A Critical Analysis of Waterproofing Compressed Earth Blocks
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Note: Ethics disclaimer can be found in Appendix F
Abstract

This research project investigated and evaluated a range of surface waterproof treatments upon compressed earth blocks and compressed stabilised earth blocks, identifying their performance and viability to be used in Uganda, Africa.

A critical review of the literature was undertaken to examine how surface water penetration affects the structural integrity of compressed earth blocks and compressed stabilised earth blocks, a suitable test method for surface water absorption, and identifying existing commercial/non-commercial waterproofs used in the UK and Uganda, as well as innovative alternative waterproofs.

From the literature review a primary test was conducted using the RILEM Test method II.4 on both compressed earth blocks and compressed stabilised earth blocks applying different waterproofs, sourced from the literature, to collect data on the rate of water absorption on these different compositions. The results from the primary test were analysed and compared with the literature review, questions were formed from the results and email interviews were completed with professional from the Good Earth Trust and Stormdry to identify the validity of the findings.

The research study concluded that surface waterproofs can be an effective way in which to decrease water penetration for compressed earth blocks and compressed stabilised earth blocks. UK commercial waterproof Stormdry was found to be an effective surface treatment on compressed earth blocks and compressed stabilised earth blocks. Potassium Silicate an innovative alternative waterproof obtained from the literature review was also a successful surface treatment and was found to be a cheaper alternative to Rover Paint for application in Uganda. It was recognised that waterproofs could decrease water penetration and can be an effective way to protect them from water damage and failure.
Acknowledgements

I would like to express my thanks to my supervisor, Mr Gordon Browne, who has helped guide me through an exceptional research experience. I would also like to take this opportunity to thank Stormdry and Good Earth Trust for all their advice and co-operation throughout this Dissertation.

Thirdly I would like thank all of my friends and family who have supported me over the last four years of my studies.
List of Acronyms and Abbreviations

CEB  Compressed Earth Blocks
CSEB  Compressed Stabilised Earth Blocks
USD  United States Dollars
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Chapter 1. Introduction

1.1. Scope of Chapter

This chapter gives a brief rationale of the fundamental reasoning for conducting this research project. It outlines the aim, objectives and key questions the project endeavours to answer. Chapter 1 gives the basis from which the research project would take shape by means of an appropriate methodology and stating a clear structure that would be implemented throughout.

1.2. Rationale for Conducting the Research Project

*Good Earth Trust (2011)* stated “According to UN-HABITAT 3 billion people lack decent housing in the world. Uganda alone needs 1.6 million new houses and is currently building some 100,000 each year”. Brick, cement, sand and timber are the major construction materials used within Africa presently. However for the majority of people in Africa, and especially in Uganda, this is unaffordable, therefore a construction technique that can solve the urban housing crisis is required (*Zami, 2011*). This technique comes in the form of earth as a construction material and progressively earth blocks. Around 30% of the world’s population and roughly 50% of the population of developing countries live in earthen structures (*Easton, 1983*). However, many of these earthen structures are inadequate with little structural integrity or durability, causing more problems for their owners than solving (*Adam and Agib, 2001*). Compressed earth blocks or compressed stabilised earth blocks solves this problem offering an affordable building material that has a high compressive strength and durability that is accessible to poverty stricken communities. The level of training needed to construct with these earth blocks is marginal compared to conventional construction materials, therefore offering a simple method that can be understood by people with a lack of knowledge in the construction industry.

In the early 1990’s Dr. Moses Musaazu, from Makerere University in Uganda developed a type of double interlocking system. This has been further improved by a Kenyan company, Magika Engineering Ltd, which developed The Magika Ground Breaker Soil Block Press which produces Interlocking Compressed (or ‘Stabilised’) Earth Blocks *Figure 1 (Magika Engineering services Ltd, 2011)*. It is a simple piece of machinery requiring limited amount of training to utilise, making it much more accessible to smaller communities.
Although this machine offers an affordable and resilient building material to be used in construction, it contains a problem when exposed areas are frequently in contact with weather elements such as rainwater. Continuous alternate wetting (rainfall) and drying would cause the earth block retaining a high amount of moisture which leads to destructive effects (Kerali, 2000). Over the years a building constructed of compressed (stabilised) earth blocks will age and surface cracks would likely appear (Keefe, 2005 p.142). This would result in water penetration and a build-up of moisture to a critical level. As stated by Keefe (2005, p.156) “compressive strength decreases with increasing moisture content and once it reaches its critical moisture content (CMC) it is likely to fail”.

From this it is evident that for a compressed (stabilised) earth block to last over the generations with minimal maintenance it requires a waterproof finish. In Uganda a waterproof finish is already in use called Rover Paints which is being applied to newly compressed (stabilised) earth block structures. However very little study or research has been done concerning the effectiveness of this waterproofing and whether it is a better water-repellent than that used for masonry in the UK. Stormdry is a prominent UK company in water-repellent protection and have a means of measuring the water absorption of a material with the use of a Stormdry Absorption Test Kit (Stormdry, 2011).

The research that was conducted involved an investigation into Stormdry, Rover Paints and additional non-organic/organic waterproofing that could be used as a water-repellent on compressed (stabilised) earth blocks. From this investigation the Stormdry Absorption Test Kit was used to test the different waterproofs on the earth blocks to identify their water-repellent performance. The waterproofs were also tested upon Michelmersh Masonry Bricks so they could be used as a control samples that provided a fair test for the earth blocks. Due to the earth compositions being made from English Soil (Clay soil) compared to Ugandan Soil (Laterite Soil) this research was only a comparison test that would hopefully give relevant results that could be implemented with regards to blocks made from Ugandan soil. Recommendations were made, if appropriate, on the most effective waterproofing to be used for compressed (stabilised) earth blocks.
1.3. Aim
To research and test surface waterproof compositions to compressed earth blocks and compressed stabilised earth blocks

1.4. Objectives
1. To identify if waterproofs can increase performance and be economically beneficial to countries such as Uganda that have an unavailability of cement.
2. To compare and evaluate the lab results to identify a clear understanding of the effectiveness of waterproofing on the earth blocks durability.
3. To test and compare how the level of water penetration visibly affects the structural integrity of Compressed Earth Blocks and Compressed Stabilised Earth Blocks.
4. To test the level of water penetration for each waterproofing on different types of earth block compositions.
5. To review published research, journals and books on earth blocks.

1.5. Key Questions
1. What factors must be considered in identifying the most appropriate waterproofing agent?
2. Is an impregnation waterproof treatment or a surface waterproof treatment more effective upon a CSEB and a CEB?
3. Is waterproofing best used as a coating or used within the earth block?
4. Could alternative waterproofing’s be an economic advantage to earth block construction in third world countries such as Uganda?
1.6. Outline Methodology

The Methodology that was executed within this dissertation contained both primary and secondary research. An in depth clarification of the method implemented within this dissertation is found within Chapter 2 – Methodology.

1.7 Structure

This dissertation is made up of seven chapters. Chapter one is an introduction to the research project, explaining the reasoning behind undergoing this research project, and declaring the aims and objectives to be achieved. Chapter one also states the key questions that were to be answered within this project. Chapter two confirms the methodology that was implemented within this research project. Chapter three, four and five contains the literature review, analysing a variety of topics relating to compressed earth blocks, moisture content and waterproofing methods. Chapter six presents the findings of the primary research and the experiment method that was used. Chapter seven contains the conclusion of the dissertation evaluating the findings and critically appraising the validation of the data, giving recommendations and further research were appropriate.
Chapter 2. Literature Review Part One

Research into Compressed Earth Block Construction and Technology

2.1 Scope of Chapter

This chapter will critically appraise the history, advancement, technical qualities, construction methods and sustainable potential of earth blocks. It aims to establish the structural identity of earth blocks and the reason for the wide variety of designs implemented throughout the world. Earth blocks will be analysed to fully comprehend their standing within construction and why it is important to continue to progress in improving the lifetime of earth blocks.

2.2 History of Earth Construction

It is first essential to look at the historical evidence of the success of earth construction. There are cities built of raw earth, such as: Akhetaten Egypt (Figure 2.2.1) and Babylon in Iraq (Easton, 1998). The Fortified city in the Draa valley in Morocco was constructed out of unbaked earth, which is around 250 years old (Figure 2.2.2).

*Figure 2.2.1 – Ancient city of Akhetaten, Egypt*  *Figure 2.2.2 – Fortified city in Draa Valley*

The great mosque of Timbuktu (Figure 2.2.3) was originally built in the year 1240 and is still standing as a visually significant and successful example of earth construction in West Africa. However, historic earth constructions have not only come in the form of cities and monuments but also defences such as the vast Great Wall of China (Figure 2.2.4) spans approximately 3,900 miles with the oldest sections being made from unbaked earth (Great Wall of China, 2011).
In Africa, the Egyptian civilisation provides abundant evidence of the use of earth in buildings as found in the early human settlements at the Merimid and Fayum sites in the Nile delta, which dates from the fifth millennium before Christ (Zami and Lee, 2011). This illustrates that the use of earth construction for building dates back to the beginning of human race.

2.3 Present Day Application of Earth Construction

Cities in the third world have, since the 1950’s, experienced unprecedented growth in terms of economic development and population increase (Zami and Lee, 2010). This is due to high rural-urban migration (Dwyer, 1981). Unfortunately, the cities of developing countries are not planned for these magnitudes of growth in population influx and nor is there the required jobs and facilities to support such huge expansion (Srinivas, 1999). According to Kamete (2006) “the housing crisis is often sold and pushed onto the agenda in predominantly quantitative terms and the mismatch between supply and demand is perhaps the scariest indicator used by proponents of increased housing delivery”. The majority of these urban local authorities and central governments did and do not have a tradition of providing housing accommodation to a large permanent population; therefore there has been a lack of urban housing (Zami and Lee 2007).

UN Habitat (1996) stated “the housing shortage alone in African cities ranges from 33 to 90 per cent”. With Good Earth Trust (2011) declared “3 billion people lack decent housing in the world. Uganda alone needs 1.6 million new houses and is currently building some 100,000 each year”. Presently brick, cement, sand and timber are the major construction materials in Africa and for the majority of people this is unaffordable, therefore a construction technique that can solve the urban housing crisis is required. This comes in the form of earth as a construction material and consequently earth blocks (Zami, 2011).

It is presently estimated that over one third (Dethier, 1981) to over one half (Smith and Austin, 1989) of the world’s population lives in some type of earthen dwelling. The history of earth buildings lacks documentation because it has often been considered inferior compared to that of stone and wood.
Modern earth buildings take many forms around the world. In the UK, the placing of damp clay soil to form walls known as ‘cob’ is particularly widespread in Devon, Hampshire, East Anglia and in the Solway Plain (Hard and Gourley, 2000). Moist soil placed between removable formwork boards is called ‘rammed earth’ and is found around the Mediterranean rim, north India and western China (Jaquin et al, 2008). Unfired clay bricks have been used as infill between timber frames as an alternative to fired masonry or concrete block work. In Germany, clay plasters are becoming increasingly popular as they are felt to improve the internal ambience of a building (Minke, 2007). In Uganda, Sudan and other African countries Compressed ‘Stabilised’ Earth Blocks (CESBs) have successfully been used (Zami and Lee, 2009).

