

**AN INVESTIGATION OF PERCEPTIONS ON THE SUITABILITY OF RAMMED  
EARTH IN THE CONSTRUCTION OF AFFORDABLE HOUSING UNITS IN ZAMBIA**

**BY**

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**A dissertation submitted to the University of Zambia in partial fulfilment of the  
requirements for the award of the degree of Master of Engineering in Construction  
Management.**

**The University of Zambia**

**LUSAKA**

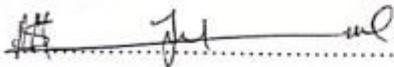
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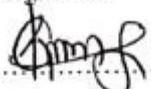
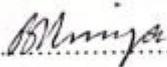
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## CERTIFICATE OF APPROVAL

This dissertation by Simbeye Raphael entitled 'An Investigation of Perceptions on the Suitability of Rammed Earth in the Construction of Affordable Housing Units in Zambia' is approved as partially fulfilling the requirements for the award of the degree of Master of Engineering in Construction Management of the University of Zambia.

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## ABSTRACT

Housing is one of the basic necessities of mankind known to affect human health and well being. Since 1964, Zambia has been struggling with the provision of housing in urban areas. Zambia's urban population rose by 52% from 5,173,450 to 7, 844,628, between 2010 to 2022. The current housing deficit is estimated at over 2,000,000 housing units compared to 860,000 units estimated in 1996. This study aimed at exploring the use of stabilised rammed earth in the construction of affordable housing units in Zambia. A mixed method approach of both qualitative and quantitative analysis was adopted, with data collected using a questionnaire as well as laboratory tests. In establishing public perception on the use of rammed earth, a total of 104 respondents were sampled. Furthermore, in assessing the properties and suitability of rammed earth for housing construction, soil samples were collected from four different locations within study area. The study revealed lack of legislation on rammed earth construction, and that the public perceptions on the use of rammed earth is mixed. Whilst there was some considerable level of agreement on its advantages mainly in terms of lower cost of construction, thermal, fire as well as moisture resistance, the respondents on the other hand were of the view that the structural strength for houses constructed with rammed earth is poor compared to ones constructed with concrete blocks. More so, that only 41.7% had knowledge on construction techniques associated with rammed earth. Furthermore, on the properties of rammed earth, the laboratory tests revealed that the cubes stabilised with 3%, 6% and 10% cement displayed increased compression strength of more than 2MPa compared to unstabilised cubes. The research therefore recommends the need for a legal framework which supports the use of stabilised rammed earth in housing construction in Zambia. This technology, if adopted, could bridge the gap in housing deficit and lead to affordable housing provision.

**Keywords:** Affordable Housing, Perceptions, Stabilized Rammed Earth

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## TABLE OF CONTENTS

CERTIFICATE OF APPROVAL .....	iii
ABSTRACT.....	iv
ACKNOWLEDGMENTS.....	v
TABLE OF CONTENTS.....	vi
LIST OF FIGURES.....	xiii
LIST OF TABLES.....	xv
LIST OF EQUATIONS .....	xvii
LIST OF ACRONYMS.....	xviii
CHAPTER ONE : INTRODUCTION.....	1
1.1 Background .....	1
1.2 Problem Statement.....	2
1.3 Aim of the Research.....	2
1.4 Research Objective .....	2
1.5 Research Questions .....	3
1.6 Scope of the Research .....	3
1.7 Significance of the Study.....	3
1.8 Chapter Synthesis .....	4
1.9 Chapter summary .....	5
CHAPTER TWO : LITERATURE REVIEW .....	6

2.1 Introduction .....	6
2.2 Definition of Rammed Earth .....	9
2.3 Historical Overview of Rammed Earth.....	9
2.4 Classification and Types of Rammed Earth.....	10
2.4.1 Pise' de terre.....	10
2.4.2 Adobe Sun Dried Bricks.....	11
2.4.3 Compressed Earth Brick.....	12
2.4.4 Perceptions on Rammed Earth .....	13
A) Primitive material .....	13
B) Rammed earth suitable for hot and rid regions.....	14
C) Labour intensive .....	14
2.5 Construction Methods and Techniques.....	14
2.5.1 Traditional Method.....	14
2.5.2 Modern method .....	14
2.5.3 Soil Identification and Preliminary Site Testing .....	16
A) The drop test .....	17
B) The jar test "Particle size test" .....	17
C) Ribbon test .....	18
D) Smell test.....	18
2.5.4 Laboratory Testing.....	18

A) Formwork .....	20
2.6 Stabilised Rammed Earth .....	20
2.6.1 Benefits of Stabilised Rammed Earth Construction.....	21
2.6.2 Aesthetics .....	21
2.6.3 Lifespan .....	21
2.6.4 Improved compression strength .....	22
A) Soil Cement Mix Ratios.....	23
B) Plasticity and Shrinkage.....	23
2.6.5 Microclimate regulation and thermal comfort.....	24
2.6.6 Sound Insulation .....	25
2.6.7 Self Job Creation .....	25
2.6.8 Fire proofing .....	25
2.6.9 Economic Benefits of Rammed Earth Construction in Sustainable Urban Housing .....	25
2.6.10 Environmental Benefits of Stabilised Rammed Earth Construction .....	25
2.7 Challenges Associated with Rammed Earth Construction.....	27
2.7.1 Water Abrasion.....	27
2.7.2 Low Resistance to Abrasion.....	28
2.7.3 Poor Tensile and Compression Strengths.....	28
2.7.4 Lack of Building Codes .....	28
2.7.5 Not all soil types are appropriate. ....	28

