maintenance than those in conventional houses, many of which have been designed explicitly to be ‘maintenance free’. If one accepts the need for increased maintenance and is conscientious in its execution, the result will bring other benefits, for many generations. While the repair of light earth buildings is quite straightforward, conscientious maintenance negates the need for it.

3.6.1  Maintenance

3.6.1.1  The most important aspect by far is to maintain regular checks for cracks or particular erosion or failures such as de-lamination which might betray a more serious durability threat. Simple, visual checking is all that is required but it should be thorough and regular. In this way almost all serious problems can be spotted early and dealt with cheaply and simply.

3.6.1.2  Plants should not be allowed to attach themselves to the plaster and detritus should be cleared away form the base of the wall. Gutters should be checked and cleaned at least twice a year where sufficient leaf build-up could present a problem and eaves and verges checked for insect infestation.

3.6.1.3  The issues which affect the durability of light earth buildings are discussed in Section 2.3. No maintenance of the light earth itself should ever be necessary under normal conditions and maintenance should be restricted to treatment and care of the surface coatings only.

3.6.1.4  Externally, the need for maintenance is not only cosmetic but practical since both clay and lime finishes will wear over time with the processes of weathering. Traditional lime finishes were traditionally given a coat of whitewash every year. The whitewash acted as a sacrificial build-up which wore down very gradually and needed periodic replacement. Limewash needs less maintenance. A similar strategy works well with modern lime and clay based external coatings where the emphasis is less on denying deterioration through chemistry and more on managed replacement of surface matter as required.

3.6.1.5  An appropriate timescale within which to consider the maintenance of external coatings is a bi-annual check with re-coats between one and five years depending on the finish.

3.6.1.6  Internally, maintenance depends somewhat on the wipeability of the surface chosen. Lime and clay plasters, and the paints generally used in conjunction with them are together less resistant to abrasion and wear than conventional synthetic paints. Where wipeability is low, this will necessitate more regular repainting over time. Otherwise, areas of high likely abrasion or in need of regular cleaning may benefit from being finished in tiles or surfaces easier to keep clean.
3.6.2  

Repair

3.6.2.1  

Where repair is necessary, it is usually because of either excessive differential movement due to moisture, or thermal movement, through excessive impact from rain or from mechanical impact or abrasion. If there is a design or construction fault, such problems will become apparent soon. It should be stressed that if the building is designed, built and maintained in accordance with good practice, the repair of elements should rarely, if ever be necessary.

3.6.2.2  

In the unlikely event of the light earth mass itself needing to be repaired, it is first necessary to remove all affected areas. Decay is the only likely cause of this, and the most likely cause will be insufficient drying out of the mass. Ensure that no damp or musty material is left and that the remaining mass is completely dry before attempting to rebuild the wall.

3.6.2.3  

Once dry, it is possible to replace the removed mass with newly monolithic mix, however, it is important with repair work not to let the remaining mass settle or move as this could lead to further cracking of the plaster coatings. For this reason, it is more effective to use pre-dried blocks, made of the same material as the original wall, to fill the gap. Ensuring that the existing mass surface is sound, all that is required is to build up the blocks and ensure a tight fit so that subsequent movement of the mass overall cannot take place. Once the mortar is dry, the whole can be re-coated taking account of the points below.

3.6.2.4  

Plaster repairs

The repair of lime coatings is a specialist skill and the reader is advised to seek the advice of those organisations noted in the Resources Section. Hairline cracks in both clay and lime based coatings are of little concern and tend to fill with the natural erosion of particles from above as they are washed down the surface of the plaster.

3.6.2.5  

The repair of clay coatings is simple but certain principles need to be followed. The main issue is that of shrinkage. Wet, fresh clay based plaster will shrink away from and not adhere to dry, existing clay based plaster.

3.6.2.6  

It is therefore necessary to pre-treat the joint or crack by ensuring that the surface is sound and then moistening it so that the surface clay is swollen and plastic. The infill material must be plastic enough to be able to mix with the existing plaster surface, yet dry enough to avoid excessive shrinkage, as this shrinkage will inevitably take place at the interface of the original crack.

3.6.2.7  

Additional sand or to a lesser extent fibres can be added to reduce and control shrinkage in the infill mix but there must remain enough clay to be sufficiently cohesive. It is worth emphasising that the repair of earthen plasters is as yet a little known subject with few expert practitioners. For this reason, as emphasised before, maintenance - which is easy and requires little skill - is preferable to repair.
3.7 Renovation

This Section discusses the use of light earth in a conservation or renovation context. Where buildings are to be renovated, it is usually necessary to insulate them to bring them up to today's insulation standards. In Germany, light earth is often chosen because of its unique mix of insulative capacity combined with its thermal capacity, vapour diffusivity and physical movement characteristics which are consistent with the materials generally used in older buildings.

3.7.1 External Insulation

3.7.1.1 The most effective way to insulate a building is to place insulation around the exterior of the building. This ensures that the insulation is not broken and is therefore much more effective, it enables the mass of the original walls to become useful thermal capacity for the balancing of internal temperatures, and it reduces the risk of interstitial condensation by ensuring that existing fabric is kept warm while any condensation risk is transferred to the insulation material itself.

3.7.1.2 External insulation of buildings tends to be more expensive, particularly if scaffolding is required to reach upper floors. It is also expensive because the insulative skin must be weatherproof, and the thickening of the outside wall can lead to the need to rework other features such as fascia boards, gutters, window cills and so on. The application of insulation is also likely to radically alter the appearance of most buildings.

3.7.1.3 Where the above prove to be surmountable problems, the use of light earth as an external insulative skin can be sufficient to render older buildings acceptable in terms of thermal performance. Blocks can be used, laid directly against the existing wall with tie pieces to ensure that the two layers do not separate. The use of blocks, as in new build situations, has the advantage of allowing subsequent rendering to be carried out soon after the blockwork has been completed.

3.7.1.4 Alternatively, it is possible to erect a framework which is attached to the existing wall but presents a face at some remove from it. The external face of the framework can be used to affix shuttering, and the gap in between can be filled with light earth mix much as described in Section 3.3. An example is shown below.

[Image: Straw-clay mix installed between shuttering and an existing external brick wall.]
3.7.1.5 Volhard, ref. 8.1.3 recommends the use of a clay slip paint application to the wall before the installation of mix for greater cohesion, he also notes that a wet mix thickness of 150mm should be considered the maximum because of the need for the mix to dry out sufficiently, bearing in mind that it can only dry out effectively from one side. Lightweight mixes will dry more readily than denser mixes.

3.7.1.6 It should be noted that the same principles of applying light earth as a relatively insulative external skin also applies to non-renovation construction. For example, light earth can be installed on the outer face of more dense earth or other blocks as part of a new build construction method.

3.7.1.7 The church at Jarna, featured in Section 7.1.3 uses light earth blocks as external face to vertical timber planks of approximately 80mm thickness. The blocks were plastered externally and in this case provide both thermal capacity and insulation, while the timber provides an internal finish and the structural strength of the wall.

3.7.2 Internal Insulation

3.7.2.1 Where the problems mentioned in paragraph 3.7.1.2 prove to be insurmountable it may be necessary to insulate internally. This is less satisfactory from a purely thermal point of view because the insulation is always broken at the point where partitions meet the external wall, and unless extensive insulation of these partitions is undertaken, these areas become cold bridges and thus potential condensation risk areas. This is exacerbated by the problem that internal insulation causes the original fabric to remain cold in the heating season and so increases the risk. Internal insulation also removes the possibility of the original wall offering any thermal or moisture balancing properties.

3.7.2.2 On the other hand, internal insulation is usually cheaper, despite causing in some cases considerable internal disruption and reducing the available floor area. The use of light earth in preference to more conventional insulative materials has several benefits. Because light earth is not a highly insulative as dedicated insulation materials, the problems of cold bridging and interstitial condensation risk are less marked, and the fact that light earth contains some thermal capacity means that some balancing of internal climate is still possible, particularly if a thick earth based plaster is used.

3.87.2.3 Additionally, as discussed in Section 2.5, the hygroscopicity of the clay, and organic fill materials if used, means that moisture in the wall is less likely to become excessive and lead to condensation.

3.7.2.4 Alternatively, it is possible to place a vapour barrier or check close to the inside face of the wall which will prevent moisture entering the wall from inside in the first place. However, this runs the risk of causing condensation on the outer face of the barrier if warm, humid conditions prevail outside for a prolonged period, of failure due to workmanship faults and negates the positive moisture balancing potential of the wall.
3.7.2.5 The procedure for installing light earth internally is the same as for external insulation, it can be installed dry, as blocks, or wet, within shuttering. An example of a combination of both methods for internal renovation is shown in the previous section, at paragraph 3.3.2.11.

3.7.3 Replacement

3.7.3.1 On rare occasions it may be possible to consider replacement of existing infill materials with light earth in order to increase thermal insulation levels without fundamentally changing the nature or appearance of the building. Assuming that an existing timber frame might be no more than 150mm thick, it is unlikely that it would be possible by this alone to comply with present ‘U’ value requirements, though it may be considered preferable to complete insulative covering on either the internal or external face as described above.

3.7.3.2 A situation such as this is described in Section 7.1.12, at Potsdam in Germany where existing conventional brick infill was replaced with light earth blocks within a historic timber frame town house.

3.7.3.3 In the UK, where an option such as this was pursued, it is likely that a more effective insulation would be required by the Building Control authorities, such as woodwool or cork board, with a plaster coating either side. However, the lack of thermal capacity in such a solution would substantially alter the thermal and moisture performance, and movement characteristics of such a building and the use of light earth might for these reasons be considered useful.

3.7.3.4 On certain projects, where the external walls have been insulated internally, there may arise a situation whereby little or no thermal capacity is left within the insulated fabric of the building. In these situations it may be considered beneficial to introduce some element of thermal capacity into the internal partitions, either by complete replacement of the partitions, or, where timber studs are retained, by filling the studs with dense earth, or relatively dense light earth blocks.

3.7.3.5 In situations where thermal mass is not required, for example there is already enough elsewhere, or the building is intended to have a relatively quick thermal response, the use of light earth in monolithic or block form may be advantageous as replacement internal non-loadbearing walls or between existing studs. Whilst reducing the thermal capacity of the walls in comparison with bricks or dense earth, light earth walls retain a high hygroscopicity and may suffer less from movement cracks due to the addition of fill materials which reduce the differential thermal and moisture movement in relation to the timber.
3.8 Construction Time and Costs

Figures for timescales and costs have been produced for this section but these should be treated with considerable caution because of the variability of circumstances under which light earth construction may be undertaken. Nonetheless, the figures will be useful in producing an estimate of timescale and costs which should be adjusted in the context of individual circumstances.

3.8.1 Programme

3.8.1.1 Monolithic light earth construction is seasonal in that relatively warm and dry conditions are required for the mix to dry once installed in the framework. Installation of the mix often takes several weeks and the drying period between 4 to 8 weeks in addition. Furthermore, plastering cannot be undertaken until the walls are completely dry and plaster must be dry before final coats are applied.

3.8.1.2 In the case of lime coating of external areas, similar restrictions on temperature and drying prevail with the effective end of the season for lime finishing being the end of September or October. Working back from this, it is clear the time frames within which monolithic construction can take place are relatively limited, as shown below.

<table>
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<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
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<td>framing</td>
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<td>drying out</td>
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<td>external and internal plastering</td>
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<td>lime finishing externally</td>
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</tr>
</tbody>
</table>

Optimum programme for monolithic light earth construction (darker blue) and shoulder months

3.8.1.3 It is not crucial that the lime plastering, if chosen, is applied immediately, it can be left until the spring of the following year if necessary, the clay based undercoat plaster will be sufficient to protect the walls for one winter. However, it is clearly preferable to complete all necessary works while the site is still a site, and has not been occupied. The option of leaving the lime does however allow a little more flexibility into the programme. Alternatively, the use of cladding means that it is only the drying out of the mix which affects the programme.

3.8.1.4 Another option is to use blocks or other pre-dried units for all or part of the process. These can be installed at any time, providing subsequent coatings can dry sufficiently. This aspect of the use of the blocks is possibly the principal benefit of blocks when considering the potential commercial uptake of light earth as a more mainstream construction option. Blocks enable the contractor to install light earth at any time of the year and reduce on site costs and time because it is much quicker to lay blocks than to install monolithic light earth mass.
3.8.2  

**Timescale and Costs**

The table below has been developed from work by Volhard, ref. 8.1.2, from the author’s own site experience, and from discussion with practitioners across Europe. The figures as shown are averages and do not betray the considerable variance between the numbers from which they are derived. The wall element used is 300mm thick, using double studs at 1000mm centres. A top rail and bracing are included but any floor or supporting structure is not. Assumptions and items with the potential to be particularly misleading are discussed below.

<table>
<thead>
<tr>
<th>Construction Element</th>
<th>Labour: Hour / sq.m</th>
<th>Cost @ labour rate of £20 / hour / sq.m</th>
<th>Material Costs: £ / sq.m</th>
<th>Total Cost: £ / sq.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double stud (2x 50 x 100, joined with OSB web) @ 1m centres, 2.5m high, as shown, incl top rail</td>
<td>0.3</td>
<td>6</td>
<td>2.55</td>
<td>8.55</td>
</tr>
<tr>
<td>Mixing of clay and water for slip using plasterers’ paddle drill</td>
<td>0.2</td>
<td>4</td>
<td>0.25</td>
<td>4.25</td>
</tr>
<tr>
<td>Self-build / inexperienced. Straw-clay infill, manually mixed and installed using temporary shuttering</td>
<td>5</td>
<td>-</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>As above, but experienced / efficient site etc.</td>
<td>2.5</td>
<td>50</td>
<td>1.25</td>
<td>51.25</td>
</tr>
<tr>
<td>As above, but using woodchip fill, mechanically mixed</td>
<td>2</td>
<td>40</td>
<td>1.75</td>
<td>41.75</td>
</tr>
<tr>
<td>As above, but using mineral fill (exp. clay beads @£70/cu.m), mechanically mixed</td>
<td>2</td>
<td>40</td>
<td>21</td>
<td>61</td>
</tr>
<tr>
<td>As above, but using permanent reed mat shuttering</td>
<td>1.5</td>
<td>30</td>
<td>3.75</td>
<td>33.75</td>
</tr>
<tr>
<td>Block laying, 300mm wide, 100mm high, 25mm long using light earth mortar, approx 20mm beds</td>
<td>1</td>
<td>20</td>
<td>19.15</td>
<td>39.15</td>
</tr>
<tr>
<td>20mm clay based plaster / render, one face only, thrown</td>
<td>0.45</td>
<td>9</td>
<td>1.55</td>
<td>10.55</td>
</tr>
<tr>
<td>5mm clay based finish plaster / topcoat, internal only, trowelled</td>
<td>0.25</td>
<td>5</td>
<td>2.15</td>
<td>7.15</td>
</tr>
<tr>
<td>5mm lime top coat / harl to external face</td>
<td>0.25</td>
<td>5</td>
<td>1.85</td>
<td>6.85</td>
</tr>
<tr>
<td>Natural paint finish, each coat, (2 coats usually required) Internal only</td>
<td>0.09</td>
<td>1.8</td>
<td>1.75</td>
<td>3.55</td>
</tr>
<tr>
<td>Lime wash finish to external face, each coat, 5 coats usually applied</td>
<td>0.02</td>
<td>0.4</td>
<td>0.85</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Time and Costs for Construction and Finishing of Light Earth Walls

It is clear from the table that material costs comprise a very small proportion of the total costs. This is unlike conventional construction where relatively high labour costs have shifted the emphasis in construction generally toward prefabrication, de-skilling, reduced site times and minimising labour costs generally. The relative proportion of labour to material costs is more akin to vernacular construction and, of more contemporary relevance, the self-build sector.
3.8.2.3  
It is easy to see that changes to materials used will have little overall effect on the cost, but even minor changes to labour rates or efficiencies will have considerable influence on the cost of the project. Criteria such as the experience, speed and skill of the workers, and the extent of mechanisation are therefore of considerable interest to the practitioner.

3.8.2.4  
Caution should be taken in particular with the labour rate quoted. Whilst £20 per hour is a reasonable and common sum to charge in the UK at present, such charges will very considerably and this alone will have a significant effect on the costs as already noted. It should be stressed that all of the tasks associated with the mixing and installation of light earth - though not necessarily framing and plastering - require little or no experience, skill or strength and as such, hourly rates for workers can be considerably lower than those quoted above. A pattern of employment that has been used in several countries, for example, is for one experienced practitioner to employ three or four labourers at half or less than half the hourly rate noted above. The savings that can be passed on to the Client render the technique cheaper than most others, in contrast to the costs displayed in the table above which suggest that LEC is in fact quite an expensive option.

3.8.2.5  
It is clear from the breakdown of labour and material costs why light earth construction would be of interest to the self build sector. Quite apart from any subjective or personal motivation, a major driver in most self-build projects is to cut costs. Many of the labour costs tend to be absorbed or subsidised by the owner-builder, but is is often difficult to identify material cost savings. Light earth, in common with earth construction and straw bale construction offers considerable material cost reductions, but, in general, at the expense of increased labour input. In situations where this labour input is effectively subsidised - whether or not this distorts the true cost of the project, light earth construction presents the self builder with the opportunity to significantly reduce the cost of their project.

3.8.2.6  
Even where full account is taken of the labour cost of the owner-builder, hourly rates need not take account of overheads in the same way as bought-in labour so the savings are real, if not always as great as is claimed.

3.8.2.7  
The table exposes the true cost of blocks, which appear more expensive than the cheapest forms of monolithic construction, but this cost needs to be balanced against the significant practical advantages discussed in 3.3.3.

3.8.2.8  
The table also indicates why mineral fill is only used where cheap supplies are available. Initial attempts to source mineral fill have not been exhaustive but indicate that £100 / cu.m is not unusual with about £70.00 / cu.m the cheapest. This cost has been used for the table. See Resources Section 8.5.6 for potential suppliers. Cork granules are available, see ref. 8.5.6.3, in the region of £50 - £100 / cu.m, depending on mix requirements and quantities required.

3.8.2.9  
VAT is not included in the costs described in the table, but materials, plant, travel etc are for those rates derived from trade quotes. Hire costs for plant are not included, nor do rates differentiate between broad wall areas and narrow sections
such as window reveals, though an allowance has been made of this in the figures.

3.8.2.10 To the timber frame costs need to be added an allowance for noggins (England) and dwangs (Scotland) around doors, windows and for later fixtures. In very rough terms the average building contains about one fifth the linear metreage of studwork in noggins. An allowance for bracing has been included in the above, assuming the use of diagonal galvanised steel strips countersunk and coach screwed into the studs.

3.8.2.11 The cost of clay is taken to be £20 per cubic metre bag. That of straw to be £15.00 per large round bale. Woodchip has been costed at about 1.5 times the cost of straw, though the opposite is the case in mainland Europe. Reed mat permanent shuttering is costed at £2.00 /sq.m. All costs exclude delivery.
3.9 Draft Guidelines for Design, Construction and Maintenance of LEC Buildings

3.9.1 Introduction

3.9.1.1 These guidelines are not intended to replace any existing advice or legislation, but to act as ancillary guidance only for the benefit of those who may be unfamiliar with the techniques and material properties described.

3.9.1.2 The guidelines are based upon those developed by the Construction Industries Division of the State of New Mexico (Appendix 9.4), adjusted to suit UK conditions, and the guidance on insurable light earth construction by Building LifePlans, see Appendix 9.5.

3.9.2 Definitions

3.9.2.1 CLAY SLIP: A suspension of clay particles in a water solution.

3.9.2.2 CLAY SOIL: Soil containing 50% more clay content by volume.

3.9.2.3 INFILL: Light earth mix placed between the structural members of a building.

3.9.2.4 LIGHT EARTH: One of a family of earth constructions with a density of less than 1200Kg/m$^3$ (DIN 18951) whereby a fill material is coated by a clay slip.

3.9.2.5 MONOLITHIC: A continuous wall without seams.

3.9.2.6 NON-LOAD BEARING: Not bearing any of the weight of the building beyond the weight of light earth itself.

3.9.3 General Assumptions and Limitations on the Use of This Guidance

3.9.3.1 The general construction of the building shall comply with all applicable provisions of the latest editions of the Building Regulations / Technical Standards and other relevant legislation.

3.9.3.2 This guidance is linked to Latent defect insurance by Building LifePlans Ltd. and relates to the Durability Class limitations stated therein. Durability classes are based on the light earth construction in a sheltered environment. Where constructed in industrial, marine or polluted environments, the insured life is likely to be 5 years shorter than stated.

3.9.3.3 Light earth construction may be higher than one storey where specifically designed with appropriate precautions.

3.9.3.4 The proposed light earth composition should be tested to confirm its suitability for walls. This includes determining the mix proportions to attain the design density.
3.9.3.5 There are many variables involved with light earth construction particularly the various clays and many different combinations of materials which comprise the clay–slip which fall outside the stated parameters. Advice from an experienced practitioner should be sought in most cases and each case should be treated on its own merits by all parties concerned.

3.9.4 Material Characteristics / Technical Design Information

3.9.4.1 Materials associated with light earth construction are unfamiliar to most in the UK construction industry. The following tested characteristics of these materials should allow for the requisite calculations and checks to be undertaken to attain Building Control and other organisations’ acceptance of light earth.

3.9.4.2 Thermal conductivity The calculation of condensation risk as well as 'U' values for SAP ratings etc. requires input of thermal conductivity for the materials which comprise the building element. The table below gives figures for tested light earth materials which can be used for this purpose. The figures have been sourced as noted below.

![Graph of Thermal Conductivity against Density]

- Straw-Clay samples. Taken from Volhard (figures taken below 600 kg/cu.m extrapolated) RH and Temp not noted.
- Straw-Clay sample prepared by LRT, University of Technology, Finland, 1995 - '97 Research 65% RH (or 3.8% moisture content), Temp not noted.
- Light Earth samples prepared by ETH of Zurich 60% RH, 25 degrees K.
- Quoted figures for Clay / Straw or reed products available in the UK from Construction Resources RH and Temp not noted.
- Light Earth samples prepared by FEB, University of Kassel, Germany, quoted in Minke’s Book RH and Temp not noted.
- Quoted figures for commercially available product in Germany RH and Temp not noted.
- Light Earth samples prepared by Gaia Architects, measured by Plymouth University (Sections 2.4 & 9.2) RH and Temp not noted.

Table of Thermal Conductivity of Light Earth against Density
3.9.3 No two light earth mixes are precisely the same and the shaded areas represents the tolerance range of figures that can be anticipated. It is advised to take the two ‘edge’ figures for a given density of light earth to establish the thermal tolerances which can be expected in the performance of the wall overall.

3.9.4.4 Vapour Resistivity

The calculation of condensation risk requires input of vapour resistivity for the materials which comprise a building element. The table below gives figures for tested light earth and associated materials which can be used for this purpose. The figures for light earth were measured by the FEB, ref. 8.6.2.3 in accordance with the German DIN 52615 Wet Method and are quoted in Minke, ref. 8.1.9.

<table>
<thead>
<tr>
<th>Material</th>
<th>Vapour resistivity per unit thickness MN s/g m</th>
<th>Typical thickness of material mm</th>
<th>Vapour Resistance for stated thickness MN s/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw-clay @ 450</td>
<td>2.3</td>
<td>300</td>
<td>0.7</td>
</tr>
<tr>
<td>Straw-clay @ 750</td>
<td>2.9</td>
<td>300</td>
<td>0.9</td>
</tr>
<tr>
<td>Straw-clay @ 950</td>
<td>3</td>
<td>300</td>
<td>0.9</td>
</tr>
<tr>
<td>Straw-clay @ 1250</td>
<td>4.3</td>
<td>300</td>
<td>1.3</td>
</tr>
<tr>
<td>LE with expanded glass @ 500</td>
<td>7.5</td>
<td>300</td>
<td>2.2</td>
</tr>
<tr>
<td>LE with expanded glass @ 750</td>
<td>7.8</td>
<td>300</td>
<td>2.3</td>
</tr>
<tr>
<td>LE with expanded clay @ 800</td>
<td>8</td>
<td>300</td>
<td>2.4</td>
</tr>
<tr>
<td>Silty earth (silt 78%)</td>
<td>6</td>
<td>450</td>
<td>2.7</td>
</tr>
<tr>
<td>Clayey earth (clay 28%)</td>
<td>7.1</td>
<td>450</td>
<td>3.2</td>
</tr>
<tr>
<td>Sandy earth (sand 56%)</td>
<td>7.3</td>
<td>450</td>
<td>3.3</td>
</tr>
<tr>
<td>Clayey earth plaster</td>
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<td>20</td>
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</tr>
<tr>
<td>Cowdung-earth-lime-sand plaster</td>
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<td>20</td>
<td>0.2</td>
</tr>
<tr>
<td>Lime plaster</td>
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<td>15</td>
<td>0.2</td>
</tr>
<tr>
<td>Lime-linseed oil plaster 20-1</td>
<td>15.2</td>
<td>15</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Vapour Resistivity and Resistance of Light Earth and Associated Materials

3.9.5 The risk of interstitial condensation should be analysed and be adequately controlled. The risk of interstitial condensation may be managed by:

a) creating a vapour resistance gradient by placing more vapour resistive materials on the inside of the wall construction and the less vapour resistive materials on the outside, or

b) using materials which can accommodate and release potential interstitial condensate.