2.4 Compressed Earth Blocks

Compressed Earth Block (CEB) is an earthen bricks compressed with hand-operated or motorized hydraulic machines (Wayne, 2010). CEB does not contain any stabilisation therefore no fossil fuel is required in the production of the CEB (Zami and Lee, 2008). Walker and Morris (2002) have presented the progress of performance-based standards for earth buildings in New Zealand covering the techniques required for CEB. Houben and Boueker (1998) have written a standard guide for CEB with Rauch (2007) investigating the CEB in accordance with European standards. Morris et al (2002) examined the technical aspects of CEB as a building material in Southern Africa and Sanya (2007) researched the sustainability of earthen Architecture in Uganda. Longfoot’s (2006) investigated developing a low-cost CEB blocks using locally available sand in Botswana with some success, but with greater specification to the properties of the sand. Ogunsusi (Ogunsusi et al (1994-1996), cited in Sanya (2007)) has written five books giving recommendations for best practises in CEB construction that have concluded CEB is economically beneficial to urban housing in poor areas of Africa.

According to Nelson (2010) the reduction of transportation time, cost, low embodied energy and pollution makes CEB more environmentally friendly than other materials, but does not have the structural integrity of man-made products such as steel and concrete making it only suitable for low-rise buildings.
2.4.1 The Advantages of Compressed Earth Blocks

There are many advantages to the use of compressed earth blocks in construction as a material as Figure 2.4.1 summarizes:

**Figure 2.4.1 – Advantages of Earth Construction**

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Author</th>
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<tr>
<td>Earth construction is economically beneficial.</td>
<td>Lal, 1995; Easton, 1998; Minke, 2006; Zami and Lee, 2007; Morton, 2007; Walker et al, 2005;</td>
</tr>
<tr>
<td>Earth construction is regarded as a job creation opportunity.</td>
<td>Adam and Agib, 2001, p.11;</td>
</tr>
<tr>
<td>Earth construction promotes local culture, heritage, and material.</td>
<td>Frescura, 1981.</td>
</tr>
<tr>
<td>Earth is available in large quantities in most regions.</td>
<td>Adam and Agib, 2001, p.11; Easton, 1998; Lal, 1995; Hadjri et al, 2007; Adam and Agib, 2001, p11;</td>
</tr>
<tr>
<td>Earth is very good in fire resistance.</td>
<td>Walker et al, 2005, p43; Hadjri et al, 2007; Adam and Agib, 2001, p.11;</td>
</tr>
<tr>
<td>Earth walls (loam) absorb pollutants.</td>
<td>Minke, 2006;</td>
</tr>
<tr>
<td>It balances and improves indoor air humidity and temperature.</td>
<td>Minke, 2006; Lal (1995, p119); Walker et al, 2005; Hadjri et al, 2007;</td>
</tr>
<tr>
<td>Suitable for very strong and secured structure.</td>
<td>Lal, 1995, p.119; Walker et al, 2005;</td>
</tr>
</tbody>
</table>
2.4.2 The Disadvantages of Compressed Earth Blocks

Figure 2.4.2 below summarises the disadvantages of compressed earth blocks (un-stabilised) in construction:

Figure 2.4.2 – Disadvantages of earth construction

<table>
<thead>
<tr>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Earth construction is labour intensive.</td>
<td>Lal, 1995, p119</td>
</tr>
<tr>
<td>CEB houses behave poorly in the event of earthquakes.</td>
<td>Blondet and Aguilar, 2007</td>
</tr>
<tr>
<td>Need high maintenance.</td>
<td>Hadjri et al, 2007</td>
</tr>
<tr>
<td>Suitable only for in situ construction.</td>
<td>Walker et al, 2005</td>
</tr>
</tbody>
</table>

2.5 Compressed Stabilised Earth Blocks

Due to the clay fraction (material smaller than 0.002 mm) within un-stabilised CEB the soil will swell on taking up water and shrinking on drying (Lunt, 1980). This therefore increases the likelihood of severe cracking and often leads to difficulties in getting renderings to adhere to the walls resulting in eventual disintegration (Lunt, 1980). The aim of a soil stabiliser is therefore to increase the soil’s resistance to the destructive properties of the weather as well as increasing the strength and cohesion of the soil to enable the blocks to take a more demanding load (Adam, 2001). The stabilised form is more suitable for the African situation due to the by-laws and housing standards that exist in these countries (Zami and Lee, 2011).

Houben and Guillaud (1994) explain that stabilising soil implies the modification of the properties of the soil-water-air system in order to obtain lasting properties which are compatible with a particular application and therefore stabilisation is nevertheless a complex problem, as there are a vast amount of parameters involved. According to King (1996) stabilised earth comes in the form of a rocklike blend of clay, silt sand, gravel, water, microscopic air bubbles and a type of binder. There are many types of binders used within CSEB such as lime, fly ash, asphalt, emulsion as well as a combination of these materials, however Zami and Lee (2008) confirms that the strongest binder is Portland cement.
Houben and Guillaud (1994) list the knowledge and skills needed for suitable stabilisation:

- Maintenance of the completed project, maintenance cost
- Project economy: cost and delays involved in soil stabilisation
- The planned improvements
- The properties of the soil requiring stabilisation
- The soil construction techniques chosen for the project and the system of construction

Houben and Guillaud (1994) also state the three different stabilisation procedures:

- **Chemical stabilisation**: other material or chemicals are added to the soil thus modifying its properties, either by a physic-chemical reaction between the grains and the materials or the added product, or by creating a matrix which binds or coats the grains. A physic-chemical reaction can lead to the formation of a new material, such as a pozzolana resulting from a reaction between clay and lime.

- **Mechanical stabilisation**: the compaction of the soil resulting in changes in its density, mechanical strength, compressibility, permeability and porosity.

- **Physical stabilisation**: the properties of the soil can be modified by acting on its texture. For example: - the controlled mixing of different grain fractions. Other techniques can involve heat treatment, drying and freezing, electrical treatment, electro-osmosis to improve the draining qualities of the soil, and giving new structural qualities.

130 different stabilising agents have been identified by researchers including cement, lime and bitumen (Lal, 1995), however no ‘perfect’ stabilizer has been discovered that can be applied indiscriminately (Houben and Guillaud, 1994).

### 2.5.1 Cement Stabilisation

Ordinary Portland cement hydrates when water is added. This reaction creates a cementitious gel that is independent of the soil (Adam and Agib, 2001). The cementation process of the earth block results in the embedding of soil particles within a matrix of cementitious gel, in simple terms this acts as a coating layer around the soil particles (Adam and Agib, 2001). Soil-cement mixes should be compacted immediately after mixing to ensure the structure of the newly created gel retains its bond and strength. The basic function of cementation is to make a soil water-resistant and increase the compressive strength of the structure of the CSEB (Montgomery, 1998).
According to Adam and Agib (2001), cement can generally be used with any soil type, but with clays (cohesive soil) it can be uneconomical because clay requires a substantial amount of cement than is usually required. Hall and Allinson (2008) confirmed this theory “In cohesive soils, many particles are finer than cement grains and this cannot be coated by cement”. To overcome this problem more cement is required to ensure all clay particles are coated.

2.5.2 Lime Stabilisation

According to Adam and Agib (2001), by adding lime to the soil as a stabiliser four basic reactions occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. It is believed that pozzolanic reaction is the most important as lime will bond with certain clay minerals to form cementitious compounds that bind the soil particles together (Adam and Agib, 2001). Lime can reduce the amount of water clay absorbs; therefore it can make the soil less sensitive to moisture and thus improve its integrity. This makes lime a suitable stabiliser for clay soils and also requires relatively simple block construction equipment to make, consequently it is more suitable for village scale production (Adam and Agib, 2001).

2.5.3 Other stabilisers

In the past stabilisers such as bird droppings, animal dung, ant hill materials, plant extracts and animal blood have been used to produce compressed stabilised earth blocks, it is believed that the waste materials generally consist of nitrogenous organic compounds which help bind together soil grains (Adam and Agib, 2001).

2.5.4 The Advantages of Compressed Stabilised Earth Blocks

According to Lal (1996), the major advantage of the stabilised earth block vis-à-vis the burnt brick (another common construction material used in Africa) is the significant saving in energy of around 70%, and such blocks are cheaper by 20 to 40% compared to burnt bricks. CSEB are also a fraction of the price of concrete blocks and timber. The stabilisation of concrete within a compressed earth block averaging at 5% (Montgomery, 1998).

Adam and Agib (2001, p.23) explains “The use and adoption of the right stabilisation method can improve the compressive strength of a soil by as much as 400 to 500% and increase its resistance to erosion and mechanical damage”. According to Bush (1984), comparative tests of un-stabilized and stabilized soils show that both the dry and wets strengths of cement stabilized soils are stronger and more water resistant than the best un-stabilised soils. Arumala and Gondal (2007) stated that CSEB are a safe alternative to masonry and if installed correctly can offer a durable sustainable home that is affordable to unprivileged people.
Figure 2.5.1 gives an indication of the ability of compressed stabilised earth blocks versus other walling materials:

![Figure 2.5.1 - Compressed stabilised earth blocks versus other walling materials](image)

As Figure 2.5.1 shows CSEB can have an inspiring compressive strength but this comes down to the type of soil used, proper mixing of suitable materials, proper compaction and curing (Adam and Agib, 2001).

According to Adam and Agib (2001), block making experiments in Sudan using various quantities of lime as a stabiliser showed marked variations between the durability of stabilised and un-stabilised compressed earth blocks. Field Test at El Haj Yousif experimental school have shown that walls constructed with cement compressed stabilised earth blocks demonstrated good weathering properties (Froude, 2011).

The greatest advantage of CSEB is the simplicity of producing these blocks Zami and Lee (2011) stated that the flexibility and simplicity in technology incorporates in CSEB affords adaptability and easy transfer of knowledge between different stakeholders in the building industry, where individuals and communities as a whole can easily participate in building their own homes in an affordable way.

According to Hadjri et al (2007), in Africa, housing construction using conventional materials is too expensive for the majority of urban areas due to transport cost amounting to approximately 40% of the total material cost. By using CSEB, it decreases the material cost because transportation is significantly reduced making a much more affordable option for poor communities (Vroomen, 2007)

Charity organizations such as UN-HABITAT and Good Earth Trust are leading the way in teaching communities the necessary technology in producing CSEB in Uganda, and other African nations (Good Earth Trust, 2011). By teaching communities this knowledge they themselves can pass on this
information to other communities allowing them to not only help themselves but their neighbours as well (UN-HABITAT, 2009).

2.5.5 The Disadvantages of Compressed Stabilised Earth Blocks

According to Zami and Lee (2011), one of the greatest challenges that prevent earth becoming the preferred choice of building materials amongst professionals, politicians, decision makers and the client is acceptability. By improving awareness and understanding of the environmental issues such as air pollution, deforestation, land degradation, energy conversation as well as affordability will help change the negative attitude in constructing with compressed stabilised earth blocks (Zami and Lee, 2011).