2.8 Building Regulations in Zambia.....	28
2.9 Summary .....	29
CHAPTER THREE : METHODOLOGY .....	30
3.1 Introduction .....	30
3.2 Research Design.....	30
3.2.1 Research Approach.....	30
3.3 Methodological choice.....	31
3.4 Research Strategy .....	31
3.4.1 Part A - Survey .....	32
3.4.2 Part B – Laboratory Experiments.....	32
3.5 Target population .....	32
3.5.1 Survey .....	32
3.5.2 Sample .....	33
3.5.3 Sample size .....	34
3.6 Data collection .....	35
3.6.1 Primary Data Collection .....	35
3.6.2 Secondary Data .....	35
3.7 Survey .....	36
3.7.1 Questionnaire .....	36
3.7.2 Laboratory Experiments .....	36

A)	Data collection procedures .....	37
i)	Material selection.....	37
ii)	Determination of particle size distribution .....	37
iii)	Compaction test (Proctors test) .....	38
iv)	Dry Density .....	39
v)	Bulk Density .....	39
vi)	Moisture Content test .....	39
vii)	Optimum Moisture Content.....	40
viii)	Casting of Rammed Earth Test Cubes .....	40
ix)	Curing procedures .....	41
x)	Moisture absorption by immersion.....	41
	3.8 Data Analysis and Presentation .....	41
	3.8.1 Descriptive statistics .....	42
	3.8.2 Reliability and validity .....	42
A)	Survey .....	42
B)	Laboratory Experiments .....	42
	3.9 Ethical consideration .....	43
	3.10 Summary .....	43
	CHAPTER FOUR : FINDINGS AND DISCUSSION.....	44
	4.1 Introduction .....	44

4.2 Background to the Findings .....	44
4.3 Survey Research.....	44
4.3.1 Sample Sizes and Response Rate.....	44
4.4 Perceptions on the use of Rammed Earth for Housing Construction.....	47
4.4.1 Specification of Rammed Earth as a Construction Material in Urban Housing.....	48
4.5 Suitability of rammed earth for housing construction .....	51
4.5.1. Material selection.....	51
4.5.1.1 Moisture Content test.....	52
4.5.2. Compaction test (Proctors test) .....	53
4.5.3 Curing procedures .....	53
4.5.3 Unconfined Compressive Strength.....	54
4.5.4 Moisture absorption by immersion.....	55
4.5.5 Residual strength.....	57
4.5.6 Rate of Drying .....	58
4.6 Exploring the cost comparisons of rammed earth to conventional building materials. ....	59
4.6.1 Comparing Unit Rate Cost for rammed earth against concrete block for wall construction. .	59
4.7 Discussion .....	61
4.7.1 Perception on the use of Rammed Earth .....	61
4.7.2 Properties of Rammed Earth .....	62
4.7.3 Cost comparison of stabilised rammed earth against concrete blocks.....	64

CHAPTER FIVE : CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS.....	66
5.1 Introduction .....	66
5.2 Conclusions .....	66
5.2.1 To establish public perception on the use of rammed earth in housing construction. ....	66
5.2.2 To assess the properties and suitability of rammed earth for housing construction. ....	66
5.2.3 To compare the cost of wall construction using rammed earth and conventional concrete block work. ....	66
5.3 Limitations of the Study.....	67
5.4 Recommendations .....	67
REFERENCES .....	69
APPENDICES .....	78
Appendix 1 – Ethical Clearance.....	78
Appendix 2 –Questionnaire .....	81
Appendix 3 - Laboratory Experiments .....	90
Appendix 4 – Comparison of Concrete and Rammed Earth Construction Cost .....	94

## LIST OF FIGURES

<i>Figure 2-1: Informal and poorly constructed houses in Grippies, Lusaka</i> .....	7
<i>Figure 2-2: Rammed earth construction of Shipundu Community School, Zambia</i> .....	11
Figure 2-3: Stabilised Rammed Earth House, Western Australia.....	11
Figure 2-4: Adobe sun-dried bricks making process .....	12
Figure 2-5: Classroom block made from hydrofoam bricks .....	13
Figure 2-6: The Great Mosque of Djenne built between 1200 and 1330.....	22
Figure 2-7: Rammed earth roof eave detail .....	27
<i>Figure 3-1: Water spraying of the sieve material</i> .....	38
<i>Figure 3-2: Sieve material in readiness for drying</i> .....	38
Figure 4-1: Professional background of respondents.....	45
Figure 4-2: Respondents' position in the firm or organisation.....	46
Figure 4-3: Respondent's experience in the Construction sector .....	46
Figure 4-4: Comparison on marketability.....	48
Figure 4-5: Percentage distribution on the use of rammed earth in construction .....	49
Figure 4-6: Marketability of rammed earth housing units against conventional housing units .....	51
<i>Figure 4-7: Drying of samples in the oven</i> .....	52
<i>Figure 4-8: Dried sample ready for</i> .....	52
Figure 4-9: Relationship between Maximum Dry density and Moisture content for sample A .....	53
<i>Figure 4-10: Curing of rammed earth cubes wrapped in polythene sheets</i> .....	54
<i>Figure 4-11: Weighing of rammed earth</i> .....	54
<i>Figure 4-12: Compressive strength test after curing at various test days</i> .....	55
<i>Figure 4-13: Cured sample undergoing compressive strength test</i> .....	55
<i>Figure 4-14: Weighing of the specimen before emersion in water</i> .....	56