3.9.6 Only clay binders may be used for the light earth mix. Any use of other binders such as lime, gypsum or cement will render the building uninsurable unless by special arrangement.

3.9.7 Fire

Tests have been carried out to assess the performance of light earth elements in fire and the following can be concluded from these.

3.9.8 Light earth elements containing cellulosic fill materials such as straw and woodchip are classified as combustible. Those containing mineral fill materials such as
3.9.4.9 Light earth elements are generally covered in plaster and so spread of flame criteria apply instead to the coatings used. Generally, the plaster used in clay based or lime based. Both of these are non-combustible and are classified as ‘Class 0’ by the Building Regulations as they do not support the spread of flame.

3.9.4.10 Fire resistance of light earth elements - without plaster coatings in order to ascertain worst case scenarios - were conducted by Chiltern International Fire as part of this research project. 300mm thick elements of straw-clay at approximately 250 kg/cu.m and woodchip-clay at 450 kg/cu.m were tested in a furnace reaching 1000 K. The detailed results of these are shown in Appendix Section 9.3. In summary, the straw-clay element suffered burn-through after 36 minutes while the woodchip-clay element maintained integrity for 2 hours after which time the test was terminated.

3.9.5 Structural Frame

3.9.5.1 Light earth shall not be used to support the weight of the building beyond the weight of the light earth mix itself. The light earth will act as wall in-fill between the structural members.

3.9.5.2 The structural support of the building shall be designed according to the Building Regulations / Technical Standards or as certified by a qualified Structural Engineer. For insurance purposes, timber framing should be at least to insurance class E: page 2.13, HAPM Component Life Manual.

3.9.5.3 Notwithstanding the above, the vertical loadbearing posts shall not be further than 1.5m apart on plan unless intermediate posts are present to support and stabilise the light earth infill.

3.9.6 Material Specification

3.9.6.1 STRAW: Straw shall be shall be free of seed heads, mould, decay and insects. It must be completely dry and remain so until mixed. Note that non-organic straw carries a 10 year insurance penalty at present.

3.9.6.2 WOODCHIPS: Must not exceed 50mm length in more than one one dimension. They shall be free of mould, decay and insects and kept dry until use. Note that woodchip including bark or sapwood carries a 10 year insurance penalty at present.

3.9.6.2 CLAY SOIL: Dry soil mixture may contain a mixture of clay, silt and sand. The clay content shall be 50% or more of the total mixture by volume.

3.9.6.3 CLAY SLIP: The clay slip binder material should be smooth and may comprise clay, silt and sand, with a minimum of 50% clay. There should be no organic matter. Slip must be thick enough to cover fingerprint and to fall within 25mm of a 150mm diameter puddle when 100ml of slip is carefully poured from a 100mm container onto a level glass plate. The constituents of clay slip are defined by their particle...
clay, <0.002mm; silt, 0.002 – 0.06mm; sand, 0.06 – 2mm.

3.9.6.4 Water used to form clay slip must be potable.

3.9.6.5 LIGHT EARTH MIX: All fill material shall be mixed with the clay slip until it is thoroughly and evenly coated so as to avoid pockets of dry material. No damp or green material should be included in the mix. The mix should be sufficiently coherent to withstand minor knocks without damage.

3.9.7 Wall Construction Generally

3.9.7.1 The exterior walls of monolithic construction shall not exceed 350mm in width. unless special precautions have been taken to ensure sufficient drying out of the centre of the wall.

3.9.7.2 Final moisture content of the light earth wall should be below 20%.

3.9.7.3 Light earth shall not be used below dpc level or where it could become saturated from ground water. The foundation or wall base shall be constructed so that the bottom of the light earth wall is at least 150mm above ground level.

3.9.7.4 Where a solid and continuous base wall or foundation is used, an approved damp proof course (dpc) shall extend across the full width of the wall between the light earth wall and the base wall. All penetrations through the dpc, as well as all joints in the barrier, must be sealed. A decay resistant sill plate shall be used over the dpc and stem wall if used. Alternatively, the wall base may be raised off the ground by at least 150mm, and is not therefore subject to the above conditions regarding dpcs.

3.9.7.5 The upper parts of the wall should be protected by a generous roof overhang; at least 600mm, unless walls are clad rather than rendered.

3.9.7.6 Corrodible metals not to be used in the construction unless adequately protected.

3.9.8 Wall Stabilisation

3.9.8.1 The light earth mix must be adequately stabilised within the wall plane. This may be achieved by consideration of post spacing, interlocking between infill and posts, and stabilising bars.

3.9.8.2 Vulnerable corners, uncompressed areas or particularly low density areas to incorporate a reinforcing mesh on which to apply plaster or render finish.

3.9.8.3 The effects of shrinkage should be managed and minimised. Shrinkage gaps should be filled.

3.9.8.4 Frames subject to vibration such as doors or windows should be soundly fixed to the structural frame. At door linings and frames the wall should be covered with plaster and architraves.
3.9.9  **Monolithic Walls**

3.9.9.1  Formwork shall be strong enough to resist bowing when the light earth materials is compacted into the forms.

3.9.9.2  Forms shall be uniformly loaded with light earth materials and be evenly tamped to achieve strong, stable, monolithic walls that are free of voids. Light earth material shall be loaded in lifts of no more than 150mm uncompacted depth and shall be adequately tamped before additional lifts or materials are added. Lifts 400mm maximum. Allow earlier lifts to cure before subsequent fillings.

3.9.9.3  Formwork shall be removed from walls within 24 hours after tamping, and walls shall remain exposed to ventilate, but protected from rain, until dry. The walls should be dried out as quickly and completely as possible after laying.

3.9.9.4  Whenever a wall in not continuously built, the top or side of the wall shall be thoroughly coated with clay slip prior to the application of a new layer of light earth material.

3.9.10  **Block Walls**

3.9.10.1  Blocks of light earth shall be bedded within clay based mortar with similar movement characteristics.

3.9.11  **Wall Surfacing**

3.9.11.1  All exterior wall surfacing material shall allow, for the diffusion of moisture through the wall. Paint or other finishes shall not mitigate against the diffusion of moisture. Note that vapour impermeable paints render the construction uninsured. Suitable paints include ‘conservation’ or ‘ecological’ paints, base on lime, clay, silicates and other materials such as borax, chalk, casein, natural waxes, pigments and oils.

3.9.11.2  Bridging shall be required at the juncture of dissimilar materials prior to the application of plaster. Bridging shall extend 50mm min. either side of the juncture. Plaster should only be applied when the light earth substrate is completely dry and settled.

3.9.11.3  Exterior wood wall cladding shall be spaced a minimum of 20mm from the light earth wall to allow for moisture diffusion and all ventilation gaps should be fully fitted with mesh to prevent rodent and insect ingress.

3.9.11.4  The surface of the light earth wall should be plastered where cladding is proposed internally or externally to prevent insect attack.

3.9.11.5  External renders and paint finishes should be considered as sacrificial surfaces which will require checking and repairs to ensure the longevity of the light earth wall.
3.9.12 **Electrical**

3.9.12.1 All electrical wiring methods, workmanship and materials in light earth buildings shall be in accordance with the latest IEE Wiring Regulations.

3.9.12.2 Electrical cables running within the light earth walls should be sized so as not to overheat or be enclosed in conduits which contain heat. Surface mounted or ducted cables may be preferred. All cable, conduit systems, electrical and junction boxes, shall be securely attached.

3.9.13 **Plumbing**

3.9.13.1 All plumbing shall be in accordance with the latest additions of the relevant regulations, byelaws and Codes of Practice.

3.9.13.2 No water services to be run within the body of the light earth construction. Where pipes have to pass through the light earth construction these should be sleeved and the ends sealed. All pipework and sanitary fixtures shall be securely fixed to the wall or structure.

3.9.14 **Maintenance Requirements**

3.9.14.1 An annual inspection should be undertaken including checking for cracks, de-laminations, erosion, overflowing gutters, plant encroachment.

3.9.14.2 Repairs should be made as necessary such as filling small cracks or holes. Where sections have decayed or suffered fungal attack, these should be cut out, dried, and replaced with sound material.

3.9.14.3 Brush off or vacuum moulds or staining organisms as necessary.

3.9.14.4 Remove plant growth as necessary.

3.9.14.5 Recoating of finish to render and plaster coatings as necessary. Recoating will depend on the finish applied as well as the wear and weathering the finish is exposed to. Typically limewash is applied annually or every 2 years.
4 Commercialism and the Future of LEC

The purpose of this chapter is to investigate the possible future scenarios for Light Earth Construction in the UK in the light of experience elsewhere.

Germany, Sweden, Finland and the Netherlands have experienced very different developments of the technique which are both unique manifestations of national circumstances, and instructive in that they relate to potential similarities in the UK. If the DTI resourcing of this project is to lead to a significant development of the technique, then it is important to take a realistic look at ways in which this effort can be most effectively delivered.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the conclusions to be drawn.

Sub-Contents

4.1 The German Experience
   4.1.1 Earth Building in Germany
   4.1.2 The Development of Light Earth
   4.1.3 Light Earth Today

4.2 The Finnish Experience

4.3 The Swedish Experience

4.4 The Dutch Experience
   4.4.1 History
   4.4.2 Straw earth building technique
   4.4.3 Significant straw earth building projects.

4.5 Discussion and the UK Situation
   4.5.1 Miscellaneous Aspects
   4.5.2 Three Potential Scenarios
Summary

(4.1) There are around 200,000 solid earth wall structures in Germany and the Germans are generally more familiar and at ease with the material. Earth buildings represent between 1-2% of all housing construction starts at present. There are estimated to be about 200 light earth buildings with several planned. Its popularity stems less from its ecological credentials than its perceived cost and practical benefits. In common with other earth building materials and products, light earth products such as blocks, along with loose materials for contractors and self build are widely and easily available. However, many in Germany feel that the future of light earth is in the provision of prefabricated units which offer labour saving and speed reduction advantages which appeal to both ecological and mainstream developers.

(4.2) In Finland, the number of light earth houses is between 10 and 20, built in the last 15 years. The principal Finnish contribution to light earth construction so far is in basic research, the development of material consistency for commercial application, along with the development of products and constructional systems through the Unit for Nature based Construction at the Helsinki University of Technology. The built projects in Finland have been successful and well received and the continuing presence and efforts of the LRT will ensure the continued development of light earth, though this is likely to be more commercial than in neighbouring Sweden.

(4.3) There are about 25 - 30 light earth buildings in Sweden, ranging from sheds to a church. One builder has been responsible for many of these, but most buildings are houses with a large element of self build. All buildings have been built with local materials, there has been no use of imported or commercial products, despite the fact that over half the buildings have been designed by Architects. There are no problems with Building Permissions, nor with financing but there appears to be little momentum in Sweden, unlike other countries and the publicity which has been developed has been largely neutral, such that the development of light earth has gone relatively unnoticed. The future development of light earth is likely to be centred around the localised, largely alternative self-build movement with an emphasis on low cost, healthy / ecological materials and simple construction.

(4.4) There are no more than 10 projects in Holland though some have been high profile and well received. There has been no use of blocks, the labour content of monolithic construction has been reduced instead by the development of mechanised straw-clay mixing.

(4.5) It is too early to accurately predict how light earth will develop in the UK and there are a number of cultural and economic variables which distort the translations from other European countries. However, three potential scenarios are discernable, though these would undoubtedly overlap in practice; the increased use of light earth in the self build sector, the increased uptake of light earth within the conventional industry due to mechanical means of mixing, and product development, particularly UK based.
4.1 The German Experience
(By Iain Frearson)

4.1.1 Earth Building In Germany

4.1.1.1 There are reputedly over 2 million dwellings extant in Germany. The majority of these will be half-timbered constructions, with massive earth wall dwellings numbering perhaps only 200,000. The majority of their inhabitants, as in the United Kingdom, will be unaware of the use of earth in their homes. However, Germans are far more conscious of the use of earth in buildings historically (particularly in eastern Germany and the less well developed areas of the western side where buildings have been less comprehensively renovated and hidden behind layers of render, plaster and paint). Germans seem to be far more comfortable with the idea of earth as a building material than we have been in Britain.

4.1.1.2 Despite a significant downturn in the use of earth since the industrial revolution, earth has played a role in housing throughout the 20th Century in a manner at odds with the marginalisation it has received in the United Kingdom, where similar changes in cultural attitudes have been more extreme. Formal building regulations governing its use have been in force in the German Democratic Republic up until 1989, when the Berlin Wall came down, and West German DIN Standards were current from 1951 until 1971. These have continued to be used as a reference for architects, builders and the authorities, etc.

4.1.2 The Development of Light Earth

4.1.2.1 The German Earth Building Regulations of 1944 officially defined the term light earth ("Leichtlehm") as an earth and lightweight aggregate mix of a density of less than 1200kg/m3. Generally, light earth in its modern form has a density of between 400kg/m3 and 800kg/m3 (and a correspondingly better insulation value). The use of light earth in its current form stems largely from new-build and renovation projects in the early 1980s. Early projects using light earth by Franz Volhard, Ute Schauer, Michael Nolte and others have included houses, a youth hostel, agricultural buildings, barns, workshops, summer-houses and others.

4.1.2.2 In this way an initial handful of (sometimes experimental) buildings has now risen to well over 200 completed projects. The rather disparate nature of the earth building sector in Germany makes an accurate assessment very difficult at the present time. However, more are on-site or planned, and the numbers are expected to grow considerably. Importantly, its use and popularity in Germany at present relates more to an understanding of the inherent advantages that light earth has to offer as a building material, than just to its ecological credentials.

4.1.2.3 Light earth has often been employed on marginal projects where additional labour costs have been balanced with the wider benefits the method has to offer. However, where the cost of labour is less of an issue (ie. private or community self-build, employment training projects, etc.), buildings with a light earth element...
are often able to compete favourably.

4.1.2.4

A good example of this is in the work of Klaus Beck and others at the Kultur Werkstatt, Hiddenhausen, where a community-based employment training programme was put together around the renovation of an 18th Century timber frame barn. The creation of a highly valued and much used community resource, the saving of a historic building, and the training/re-skilling of a number of local unemployed people came together using the advantages of a light earth technique. More often, people are prepared to trade-off different elements within a project to achieve wider benefits, as well as a healthier, more environmentally-friendly finished product. Increasingly, the light earth sector is able to offer a material and method which is able to compete on equal terms on a far wider range of building projects (including community halls, social housing, educational buildings, as well as private houses, workshops and studios).

4.1.3

*Light Earth Today*

4.1.3.1

As with earth products generally, light earth has been increasing its share of the market (earth construction represents about 1-2% of the total construction starts at present[^1]). The late 1990s saw significant increases in sales of earth products generally and the number of companies using earth on refurbishment and new-build projects[^17].

4.1.3.2

However, Germany’s current economic difficulties have hit the building industry particularly hard and, despite their more specialist market position, light earth projects have not been shielded from the fallout. The number of ecological housing projects peaked in the 1990s, after large increases in both the public and private sectors in the immediate post-re-unification period[^15]. Energy efficient housing has continued to be popular, having a high political and media profile, but less so housing using healthy and natural materials where the advantages are not so broadly recognised.

4.1.3.3

However, many are confident that this situation will change. The market for healthy building materials, increasing by about 25% annually before the current downturn[^19], is expected to grow once more.

4.1.3.4

Builders merchants and do-it-yourself chains all have to a varying degree, a range of ecological products available. Indeed, many have specific sections devoted to them, and there are a growing number of specialist suppliers, such as Claytec and Elwa Lehm GmbH, offering the basic materials for light earth, as well as some limited design advice. There is a wide and ever growing range of architects and designers offering specialist light earth design advice. Some specialist builders and developers will offer such a service as part of a bigger package, and are often brought in by a client before the architect or designer is involved.

4.1.3.5

Organisations promoting the use of earth such as KirchBauhof[^6] and the Dachverband Lehm[^1] have been instrumental in recent years in raising awareness of the potential of light earth and earth construction in general. The organisation of a number of conferences, a range of training programmes, and design guidance,
4.1.3.6

The 1990s saw the increases in the mass-production of light earth products and materials, by companies such as Casadobe, Haacke & Haacke, Hanauerland Werkstätten (“RecyKork”), and many others. Manufacturers and materials suppliers continue to develop prefabricated light earth elements (for example, Sy.DuK GmbH Seelow “bioCell”) in the form of bricks and blocks, panels and boards, whole wall elements, etc., as well as light earth mixes delivered to site in silos ready for use\(^1\). The feeling across the industry is that if light earth is to develop in the future beyond self-build and associated niche markets, some form of prefabrication is necessary.\(^{2,25,26}\)

4.1.3.7

Prefabrication is seen to bring a number of advantages:

i) Ease of construction, reducing the amount of labour needed on site, reducing the space needed on site.

ii) Reduced labour costs and the reduced need for skilled labour on site (practical experience of earth building is much depleted in the industry, and building trade skills generally are being slowly eroded).

iii) Reduced drying time on site (reducing construction times and initial moisture levels in the finished building).

iv) Harmonisation with modern building practice, to make use of existing skills, helping make its wider uptake easier.

4.1.3.8

It is mineral light earth that has been the focus of many German manufacturers’ attention, as they look for novel solutions to exploit a growing market. Many feel that mineral light earth has an advantage in that the consistency and quality of the finished product is better. Mineral light earth does, however, raise a number of interesting issues somewhat at odds with the ecological characteristics that attract many people to light earth in the first place.

4.1.3.9

With some mineral light earth aggregates there are concerns at present over:

a) Waste disposal issues.

b) Increased embodied energy of the aggregate.

c) Perceived higher levels of radioactivity in some aggregates.

d) The treatment of some aggregates with chemical additives such as bitumen or silicone to make them water repellent.

e) Increased levels of hazardous dust when working with some aggregates.

f) The use of a material which is seen to be less natural than, say, wood light earth or straw light earth.

4.1.3.10

However, straw light earth and wood light earth continue to be further developed
themselves by manufacturers and materials suppliers, and often offer a cheaper, a
more readily available, and a more environmentally friendly resource.

4.1.3.11

The current development of light earth by the building industry is intended to find
ways to enable it to be more easily incorporated into the conventional building
process. This seeks to avoid forcing architects and builders to make a choice
between a particular light earth building method or another more conventional
one, and instead select light earth products for a particular task. In this way, the
material is being made more adaptable. It is important to re-state that light earth
is increasingly being marketed on the practical benefits to the construction
industry, and not solely on its ecological credentials. The development of light
earth now has a momentum sustained not only by its environmental attractions for
clients, but in its commercial exploitation by a construction industry aware of the
wider advantages it offers.

Notes

   International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon,
4. Ibid.
   pp3.1.1-3.1.2
    (Reichsgesetzblatt, 1944)”.
15. Gernot Minke, Earth Construction Handbook. The Building Material Earth in Modern Building,
20. KirchBauhof is a charitable organisation, set up in the early 1990s for a single community-based
    renovation project in Berlin-Kreuzberg. Its success here led to the development of a range of
    education and training programmes within the Berlin area. Specialising in an environmental
    approach, KirchBauhof has a high profile in the promotion of earth building techniques.
21. The Dachverband Lehm e.V. is the German umbrella organisation for earth building, set up in 1992
    with the goal of promoting and developing earth as a building material. It organises conferences,
    education programmes, and provides technical support, etc., and was instrumental in the issuing
    of the new earth building rules and recommendations – the Lehmbau Regeln (see 22 below). These
    are accepted by the German Länder (or regional state governments), and are recommended for
    becoming part of formal regional building regulations (Horst Schroeder, Terra 2000, p427.).
22. Dachverband Lehm e.V., Lehmbau Regeln, (Wiesbaden: Friedr.Vieweg & Sohn Verlagsgesellschaft
    mbH, 1999).
4.2 The Finnish Experience
(By Päivi Tekula)

4.2.1 The interest in healthy buildings is on the increase and the Finnish media has made light earth construction known to the public in a positive light. As this is not a traditional way of building in Finland, the number of self-built houses is still small, between 10 and 20 in recent years. The principal Finnish contribution to light earth construction so far is in the basic research, the development of consistency of the material for commercial application, products and constructional systems as well as the mechanisation of production.

4.2.2 In the beginning of the 1990’s The Helsinki University of Technology started a project entitled ‘The preparation and use of nature-based building materials as a secondary livelihood for Farmers’ [ref 8.1.3 / 8.3.10], followed by other similar projects coordinated by the research Unit for Nature-based Construction (LRT). The results enable farmers, entrepreneurs or others to do preliminary calculations of production and building costs.

4.2.3 In a recent EU funded project (www.hut.fi/Units/LRT/UCBP) LRT developed a mixture of clay, hemp shieves and wood fractions that seems to be a promising consistency of light earth building material. The density is 700 kg/m³ and the products are more solid but with the same thermal conductivity as when using only straw mixed with clay at a density of 350 kg/m³.

4.2.4 This might be an ideal material for Middle European countries where insulation requirements are not as strict as in Scandinavia. There seems to be potential for developing this into a self-bearing structure in one-family houses. However, most light earth structures still require a load bearing wooden frame.

A single family house of clay-straw blocks designed for FARMA –agricultural centre for the Building Fair by Teuvo Ranki in Raisio 1997. The house was a success and is now inhabited.
4.2.5 Farmer Timo Lehtonen (tj.lehtonen@kolumbus.fi) built a production line to produce the clay-straw blocks for the house in Raisio and is now planning to build a manufacturing hall to better accommodate his business during the winter. According to Mr. Lehtonen, a certain demand exists but in order to make the business profitable the producer must also act as the contractor of the building project and the assembler of his products. Clients request that the producer takes the responsibility of quality issues and guarantees the final product.

4.2.6 The production line for clay-hemp shives-wood fractions products would not differ much from the line of concrete blocks except that the drying takes longer and may require additional heating and ventilation.

4.2.7 All Finnish LEC houses that have been built have passed the normal building regulations but in some cases the authorities required additional expert opinions by LRT.
4.3 The Swedish Experience
(By Eva Rut-Lindberg)

4.3.1 Geography
Sweden is a country with a large area and a small population. From the north to
the south it measure 1 572 kilometres, from the west to the east large parts
measures around 400 kilometres. In an area of 449 964 square-kilometres 9
million people will soon live and of them around 80% will live within the Stockholm
region and south. It means that the majority of the population is living in about
1/3 of the country.

4.3.2
Over half - 52% - of the land area is under forest, while 17% and 11%
respectively comprise bare rock and mire. 9% is under water, in lakes or rivers,
and 3% is built up, leaving only 8% for agricultural land. Generally the biggest
areas of forests, water, mountains and mires are found in the north and the
agricultural land in the south.

4.3.3 Light Earth Buildings
Today 25 - 30 light earth buildings can be found in Sweden. Most of them are
situated in rural areas and most of the builders have chosen light earth as an
alternative building material for environmental reasons. Rich clay is easily found in
Sweden because of the ice age 10 000 years ago that left sand, silt and clay from
the melting glacial rivers. The south of Sweden then was under the water surface
and at those areas the agricultural land now can be found. For people living in
those areas it is natural to use clay and straw if they want alternatives for
common insulation materials.

4.3.4
The erected buildings of light earth are of different kinds. The range reaches from
small private sheds to a church for the Anthroposophical Movement in Jarna [ref
Section 7.1.4]. All buildings have been made with clay from the site (or close to it)
with local materials such as straw and wood-chip added. Only in a few cases
expanded clay has been used, mainly in situations where one should be careful
with using organic materials.

4.3.5
As most of the buildings are made of local and on site materials they are also built
with monolithic construction. Only for those parts which are difficult to pack have
blocks been made. That was the case with the church in Jarna. As monolithic
straw-clay walls must dry from both sides, the big oval church room was made of
standing planks insulated with prefabricated straw clay blocks. The manufacturing
of the blocks was made on a simple table for manual compressive works and
during a period of three month some 7 000 straw clay blocks were produced.
Following summer the blocks were stacked around the 8 - 9 metres high plank
wall and rendered as the wall was raised. The lower walls around the foyer were
made monolithic with the posts in the middle of the walls and the shutters placed
on distance-blocks when packing with straw-clay.

4.3.6
In spite of the fact that neither commercial nor imported products of straw clay can
be found in Sweden almost 50% of the erected buildings are designed by
architects. The buildings with light earth insulation are spread over a big area and
only a few buildings are owned by the same proprietor. Solely one contractor is
working full time with earth and clay building and that person [Johannes Reisterer] has been involved in about 30% of the projects.

4.3.7 Light Earth Issues

The basic reasons for use of light earth building materials today are health and ecology. But what ecological building materials means sometimes differ between the public at large and the big building companies. The latter have special criteria for healthy building and one is to be careful about use of organic materials like wood. As one never can avoid organic materials because of its use in wall-papers, roof trusses, door- and window-frames, floors etc it is very important to have a dry environment when buildings are erected.