Sanya (2007) has researched the suitability of earth architecture in Uganda and found that CSEB is not economically beneficial in the Ugandan context because of the unavailability of cement. This has also been found in other African countries. As Alagbe (2007) explained amongst most social groups CSEB is considered to be second-class and generally inferior building material.

Alagbe (2009) stated that durability of CSEB in exposed areas such as the gable end will be reduced, due to the area being affected by medium and high rainfall, thus it must be regularly maintained and properly protected. Alagbe (2009) also stated that CSEB has a low resistance to abrasion and impact especially in the event of earthquakes which is a yearly occurrence in most African countries.

According to Adam and Agib (2001), CSEB has a low tensile strength therefore causes it to be a poor resistant to bending moments and should only be used in compression e.g. bearing walls, domes and vaults.

According to Montgomery (1998), the type of soil used in the construction of a building can have a huge effect on the structure and durability of the CSEB, but also the type of stabiliser to be used is also determined on the type of soil available. Adam and Agib (2001) stated how lime is suited to clay soils whereas cement is preferable for sandy soil. Zami and Lee (2009) confirmed that an investigation into the type of soil and stabiliser available should be considered before construction is commenced.

2.5.6 Summary

From the literature review building with earth blocks is considered to be a low cost and energy efficient technology compared to other construction materials. The arguments, from the available literature favour, stabilised and un-stabilised compressed earth blocks in the construction of urban housing in third world countries.
It is notable that the drawbacks of compressed earth blocks mentioned by different authors in Figure 2.4 can be addressed and solved by incorporating different stabilisers into the compressed earth block. Reduction of cracks, enhancement of binding force, increasing compressive strength and an increase in thermal insulation of compressed earth blocks is explained by different researchers, such as Houben & Guillaud, (1989); Maini, (2005); Minke, (2006) and Walker, (2004) in their published books and publications. However to make it effected the people constructing with this material must understand the disadvantages, which normally depend upon the soil quality which adversely affects the block quality, causing shrinkage cracks and lower wall strength compared to that of high-quality fired bricks and concrete. Organisations such as UN-HABITAT have helped largely to address the problem of misunderstanding in earth block construction, by conveying the transfer of knowledge between communities that it is easily viable due to the flexibility and simplicity of the manufacturing of earth blocks.

It is likewise evident that the financial benefits of low-cost compressed earth block construction in developing countries is dependent on the cost of additives (such as cement), as well as the transportation cost of delivering the raw materials to site. In places such as Uganda, cement will not always be readily available due to cost and exportation, therefore making it even more paramount that cheap effective waterproof can be utilised to help tackle water erosion problems due to the lack of a stabiliser. This is also backed up by Zami and Lee (2009, p.269) that stated “when produced locally, with natural resources, semi-skilled labour and few transport needs, contemporary earth construction for low-cost urban housing can be very cost effective, according to context and available skills”. So by using natural resources i.e. soil, earthen construction is cost effective and accessible to poor stricken communities, but will still have the water erosion problem due to no additives, once again making waterproofing a valuable concept in protecting exposed areas.

The key question ‘could waterproofing be economic advantage to earth block manufacturing in third world countries such as Uganda’ in theory could be economically advantageous to communities that cannot afford additives or have high quality soil (therefore not needing additives) because waterproofing offers an alternative to protecting exposed areas, but the waterproofing would need to be locally sourced or cheaper than cement to import. As reviewed in the literature it is seen that compressed stabilised earth blocks can still be affected by heavy rainfall over long periods of time thus still making waterproofing economically advantageous as it will reduce maintenance costs and also increase the life span of the construction.

To ensure the waterproof is impermeable to water and can stand up to serve weather it is paramount to test the moisture control and surface water absorption of the earth block which is reviewed in the next chapter.
Chapter 3. Literature Review Part Two

Investigation into the effects of moisture within Earth Blocks and the application of the RILEM Test Method II.4

3.1 Introduction

Within this chapter a thorough investigation will be conducted, analysing the effects of moisture upon and within earth blocks, leading on to the complications of high level moisture which can cause difficulties for earth blocks within a structure. The capability of the RILEM Test Method II.4 will also be critically appraised for its effectiveness and accuracy in determining moisture penetration.

3.2 Water in Earthen Structures

There is a small but set volume of water present in the form of liquid bridges between soil particles in earth structures when air dried (Jaquin, 2009). According to Jaquin (2009, p.4), “This water is under tension and the magnitude of the pore water pressure (suction) is related to the relative humidity of the surrounding air”. It has been identified by Wilson, et al. (1995) that the evaporation of water from unsaturated soils is proportional to the suction. However Jaquin (2008) argued that this evaporation will continue from the earth structure until the relative humidity of the pore air is equal to the humidity of the surrounding air. Due to this according to Jaquin (2009), the strength and stiffness of earth structures, and therefore their inherent viability is a function of the mean relative humidity of a region. This makes it suitable for countries such as Uganda who have high humidity level regions.

3.3 Water Absorption and Moisture content

Water absorption is a characteristic of clay and cement content and is often related to the strength and durability of earth blocks, consequently it is important to identify the rate of water absorption of earth blocks (Riza, Rahman and Zaidi, 2011). According to Oti, Kinuthia and Bai. (2009), water absorption rate decreases with increasing age of earth blocks. Riza, Rahman and Zaidi (2010) confirmed that a high rate of water absorption of a specimen may cause swelling of the stabilized clay fraction which will result in losing strength with time. Walker (2004) observed that water absorption and porosity increases with clay content and decreasing with cement content. Between cement, lime, cement-lime and cement-resin, combination cement showed the lowest absorption both in capillary absorption and total absorption (Guettala, Abibsi and Houari, 2006).
Moisture content affects strength development and durability of earth blocks having a significant influence on the long term performance and the effectiveness of the bonding with the mortar at the time of construction (Riza, Rahman and Zaidi, 2011). Once the earth block is dry, water is rapidly drawn out of the mortar preventing good adhesion and proper hydration of cement (Oti, Kinuthia and Bai, 2009). Due to this Adam and Agib (2001) stated that to achieve maximum strength, CSEB need a period of damp curing, where they are kept moist, to prevent rapid moisture evaporation.

3.4 CEB and CSEB Failure due to Moisture

Moisture related deterioration in compressed (stabilised) earth blocks is due to seasonal or continuous alternate wetting (rainfall) and drying which lead to the block retaining sufficiently high amounts of moisture which leads to destructive effects (Kerali, 2000). The softening and abrasive action of moisture leads to erosion of exposed surfaces (Gooding and Thomas, 1995).

Keefe (2005) stated that over the years a building constructed of compressed (stabilised) earth blocks exposed to the elements will be affected by rainwater and due to the ageing of these blocks surface cracks will appear. This will result in water penetration and a build-up of moisture to a critical level (Keefe, 2005). According to Keefe (2005, p.156) “compressive strength decreases with increasing moisture content and once it reaches its critical moisture content it is likely to fail”. Nelson (2010) confirms this by stating, minimal moisture content results in better strength, water resistance, durability and thermal mass in the blocks.

Kerali (2000) stated the actual destructive action of moisture once the block has been penetrated is the dissolution and softening of loose particles and the pore pressure generated will result in a disruptive internal stress. Therefore the capacity of the block to resist the disruptive action of moisture will differentiate the life span of the Earth Block (Kerali, 2000).

According to Houben and Guillard (1994), in a compressed stabilised earth block, the cement binder undergoes a three-phase reaction with the clay component of the soil. This three-phase reaction will result in a three matrix mix consisting of an sandy matrix bound with cement, a matrix of stabilised clay and a matrix of un-stabilised soil. Assuming the matrix of the un-stabilised soil is the greatest component of the block it is predicted that the continued exposure of moisture would lead to irreplaceable loss of material from the block over time due to the considerable un-stabilised matrix.

Due to this likely hood of failure Adam and Agib (2001) suggested a render or a type of water-proof finish that protects the surface of the earth block. This is investigated and reviewed in Chapter 4. However to test if the waterproof is effective and to know how water absorbent the block is the RILEM Test Method II.4 is an appropriate way to test surface water absorption.
3.5 The RILEM Test Method II.4

As stated by Lawrence (2010), RILEM stands for Reunion International des Laboratoires D’essais et de Recherches Sur les Materiaux et les Constructions, which is the International Union of Testing and Research Laboratories for Materials and Structures. Within RILEM a technical committee, Commission 25-PEM, developed tests to measure the deterioration of masonry and to assess the effectiveness of treatment methods. Commission 25-PEM (1980) stated that this test is called the RILEM Test Method II.4 which is used to measure the quantity of water absorbed under low pressure by a definite surface of a porous material (i.e. masonry and earth block) over a determined amount of time. ZYCOSIL (2011) confirmed the RILEM Test Method II.4 is for measuring the volume of water absorbed by a material within a specified time period.

According to Commission 25-PEM (1980), the field application is to characterize the weathering effects (driven rainfall) on the chosen material or to assess the effect on an impregnation treatment, of a treatment changing the superficial permeability (i.e. waterproofing). Lawrence (2010) explained that Penetration of driving rain into wall surfaces result in horizontal transport and the test can be used to determine the degree of protection afforded by a waterproofing treatment.

Basham and Meredith (unknown) describes the RILEM Test Method II.4 involves the RILEM test tube which is a pipe like device as shown in Figure 3.5. The tube or stem portion is graduated from 0.0 to 5.0 ml with each gradation representing an increment of 0.5ml. The volume of water absorbed over a specified time is read from this graduation. Commission 25-PEM (1980) clarifies that the RILEM Test can be used in horizontal and vertical positions depending on the application required. The RILEM Test Method II.4 will be used in this research project to test the performance of different waterproofs upon compressed (and stabilised) earth blocks. According to Safeguard, (2011) the water pressure driving through the gauge equates to that applied by wind driven rain with a speed of 98mph.
3.6 Summary

From this chapter it clearly shows the key role moisture plays in compressed earth block failure. As explained by different literature, water absorption in the earth block is often related to the compressive strength where a high rate of water absorption can result in the earth block losing strength with time. This investigation into literature concludes that for exposed areas where rainfall will be consequently be heavy in different seasons compressed earth block stabilised or un-stabilised require a type of waterproofing that will protect the block from moisture failure.

Source: Lawrence (2010, p.4)
Chapter 4. Literature Review Part Three

Investigation into earth block waterproofing Materials and Methods

4.1 Introduction

This chapter will investigate the importance of waterproofing earth blocks from external weather elements and critically appraising the literature on the effectiveness of existing earth block waterproofs.

4.2 Earth Renders

*Artesano (2011)* stated that a building constructed from earth, requires a layer of protective render on the exterior to protect the structural components from the effects of weathering. As reviewed in the previous chapters there has been a considerable resurgence of earthen building techniques. A particular advance would be the widespread use and acceptance of earth renders for earth structural buildings such as compressed earth blocks (*Artesano, 2011*). Earth plaster is nothing more than sand and clay mixed together in the proper proportions to prevent cracking (*Owens, 2010*). According to *Owens (2010)*, depending on the level exposure to the elements earth render can last up to seven to ten years without maintenance.

