MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

DEPARTMENT OF ARCHITECTURE AND PHYSICAL PLANNING

Interlocking Stabilised Soil Blocks; An evaluation of the use of the building material in low-cost housing in Uganda.

A study of the Dry Stacked Method

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A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF ARCHITECTURE

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Special thanks got to Mr. Herbert Mugisa, Mrs. Catherine B and Mrs. Joy of Hydraform for the resourceful information they provided.

DECLARATION

I Morris Atuhwera, hereby declare to the best of my knowledge that this project proposal report submitted, is my original work and has not been presented to any other University, Institute, organisation or published except where due reference has been made. This dissertation has been submitted with the approval of my supervisor, Arch. Doreen Kyosimire.

Signature..................................

MORRIS ATUHWERA 09/U/3003/PSA

March 2015

This design project report has been submitted for examination with my approval as the University supervisor for the above mentioned candidate.

Signature.................................. Date...17/11/2015...........

Arch. DOREEN KYOSIMIRE

ABSTRACT

Luweero district has had a history of war that left part of the region devastated. The housing deficit that arose as a result has led to challenge of informal growth marked by structures that are constructed with semi-permanent or temporary materials as the majority of residents cannot afford using modern building materials. This has resulted to the depletion of the natural vegetation in the quest of acquiring/making building materials that are socially accepted. The project proposal introduces interlocking stabilised soil blocks (ISSBs) as a means of providing low cost housing that is eco-friendly.

The study sought to evaluate the extent to which low cost housing can be achieved by using of interlocking stabilised soil blocks as the building material. Studies were done on structures constructed using ISSBs on projects within the central region in Nansana, Wakiso district and Luweero district. The variables under investigation included affordability, eco-friendliness, aesthetic and durability qualities, psychological aspects of the building material, social influences and cultural beliefs.

The data collected was analysed both qualitatively and quantitatively, and represented using illustrations/sketches, graphs and charts.

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ABBREVIATION AND DEFINITION OF TERMS

CEB: Compressed Earth Blocks

CSEB: Cement Stabilised Earth Blocks

CRATerre: Earth Architecture Research Laboratory in Grenoble, France

ISSB: Interlocking Stabilised Soil Blocks

MDG: Millennium Development Goals

MFPED: Ministry of Finance, Planning and Economic Development

NEMA: National Environment Management Authority

NGO: Non-Governmental Organisation

PISAT: Presidential Initiative to Support Appropriate Technology

UN: United Nations

UNBS: Uganda National Bureau of Standards

UNBOS: Uganda National Bureau of Statistics

CHAPTER ONE

INTRODUCTION

1.1 Background

Vernacular architecture has long seen the use of earth as a convenient building material because of its sustainable aspects most especially in rural areas. The traditional building techniques often use a lot of wood and the reconstruction needs risk to further accelerate environmental degradation. The making of these construction materials among other human and economic activities, according to the NEMA (2010) are responsible for the exhaustion of natural resources that is now causing an alarm[1].

Earth construction techniques have been replaced by burnt bricks and concrete blocks as a material of choice for construction even in the most remote of places, placing pressure on the countryộs natural vegetation in addition to the reliance on biomass for the energy needs by over 92% of the population, primarily wood fuel to enable them carry out their undertakings[2]. NEMA state of environment report, 2010 cited in MDG report (2013), agrees that the link between Ugandaộs natural resource and economic development can clearly be comprehended in the energy sector.

To tackle the current environmental crisis, a total change of the patterns of production, distribution and consumption through new approaches like the Green Economy where research and development of green technologies/processes that effectively reduce climate change and damage to the environment are recommended.

The UN-HABITATộs commitment to support sustainable development has seen the promotion and development of appropriate technologies which use materials, methods or practices that help preserve the natural environment[3]. One of these technologies is the Interlocking stabilised soil blocks which makes use of earth/soil that is compressed within moulds to form blocks.

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[1] National Environment Management Authority (NEMA) (2010) State of the environment report Available at: www.nemaug.org

[2] Ministry of Finance, Planning and Economic Development (2013, Sept) Millennium Development Goals Report for Uganda

[3] UN-Habitat (1996) Earth Construction Technology, UN-Habitat. Nairobi

The idea of earth construction technology is not a new platform, prior research has been done on some methods, particularly in stabilised earth blocks[4] (Robert, 1997) and direct shaping method[5] (Kenneth, 2000) let alone in Cement Stabilised Earth blocks (CSEB). However, this research focuses on the dry stacking method of wall construction where no mortar is bedded in the courses.

1.2 Problem statement

Nations in the world over are concerned with the use of convenient, cheaper and sustainable methods of achieving development with minimum impact to the environment since the conventional methods used pose a global challenge with the carbon emissions through their process of production.

Contemporary earth construction to a large extent shows significant evidence solving housing crisis in the developed countries still addressing excessive carbon dioxide emissions, global warming and climate change. But environmental sustainability is still a major challenge and the built environment discipline professionals are facing this enormous task to tackle the problem all over the world.[6]

Particularly in Uganda, it is estimated that the deforestation rate is at 1.8% per year and this quotation by the Uganda Bureau of Statistics (UBOS, 2012: 2) is attributed to the continued encroachment by human activities and conversion of forest land to other land uses[7].

Although a number of some building materials we use today are being re-engineered to enhance the performance, reduce costs or made more appealing which in turn is changing the face of Ugandaœs construction sector that is geared towards a positive development expected to improved living and housing standards, the sectorœs dependence on natural resources such as

[4] Robert Komakec (1997) Stabilised Earth Block buildings in Kampala (Unpublished)

[5] Kenneth Amunsimiire (2000) A study of Earth Construction by the Direct Shaping method in Bungokho, Mbale (Unpublished)

[6] Zami, M.S and Lee, A (2008) Contemporary Earth Construction in Urban Housing ï Stabilised or Unstabilised? The Crescent, Salford, United Kingdom

[7] Uganda Bureau of Statistics (UBOS) (2012, Jun) Statistical Abstract Available at: www.ubos.org (Accessed Sept 2014)

extraction of clay in wetlands for brick making, hard core mining and sand mining does not augur well for the future. Watuma (2013) shows that the extraction has, for instance, disfigured the overall topography and altered the biodiversity and ecosystem of many areas[8].

With the construction costs shooting over the roof, (*Make high quality, low cost building bricks, save costs,* 2013) argues that ôany way to cut down on costs is a welcome reliefö[9]. So one has to seek professional advice on how best they can obtain quality building materials with eco-friendly properties at a lower and affordable cost.

The search for solutions to the existing housing deficit in the country has seen various building materials and methods being explored, one of which is the use of stabilised soil blocks. The ISSB as a building material is gradually emerging but the technology is however no common and conspicuous by its absence from the national statistics[10] (Sanya, 2007).

It is with this view that the research seeks to ascertain the performance of the interlocking stabilised soil blocks in addressing the issues pointed out above.

1.3 Objectives

The overall objective of the research is to address the use of interlocking soil blocks as an affordable/economical construction material that is also eco-friendly material.

Some of the specific objectives include the following;

1. To examine whether the building process reflects on the socio-cultural needs of the urban poor.
2. To assess the ISSBôs psychological aspects in relation to the usersô requirements.
3. To examine the spatial attributes of the interlocking stabilised soil blocks.

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[8] Watuwa Timbiti (2013, April 3rd) Human Activities Choking Ugandaôs wetlands. Article in the New Vision newspaper, (Accessed Sept 2014)

[9] Anon. (2013, April 10th) Make high quality, low cost building bricks, save costs. Article in Daily Monitor newspaper, (Accessed Sept 2014)

[10] Tom Sanya (2007) Living in Earth; The sustainability of earth architecture in Uganda. PhD thesis, Oslo School of Architecture and Design, Norway

1.4 Research questions

Some of the questions that will help collect data include the following;

1. How does the building process reflect on the socio-cultural needs of the urban poor?
2. What spatial qualities and psychological aspects do the ISSB present as an appropriate building material?
3. How has the material addressed the spatial requirements of the users?

1.5 Scope of the study

1.5.1 Geographic scope:

The study is a survey on projects where the ISSBs were used within central Uganda in the district of Wakiso. However, specific studies will be made of projects from other parts of the country where the dry stacked method of construction has been successfully used.

1.5.2 Context scope:

The research focuses on the dry stacked method of wall construction. Interlocking blocks studied will be those used in this technique of wall construction where a mixture of soil and a stabilizing agent (either lime or cement) is compressed within different moulds using manual or motor-driven press machines. Due to the concerns of affordability, user-friendliness and ease of movement, emphasis will be placed on the blocks made by the manual press machines.

This research focuses on key informants/resource persons and users that are engaged or have deployed this kind of wall construction method and emphasis will be placed on residential building type for purposes of data collection. The research is based on information from residents, engineers and block machine suppliers like Hydraform Uganda as well as any other related form of information.

Building design factors like orientation and other aspects like ventilation and lighting properties are not considered. However, building economics and structural aspects are observed for purposes of achieving the objectives of this research.

1.6 Significance of the research

The research will help address the challenge of deforestation partly caused by the construction sectorôs dependence on the natural resource for the manufacture of building materials. It will present the construction method as an environmentally-friendly and affordable alternative technology for the poor.

The research will also help design professionals accredit and recommend the use of ISSBs and the dry stacked method of wall construction by assessing its performance and providing reverence on the method.

1.7 Justification of the study

Rapid economic growth and development within urban areas has seen the rise in the number of informal settlements in the city suburbs which are mainly attributed to rural urban migration. Meeting the need for adequate housing of such influx requires sustained development in technologies that have minimal impact on the environment and low cost of construction, and thus the inquiry into how the ISSB have performed.

The idea of using the interlocking stabilised soil blocks, particularly using the dry stacked method appeals for such informal settlements because most dwellers within these areas still use earth (sun dried/burnt bricks) for constructing their homes and the frequently used building method and the artisanal skills are much less similar to this method of wall construction under critique. Thus the assessment of the building material will help analyse the factors that influence the use of the ISSBs and ultimately devise ways of improving the building materialôs wide scale use in the country.

1.8 Methodology

The research adopts a mixed approach with both qualitative and quantitative research design since it requires objective and subjective inquiry. The methods for collecting data will include the following:

- Literature review ï A review of available data that exists on the subject will provide a comparative analysis using material such as books, newspapers, reports and publication related to the subject.

- Case study strategy will be employed to for it allows the use of multiple data collection techniques. Here a research site will be visited.

The other methods of collecting data that will be employed include the following:

- Focus group discussions with people from the study area will help analyse the existing circumstances and will be used as a basis for formulating the interviews and questionnaires.
- Individual interviews with key informants and users.
- Visual observation and photography will also be used.
- Data analysis and representation - Data collected will be manually and digitally analysed, and illustrations such as graphs and charts will be used to present the details from which conclusions and recommendations will be drawn.

1.9 Structure of the report

The dissertation has been organised into seven chapters namely; Chapter one which gives the general overview of the topic introducing the problem, research objectives, questions and justification of the study. Chapter two which encompasses the literature review discusses and examines the existing material in relation to the studyôs aims and objectives. Chapter three elaborates the issues of research design and the methodology adopted to effectively execute the study. Chapter four presents a case study whereas both field surveys, site findings and empirical investigations are covered in chapter five. Chapter six discusses the findings and analyses the emergent issues under the heading; Discussions. The last chapter presents a general discussion from the research that formulates the overall conclusions and recommendation.

CHAPTER TWO

LITERATURE REVIEW

This chapter in retrospect to the available information seeks to examine and assess the existing material in relation to the studyôs aims/objectives. This was done using material from books, seminar submissions, journals, published and un-published theses, reports and newspapers.

2.1 Background

Since ages ago, earth has been used all over the world as a building material and the history of construction shows that builders have always been able to evolve their habitat taking into account locally available resources to meet their needs while adapting to social constraints and local climatic risks. dõUrzo (2010) suggests putting the local population at the centre of the needs assessment and evaluation of local capacities through enhancing and demonstrating the potential of local materials for building quality buildings. UN-Habitat (2012) in its report, points out that social sustainability should aim at empowering people from all incomes, age regardless of gender to be part of the housing construction process. The researcher therefore finds it necessary for the study to investigate the extent to which the communities or end-users were involved in the building process as will in turn help to assess the materialôs ease of workability.