4.3.8

From the authorities a criterion for healthy buildings is demand for good ventilation. The air in a house should be changed every second hour when people are staying there. One reason is to take away the moist air humans and other living creatures produce, another is to take away emissions.

4.3.9

The trend of today in the small group of ecological self-builders is that straw-bales are used for insulation in a timber-frame construction. The walls can then be treated with clay-plaster (indoors) and clay- or lime-rendered (outdoors). In contrast with monolithic straw-clay constructions the erecting of the straw-bale walls are dry and quick – something to learn from in the developing of light earth insulating materials.

4.3.10

Almost all of the single-family houses where light earth has been used are erected, or organised, by the proprietors themselves. Sometimes courses or workshops have been arranged in connection with the construction, not unlike the American way of barn-raising parties.

4.3.11 Permissions

There are usually no problems when asking for building permission in Sweden. In the countryside building-permission from an architectural point of view is not needed. For public buildings the authorities concern themselves with function, and the permission has less to do with materials. That means for instance that disabled persons must have full access to the building and to show security solution of evacuation in case of fire.

4.3.12

In Sweden you have to calculate an energy-balance when you are designing a new building. That means that it should not use more than a specified amount of energy for heating. If the walls have bad thermal insulation more insulation can be added to the roof, or windows with better U-values can be used. To improve the energy-balance warm outgoing air from the ventilation could be heat-exchanged with the incoming fresh air during the winter.

4.3.13 Finance

For people wanting to build with clay- and earth based materials there are usually no problem with financing, as the banks trust the building authorities permissions and the surveyors up followings. In Sweden there are even two alternative banks, which more or less encourage their customers to live in an ecological way. The anthroposophic movement runs one of them.

4.3.14 Publicity

Publicity about ecological and alternative building materials has been very poor in
Sweden, and neither bad nor good. Little is written in papers or magazines, and
when something is published the journalists are quite neutral. As neither
commercial nor imported products of light-clay can be found in Sweden it is not
surprising that most of the buildings in Sweden are erected by contractors who
have not been in touch with light earth or earthen building materials.

4.3.15

Generally there is some scepticism about earthen buildings as they are associated
with poverty and bad levels of living, but with good examples the attitude can
change for the better.

4.3.16

It is likely that the interest for earthen building materials will grow from the
customers if they know about the materials. Made as blocks with the right ratio of
clay and organic materials the insulation will not take fire, can store some heat
and even have a slight impact on the relative humidity indoors – if not covered
with plastic paints or wallpaper. But it will probably take a long time to get through
to the building companies, as they are not likely to try things they not are used to.

4.3.17 Conclusion

From the statistics in the beginning of this article the conclusion can be drawn that
light earth building materials composed with waste materials from the forestry
industry and peat from the mires have the best potential to develop on a bigger
scale in Sweden.

4.3.18

Most important for the marketing of light earth products is that the construction
method must be easy to handle. That means development of prefabricated blocks
or panels. Today light earth building materials should not be recommended for
multi-storey buildings as there is not enough knowledge about creep and other
effects in the long term.

4.3.19

The big supply of timber has made the Swedes a wood-building people, from the
era of the Vikings until today. Therefore the traditional building material for single-
family houses in Sweden is wood. But clay has been used, for plastering the log-
cabins and for wattle and daub.

4.3.20

Because of the relatively poor thermal-values for light earth materials [compared
to straw bale] and the fact that it is only possible to erect monolithic walls during
the summer-season, light earth building materials are not suitable for houses in
dense cities. As the builders want as much floor-area as possible to let on the
property the walls has to be as thin as possible. That is a disadvantage for natural
building materials as straw-clay and timber. But the tradition and use of timber-
frames for small buildings and single-family houses can make light earth products
as a competitive alternative for the insulation made of glass- or mineral wool. But
not until someone will establish a suitable plant for production of light earth
building materials.
4.4 The Dutch Experience
(By Sjap Holst)

4.4.1 History

4.4.1.1 It was in the year 1982 that I got acquainted with the straw-earth building technique. Hugo Houwen, director of CRATerre, was building a little atelier for his brother at Overijssse in Belgium. At that time, Franz Volhard, member of CRATerre, was writing his book on light earth construction. It was decided to use this little project as a test case to introduce light earth building in Belgium. I was invited to participate in the building process. This was the beginning of my involvement with straw earth building. In 1983 I graduated at the Technical University of Eindhoven on an earth building design project. Ever since I have tried to implement earth building in my own projects as well as in general. Since 1990 I have given theoretical and practical courses on earth construction annually.

4.4.1.2 At first building permits were given only for experimental earth building. Due to my efforts earth building has gained in popularity and is now accepted as a major sustainable building method. But because of the fact that earth building techniques are laborious, they are not applied in large scale projects until recently.

4.4.1.3 Nevertheless today I can count about 10 small light earth buildings on our country, together with many other hybrid buildings in which somehow earth is involved as building material. Surely there are more unknown buildings, since people who followed my earth construction course started to design and build light earth projects on their own. Many architects now use earth for instance as internal rendering in their designs. In the Netherlands earth building is leading now its own life on a small scale, far beyond my control.

4.4.1.4 I have the impression that building with earth is somehow related to the conjuncture [economic buoyancy] of the country. When it is low, people show more interest in earth building and projects get off the ground. Even sustainability becomes a hot item. If its high, there is no interest at all in building with earth and there is less concern for the environment. Even politically sustainability becomes a minor issue. Until recently we had a high conjuncture and consequently there was no interest whatsoever in earth building. As we are now about to return to a bad economical period, earth building might enjoy a revival. This will give the earth construction development a new impulse.

4.4.2 Straw earth building technique

4.4.2.1 The straw earth building technique consists of pouring and pressing long straw fibres mixed with mud into a movable shuttering fixed against a wooden skeleton. Walls with a density of 500-600kg/m³ can be built.

4.4.2.2 This requires a lot of labour. Since all straw earth buildings in Holland are custom owner made this is not a big problem. For bigger projects however, time and labour become very significant related to the budget. To reduce labour and increase speed substantially I invented a special mixing machine to mix up long
straw fibres with mud. [Shown para 3.1.4.16] Now we can produce perfect straw earth mixture at 2-3m³/h with 2-3 persons.

4.4.2.3 Now the bottleneck consists in pouring and pressing the straw earth mixture into the shuttering as well as the drying time of the walls. This could be avoided by industrially producing prefabricating building elements. However in our country the market is not ready for this approach.

4.4.3 Significant straw earth building projects.

4.4.3.1 Self made homes at Rosmalen 1988 and 1990.
A little house, bungalow type, designed by architect Frans van Dillen was built by the female owner in 1986/88. Eco-design [Sjap’s Architectural Practice] made all the drawings according to earth construction best practice and advised the builder.

4.4.3.2 The straw earth outside-walls have a thickness of 40cm, those inside of 20cm. The main load bearing wood frame construction is of second hand wood and located inside the straw earth walls. The house has an integrated wall heating system. Wall surface is rendered inside with earth and outside with a traditional lime plaster consisting of a mixture of lime, sand, cottage cheese and horse hair. The building is designed to fit another story on top of it, to be built later on.

Straw-Clay bungalow at Rosmalen, 1988

4.4.3.3 Nearby this bungalow, a two story straw earth house was built by the owners during 1987-1991. Also designed by architect Frans van Dillen. This time no professional help for earth construction was needed, because the skills were available among the inhabitants of the neighbourhood. At that time sustainability and health were not the issue. Building cheaply was the main reason to build by yourself with earth combined with second hand materials.

4.4.3.4 Atelier at Vessem 1990-1993.
My nephew wanted to build an atelier from an old barn at his farm at Vessem. So we joined forces and within two weeks we got the building permit to transform the barn into an atelier made of straw earth. In 1990 I started to give earth construction workshops at the site every summer for three years. We used limestone for the plinth, recycled wood for the framings and local straw and earth for the 30cm walls. We even used water from the little river nearby. Everything
was hand made, except for the mud, which was produced using a special mixing machine I bought for the occasion.

4.4.3.5

During the courses, there was room and time for experiments. We built composite walls with earth bricks, stuck together by simply wetting and stacking them in bond (without any mortar) to act as lost forms at the inside, combined with a straw earth insulation wall at the outside. It worked very well. The earth walls are now protected at the outside by wood cladding.

Atelier at Vessum, 1990-93

4.4.3.6

Cultural Centre at Leende 1991-
Eco-design designed for a wealthy Client, who wanted to create an art collection of his own, an art building with ateliers, exposition room and living space made of straw and earth. The 40cm straw earth walls placed on a limestone plinth, envelop the wood frame load bearing construction made with local trees. The building was built by a small contractor whom Eco-design instructed how to build with straw earth. We also used for the first time the especially developed straw earth mixing machine, and speeded up the building rate enormously.

4.4.3.7

Due to starting problems caused by opposition of local inhabitants, the building started with 4 years delay. Sadly the Client died some years later and the building process was stopped. So the Cultural Centre could not be finished. Now the building, with its unfinished walls, is turning into a ruin because of both lack of money and interest by the heirs. [This the building described in Case Study 7.1.8]

4.4.3.8

In 1993 Eco-design was asked to advise for a experimental sustainable straw earth building to be used by the neighbourhood for social gatherings. This building, designed by the same architect who designed the whole neighbourhood, was built by means of workshops with volunteers. The walls consist of a wooden skeleton bearing a sod roof, filled up with 40 cm straw earth placed on a brick plinth. We also experimented with straw earth insulation between the floor beams. After 6 years, a mould problem occurred in the floor beams as well as the wood framing.

4.4.3.9

The mould on the floor beams, known as 'brown rot', was caused by a lack of ventilation and drainage in the cavity beneath the floor. The mould on the wood framing however was due to the excessive long drying period of the 40cm walls. Since the straw earth was in remarkably good condition and the wood framing was
only partially attacked by mould, I believed that the earth building could have been saved. However, the owners preferred to destroy and rebuild it with brick walls and a concrete floor. So this earth building no longer exists.

Community Use building at Utrecht, 1994

Unfortunately all evidence of the straw earth and wood construction had been destroyed before we could investigate what was the real cause of this pathology. However, in the future we will not use any straw earth or other organic fibres as insulation within wooden ground floor beams, because good dry conditions in ground floor cavities cannot be guaranteed.


As a result of a little straw earth demonstration project Eco-design did at Delft in 1989 which was commissioned by the municipality, architect Ernst Israels designed and built, together with volunteers, his own straw earth house in the middle of the city of Delft. Eaves over-hangs are made of glass, outside walls are partially rendered with earth partially made of brickwork. The roof has a terrace, a garden and a waste water cleaning reed pond on top of it!

Urban Infill House at Delft, 1994

The 40 cm straw earth walls with load bearing wooden structure ensure good thermal insulation. Inside there are two living spaces, kitchen, sleeping rooms, working spaces as well as a compost toilet. All inside walls are rendered with earth. The design takes account of passive solar energy. After 6 years the outside earth rendering showed some pathology, and some simple maintenance was
Little office building at Swifterbant 1995.

At the experimental farm at Swifterbant, belonging to the Agricultural University of Wageningen, a little office building situated between two stable units, was built in straw earth with help of students. The whole farm building was designed by CHV-architectural office at Veghel, who specialize in farming design. Eco-design advised them concerning the details for straw earth construction and instructed the students how to build with straw earth technique.

Private house at Ezinge 1996.

This little house built with straw earth was actually a test case for the owner / builder who attended my earth building course. Later on he'll build a much bigger house. Once the big house is ready, the first will become a guesthouse. The little house was designed by another architect together with the owner. The ground-floor is insulated with sea shells, with a 30cm walls of straw earth with wooden skeleton, wood stove for heat, compost toilet as well as a reed bed pond.

The Oase pavilion at Beuningen 2000. [Ref 7.1.7]

In 1996 the OASE foundation commissioned Eco-design to design a special pavilion as part of the garden related to the convent. It had to be something different from the usual prefabricated wooden sheds you can buy everywhere. So Eco-design designed an organic shaped round building with a sod roof shaped like a leaf. It has a circular main space and an attached utility shed for garden tools.

When OASE designed the garden, they planned a pond. So we used the extracted earth to create the pond mixed with water from the same pond and straw to build the straw earth pavilion. The walls of the main space are 35cm, the shed 25cm thickness, both placed on a brick plinth. The load bearing wooden structure together with the roof and concrete/brick foundation was built by a small contractor. All the earth building was done by volunteers during several workshops. Inside the walls are rendered with earth, outside with a traditional earth-lime plaster mixed with horse urine. There is no heating in the building, since it is only used during the seasons when the garden is in flower and open to the public. The pavilion is used for expositions, music and literary gatherings.
4.5 Discussion and the UK Situation

4.5.1 Miscellaneous Aspects

4.5.1.1 With only three light earth buildings so far erected in the UK, and only one of these subjected to Building Control, it is too early to accurately predict what may develop in the UK. It can be said, however, that the information contained in this document is likely to be valuable in helping would-be builders over some of the obstacles which can prevent innovative projects ever getting off the ground.

4.5.1.2 The study trip to Germany, and other European visits have been most instructive in what the future may hold for the UK, but inevitably, the factors determining the development of light earth are not always to do with the technique itself, but are sometimes economic, cultural, social even.

4.5.1.3 In Holland, for example, and this is likely to be true to a certain extent in most countries, Sjap Holst identifies the correlation between economic buoyancy in the country overall, and an interest in light earth and other sustainability issues. A strong or weak pound will affect both the relative cost of imported light earth materials as much as it affects confidence generally in the construction industry. Whether or not the UK joins the euro might affect the relative values and desirability of European products. On the other hand, large scale economics is less likely to affect considerations of self builders, though the fluctuations in house prices will no doubt affect confidence in investing in unusual materials.

4.5.1.4 Socially and Culturally, a number of factors have been noted in the various trips abroad which have affected the uptake or general public view of light earth. In Sweden, for example, some of the most significant light earth buildings have been initiated by those within the anthroposophical movement. This has affected the wider public view of the technique as something, perhaps more 'alternative' than it need be. It is subsequently instructive that most of the self builders in Sweden are, at least sympathetic to the social and ecological aspects of the anthroposophical perspective and so are not put off by the association.

4.5.1.5 In contrast, light earth development in Finland has been driven by a research base at the Technical University in Helsinki with a strong emphasis on research / technical aspects of light earth mixes, the potential commercial applicability and a rural socioeconomic emphasis on bringing value to farmers, foresters and the like. In this way, there appears to be no similar association of light earth with alternative ideologies and the development has been supported by many agencies interested in rural economic regeneration. In addition, the most publicised light earth building, at Raisio, was designed in a pleasantly modern style which has helped the public view of the technique.

4.5.1.6 Ironically, it is in Finland where some of those most influential in the development of light earth are now looking more favourably upon the use of straw bales, for the two simple reasons that they do not need to dry out, and that they offer greater insulative value - of obvious merit in such a cold climate. The argument is compelling and is instructive particularly for the colder regions of the UK.
4.5.1.7

The development of light earth is usually closely linked to that of both straw bale and other forms of earth construction. Where these become more widespread and accepted, so it is easier for light earth to develop and vice versa. In the UK straw bale construction is gaining ground but with one or two exceptions, remains a rather grass roots movement with little enthusiasm so far from the wider design and construction industry. Earth building by contrast is just beginning to develop a presence but is able to build on a considerable vernacular tradition in many parts of the UK. Light Earth does not have the benefit of a tradition to support its development in the UK, nor perhaps the immediate advantages of straw bale so is likely to lag behind the others whilst at the same time benefiting from the greater publicity and hopefully acceptance of the other techniques.

4.5.1.8

The development of light earth is also closely related to the individual interests of those who pursue its development. This is clear in Germany where several individuals and organisations are involved in the development of light earth, each with a different view of the future - into which many have invested - and who are almost invariably at odds with one another.

4.5.1.9

The work of Klaus Beck is particularly interesting in that he has managed to bring together a strong environmental and health based interest with an equally engaged social agenda; involving formerly unemployed people, delivering training and confidence whilst at the same time marrying different funding strategies to achieve not only ecologically benign buildings, but at lower cost because of the use of government subsidies for the training and development of the unemployed. That the buildings are produced to an extremely high quality says as much for the capacity of those taken on, as it does for the quality of the training and supervision.

4.5.1.10

An altogether different approach has been taken by Jorg Depta in Berlin who has built many light earth projects with an increasing interest and involvement in prefabrication. Whilst not using blocks, he has developed the mechanised spraying or pumping of light earth mixes and is presently involved in the production of 3m high prefabricated panels which he wholeheartedly believes are the only economic way forward for light earth. This route has obvious parallels with the Egan-centred thinking of much of the UK industry at present.

4.5.1.11

The two approaches exemplify two potential views of how to develop light earth on a widespread basis. The latter, in common with much industry thinking sees the widening of applicability essentially as being mechanically based; if one person can make a certain number of hand made blocks in a certain time, with high labour rates, one can be certain that a machine could make the same blocks more quickly and cost effectively. The argument therefore is to reduce the labour quotient, replace with mechanisation and deliver better, cheaper buildings for the Client. The former takes cognisance of the huge potential of both unused labour, and existing government subsidy, to essentially cancel out the additional cost of labour associated with high labour cost / low material cost construction. While the former view inevitably leads to de-skilling, the latter does the reverse and is certainly the most socially benign approach. Nonetheless, both have a validity and
potential which can be developed in the UK.

4.5.2 Three Potential Scenarios

4.5.2.1 Based on observation of European development of light earth, there are three likely ways in which light earth can develop in the UK. These are not mutually exclusive, indeed, developments in one will undoubtedly encourage and support development in the others. There is also an element of overlap between them but for clarity, they may be envisaged as: a) self build, b) mechanisation, and c) product development.

4.5.2.2 Self Build

The self build scenario involves the increasing uptake of light earth amongst the self build community which is large and accounts for a significant proportion (estimates depend on the definition of self build but may be as high as a third) of houses constructed in the UK. Many of these people will not be doing any actual building work themselves and the majority will not deviate from conventional construction because it is already a considerable risk with often quite slim margins. Nonetheless many could benefit in simple economic terms from the use of light earth.

4.5.2.3 It is with the self build sector that the advantages of light earth are most obvious economically since they dovetail into the existing logic for being involved in self build. Quite apart from any emotional motivation for building one’s own house (which is a very much more significant cultural aspect in Scandinavia and New Zealand, for example), and leaving aside issues of ecological or healthy design, the principal motivation in self build is in some way to reduce the costs of acquiring a house by substituting some of the time normally associated with a developer or main contractor with one’s own.

4.5.2.4 How this is factored into the overall cost analysis is different with almost everyone, ranging from being discounted entirely, to a sensible hourly rate conscientiously applied at all times. In any event, the logic is in place to reduce some part of someone else’s labour cost with one’s own. The materials conventionally used for buildings cost more or less the same whether bought by a contractor or self builder (as long as contractors’ rates can be negotiated) so the only room for manoeuvre is labour.

4.5.2.5 The great advantage of light earth is that the material costs are much lower than for a conventional construction, but this is broadly at the expense of additional necessary labour. Depending on how this additional labour is costed by the self builder, the potential savings can be significant.

4.5.2.6 In addition, and as already discussed, the technique is safe and easy to carry out without special skills, the materials are widely available and the technique does not in any way dictate the actual look of the house so that it may appear entirely conventional when completed if necessary. A greater percentage of self builders are interested in health and environmental issues (it is often the main reason for becoming involved) and so the ecological advantages of light earth will have a greater influence in this particular sector.
4.5.2.7 Realistically, based on experience in Europe and with an understanding of the UK situation, this simple scenario, of increasing usage of the technique by self builders is the scenario with the most potential and is the most likely to develop.

4.5.2.8 Mechanisation The second scenario is through development of mechanical means of mixing and installation which render light earth not only economical in materials but in labour too. On example of this was developed by owner builders in New Zealand, another by Sjap Holst in Holland, see paragraph 3.1.4.16. This machine removes the ‘bottleneck’ in the construction process associated with the preparation and mixing of the light earth mix, greatly increasing the amount that can be installed in the same time.

4.5.2.9 Using a machine like this would not only speed up the efforts of self builders, but would encourage the use of the technique by more conventional contractors and could lead, as in New Zealand and Germany, to the development of specialist contractors who could provide materials and an installation service for any type of construction project at a reasonable rate. The technique would then appeal more to larger scale operators who could marry economy with obvious sustainability benefits.

4.5.2.10 This scenario obviously benefits the first scenario, but could also develop alone which is essentially what has happened in Holland.

4.5.2.11 Product Development The third scenario - which is already underway - is the introduction and development of light earth products, mainly blocks but also prefab panels, boards and such like which simply replace less ecologically benign products.

4.5.2.12 As mentioned already in Section 3.3, such products are already on the market and have had very little penetration thus far. This is largely due to their relatively high cost (they are all imported from Germany or Austria), which puts off those who do know about them, or because few people are yet aware of their existence. The two developments which could significantly affect this would be the creation of a UK based manufacturing plant, or more likely the adjustment of an existing plant to make light earth products (this has been tried on a very small scale in Scotland by Errol Bricks, ref 8.5.6.6), or by greater publicity to include well received example projects.

4.5.2.13 Of the three scenarios this is the least likely at present but has perhaps as great a potential as the first since it accords with the current industry preference for prefabrication and would allow light earth to be used in many situations beyond those developed by enthusiasts.
5  Technical and Financial Approval

The purpose of this chapter is to investigate the possible future scenarios for Light Earth Construction in the UK in the light of experience elsewhere.

Any unknown technique will require to be proved to be an adequate method of construction and following that, will need to be accepted by those authorities and organisations which bestow either technical or financial approval on construction projects. It is hoped that this project will enable this process of acceptance to be completed at the very beginning of the introduction of the new technique and in this way improve the competitiveness of the UK industry.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the conclusions to be drawn.

Sub-Contents

5.1  UK Planning Conditions
5.2  UK Building Warrant Conditions
5.3  UK Valuation
5.4.  UK Mortgage Conditions
5.5.  UK Latent Defects Insurance
5.6.  UK Property Insurance
5.7  UK Architects’ Professional Indemnity Insurance
Summary

(5.1) The use of light earth as a material has no effect on Planning Department considerations and will neither enhance or detract from a project’s likelihood of acceptance.

(5.2) There should be no insurmountable problems with Building Control, although Officers will have legitimate concerns about a technique which is new to them and are likely to require confirmation of fire behaviour, and thermal and moisture / vapour characteristics, all of which can be found in the report.

(5.3) Because of the natural reticence of both purchasers and lenders, it is likely that the value of light earth buildings will be up to 10% less than ‘normal’ valuation.

(5.4) None of the Valuers or Mortgage Lenders approached could see a reason why light earth should not be mortgageable, provided a sound valuation had been made against which to lend, the property was insurable, and insured, and had a recognised service life, such as would be provided by a Latent Defects Insurance policy.

(5.5) Light Earth has been comprehensively assessed by one of the principal Latent Defects Insurers and Assessors who has awarded the technique a range of anticipated life spans according to various constructional criteria which are noted in their report which is transcribed in Appendix 9.5.

(5.6) It was made clear that several Property Insurers would carry the risk of light earth construction, at between 25% - 50% above the normal rate on the basis of it being a ‘non-standard’ construction method, though all approached were keen to stress that each case would be taken on its own merit.

(5.7) The use of light earth as a material would not have an effect on an Architect’s Professional Indemnity Insurance provided the technique did not prove to be a particularly risky one.
Each of the following organisations or individuals were sent copies of the relevant sections of the report after agreeing to consider the technique and respond with their view of light earth construction and its acceptability from their professional viewpoint.

5.1 UK Planning Conditions

5.1.1 The statements below on the issue of Planning are based on conversations with the Local Authority Planning Department Officer specifically with regard to the building at Littlecroft, but also with reference to the issue of light earth generally.

5.1.2 The use of light earth as a material has no effect on Planning Department considerations and will neither enhance or detract from a project’s likelihood of acceptance.

5.1.3 There may however be practical implications if, for example, a requirement of the Planning approval is the cladding of the building in rubble stonework as may be likely in some reserved areas such as Conservation Areas or Areas of Outstanding Natural Beauty. This would however be no more inconvenient or costly than with a conventional timber frame house similarly obliged.

5.2 UK Building Warrant Conditions

5.2.1 The following is based on conversations with Jon Hollely, an independent approved Building Inspector, ref 8.5.4.1, and with the discussions and correspondence between the author and Scottish Borders Building Control with regard to the building at Littlecroft which is described in Chapter 6.

5.2.2 Essentially, Hollely sees no problems with light earth which could lead to a refusal, though there would be legitimate queries about some aspects. He has extensive experience of straw bale and earth construction so is familiar with many of the issues which are distinct from conventional construction. His only concern is of the absence of UK based, long term understanding or empirical evidence of the behaviour of moisture within light earth construction. This concern is not enough, in his opinion, to prevent acceptance of the technique but it leads to a desire to see a greater degree of accelerated testing or investigation, beyond that which was proposed, or is possible in this study.