*Artesano (2011)* described earth render to be a breathable waterproof with extremely good hygroscopic qualities. In most materials hygroscopic qualities relate to the capillary structure of the material, whereas in earthen renders moisture can also be drawn in and held by ionic bonding with clay particles themselves, slowly releasing the moisture over a period of time. According to *Keefe (2005)*, breathability between the earth blocks and exterior render is of considerable importance, because if moisture build-up occurs between them it will result in the failure of the plaster and exposure of the earth blocks to the weather.

*Ruskulis (2002)* explained that earth-based renders are often a combination of earth with other natural materials such as wheat straw or cow dung, or with mineral additives such as bitumen, to improve the basic qualities of the earth by acting as stabilisers, hardeners, and waterproofs. *Ruskulis (2002)* also stated that the earth plaster will only be as good as the quality of construction therefore requiring skilled workmen with extensive knowledge of earth rendering.
According to Adam and Agib (2001), earth renders are affected by the quality of the soil used and the area in which the building is being constructed. If in an area of frequent heavy rain earth renders will erode in time causing considerable amount of repairs. Even in more humid climates earth renders will often require yearly repairs to ensure the effectiveness of the earth render stays in tacked.

Ruskulis (2002) summarized that earth render is an economically and sustainable waterproof, but requires considerable maintenance to that of other man-made waterproofs making it a time consuming and short life-span render.

4.3 Cement Render

As described by Adam and Agib (2001) cement render is very common finish for compressed earth block construction and offers an impermeable finish. It also gives an atheistic finish of other concrete buildings distinguishing the fact that it is an earthen structure. However according to Atresano (2011) and Chiras (2000) cement based renders have a low permeability; they tend not to allow a wall system to breathe, which promotes condensation through cracks and leaks. Their evidence suggests that this trapped moisture will build up and slowly erode the earth blocks and the bond holding the render in place, therefore destroying the structural integrity of the wall.

4.4 Impregnation

As stated by Adam and Agib (2001, p.53) “the soil is impregnated with a natural or chemical product which gives the following properties to the wall:

- Waterproofing
- Mixing of fine grains and particles to the surface thus hardening of the exposed wall surface
- Colouring

According to Houben and Guilaud, (1994), the impregnation product can be applied with either a brush or a spray-gun.

4.4.1 Linseed Oil

A prime example of a natural impregnation product is Linseed oil (Adam and Agib, 2001). Maeder and Wiegand (Unknown) explain that the linseed oil is the extract from flax plants, it come into two types raw (without chemicals) and boiled (with chemicals) linseed oil. The main difference between these two types is that boiled linseed oil contains chemical drying agents which cause it to dry quicker than that of raw linseed oil. Hall (2002) stated its effectiveness as a preservative and a waterproof, widely used in Australia and New Zealand for earthen walls.
4.4.2 Potassium Silicate

An example of a chemical impregnation product is potassium silicate. According to *Edison Coatings (2011)*, potassium silicate can be air dried to walls forming a film that maximises water resistance, bond strength and long-term durability. *Keefe (2005)* stated that potassium based products have water vapour permeability characteristics similar to that of earth constructed walls, allowing the wall to breathe more easily.

4.5 Stormdry

*Safeguard (2011)* the manufacturers of Stormdry stated “Stormdry is a colourless, breathable, water-repellent treatment for brick, concrete and stone walls. Once Stormdry has been applied to the wall surface it will permeate deeply (figure 5.41) before curing to form a water-repellent barrier”. According to *Safeguard (2011)*, Stormdry penetrates (impregnation waterproof) more deeply than traditional liquid-applied water repellents, therefore improving Stormdry’s crack-bridging ability. This will allow for water-repellence beyond the depth of small cracks as shown in figure 5.41. Also because Stormdry penetration is high, it will penetrate deeply into the more porous surfaces such as earth blocks.

*Figure 4.4.1- Stormdry deep penetration*

*Safeguard (2011)* stated that Stormdry has been tested to ENISO15148:2002 (E), demonstrating its effectiveness on concrete, mortar, brick and sandstone. The graph in *figure 5.42* demonstrates that the water uptakes for Stormdry treated samples were considerably lower than for untreated samples. *Safeguard (2011)* clearly indicates that Stormdry is only as effective as the depth of penetration within the material.

*Source: Safeguard (2011)*
Figure 4.4.2 - Stormdry Masonry protection on different substrates

However Safeguard has not only tested on conventional industrial materials but have also experimented on improving the water resistance for earth blocks (Safeguard, 2009). The samples obtained were small pressed earth blocks. Stormdry was applied to one of the samples and after 28 days of curing, New Zealand standards drip test was utilised to test the water absorption of the sample (Safeguard, 2009). Table 5.41 shows the results obtained from the experiment.

Figure 4.4.3 – Water absorption of treated and untreated pressed earth blocks

<table>
<thead>
<tr>
<th>Minutes</th>
<th>Stormdry applied</th>
<th>Untreated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.06</td>
<td>11.68</td>
</tr>
<tr>
<td>4</td>
<td>0.11</td>
<td>17.5</td>
</tr>
<tr>
<td>7</td>
<td>0.22</td>
<td>fell apart</td>
</tr>
<tr>
<td>11</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>1.18</td>
<td></td>
</tr>
</tbody>
</table>

Source: Safeguard (2009, p.1)
The results obtained from this experiment clearly show the significant benefit of Stormdry in improving water resistance.

4.6 Enviroseal

Enviroseal is a water repellent emulsion that is very similar to that of Stormdry. According to Basement Living, (2012) “When surfaces have been treated with Enviroseal they remain permeable to vapour. This means that any moisture which is within the structure is not trapped in any way furthermore it is also Alkali resistance”. It is also identifies the improvement of the overall insulation as the walls will be kept dry. BASF, (2012) identifies that Enviroseal is only effective if deep penetration occurs upon the material to ensure all small cracks are covered.

4.7 Engine Oil

This waterproof was identified from Browne (2009) report which established engine oil to be a relatively effective waterproof on stabilised interlocking rammed earth blocks. According to Browne (2009) due to its affordability and it being a waste product from vehicles it is a cheap alternative to other more expensive waterproof options.

4.8 Emulsion Paint

Emulsion Paint is mainly used as an atheistic for walls. However According to Dulux, (2012) the oil bases used within emulsion paint produce a protective layer to the surface it covers which makes the material it is coating water resistant from surface penetration. It is important to note that DIY How To, (2012) identifies that emulsion paint is only water resistant and not a waterproof agent.

4.9 Summary

The findings from this chapter gives a critical appraisal of existing waterproofs that have been utilised upon compressed earth blocks and innovative new products such as Stormdry, that may benefit the waterproofing of the compressed earth block. This chapter has given a clear understanding of the variety of waterproofs, therefore permitting an educated selection in waterproofs that will be tested within this research project.
Chapter 5. Methodology

5.1 Scope of Chapter

The Methodology implemented in this dissertation consisted of primary research in the form of a laboratory experiment that analyse how effective proposed waterproofs are in conjunction with compressed earth blocks. From the results of the laboratory experiment interviews were conducted to gain greater insight and understanding of what was found. It also contains secondary research in the form of a literature review.

5.2 Research Methods

This chapter explained the rationale for the authors chosen methods of research to best answer the dissertations aim, objectives and key questions.

5.3. Secondary Research

The literature review is a critical evaluation and should show that the writer has studied existing work of the subject with insight (Haywood and Wragg, 1982). The review will consist of journals, books and publications backed up with academic sources where possible. From this it will enable the identification of the main issues and the understanding to be drawn from comprehensive knowledge to better answer the key questions, and also to use more effective primary research that gave solid results.

Initial research has shown that there has been no in-depth investigation into progressive alternative waterproofs that could be utilised upon compressed earth blocks. Therefore it was important to critically analyse existing documents that evaluated compressed earth blocks and waterproofs, but also the rationale that required compressed earth blocks to have a waterproof layer in exposed areas. There was also an investigation into how water and moisture penetrates a compressed earth block, and the affects they had on the integrity of it. This helped to better understand what waterproofing prevents and, the seriousness of compressed earth blocks failing due to critical amounts of water and moisture.

The three chapters within the literature review focused on the production of blocks, how resilient they are to water penetration and various existing or potential surface treatments that could waterproof earth blocks.

Quantitative research method was applied in this research project. It can be defined as an inquiry into a human problem which is based upon testing a hypothesis or a theory that are composed of variables, measured with numbers and analysed with statistical procedures to identify whether the hypothesis or
the theory hold true (Cresswell, 1994), cited in Naoume, 2007). This is preferable to other methods due to the need to collect factual evidence from the water absorption test and study the relationship between the waterproofing, compressed earth block and compressed stabilised earth block to fully accomplish the aim, objectives and key questions.

The following were the key literature:

- Adam, E and A. Agib. 2001. Compressed Stavilised Earth Block Manugacture in Sudan
- Safeguard. 2011. Stormdry Masonary Protecion Cream
- UN HABITAT. 2009. Interlocking Stabilised Soil Blocks
- Sanya, T. 2007. Living in earth – the sustainability of earth architecture in Uganda

5.4. Primary Research

The laboratory experiment consisted of earth block construction, waterproof application and the water absorption RILEM Test. Each stage has its own method which was detailed within Chapter six. The results of the experiment were obtained and displayed in table and graph formats to best offer comparable examination.

The method used to produce the compressed earth blocks and compressed stabilised earth blocks were derived from the UN HABITAT, (2009) booklet that explained a stage by stage method in constructing the earth blocks, from the raw building materials to the finish product. This method was stated in Chapter 6 p.37. The reason for using the UN HABITAT method of construction was because the United Nation’s agency for human settlements (which promote socially and environmentally sustainable towns and cities), had an in-depth knowledge in earth construction and the implementation of it in poverty stricken areas around the globe. Thus this made it a reliable source from which to obtain a relevant and accurate method for the primary research.

To produce the earth blocks The Magika Ground Breaker Soil Block Press was used due to it being made by a reputable company called Magika from Kenya that manufactured and supplied this item to countries throughout Africa (Magika Engineering services Ltd, 2011). The earth mix was all produced on the same day and from the same source of materials. Clay and sand was used within the earth mix to produce a material that was close to laterite soil that is found in Uganda to make the result more relevant.

A pilot study was conducted to investigate the surface water absorption using the Stormdry Water Absorption Kit and the RILEM Test Method II.4. The pilot study was a small-scale version of the primary experiment that specifically examined the method and instrument involved. By completing a pilot study it gave forewarning of any faults that may occur so providing the opportunity to make changes before the primary experiment begun. The pilot study is shown in Appendix B.
The RILEM Test Method II.4 was developed by the Commission 25-PEM, a technical committee from the International Union of Testing and Research Laboratories for Materials and Structures, which tested the deterioration of masonry and to assessed the effectiveness of treatment methods. Unlike other methods such as BS EN 772-21:2011 which involved sinking the entire masonry brick into water to test the water absorption, The RILEM Test can be used on the surface area (such as the side face of a brick) to replicate rain water impaction and penetration. This was an important argument for using this method as unlike other methods The RILEM Test can pacifically measure the water absorption upon an area where the waterproofing has been applied. Therefore enabling the primary research to accurately obtain results on how effective each waterproofing was, as well as enabling easy comparison and examination. A more in depth explanation of The RILEM Test Method II.4 is shown in Chapter 4 p.30.