Wide-scale adoption of indigenous building materials such as earth in developing countries has been limited by various constraints. UN-Habitat (1985) observes that innovative materials have been produced only to levels of research output and have not had the desired impact on the building material market. It also notes that low-income construction programmes are based on principles of community participation or self-help construction and the building material being at times the only item of cost. The report highlights the three interrelated variables that guide the concept of indigenous building materials as:

- Use of locally available factor inputs.
- Affordability by the low-income population.
- Orientation to the construction needs of the majority.

The choice of material is also heavily influenced by what is available locally, following the principle of minimising transport costs since every project is different, and has varying location and community needs (Rob, Richard and Andrew, 2012). One of the resolution of this book was the need to explore other variations in the use of soil-based building materials, suggesting rammed earth and stabilised soil blocks as appropriate wall construction techniques since they provide a culturally acceptable solution in sub-Sahara Africa. The study will carry out a survey to analyse the cost implications of the use of the ISSBs with the view that if the above factors were comprehended and satisfied, then the issue of construction cost will thereafter be assessed.

The potential use of soil to build dwellings is however hampered by widespread socio-cultural perceptions that modern materials are substantially better than traditional ones. Sojkowski (2002) mentions the fact that earth materials are perceived as ósubstandardô or ósecond classô while modern materials are viewed as a ósymbol of affluenceô since urban residents associate earth houses with poverty and low socio-cultural status. Balche, B. et al (2008) argues that to address this drawback, there is need for research and implementation of earth design and construction improvement techniques and methods to address aesthetic, performance and maintenance requirements as limiting factors.

In the journal *Buildings*, Ibuchim, O and Junli, Y (2012) analyses the relevant factors and variables that influence the selection of appropriate building materials or products by design professionals and users for use in a given building project. Some of the factors highlighted in the analysis of a range of sustainable building materials are based on environmental aspects (embodied energy), economic issues (market prices and construction cost) and social variables (thermal comfort, aesthetics, ability to construct quickly, strength and durability). This research will seek to analyse the ISSB using some of these factors in order to assess the materialôs performance.

A comparison between what a given household or population group can afford and the capital and maintenance costs of their preferred housing types can be used to analyse the housing demand. Geoffrey (2010) approximates 31 per cent of the national population as leaving below the official poverty line of one US dollar a day, suggesting issues of affordability of any form of housing especially one that conforms to official standards and regulations.

This is explained in-depth by Sanya (2007) stating that materials portray the usersô poverty since they are a visible part of the building, highlighting that people with low income often have materials chosen or used inappropriately with their shelters contrasting heavily from the rich menôs. In a study where a hut and a brick building were compared, the latter was found to be widely socially accepted because it is bigger, aesthetically interesting, and has spatial and functional advantages in layout. However, the brick building has a high environmental load and offer little support to the local economies, still remaining a dream many Ugandans cannot afford. This research seeks to investigate the extent to which the ISSBs have been socially adopted by urban poor as an alternative to the conventional building materials used.

In his PhD thesis *Living in Earth*, Sanya (2007) concludes that cement stabilised earth blocks causes more air pollution compared to the conventional fire bricks which presents the stabilised soil block technology as an environmentally unsustainable material. However, a number of research publications reviewed seem to suggest otherwise. For example, a comparative analysis of energy consumptions and carbon dioxide emissions of CSEB, Wire cut bricks, country fired bricks and concrete blocks shows that CSEB consume the lowest energy and have the lowest carbon emissions (Maini, 2005).

The CRATerre (2005) publication on the pilot project in Bushenyi makes a feasibility study on the existing earth construction materials/methods i.e. wattle and daub, fired bricks and adobe blocks, identifying problems associated with their use. One of the proposed solutions is the use of stabilised earth blocks as an alternative building material to fired bricks thus prompting an inquiry in the potential use of ISSB.

Stabilised soil blocks technology has also had vast application even in the road construction because of its eco-friendly and cost effective aspects. Francis (2012) in a newspaper article states that the use of interlocking stabilised soil blocks technology is slowly increasing in Kenya, and more Kenyans are opting for the technology over the usual masonry stone and mabati iron sheet walling.

The composition and properties of earth as a building material are explained in Minke (2006). The author also gives insight on the test used to analyse the composition of soil to determine its suitability of using earth/soil as a building material, and this will be expounded on in soil analysis. The factors that necessitate soil stabilisation and the three stabilisation procedures are explained by Houben, and Guillaud, (1994).

With the background analysis and literature reviewed, it is apparent that the following key issues need to be given attention:

Most authors evaluated the different sustainable materials as being an appropriate technology which I think goes beyond achieving ecological aspects to addressing both social and economic factors in relation urban poor for the case of Uganda.

The decision to use such appropriate technologies has to some extent come out of studies that have incorporated technical and economic factors. Socio-cultural factors such as understanding the capabilities of communities in question or whether the building process will support retrofitting and piece meal development a phenomena used by the urban poor majority.

The socio-cultural perceptions about the use of earth as building material are as a result of the continued gap between awareness and implementation that exists within the society. Efforts to bridge the existing knowledge gap have been identified and initiated in some reports though most of these strategies have failed to see the issue accomplished.

Conclusions made on most studies done on appropriate technologies are based on pilot projects in a given area. There exist uncertainties on whether such technologies will perform the same way regardless of being in different geographical settings.

In this study, limited illustrations have been used but there are different profiles and systems of interlocking stabilised soil blocks that warrant investigation. Examples of such interlocking blocks include the following:

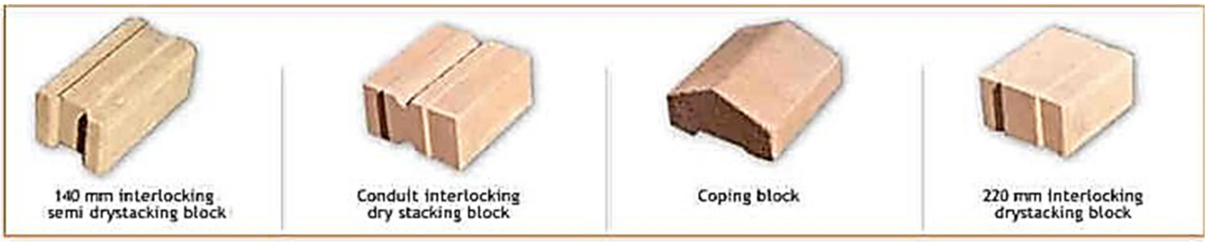


Figure 2-0-1: Hydraform range of blocks (Source: Hydraform)

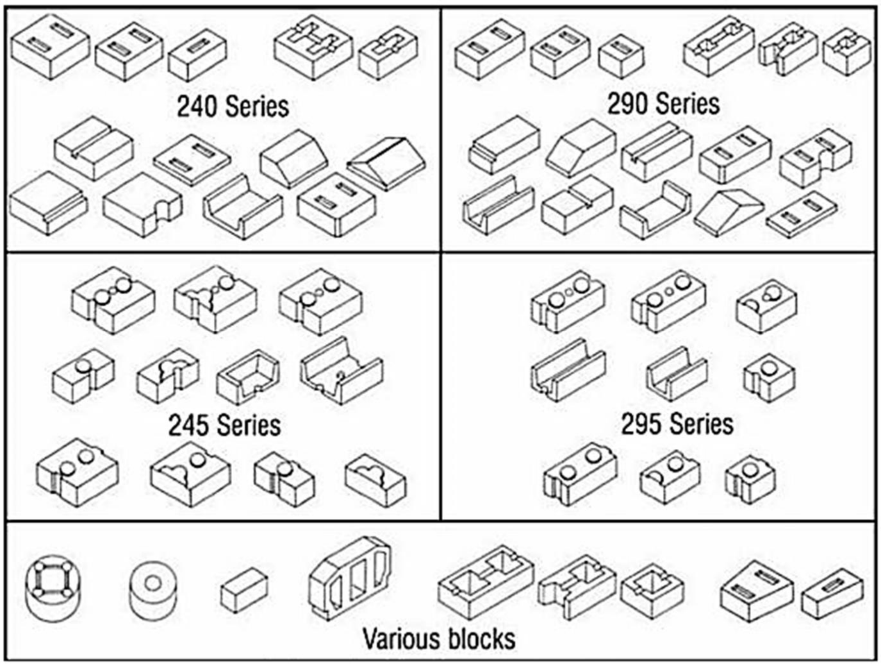


Figure 2-0-2; Blocks produced by the Auram press 3000

Give the research time frame, the study will be based on the Hydraform interlocking dry stacking blocks.

2.2 Soil analysis

The fact that soil has been found to significantly differ over a limited coverage makes it important to carry out tests on soils to be used in construction so as to confirm their engineering properties and behaviour. Soil classification enables one to assign a sample of soil to one of a limited number of groups depending on the material properties and characteristics of the soil. The classification groups according to Smith (1998, p 6) are used as a system of reference of the soil which can be classified by carrying out identification tests. There are two types of identification tests, namely:

- Field tests which are mainly based upon visual recognition.
- Laboratory tests which include several speciality test to help eliminate human error.

To carry out test, fresh soil samples from the study area were identified and collected from three different locations on the site using hoes by removing the topsoil first before extracting the samples usually at depths of 300mm and below. Each of the soil samples was then concealed in a waterproof polyethene bag and labelled for transportation to laboratories.

The fact that soil identification alone does not assess the mechanical performance of the building material, carrying out performance tests is usually critical. Given the constraints involved which included financial limitations to carry out the lab tests and the short time schedule that made it less than ideal to have sufficient tests done since each test required prior preparation. It is for these reasons that this research focusses on field tests

Soil properties

Soil consists of grains usually rock fragments or clay particles, with water and air or water vapour in the void spaces between the grains. These compositions according to Atkinson (1993: 45) are responsible for mechanical properties of the soil (its strength and stiffness)[11]. The categories that are best used to describe soil properties are particle size distribution, plasticity, cohesion and compaction.

<u>Particle size distribution</u>

The most important features of soil grains are their size, grading, shape and surface texture of the grains. BS 1377 classifies soil as: -

- Gravel: 60mm - 2mm
- Sand: 2mm ï 0.06mm
- Slit: 0.06mm ï 0.002mm
- Clay: less than 0.002mm

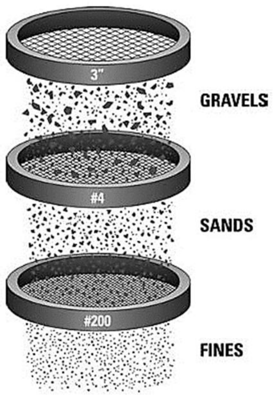


Figure 2-0-3: Sieve analysis of soil (Source: Caterpillar 2006)

[11] John Atkinson (1993) An introduction to the Mechanics of soils and foundations McGraw-Hill book company, London

During the study, a dispersion test was carried out on four soil sample to determine how the soil will be compacted (see Figure below)

Figure 2-4: Dispersion test to check the gradation of the soil samples.

<u>Plasticity</u>

Plasticity is the ability of a soil to undergo unrecoverable deformation without cracking or crumbling. The atterberg limit tests are used to determine the plasticity or consistency of soil by calculating the plastic and liquid limits which are transitions between plastic and solid state, and the transition state from a liquid to plastic state respectively. Shearing strength, though constant at liquid limits, varies at plastic limits for all clays. A highly plastic clay has higher shearing strength at the plastic limit and the threads at this limit are rather hard to roll whereas a lean clay can be rolled easily at the plastic limit and thereby possesses low shearing strength.

The plastic and liquid limits help specify the sensitivity of soil to variations in humidity and can be used to determine water-soil mix ratios. Their difference (Plasticity Index) thus helps in determining the plastic behaviour of the soil.

<u>Soil bonding</u>

Soil has a number of internal binding forces which act to give coherence to the soil grains and as a result causes it them to aggregate. Particles with a diameter >0.002mm are highly cohesive and are resistant to deformation when in sufficient quantities that they touch one another. Mineral particles <0.002mm on the other hand have a moderate/weak force, and in soil composition, clay plays the part of cement of providing cohesion to the soil through its ability to hold the grains together.