5.2.3 Scottish Borders Building Control were similarly interested in the vapour diffusive behaviour of light earth, along with thermal performance and fire behaviour, but were satisfied by the German based information provided. All of these concerns should be adequately answered by the information in Chapter 2 of this report, and with the benefit of being in English!

5.2.4 If there are problems persuading Building Control officers, Hollely noted that it is in fact up to the Officer / Department to prove that the proposed detail or technique is NOT acceptable, rather than the other way around. However, he also noted that if people are having difficulties with their local Building Control Officer on the
subject, that he would be willing to act as their inspector, and would be able to issue Building Warrant approval in lieu, if necessary, and assuming he was happy with the proposals.

5.3 UK Valuation

5.3.1 The following is based on discussions and correspondence with Robert Still of Allied Lorne Brown Surveyors in Melrose, ref 8.5.4.3, who were approached to give both a specific valuation for Littlecroft and to comment generically about the issues surrounding valuation of light earth. His response is largely transcribed below.

5.3.2 “Having had the opportunity to read through the technical information which you provided following our useful site meeting, I confirm that I do not see any reason, in principal, why this type of construction should not be acceptable for mortgage lending purposes. As you are aware, this firm acts for the majority of major Lending Institutions and, whilst they all have different guidelines and policies towards types of construction acceptable for mortgage lending purposes, there tends to be a common policy that, where a type of dwelling is considered marketable for owner occupation, it will be considered on the merits of the individual unit. This means that, in practice, unless there is a stated policy on not offering mortgage facilities on dwellinghouses of a particular constructional type, the decision to lend will be influenced by inter alia the Valuer’s assessment on site. It is interesting to note that at least one major Lending Institution makes specific reference to localised types of construction such as cobb, flint, clay lump, wattle and daub etc., being generally acceptable unless the Valuer considers otherwise.

5.3.3 The concept of value is determined by the inter-relationship between “marketability” and “mortgageability”. Inevitably, any dwellinghouse perceived as being of ”non-conventional” construction will create a certain reticence in the eyes of both prospective purchasers and lenders, circumstances which will be reflected in value. Unfortunately, this effect on value can only be properly ascertained once a sufficient sample of sales of buildings of light earth construction has been recorded. It is my opinion, however, from the evidence of sales of a broad range of dwellinghouses of “non-conventional” construction, that the difference in value is unlikely to exceed 10%. This difference is likely to diminish, as and when the light earth building technique becomes increasingly established in the housing sector.”

5.3.4 This general information was borne out in his specific valuation of the property at Littlecroft.

5.4 UK Mortgage Conditions

5.4.1 Contact was made with both the Ecology Building Society, ref 8.5.4.4, who lend on domestic properties, and Triodos Bank, ref 8.5.4.5, who lend on commercial properties with regard to the mortgageability of light earth construction.
5.4.2 Sue Cooper, Loan Manager at the Triodos Bank responded by email as follows: 
"This type of construction is something that we would be interested in. The key areas for lending are:
• the professional valuation of a property constructed with this technique to ensure that it has a market value against which we can lend
• the ability to insure the property
• the length of the loan needs to be linked to the expected life of the property."

5.4.3 These three aspects have been adequately covered by other sections in this chapter, such that there would be no problem - related to the use of light earth - with securing a commercial mortgage with Triodos.

5.4.4 Essentially the same criteria applied with the Ecology Building Society, for whom Paul Ellis commented that although each project needed to be considered on its own merits, essentially the Society would not have a problem with lending on light earth properties.

5.5 **UK Latent Defects Insurance**

5.5.1 There are three principal insurers in the private sector house building market and one for Housing Associations. The three are Zurich Municipal, Trenwick and NHBC, whilst Housing Association Property Mutual Ltd. (HAPM) work largely with Housing Associations. Originally NHBC and Trenwicks were approached but ultimately declined to become involved in the project, although there are signs that NHBC are becoming more interested in unusual techniques. Zurich Municipal were dismissive of a similar project on straw bale and were not approached. HAPM were also approached and, through their new business arm, Building LifePlans Ltd., ref 8.5.4.6, undertook an assessment of light earth construction which is transcribed in full in Appendix 9.5.

5.5.2 If the guidelines in the above document are followed, and subject to site visits and other details and specifications being acceptable, light earth construction can be insured against latent defects by Building LifePlans to the number of years noted in the document. Insured lives depend largely on the materials used and vary from 60 years for mineral fill options, 35 years for woodchip-clay options (minus ten years if bark is present) to 30 years for straw-clay and other cereal type fills.

5.6. **UK Property Insurance**

5.6.1 Two companies were approached to comment on their view of light earth construction with regard to building insurance. One was Ainley’s Insurance Brokers, ref. 8.5.4.6, who originally agreed to take part in the research and have a history of offering insurance to building types such as thatched or traditional ‘half-timbered’ houses. They were also involved in similar research into the insurance risks associated with straw bale construction. The other company were Norwich Union, via Edinburgh Risk Management, ref 8.5.4.7, who act as brokers for Neil Cockett, the Client for Littlecroft. In this way the risk could be assessed both in
theory and for a real case study.

5.6.2 In both cases, the response was that light earth buildings would be considered as ‘non standard’ and as such would be rated at approximately 25% - 50% above the normal rate, depending on the particular circumstances. Both stressed however that each case is considered on its own merit. Both, in conversation, were keen to know if valuations etc. had been made and when told that they had and that the valuation did not raise any problems, were more relaxed about the issue.

5.6.3 Both made reference to the fact that information on other ‘non-standard’ construction was filtering through to the Insurance Press and that many insurers would carry the risk.

5.6.4 In commenting on the mortgageability of light earth, Paul Ellis of the Ecology Building Society also passed on the numbers of Insurers or Brokers who have arranged cover for some of the Society’s more unusual proprieties. These were:

Selfbuilder.com 01732 744732
J N Dobbin (Holdings) plc 01628 771877
Slater Marchant 01756 75253

5.7 UK Designers’ Professional Indemnity Insurance

5.7.1 In order to assess the implications for designers intending to work with light earth construction, a Professional Indemnity agent, RIAS Insurance Services, ref 8.5.4.8, who cover a large number of Scottish Architectural practices were approached for their comments.

5.7.2 Essentially, the view of the Insurers is that until a type of construction, and light earth construction would be no different, was shown to be a particular problem or risk, Insurers would not refrain from offering cover.

5.7.3 It should be stressed however that any Designer undertaking a light earth design should be clear that the Client, other Design Team members, the Main Contractor, and their own PI Insurer are fully aware of the nature of the material and that everyone involved is cogniscent of the implications. They should also take all reasonable steps to ensure that they know as much as possible about the technique so that they could not be accused of a lack of ‘Duty of Care’ toward their Client. These two points were not mentioned by the Insurer but stem from the author’s own investigations into the use of innovative materials and buildings.
6  

Worked Example: Littlecroft

The purpose of this chapter is to describe in more detail the development of one project, the only one which has been put through the particular rigours of the UK Planning and Building Control regimes, and in this way to be most instructive for any other project in the UK.

To this chapter will be added a section on the monitoring of both Littlecroft and another, English example of light earth construction for comparison. This section will be delivered in December 2003.

A Sub-Contents section is included to allow an overview of the Chapter and a following Summary briefly outlines the conclusions to be drawn.

Sub-Contents

6.1  Design and Approvals
   6.1.1  Initial Design, Preparation and Planning Approval
   6.1.2  Structure and Building Control Approval

6.2  Construction Process
   6.2.1  Site Preparation and Structural Frame
   6.2.2  Wall Raising
   6.2.3  Other works / Finishes

6.3  Monitoring
   3.3.1  To be completed...
Summary

(6.1.1) Having purchased and moved in to the property in January 2001, the clients required some additional space and it was agreed to provide this in a separate building situated in the garden. The building measured 46m² internally and was dug into the ground and given a low and shallow pitched roof to avoid overshading a neighbour. Discussions were held with all affected neighbours and with potential contractors to iron out any problems. After discussions with the local Planning Department it became clear that the building, with minor adjustments, constituted permitted development and so did not require Planning Consent in this case.

(6.1.2) Discussions were also held with a Structural Engineer and with the local Building Control Officer to inform them of the unusual aspects of the construction. Loads with which the Engineer were not familiar were confirmed in writing so that he could issue a Structural Certificate for the project. The Building Control Officer accepted the proposals after additional information regarding the thermal, vapour permeability and fire resisting properties were submitted along with a condensation risk analysis. Building Control approval was granted on 12th June 2001.

(6.2.1) The site was cleared and individual pads poured with steel shoes to take the loads of the suspended timber floor. The loadbearing side walls and central posts were then erected, the roof structure spanned between them and a breather membrane stretched over to provide a weatherproof space within about six weeks.

(6.2.2) The light earth walls were raised in two distinct ways. Prior to site start, woodchip-clay blocks were made off-site and allowed to dry. Following the frame erection, straw-clay walls were largely installed in half of the building in a series of volunteer workshops over a series of weekends. These were followed by the installation of the dried blocks to the other half of the building in three consecutive days.

(6.2.3) The principal jobs, once the straw-clay walls were dry, was the installation of insulation to floor and ceiling, ceiling lining, heating and other service installations, wall plastering and external rendering, floor finishes and Lastly surface coatings. External finishes and the soiling and planting of the roof will be completed by the end of 2002.
6.1 Design and Approvals

6.1.1 Initial Design, Preparation and Planning Approval

6.1.1.1 Preparatory Work

The Clients Neil Cockett and his wife Ann purchased the property named ‘Littlecroft’ in the village of Eildon, near Melrose and moved in during January of 2001. The property was a small stone cottage about 200 years old with a sizeable garden. It was smaller than their previous house and so it was proposed to build an extension of two main rooms. One a study for Neil to house his books, desk, computer etc., and the other to be a Guest Room and/or Day room for Ann. It was originally intended to incorporate a small bathroom and kitchenette.

6.1.1.2

The cottage was small but self-contained and it was agreed that an extension built on to the cottage would be out of keeping and result in the need for corridors and low ceilings which could be avoided if a separate building was erected. It was agreed that this should be located in the south-east corner of the garden and a survey was undertaken to establish exact distances, boundaries and levels.

6.1.1.3

The new building was close to the boundary with the neighbour on the east, so it was decided to keep the building as low as possible and ‘soften’ the impact with a planted roof which could also be kept fairly shallow in pitch to reduce the overall height. (This was also an issue for the Planning Department as noted later). The building was designed to be dug into the ground to reduce the overall height still further but a ‘sump’ effect was avoided because the ground sloped steeply downward at the very corner of the site allowing the building to appear low on one side, yet raised off the ground on the ‘blind’ side.

6.1.1.4

Both Architect and Clients made an effort to inform all the close neighbours about the proposed development. In each case the unique nature of the construction process was explained and discussed in order to minimise the risk of uninformed rumours. The pro-active approach resulted in support generally for the project despite the generally conservative nature of the community.

6.1.1.5

Even before addressing issue of Planning, discussions were initiated with two potential contractors in recognition of the relatively unusual nature of much of the construction process. Through discussion it became clear that the unusual aspects comprised a distinct ‘package’ of work with the majority of the work essentially conventional in nature. This avoided any potential for the contractors being put off by a perceived “risky” project and raising prices artificially.

6.1.1.6 Planning Approval

The Planning Department of the local authority, the Scottish Borders Council, was contacted and a meeting arranged on site with the local Planning Officer. At this meeting the Officer made it clear that the aspect of light earth construction made no material difference to her considerations.

6.1.1.7

Her concerns were whether or not the project represented permitted development under the terms of the Town and Country (General Permitted Development) (Scotland) Order 1992. As long as the overall height did not exceed 4m, certain
distances were maintained from boundaries and a number of other conditions were adhered to, the project was acceptable. The only possible problem was that the building was used “...for a purpose incidental to the enjoyment of the dwelling house and be ancillary to it. It should not be occupied as a separate residential unit...” Once it was established that this was the case, the project was deemed acceptable.

6.1.1.8

Thus on 26th April 2001, the Planning Officer wrote confirming that a formal planning application was not required as the project constituted permitted development. Where planning permission is required for a project, as is normally the case, it was made clear that its construction technique was not significant except insofar as this affected the outer appearance of the building.

6.1.2

Structure and Building Control Approval

6.1.2.1

At the same time, discussions were held with SEPA (Scottish Environmental Protection Authority) with regard to the sewage. These concluded in the abandonment of the bathroom and kitchenette due to the difficulty in agreeing acceptable treatment options.

6.1.2.2

Discussions were also held with a Structural Engineer. A Structural Engineer’s Certificate is normally required by Building Control for any structure not conforming to standard, known structural solutions. After an initial meeting to discuss the project, the following letter was sent by way of confirmation of unusual loads with which the engineer might not be familiar.

"Proposed Extension to Littlecroft, Eldon, TD6 9HB

Dear Sir,

...We agreed that before you finalise your design that we meet and discuss the proposals.

You will see that there is much that is unusual about the scheme - it is also the vehicle for an amount of DETR [DTI] testing on light earth which we will be carrying out this and next year. There are some pertinent facts that may be of use to you.

The density of the 300mm ‘light earth’ walls is intended to be approx 450kg / cu.m. This is however subject to all number of site and manufacturing variables and I suggest we stick to at least 550kg/cu.m for the purposes of loading.

The walls will be plastered with 25mm each side of a clay based plaster / render with a 5mm lime render finish to the outer coating.

The density of the floor blocks should be about 1500kg/cu.m. These are less than 50mm deep and occupy the gaps between the floor bätens. [This was replaced with a weak lime / sand mix].

The reduced roof layers make up only approx. 75mm now, but of course these will become saturated, then there’s the snow...

The shelving indicated will be filled with books which I guess will put quite an extra basic load onto the structure.

The galv. metal strap bracing should be fixed to the inside of the studs to avoid any potential condensation problems.

Having dug myself a porosity test hole on Sunday I can testify that the soil goes down about 300mm, then you hit pretty solid clay, though with quite a lot of rocks. By all accounts the soil is very heavy around Eldon so I believe this is representative. I assume that you would not visit the site when the pads are dug - could you confirm how we are to ensure compliance with your advice in this regard.

I hope the above is helpful and sufficient for your needs just now."
6.1.2.3

With the above information, the engineer was able to confirm the requirements of the structure and issue a Structural Certificate to comply with the Building Regulations. Light earth walls tend to simplify foundation design because a separate rendered block wall and foundation are not required, but they are not ‘light’ in comparison to conventional timber frame loads.

6.1.2.4 Building Control

Discussions were also started at an early stage with Building Control and two meetings arranged in their offices. After lengthy discussion, the Officer was happy with the proposals but required confirmation of ignitability, thermal conductivity and vapour permeability figures. These were sourced from German information and enclosed with the Building Control Submission. In addition, a condensation risk analysis was requested to establish the performance of the wall in winter conditions. It should be stressed that had the application been submitted without prior discussion, it would have been more time consuming to overcome his legitimate concerns. The following letter accompanied the Building Warrant submission.

Proposed Additional Accommodation at Littlecroft, Eldon, TD6 9HB

Dear Sir,

Please find enclosed a Building Warrant Application on behalf of my clients, for the above named works, along with three copies of the following drawings:

0105/201 Existing Site 1:200
0105/202 Proposed Site 1:200
0105/205 West Elevation 1:100, 1:50
0105/206 Other Elevations 1:100
0105/207 Cross Section 1:25
0105/208 Long Section 1:50, 1:10
0105/209 Standard Details 1:10
0105/210 Groundworks Plan 1:50
0105/211 Substructure Plan 1:50
0105/212 Main Plan 1:50
0105/213 Roof Plan 1:50

I further enclose a cheque for £462.00. A Structural Certificate will be sent under separate cover to yourselves direct from the Structural Engineer.

We have discussed the project a couple of times and I know you are familiar with some of the unusual techniques of construction proposed to be employed.

In order to help your assessment of their suitability, I have also enclosed a copy of a Condensation Risk Analysis and Diagram for two densities of the type of Light Earth Construction proposed in order to take account of the inevitable variations that will take place on site. Please note however, that over half of the walls will be constructed of pre-dried blocks made within tighter tolerances than will be possible on site.

The diagram indicates a small area of possible interstitial condensation risk as you will see, however, I would stress that this is not the case when the outer temperature is changed to 1 degree C, furthermore, all the materials employed are relatively highly vapour permeable and hygroscopic, with the outer layer having the highest permeability to the passage of moisture. This, and the differential vapour pressures will ensure that moisture does not tend to remain in the structure.

To support the figures given in the above mentioned analysis, I have also enclosed copies of relevant German and UK literature giving the measured figures for Light Earth at the densities proposed to be used at Littlecroft. The properties of the clay and lime plasters are commonly available in the UK.

Enclosed support sheets 1 to 3 indicate measured thermal conductivity figures to enable a W/mK figure to be assigned to the Light Earth. There is good consistency amongst the German authorities on this and the numbers concur generally with British documentation so I hope this will be straightforward.

Sheet 5 gives an indication of the essentially non-ignitable behaviour of light earth mixes, though the significance of this is somewhat reduced when behind 25mm either side of clay or lime plaster / render.

... Please contact me if you require further clarification on any point.
6.1.2.5 Condensation Risk

Accompanying the letter was the condensation risk analysis as described. This is reproduced below in four sections with brief explanations of the process of calculation, though refer also to Section 2.4.3. for further explanation if necessary.

6.1.2.6

A condensation risk analysis requires two lines to be plotted against a diagrammatic wall section of the proposed wall under assumed winter conditions. The two lines represent the temperature of the structure as it cools gradually through the section from inside to out, and the dew point temperature as that too drops as it moves through the section. If the former dips below the latter, it may be assumed that condensation could occur. In order to establish the positions of the lines, the following calculations must be undertaken which require the thickness, density, thermal conductivity and vapour resistivity of the materials to be input as shown in highlighted boxes.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density kg/cu.m</th>
<th>thickness m</th>
<th>lambda W/mK</th>
<th>thickness / lambda (thermal conductivity)</th>
<th>thickness / lambda (thermal resistance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay Plaster</td>
<td>1000</td>
<td>0.0025</td>
<td>0.35</td>
<td></td>
<td>0.007</td>
</tr>
<tr>
<td>Light Earth</td>
<td>400</td>
<td>0.3</td>
<td>0.12</td>
<td></td>
<td>2.500</td>
</tr>
<tr>
<td>Lime Render</td>
<td>1600</td>
<td>0.0025</td>
<td>0.85</td>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td>External Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>total wall R: 2.688</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(total wall thermal resistance)</td>
</tr>
</tbody>
</table>

Thus the total wall thermal resistance (R) is calculated, including the internal and external surfaces. Once this is known, the gradient of the overall temperature drop (ØT) can be calculated through the structure by calculating the temperature drop across each homogeneous material in the wall (ΔØ).

<table>
<thead>
<tr>
<th>Temperature Drop</th>
<th>Temperature Drop</th>
<th>Boundary Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 degrees int.</td>
<td>ΔØ = ΔR/R x ØT</td>
<td>in</td>
</tr>
<tr>
<td>0 degrees ext.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 overall drop</td>
<td></td>
<td>0.915</td>
</tr>
<tr>
<td></td>
<td>0.053</td>
<td>19.085</td>
</tr>
<tr>
<td></td>
<td>18.601</td>
<td>19.032</td>
</tr>
<tr>
<td></td>
<td>0.022</td>
<td>0.431</td>
</tr>
<tr>
<td></td>
<td>0.409</td>
<td>0.409</td>
</tr>
<tr>
<td></td>
<td>2.688</td>
<td></td>
</tr>
</tbody>
</table>

Thus the temperature drops between elements of the wall can be plotted from 20K to 0K. What is needed next is to chart the same progress though the wall of the dew point temperature. Once this is known, the two can be plotted together.
and any overlap will theoretically lead to a condensation risk.

6.1.2.9

The first step is to establish total vapour resistance through the wall. This is the sum of the vapour resistances of each material in the wall, as shown below.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
<th>thickness</th>
<th>vapour resistivity $rv$ (MN s/gm)</th>
<th>vapour resistance $Rv = rv \times m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Surface</td>
<td>negligible.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay Plaster</td>
<td>1000</td>
<td>0.025</td>
<td>12</td>
<td>0.300</td>
</tr>
<tr>
<td>Light Earth</td>
<td>400</td>
<td>0.3</td>
<td>2.4</td>
<td>0.720</td>
</tr>
<tr>
<td>Lime Render</td>
<td>1600</td>
<td>0.025</td>
<td>9</td>
<td>0.225</td>
</tr>
<tr>
<td>External Surface</td>
<td>negligible.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\text{total wall } Rv = 1.245$

6.1.2.10

Once the individual and total vapour resistances of the wall are known, these can be used to calculate the vapour pressure drop across the structure as shown below. Each individual pressure drop across a material is derived by dividing its vapour resistance by the total wall resistance and multiplying by the total pressure drop. Typical vapour pressures for internal and external conditions at the noted temperatures are given in the top left, with the subsequent total pressure drop.

<table>
<thead>
<tr>
<th>Vapour Pressure Drop</th>
<th>VP Drop</th>
<th>Vapour Pressure at Boundary</th>
<th>Dew Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>int. vap. press.</td>
<td>$\Delta Pa = rv/Rv \times Pa$</td>
<td>at boundary</td>
<td>deg C</td>
</tr>
<tr>
<td>ext. vap. press.</td>
<td>$\text{total wall } Rv = 1.245$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.1.2.11

From the boundary vapour pressure figures can be ascertained the dew point temperature at each boundary by the use of a Psychometric Chart. A psychometric chart is a series of charts combined to plot the variables used to specify humidity, particularly in relation to temperature. Charts may be available from text books or from BRE Digest 110. Contact BRE, ref.8.6.1.5.

6.1.2.12

Using the chart, plot horizontally across from the vapour pressure noted to ascertain the dew point temperature. Vapour pressure tends to be given in millibars, not pascals. Note that 1 millibar equals 100 Pa. With the dew point charted it is possible to plot the dew point gradient. The two gradients derived from the calculations above are shown below and indicate an area of condensation risk toward the outer edge of the light earth and the inner edge of the outer coating.
Condensation Risk Analysis Diagram showing temperature drop against dew point temperature drop in a light earth wall, arrived at by calculation shown above and indicating a condensation risk in the green area.

6.1.2.13 Despite these indications that condensation could occur in theory, the Officer accepted that the risk was not great considering the vapour permeability and the hygroscopic nature of the materials involved.

The performance of the light earth in fire was also of concern but the fact that it was completely encased on both sides with non-combustible plasters, and that German literature indicated that it was difficult to ignite persuaded the Officer that it did not pose a threat. This being the case, approval was granted on 12th June 2001.
6.2. Construction Process

6.2.1 Site Preparation and Structural Frame

6.2.1.1 Site Preparation

After plants and turf were moved, the site area was cleared by a digger and soil dumped elsewhere on the site for later re-use on the roof. The area was levelled and then the digger left while setting out took place. From this, holes were dug once more by the digger, and concrete poured to form the pads shown below.

Left, view of the site, top left corner of the garden, as viewed from the bedroom dormer window, and, right, with ground cleared, levelled and pads formed, looking back at the house.

6.2.1.2

On these pads were placed galvanised steel stub columns with angles welded to the sides to give support to the main longitudinal floor beams which rested on them and were bolted through. The steel stub columns are shown below, left, and the main beams shown right, with cross joists being fixed in between.

Left, galvanised steel stub columns, and right, floor structure under construction

6.2.1.3

Whilst it involved more site clearance work, the design decision to create a suspended ground floor on pads, rather than a more conventional solid slab floor with trench founds and stub walls had a number of advantages. It reduced the quantities of steel and concrete - both environmentally damaging - required to about a tenth of what would have been used, and allowed all other materials to be organic in origin because of the ventilated sub-floor. This also meant that no dpc or other moisture barrier was required so all construction could be moisture transusive, and the insulation levels could be considerably improved, both in the floor, and at the junction between floor and wall. Given the environmental nature
of the project, such advantages swung the balance in favour of a suspended floor.

6.2.1.4 In order to present a level access, the building had to be "sunk" into the ground, but this did not create a sump because the ground sloped steeply away in the corner of the site so moisture could drain away and ventilation flow readily under the building. A land drain was installed on the higher side to prevent any build-up of water from the ground adjacent to the building.

6.2.1.5 Main Structure

The main carcass of the building, including the floor plate was constructed in three weeks. On the floor were located the double studs, two central lines of columns and beams were erected and rafters stretched between beams and wall studs shown below. Finally, curved OSB (Oriented Strand Board) plates were installed between the two central beams to create the central curved section.

![Images showing construction process.](image1)

Left, side wall double studs and central post and beams installed and braced temporarily and, and right, installation of rafters between.

6.2.1.6 A vapour permeable membrane was fixed over the main roof area to provide a shaded and dry space underneath in which to work, this was then covered with sarking boards and lastly the fairly involved overhanging verge and eaves joinery was completed before the start of the wall raising.