In the primary research two fired Michelmerh bricks and two unfired Michelmersh bricks were tested for their water absorption. This was done to identify a benchmark to enable a standard by which the earth blocks could be measured and judged. They were also collected from the same source day to increase equality. The rationale for choosing Fired Michelmersh bricks was the low compressive strength of 6 N/mm\(^2\) which was comparative to the standard compressive strength of compressed stabilised earth blocks (Michelmersh, 2012). The compressive strength for unfired Michelmersh bricks and compressed earth blocks were also similar. Therefore high compressive strength would not hinder or affect any results relating to the water absorption benchmark.

Once the quantitative results were obtained and analysed, email interviews were conducted to obtain views from professionals in the compressed earth block and waterproofing industries. The interviews were conducted using a semi-structured method. Unstructured questions were asked to start with, and increased structuring was introduced only later during the interview, therefore preventing the interviewee’s viewpoints biasing the interview (Naoum, 2007). By using this method it also allowed for the professional views to be accounted for and to enable educated questions that could explore factors that are directly concerned with the primary research. Results obtained from the interview were of a qualitative nature these interviews influenced the chosen testing methodology and the way in which I conducted the experiment to maximise successful results from the primary research (Naoum, 2007). The results from the qualitative interviews permitted a greater insight and interpretation of the quantitative results obtained from the primary research which lead to further research and support to the final conclusion of the dissertation.
Chapter 6. Primary Research

6.1 Introduction

This chapter identifies the methods that were both used to complete the prep-work and experiment that were referenced from the literature review. The chapter goes onto describe and analyses the results obtained from the experiment where key observations were evaluated.

6.2 Materials

Below is the list of materials required to complete this experiment:

1. Earth Block Construction
   1. Steel tray
   2. One handed metal mallet
   3. Shovel
   4. 6mm Sieve that fits onto a bucket
   5. Bucket
   6. The Magika Ground Breaker Soil Block Press
   7. Cement
   8. Water
   9. Sand
   10. Stromdry
   11. Rover Paint

2. Preparation Work for the RILEM TEST
   1. Small Paint brushes
   2. Waterproof Agents:
      - Cement Render
      - Emulsion paint
      - Engine Oil
      - Enviroseal
      - Flour/water paste
      - Linseed Oil
      - Potassium Silicate
      - Rover Paint
      - Stormdry
3. RILEM TEST METHOD II.4 (Water Absorption Test)

   1. A full Stormdry Water Absorption Kit:
      o 4 gauges
      o Water beaker
      o Adhesive Putty

   2. Elastic Bands
   3. Stopwatch
   4. Stormdry water absorption graph paper

6.3. Experiment Method

This section will describe three methods: the UN HABITAT method utilised to manufacture the compressed (stabilised) earth blocks, the application method for the waterproofs and the RILEM Test Method II.4 that will be used to measure water absorption.

6.3.1 UN HABITAT Method of Manufacture

1. Excavation

Usually the soil is excavated from sub-levels in the ground. However in this experiment the clay soil was obtained from a local brickwork factory which was then dried out within the laboratory. Once the soil had dried out to a sufficient amount they were continuously placed into a metal try where they were broken into small particles in preparation for sieving.

*Figure 6.3.1 – Soil placed into the metal tray  Figure 6.3.2 – Clay soil being broken down into smaller particles*
2. Sieving

Once the soil has been broken down enough it is then put through a sieving process in order to achieve 6mm granules to offer good compaction and finish when applied into the Magika Ground Breaker Soil Block Press. Once all the soil has been sieved it was then left to dry for two weeks to maximise effectiveness.

*Figure 6.3.3 – Crushed soil placed into sieve*  *Figure 6.3.4 – Soil after it has been sieved*

3. Mix Preparation and Mixing

For the stabilised compressed earth blocks the soil was weighed and a 5% measurement was taken to identify the amount of cement required within the mix. Upon mixing the dry matter water was introduced for wet mixing, thus activating the cement and instigate reaction.

*Figure 6.3.5 – Dry sieved soil*  *Figure 6.3.6 – Soil mixed with Portland cement*

4. Measuring the Mix

The stabilised and un-stabilised soil were placed with the optimum quantity being measured by making the soil level at the top of the mould as shown in *Figure 6.6*. It is important to mention the plain soil was placed in the machine before the stabilised to ensure no contamination occurred.
5. Compression of the Mix

Once the earth has been placed into the mould the lid is fastened on top of the machine and the earth is compacted by the use of a lever. The term used by Magika is the ejection stroke which involves pulling down on the lever, causing the mould to push upwards, therefore compacting the earth against the lid. Once the lever has been pulled down fully the lid is removed and the lever swung back to the other side to release the new form compressed earth block from the mould (Magika, Unknown, p.13). A more detailed explanation of the method used is explained in Appendix A.

6. Removal of the Block

Before the removal of block from the mould the texture and quality was checked. If the block was unsatisfactory it was place back into mix. When the block was of optimal quality it was carefully removed and placed in a sheltered area for curing. Curing is the process of controlling the setting or hardening of the cement, in order to acquire maximum strength and stop disintegrating. The earth blocks were cured in humid conditions to obtain the best results.
6.3.2 Waterproofing Application onto Earth Blocks

6.3.2.1. Linseed Oil Waterproof

Method is in accordance with Meagen, (2011) ‘Applying Linseed Oil’

1. With a small brush the linseed oil was applied to the earth block in long strokes.
2. It was left for 30mins to allow the linseed oil to soak into the earth block and with a soft cloth any excess was removed
3. This process was repeated three times to allow the linseed oil to penetrate deeply into the earth block to acquire the best result

6.3.2.2 Potassium Silicate

Potassium silicate was an experimental specimen within use with earth blocks. It is usually used as an additive in paint to make the paint more permeable. Due to the lacking of knowledge of the method to best apply the potassium silicate to the earth block the same method as the linseed oil will be used to keep continuity.

6.3.2.3 Enviroseal

Method is in accordance with Enivroseal (2011) ‘Application’

1. The treatment was applied with a small brush using uniform coating to the surface. The treatment was started at the highest point working from side to side.
2. Due to the earth block being highly absorbent surface two coats were applied with a 2 hour interval.

6.3.2.4 Stormdry

Method is in accordance with Stormdry (2010) ‘Application Guidelines’

1. Stormdry was applied by brush with a target coverage of 200ml/m².
2. The surface was checked for any ‘missed’ areas that have not been treated (e.g. voids).
3. Only one coat was required

6.3.2.5 Rover Paint

Due to there being no method available for the application of this waterproofing the same method principle for Stormdry was utilised for Rover Paint.

6.3.2.6 Cement Render

Method is in accordance with Agib and Adam (2004) ‘Renders’

1. A mix of ¼ cement, ¾ sand and a dash of water was produced in a small bucket for the cement render.
2. This was then applied to the surface of the earth block in a single thick layer with use of a small trowel. This was then left for 14 day period to ensure the render is cured to optimal effect.

6.3.2.7 Flour/Water Paste

This was an experimental specimen produced from a mixture of ⅓ water and ⅔ flour and was applied with a small brush in one thick layer to the earth block.

6.3.2.8 Emulsion Paint

Again this was an experimental specimen with no written documentation on its application onto earth blocks. Therefore a suitable method was used in which one medium layer of emulsion paint was applied to the earth block surface.

6.3.2.9 Engine Oil

Method is in accordance with Browne (2009) ‘Surface Treatments’

One thick coating was applied to the earth block surface with a small brush with special attention to all voids being well covered.
6.3.3 Water Absorption Measurement Test

The method of application is in accordance with Stormdry, (2011)

1. Before the Stormdry Gauge is applied a mastic adhesive is placed around the edge of the gauge in an ‘O’ ring ensuring there is no air gaps.

   *Figure 6.3.10 Mastic Adhesive*

2. The Stormdry Gauge was firmly placed onto the specimen for testing. The gauge was placed upright, with an elastic band wrapped around the gauges and specimens to ensure adhesion. Due there being two waterproofs on each of the side of the specimens two gauges were applied to cover for waterproofs.

   *Figure 6.3.11 Example of gauges ready for testing*
3. This process was repeated four times with 8 gauges being set up for water absorption measurement at a time.

*Figure 6.3.12 Example of Preparation work completed for testing*

4. Once each set were prepared the each gauges were filled simultaneously up to the point of 0. As soon as the gauges were filled the timer was started. Each gauge was measured every 5 minutes for 60mins to accurately examine the water absorption of each specimen. The results of this experiment are shown in the next section 6.4.
6.4 Experiment Results

6.4.1. Experimental Comparative Table and Graphs

Figure 6.4.1 Plain CEB Comparative Table

<table>
<thead>
<tr>
<th>Waterproof Agent</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stormdry</td>
<td>0.01</td>
</tr>
<tr>
<td>Envirosel</td>
<td>0.04</td>
</tr>
<tr>
<td>Emulsion Paint</td>
<td>0.08</td>
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<tr>
<td>Flour/Water</td>
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<tr>
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<tr>
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<tr>
<td>Un-waterproofed CEB</td>
<td>0.69</td>
</tr>
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</table>

Figure 6.4.2 Plain CEB Comparative Graph

6.4.2 Plain Compressed Earth Block Summary

Figure 6.4.1 and 6.4.2 identify that Stormdry was the most effective waterproof agent with a water absorption rate of 0.01ml/min and followed closely by Envirosel with a result of 0.04ml/min. It is important to note that the Rover Paint result had a significantly higher water absorption rate than that
of its United Kingdom waterproof counterparts Stormdry and Enviroseal. The results also show that all types of waterproofs tested within this experiment have a large effect in reducing water absorption compared to a un-waterproofed CEB.

**Figure 6.4.3 CSEB Comparative Table**

<table>
<thead>
<tr>
<th>Waterproof Agent</th>
<th>Water absorption (ml/min)</th>
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<td>Flour/Water</td>
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<tr>
<td>Potassium Silicate</td>
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<tr>
<td>Emulsion Paint</td>
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</tr>
<tr>
<td>Rover Paint</td>
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<tr>
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<td>Cement Render</td>
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<tr>
<td>Linseed Oil</td>
<td>0.56</td>
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<tr>
<td>Un-waterproofed CSEB</td>
<td>0.60</td>
</tr>
</tbody>
</table>

**Figure 6.4.4 CSEB Comparative Graph**

[Graph showing water absorption over time for various waterproof agents and un-waterproofed CSEB.]
Figure 6.4.5 Michelmersh Fired Brick
Comparative Table

<table>
<thead>
<tr>
<th>Waterproof Agent</th>
<th>Water absorption (ml/min)</th>
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<tr>
<td>Envirosal</td>
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<td>Emulsion Paint</td>
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<td>Engine Oil</td>
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</tbody>
</table>

Figure 6.4.6 Michelmersh Fired Brick Comparative Graph
**Figure 6.4.7 Michelmersh Unfired Brick Comparative Table**

<table>
<thead>
<tr>
<th>Waterproof Agent</th>
<th>Water absorption (ml/min)</th>
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<tr>
<td>Potassium Silicate</td>
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<tr>
<td>Envirosal</td>
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<td>Flour/Water</td>
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<td>Emulsion Paint</td>
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</tr>
<tr>
<td>Linseed Oil</td>
<td>0.54</td>
</tr>
<tr>
<td>Engine Oil</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**Figure 6.4.8 Michelmersh Unfired Brick Comparative Graph**

**6.4.4 Michelmersh Unfired Brick and Michelmersh Fired Brick Summary**

It can be seen from the results that the fired brick in general was the most absorbent of all the materials with only Envirosal being the exception. The unfired brick has results similar to that of the CSEB and compressed earth block therefore giving an appropriate benchmark to for the results found.
The results show both waterproofs worked successfully within the earth blocks. Stormdry has the same effectiveness within the earth block as it does as a protective layer and Rover paint has actually performed better as a stabiliser than that of a waterproof layer.
Chapter 7. Conclusion

7.1 Scope of Chapter

This chapter will look to encompass the whole dissertation and bring the chapters to a final conclusion. It will incorporate the key points from the literature review, the primary research and discussion, cross analysing and evaluating these against one another. Information and opinions obtained from professionals in this field will also be used in accordance with the results to produce further accuracy in the perception of what the findings show. The ability to complete Aim, Objectives and Key Questions will also be evaluated and discussed in context with what was answered within the dissertation.