Soil improvement

Sometimes referred to as soil stabilisation, soil improvement is the alteration of any property of soil to improve its engineering performance. Soil improvement increases shear strength and reduces permeability and compressibility. The methods of soil improvement considered in this research are mechanical compaction, and use of admixtures.

Compaction forces the soil fabric into a dense configuration by expelling air using mechanical effort with or without the addition of water. Soil compaction helps in increasing the soil strength and load-bearing capacity, and reduces settlements, soil expansion and contraction.

Murthy suggests that the physical properties of soil can also be extensively improved by the use of admixtures such as lime and Portland cement, and process of soil stabilisation involves mixing the soil with a suitable additive which changes its properties and then compacting the mixture suitably[12]. Lime stabilisation is extensively used to decrease swelling potential and pressure in clay, and soil-cement stabilisation improves the engineering properties (structural strength, waterproof and erosion protection) and reduces the ability of the soil to expand by drawing in water.

[12] Murthy V Geotechnical Engineering: Principles and practices of soil mechanics and foundation engineering, Marcel Dekker. New York

CHAPTER THREE

3. METHODOLOGY

3.0 Overview

The purpose of this research is to investigate extent and form a critical opinion to which the interlocking stabilised soil blocks have been used as a building material in low cost housing through analysing the wall construction method in relation what is conventionally used. The research is aimed at presenting interlocking soil blocks as an appropriate technology that that has the potential of addressing the housing needs of low-income populations.

The research question guiding this research are:

1. How does the building process reflect on the socio-cultural needs of the urban poor?
2. What spatial qualities and psychological aspects do the ISSB present as an appropriate building material?
3. How has the material addressed the spatial requirements of the users?

This chapter aims at defining the methods for achieving answers to the questions above and will also define the structure and procedures adopted for data collection.

3.1 Research approach

The Research adopted is a mixed approach with both qualitative and quantitative research design since it requires objective and subjective inquiry. Qualitative research design uses data and content that ñorganicallyò comes forth from the case study area. McMillan and Schumacher (1993, p. 479) defined qualitative research as, ñprimarily an inductive process of organizing data into categories and identifying patterns (relationships) among categories.ò This research design is a non-mathematical but has been chosen for its explorative aspects and its potential to seek solutions to problems identified.

Quantitative research design on the other hand is defined by Creswell. J. W (2003, p. 18) as one where the investigator uses post-positivist claims for developing knowledge (i.e. cause, reduction to specific variables and questions, use measurement and observation, and the test of the theories), and employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistical data.

The diagram below shows the framework of the factors and variables:

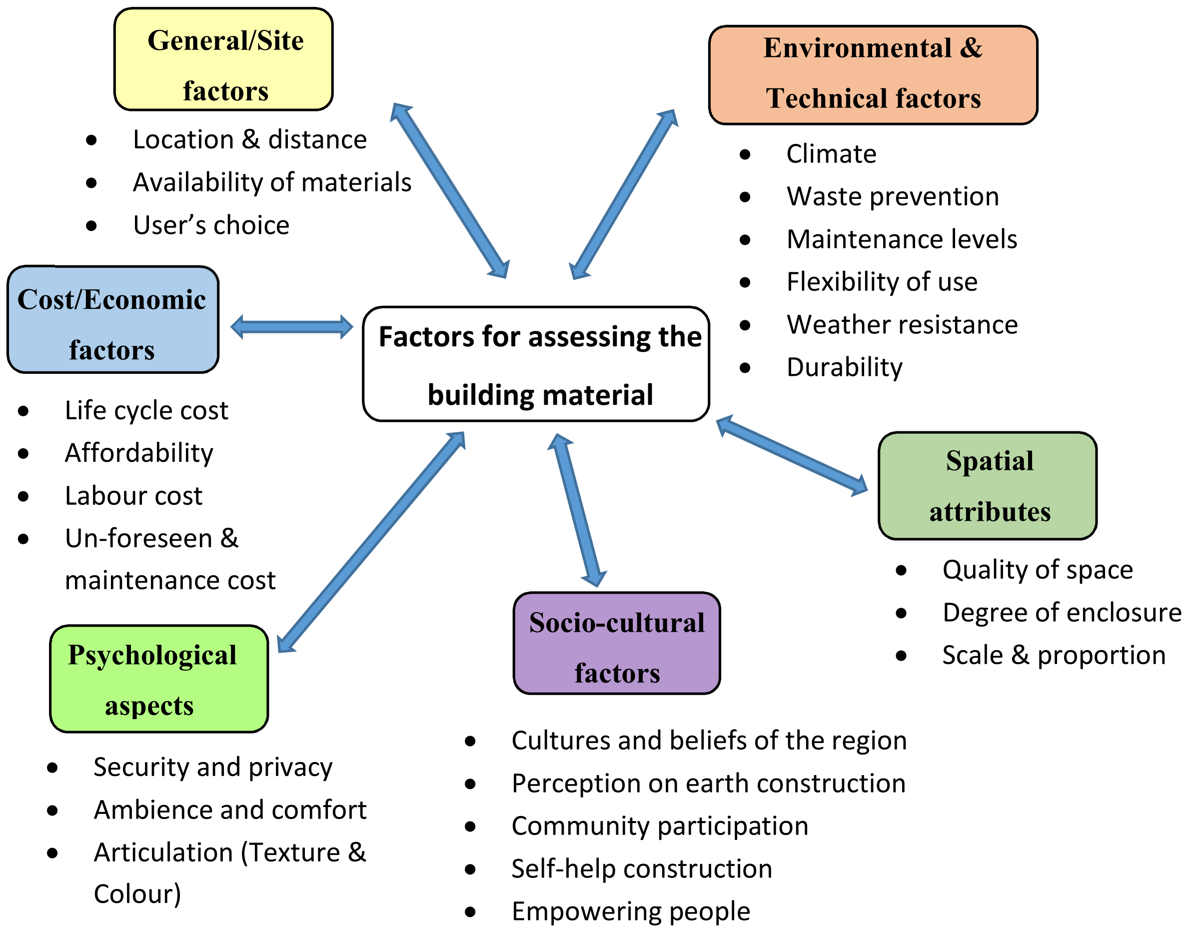


Figure 3-1: Framework of factors for evaluating the building material (Source: Author. 2014)

3.2 Research design strategy

The research strategies will be methods employed in which the problem will be studied and analysed. The problem in this research will be examined in two ways after which the arising arguments will be interpreted in relation to the data generated. The first stage will be required to address the performance of the building material using data from the analysis of its cost and general site factors in the Ugandan context. This is aimed at generating quantitative data for this study. The second stage will use the quantitative data along with qualitative arguments to explain and assess the abstract factors (environment, socio-cultural aspects, spatial qualities and psychological aspects) by giving distinct ideas using case studies. The discussion chapter will then contextualise the arguments from the two stages.

The mixed approach adopted uses the sequential strategy with the researcher seeking to elaborate on the findings of one method with another. The study will begin with a quantitative method where certain theories and concepts shall be tested then be followed by a detailed exploration with a few cases using qualitative research design.

The first stage will use simulation to help generate data to aid in the analysis of cost/economic, and site factors in relation to the use of the ISSBs. Simulation is in this case used because itôs hard to monitor and observe the above aspects from an already existing building, thereby generating dependable data which will be obtained from empirical findings or literature. The data will then be tabulated using mathematical computer models employing Microsoft Excel program.

A 3-bedroomed house will be used for the mathematical simulations as the unit of analysis which will in turn be used to assess the performance of the ISSBs. The analysis will be based on a $1m^2$ wall section cut out to generate the simulations.

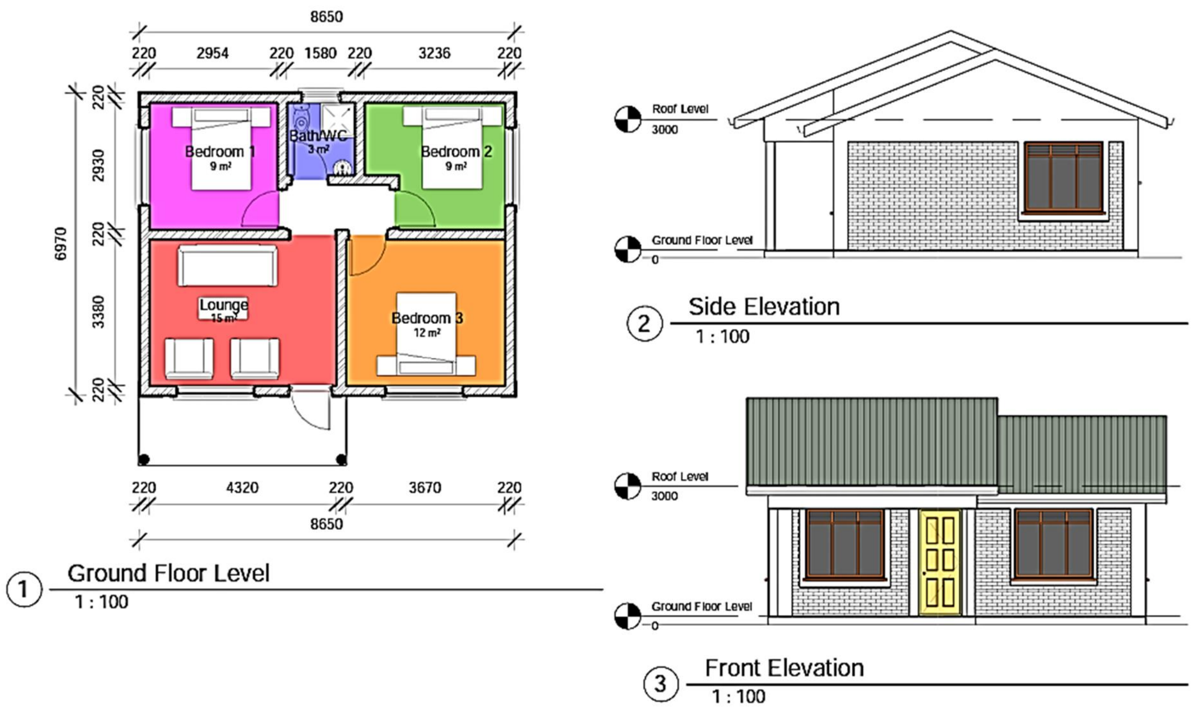


Figure 3-2: Layout of the housing prototype.(source: Hydraform)

To construct the prototype, one requires inputs such as earth, water, labour and other materials which will be categorised into two groups; Labour costs and material costs. Results from the simulations will give quantities and costs of the inputs used in the production and construction process.

In stage 2, the variables and factors highlighted earlier in the literature review will be used to analyse the building material in the study. This section will use quantitative data along with the arguments generated to evaluate the materialô s performance against the other aspects i.e. environmental, technical and socio-cultural factors. This will be followed by the discussion chapter from which conclusion and recommendations will be drawn.

The diagram below shows the research design of this study.