![Images showing membrane installation.](image2)

Left, internal view showing curved central plates and membrane over, and right, completing eaves joinery.
6.2.2 Wall Raising

6.2.2.1 Shuttered construction

In common with many light earth projects, workshops were used to create part of the walls. In all four separate workshops were held on four days with between eight and twelve people attending each. In addition to simply benefiting from the labour and enthusiasm of each volunteer, these workshops were explicitly publicised to bring the technique to the attention of a wide range of people as part of the wider aims of the research project.

[Image: Left, one workshop group pose in front of part of 'their' wall, and right, involving children in construction on a safe site has important implication for families for whom self building is more than simply a means of saving money.]

6.2.2.2

Also in common with other light earth projects, it was discovered that the workshop approach is not an efficient means of building walls quickly! As noted in Section 3.8 Costs, the difference in work rate between an experienced and inexperienced worker can be considerable and it was felt afterwards that their principal benefit had been to introduce the technique to people. The workshops achieved slightly less than half the wall area required and these areas were completed in the following weeks by the Architect, Main Contractor and others on an ad hoc basis.

6.2.2.3

Furthermore, a number of wall areas had been tamped too hard and took too long to dry out. Certain sections had to be removed, and the material mixed back in with new material. Those areas which had been tamped too hard took much longer than others to dry as had been feared and, combined with an unusually wet and dull summer overall, the drying out period was extended from the anticipated 6 weeks to about 10 weeks.

6.2.2.4

This caused some concern and meant that when external plastering was ultimately applied, a couple of the denser wall areas were still slightly damp in the centre. Whilst formally bad practice, there was in practice little alternative and there was no separation of the plaster from the wall as might have been expected.

6.2.2.5

All in all it became clear that the technique allows for considerable tolerances and is in this way quite a “forgiving” method of construction, reinforcing its usefulness to the self build sector in particular.

6.2.2.6 Block Construction

One half of the building was infilled with pre-dried blocks of woodchip-clay rather
than shuttered straw-clay. These walls were constructed after the workshops but before the end of the shuttered infilling process. Some left over blocks were used to infill the higher sections of some wall areas which had been started in shuttered infill construction.

6.2.2.7

The mortar joints used for the blocks were approximately 20mm and the mortar included small woodchips to both bulk out the mix and induce similar movement characteristics in the mortar as in the blocks. Even with the thick mortar bed chosen, the walls were completely dry in about three weeks.

![Image](image_url)

Left, infilling the upper section of the southern gable wall with blocks, and right, the completed north gable infilled with blocks and with the mortar still damp.

6.2.3

*Other works / Finishes*

6.2.3.1

The delay in the drying of the shuttered light earth walls did not affect progress as other tasks could be carried out while the walls dried as long as they did not impede the drying out process. The main process in this period was completing the ceiling insulation and finishes. Sheeps wool was placed between the rafters, a paper vapour check stapled to the rafter undersides and off-sawn boards fixed to form the ceiling finish, as shown below, left.

![Image](image_url)

Left, measuring and fixing ceiling boards, and right, filling the floor joists with sheeps wool insulation before fixing hardboard over as a vapour check and taping joints.
Next the floor was infilled with insulation, see above though this was left as late as possible to maximise the beneficial effects of ventilation from beneath the walls and through the open floor joists.

Once the shuttered walls were dry, the external plaster was applied. This was ‘thrown’ onto the wall surface then smoothed manually. Some of the lightest areas of straw-clay proved difficult to plaster in this way being relatively soft so that the ‘hurled’ clay plaster tended to bounce somewhat. These areas, and the corners needed to be reinforced to give an adequate substrate which also resisted thermal and moisture related movement. Metal mesh can be seen, below left.

Left, half complete clay plaster on a section of block wall, awaiting the metal mesh reinforcement to the corner, and right, completed first ‘scratch’ coat of plaster.

Attentions were then turned inside where the internal plaster was applied. Before this could go ahead however heating pipes were installed within the floor depth and the face of the walls, as shown below. The pipes were 10mm outer diameter and so were wholly buried within the 25mm depth of plaster applied.

Left, 10mm diameter heating pipes fixed to the floor and walls, and right, showing the completed base plaster coat with accelerated drying indicating the position of heating pipes within.
The heating pipes within the floor were threaded through battens, as shown below and covered with a weak lime, clay and sand mix to a depth of 50mm for thermal capacity above the insulation layer. The completed floor screed is shown below, right, with the floor boards being installed on resilient strips over the top.

Left, half complete clay plaster on a section of block wall, awaiting the metal mesh reinforcement to the corner, and right, completed first 'scratch' coat of plaster.

The purpose of installing pipes in the floor and walls, as opposed to installing simple radiators relates to an understanding of the relationship between heating and health. An important aspect of the use of earth and light earth construction is the potential these techniques offer to improve the indoor climate through humidity regulation mainly and thus the health of occupants. Since humidity and heating are intimately related it was important to optimise the performance of the building by creating the ideal heating environment to support the humidity regulating effects and to promote healthy indoor climate.

This was achieved by creating a heating system which:
- Ensured surface temperatures higher than the ambient air temperature reducing occupant radiant heat loss, allowing for lower air temperatures which are themselves better for health
- Keeping heating emitter surface temperatures fairly low so avoiding air circulation / convection and scorched dust which irritates throat membranes
- Avoiding excessive temperature gradients, where the one part of the room is too hot, while another is too cold, as is usual with convection heating
- Avoiding too much air movement. This leads to dust circulation and, since moving air cools, even if warm, can be counter-productive. Air movement also causes friction between the air and surfaces leading to ionisation and electrostatic charge

As soon as the heating system was on, the windows and doors were installed along with associated joinery to reveals, cills and so on. Internal walls were infilled between studs with dense earth blocks to provide additional thermal capacity and these and the external walls were then plastered in a thin finish coat of proprietary clay plaster to give a smooth and unified finish to all surfaces.

Once all the 'wet work' had been completed, the oak floor boards, which had been acclimatising within the building for several weeks were laid over resilient strip to provide a 'floating' floor. Once these were installed, skirting boards, architraves
and other finishing joinery was fixed. The floor boards were temporarily covered while painting took place of walls, ceiling and internal joinery, and lastly the floor itself was oiled and waxed.

Left, Study showing completed finish plaster coat, and right, showing completed painting, skirting boards and finished floor, electrics and fittings.

It was then possible for the second electrical fix and fitting such as shelving to be installed so that the Clients could move in.

Showing completed external render and painting with roof partially complete and lots of landscaping to do!

At the time of writing, external works are yet to be completed, including the painting of external joinery, the finishing of laying of the earth on the roof and landscaping generally.
6.3. Monitoring

To be completed...
The purpose of this chapter is to bring to the reader’s attention a few of the many buildings already constructed using Light Earth in a variety of climatic situations many of which are similar to that of the UK. Without the benefit of experience in this country, it is important to learn from the experiences of those who have attempted similar construction types.

With the exception of Professor Sverre Fehn’s project in Mauritzberg, the author has visited, or been involved in the construction of all of the projects listed, and has attempted to put down in writing the salient points from each, with input and advice from the Architect or Builder in many cases.

There is no summary for this Chapter but a Sub-contents list is provided below.

Sub Contents

UK Examples

7.1.1 Private House Extension, Melrose, The Borders, Scotland
7.1.2 Artist’s Studio, Swindon, Wiltshire, England
7.1.3 Private House Extension, South Hams, Devon England

European Examples

7.1.4 Church, Jarna near Stockholm, Sweden
7.1.5 Summer Cottage, Mauritzberg Estate, Norrkoping, Sweden
7.1.6 Workshop and Store, Jarna near Stockholm, Sweden
7.1.7 Garden House at ‘Oase’, Beuningen, The Netherlands
7.1.8 Culture Centre, Heeze, Eindhoven, The Netherlands
7.1.9 Private House, Raisio near Turku, Finland
7.1.10 Private House, Rheinsberg, Land Brandenburg, Germany
7.1.11 Barn Refurbishment, Hiddenhausen, Spenge, Germany
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7.1.14 Private House, Liepe, Eberswalde, Germany
7.1.15 Weekend Cottage, Geltow, Berlin, Germany
7.1.16 Sheltered / Serviced Housing Block, Berlin - Spandau, Germany

Worldwide Examples

7.1.17 Private House, Dairy Flat, near Auckland, New Zealand
7.1.18 Private House, Pungaere, near Kaikohe, New Zealand
Private House Extension, Melrose, Borders, Scotland

General History and Description of Project

The Client approached the Architect with need for additional accommodation to their recently purchased property. The Client required a Library / Study, Dayroom and additional storage. They were open to use of innovative techniques and agreed to make use of a portion of their garden space for this experimental new build.

General Description of Construction

4.8 x 11.8m stand alone building with softwood primary and secondary structure - suspended floor on galvanised steel 'stilts' with double stud walls above. The roof rafters are supported at the eaves on the double studs and at the ridge by a series of exposed columns internally (see left). A 600mm overhang was used around the building to protect the rendered walls.

The Light Earth infill consists of a range of options: preformed woodchip blocks, two types of clay and woodchip mix cast insitu - one with larger, 'green' chips along with unchopped straw laid more or less in layers, the other smaller, dried chips with chopped straw pre-mixed before being placed in the walls. A standard straw clay mix was also used.

On both sides the walls are rendered with a clay and sand mix using chopped straw, with a finer mix using animal hair over that and limewash to finish. Straw clay - using clay from the site excavation - was also used for the planted roof base material.

Particular Issues

It had been originally intended to use straw clay in the floor but the unresolved issue of drying out meant the Architect opted instead for sheeps wool. Wool was also used in the ceiling in lieu of straw clay due to it's higher insulation level.

The local Building Control Officer was helpful and sympathetic, and was prepared to accept annotated German literature, along with a Condensation Risk Analysis as evidence of the material characteristics of the material. It should be noted however, that this is not necessarily an option available to anyone and British based information would have been more readily accepted.
Roof / Ceiling Construction

Planted roof over Light Earth mix as sub base, over fleece, over ‘Hypalon’ synthetic rubber liner, over fleece slip layer on 25mm timber boards laid over ventilating battens (vented ridge and eaves) over ‘Roofshield’ breather membrane over 250mm rafters, with 250mm sheeps wool infill, British Sisalkraft 410 vapour check paper stapled to underside, 20mm sawn face timber boards to ceiling

Wall Construction

25mm straw reinforced clay / sand render with limewash over 300mm double studs with a variety of Light Earth mixes within 25mm clay / sand internal plaster, reinforced with straw and animal hair, clay paint surface heating pipes embedded within plaster depth in places.

Floor Construction

20mm oak floor boards over 3mm resilient layer on 50x50 sw battens @ 500mm centres infilled with dry lime / sand mix, within which heating pipes are embedded over 3mm tempered hardboard on 250 sw joists with 250mm sheeps wool infill 15mm panelvent boards to underside
Artist’s Studio, near Swindon, North Wiltshire
England

General History and Description of Project

This building is a painting and music studio. The building is an ancillary building and some leeway was allowed for experimental construction.

As far as possible eco-friendly, locally sourced and reused materials were used. The clay came from the site itself, from foundations and waste water system excavations. The straw came from a nearby farm. The foundations were made with secondhand blocks dressed on site and crushed concrete from demolition.

Window frames were end-of-line stock and the doors were made on site. All the exposed timber has been finished with eco-friendly coatings.

General Description of Construction

The main construction is a load bearing wooden frame. The walls were then infilled with a chopped straw and clay slip mixture cast between wooden shutters. Finally the walls have been lime rendered inside and out.

The roof is covered with Ondulene (corrugated vegetable fibre board impregnated with bitumen) and the space between that and the interior timber cladding has been filled with Eco-Fibre.

The humidity and temperature of the building and walls have been monitored. The interior temperature varies only a few degrees between upper and lower extremes and making for a pleasant working space heated solely by a log-burner in winter time.

Particular Issues

The beaten earth floor has proved problematic and is not yet complete. It is formed by a 100 mm dense mix of chopped straw clay slip and sand. Under there is a damp proof membrane, and under this is a 150 mm layer of leca.

Unfortunately this took a long time to dry out and has become damaged and dusty. The problem will be rectified by a final layer of clay, sealed with linseed oil.
Roof / Ceiling Construction

Ondulene (corrugated vegetable fibre board impregnated with bitumen) battens over breather membrane. Eco-Fibre between 200 mm rafters. Timber lining fixed direct to rafters.

Wall Construction

450 mm thick walls. 37.5 mm lime plaster on both sides. Straw/clay mix infilled between approx 150x150 mm solid timber frame with 50x50 mm timber frame in the walls. Frame on dpc over refoundation on second hand blocks and crushed concrete hardcore base.

Floor Construction

Final layer of 50 mm beaten clay sealed with linseed oil, on dense mix of 100 mm straw/clay with sand, on 150 mm layer of leca (moisture free draining) over hardcore.
Private House Extension, South Hams, Devon, England

General History and Description of Project

Client approached Architect with need for additional accommodation to their recently purchased, ex council owned property. Client is specialist oak frame builder so a traditional pegged green oak frame was the obvious choice, with light earth infill to the walls and, unusually, the floor. Part conservatory, it is used as a dining and general purpose area with views over the garden and beyond to the sea inlet.

General Description of Construction

2.7 x 6.6m simple lean to construction onto conventional 1940s masonry house. Principal structure is a green (undried) oak frame with relatively conventional softwood secondary structure and cladding. Suspended timber floor and timber roof construction.

The Light Earth mix in both the walls and floor was a straw-clay mix, the same proportions and moisture content in each case. In the walls this was installed with formwork within a double stud system. No armature system was used as is common in the US.

In the floor, a curved plywood form was produced between two battens fitted to the low sides of each joist. This curve offered sufficient resistance to the downward force of the mix and installation process, and gave the resultant dry mix an element of structural strength once the plywood form had been removed.

Particular Issues

The main problem was with the drying out of the mix in the floor. Taking longer than expected to dry, this had a knock on effect on other trades, and ultimately, the completion date of the project.

This was not anticipated because, as can be seen from the images above and on the next page, there is a ventilated area of some depth beneath the floor with no obvious difference between the walls and floor, yet the walls dried out as expected.

This experience is similar to a temporary project constructed in France, now demolished, which also suffered particularly in the floor. The research aims to discover the reason for this.
Roof Construction
Local slates on battens over breather membrane on 250x62 rafters @ 600 centres resting on 200x150 wall plate / tie sawn face timber boards fixed through vapour check to form ceiling plant based paint finish

Wall Construction
200x62 vertical studs infilled with shuttered straw-clay vapour check internally with sawn boards and plant based paint finish breather membrane externally horizontal battens vertical sawn face softwood batten on board cladding

Floor Construction
Hardwood t+g boards over vapour check on 250x50 joists @ 600 centres infilled with straw-clay supported temporarily by 3mm plywood formed into an arch by battens as shown, no surface treatment to underside

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Construction View showing infill of straw clay mix between floor joists
Community Church, Jarna, near Stockholm, Sweden

General History and Description of Project

The Anthroposophical Movement, based on the teachings of Rudolf Steiner (who designed the famous Goethenaeum, in Germany) has maintained a widespread community in and around the village of Jarna, a half hour drive from Stockholm, for about twenty years.

The church is one of several unusual and innovative projects, both in design and construction, around Jarna. The design is based on two overlapping circles in plan, with an oversailing roof on one end which dips down toward the altar to allow two high level rooflights to emit indirect light either side of the altar.

The building is not yet complete, and work is done on it as and when funds allow. For example, a large stained glass panel is proposed for the wall above the entrance, see above.

General Description of Construction

The whole building sits on a relatively standard concrete slab. The walls of the main church area are 80mm thick by approximately 100mm wide sawn planks, standing on end and joined together to form a simple, single skin wall. This is stained internally and covered with light earth blocks simply stacked up against the outside. These are held against the timber with wall tie type connections and the blocks are rendered in a clay and sand render. The finishing coat is yet to be applied.

Light earth was also used as a roof insulation and as an exposed ceiling finish in the wrap-around lean-to area, which serves as an entrance lobby, circulation space and informal exhibition area.

Particular Issues

A number of clay/sand render recipes have been tried on the light earth blocks externally, and the community are still monitoring (informally) their movement and weathering to assess how best to complete the render.
Details to be confirmed by Architect

Walls:
- Hand made Straw-clay Blocks
- Density: 500kg/cu.m

Floor:
- n/a

Ceiling:
- Shuttered Straw-clay
- Density: c. 400kg/cu.m

Heating:
- Gas fired boiler fuelled
  underfloor system

Tests:
- Informal only

Monitoring:
- None

Insurance:
- Unconfirmed

Mortgage:
- None

Contact Details:
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- Prisma Arkitekter
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- SE-153 22
- Jarna
- Sweden

Internal view of Lobby area showing exposed straw clay ceiling

Construction View showing straw clay blocks being laid up against the timber inner wall
General History and Description of Project

The site was planned by Sverre Fehn as a leisure and golf centre with a number of summer cottages on site. This one cottage was chosen as a prototype for future buildings. It was originally designed to be built in brick, but was changed to straw-clay, without making any alterations to the design.

The clay used came from the site.

General Description of Construction

Construction work was done by a group of architectural students and work was completed in eight weeks. Preformed straw-clay blocks were made, based on a 2m module which was enough for one layer between supports. Each 2m module consisted of 3no. 190x270x540mm blocks and 1no. half length block using 640 blocks in total. The building also contained some freestanding external rammed earth walls.

The preformed block were made in plastic faced plywood moulds fixed with steel brackets to a table, with a removeable bottom plate. The mould was sprayed with clay slip to ease removal. The mix was rammed in using a wooden mallet, dense at the edges, loose in the centre. The sides were removed later and the blocks left with top and bottom plates still on, to dry on open boarding in sunny, ventilated area. They were ready to use after two weeks during which the foundations and structural frame were erected.

All external walls were rendered on the outside with a clay / sand render, and on the inside with a lime / sand plaster.

Particular Technical Issues/ Problems

Some details of original brick design were not extremely well suited to straw clay. This made certain aspects of the construction more difficult in some places. Despite this, the construction of the house was completed without having to make alterations to the design, though the lack of an overhang - not strictly necessary for a brick wall - might lead to weathering problems in the long term.
**Roof / Ceiling Construction**

horizontally laid timber lapped boards, over bituminous felt layer over plywood curved over timber battens over timber minor purlins over curved timber arch / trusses with insulation infilled timber boarded ceiling finish

**Wall Construction**

25mm straw reinforced clay / sand external render with silicate solution over 150mm single studs embedded within 270mm wide straw-clay blocks laid in clay / straw mortar 25mm lime / sand internal plaster, clay paint surface

**Floor Construction**

tiling / carpet on 100mm concrete slab with heating pipes embedded on dpc over bounded leca granules over bounded gravel

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**Contact Details:**

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Stockholm  
Sweden
Workshop / Store, Jarna, near Stockholm, Sweden

Exposed south facing gable elevation shows no signs of weathering despite lack of overhang protection from the verge.

**General History and Description of Project**

In a largely wooded former quarry, a group of parents set up, built and now run a Rudolf Steiner (Waldorf) school. The success of the school has led to the site being developed for other functions, and there is a more or less ongoing construction programme.

This required workshop space and decent dry storage, hence the construction of this building, on a central part of the site to service the work programme.

**General Description of Construction**

Unusually, the walls of the building are made of leca (expanded clay granules) and a clay slip rather than the more usual straw or woodchip. This is generally a more expensive option (certainly in the U.K.) unless a cheap source of leca can be found. However, there are no mould or decay issues since the entire mix is essentially inorganic.

The ceiling of the building also uses light earth. In this case straw clay is wrapped around a timber pole, forming a kebab like cylinder. Each of these elements is laid side by side to form the ceiling finish as shown (left). This is an example of the traditional German technique illustrated in Volhard’s book. This technique is suitable for a workshop but is likely to be considered unsuitable for domestic or commercial application since it is impractical to effectively ‘seal’ the strawclay and avoid dust from both clay and straw dropping.

**Particular Issues**

Unlike straw which holds itself together well within a wall, leca based light earth form in some ways is quite a vulnerable, unreinforced mass.

To overcome this, a greater percentage of clay is normally required for building and this results in a relatively thermally massive wall. However, this is not a problem for an unheated workshop building. Infact , two other buildings on the site are of more conventional solid earth construction, so this is actually better thermally than these in any case.
Roof / Ceiling Construction

Clay tiling
over breather paper
on 150x50 rafters
on purlins
on 200x75 braced timber trusses
resting on wall plate
infilled with straw-clay cylinders
wrapped around pole set within
runners fitted to truss members
"backfilled" with straw-clay mix
breather membrane over

Wall Construction

pigmented limewash over
100mm single, embedded studs centally
within 350mm leca-clay mix around
pigmented limewash internally.
on stone plinth wall and foundation
with lime mortar
without dpc

Floor Construction

approx. 150mm compressed
clay / lime / sand mix with linseed oil
to top layers
on free draining gravel
on hardcore layer

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Close up showing sizeable
timber garage door frame
fixed into stoework wall
base, rather than into Light
Earth mix.

Side view showing arched shuttered windows and traditional roof detailing of the area.
Garden House, 'Oase', Beuningen, The Netherlands

General History and Description of Project

'Oase' is a charity in Beuningen who own a large house and garden where people with learning difficulties, amongst others, are trained in horticulture and general gardening skills. The fruits of their labours are sold to support the charity’s work.

The extensive gardens require a good store room, and the charity also wanted a room or pavilion where people might reflect on nature and the garden around. In common with many charities, 'Oase' had almost no money, so the building was built over a four year period, whenever monies and effort were available.

General Description of Construction

A curved concrete trench foundation was laid and on this a brick plinth wall to 450mm above gl. On this is a centralised series of posts, tied top and bottom with cill and wall plates on each side.

The straw clay mix was installed using individually curved shutters, fixed back to posts located 'behind' the shutters since there were no other timbers in the surface of the wall. The straw-clay mix was made up in a specially designed and fabricated, adjustable, motorised drum which enabled much faster mixing with most labour dedicated to filling the wall and moving formwork.

The walls are plastered with a traditional mix of clay, lime, horse urine and animal fibres (horse and pig hair etc.) and appear to be in pristine condition, albeit after only a year or so.

Particular Issues

The curved shape, and the decision to create the walls in light earth, meant that individual shutters were created to the different curves of the walls in different places. This significantly added to the complexity - and hence timescale - of the works, however, the timing was improved by the invention and use of a motorised drum for mixing the straw-clay (see chapter 4).

The length of time of the construction is not a reflection on the use of Light Earth so much as on the complexity of the design and the financial limitations of the client.
Roof / Ceiling Construction
Planted roof over
synthetic bitumen based liner, over
polythene slip layer
on 25mm timber boards
on timber rafters,
forming both cantilevered overhang
and ceiling joists
clay paint finish

Upper Wall Construction
25mm animal hair reinforced clay /
lime / sand / urine
render with limewash over
100mm single, embedded studs
centrally within
300mm straw-clay mix around
25mm clay / sand / animal hair
internal plaster,
clay based internal emulsion finish.

Lower Wall Construction
300mm wide solid brick wall,
450mm high on dpc
on 300mm wide concrete trench
found

Floor Construction
brick and tile pieces laid in sand
on compressed earth
on free draining hardcore layer
“Culture House”, Heeze, near Eindhoven
The Netherlands

General View showing completed straw-clay work but no render or joinery

General History and Description of Project

The project was mooted by a local philanthropist as a place for local artists to both work, store materials and exhibit. Curiously sited in woodland near the town of Heeze, the building was left unfinished when the Client died in 1996.

General Description of Construction

Timber frame with timber, partially flat roof on a 450mm high brick plinth wall. A conventional concrete trench with earth floor slab with dpc.

The project is unusual in that it was constructed with a central framework which was ‘buried’ within the light earth mix, resulting in an unbroken light earth surface. This necessitated a separate framework both inside and out, with the shuttering fixed back to this. Whilst this involved more effort throughout the construction, it has the advantage of no bridging being required between exposed timber faces and light earth mix. A timber eaves ring beam was exposed for fixings internally.

Particular Issues

The project was started in 1994 and work, only carried out on a part time basis by two workers, was stopped in 1996 when the Client died. The walls are 350mm thick, reasonably thick for shuttered straw clay, with 25mm clay render to each side being proposed.

The project is of particular interest largely because we can thus witness the effects of weathering on a largely unfinished light earth envelope, even after 5 years.

It is instructive that the straw clay mix appears in pristine condition without sign of decay anywhere, despite the fact that the site is sheltered by surrounding spruce which mitigate against the drying out benefits of the wind, and the fact there is no heating to help dry out the structure during the winter.
Roof / Ceiling Construction
(as envisaged, not completed as drawn)
Planted roof over synthetic bitumen based liner, over polythene slip layer on 25mm timber boards on composite timber truss, with 20mm hemp / flax batt insulation within 200mm lower horizontal member, forming both cantilevered overhang and ceiling joists vapour check to underside internally, 15mm reinforced clay boards to ceiling with clay paint finish

Upper Wall Construction
25mm straw reinforced clay / sand render with limewash over 100mm single, embedded studs centrally within 350mm straw-clay mix around 25mm clay / sand / straw internal plaster, clay based internal emulsion finish.