7.2 Conclusion

One of the most interesting results obtained from the experiment was the difference in effectiveness of Stormdry on the Plain CEB and the CSEB. As Figure 6.4.1 and 6.4.2 show for Plain CEB Stormdry achieved a 0.01ml/min water absorption rate whereas Stormdry on CSEB had a water absorption rate of 0.14ml/min. This is a difference of 0.13ml/min which would therefore indicate that Stormdry is a more effective waterproof on a Compressed Earth Block that does not contain a cement stabiliser. Figure 6.4.9 and 6.4.11 identifies that Stormdry is also effective within side the earth block achieving the same result of 0.01ml/min as a surface waterproof layer. Reasoning for this is Stormdry’s effectiveness as a waterproof relates to the depth of penetration the Stormdry can achieve upon the material as explained in the Literature Review, p 34. Stormdry must penetrate deeply to effectively repel water and still be breathable. According to Stormdry, (2012) the depth of penetration is related to both the pore structure and pH. At high pH such as new concrete the bonding reactions are faster which means the depth of penetration is lower, due to viscosity building rapidly. In context with this research the Compressed Earth Block stabilised with cement will be less effective because of the cement content reducing the penetration of the Stormdry, thus causing it to be a less permeable on CSEB than CEB. This can also be said for Enviroseal which also heavy depends on deep penetration as identified in the Literature Review p.36.

From the Interview with Stormdry, (2012) it was also established that the alkalinity of the cement influences the penetration of the waterproof, which is certainly true for Stormdry, example of this is Stormdry’s penetration into a brick surface is 12 mm for a brick Fletton but reduced to 6mm with the same brick treated with alkali. This explanation supports the results obtained from the primary research p.45 as both Stormdry and Enviroseal were more effective on Plain CEB (no alkaline content) than CSEB (with alkaline content). It is important to note that the level alkaline within the cement will determine the level of penetration within the stabilised earth block. Therefore a recommendation and further research would be the possibility of using low-alkali cements within a
stabilised earth block. The results also show that waterproofs that rely upon forming an impermeable layer rather than penetration such as flour/water and emulsion paint were more effective on CSEB than CEB. This supports that impregnation waterproofs do not perform as well on a cement stabilised compressed earth block compared to a waterproof that produces a non-penetrative layer of water protection. However it is important to note that although flour/water was the most effective waterproof and emulsion paint was joint second upon CSEB Appendix D.2.2 and D.2.3 indicate that these protective layer treatments are not hard wearing with both being damaged from the adhesive putty of the gauge. This could be an issue concerning the durability of these waterproofs as day to day wear and tear will cause these surface treatments to erode. In regards to Key Question 2 impregnation waterproofs are suitable for CEB as the primary research shows that both Stormdry and Enviroseal (both impregnation waterproofs) were most effective upon this surface. However for CSEB flour/water surface treatment was the most effective waterproof, but the identification of wear and tear issues would conclude that impregnation waterproofs again would be most suitable as the durability of these waterproofs would be more beneficial due to low maintenance and the lower likelihood of moisture bypassing the waterproof.

Appendix D 1.3 and 1.4 show that the most effective waterproofs upon CEBs Stormdry (0.01ml/min) and Enviroseal (0.04ml/min) had no visible damage from the experiment showing that the integrity of the CEB was kept intact. However for the rest of the waterproofs the amount of water penetration caused the CEBs to take visible damage showing how the CEBs had lost its structural integrity on the point of contact. However on CSEBs no visible damage was seen throughout the waterproofs establishing how stabilising an earth block increases the structural strength of the block dramatically. This corresponds with the information evaluated in the literature review p.25 where according to Adam and Agib (2001) a cement stabiliser can increase the resistance of erosion by 400% to 500% which the images from the experiment clearly show. It is important to identify from the literature review p.30 that the water pressure from the gauge onto the earth block equates to wind driven rain of 98mph and due to the experiment having duration of an hour. In reality this would relate to severe weather conditions, therefore giving an indication of how well the waterproofs will perform in some of the worst weather conditions that will be presented against them. In accordance with objective 3 it can be seen that the level of penetration can cause greater damage to CEBs than CSEBs, however the waterproofs that were effective upon the CEBs (Stormdry and Enviroseal) had minimal damage showing that the waterproofs that prevent a substantial amount of water penetration will keep the integrity of the block intact, however if the waterproof inadequately prevents water penetration the CEBs will structurally deteriorate quickly. This however is not true with CSEBs and the hour long experiment did not visibly affect the CSEBs structurally, this therefore shows the level of water penetration will need to be greater upon a CEB than that of a CEB to visibly affect the surface.
The primary research distinguishes that although certain waterproofs are more effective on both CSEBs and CEBs, when left unprotected all waterproofs have a lower water absorption rate than leaving them exposed. *Figure 6.4.1 and 6.4.2* identify that having a waterproof makes a vast differences in the water absorption rate for CEB. Even with the poorest performing waterproof Linseed oil the water absorbed per minute (0.24 ml/min) is nearly three times lower than leaving it unprotected (0.69 ml/min), whereas waterproofing the CEB with Stormdry (0.01 ml/min) the absorption rate is 69 times lower. This also identifies that although Rover Paint is less effective on CEB, the waterproof still dramatically decreases the water absorption. CSEB on the other hand did have waterproofs that were close to unprotected water absorption rate such as cement render and linseed oil. However the results do show that waterproofs that did not perform as well on CSEB such as Stormdry and Enviroseal still were very effective compared to leaving it unprotected. *Figure 6.4.3 and 6.4.4* show Stormdry had a result of 0.14 (ml/min) which is more than 4 times lower than that of un-waterproofed CSEB with a result of 0.60 (ml/min). By evaluating the difference between waterproofed and un-waterproofed it can be identified that although manufactured waterproofs do not work as effectively on CSEB compared to CEB they still dramatically reduce the water absorption rate on both types of block. As Kerali (2000) states in the literature review p.29 the actual destructive action of moisture is when it penetrates the earth block causing disruptive internal stress. Therefore according to Kerali (2000) the capacity of the block to resist the disruptive action of moisture will differentiate the life span of the earth block. From the primary research it clearly shows that the waterproofs reduce moisture penetration for both CSEB and CEB, therefore in theory these blocks will have a longer life span than un-waterproofed blocks. This would lead to a vast improvement in the structural integrity over the life time of any earth block construction. This therefore answers objective 2 and clearly finds that compressed earth block constructions stabilised or plain will benefit from having a waterproof coating as it will increase the lifetime of the building but also reduce the maintenance required.

According to Green Earth Trust (2012), Rover Paint is the most common waterproof in Uganda and is used regularly on CSEB buildings. As the results show in *Figure 6.4.3 and 6.4.4* potassium silicate and emulsion paint both had the same water absorption of Rover Paint at 0.11 ml/min. Conversely the photo in Appendix D 3.7 show emulsion paint was heavily eroded by the hour long experiment due to it being protective layer treatment and its integrity over a longer period is questionable. However as 5.4 of the literature review p.33 states potassium silicate is an impregnation treatment same as Rover Paint and due to this characteristic are permeable for a greater length of time. Green Earth Trust (2012) explains that for many small Uganda communities Rover Paint can be slightly unaffordable and restrictions on its use are often applied when constructing a CSEB building, therefore an effective cheaper alternative would be very desirable for these communities. Due to this further research was performed from the primary research results identifying that potassium silicate has the potential to be
an alternative waterproof. This further research was successful in obtaining a Pro Form Invoice from PQ Silica South Africa Ltd that produces Potassium Silicate. With the help of Green Earth Trust (2012) it was possible to calculate the average cost of waterproofing typical CSEB building with Rover Paint and potassium silicate (Appendix E). From these calculations it was identified that potassium silicate will cost 3 USD per litre whereas Rover Paint costs 5 USD per litre. This is a difference of 2 USD per litre and due to it taking 20 litres of waterproof to cover one basic CSEB building this could amount to a huge saving of 40 USD for the constructors and home owner. Therefore as Key Question 4 states ‘Could alternative waterproofing’s be an economic advantage to earth block construction in third world countries such as Uganda?’ and answer to this could be potassium silicate as a cost saving waterproof that could be viable for CSEB construction in Uganda making it possible for more poorer communities to have access to efficient waterproofing for their homes and communal buildings.

The literature review p.26 identifies that according to Sanya (2007) research, CSEB is not economically beneficial in the Ugandan context because of the unavailability of cement. Earth Trust (2012) agrees with this statement explaining “in Uganda the cost of stabilizer (cement) in CSEB has always been prohibitive – accounting for more than 50% of the cost of the block”. Due to high cost and low availability of cement the primary research shows that waterproofs can be an alternative to help improve the performance of a plain CEB to resist water penetration and to be a low cost way in which improve this compared to cement stabilisation. This however does depend on the accessibility of the waterproofs to the location of the site. From this objective 1 has been considered and the primary research shows that the waterproofing can increase the performance of moisture resistance and be beneficial economically to Ugandan communities.

Stormdry and Rover Paint were not only tested as surface waterproof but also as a stabiliser waterproof agent. From Figure 6.4.9, 6.4.10 and 6.4.11 both waterproofs were successful in producing low water absorption rates with Rover Paint actually being more effective as a stabiliser (0.09 ml/min) than a waterproof surface treatment on both CEB (0.18 ml/min) and CSEB (0.11ml/min). This test was in junction with Key Question 3 which stated “Is waterproofing best used as a coating or used within the earth block”. From the test in can be seen that using the waterproofs inside the block were as good as if not better than their counterparts as surface treatments, however it is important to note that the effect of adding a waterproof stabiliser has to the compressive strength of the earth block is unknown, as the waterproof stabiliser may cause a decrease in its strength thus making it non-viable for load bearing walls. Therefore further testing is required to identify waterproof stabilising as an effective waterproofing alternative.