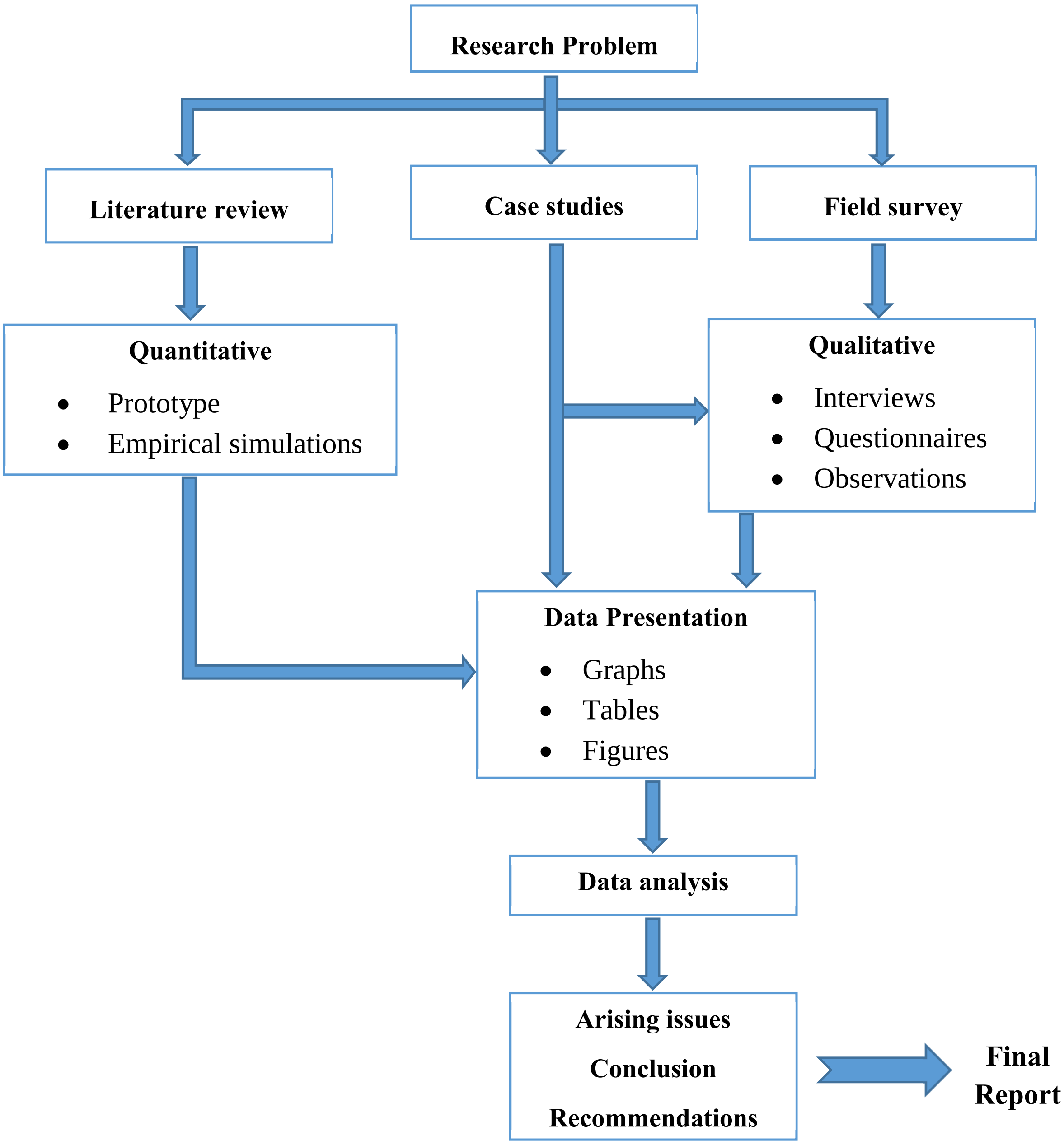


Figure 3-3: Summary of the Research Design. (Source: Author, 2014)

3.3 Data collection methods

The methodology chapter postdates chapter two because the latter identifies aspects under scrutiny and this chapter rather describes ways how information is to be gathered. The methods to be used are as follows;

Literature review

The fact that related information about the subject already exists, the review helps to identify the gaps that have not been address by the previous researcher and set parameters that the research is based on. Literature review will be conducted basing on the set objectives and its selection should meet the following criteria:

- Should reflect on the social spatial and environmental implications of housing developments.
- Earth construction technologies that adopt/integrate local capabilities and competences.

Case studies

Specific studies will be done on projects that have successfully incorporated the building material or method. Analysis will be based on the building materialôs performance in relation to the environmental, cost/economic and technical factors, and social aspects in relation to the construction process. Open ended interviews will be used for this data collection method since case study respondents are considered to be informants not respondents and the interview data shall be taken to be verbal reports only where the informant is the authoritative source. The information will only be valid when it is collaborated with other types of data such as documents (Yin 2003).

3.4 Data collection techniques

The tools that will be used to gather information will include the following:

Visual observation

Since the research will be studying a case where the ISSB have been used or in use, concern shall be in representing as much detail as possible through making sketches and notes, photography, take recording where applicable. Research site visits without predetermined questions or conducting interviews where individuals are allowed to talk openly about the topic, will be used a pilot study that will enable the researcher to formulate research questions for the inquiry stages.

Focus group discussions

The research will employ interviews of the key users of the ISSB to ascertain the reasons for their choice of this building material, the benefits and challenges they face or faced in the wake of using the material and technique. Key stakeholders with interest in this appropriate technology will be identified and conversational and open-ended interviews will be used to get information from the respondents. Some of the stakeholders with whom interviews will be conducted include the end-users, designers, contractors and government regulators.

Individual interviews

For purposes of this investigation, research questions will be directed to key informants especially organisations and persons with experience in this method of constructions, individuals who have deployed, used or lived in buildings constructed using this building material. Design professionals especially architects, engineers and contractors will also be interviewed so as to obtain their opinion on the use of interlocking stabilised earth blocks giving the dissertation authenticity.

3.5 Analysis and synthesis of data collected

The case study in this research will be done on more than one study areas as the intention of this research is to investigate the current issues and key variables facing the use of ISSB in relation to its performance to establish the design potential and defects of the building material and method of wall construction. The four formats of writing a case study according to Yin (2003) are single case study, multiple case version, questions and answers format, and multiple case study in which no single cases are presented. This study adopts the multiple case version where a different case study will be used to acquire specific information about a given issue.

Data collected will be manually and digitally analysed, and illustrations such as graphs and charts will be used to present the details from which conclusions and recommendations will be drawn.

CHAPTER FOUR

CASE STUDIES

4.1 Study one

Location: Sakali, Darfur, South Sudan

Client: State ministry of physical planning and public utilities

Project: Resettlement housing program

Figure 4-0-1: Location and Map of South Sudan

Sudan has a long history of war part of which was in Darfur between the government forces and the allied militia that resulted in large scale displacements estimated at 1.9 million people in the area of Darfur alone. The project has built six housing units for vulnerable families (widows and the handicapped), as pilot demonstration buildings to test the appropriateness of stabilized soil block technology, its cost and quality compared to other building materials. The project has one single room (4 metres by 4 metres), a toilet/shower, a kitchen, and a boundary wall.

Location and context

Sakali, which is a resettlement area on the outskirts of Nyala, is a test case. During the dry season, drought very much affects agricultural activities and, of course, the production of building materials. The area experiences torrential rains and frequent flooding meaning the need for water resistant building materials is crucial.

Figure 4-0-2 & Figure 4-3: The conditions during the dry and wet season respectively

It is because of this that most of the structures in this region have a raised plinth level to deal with the flooding issue as shown in figure below.

Figure 4-4: Showing the raised plinth level.

Since war broke out in 2003, about two million people have been displaced from their homes in Darfur and there exists a challenge faced by regional governments of providing infrastructure and basic services for the resettlement and reintegration of internally displaced persons, which resulted in increased urbanisation and high demand for building materials most of which are imports from neighbouring countries. The use of imported materials was reduced by using locally-made Portland cement and locally- sourced stabilizers.

Material availability

Since war broke out in 2003, the regional governments have been faced by a challenge of providing infrastructure and basic services for the resettlement and reintegration of internally displaced persons, which has resulted in increased urbanisation and high demand for building materials most of which are imports from neighbouring countries.

With the exception of cement, all the basic components for the production of stabilized soil blocks (clay, sand, and water) are readily available throughout Darfur, even though the physical and chemical characteristics varied from place to place. Viable alternative raw materials needed to be found to keep the production cost of the blocks competitive since the cost of cement was double in Darfur. Since several limestone deposits existed in the area, lime and other materials like volcanic ash, and pozzolana were viable alternative binders.

Figure 4-5: Arabic gum (source: UN-Habitat)

Participatory planning and design

In Sakali, the team supported the community in developing criteria to identify the most vulnerable groups for habitat demonstration projects through conducting community meeting.

Figure 4-6 & 4-7: Group discussions and community meeting respectively. (Source: UN-Habitat)

The community together with the team also helped design and developed a housing model that could allow for future expansion by adding rooms according to the needs and ability of the families.

Figure 4-8: Site layout of individual plots. (Source: UN-Habitat)

This helped identify and utilized many skills already present among community members which was critical for the construction phase thereafter.

Spatial design

The team also explored different alternatives to reduce energy consumption in the pilot housing project. The pilot prototype provided a unique opportunity to research different architectural types and arrangements in Darfur native to the community with those goal was to maximize the use of available land, match cultural values, minimize energy consumption, optimize natural design strategies for ventilation, lighting, etc. as shown in Figure 4-9 below.

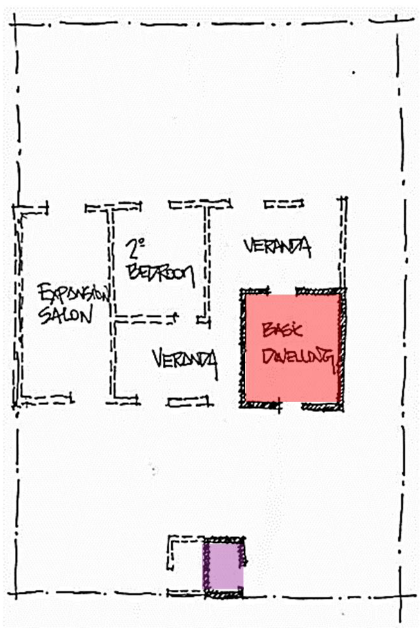


Figure 4-9: The spatial layout of the proposed building.

Building process

The pilot housing model developed has one single room (4 metres by 4 metres), a toilet/shower, a kitchen and a boundary wall around the site, but the site layout considers future expansion with room for expansion due to the needs and the ability of the family. This layout of spaces suggests that the building method allows for piece-meal development with partial construction which in most cases could be as a result of financial limitation or future developments as their requirements/needs of the end-users change with time.

4.2 Study two

Location: Makerere University, Kampala, Uganda

Project: Transforming the Rugby pitch into a quality field site with complete support facilities.

Funded by: Presidential Initiative to Support Appropriate Technology (PISAT)

The project objective was to use ISSB technology in the construction of facilities that included a club house with locker rooms and dining area, seating stands, toilets, perimeter wall and ISSB water tank in a bid to help improve the rugby field. The stabilised interlocking soil blocks used to make the retaining wall were made with a higher proportion of sand than soil in order to produce strong blocks that would be left un-plastered. The reason for choosing this project as a case study is that it enables us to analyse the blocksô tolerance to the elements of weather given that the building material is exposed.

Spatial design

The existing built structure/s on site takes on a rectangular form or modular where the double interlocking stabilised block was opted for use in their construction. However, due to the structural requirements of the water tank to be constructed, curved double interlock blocks were opted for use.

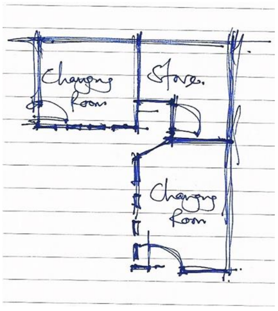


Figure 4-10: The spatial layout of the Existing building on site.

Finishes

The buildingôs interior is plastered with a lime coating/finish which is contrary to the exterior walls that are rather left exposed. Despite the fact that the blocks have the ability to resist rain water infiltration, the block wall was plastered to a mark 700mm above the plinth level to prevent it from block wear.

Figure 4-11: Showing Plastered interior walls and exterior region respectively.

Aesthetics

The exposed walls make the whole build true to material with the ISSBsô texture and colour as the final wall finish. The joints between the blocks are further emphasised with a dark colour/paint which highlights the masonry and in turn makes the block work to standout.

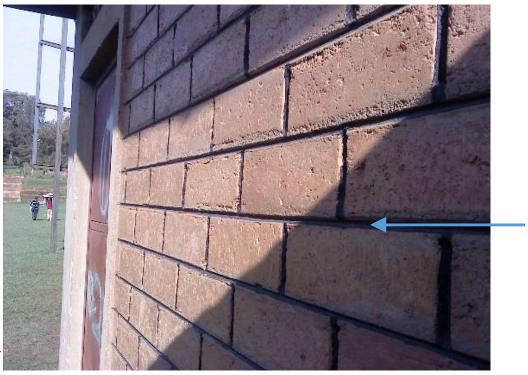


Figure 4-12: Showing the Highlighted block work joints.