Lower Wall Construction
350mm wide cavity brick wall, 450mm high with 150mm rigid full fill cavity insulation, all on dpc on 350mm wide concrete trench found, protrudes 150mm above gl

Floor Construction
25mm compressed clay, linseed and starch tiles onto compressed clay / sand mix on 100mm rigid insulation on dpc both turned up at perimeter on hardcore layer

Closer view, even after 5 years the straw-clay is in mint condition without evidence of mould, decay or shrinkage.
Private House, Raisio, near Turku, Finland

General History and Description of Project

This one family house was built in 1997 as part of a housing fair and is surrounded by similar style buildings in a cul-de-sac, though none of the others are constructed in Light Earth. The fair comprised a number of clusters of housing groups, each intended to display various methods of ecological construction. The quality of all houses is extremely high and the setting of the buildings skilfully within woodland and rocky outcrops adds greatly to the appeal of these houses which have all quickly sold.

General Description of Construction

Timber frame throughout at 600mm centres with straw-clay block infill (600mm length x 400mm depth x 130-150mm height) to all ground floor areas. The top floor walls are more conventionally insulated, mainly to reduce the overall weight of the construction and hence the foundations. For the same reason, while the ground floor is mostly rendered, the first floor is timber clad.

All internal surfaces are plastered with a mineral paint finished clay / sand / fibre plaster.

Particular Issues

This appears to be the only European example so far encountered outside Germany where straw-clay blocks have been manufactured as a more or less one-off commercial operation. The blocks for the church at Jarna were all hand made.

This is unusual because it is generally uneconomic to produce a batch of blocks of this size and consistency which cannot be extruded (without difficulty) and so must be compressed. This means a high ration of manual labour and preparation to machine work. Because of this, in areas where such blocks have not been made commercially, it is generally cheaper to make the Light Earth insitu. This was certainly the case in Scotland.

However, the block manufacturer in this case is a part time farmer who also runs what might be loosely called an agricultural building firm based largely on soil-concrete block and other miscellaneous fabrications. His overheads are very small and many of the issues facing commercial block and brick makers do not apply.
Walls:
Straw-clay Blocks
Density: 550 kg/cu.m

Floor:
Ceramic tiles and parquet floors.

Ceiling:
Board

Heating:
Wood fired central heating with electric backup.

Tests: by Timo Lehtonen manufacture of straw-clay blocks. Results not confirmed to date.

Monitoring: None

Insurance: Not known

Mortgage: Not known

Details unavailable

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Finland

Entrance of House under a covered lean-to which protects the lime rendered lower wall

Inset View, right, ‘Honesty Window’ showing straw clay block construction behind lime plaster

Construction View showing straw clay blocks between studs
**Private House, Rheinsberg, Land Brandenburg, Germany**

In the mid-1990s, the Mayor of Rheinsberg and his wife were considering building a new 4 bedroom family home. They contacted Naturhaus Rheinsberg to help them because they were keen to use more natural building materials and methods and earths in particular.

In addition, they wished to support a local company and the small town’s developing economy. The house was to be built using some self-build input, with the client employing the individual building trades direct.

### General Description of Construction

The structure was a site-assembled part-prefabricated timber frame using a system developed by the frame builders, Zehrer Holz und Fertighaus. The basic wall panel structural elements were assembled on-site with the roof finish in place within 7 days.

The timber frame sat on a substantial cast in-situ concrete foundation. Upper floor joists and roof rafters were fitted individually on-site. Such frames can be bought more-or-less off-the-peg throughout Germany, and insulated, clad and roofed in a range of materials and methods.

The light earth blocks were prefabricated by the client before any work began on site. This was to both reduce overall build costs, and to reduce the drying time - the light earth building work did not begin until mid/late summer, so shuttered light earth would have had little time to dry out).

The mix was a combination of wood chips with no bark content (which was a waste product from a local saw-mill) and sub-soil (an unwanted sand/silt spoil from a local brick/tile clay pit).

### Particular Issues

The house was cheaper than a conventionally-built house, which enabled the client to have a larger house of a higher specification than normal. No problems were encountered with Building Control as earth building principles were well understood by the local authority.
Roof / Ceiling Construction

Clay pantiles on counter-battens on battens on membrane over timber sarking boards on battens 225 x 75mm notched rafters to take internal 20mm timber facing boards infilled with 200mm sheep's wool.

Wall Construction

20mm clay / sand render with limewash over 50mm woodwool boards screwed to secondary frame of 150 x 50 timbers infilled with loose fill cellulose insulation bitumen impregnated softboard backing over light earth (woodchip / clay) blocks set in earth mortar within 160mm thick primary timber structure with 20mm clay / sand self colour plaster.

Ground Floor Construction

tiles / timber boards on sand / battens over dense, rigid insulation on concrete slab / trench raft

Woodchip-clay blocks made on site by the Client stacked and air drying.

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View showing primary frame construction underway with roof complete.
Craft Training Workshop, Hiddenhausen
Germany

Overall view from the South East showing the completely replaced lower walls, light earth, and untouched upper brick infill walls

General History and Description of Project

'Heimstatte Dunne' is a charity devoted to training and housing the long term unemployed through work, often building related, financed by the Government in lieu of unemployment benefit.

This particular project, unusual in being a refurbishment project, provided training for six men and created a Workshop space where mainly children are taught art, crafts and other traditional and rural skills.

General Description of Construction

The original construction was a substantial ‘half-timbered’ frame with brick or straw reinforced earth infill. The roof was tiled and floor of beaten earth within a stone plinth wall.

The roof and plinth wall were refurbished more or less as they had been, though the earth floor was replaced with an insulated concrete creed. Insulation was added to the roof.

Due to planning restrictions, previous refurbishment projects of a similar nature had involved placing bricks within the exposed frame on the external face, with light earth blocks fitted in behind to afford some insulative effect.

For the first time on this project, the Architect was allowed to replace the infill panels with light earth only, and increase the width of the wall internally to form a 350mm total wall depth entirely of shuttered woodchip-clay mix. The external face was rendered in lime / sand, and the internal finishes in a clay / sand plaster.

Particular Issues

The actual light earth work was started in October and continued in the following five months or so. This is the worst possible time to undertake the work, the mix has less chance to dry out due to the direct wetting of rain, high humidity and lack of sunshine.

The external face of the walls was covered in a reed matt but otherwise left without shelter to maximise the potential of the wind to dry the mix. By all accounts a risky solution, the mix dried out and has not been a problem.
Roof / Ceiling Construction

Clay pantiles on counter battens on battens over breather membrane. 100 x 50 secondary rafters infilled with cellulose insulation timber board internal finish.

Wall Construction

2 coat 20mm lime / sand render on reed mat over
310mm woodchip-clay light earth mix infilled between c. 160 x 120mm existing primary oak frame and 100 x 50 mm internal secondary framing.
2 coat 20mm clay / sand plaster over reed mat internally.

Floor Construction

20mm oak boards on battens on 75mm concrete screed over 100mm polystyrene insulation on existing rammed earth over existing small stones grading to large stones over between 400mm to 800mm all within existing stone / lime mortar plinth wall.

Walls:
Shuttered Woodchip-clay
Density: 800 kg/cu.m
(The Architect and Builder mentioned that this density - though inadequate in insulation terms, meant that the mix and the timber frame were of similar density and thus tended to move, due to thermal and moisture fluctuations at the same rate. This, they argued, increased the lifetime of the building considerably)

Floor:
n/a

Ceiling:
n/a

Heating:
Not known

Tests: None

Monitoring: None

Insurance: Conventional

Mortgage: Conventional

The Central internal space, formerly for threshing, where the training workshops are undertaken. The internal walls are thinner than the external ones but of the same light earth mix within oak frames.

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General History and Description of Project

The project was created by the Architect, a local social housing provider and the charity "Heimstatte Dunne" - a charity devoted to training and housing the long term unemployed through work through Government finance in lieu of unemployment benefit.

The project was to provide four apartments, two one-bedroom, one two-bedroom and one family sized, to take people on the waiting list. It was intended to provide an exemplar of social housing provision using only the most benign ecological materials, proving that they can be provided at the same price.

General Description of Construction

Sitting on standard concrete trench foundations, the construction is of wide timber external frame with standard structural 150mm square internal post partitions. The internal partitions are infilled with unbaked earth blocks while the outer frames infilled with a clay slip and woodchip mix, held in on both sides with reed matting.

The inside is clay plastered while the outside is covered in a bitumen based softboard. Battens provide a ventilated cavity and rough sawn timber boarding or mineral panels are used as a rainscreen. The timber boards are painted with blue paint based on wode, a plant used for dyes in medieval times but largely ignored now.

There is a suspended timber ground floor and a standard timber truss roof construction. The first floor is constructed using solid timber 'brettstapel' panels.

Particular Issues

The project was for social housing and required to be no more costly than the standard (relatively low) cost per square metre rate for such accommodation. In general terms, the slightly higher cost of the ecological materials was offset by incorporating self-build and training into the construction process and engaging 'Heimstatte Dunne' to project manage the training process.
**Roof / Ceiling Construction**

Clay pantiles on counter battens on battens over breather membrane. 150 x 50 trusses infilled with cellulose insulation above ceiling painted plasterboard internal finish.

**Wall Construction**

sawn boards or mineral panel over battens to form cavity, on softboard fixed back to studs over reed mat 'shuttering' over 300mm woodchip-clay light earth mix infilled between 100 x 50 mm separated ladder framing.

2 coat 20mm clay / sand plaster over reed mat internally.

**Floor Construction**

20mm pine boards on hardboard on 200x50 floor joists infilled with cellulose, softboard underside over ventilated air space wall supported on concrete block / rendered dwarf wall on concrete trench fill.

Showing the construction of the external walls. The builder is tamping down the woodchip-clay mix between the frame and reed mat 'permanent shuttering', before the mix is allowed to dry and then plastered.
Retail / Flats Refurbishment, Potsdam
Germany

Street Facade (South) with render sculpture 'exposing' the timber frame underlying what was a cement rendered facade, now replaced with clay

General History and Description of Project

The building was originally built around 1700 - 1720, as part of what was described as the second Baroque re-building under Freidrich Wilhelm 1st.

The refurbishment work took place between 1993 and 1994 following the re-unification of Germany and as part of the widespread investment in the old east.

General Description of Construction

The existing building - in common with most properties on the street - was constructed with rendered solid brick walls at ground floor, reverting to timber frame at first and attic floor levels, infilled with bricks.

The refurbishment took a 'conservation' approach, aiming to replace like with like wherever possible. Duepartly to age and unsympathetic past works, some of the timber and straw-earth infill (between floors only) had to be replaced. The bricks in the external walls above ground floor were replaced with shuttered light earth to improve the overall energy efficiency of the flats.

The light earth mix was of clay slip (from Glindow, near Potsdam), expanded slate (from Thuringia, near the Czech border) and straw from nearby villages for reinforcement. All walls, including the single skin brick ground floor walls had existing cement or lime plasters removed and were replastered with manually applied clay based plasters with final lime coats and casein and limewash finishes.

Particular Issues

Because the project took place largely over the winter months, in particular the light earth work, it was decided to mechanise the mixing, application and drying of the mix. A conventional screed mixing machine was used to mix the light earth mass and a conventional pump mechanism was used to raise and install the mix, through the internal formwork. There were problems with both machines because the earth was not completely free of small stones which caused some damage. An industrial scale drier was also employed to dry the mixture from inside.
Roof / Ceiling Construction
Replacement of existing tiles, battens, membrane over existing rafters partially infilled with 200mm cellulose insulation
Painted plasterboard ceiling finish

Wall Construction
5mm lime / sand render with limewash over 15mm clay plaster on 140 - 170mm light earth infill panels with existing timber frame 15 +5mm clay / sand internal plaster, casein paint surface.

(1st & 2nd)Floor Construction
timber boards on battens to make level, over existing joists infilled with straw-clay density approx. 1200 kg/cu.m
timber boards beneath, with reed mat and clay plaster ceiling finish with casein paint surfac

Walls:
Shuttered Expanded slate / straw-clay
Density: ___?? kg/cu.m

(1st and 2nd) Floors:
'strohlehm' (=straw-loam) but denser than straw-clay, at approx. 1200 - 1500 kg/cu.m

Ceiling:
as above

Heating:
Not known

Tests: None

Monitoring: None

Insurance: Conventional

Mortgage: Conventional

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View of the rear of the building.
Inset: View of the interior of the ground floor retail premises.
Family House, Liepe, near Eberswalde, Germany

Building Type: Family House
Address: Liepe, nr Eberswalde, Land Brandenburg, Germany
Client: Mr. & Mrs ??
Architect: Michael Nothelfer
Contractor: Largely self-build
Cost: Not known
Size: c. 250 sq.m (incl. terraces and garage)
Metre sq. rate: Not known

View from the East showing the ‘half timbered’ construction and light earth infill started on the lower ground floor only.

General History and Description of Project

The clients are a young couple who describe themselves as being not particularly well off. Despite this they wanted a large and ecologically benign house. To afford this they located the project in the relatively cheap rural east, close to the Polish border, and elected to do the majority of the work themselves.

General Description of Construction

The house is a three storey construction with quite a small floor plate. The lower ground floor is at ground level at the entrance but the house is built into a hillock such that the upper ground floor opens onto a terrace and to ground level at the top of the hillock.

The lower ground floor is partly insitu reinforced concrete where it is buried, and, in common with the rest of the construction where it is exposed, made from 160mm square native pine timbers in a largely traditional ‘half-timbered’ style. A clay pantile roof with large overhangs protects the upper walls.

The mass infill to the external walls is a mix of (mostly) cherry stones and washed cow manure in combination with clay slip. Unusually, this is fitted inbetween the main and secondary structure then extends beyond both to form an unbroken external face. The roundness of the stones and the small size of the manure fibres mean the mix is not held together as well as with straw. More clay needs therefore to be added reducing the efficiency of the mix as an insulant. However, this is not a significant problem.

This mix is also used in the internal walls, between large section square timbers with central battens fixed so as to prevent the mix being dislodged. It is also used as insulation and deadening in the intermediate floors and, with sheeps wool, also in the roof.

Particular Issues

Light earth - particularly the unique combination of cherry stones and cow manure - suited the client well since the material costs were extremely small whilst the increased labour costs were met by themselves.
Roof / Ceiling Construction

Clay pantiles on counter-battens on battens on membrane on timber sarking boards on battens on membrane 225 x 75mm notched rafters to take internal 20mm timber facing boards infilled with approx 50mm light earth mix and 150mm sheep's wool

Walls:
Shuttered Cherry stone / washed cow manure / clay
Density: c.450 kg/cu.m

Floor:
Same mix as above poured in between 250mm joists and timber boards above and below

Ceiling:
As above, also 150mm sheep's wool in bags

Heating:
Single wood stove with back burner feeding hot water pipes running at low level behind timber foils, gaps above and below to form basic convective heating system also hollow blocks above pipe to form hypocaust system in certain wall areas.

Tests: None
Monitoring: None
Insurance: Not known
Mortgage: Not known

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Ground Floor Construction

Bricks on edge on
150mm dry beaten earth on membrane on 250mm gravel / small stones on 250mm large stones / hardcore

View of the entrance showing the garage and entrance hall 'extension'
Holiday / Weekend House, Geltow, nr Potsdam
Germany

General History and Description of Project

The project was built to act as a weekend retreat and holiday base for two families (including the Depta family, Jorg Depta being the founder of ‘Lehmbauwerk’) who are all friends so it was largely self built on a communal basis.

General Description of Construction

The walls of the project are located on brick plinth walls with an angled top outer course acting as a drip to the render.

The walls are formed with two 100 x 50mm studs held apart to form a wall 250mm wide. This was infilled with woodchip-clay between plywood formwork. The formwork was removed to allow the mix to dry. Externally, 50mm red mats were fixed to the studs and a clay based render sprayed onto the mats (see image, left) with the top coat trowelled smooth, except part of the north and west facades which are most exposed to the rain and were timber clad. Internally, the plaster was applied direct to the mix and exposed studs.

A heavyweight planted roof with solar water panels rests directly onto the walls with some central posts. The floor is of oiled bricks onto 100mm rammed earth on 100mm of gravel over 300mm of limestone pebbles with no (need for) dampproof course or separate insulation.

Particular Issues

The project is unusual in being built with relatively small sections (100 x 50mm) of timber by German standards, but akin to elsewhere in the world.

Since building this project with woodchip, Lehmbauwerk have subsequently only used expanded glass reinforced with straw (see examples 7.1.16) maintaining that it is the only way to be confident of consistent quality. Depta notes that woodchip is fine for self build groups as long as there is someone on site with experience to ensure correct construction and drying etc.

With expanded glass (i.e. non-organic material) there is less risk of any problems with decay.
**Roof / Ceiling Construction**

Planted layer build-up over waterproof membrane on slip layer on timber sarking boards on ventilated space over rafters with breathable membrane over, infilled with 250mm cellulose insulation and painted clayboard ceiling finish.

**Wall Construction**

25mm sprayed clay / sand / unwashed cow manure / casein render over 25mm reed mat fixed back to 100mm double studs (painted with clay paint to increase adhesion) forming a 250mm woodchip-clay mix outside there is a 50mm red mat, 25mm of same mix plaster, clay based emulsion surface.

**Floor Construction**

72mm brick-on edge with a 'Danish' oil finish over 50mm rammed earth over 18mm plaster and 100mm expanded clay over 300mm limestone pebbles.

View of the Shower room, showing the rammed earth partition wall, coated with two coats of sprayed and sponged linseed oil to make it completely water resistant. The use of otherwise moisture porous finishes such as the clay based plaster reduces the condensation on windows and the risk of surface mould.

Internal view looking past the 'kakelofen' to the conservatory.

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**Shared / Serviced Housing, Berlin - Spandau**

Germany

In what would appear to be an arrangement unfamiliar to the UK situation, a private individual bought the land and has financed the building which is designed to separately house 3 elderly couples (1 floor each) with help and support on hand should it be required. The couples share a kitchen and will apparently eat together in general.

The flats are rented to the couples with the additional cost of the support built in to the rent. The developer has a particular interest in ‘healthy’ and ‘therapeutic’ spaces, hence the natural building approach.

**General Description of Construction**

The building is three storey, timber framed with clay based finishes throughout the interior. Details are as shown below. The light earth is discontinuous through the three floors to avoid excessive shrinkage.

**Particular Issues**

It is fairly unusual to see light earth exposed at external corners because of light earth’s relative lack of strength and stability. Unlike the other examples shown, this project is unique in the use of reinforcing mesh at such corners. The detail is less of a risk when the mix is mostly of straw, since this has a capacity for ‘self’ reinforcement, as is the case at the Culture House near Eindhoven (7.1.7) and near Auckland in New Zealand (7.1.9).

The mix at the workshop at Jarna in Sweden (7.1.5) uses expanded clay balls only with unreinforced corners. The mix needed to be clay-rich and heavy to make up for this. Here, the mix is similar - expanded glass balls - though with the addition of some straw. Whilst the workshop at Jarna would appear to be the most at risk of damage, it was also built by, and for, an intentional community of adults and children and is not a commercial or public property. This building, on the other hand, is being built by a private developer with standard contractual arrangements. As a sub-contractor with ultimate responsibility for the durability of the light earth mix, Lehmhauswerk sensibly opted for the ‘belt and braces’ approach in this instance.
Roof / Ceiling Construction

Tiles on battens on counter-battens on breather membrane over rafters infilled with cellulose insulation vapour check and timber boarding to inside face

Wall Construction

25mm lime / sand render to face externally over 350mm light earth (expanded glass / straw / clay) infilled between approx 160 x 180mm central solid timber frame with 25 x 38mm outriggers held off main timbers by packers / spacers 25mm clay / sand plaster to internal face with lime and casein added to top coat

Floor Construction

10mm quarry tiling on cement screed on 75mm rigid insulation on compacted expanded glass 'gravel' over 300mm hardcore
Private House, Dairy Flat, near Auckland, New Zealand

Building half complete showing wide overhang / verandah on two sides

General History and Description of Project

The project was a fairly standard, if ‘ecological’ residence for a private client, in the rapidly developing area north of Auckland. The majority of the building is of insulated standard timber frame, but the ‘annex’ shown above was to be made with Light Earth.

The client was keen to try the technique whilst the architect, though sympathetic to the aims of the technique, was not familiar with it and so handed the design and construction of the walls only over to a specialist design/build contractor.

In this way the floor, main structure and roof was ready and complete when Earthforms, the Light Earth Contractor took possession of the site.

General Description of Construction

6 x 8m timber frame annex to a much larger L-shaped house forms the easternmost end and is roofed with a corrugated steel hipped roof with a 2m verandah to south and east. The (sunny) northern facade has only a 500mm overhang to benefit from solar gain. The floor is a solid concrete slab with a bitumen coat as adpc under the straw-clay walls.

The frame is single 100 x 50mm softwood studwork at 600mm centres. The straw-clay mix was installed within formwork attached to both secondary studwork and temporary outer studs, reoved at the end of the construction period.

Particular Issues

The main problem experienced by Earthforms was that, by trying to ‘fit in’ with the standard, single stud frame construction, construction time was extended through the need to build secondary framing around doors and windows, and also to construct an outer frame to which to attach the formwork.

The delays in construction time had a knock on effect on the wider construction project in that areas of Light Earth required to be finished before the building could be made weathertight and so ready for heating and second fixing of services etc were late, causing minor delays overall. The client however was extremely happy with the result.
**Roof / Ceiling Construction**

Enamelled corrugated steel roofing sheets on timber trusses, with ventilated attic space, plasterboarded ceiling to undersides of trusses, with 150mm commercially available sheeps wool on a vapour check behind plasterboard.

**Wall Construction**

25mm lime / sand render with limewash over 100mm single, embedded studs centrally within 300mm straw-clay mix around 25mm lime / sand internal plaster, plant based emulsion surface.

**Floor Construction**

10mm quarry tiling onto screeded 250mm concrete slab on hardcore etc.
Private House, Pungaere, nr Kaikohe, Northland
New Zealand

External view showing roof overhangs and completed joinery and lime render

**General History and Description of Project**

The architect produced a set of drawings to what would be somewhat akin to Building Regulation standards in the UK. These were then taken by the client - a joiner by trade - and developed in detail through the process of construction.

The Light Earth element of the work was also developed by the client as the architect was not familiar with the technique and produced fairly sketchy references to it in the drawings. Building Control is less stringent in New Zealand than in the UK.

Having no straw on or near the site, but wishing to remove some softwood trees on his land, the client opted to chip the wood and use woodchip-clay in lieu of straw. This was reasoned to be both the pragmatic solution and perhaps ‘greener’ than importing straw from what could have been some considerable distance. At the time, this was the only example in New Zealand of the use of woodchip.

**General Description of Construction**

A fairly complex multi-cellular plan in the form of two ‘wings’ on plan, and of several curved roof sections in elevation which step up to a two storey section in the centre.

The structure is timber frame throughout, using double studs to form 300mm wide external walls, formed insitu. The whole is on a conventional concrete slab floor with a curved corrugated steel roof.

The Light Earth mix was varied from front to back of the building to reflect the different thermal insulation / thermal mass requirements of each. The external walls are lime finished externally with a clay and sand plaster internally.

**Particular Issues**

Having opted for woodchip, the main advantage over straw which became immediately apparent was how much faster was the construction time since all the mixes could be made up in a conventional concrete mixer, so eliminating the need for either a special machine, or the considerable hours of manual mixing required for straw-clay.
Roof / Ceiling Construction

Enamelled corrugated steel roofing sheets on purlins to form a curve, with 150mm commercially available sheep's wool on a vapour check between curved laminated battens to form curve, and timber boards in line with the purlins to express the curve internally.

Wall Construction

25mm lime / sand render with limewash over 100mm double studs forming a 300mm woodchip-clay mix. 25mm clay / sand internal plaster, plant based emulsion surface.

Floor Construction

10mm quarry tiling or timber boards on battens, onto screeded 250mm concrete slab on hardcore etc.
8 Resource Guide

The purpose of this chapter is to provide the reader with all relevant resources for their own further investigation of the subject. The body of this text is ongoing and will be updated and expanded throughout the project.