From the information and data gained from the literature review and primary research the Aim of the dissertation was fulfilled. This is due to the literature review identifying the restraints of CEBs and
CSEBs, which lead to further research into possible waterproofs that would adhere to this material. This research enables an appropriate test method that simulated rainfall absorption into an earth blocks to gain results that tested waterproof compositions to compressed earth blocks and compressed stabilised earth blocks that enabled critical evaluations of suitable waterproofs that could be used within Uganda.

7.3 Recommendations

From the research investigated and gathered within this research project it was identified that the majority of waterproofs used upon CEBs and CSEBs significantly reduced surface water absorption compared to them being untreated. This consequently improves the durability and structural integrity of the blocks, allowing for less maintenance and better performance of the earth block building.

However it is important to note that waterproofs are more effective upon CEB than CSEB due to the bonding reaction between the stabiliser and waterproof causing an increase in surface water penetration. Although from the information analysed within the conclusion CEB inhibit more damage from water absorption due to the lack of a stabiliser, thus identifying that it would be recommended that waterproofs upon CSEB is advisable due to the earth block itself having more resistance to water damage.

Stormdry was found to be the most effective waterproof upon CEB and therefore it is recommended that it would be used upon CEB in Uganda where cement stabiliser is often too expensive to obtain, this however will depend on the cost of importing Stormdry. Potassium silicate was found to be an innovative waterproof that performed as effectively as Rover Paint (existing Ugandan waterproof) upon CSEB. From the evaluation within the conclusion it was found that potassium silicate was also a cheaper alternative to Rover Paint in application within Uganda. Due to these findings it is recommended that potassium silicate is trail tested within Uganda to further identify its effectiveness as a CSEB waterproof. Potassium silicate could be an effective alternative for Ugandan’s poorer communities that do not have the finances to purchase Rover Paint.

From the information and data gather and evaluated throughout this research project the main recommendation is that having a waterproof on either a CEB or a CSEB is advisable over having none, although some waterproofs work better on CEB than CSEB and vice versa or that CSEB can be a better choice to waterproof, by having either CEB or CSEB untreated will significantly increase the surface water they absorb, thus concluding the most important recommendation is to waterproof CEB and CSEB.
7.4 Limitation of Research

It is important to note that due to the earth compositions being made from English Soil (Clay soil) compared to Ugandan Soil (Laterite Soil) this research was only a comparison test that hopefully gave relevant results that can be implemented with regards to blocks made from Ugandan soil. Also only a small sample was used in this research project and for conclusive evidence of results a greater amount of samples would be required.

7.5 Areas of Further Research

The research could be expanded by trial testing the most effective and cheap alternatives in Uganda or other African countries. This is because Ugandan soil (laterite soil) is very different from that of UK soil (clay soil) thus the chosen waterproof may react better or worse with the laterite soil. Also the samples in this research project were tested in a controlled environment on singular blocks and further research could be to implement with these waterproofs on actual earth block buildings in Uganda to identify their performance against actual weather cycles over a period of time.

A third area of further research could be to identify the effectiveness of waterproofs upon the joints between the earth blocks. Within this research project the area of examination was limited to the surface area of the block and not the joints that connect these blocks together. An analysis could be conducted that primarily looks at waterproofs upon the joints thus identifying if the waterproofs can act as a permeable barrier over the entire earth block wall.

Further research could be to investigate the possibility of using waterproofs within CEBs as the primary research identifies its effectiveness to prevent water absorption but not in terms of the effect to the structural integrity of the block.
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</table>
Making Blocks

Introduction
The stages described in this section are very important and must be strictly followed, if good blocks are to be produced. Any temptations to skip the process described may lead to the production of poor quality blocks.

1. Soil preparation
   - The soil is dug and the big lumps are crushed before the sieving is done.
   - The soil is then sieved through a 6 mm sieve. Note that the particles which are retained on the sieve can be further crushed and sieved again.

2. Batching and mixing
To carry out this operation, you must refer back to the results of your box test to see the ratio of cement and soil you are supposed to use. For all batching, you must always use the bucket.
   - Using the bucket, batch out the soil and cement required for a particular production.
   - Using the shovel, the cement and soil are mixed 3 times dry until the mix is one uniform colour.
   - Water is then added gradually until it is enough. This is an operation which requires special care as the mix is only required to bind itself. If you squeeze the mix in your hand, no water should come out in between your fingers.

3. Loading the Press
   - The press is opened
   - The piston is checked to ensure that it is sitting on the adjusted knob.
   - The inside of the mould box is oiled. This is only done at the start and when the blocks tend to stick.
   - The mould box is then filled flush on top with the mix.
   - The mould cover is dropped gently to cover the mould box. In so doing, the soil inside is pre-compacted.

4. Compacting the block
The handle is brought to the vertical position ensuring that the rollers fit in their curved position.
   - The lever latch is opened as the person on the other side takes over the handle to compact the block.
   - The handle is brought down by the person compacting the block until the lever arm touches the compaction stopper has been achieved.
5. **Ejecting the block**
   The handle is now passed over to the person on the opposite side of the press to start the ejection stroke.
   - The lever latch is locked in position, while the handle is moved from the vertical position so that the cover can be opened.
   - The handle is now brought all the way down as the block is being ejected all the way up.
   - The block is now removed gently by holding along the long sides and taken to a well sheltered floor/ground for curing.

   Compressing the block.

   Ejecting the block.

   Warning
   The handle should never be pushed down for the ejection or compaction stroke by two people at anytime. This can make the machine to break down.

   Curing
   The last process of making blocks is curing. This starts the following day after production when the blocks are approximately 24 hours old. Curing is the process of controlling the setting or hardening of cement, in order to acquire maximum strength and stop disintegrating. To acquire maximum strength for any cement product, the product must set slowly in wet or humid conditions.

   This is what is referred as curing. If curing is not done properly, then the final product will be of poor quality all the time and money spent in producing the blocks will have been wasted. The curing procedures are described below.

   **How to cure the blocks.**

   There are two simple ways of keeping the blocks dump to ensure that they are well cured.

   **(A) 1st Method**
   - The blocks are covered with grass, leaves or any other suitable material to protect them from direct sunlight.
   - The blocks are then watered every morning and evening for a minimum of 7 days.

   Curing the Blocks by covering them with grass.
Appendix B – Pilot Study

1. Introduction

This pilot study was completed as a pre-test of the investigation into surface water absorption of compressed earth blocks using the Stormdry Water Absorption Kit (Figure 1). The pilot study was a small-scale version of the primary research that specifically inspected the method and instruments that will be used for the full-scale study. By completing a pilot study it will give forewarning of any faults that may occur in the main primary research.

Figure 1.1 – Stormdry Water Absorption Kit

2. Aim

This pilot study aims to establish any faults in the primary research method and to identify any necessary adjustments

3. Objectives

1. Ensure all instruments are you used to the correct method
2. Record any faults that occur within the pre-test

4. Limitations

Due to the time scale of the Pilot Study no waterproofing was used on either of the samples. Therefore the Stormdry Gauges were used upon the natural surface of both samples. The pilot study was exclusively to do with the ability of the test kit and the method of the primary research.

5. Method
1. A standard Michelmersh masonry brick and interlocking compressed stabilised earth block was used as the samples for the pilot study. The stabilised material within the earth block was 5% cement.

2. The Stormdry Gauges were stuck upon both samples with mastic adhesive and slowly filled until the water level reaches the 0ml mark on the Stormdry Gauge as shown in Figure 5.1.

3. As soon as both gauges were filled the timer was started. The gauges were continually checked to see the rate of water level depreciation and recorded at 5, 10, 15, 30 and 60 minute intervals (Figure 5.2).

4. With the recorded results they were used to produce a water ingress graph to show the water absorption rates.

5. **6. Results**

By recording the rate of water absorption of the earth block and masonry brick it was possible to produce the following table and graph. This will allow for further understanding and investigation in discussion for the primary research method.
Table 6.1- Water Ingress Table Results

<table>
<thead>
<tr>
<th>Minutes</th>
<th>Earth Block Water Absorption (ml)</th>
<th>Masonry Brick Water Absorption (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1.20</td>
<td>4.50+</td>
</tr>
<tr>
<td>10</td>
<td><em>Detached</em></td>
<td>4.50+</td>
</tr>
<tr>
<td>15</td>
<td><em>Detached</em></td>
<td>4.50+</td>
</tr>
<tr>
<td>30</td>
<td><em>Detached</em></td>
<td>4.50+</td>
</tr>
<tr>
<td>60</td>
<td><em>Detached</em></td>
<td>4.50+</td>
</tr>
</tbody>
</table>

Graph 6.1 – Stormdry Water Ingress Graph
minutes absorbing the water past 450ml. Whereas the earth block had a reading of 120ml at the 5 minute recording interval but it proceeded to disintegrate resulting in the adhesion to fail at 7:01 minutes.

6.1 Observations

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Image</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:42</td>
<td><img src="image1.png" alt="Image" /></td>
<td>At 42 second it can clearly be seen that the masonry brick has already begun to absorb a considerable amount of water compared to the earth block which has only begun to dip below 0ml.</td>
</tr>
<tr>
<td>1:55</td>
<td><img src="image2.png" alt="Image" /></td>
<td>At 1:55 minutes the earth block has started to absorb the water with it halfway between 0ml and 100ml. Whereas the masonry brick has absorbed over half of the water within the gauge and evidence of a water circle was beginning to appear surrounding the mastic adhesive.</td>
</tr>
<tr>
<td>2:16</td>
<td><img src="image3.png" alt="Image" /></td>
<td>2:16 minutes the masonry brick has clear visual evidence of the water absorbing into the brick and has just hit the 300ml mark.</td>
</tr>
<tr>
<td>Time (Minutes)</td>
<td>Image</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td>2:29</td>
<td><img src="image1.png" alt="Image" /></td>
<td>At this stage the earth block is performing much better than that of the masonry brick with it still only just reaching 100ml mark.</td>
</tr>
<tr>
<td>4:16</td>
<td><img src="image2.png" alt="Image" /></td>
<td>At this point the masonry brick has now gone past the 450ml mark and has failed to reach the first recording interval of 5 minutes. The earth block however is maintaining its slow absorption rate but as the next image shows the earth block is starting to disintegrate within the gauge.</td>
</tr>
<tr>
<td>4:25</td>
<td><img src="image3.png" alt="Image" /></td>
<td>This image clearly shows how the earth block is disintegrating within the gauge and the water is starting to spread away from the entry point.</td>
</tr>
<tr>
<td>7:01</td>
<td><img src="image4.png" alt="Image" /></td>
<td>At 7:01 minutes the earth block disintegrated enough for adhesion failure between the mastic adhesive and the earth block causing the gauge to become detached spilling the water within it.</td>
</tr>
<tr>
<td>Time (Minutes)</td>
<td>Image</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td><img src="image1.jpg" alt="Image 1" /></td>
<td>From these two images it is possible to see how the water has penetrated into the earth block rather than spreading across the surface.</td>
</tr>
<tr>
<td></td>
<td><img src="image2.jpg" alt="Image 2" /></td>
<td>The masonry brick on the other hand the water has spread across its surface and into the brick.</td>
</tr>
</tbody>
</table>
7. Discussion

By analysing the results and observations obtained from the pilot study it is very clear that the masonry brick is much more absorbent than that of the earth block where it acted in a ‘sponge effect’ soaking up the water in all directions. The water in the earth block on the other hand did not spread across the surface but penetrated deeper into the block and spread unevenly. In stabilised compressed earth blocks the addition of cementations binders’ (Portland cement) increases porosity (Appendix B.1) and sorptivity (Appendix B.2) significantly (Hill and Allinson 2008, pg.692). Thus leaving voids within the earth block resulting in a high rate of absorption. As stated by Hall and Allinson (2008, pg. 688) “In cohesive soils, many particles are finer than cement grains and thus cannot be coated by cement”. Due to this Stabilised earth blocks do not have uniform absorption as water will be absorbed differently between the cement-soil particles and the plain-soil particles causing uneven spread of water absorption (Hill and Allinson 2008, pg.692). This can be clearly seen from the images from the 6.1 observations. The reason for the water penetrating horizontally rather than vertically into the earth block is due to the horizontal pressure being applied from the water exiting the gauge as shown in Figure 7.1. Because of the voids explained early and the pressure from the gauge the water will penetrate deeper into block than spreading outwards.