Durability

4.3 Study three

Location: Luweero District, Uganda

Building type: Residential

A series of interviews and a field study were conducted in Luweero District to ascertain the userõs perception on the use of interlocking stabilised soil blocks while examining the factors and aspects that the technology presents. The project is located within a residential area in a rural setting. The buildings in the neighbourhood are mainly constructed burnt bricks and the other temporary structure are constructed in mud and wattle.

The site was an ideal area to study for this research because:

1. The project is one that upholds some of the principles of an indigenous building material within an urban setting such as use of locally available resources (materials and manpower).
2. The projectõs location and close proximity to a number of buildings constructed using other materials making it rather easy to comprehend.

Social acceptance

Since the process of making ISSB does not require specific skill sets due to the fact that the process is quite similar to the conventional methods used, the builders and users easily adapted to the building system. This building was constructed under self-help or mutual aid techniques where user and the locals that participated in making the building blocks or in the construction of the house were trained to acquire the relevant skill required. This created local value as natural materials are used and native labour was engaged.

Figure 5-4: Community involvement in the construction process

Dry stacking due to the interlocking nature of the blocks does not require skilled labour and the ease of assembly reduces on the time taken for construction. This tremendously reduces the labour costs.

Spatial design - form, size and scale

The design of the building takes on a rectangular form with subtractive transformation drawing away from the regular square or rectangular shape. The form is further articulated by plastering of the wall edges, door and window outlines which to some extent emphasises the highlighted elements. The scale of the building in relation to the neighbouring structures is relatively the same which enables it to merge within its context.

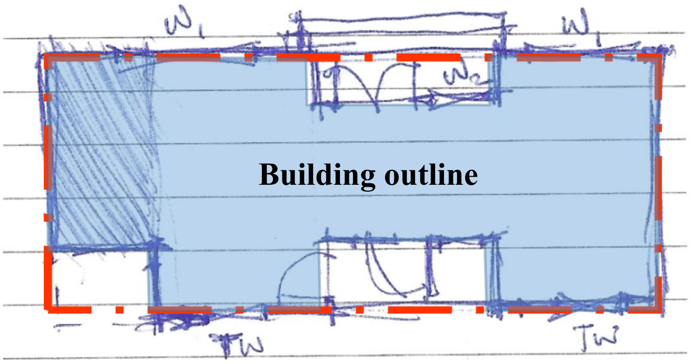


Figure 5-5: Sketch showing Form articulation (Source: Author, 2014)

Aesthetics

The uniformity and accuracy of laying the blocks gives an extremely appealing face-brick finish that provides for pre-pointed straight masonry. The walls are exposed still which gives flexibility of achieving the final finish.

Figure 5-6: Form articulation of the building

Colour

The soil blocks used are maroon in colour a feature which is dependent on the soil used, which in this case was murram (see Figure 5-6 above). The block colour not only makes the building appear to fit suitably in the context but also is easily related to by most people.

Figure 5-7: Block samples showing different colours

Finishes

The exterior was left with an exposed wall finish, saving on plaster and finishes since the blocks have the capacity to resist direct or capillary infiltration of rainwater or flowing water than sand-cement blocks. The inside walls were rather finished with a plaster coating for its decorative role.

Figure 5-8: Boundary wall with interlocking block (Source: Hydraform)

Durability

The use of stabilising agents helps to give the blocks structural strength, increasing its hardwearing properties and resistance to abrasions and scratches on impact. The strength of blocks basically depends on the quality of materials used, correct procedure of block production and consistency during soil compaction.

The integration of reinforcements within conduit blocks can be done to improve structural performance in earthquake prone areas.

Figure 5-9: Bonding corner edges with Steel bars.

CHAPTER FIVE

RESEARCH FINDINGS

4.4 Generating quantitative data

As earlier explained, simulation will be used to generate dependable data from empirical findings and literature because itôs hard to monitor and observe the above aspects from an already existing building and the fact that the building technique is relatively new with insufficient data to enable the evaluation of the building material and method of wall construction.

Mathematical simulations are based on a 3-bedroomed house from which the cost and general site factors are analysed. The computations are broken down into two aspects i.e. material inputs and labour inputs where the material input include natural raw materials, cement and transport, and labour inputs are skilled and unskilled labour (masons and porters). The calculations are done basing on a $1m^2$ wall cut out from a housing prototype built using ISSBs where the number of blocks per unit area is used to estimate the total number of blocks used in the construction, which in turn helps to calculate the quantity of materials used.

For every inputôs breakdown, its quantity and cost amount are used to generate a rate per cubic metre since the unit of measurement is known and when multiplied by the volume of the input used, the cost is obtained. The obtained values are then added up to get the grand total represents the total quantities of the material and labour inputs used in the prototype.

The results are later used in comparison with the results obtained when the simulation is computed using burnt bricks as the building material on the housing prototype. Burnt bricks are chosen as an ideal unit of comparison in this analysis because the material is widely used and socially accepted in the country though it falls out of budget of the poor, it still remains a dream many Ugandans cannot afford.

The mathematical simulations for ISSBs are presented up leaf.

Note: The cost of the roof structure is taken to be a constant with an assumption that it is similar to the conventional roof system used for the brick wall structure with which the comparison is made. The total cost will too exclude the cost of the foundation footing and ring beam where the same assumption is used.

Calculations for Material inputs.

The ISSB wall is a 220mm thick plastered on one side comprising of a 600mm plinth wall that rests on a concrete foundation footing, 460mm high top courses resting on the 2.5m dry stacked wall. The former two are embedded in mortar for strength and stability.

The wall section and plan below show the constituents of the ISSB wall and general layout of the prototype.

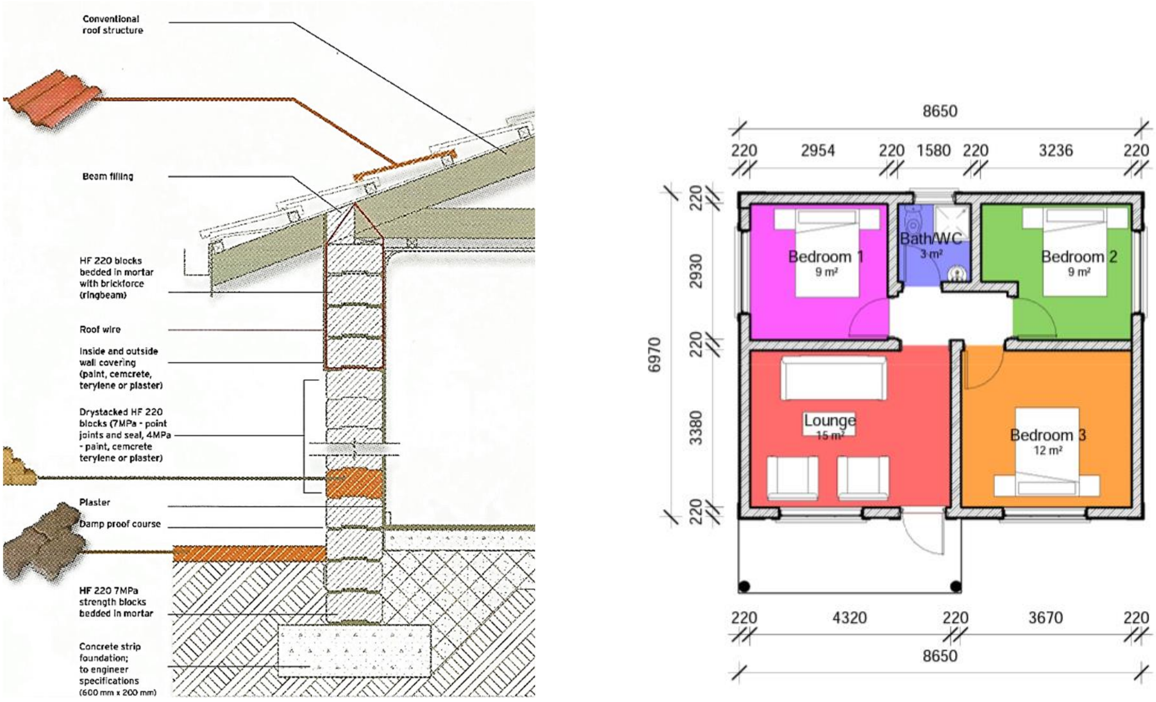


Figure 5-0-1: Wall section and layout of the housing prototype used for mathematical simulations (Source: Hydraform)

The calculations are based on a $1m^2$ wall which is estimated to have 37 blocks of 240mm length by 115mm height by 220mm width. This is multiplied by the total area of walling to obtain the total number of blocks. The quantities of components used are then calculated, which when multiplied by their cost per cubic metre rate give the sub-total cost of the components. The sub-totals are then summed up to give the total cost of the block wall. Part-calculations used to obtain the rate will be shown in the appendix.

The total figures for quantities of material inputs and their corresponding cost are given in the table below.

	Amount	**Unit**
Number of blocks per 1m²	37	blocks
Total wall area	169.8	m^2
Total number of blocks [13]	6283	blocks
Volume of soil required [14]	58.11	m^3
Total cement bags required [15]	204	bags
Reference one 50kg bag	0.042	m^3
Volume of cement required	8.57	m^3
Cost of cement per m^3	714,285.71	UGX
Cost of cement	6,121,428.54	UGX
Volume of building sand [16]	6.44	m^3
Cost of sand per m^3	55,000.00	UGX
Cost of sand	354,200.00	UGX
Total cost	6,475,628.54	

Table 5-1: Showing quantities of material inputs and their corresponding monetary value (Source: Author)

<u>Calculations for labour inputs</u>

The labour inputs included the both skilled and unskilled labour required to carry out activities of block laying and plastering. The total number of blocks to be laid were generated from the multiple of number of blocks per square metre and total area of walling. For the prototype in ISSBs, the interior walls, wall edges and opening (window and door) outlines of the exterior

[13] Blocks required for super structure, ring beam and footing

[14] Soil m^3 required for block Production only

[15] Cement bags required for blocks, plaster and mortar

[16] Building sand m^3 required for plaster and mortar

are plastered (see figure 5-2) which is different in the case of brick walls where both side are plastered.

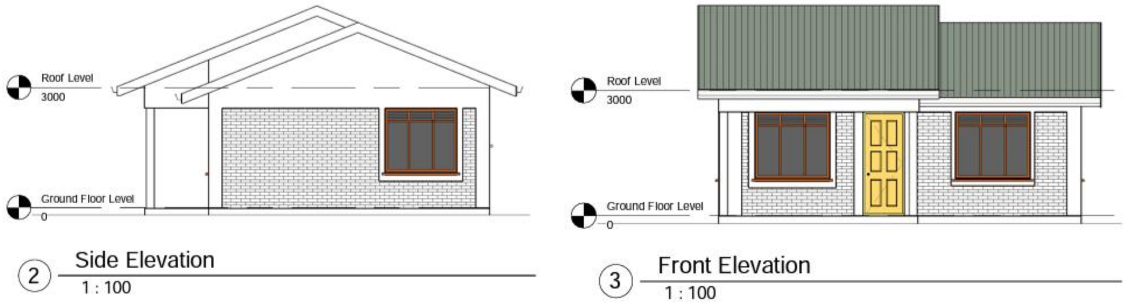


Figure 5-2: Elevations of the housing prototype in ISSBs

For purposes of these simulations, several estimates are made which include the number of blocks laid by 1 mason and porter and the time taken to plaster 1 square metre of wall which are adopted from Sanya (2007). These estimations are used to approximate the work done in a day as the wages were paid per day. The total cost of the labour is obtained by the summation of the subtotals of block laying and plastering which are generated from the product of the work done and wage paid, and the product of the plastering wage and the time (in days) taken to plaster the walls.

The table below the total cost of the labour inputs and the individual costs of carrying out the activities:

Earth excavation	**Amount**	**Unit**
Volume of soil required	58.11	m^3
Labour[17]	29.05	Man-days
Wage	3000	UGX per man-day
Total excavation wage	87,150.00	UGX
Block laying		
Total number of blocks	6283	Blocks
Labour	15.7	Mason- porter days

[17] $2m^2$ are excavated per man-day Douline (2003) cited in Sanya (2007)

Wage	8,500.00	UGX per mason-porter days
Total laying wage	133,450.00	UGX
Plastering		
Total area to be plastered	163.34	m^2
Labour	5.1	days
Plastering wage per m^2	3000	UGX
Total cost	15,300.00	UGX

Table 5-2: Showing the individual cost of activities and total cost of labour inputs. (Adopted from Sanya, 2007)

4.5 Field survey

During fieldwork, it was observed that most buildings constructed using ISSB were single level residential buildings that adopted a rectangular or square form/shape. Iron sheet were the most commonly used material for the roof structure and the interior walls were plastered and painted to the ownerô s preference. The exterior walls were left un-rendered and took on the colour of the soil used for block production.