8.1.1 Laporte, Robert 
Mooseprints, A Holistic Home Building Guide
Robert Laporte, New Mexico 1993

8.1.2 Volhard, Franz
Leichtlehm e Alter Baustoff - neue Technik
(Light Earth Building - Old Building Material - New Technique)
(In German)

8.1.3 Westermarck, Mikael
Lyonnormukaiset Rakennusaineet. Teknillinen Korkeakoulu
Rakennustieto Oy, Helsinki 1998
(With Eija-Reetta Heuru, Prof. Bengt Lundsten)

8.1.4 Berge, Bjorn
(The Ecology of Building Materials)
(pp.289 - 290)

8.1.5 Elizabeth & Adams
Lyne & Cassandra Natural
Alternative Construction Contemporary Building Methods
John Wiley & Sons, New York 2000
(pp.195-208, 297-308)

8.1.6 Fauth, Wilhelm
Der Praktische Lehmbau
(The Practice of Earth Building)
Wiesbaden 1946

8.1.7 Houben & Guillaud, Hugo & Hubert
Earth Construction, A Comprehensive Guide
(pp. 186 - 187, also 146 - 160)

8.1.8 Lindberg, Eva-Rut
Gjort av Jord (Made of Earth)
Royal Institute of Technology, Sch. of Architecture
Stockholm, 2002
(pp. 59 - 77, also App 2, pp.29-44)

8.1.9 Little & Morton, Becky & Tom
Building with Earth in Scotland
Innovative Design and Sustainability
Scottish Executive Central Research Unit
Edinburgh 2001
(pp. 17 - 18, 24, 31 - 32)

8.1.10 Minke, Gernot
Earth Construction Handbook
Building Material Earth in Modern Construction
WIT Press, Southampton UK 2000
(pp. 53 - 55)

8.1.11 Steen, Steen & Bainbridge, Athena, Bill & David
The Straw Bale House
Chelsea Green Publishing Company, Vermont
1994 (pp.118 - 119)
8.1.12 Stulz, Roland  
**Appropriate Building Materials**  
A Catalogue of Potential Solutions  
SKAT Swiss Centre for Appropriate Technology and Intermediate Technology  
Publications, St Gallen Switzerland 1983

8.2. Periodical Articles

8.2.1 Arundel, Anthony  
**Indirect Health Effects of Relative Humidity in Indoor Environments**  

8.2.2 Chappell, Steve  
**Timber Frame Enclosure Options**  
Joiners’ Quarterly NO.38 USA

8.2.3 Fanger, Ole  
**Hidden Oils in Sick Buildings**  
ASHRAE Journal, No. 1988

8.2.4 Fauth, Wilhelm  
**Der Strohlehmstanderbau**  
Bauwirtschaftlicher Siedlerlehrdienst H. 3, Eberswalde Berlin 1933

8.3. Other Published / Unpublished

8.3.1 Arbeitsgemeinschaft Jaklin - Depta  
**Entwicklung raumhoher, lastabtragender Aussenwand-Lehmbaufertigsteile**  
Promotional Pamphlet describing pre-fabricated LE panel. Available from Jorg Depta tel: 00 49 30 7901 6459

8.3.2 Dachverband Lehm  
**Lehmbau Regeln**  
(Earth Building Rules)  
Vieweg & Sohn, Wiesbaden 1999

8.3.3 Dancey, Chris  
**Commercial Hemp and Clay Infill for Timber Frame Buildings**  
Unpublished informal paper, Canada 2000

8.3.4 Dachverband Lehm  
**Lehm 2000 (Earth 2000)**  
Proceedings of Conference on Earth Construction held 17-19 Nov. 2000 in Berlin  
Overall Verlag, Berlin 2000

8.3.5 DETR  
**Building a Better Quality of Life**  
A Strategy for more Sustainable Construction  
DETR, London April 2000

8.3.6 Grandjean, E  
**Fitting the Task to the Man**  
An ergonomic approach  
Taylor & Francis Ltd, London 1982  
Particularly Chapter 17.

8.3.7 Lehtonen, Timo  
**Luonnonmukaisuutta Parhaimmillaan - Talo Savesta!**  
Published Pamphlet describing the Demonstration LEC House at Raisio, by the Manufacturer of the LE Blocks

8.3.8 Westermarck, M  
**The Manufacture and Use of Nature-Based Building Materials as a Secondary Livelihood for Farmers**  
1st English Resume  
The Unit for Nature-Based Construction, Helsinki University of Technology,
8.3.9  Westermarck, M  Part 4: A Partial Study of Light Clay Blocks  (Being Part 4 of Initial Research for 'The Manufacture and Use of Nature-Based Building Materials as a Secondary Livelihood for Farmers' - As above. Unpublished, available from author informally in English, otherwise only available in Finnish, see 8.1.3 above)


8.4.  Websites

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www.earthship.org  U.S organisation
www.hut.fi/ Units/LRT/UCPB.htm  Finnish research
www.uni-kassel.de/fb12/fachgebiete/feb  German Uni. research
www.dachverband-lehm.de  German organisation
www.aecb.net  UK ecological organisation
www.dab.uts.edu.au/EBI/links.html  Australian organisation
www.craterre.archi.fr/homepage.html  French organisation
www.moderner-lehmbau.de/index.html  German organisation
www.baubiologie-regional.de/lehmbau/  German organisation
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  e: 

8.5.3.3 Detlef Kaluza
Takou Bay Road
RD2 Kerikeri
North Island
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  tel: 00 64 9 407 4080
  fax: wintec@xtra.co.nz
  e: 

8.5.3.4 Danny Buck
2817 Calle Princesa Juana
Sante Fe
New Mexico 87505
USA

  tel: 
  fax: fiodanbuck@roadrunner.com
  e: 

8.5.3.5 Robert Laporte
New Mexico

  tel: 00 1 505 471 5314
  e: margaretbla@earthlink.net
8.5.4 **UK Technical / Financial Approval**

**Building Control Issues**

8.5.4.1 **John Hollely**  
44 St. James  
Beaminster  
Dorset DT8 3PW  
tel: 01308 488 656  
fax: 01308 488 163  
e: jon@approvedinspector.com

8.5.4.2 **Dirk Bouwens**  
EARTHA secretary  
Ivy Green  
London Road  
Wymondham  
Norfolk  
NR18 9JD  
tel: 01953 601 701  
e: dirkbouwens@aol.com

8.5.4.3 **Allied Lorne Brown**  
Robert Still  
Station Gate  
Melrose  
TD6 9PS  
tel: 01896 822 556  
fax: 01896 823 124  
e: melrose@alliedsurveyors.com

8.5.4.4 **Ecology Building Society**  
Paul Ellis  
18 Station Road  
Cross Hills  
Keighley  
West Yorkshire  
BD20 5BR  
tel: 01535 635 933  
fax: 01535 636 166  
e: info@ecology.co.uk

8.5.4.5 **Triodos Bank**  
Sue Cooper  
Brunel House  
11, The Promenade  
Bristol  
BS8 3NN  
tel: 0117 973 9339  
fax: 0117 973 9303  
e: mail@triodos.co.uk

8.5.4.6 **Building LifePlans Ltd.**  
(HAPM Ltd. no longer takes on new business)  
Peter Mayer  
International House  
26 Creechurch Lane  
London  
EC2A 5BA  
tel: 0207 240 8070  
fax: 0207 836 4306  
e: p.mayer@bpg-uk.com

8.5.4.7 **Ainley’s Insurance Brokers**  
Geoff Otty  
2 Acre Street  
Lindley  
Huddersfield  
West Yorkshire  
HD3 3DU  
tel: 01484 425 711  
fax: 01484 451 208  
e: ainleys@quista.net

8.5.4.8 **Edinburgh Risk Management**  
John Sharp  
Heritage House  
43 Northumberland Street  
Edinburgh  
EH3 6JQ  
tel: 0131 556 2535  
fax: 0131 556 7020  
e: erm@edrisk.co.uk

8.5.5.8 **Country Heritage Insurance Agency**  
Roger Chunnoo  
Heritage House  
15 Colchester Road  
Bures Hamlet  
Suffolk CO8 5AE  
tel: 01787 229 121  
e: info@country-heritage.co.uk

8.5.5.8 **Architects’ PI Insurance**

8.5.4.8 **RIAS Insurance Services**  
Gordon Moir  
Orchard Brae House  
30 Queensferry Road  
Edinburgh  
EH2 2HS  
tel: 0131 311 4292  
fax: 0131 311 4280
8.5.5  UK Product Manufacturers / Importers

8.5.5.1  Construction Resources
16 Great Guildford Street
London SE1 0HS

tel: 0207 450 2211
fax: 0207 450 2212
e: info@ecoconstruct.com

8.5.5.2  Natural Building Technologies
Cholsey Grange
Ibstone
High Wycombe
HP14 3XT

tel: 01491 638 911
fax: 01491 638 630

8.5.5.3  C. Olley & Sons (Cork Importers / Product Manufacturers)
Iberia House
Finchley Avenue
Mildenhall
Suffolk IP28 7BJ

tel: 01638 712 076
fax: 01638 717 304

8.5.5.4  Fibo Exclay UK Ltd. (Expanded Clay Granule Importers)
Focal House
18 - 19 Berth
Port of Tilbury
Essex RM18 7HL

tel: 01375 840 396
fax: 01375 840 397

8.5.5.5  Silvaperl. (Expanded Clay Granule, Perlite and Vermiculite Suppliers)
Albion Works
Ropery Road
Gainsborough
Lincolnshire DN21 2QB

tel: 01427 610 160
fax: 01427 811 838
e: silvaperl@william-sinclair.co.uk

8.5.5.6  Errol Bricks (Unbaked earth bricks and other earth materials)
Errol Brick Company Ltd
Inchcoonans Brickworks
Tayside

tel: 01821 642 653
fax: 01821 642 427
e: andrew@errolbrick.co.uk

8.6.  Organisations

8.6.1  UK Organisations

8.6.1.1  Centre for Earthen Architecture
University of Plymouth
Hoe Centre
Notte Street
Plymouth
Devon PL1 2AR

tel: 01752 233 600
fax: 01752 233 634

8.6.1.2  School of Civil and Structural Engineering
University of Plymouth
Palace Court
Palace Street
Plymouth
Devon PL1 2DE

tel: 01752 233 664
fax: 01752 233 658

8.6.1.3  Scottish Lime Centre Trust
The School House
Rocks Road
Charleston
Fife KY11 3EN

tel: 01383 872 722
fax: 01383 872 744
email info@scotlime.org

8.6.1.4  Association of Environment Conscious Building (AECB)
Nant-y-Garreg
Saron
Llandysul
Carmarthenshire
SA44 5EJ

tel: 01559 370 908
email: admin@aecb.net

8.6.1.5  Building Research Establishment (BRE)
Garston
Watford
Hertfordshire
WD2 7JR

tel: 01923 664 000
web: www.bre.co.uk
8.6.2 Worldwide Organisations

8.6.2.1 Straw Bale Construction Association
P.O. Box 149
227 Otero Street
Santa Fe
New Mexico
USA 87504

tel: 00 1 505 982 9521

8.6.2.2 State of New Mexico, Construction Industries Division
(Clay Straw Guidelines)
725 St. Michael’s Drive
P.O. Box 25101
Santa Fe
New Mexico 87504

8.6.2.3 Forschungslabor fur Experimentelles Bauen (FEB) ((Building Research Institute))
University of Kassel
Am Wasserturm 17
Kassel
D-34128
Germany

tel: 00 49 561 883 050
fax: 00 49 561 988 21 08
e: feb@architektur.uni-kassel.de

8.6.2.4 CRATerre - EAG
Maison Levrat - BP53
Villefontaine
38092
France

tel: 00 33 474 95 43 91
fax: 00 33 474 95 64 21
e: craterre@club-internet.fr
9 Appendices

Some of what is written in the following appendices has been incorporated into the main body of text at the appropriate point and reference made accordingly. What follows are the verbatim reports as supplied by the various partners and contractors to the project, and others, with paragraph numeration added for the purposes of consistency.

9.1 Experimental Clay / Woodchip Blocks – Initial Test Results
Written by Rebecca Little

9.2 Thermal Properties of Clay-Straw and Clay-Woodchip Samples Supplied by Gaia Architects as Part of DTI Funded Research
Written by Dr. Stephen Goodhew, University of Plymouth School of Civiel and Structural Engineering

9.3 Indicative Fire Resistance Test Results
Written by Chiltern International Fire Consultants

9.4 State of New Mexico Construction Industries Division Clay Straw Guidelines
Written by the State of New Mexico Construction Industries Division

9.5 Durability Classes and Insured Lives for Light Earth Construction
Written by Building LifePlans
9.1 Experimental Clay / Woodchip Blocks – Initial Test Results

9.1.1 Test Objectives

9.1.1.1 To establish a working methodology for the production of hand-formed earth / woodchip blocks to be used in the external walls of a demonstration building at Littlecroft, Melrose and for testing as part of Gaia Architect’s DETR [DTI] funded research.

9.1.2 Block requirements

9.1.2.1 Low density material to provide adequate thermal resistance. Strength and durability during handling and construction.

9.1.3 Precedents

9.1.3.1 There are many examples of this type of construction in northern Europe. Particular reference was made to experiments being carried out in Germany with regards to moulding techniques and mixes.

9.1.4 Outline of the Test Procedure

9.1.4.1 During May 2001 a series of test blocks were produced at Errol Brickworks using clay sub-soil, sourced from the Carse of Gowrie, and coarse green woodchips (mainly Larch, Douglas Fir and Scots Pine in origin). These materials were combined, with a small amount of water, in a vertical shaft, electric clay mill. The amount of water needed to obtain a good mix varied according to the moisture level in the clay soil and the relative proportions of clay and chips in each mix.

9.1.4.2 The clay / woodchip mix was formed into blocks using simple wooden box moulds set on pallets. The material was dropped into wetted moulds and lightly compressed using a hand held wooden tamper and/or the feet. A "good mix" meant the material could be easily compressed and released from the mould without damage to the block. A poor mix tended to stick to the mould (too dry) or resulted in a block which slumped once the mould was removed (too wet). Once the moulds were filled and compressed to the required level they could be removed vertically to leave the blocks on the pallet. The blocks were then left to dry in a covered shed over a period of days and weeks until they were firm enough to be stacked on edge. Although the blocks were stored under cover the drying time varied according to the weather conditions outside.

9.1.4.3 The weights and densities of the test blocks were recorded during June 2001 and November 2001 while they were still being stored in an unheated space. It is assumed that the blocks will dry out further if they are introduced to a warm, dry environment and, as a result, there will be a further reduction in their bulk densities.

9.1.5 Interpretation of the Results
9.1.6.1 The tests described above proved extremely useful in establishing an efficient working methodology for the small-scale production of earth / woodchip blocks. The additional information on block types and densities may also give some indication about the thermal performance of different test blocks. However, the blocks were not produced under controlled conditions and some caution should be taken when interpreting the test results. For instance, no effort was made to measure the amount of compression or the total material used to form each block and these factors will largely determine the density of the dry material. Despite these limitations these initial block tests could inform more thorough and controlled testing of block types and mixes. They also raise relevant questions to be addressed with further research.

9.1.6 Summary of the Test Results

9.1.6.1 The following observations refer to working practice, measurements and weights of semi-dry blocks from May to November 2001. Further records should be taken when the blocks have completed drying in a heated environment.

9.1.6.2 It has been assumed that lighter blocks could be produced by higher woodchip to clay ratios in the block mixes. In general this does appear to be the case for the blocks tested, but the difference in densities between different mixes is small and inconsistent at this stage in the drying process. It is likely that moisture has yet to be released from the green woodchips and this type of drying may reduce block densities at a later date.

9.1.6.3 A clay to woodchip ratio of 1 to 10 appears to be the outer limit for workability but the blocks were not strong enough to remain intact during transport. A ratio of 1 to 6 was chosen for the bulk block production. These blocks are easily formed, reasonably durable and are comparable with blocks produced in Germany.

9.1.6.4 The most significant factor affecting bulk density appears to be the size of block produced, suggesting that compression has varied according to the dimensions of the mould in use. In general the medium sized moulds produced denser blocks but these differences are becoming less apparent as the blocks continue to dry out. The choice of mould size for the bulk block production was determined by speed of production, drying time, ease of handling and wall dimensions of the finished building.

9.1.6.5 The brown clay soil used in a small number of the blocks appears to produce lighter, quicker drying blocks. This type of clay soil has a lower clay content than the red variety but this does not seem to affect the strength of the dry block. It was not available in large amounts at the time of testing but merits further research.
### Test Block Information

<table>
<thead>
<tr>
<th>BLOCK NO</th>
<th>BLOCK SIZE</th>
<th>CLAY TYPE</th>
<th>MIX: PARTS CLAY TO WOODCHIP</th>
<th>BULK DENSITY in kg/m³</th>
<th>1Jun '01</th>
<th>1Nov '01</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>small</td>
<td>red</td>
<td>1 to 3</td>
<td>593</td>
<td>543</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>small</td>
<td>red</td>
<td>1 to 8</td>
<td>740</td>
<td>519</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>small</td>
<td>brown</td>
<td>1 to 8</td>
<td>444</td>
<td>444</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>small</td>
<td>brown</td>
<td>1 to 10</td>
<td>444</td>
<td>407</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>medium</td>
<td>red</td>
<td>1 to 5</td>
<td>1209</td>
<td></td>
<td>752</td>
</tr>
<tr>
<td>6</td>
<td>medium</td>
<td>red</td>
<td>1 to 6</td>
<td>1154</td>
<td></td>
<td>727</td>
</tr>
<tr>
<td>7</td>
<td>medium</td>
<td>red</td>
<td>1 to 7</td>
<td>1180</td>
<td></td>
<td>729</td>
</tr>
<tr>
<td>8</td>
<td>large</td>
<td>red</td>
<td>1 to 4</td>
<td>924</td>
<td></td>
<td>628</td>
</tr>
<tr>
<td>9</td>
<td>large</td>
<td>red</td>
<td>1 to 5</td>
<td>684</td>
<td></td>
<td>644</td>
</tr>
<tr>
<td>10</td>
<td>large</td>
<td>red</td>
<td>1 to 6</td>
<td>739</td>
<td></td>
<td>739</td>
</tr>
<tr>
<td>11</td>
<td>large</td>
<td>red</td>
<td>1 to 7</td>
<td>702</td>
<td></td>
<td>665</td>
</tr>
<tr>
<td>12</td>
<td>large</td>
<td>brown</td>
<td>1 to 6</td>
<td>775</td>
<td></td>
<td>683</td>
</tr>
<tr>
<td>13</td>
<td>large</td>
<td>brown</td>
<td>1 to 8</td>
<td>554</td>
<td></td>
<td>517</td>
</tr>
</tbody>
</table>

**BLOCK SIZES/DIMENSIONS IN m (height x length x width)**

- small: 0.15 x 0.225 x 0.3
- medium: 0.15 x 0.3 x 0.3
- large: 0.210 x 0.44 x 0.3

Rebecca Little
9.2 Thermal Properties of Clay-Straw and Clay-Woodchip Samples Supplied by Gaia Architects as Part of DTI Funded Research July 2002

9.2.1 Contents

9.2.2 Introduction

9.2.2.1 The University of Plymouth’s School of Civil and Structural Engineering was commissioned to carry out a series of thermal measurements upon a range of sample building materials supplied by Gaia Architects.

9.2.2.2 This initial report of preliminary results has been undertaken to allow Gaia Architects an indication of the thermal properties of the samples supplied. However, a more representative series of results will be forthcoming shortly and in this light the results contained in this initial preliminary report should only used as a guide.

9.2.2.3 The samples were of two materials, clay straw, (a mixture of wheat-straw and clay) and clay wood-chip, (a mixture of chips of softwood, with chips varying in size from approximately 50mm x 20mm x 30mm to 20mm x 10mm x 10mm and clay).

9.2.2.4 These materials were supplied in two sample sizes depending upon the thermal measurement that was undertaken. 150mm cubes of material were supplied to establish thermal conductivity and thermal capacity measurements. 50mm cubes of material were used to separately establish a thermal capacity measurement to allow corroboration of the results from the other technique.

9.2.3 Methodology

9.2.3.1 As described in the introduction, two separate thermal measurements were undertaken upon the samples supplied.

9.2.3.2 The first series of measurements used a transient probe technique developed at the University of Plymouth, based upon a probe originally developed at the University of Cranfield. This technique involves the insertion of a needle-like probe, with a heater and heat sensor running down the centre of the inside of the probe. From an analysis of the power supplied to the heater and the temperature rise over time, the thermal conductivity and thermal capacity of the samples may
be calculated. The 150mm cubed samples were measured using this technique.

9.2.3.3
A second series of measurements were undertaken using a method of mixtures to establish the thermal capacity of the 50mm samples. In this process, samples are heated to a high temperature over a 24hr period and rapidly transferred to a known quantity of liquid at a known temperature held within a heavily insulated container.

9.2.3.4
To ascertain the thermal properties of the samples with any degree of certainty a density value was required for each sample. Some difficulties were encountered as some samples were very uneven in size and others were fragile. Further problems were encountered, as some samples were denser than others were and so average values were used to even out any variations. However, the materials are of their very nature, quite variable in composition so this form of variation will have to be contended with, no matter how well the samples are prepared.

9.2.4
Results of the Density Measurements

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Density kg/ cu.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4</td>
<td>145</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4</td>
<td>450</td>
</tr>
</tbody>
</table>

Table 1. Density Measurements of Clay-Straw and Clay-Woodchip Samples.

9.2.5
Results of the Thermal Probe Measurements

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Thermal Conductivity W/mK</th>
<th>Average Thermal Capacity J/kgK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4 x 150mm cubes</td>
<td>0.07</td>
<td>Inconclusive at Present</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4 x 150mm cubes</td>
<td>0.15</td>
<td>1500</td>
</tr>
</tbody>
</table>

Table 2. Thermal Probe Measurements of Clay-Straw and Clay-Woodchip Samples.

9.2.6
Results of the Method of Mixtures Measurements

<table>
<thead>
<tr>
<th>Material</th>
<th>No. of Samples</th>
<th>Average Thermal Capacity J/kgK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay-Straw</td>
<td>4 x 50mm cubes</td>
<td>1000</td>
</tr>
<tr>
<td>Clay-Woodchip</td>
<td>4 x 50mm cubes</td>
<td>1500</td>
</tr>
</tbody>
</table>

Table 3. Thermal Capacity Measurements of Clay-Straw and Clay-Woodchip Samples.

9.2.7
Comparison of Results with Published Data

9.2.7.1
The main source of thermal information pertaining to earth and earth derived
building products is Gernot Minke’s Earth Building Handbook (Resources 8.1.9, pp 55-58). The following graph shows the thermal conductivity and density values of some samples measured by Minke compared with the Gaia samples. It can clearly be seen that there is a correlation between the density of the sample and the thermal conductivity of the samples (as was predicted by Minke). The best-fit line has been included to illustrate this correlation.

![Thermal Conductivity Values against Density Measurements of Gaia Clay-Straw and Clay-Woodchip Samples.](image)

Figure 1. Thermal Conductivity Values against Density Measurements of Gaia Clay-Straw and Clay-Woodchip Samples.

9.2.8 Discussion

9.2.8.1 The samples of the two building materials that have been provided for the University to measure their thermal properties, are both quite novel in nature.

9.2.8.2 The samples are produced from natural materials using an in situ process that tends to introduce variances in the structure and composition of the finished product. The samples provided are, by their nature, smaller than the in situ material and therefore can be produced and compacted in a different way possibly leading to discrepancies between the finished wall and provided samples. This has to be borne in mind when the reader attempts to relate any of the thermal measurements contained in this report to any built structures of similar materials.

9.2.8.3 Because of this possible discrepancy, the author has provided a graph, see figure 1, to allow the estimation of the thermal conductivity of a similar earth/plant based building material if the enquirer has knowledge of the 'as built' density. (The obvious proviso is that the composition of the earth and plant material matrix does not stray far from those in common use at the present time, as it is felt that this may directly influence the previously stated relationship.).

Dr. Steve Goodhew
9.3 Chiltern Fire Report

9.3.1 Indicative Fire Resistance Test - Chilt F02048 (Straw-Clay Samples)

9.3.1.1 This letter is to confirm the results of an indicative fire resistance test performed, to the temperature and pressure conditions outlined in BS 476: Part 20: 1987 on behalf of your company under the above reference on the 25 July 2002.

Specimen construction

9.3.1.2 Specimen construction to be read in conjunction with figures 1 and 2.

9.3.1.3 The specimen was 700mm wide x 1000mm high x 220mm thick. The exposed area of the specimen was 510mm wide x 900mm high. The specimen consisted of light earth compound with softwood sub-frame. The vertical members of the softwood sub-frame consisted of a 100mm x 50mm thick stud and a 45mm thick stud separated by 75mm. The vertical studs were held in place by a 13mm thick chipboard base. On the unexposed face was a 13mm thick chipboard facing.

9.3.1.4 The ‘light earth’ consisted of a straw/clay mix (specific details unknown by Chiltern Fire)

Supporting construction

9.3.1.5 The specimen was fitted into a Thermalite blockwork wall and fixed into place using a silicon sealant. To prevent flaming from the top of the specimen, 6mm Supalux was fitted to the tops of the timber uprights. There was 15mm Fireline plasterboard architrave fitted around the edge of the specimen to protect the timber framing.

9.3.1.6 Throughout the duration of the test, the pressure within the furnace was maintained at 16 Pascal’s at mid-height, which simulates a height of 3.5m to the head of the specimen.

9.3.1.7 An ambient temperature of 20 degrees Celsius was recorded at the start of the test.

Thermocouple positions

9.3.1.8 Three thermocouples were used to monitor the internal temperature of the specimen throughout the duration to the test. The thermocouple were located at 190mm from the top of the specimen and at three different depths. The thermocouples were located at 50mm, 100mm and 150mm into the specimen.