*Figure 7.1 – Water pressure against earth blocks*

The pilot study also brought up an interesting example of how earth blocks and masonry bricks act without any waterproofing when put under pressure of water. As it can be seen from the results the masonry brick did not even make it to the first record interval showing how pronounce its water absorption capabilities are. This is due to its high porosity which comes from its fine capillaries thus causing the capillary effect (Clay Bricks, 2011). G. Eckhart (2011) explains capillary effect to be
“movement of water through very small spaces due to molecular forces called capillary forces”. As stated by Clay Bricks (2011) “By virtue of the capillary effect, the rate of moisture transported in the brick is ten times faster than in other building materials”. Although moisture does not affect the integrity of the brick, the contamination (i.e. salt and weathering agents) that may be in the water that is being absorb can cause chemical attacks which will cause erosion (Clay Bricks, 2011).

This confirms that the earth blocks and masonry bricks both act differently to water absorption, earth blocks with their ununiformed characteristic and masonry bricks with their capillary characteristic.

Due to the characteristic of the earth block it will be recommended for the primary research method that a form of support is given to the Stormdry Gauge during the testing of each of the earth blocks to ensure that the gauges do not become detached from the earth blocks. Also by doing this it will allow the primary research test to focus on the water absorption of the earth blocks rather than the structural strength.

From the pilot study it is evident that the Storm Dry Test Kit works successfully with each piece of equipment working effectively. It also confirmed that earth blocks and masonry bricks alike are water absorbent without any waterproofing, and as it can be seen from the pilot study it can lead to disastrous strength failure for earth blocks in particular.

When examining results and observations of the pilot study it is clear that the area of water absorption within a stabilised compressed earth block is relatively small and because of this it will be possible to have at least two different waterproofs on each side of the earth block. This minimise the amount of earth blocks that will need to be constructed saving valuable time.

8. Conclusion

The pilot study enabled a greater understanding of how water absorption takes place in both the earth block and masonry brick. It also clarified the effectiveness of the Stormdry Water Absorption Kit at testing the speed of water absorption. It also gave me a greater understanding of how both none waterproofed earth block and masonry brick react to water absorption and why waterproofing is an important factor in maintaining the integrity of both samples. Changes will also be made to the primary research method due to the earth block gauge becoming detached in the pilot study. Investigation will begin in ways in which to support the gauge through the primary research test to ensure that accuracy on water absorption is maintained.

Appendix B.1 – Porosity and Porous Definition

po·ros·i·ty

1. The state or property of being porous.
2. A structure or part that is porous.

3. The ratio of the volume of all the pores in a material to the volume of the whole.

Source: Farlex, (2011)

po·rous

1. Full of or having pores.

2. Admitting the passage of gas or liquid through pores or interstices.

3. Easily crossed or penetrated.

Source: Farlex, (2012)

**Appendix B.2 - Sorptivity**

Is described as a measure of the capacity of the medium to absorb or desorb liquid by capillarity.

Source: Farlex, (2012)
Appendix C – Individual Tables and Graphs of Waterproofs

### Engine Oil

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain CEB</td>
<td>0.13</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.37</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.70</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>1.43</td>
</tr>
</tbody>
</table>

![Engine Oil Graph](image)

### Potassium Silicate

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.04</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.11</td>
</tr>
<tr>
<td>Plain CEB</td>
<td>0.18</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>1.22</td>
</tr>
</tbody>
</table>

![Potassium Silicate Graph](image)
### Emulsion Paint

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.20</td>
</tr>
<tr>
<td>Plain CEB</td>
<td>0.08</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.11</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>0.51</td>
</tr>
</tbody>
</table>

#### Linseed Oil

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain CEB</td>
<td>0.24</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.54</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.77</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>1.32</td>
</tr>
</tbody>
</table>

---

**Emulsion Paint**

![Graph showing water absorption over time for different materials using Emulsion Paint.](image)

**Linseed Oil**

![Graph showing water absorption over time for different materials using Linseed Oil.](image)
### Rover Paint

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSEB</td>
<td>0.11</td>
</tr>
<tr>
<td>Plain CEB</td>
<td>0.18</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.20</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>0.85</td>
</tr>
</tbody>
</table>

![Rover Paint Graph](image1)

### Flour/Water

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSEB</td>
<td>0.09</td>
</tr>
<tr>
<td>Plain CEB</td>
<td>0.12</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.11</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>0.85</td>
</tr>
</tbody>
</table>

![Flour/Water Graph](image2)
**Envirol Seal**

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelmersh Fired Brick</td>
<td>0.00</td>
</tr>
<tr>
<td>Plain CEB</td>
<td>0.04</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.06</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.37</td>
</tr>
</tbody>
</table>

**Stormdry**

<table>
<thead>
<tr>
<th>Material</th>
<th>Water absorption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain CEB</td>
<td>0.01</td>
</tr>
<tr>
<td>Michelmer Unfired Brick</td>
<td>0.16</td>
</tr>
<tr>
<td>Michelmersh Fired Brick</td>
<td>0.64</td>
</tr>
<tr>
<td>CSEB</td>
<td>0.67</td>
</tr>
</tbody>
</table>
Appendix D – Photos of the Primary Research

Appendix D.1 – Plain Compressed Earth Blocks after the experiment

Appendix D.1.1 – Engine Oil and Emulsion Paint

Appendix D.1.2 – Potassium and Linseed Oil
Appendix D.1.3 – Rover Paint and Stormdry

Appendix D.1.4 – Flour/Water and Enviroseal
Appendix D.2 – Compressed Stabilised Earth Blocks after the Experiment

Appendix D.2.1 – Cement Render

Appendix D.2.2 – Flour/Water
Appendix D.2.3 – Emulsion Paint

Appendix D.2.4 – Rover Paint
Appendix D.2.5 – Engine Oil

Appendix D.2.6 – Stormdry

Appendix D.2.7 – Potassium Silicate
Appendix D.2.8 – Enivroseal

Appendix D.2.9 - Linseed Oil
Appendix D.3 – Fired Michelmersh Brick

Appendix D.3.1 – Flour/Water

Appendix D.3.2 – Potassium Silicate
Appendix D.3.3 – Enviroseal

Appendix D.3.4 – Linseed Oil
Appendix D.3.5 – Stormdry

Appendix D.3.6 – Rover Paint
Appendix D.3.7 – Emulsion Paint

Appendix D.3.8 – Engine Oil
Appendix D.4 Unfired Michealmersh Brick

Appendix D.4.1 – Flour/Water and Potassium Silicate

Appendix D.4.2 - Stormdry and Rover Paint
Appendix D.4.3 – Emulsion Paint

Appendix D.4.4 – Engine Oil

Appendix D.4.5 – Linseed Oil
Appendix D.4.6 – Enviroseal

Appendix E – Potassium Silicate and Rover Paint Calculations

On average, a residential housing unit (basic) measures approximately 200m$^2$ in surface area (externally).

As stated by *Green Earth Trust, (2012)* 1 litre of waterproofing covers 10m$^2$ with brush application.
\[
\frac{200}{10} = 20 \text{ litres}
\]

This calculation identifies that at least 20 litres of waterproofing is required to paint a basic house.

Rover Paint within Uganda cost 5 USD per litre \((Green Earth Trust, 2012)\). Whereas potassium silicate costs 3 USD per litre \((PQ Silicas South Africa Pty Ltd, 2012)\).

\[
\text{Rover Paint}
\]

\[
5 \times 20 = 100 \text{ USD}
\]

\[
\text{Potassium Silicate}
\]

\[
3 \times 20 = 60 \text{ USD}
\]

This is a saving of 40 USD for every basic house within Uganda.

**Appendix F – Ethics Disclaimer**
# ETHICS RELEASE CHECKLIST FOR RESEARCH AND ENTERPRISE PROJECTS

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. Will the project involve human participants other than the investigator(s)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1a. Will the project involve vulnerable participants such as children, young people, disabled people, the elderly, people with declared mental health issues, prisoners, people in health or social care settings, addicts, or those with learning difficulties or cognitive impairment either contacted directly or via a gatekeeper (for example a professional who runs an organisation through which participants are accessed; a service provider; a caregiver; a relative or a guardian)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1b. Will the project involve the use of control groups or the use of deception</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1c. Will the project involve any risk to the participants’ health (e.g. invasive intervention such as the administration of drugs or other substances, or vigorous physical exercise) or involve psychological stress, anxiety, humiliation, physical pain or discomfort to the investigator(s) and/or the participants?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1d. Will the project involve financial inducement offered to participants other than reasonable expenses and compensation for time?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1e. Will the project be carried out by individuals unconnected with the University but who wish to use staff and/or students of the University as participants?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1f. Will personal data OTHER THAN gender, age and address of participants be collected as part of the project? (For monitoring and data analysis purposes only. When asking for age, use age brackets, such as 16-24, 25-39, 40-49, 50-59, 60+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2. Will the project involve sensitive materials or topics that might be considered offensive, disturbing, politically or socially sensitive, deeply personal or in breach of the law (for example criminal activities, sexual behavior, ethnic status, personal appearance, experience of violence, addiction, religion, or financial circumstances)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3. Will the project have detrimental impact on the environment, habitat or species?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4. Will the project involve living animal subjects?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5. Will the project involve the development for export of ‘controlled’ goods regulated by the Export Control Organisation (ECO)? (This specifically means military goods, so-called dual-use goods (which are civilian goods but have a potential military use or application), products used for torture and repression, radioactive sources.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scenario: An Ethics Release applies to the project.

- The information contained in this checklist is correct.
- I have assured the ethical considerations in relation to the project in line with the University Ethics Policy.
- I understand that the ethical considerations of the project will need to be re-assessed if there are any changes to it.

Signed by (ALL) the Investigator(s):

If the principal investigator is a student:

I confirm that, as supervisor:

- I have discussed the ethical considerations in relation to the project with the investigator(s) involved.
- I have read and agreed the information in this checklist.
- I will monitor progress of the project.

Signed: [Signature]

Print Name: [Signature]

Date: 3/9/12


03/05/2012