The survey conducted both interviews and collected data using questionnaires to get the usersô perception and performance of the interlocking stabilised soil blocks as a building material in the construction industry, and some of the results are shown below:

Interview results

Six residents living in ISSB-constructed houses were interviewed on eight key issues which include: aesthetics, affordability, thermal comfort, colour and material texture, workability, maintenance requirements and quality of space.

Five interviewees were comfortable with the general appearance of their houses compared to the conventional houses, only one of them thought otherwise stating that he would have preferred having the exterior building plastered provided the resources were available.

All interviewees assented to the fact that their houses were affordable compared to those in which conventional building material were used. The mixture composition for block production uses sand, earth and cement, where the former is readily available from the site at no cost.

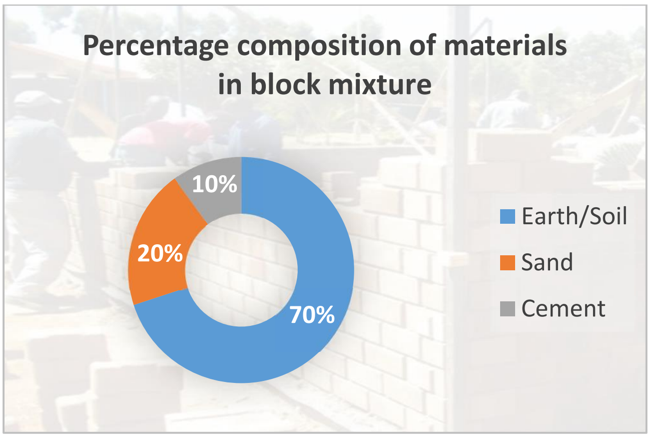


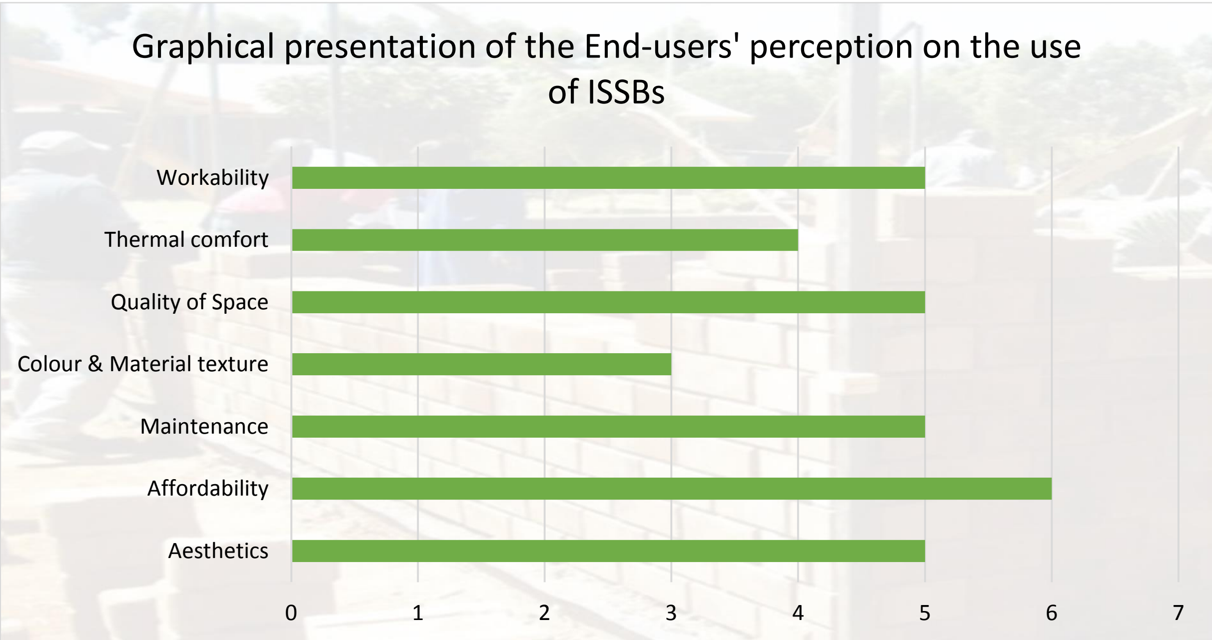
Figure 5-3: Percentage composition of raw materials

Four out of the six interviewees declared that living in ISSB-built houses was comfortable with heat regulated interiors. The remaining two stressed that their interior tended to be very hot during the day and cold at night. The lack of a ceiling brings about direct heat transfer mainly from the iron sheet clad roof structure which has a high thermal conductivity.

The issue of block colour and texture saw one of the respondents express their dissatisfaction with the dark colour of the blocks though he had a fair opinion about the materialôs fine texture. Three respondents were pleased with the colour and smooth effect of the soil blocks since they were machine-made. The other two interviewed were indifferent about the issue.

The majority of the interviewees said the projects were undertaken on self-help basis with five out of six having individually participated at one point during the construction of their houses. The other respondent did not participate in the building process. The level of involvement of the users shows that the skill sets required for the building process can easily be channelled to the local people.

Five out of six interviewees have not noticed any defect that required maintenance and one out of six respondents had detected a water penetration defect due to suction. The fact that the houses were recently built leaves a possibility that the defects might happen in the near future.



Graph 5-1: Users' views on the use of ISSBs (Source: Author, 2014)

In the study, material colour/texture and aesthetics are analysed as separate entities though the two complement each other in one way or the other. The survey reveals the need to address the issue of the materialôs colour as this will provide a wide range of decorative render options which in turn will ultimately improve the overall aesthetics of the buildings.

From the interviews conducted, the building material is said to be affordable which is also reflected in the cost simulations made. This is because the natural raw material (earth) which constitutes the largest volume is obtained at no cost from the site, meaning there are no transport cost involved.

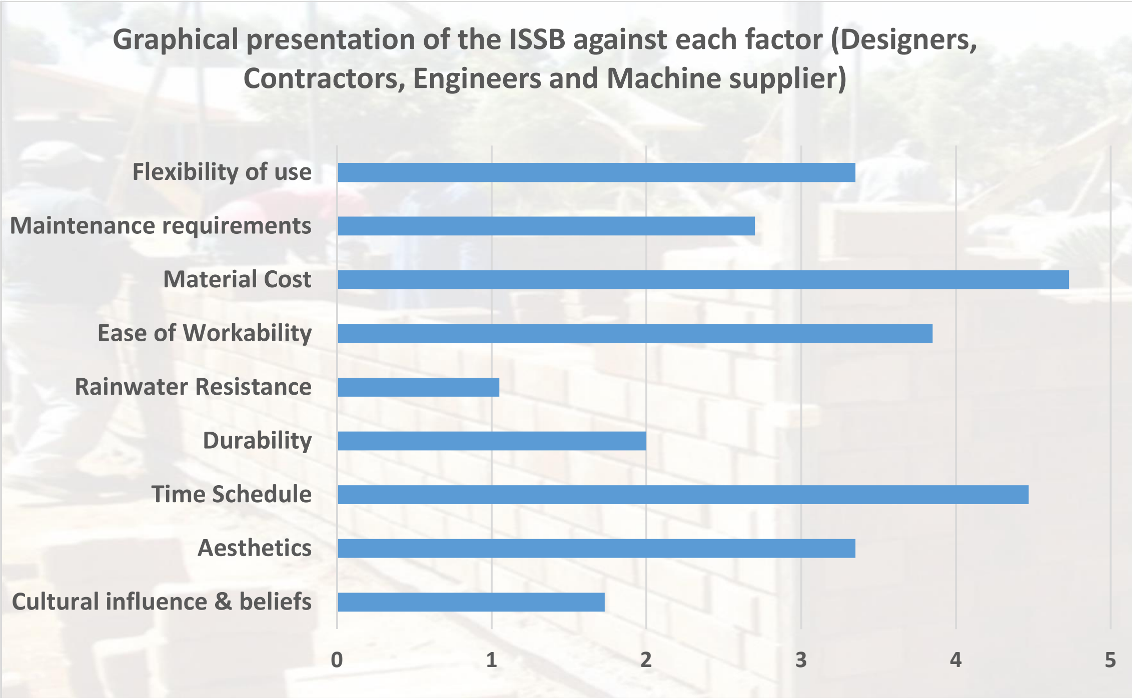
Questionnaire results

This study conducted a survey to ascertain the performance of ISSB on seven key issues which included: time schedule, durability, maintenance requirements, weather resistance, material cost, easy workability, flexibility in use, and cultural and belief influence on the use of the building material.

Of the 35 questionnaires issued out randomly to design practices, engineers and block machine suppliers, 19 were filled and collected back. An analysis and presentation of the key issues using a five-point likert scale was done by comparing their mean value.

With the majority of respondents having participated in residential projects more than any other building type, only 11 % had employed or specified the stabilised soil block technology in at least one of their projects. However, most of the respondent expressed their interest using the technology in the future provided its flaws like any new technology are addressed. The respondents were asked to rate some of the factors and aspects that the ISSB presents as an appropriate building material.

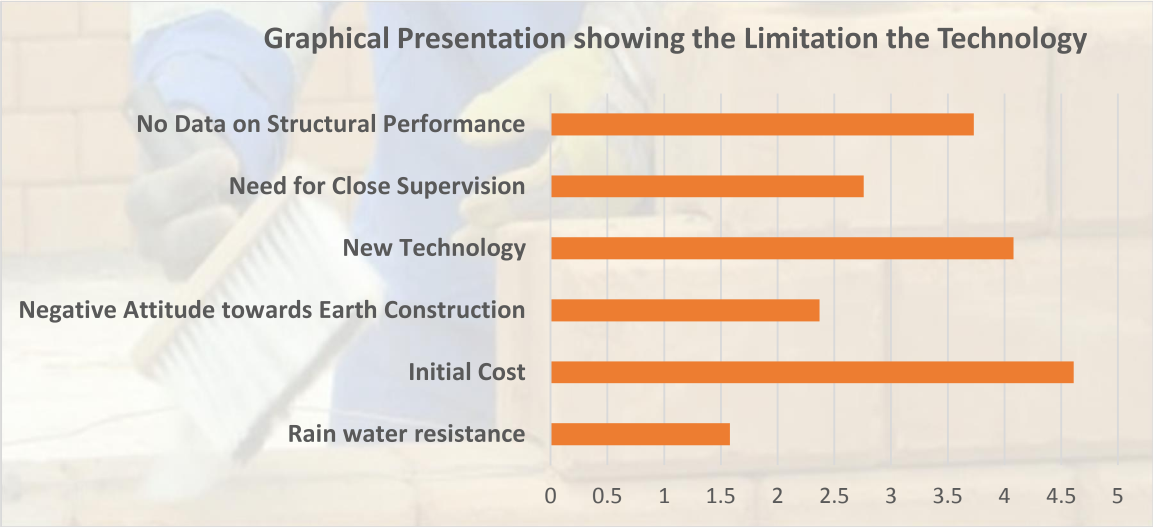
The results shown in graph 5-2 indicate that material cost was awarded the highest mean benefit of using the technology with a mean rating of 4.73. Time-scale factor followed with a mean rating of 4.47 and easy workability (4.21). The respondentsô opinion on some technical and psychological aspects was requested where a unanimous judgement could not be reached between aesthetics of the material and flexibility of use to achieve spatial requirements of the users. Cultural influences and beliefs were highlighted as a deterrent to the building materialôs adoption and use with a mean value of 1.73 and the materialôs resistance to water with a mean value of 1.05.