9.3.1.9 One additional thermocouple was located on the unexposed face of the specimen. This thermocouples was located 170mm from the top of the specimen and was centrally fitted.
Graph showing the temperature profile of the specimen during test

1) Thermocouple installed within compound 70mm from the exposed face
2) Thermocouple installed within compound 120mm from the exposed face
3) Thermocouple installed within compound 170mm from the exposed face

**Primary Observation**

<table>
<thead>
<tr>
<th>Time</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.32</td>
<td>The top of the chipboard face ignited, causing flaming from the specimen in excess of 10 seconds</td>
</tr>
<tr>
<td>37.07</td>
<td>Test terminated</td>
</tr>
</tbody>
</table>

Pre test mass 26 kg
Post test mass 23.7 kg

**Observations**

Pre Test observation at the beginning of the test the specimen had a total mass of 26kg.

00.00 Test started
01.54 There are glows visible across the straw face on the exposed face.
02.47 The straw ignited at 500 * C
04.25 The straw on the exposed face has a faint purple flaming across the sample and there are a number of large glows visible.
07.43 There is an increase in the level of smoke issuing from the sample.
08.55 The top 200mm of the sample is glowing, the rest of the sample appears to be blackening.
There is a continued increase in the level of smoke issuing.

The exposed face of the sample is glowing completely. The unexposed face is showing signs of burn through on the left hand side of the sample.

A popping noise can be heard from inside the furnace.

There is a glow visible at the top right of the sample between the Thermalite block and 2 x 4 wood.

The popping noise can be heard again from inside the furnace.

The popping noise can be heard again from inside the furnace.

The straw on the exposed face is dropping down from the head of the sample by approximately 50mm.

There is burn through across the head of the chipboard front.

The top of the chipboard face ignited causing flaming from the specimen in excess of 10 seconds.

Test terminated.

Post test observations

After the testing for 37 minutes, the specimen had a total mass of 23.7kg, which was a loss of 2.3kg.

Key to figures

The key below relates to the construction details for the test (refer to drawing)

1) Light earth compound
2a) 100mm x 50mm timber upright (soft wood)
2b) 45mm x 45mm timber upright (soft wood)
3) 13mm chipboard (700mm x 220mm)
4) 13mm chipboard (1000mm x 700mm)
5) 6mm Supalux (1000mm wide x 700mm deep)
6) Fixings holding chipboard face in position
7) Supporting construction

Whilst these reports relate to an investigation, which utilised the exposure conditions given in BS476: Part 20: 1987, the full requirements of the test were not complied with. The information is provided for the test sponsor’s information and should not be used to demonstrate performance against the standard nor compliance with regulatory requirements.

The test was not conducted under requirement of UKAS accreditation.
9.3.2. Indicative Fire Resistance Test - Chilt F02049 (Woodchip-Clay Samples)

9.3.2.1 This letter is to confirm the results of an indicative fire resistance test performed, to the temperature and pressure conditions outlined in BS 476: Part 20 1987 on behalf of your company under the above reference on 19 August 2002.

Specimen construction

9.3.2.2 Specimen construction to be read in conjunction with figures 1 and 2.

9.3.2.3 The specimen was 710mm wide x 1020mm high x 220mm thick. The exposed area of the specimen was 750mm wide x 850mm high. The specimen consisted of 'light earth' compound with softwood sub-frame. The vertical members of the softwood sub-frame consisted of a 45mm thick stud separated by 60mm gap. The vertical studs were held in place by a 20mm thick chipboard base. On the unexposed face was a 20mm thick chipboard facing.

9.3.2.4 The 'light earth' mix consisted of a clay/wood chip mix, (specific details unknown by Chiltern Fire).

Supporting construction

9.3.2.5 The specimen was fitted into a Thermalite blockwork wall and fixed into place using a silicon sealant. To prevent flaming from the top of the specimen, 6mm Supalux was fitted to the tops of the timber uprights. There was 15mm Fireline plasterboard architrave fitted around the edge of the specimen to protect the timber framing.

9.3.2.6 Throughout the duration of the test, the pressure within the furnace was maintained at 16 Pascal’s at mid-height, which simulates a height of 3.5m to the head of the specimen.

9.3.2.7 An ambient temperature of 24 degrees Celsius was recorded at the start of the test.

Thermocouple positions

9.3.2.8 Three thermocouples were used to monitor the internal temperature of the specimen throughout the duration to the test. The thermocouple were located at 190mm from the top of the specimen and at three different depths. The thermocouples were located at 50mm, 100mm and 150mm into the specimen.

9.3.2.9 One additional thermocouple was located on the unexposed face of the specimen. This thermocouples was located 170mm from the top of the specimen and was centrally fitted.
Graph showing the temperature profile of the specimen during test

1) Thermocouple installed within compound 70mm form the exposed face
2) Thermocouple installed within compound 120mm form the exposed face
3) Thermocouple installed within compound 170mm form the exposed face

**Primary Observation**

9.3.2.10

<table>
<thead>
<tr>
<th>Time</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 min</td>
<td>Test terminated. No burn through of the specimen had occurred. The maximum unexposed face temperature reached during the test was ?? Degrees C.</td>
</tr>
</tbody>
</table>

**Observations**

9.3.2.11

Pre Test observation At the beginning of the test the specimen had a total mass of 102.5 kg.

<table>
<thead>
<tr>
<th>Time (Minuets)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>00.00</td>
<td>Test started</td>
</tr>
<tr>
<td>03.52</td>
<td>There is smoke issuing from along the top edge.</td>
</tr>
<tr>
<td>04.49</td>
<td>There is an increase in the level of smoke issuing form all four edges.</td>
</tr>
<tr>
<td>06.48</td>
<td>The is an increase in the level of smoke issuing.</td>
</tr>
<tr>
<td>08.36</td>
<td>Smoke continues to issue.</td>
</tr>
<tr>
<td>22.00</td>
<td>Smoke continues to issue.</td>
</tr>
<tr>
<td>23.05</td>
<td>The smoke face is intact.</td>
</tr>
<tr>
<td>32.10</td>
<td>There is a slight decrease in the level of smoke issuing.</td>
</tr>
<tr>
<td>35.45</td>
<td>Exposed face, the softwood frame has cracked and is starting to fall away.</td>
</tr>
<tr>
<td>46.10</td>
<td>Exposed face, layers of horizontal lines are appearing.</td>
</tr>
<tr>
<td>54.05</td>
<td>Smoke continues to issue.</td>
</tr>
</tbody>
</table>
Specimen satisfactory. Smoke continues to issue.

There is an increase in the level of smoke issuing from along the top edge and 180mm down each edge.

There is an increase in the level of smoke issuing from the top of the specimen.

Test terminated. No burn though of the specimen has occurred. The maximum unexposed face temperature reached during the test was ?? Degrees C.

**Key to figures**

9.3.2.12

The key below relates to the construction details for the test (refer to drawing)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2)</td>
<td>Clay/wood chip compound</td>
</tr>
<tr>
<td>2)</td>
<td>45mm x 45mm timber upright (soft wood)</td>
</tr>
<tr>
<td>3)</td>
<td>20mm chipboard base (710mm x 220mm)</td>
</tr>
<tr>
<td>4)</td>
<td>20mm chipboard (1000mm x 700mm)</td>
</tr>
<tr>
<td>5)</td>
<td>6mm Supalux (750mm wide x 220mm deep)</td>
</tr>
<tr>
<td>6)</td>
<td>Fixings holding chipboard face in position</td>
</tr>
<tr>
<td>7)</td>
<td>Supporting construction</td>
</tr>
</tbody>
</table>

9.3.2.13

Whilst there reports relate to an investigation, which utilised the exposure conditions given in BS476: Part 20 1987, the full requirements of the test were not complied with. The information is provided for the test sponsor’s information and should not be used to demonstrate performance against the standard nor compliance with regulatory requirements.

9.3.2.14

The test was not conducted under the requirement of UKAS accreditation.
9.4 State of New Mexico Construction Industries Division Clay Straw Guidelines

9.4.1 Definitions

9.4.1.1 CLAY SLIP: A suspension of clay particles in a water solution.

9.4.1.2 CLAY SOIL: Soil containing 50% more clay content by volume.

9.4.1.3 INFILL: Straw clay which is placed between the structural members of a building.

9.4.1.4 LIGHT CLAY: A mixture of clay and straw compacted to form an insulating wall.

9.4.1.5 MONOLITHIC: A continuous wall without seams.

9.4.1.6 NON-LOAD BEARING: Not bearing any of the weight of the building beyond the weight of light clay itself.

9.4.1.7 PROTECTIVE WRAP: Kraft waterproof building paper or asphalt-saturated rag felt used to wrap structural members.

9.4.1.8 STRAW: The stalk or stem of grain from wheat, rye, oats, rice or barley left after threshing or when the seed head has been removed.

9.4.1.9 TREATED WOOD: Wood treated with an approved preservative under the treating and quality control requirements specified in the UBC standard No. 25-12 or an ICBO approved coating.

9.4.1.10 WOOD OF NATURAL RESISTANCE TO DECAY: The heartwood of bald cypress, black locust, black walnut, the cedars and redwood.

9.4.1.11 VOID: Any space in the light clay wall that allows a 2" sphere to be inserted into it.

9.4.2 Standards for Non Load-bearing Light Clay Construction

General

9.4.2.1 Light clay shall not be used to support the weight of the building beyond the weight of the light clay material. The light clay will act as wall in-fill between the structural members or surrounding them.
9.4.2.2 The structural support of the building shall be designed according to the Provisions of the Uniform Building Code (UBC). All loadings shall be as required by Chapter 23 of the UBC for vertical and lateral loads.

9.4.2.3 The general construction of the building shall comply with all provisions of the Uniform Building Code (UBC).

9.4.2.4 For the purposes of placement of perimeter foundation insulation, the light clay may overhang the bearing surface of the foundation up to the thickness of the perimeter insulation, but in no case greater than 4" inches.

9.4.2.5 Unless otherwise provided for in the Standard, the following codes are minimum requirements:

a. Uniform Building Code (ICBO);
b. Uniform Mechanical Code (ICBO);
c. Uniform Plumbing Code (ICBO);
d. National Electrical Code (NFPA);
e. State of New Mexico Electrical Code;
f. L.P. Gas Codes;
g. ANSI;
h. Current Energy Conservation Code;
i. New Mexico Building Code;
j. Any additional codes and standards as may be adopted by the C.I.D.

9.4.3 Material Specification

9.4.3.1 STRAW: Straw shall be wheat, rye, oats, rice or barley, and shall be free of mold, decay and insects.

9.4.3.2 CLAY SOIL: Dry soil mixture may contain a mixture of clay, silt and sand. The clay content shall be 50% or more of the total mixture by volume.

9.4.3.3 STRAW/SILP MIXTURE: All straw stalks shall be mixed with the clay slip until they are thoroughly and evenly coated so as to avoid pockets of dry straw.

9.4.4 Wall Construction

9.4.4.1 The exterior walls shall be a minimum of 12" inches thick unless otherwise approved by the certifying architect or engineer.

9.4.4.2 Light clay shall not be used below grade. The foundation shall be constructed so that the bottom of the light clay wall is at least six inches above final exterior grade.

9.4.4.3 A moisture barrier shall extend across the full width of the stem wall between the light clay wall and the stem wall. The moisture barrier shall consist of an ICBO approved moisture barrier. All penetrations through the moisture barrier, as well as all joints in the barrier, must be sealed with asphalt, caulking or and ICBO
9.4.4.4 All wood structural members embedded in exterior light clay walls shall be of wood of natural resistance to decay, or shall be treated wood or wood protected with approved coatings, or protective wrap. All non wood structural members shall be resistant to corrosion or coated to prevent corrosion with an approved coating.

9.4.4.5 A moisture barrier shall be installed at all window sills prior to installing windows.

9.4.4.6 A decay resistant sill plate shall be used over the moisture barrier and stem wall.

9.4.5 Wall Reinforcing

9.4.5.1 Vertical wall reinforcing shall be a minimum, of 2x4’s, 32” on center, secured to sills and plate or gable rafters. This reinforcing shall be blocked every 8’ feet vertically with 2x4 blocks placed horizontally.

9.4.5.2 Nonstructural horizontal stabilizing bars shall be installed at 24” on center vertically and secured to vertical members. Nonstructural stabilizing bars may be one of the following: V2” bamboo, V4” fiberglass reinforcing rod, 3/8” steel reinforcing rod, 1/4” wood doweling, I x I hardwood, I x2 softwood.

9.4.6 Monolithic Walls

9.4.6.1 Formwork shall be strong enough to resist bowing when the light clay materials is compacted into the forms.

9.4.6.2 Forms shall be uniformly loaded with light clay materials and be evenly tamped to achieve strong, stable, monolithic walls that are free of voids. Light clay material shall be loaded in lifts of no more than 6” inches and shall be thoroughly tamped before additional lifts or materials are added.

9.4.6.3 Formwork shall be removed from walls within 24 hours after tamping, and walls shall remain exposed until dry. Any voids present once forms are stripped should be patched with straw clay mixture prior to plastering.

9.4.6.4 Whenever a wall in not continuously built, the following procedure shall be used to prevent cold joints: The top of the wall shall be thoroughly coated with clay slip prior to the application of a new layer of light clay material.

9.4.7 Openings

9.4.7.1 Rough bucks and/or door and window frames shall be imbedded in the light clay walls at the perimeter of the openings and fastened securely to wooden structural members.

9.4.8 Wall Surfacing

9.4.8.1 All exterior wall surfacing material shall allow, for the diffusion of moisture through
9.4.8.2 Bridging shall be required at the juncture of dissimilar materials prior to the application of plaster. Acceptable bridging materials include: expanded metal lath, fiberglass mesh, tape or burlap. Bridging shall extend a minimum of 2" on either side of the juncture.

9.4.8.3 Exterior wood wall siding shall be spaced a minimum of 3/4" inches from the light clay wall to allow for moisture diffusion. The siding shall be fastened to wood furring strips. Furring strips shall be securely fastened to the 2x4 vertical wall reinforcing.

9.4.9 Electrical

9.4.9.1 All wiring within light clay walls in residential construction shall be Type UF or approved conduit systems.

9.4.9.2 All wiring within light clay walls may be channeled or embedded in the walls, maintaining a minimum depth of one and one-fourth inches (1-1/4") from the surface of the interior of the light clay wall surface.

9.4.9.3 All cable, conduit systems, electrical and junction boxes, shall be securely attached to the light clay wall or wall framing.

9.4.9.4 All electrical wiring methods and materials in light clay walls shall meet the provisions of the National Electrical Code, and any other applicable State codes or standards currently in effect within the State of New Mexico.

9.4.10 Plumbing

9.4.10.1 All plumbing shall meet all provisions of the Uniform Plumbing Code, Uniform Mechanical Code and New Mexico Plumbing and Mechanical Code, and any other applicable State codes or standards, currently in effect within the State of New Mexico.

9.4.11 Professional Seal Requirement and Certificate of Occupancy

9.4.11.1 Construction documents detailing the structural design of the structure shall be prepared by a licensed New Mexico architect or structural engineer. The architect or engineer stamp must be affixed to each page of the plans detailing construction of the structure with the design professionals signature and date affixed over each stamp.

9.4.11.2 Prior to issuance of a Certificate of Occupancy by the Construction Industries Division, an inspection report must be proved to the General Construction Inspector by the licensed New Mexico architect or structural engineer. The report shall attest to the building’s structural integrity and conformance with the permitted drawings.
9.5  Durability Classes and Insured Lives for Light Earth Construction  January 2003

9.5.1.  Durability Classes and Insured Lives - Table

[Insured] Life  Walling and cladding / Cast in–situ walling / Light earth — description

A1 – 60  Light earth walls comprising mineral fill material – clay mix cast in–situ around timber frame structure.
Mineral fills include: expanded clay, glass beads, pumice or expanded perlite.
Reinforcement agents or permanent formwork incorporated to overcome lack of mineral fill adhesion.
Thickness of wall between 100mm – 300mm. Minimum density of finished wall 250kg/m$^3$.
Minimum clay content 50% with no organic matter.
Plaster and render coatings to be lime or clay based, so as to be breathable, minimum thickness 25mm.

B1 – 35  Light earth walls comprising wood chip fill material – clay mix cast in–situ around timber frame structure.
Wood chip of hardwood or softwood heartwood excluding bark. Moisture content less than 16%. No decay, mould or insects present. Maximum size 50mm.
Thickness of wall between 100mm – 300mm. Minimum density of finished wall 250kg/m$^3$.
Minimum clay content 50% with no organic matter.
Plaster and render coatings to be lime or clay based, so as to be breathable, minimum thickness 25mm.

C1 – 30  Light earth walls comprising 'organic' straw (cereal) fill material – clay mix cast in–situ around timber frame structure.
Straw includes: barley, wheat, maize or rye. Straw should be clean and dry; there should be no seeds, weeds, green matter, decay, mould or insects present; moisture content less than 16%.
Stalk length 150mm – 400mm.
Minimum clay content 50% with no organic matter.
Thickness of wall between 100mm – 300mm. Minimum density of finished wall 250kg/m$^3$.
Plaster and render coatings to be lime or clay based, so as to be breathable, minimum thickness 25mm.

C2 – 30  Light earth walls comprising 'organic' fill material – clay mix cast in–situ around timber frame structure.
Organic fill materials include: rice stalks, flax, hemp or reeds. Organic fill should be clean and dry; there should be no seeds, weeds or green matter; moisture content less than 16%. Stalk length 150mm – 400mm.
Thickness of wall between 100mm – 300mm. Minimum density of finished wall 250kg/m$^3$.
Minimum clay content 50% with no organic matter.
Plaster and render coatings to be lime or clay based, so as to be breathable, minimum thickness 25mm.

UI  Uninsured, i.e. Light earth walls not to above specification.

Adjustment factors  If combined with synthetic binders for example: rapid setting cement or gypsum. Or vapour impermeable coatings or paints used:  not insured.
Artificially grown straw, that is non–organic:  – 10 years.
Woodchip including bark or sapwood:  – 10 years.
Industrial, marine or polluted environments:  – 5 years.
9.5.2. **Maintenance Requirements**

9.5.2.1 Annual inspection... including checking for cracks, de-laminations, erosion, overflowing gutters, plant encroachment.

9.5.2.2 Repairs as necessary. For example; fill small cracks or holes, where sections have decayed or suffered fungal attack, these should be cut out, dried, replaced with sound material.

9.5.2.3 Brush off or vacuum moulds or staining organisms as necessary.

9.5.2.4 Remove plant growth as necessary.

9.5.2.5 Recoating of finish to render and plaster coatings as necessary.

9.5.2.6 Recoating will depend on the finish applied as well as the wear and weathering the finish is exposed to. Typically limewash is applied annually or every 2 years.

9.5.3. **Assumptions**

9.5.3.1 Durability classes are based on the light earth construction in a sheltered environment.

9.5.3.2 Light earth constructed buildings to be one storey high.

9.5.3.3 The proposed light earth composition should be tested to confirm its suitability for walls. This includes determining the mix proportions to attain the design density.

9.5.3.4 Light earth wall built as non-load bearing wall; loads are transmitted through the timber frames. Timber framing at least to insurance class E: page 2.13, HAPM Component Life Manual.

9.5.3.5 The clay slip binder material should be smooth and may comprise clay, silt and sand, with a minimum of 50% clay. There should be no organic matter. A viscosity test should result in a 150 ± 25mm diameter circle of slip when 100ml of slip is poured onto a level glass from a height of 100mm.

9.5.3.6 Water to be potable.

9.5.3.7 Light earth wall mix tamped down to ensure there are no voids.

9.5.3.8 Allow earlier lifts to cure before raising shuttering and subsequent fillings. Lifts 400mm maximum.

9.5.3.9 All clay surfaces to be covered with some form of protective coating as soon as practicable after striking the shuttering. Voids on surface filled after shuttering removed.
9.5.3.10 Corrodible metals not to be used in the construction.

9.5.3.11 The walls should be dried out as quickly and completely as possible after laying.

9.5.3.11 Final moisture content of the light earth wall should be below 20%.

9.5.3.12 Vulnerable corners, uncompressed areas or particularly low density areas to incorporate a reinforcing mesh on which to apply plaster or render finish.

9.5.3.13 The effects of shrinkage should be managed and minimised. Shrinkage gaps should be filled.

9.5.3.14 The risk of interstitial condensation should be analysed and be adequately controlled.

9.5.3.15 Frames subject to vibration such as doors or windows should be soundly fixed to the structural frame. At door linings and frames the wall should be covered with plaster and architraves.

9.5.3.16 Light earth walls should be kept free from constant wetting and be well ventilated. This may be achieved by inclusion of a damp-proof course as protection from ground water, keeping the area adjacent to the wall free from storage or plantings, incorporating a weather resistant plinth at ground level extending at least 150mm above ground level, incorporating land drains around the building to remove ground water. Light earth walls should not extend below the damp-proof course.

9.5.3.17 The upper parts of the wall should be protected by a generous roof overhang; at least 600mm, unless walls are clad rather than rendered.

9.5.3.18 If paints are used they should be vapour permeable. Paints used externally should have a higher vapour diffusity, that is be more vapour permeable, than paints used internally to ensure that vapour flowing from the interior can escape through the exterior.

9.5.3.19 Electrical cables running within the light earth walls should be sized so as not to overheat or be enclosed in conduits which contain heat. Surface mounted or ducted cables may be preferred.

9.5.3.20 No water services to be run within the body of the light earth construction. Where pipes have to pass through the light earth construction these should be sleeved and the ends sealed.

9.5.4 Notes

9.5.4.1 Light earth construction is defined as one of a family of earth constructions with a density of less than 1200Kg/m\(^2\) (DIN 18951) whereby a fill material is coated by
a clay slip. Light earth construction using blocks is not considered.

9.5.4.2 The durability classes are based on the best research available. There are however many variables involved with light earth construction particularly the various clays and many different combinations of materials which comprise the clay–slip which fall outside the durability class parameters. Advice from an experienced practitioner should be sought in these cases.

9.5.4.3 Light earth construction may be higher than one storey where specifically designed with appropriate precautions.

9.5.4.4 The constituents of clay slip are defined by their particle size: clay, <0.002mm; silt, 0.002 – 0.06mm; sand, 0.06 – 2mm.

9.5.4.5 Straw and organic fill material may be chopped or laid as is. Chopped material may be easier to work. The important criteria is that the fill material is evenly mixed with the clay–slip matrix. Fill material laid multi-directionally may enhance stability of the wall.

9.5.4.6 Achieving adequate drying out may involve dovetailing the building programme with the climatic regime of the site or providing an environment whereby the building can dry out during wetter and colder seasons.

9.5.4.7 Light earth walls wider than 300mm are possible however, the risk of the centre not drying out increases. Where walls are greater than 300mm thick special precautions should be used to ensure the centre of the walls dry out.

9.5.4.8 If rot or decay has occurred the cause should be determined and the underlying defect or deficiency remedied rather than just the symptom.

9.5.4.9 The durability classes relate to ‘typical’ light earth construction using lime or clay based plaster internally and lime or clay based render externally in a sheltered environment. A variety of alternative coating, claddings or finishes are possible, provided the concept of a microporous, ‘breathable’ or ‘moisture transfusive’ wall system is maintained to ensure vapour egress.

9.5.4.10 External cladding, may be the only suitable option in severe environment. In any case where external cladding is proposed a ventilated cavity — at least 20mm wide — behind the cladding needs to be maintained to ensure moisture from the building fabric can escape.

9.5.4.11 Plaster and render to be applied only when the light earth is dry and stable. Include bridging (reinforcement) to extend 50mm at junctions with dissimilar materials, for example at light earth and timber frame junctions.

9.5.4.12 The surface of the light earth wall should be plastered where cladding is proposed internally or externally. This prevents insect attack.

9.5.4.13 External renders and paint finishes should be considered as sacrificial surfaces
which will require checking and repairs to ensure the longevity of the light earth wall.

9.5.4.14

The risk of interstitial condensation may be managed by:
a) creating a vapour resistance gradient by placing more vapour resistive materials on the inside of the wall construction and the less vapour resistive materials on the outside, or
b) using materials which can accommodate and release potential interstitial condensate.

9.5.4.15

Suitable paints include ‘conservation’ or ‘ecological’ paints, base on lime, clay, silicates and other materials such as borax, chalk, casein, natural waxes, pigments and oils.

9.5.5. Explanation of Insurance Life

9.5.5.1

The insured life is reliant on good design and installation practice. When a building is insured by Building LifePlans (BLP) the risk management process incorporates a technical review which appraises the design and detail of each scheme. Workmanship is confirmed by at least one site visit.

9.5.5.2

The insured life information is often viewed independently within the component life manuals. Key design, detail and installation criteria may be defined within various sections of the insurance life data sheet, namely the ‘insurance class — durability description’, ‘assumptions’ and ‘notes’. These reflect durability issues which specifiers should be aware of; but they are not a substitute for a scheme specific, comprehensive specification. There is more such information than usual in this insured life data sheet as light earth construction is not the subject of a traditional British, European or International standard.