Graph 5-2: Factors that influence the adoption of interlocking soil blocks. (Source: Author, 2014)

The graph above shows that the material has a low resistance to rainwater which is because the external face of the building material is left exposed to rainwater making it susceptible to wearing down. Dry stacking makes the assembly of the block work easy and fast, reducing the overall time of the building process and it is for this reason that time schedule is considered a desired attribute of using the ISSBs. On the other hand, the material was still perceived by the majority of people as vernacular and as a result the negative attitude towards earth construction.

The respondents were also asked to rate a number of factors that discredit the use of the ISSB in the construction industry. Graph 5-3 shows that the majority considered initial cost of the machinery was the main hinderance to the building materialôs use and the fact that itôs a new technology with a mean value of 4.61 and 4.08 respectively. The negative attitude towards earth construction was rated at a mean value of 2.37 Respondents also pointed out the nonexistence of data on the structural performance of the building material (3.73) and the need for close site supervision especially during block manufacturing (2.76). Low water resistance was registered lowest scoring with a mean value of 1.58.



Graph 5-3: Limitations of the ISSB technology. (Source: Author, 2014)

The analysis of these factors that impede the use and adoption of the stabilised soil block technology will help to identify the causes from which recommendations will be drawn.

4.6 Summary of the research findings

The study was carried out to evaluate the use of interlocking stabilised soil blocks as a building material in low-cost housing in Uganda.

The cost of construction materials has been seen to affect the adoption and use of a given building material in the survey. The ISSBs were assessed to be comparatively cheap to conventional materials owing to the reduced transport costs since the block production is done on-site.

Peopleϋs perception on the use of ISSBs has been indicated to be positive as the building material was viewed as structural strong, aesthetically pleasing, cost effective and easy to work with.

The initial cost of acquiring the block making machinery was noted to be the main setback of the technology since the target population is said to be mainly comprised of low income earners. The study also recognised on a positive note that the technology was being taken up by government institutions and non-profit organisation.

The building process was analysed to be similar to the conventional building methods but was noted for its ease of integrating local and unskilled manpower through training. The building process was also noted to enhance community relationships as it offers opportunities for people to interact by doing something together.

The stabilised soil technology has not only improved the housing conditions but also has impacted greatly on the livelihood of the people and community through job creation and sale of materials and tools used.

The building materialôs low tolerance to humid conditions was noted as a hinderance to the use of the ISSBs following the low resistance to rainwater. It also emerged that the use ISSBs does not support piece-meal development, a practice engaged in by the urban poor in the informal settlements.

The study revealed that the wall construction method is fast which is as a result of mortar-less assembly of blocks which reduces the time of construction and uses less skilled manpower since the blocks are self-aligning.

The blocks were found to have a vast colour scheme, smooth finish and aesthetically pleasing with pre-pointed straight, self- finished machine made masonry.

Most projects observed were residential houses that were rectangular in shape which implied that the material has rarely been applied in the construction of curved structures other than modular water tanks, thus not flexible in use.

The application of a coating to the external walls with a render, cement-based water proof finish or water repellent can be used to limit water intrusion mainly through capillary and suction as a way of reducing the maintenance requirements.

CHAPTER SIX

DISCUSSION

This chapter analyses the relevance of the theoretical framework to the findings of the study and thus attempts to answer the level to which the stated objectives and research questions have been achieved and answered respectively. This enables the researcher to bring forth well-established conclusions and recommendations after a careful comprehension of the problem under investigation.

In Uganda, the use of earth is already a conventional method widely used throughout the country and the affected populations have a good understanding of certain types of soil used in traditional block making. This creates the opportunity for ensuring sustainability with respect to the successful integration and evolution of earth technologies. Some of the issues analysed in relation to the use of ISSBs are as follows:

Socio-cultural aspects of the building material

From the literature reviewed, it was argued that peopleȏs perception on earth construction hampered its wide scale adoption and use where it was viewed as a substandard material that is predominantly associated with low social status as the majority of people who use it are poor (Sojkowski, 2002). This can be explained from living standard point of view where 25% of the countryȏs population is considered poor meaning they cannot afford socially accepted modern materials (UBOS, 2012) limiting their material pallet from which to choose. Graph 5-2 points out/shows cultural influence and beliefs among other factors under investigation as one of the aspects that has held back the widespread use of the ISSBs. This is because the building material is still being perceived by people as vernacular and incapable of being used to construct a permanent building.

The research findings however make a counterargument where statistics indicated that the ISSBs are rather aesthetically pleasing, structurally strong and need minimal maintenance requirements, technical and performance issues which, if addressed according to Balche and et. al (2008) could have the building material being specified and selected by designers and contractors.

During the survey, it was also noted that the block making machines used were majorly automated making it impractical for our context since the financial status and incomes of the target users rendered them incapable of purchasing the machinery due to its high initial cost. This is reflected in graph 5-3 where the cost of acquiring the machines is said to be the main drawback from using the building material by interested parties and a result, it is a recurring pattern according to Mr Mugisa (Hydraform) that the majority of projects where the building technology has been used are commissioned rather by the government or non-profit organisations and not the local people.

Cultural acceptance

As earlier mentioned in chapter five, the dry stacked method of wall construction is more less similar to the conventional building methods in that it allows for easy integration of unskilled local people through training and development of skills required for block making and laying. UN-Habitat (1985) explains the definition of an indigenous (local or traditional) building material in the context of low-income population as one that is accessible and affordable, and continues to highlight the three principles that guide the idea of these materials:

1. Use of locally available factor inputs (materials, labour and etc.)
2. Affordability to low-income population.
3. Orientation to the construction needs of the majority.

From literature, the author categorises the ISSBs under innovative or appropriate materials which represent efforts to improve the low quality of traditional building materials through research and experimentation. It is observed from the field surveys that the houses were built using materials that were sourced from the site to make soil blocks while engaging both skilled and unskilled labour that was from the siteôs vicinity. The integration of local people, to the author means that the skills necessary during the building process and method of construction can be easily passes on to a community, a case that could result in the adoption and use of the building material thus being accepted by the society as the case of Sakali, South Sudan.

It also is observed in this study that the stabilised soil blocks present an improvement on traditional earth building techniques within these rural communities as it can easily be compared to the other materials such as burnt bricks and sand-cement blocks. Despite this, ISSBs have continued to be associated with traditional building materials/methods such as adobe, mud and wattle types of wall construction that are not stabilised, a perception that has stuck in the minds of many.

The materialôs easy workability, which is illustrated in the research findings (see graphs 5-2) to a large extent was as a result of incorporating the local people within the building process, which creates devotion within the community by developing a sense of belonging and attachment in the occupants who use it and the society that participated or rather in which it is located. This is affirmed by Zani and Lee (2008) where they argued that construction in earth has the uniqueness of manifesting the cultural heritage of any people and thus encouraging the continued use of the material which helps to maintain and preserve the cultural values embedded in earth buildings.

Sanya (2007) collaborates the above arguments saying local production based on locally available materials offers opportunities for people to interact by doing something together which according to site observations involved the sourcing raw materials, preparation and process of making the soil blocks. This also enhanced community relationships as family members and neighbours were involved in the entire building process.

Community participation

dôUrzo (2010) states that putting the local population at the centre of the needs assessment and evaluation of the local capabilities is key through demonstrating the potential of local materials for constructing quality buildings. This is reflected in case study one identified, where local work force was trained to produce and build with stabilised soil blocks. In Darfur for example, the training of 123 people on stabilised soil block technology impacted positively through job creation, income and livelihoods generated by the various construction projects that resulted from the development of the settlement. There was also a change in the employment pattern from a male dominated construction sector as women also acquired new skills in soil preparation, curing and block laying which elevated their status in their communities.

Material sourcing

The first case study showed the challenges of providing infrastructure and other basic services that were overcome amidst the scarcity of materials due to their high demand that resulted in the profusely high cost of acquiring them. The use of local resources that existed within the area helps to have the production cost of the building material kept to a minimum as a viable option. This result reflects on the argument by Rob et al. (2012) that the choice of building material will heavily be influenced by what is locally available given the different project locations and the need to minimise the transport costs. In this resettlement project, different experiments were carried out on new binders in the making of stabilised soil blocks using arabic gum as a promising material within the region highlighting the need for research on other appropriate materials. This points to the CRATerre (2005) publication that suggests the need for building materials to be subjected to a review in order to adapt them to the evolution of societies and their environment even though they are not satisfactory at the time of their conception, and this can be achieved through experimentation, linking research and dissemination of research.

Spatial design and form articulated

During the survey, it was observed that most buildings took on a rectangular or square form which not only relates with the neighbouring structures but is a form that is simple in nature and their design has a role in the strength of the buildings. The Hydraform blocks are based on a modular system (240mm x 115mm x 200mm) as shown in figure 2-1 meaning the layout is limited to be within the above dimensions, or else there will be more blocks wasted by cutting to attain a certain dimensions of the buildings. The results from graph 5-2 indicated that the material is flexible and can be used and applied in numerous designs. The ISSBsôuse in curved structures is limited as the geometry of the block can be easily employed on rectangular forms, an argument that diverges from the findings pertained.

It is for this reason that the argument that the ISSBs are not flexible in their use as it was noted by some design professionals that as one of the issues that has deterred them from specifying the building material. The author, during the site visits also observed that the building form was articulated by plastering the wall edges and opening (door and window) outlines, which emphasises the highlighted elements. This together with the transformations in the form of the building give the structures a different attribute and character from the other buildings within the context studied.

Building process and time schedule

The building process in this study was analysed to be marked by resemblances in their methods of sourcing raw-materials, preparation to mention but a few to the conventional building methods. It was observed in the case study one that the building method allows for partial construction where the spatial layouts in this case were intended to maximise the use of the available land and matching the cultural values. These piece-meal developments are however not encouraged in many publications reviewed as they are prone to wearing and dampness since they are not water proof and are liable to develop the above weathering defects if overexposed. This argument is depicted in the graph 5-2 where the resistance of the ISSBs to rain water is highlighted as the main factor that is impeding the use of the building material since their durability cannot be guaranteed with the materialôs low tolerance to humid conditions. From the site surveys done, it was observed that the majority of the buildings had large roof overhangs which are intended to protect the walls from the incident rain and it is for this reason that the overhang should preferably be not less than 600mm.

It was also observed that the wall construction method has greater accuracy levels since the blocks are self-aligning as long as the first course is levelled and plumbed, has a quick /fast speed of erection and requires less skilled man power. The findings in graph 5-3 reflected on this argument with time schedule (speed of construction) as a variable that has influenced the designers and contractors to specify or use the ISSBs in some of their projects. Dry stacked blocks can be laid up to five times faster than the conventional as a five-man crew can erect and finish one unit within not more than one week (Rob, Richard and Andrew, 2012). This is because the stackable interlocking blocks differ from the conventional blocks in such a way that the units are assembled without the use of mortar resulting into the reduction in the construction time and required skilled man power as the blocks are self-aligning. The interlocking stabilised soil blocks manual press is the most affordable block option of block making in that it is convenient in rural settings due to the fact that it is manually operated and easy to use. But most importantly, the manual press produces 400-800 blocks in an 8-hour work day using a 2-4 workers (UN-Habitat, 2009) thus reducing the time required for blocking making/production process.

Comfort rating

The study, from graph 5-1 showed that the spaces are ambient and comfortable with the indoor conditions relatively cool which is credited to the blocksô density that makes the building material acquire a low thermal conductivity. It is for this reason that the spaces within are usually cool during the hottest time of the day and contrary at night where the walls radiate the heat energy absorbed during their dayôs exposure to the sun, making the space inhabitable at any time of the day. The other comprehensible account is the block wall colour, when left unrendered, psychologically yields a warm feeling given that the building material takes on the brown colour of earth.

Degree of enclosure

The enclosing walls create a field/space that is directed inward or introverted which would ideally leave the users to have their own perceptual experiences about the space depending on the form, scale and perhaps the proportions. The openings placed on the primary walls of the building enabling the indoor spaceȏs surfaces and articulations to be revealed by direct or otherwise ambient light that profuse through. The configuration and pattern of the surfaces and openings help to define the space with certain spatial qualities in turn influencing how the spaces ought to be functionally utilised. In case studies 2 and 3, it was observed that the openings are often centered along the enclosing planes appearing as a bright figure on the dark adjacent block surface. This on the other hand helps to give visual balance to the surfaces around the opening and the space within proportionately, as we humans are innately comfortable in a balanced setting. The findings in graph 5-1 showed that the built spaces have qualities that surpass their earlier dwellings however intangible that most found hard to explain but rather affirmed that their personal conditions (as distinct from material comfort) under which they lived had altered. Despite most buildings studied being moderately sized, users, particularly those that lived in houses whose interior walls were not plastered highlighted that the rooms are adequate enough. The shadow gaps along the courses when light illuminates the blockwork gives the illusion of a broader space than there actually is as the room is stretched along the horizontal axis.

Privacy and Visual connection

The fact that the dry stack method of construction relies on the self-weight of the blockwork for structural stability limits the number and size of openings that can be accommodated so as not to compromise on the integrity of the structure. The central positioning of the openings along the enclosing walls helps to maintain sense of enclosure without weakening the form definition and thus gives visual emphasis on the volume of the space within as it is illuminated. This bestows a sense of privacy and security on the users as the focus is directed inside the defined boundaries. The ISSBs a building material not only look secure but also feel strong than the widely used mud and wattle in rural areas or wood structures and iron sheet structures in the slum areas within the city suburbs.

As a consequence however, this limitation affects the visual relationship between the enclosed space and its outdoor surroundings where by constraining the space to its boundaries and restricting the interaction beyond into the broad natural scene.

Aesthetic qualities

The study, from graphs 5-1 and 5-2 showed that the building material is aesthetically pleasing with a face-brick finish that provides for pre-pointed straight masonry which is mainly attributed to the fact that the blocks are machine-made making it easy to achieve uniform block dimensions that are self-finished and also give certainty of durability of the ISSBs. This notion is contrary to the literature reviewed where the peopleôs perception on earth constructions was said to substandard and traditional, and the need to have the aesthetic and performance requirements of these earth construction techniques addressed was raised as a pressing issue. The findings from the literature reviewed therefore act contrary to the conclusion that the publicôs opinion and perception on ISSBs is gradually gaining complacency and admiration from its end- users and the immediate community within which the material was used.

The survey conducted also revealed that the external walls of most buildings observed were left un-rendered and the interior walls plastered and painted though the former can, according to Mr Herbert be rendered as an option that is rather not required. It is critical to understand that whilst most cases studies during the survey had their exterior wall exposed, plastering and application of a decorative render with paint would enhance the appearance of the building. But since the majority of the developments were considered to be low-cost, the application of an exterior render would only increase the construction cost and thus the alternative was averted.

Material colour and texture

The interlocking stabilised soil blocks were observed, during the survey to have a vast colour scheme which was highly attributed to the colour of the soil used since the latter took the eminent proportion in the composition used in the production of the blocks (see Figure 5-3). For this reason, the author thinks the end-users have no control over how their buildings should ideally look like depending on oneôs preference.

It was also observed that the soil blocks had a smooth texture that is attributed to the machine compaction process of making the blocks whose quality finish was noted to be left exposed in many cases without a rendering. The face-brick colour and smooth finish of the buildings studied to a large extent enabled them to fit suitably within nature since itôs in a material that most people relate to, earth. This not only becomes a cost reducing strategy by saving plaster and other rendering materials and finishes, but rather gives the building a unique visual quality.

Cost of construction

From the empirical simulations, it is observed that the cost of the building materials (ISSBs and brick) is relatively the same with the cost of burnt bricks slightly lower than that of interlocking stabilised soil blocks (compare costs in tables 5-1 and table D in the appendix). The difference in the cost is as a result of the raw material inputs with which the ISSBs are produced and the transport cost that one incurs to have delivered to the site.

However, it was also observed that the cost of preparation and assembly of the housing unit varies considerably with brick construction costing more than ISSBs. This can be explained from a time schedule view point where time taken to construct the same prototype with ISSBs is less compare to when using burnt bricks and given the fact that most tasks/activities are paid on a daily basis, either per day or per square metre. This means that activities will always take long or delay to be completed implying that more money will be spent since the more an activity holds up in a construction process, the longer other tasks that would have happened simultaneously or after its completion will have to also lag behind schedule.

Maintenance requirements

The study also revealed that ISSBs have a less resistance to rainwater which one of the factors that has restricted the use of the building material according to the inquiry made (see graph 5-2). Block with less than 1800kg/m^3 made with low-cement proportions of less than 6% exhibit low tolerance to humid conditions if left un-rendered. Such ISSBs according to Noel, peter and Alinaitwe (2014) are not very durable and will deteriorate in less than 10 years. Hydraform recommends a mixing ratio of 3:2:1 soil, sand and cement which yields a blocks of 7 MPa, a value which is above the minimum required compressive strength of 2.5 MPa (UNBS, 2009). The ISSBôs hard-wearing properties and resistance to rainwater penetration was found questionable despite the fact the materialôs strength increases with the amount of cement used as some of the walls which were broadly exposed to the elements of weather showed sign of erosion which could have resulted from moisture suction from the ground or from pitched rainfall.

From the authorôs physical observation, the materialôs hard-wearing and resistance to rainwater penetration was found questionable as it was assumed that a block with more than 3.5 MPa is durable and strong enough to resist the defects, and this in a survey carried out, is impeding the adoption and use of the building material.

These defects according to Hebert, can be altered by application of a coating to the external walls with a render, cement based water proof finish or water repellent such as petroleum products like burnt oil to reduce the leakage and dampness from incident water. Permeable reducers can be used to limit water intrusion through capillary or suction effect by forming crystals within the pores of the concrete. Examples of such permeable reducers include acronal S400 and masterseal 501.

The results of this study also highlighted a number of factors that deter the use of ISSB in the construction industry including the high initial cost of block making machinery, lack of data on the structural performance of the material and the stabilised soil block technology being a relatively new concept in the country. This is mainly because the general public has mixed feeling about the technology and also the precedence set by the first people to use the building material and technology did not pose a good example since they did not take heed of the procedures put in place to attain quality results as they wanted to cut corners with intentions of hugely reducing the cost.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The study explored a number of contributions and drawbacks associated with the use of interlocking stabilised soil blocks as a building material in the construction of low-cost houses. The study also established issues impeding the successful use of the ISSBs in construction. This chapter gives the summary of the findings as per the study objectives and also presents recommendations and conclusions of the study, highlighting possible areas for future research.

6.1 Conclusions

The study portrayed the societyøs interest to use the interlocking stabilised soil blocks as a sustainable and eco-friendly construction material in their process of manufacture and exhibited unrivalled potential of meeting the housing deficit in the country. The aesthetic quality, material colour and texture of the ISSBs vary from generally acceptable to excellent design criteria depending on the level of workmanship.

Despite the structural strength of the blocks being above the required minimum standard, the ISSBs have low tolerance to humid conditions which questions the blocksô durability. The cost of the commonly used electric and diesel block making machines is high and not affordable to the urban poor. The quality of space of the dwellings has greatly been enhance despite the building materialøs inability to be retrofitted posing a challenge as the target group indulges more in the piece-meal practice of construction. The technologyøs capacity to enhance community relationships, improve peopleøs living standards and empower communities through interactions, employment opportunities, and training and development of skills is desirable. The technology is also beginning to be explored by the private sector from a predominantly government and NGO segment shows that the technology is being embraced by the ordinary person.

The factors and variables that greatly influence the use and adoption of the interlocking stabilised soil blocks are low cost of materials for block production, reduced time of construction and the ease of workability. The building material also exhibited setbacks which included the high initial cost of machinery, mixed feeling about the new technology, materialøs low tolerance to humid conditions and the lack of data on the structural performance of the material in the national archives. The other variables that were studied include the ambience and thermal comfort, privacy and security concerns, maintenance requirements, durability and its flexibility in use.

6.2 Recommendations

The following recommendations were arrived at through discussions and conversations with several individuals that included professionals in the design and construction industry, end-users and staff of the machine suppliers (Hydraform). The study makes the following recommendations;

The government and the policy makers should be involved in quality control by establishing minimum standards of the blocks required for their production regardless of where it takes place i.e. craft/small units or industrial units. This will eliminate substandard materials being used for construction or sold on market. Efforts should also be made through initiatives by the government to have the cost of machinery reduced providing tax deduction and write-offs to encourage the purchase of block making machines by the private sector.

For the production of ISSBs, the use of electric and diesel block making machines ought to be replaced by the manual press machines. This is ideal for both informal and rural areas where such energy resources are limited or not present and more so the manual press can easily be operated by the local people. This will in turn help reduce the cost of acquiring the machinery.

Promotion and raising awareness of the masses on the use and adoption of the alternative building technology through training so as to disseminate skills and information to the academic institutions and communities, where the ISSBs are presented as a potential replacement to the conventionally used building material allowing for zero consumption of firewood.

There is need for more research into the interlocking soil block design bringing forth a wide range of presses which can be used in all contexts to meet the different needs and objectives, making the building material very flexible in achieving varying architectural realisations. This will make ISSBs suitable for use in various infrastructure programmes.

The resistance of the ISSBs to wearing and water penetration can be achieved through both design and precautions. Roofs with long overhangs help to protect the walls from incident rain but nevertheless, the external walls need to be rendered with plaster or a coating of cement-based water proof finish or water repellent to reduce the leakage and dampness from incident water.

6.3 Possible issues for further research

To end this study, some areas that were noteworthy for further research so as to come up with solutions to the problem. An inquiry into these areas will help address the limitation that influence the use and adoption of the interlocking stabilised soil blocks. Some of the issues include the following;

The effect of low resistance to humid conditions observed in many cases calls for an inquiry into measures of how the ISSBs can be made to withstand the wet conditions so as to enhance the durability of the blocks.

Studies on how quality control can be ensured and achieved on both small-scale and industrial production units will help to work out common standards.

The extent to which the material can address the spatial requirements of the users.

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Tables of cost calculation for the simulation

Cost of Sand

	Amount	Unit
Quantity	3	m^3
Material + Transport cost	165,000.00	UGX
Cost per cubic metre	55,000.00	
assuming one tipper lorry is $3m^3$		

Table A: Cost estimations for sand.

Cost of cement

	Amount	Unit
Reference one 50kg bag	0.042	m^3
Material + Transport cost	30,000.00	UGX
Cost per cubic metre	714,285.71	
50kg bag = 42 litres and 1000 litres = $1m^3$ assuming one dyna truck carries 100 bags[3]		

Table B: Cost estimations for cement.

Cost of water

	Amount	Unit
Reference	20	litres
Material cost	-	UGX
Transport cost	100	UGX
Total cost	100	UGX
Cost per cubic metre	5000	UGX
$1m^3$ = 1000 litres		

Table C: Cost estimations for water.

Mortar plaster calculations. Mix ratio **1:6** (cement: sand)

(1/6)m^3 cement + $1m^3$ sand = $1m^3$ of mixture
(1/6)m^3 cement + $1m^3$ sand + (1/5) water reduces volume (Douline, 2003)
To give $1m^3$ of mortar therefore requires multiplying the mixture by a factor of 1.2

Using the material cost of the above table gives the cost of $1m^3$ of mortar/plaster

= 1.2 (0.17 x 714,285.71 + 55,000 + 0.2 x 5,000) = **210,057.14**

Allow for 20% wastage to get the final cost = **252,068.57 UGX**

<u>Cost calculations for Brick header wall using 22cm x 14cm x 8cm brick</u>

Brick cost	**Amount**	**Unit**
Area of walling	169.8	m^2
Number of bricks in 1m^2	68	Bricks
Allow for 25% breakage	17	Bricks
Total number of bricks	14433	Bricks
Cost per brick	160	UGX
Total cost of bricks	2,309,280.00	UGX
Mortar cost		
Mortar volume per brick	7.55	$m^3 \times 10^{-4}$
Total mortar volume	10.9	m^3
Cost per m^3 of mortar	252,068.57	UGX
Total mortar cost	2,747,547.41	UGX
Plaster cost		
Plaster volume	4.27	m^3
Cost per m^3 plaster	252,068.57	UGX
Total plaster cost	1,076,332.79	UGX
Laying cost		
Labour	72.165	Mason-porter days
Laying wage	8,500.00	UGX per mason-porter days
Total laying wage	613,402.50	UGX

Table D: Cost estimation for the prototype constructed using bricks.