*Figure 4-15: Water absorption by* ..... 56

*Figure 4-16: Placing of rammed earth cubes in an oven* ..... 58

*Figure 4-17: Fired rammed earth cubes* ..... 58

Figure 4-18: Key hydraulic and thermo - chemo process and associated temperature ranges during typical clay brick firing ..... 63

## LIST OF TABLES

Table 2-1: Percentage Distribution of Households by type of Housing Unit by Residence, Stratum and Province, in Zambia .....	8
<i>Table 2-2: Minimum width of strip foundation in rammed earth.</i> .....	16
Table 2-3: Recommendations for soil suitability .....	17
Table 2-4: Ribbon test evaluation. ....	18
Table 2-5: Compressive Strength test specimen details.....	19
Table 2-6: Recommended design values for characteristic Unconfined Compressive Strength .....	20
Table 2-7: Cement-stabilised rammed earth Compressive Strength.....	23
Table 2-8: Rammed earth Permissible linear shrinkage to various codes and standards.....	24
Table 2-9: Typical thermal characteristics of walls of different construction materials.....	25
Table 2-10: A comparative analysis of energy consumption and carbon dioxide emission of four types of building materials.....	26
Table 2-11: Comparison of foundation types carbon dioxide emissions. ....	27
Table 3-1: Categories of target population .....	33
Table 3-2: Sample size justification.....	35
Table 3-3: Number of stabilised and unsterilized cubes .....	40
Table 4-1: Summary of population sizes, sample sizes and response rates .....	45
Table 4-2: Perception on the use of Rammed Earth for Housing Construction.....	47
Table 4-3: Comparison of specification and usage of construction material during design and construction .....	49
Table 4-4: Recommendation of Rammed earth and other building materials to developers by Design professionals .....	50
Table 4-5: Comparison of the cost of rammed earth to other conventional building materials.....	50

Table 4-6: Test soil composition.....	51
Table 4-7: Moisture content Determination.....	52
Table 4-8: Optimum Moisture Content and Maximum Dry Density.....	53
Table 4-9: Compression strength results at 7, 14, 28 and 56 days.....	55
Table 4-10: Moisture absorption by immersion.....	56
Table 4-11: Relationship between moisture content, time and stabiliser.....	57
Table 4-12: Compression Strength results after fire tests .....	57
Table 4-13: Rate of Drying .....	58
Table 4-14: Cost comparison of rammed earth to other construction building materials.....	59
Table 4-15: Summary of Construction cost for a 101.5m <sup>2</sup> concrete block house.....	60
Table 4-16: Summary of Construction cost for a 101.5m <sup>2</sup> stabilised rammed earth house.....	61
Table 4-17: Hydraulic and thermo-chemo dynamic processes associated with clay brick firing.....	63

## LIST OF EQUATIONS

Equation 3-1 Calculating Sample Size .....	34
Equation 3-2 Calculating Sample Size correction .....	34
Equation 3-3 Calculating Dry Density. ....	38
Equation 3-4 Calculating Bulk Density .....	39
Equation 4-2 Calculating Unconfined Compression Strength.....	46

## LIST OF ACRONYMS

ASTM E	Standard Terminology for Sustainability Relative to the Performance of Buildings
CSO	Central Statistics Office
ICS-UNIDO	International Centre for Science and High Technology of the United Nations Industrial Development Organization
MHID	Ministry of Housing Infrastructure and Development
MLGH	Ministry of Local Government and Housing
NZS	New Zealand Standard, Wellington, New Zealand
SAZS	Standards Association of Zimbabwe
SRE	Stablised Rammed Earth.
ZDA	Zambia Development Agency
ZSA	Zambia Statistics Agency
UKAID	United Kingdom Agency for International Development
WCED	World Commission on Environment and Development. Oxford University Press, Oxford.

## CHAPTER ONE : INTRODUCTION

### 1.1 Background

According to United Nations (2013), cities and towns have become the primary living space. More than half of the world's population has been living in towns and cities since 2007 and the estimates indicate that by 2050, the urban population will exceed 70% of the world population (Pacheco et al., 2012; UN, 2013). In developing countries more than 1 billion will move from rural areas to cities and towns by 2030 (UN-Habitat,2003;2010; 2020; Amin *et al.*, 2015; Melian et al., 2016). According to Zami and Lee (2010), cities in developing nations have been experiencing unprecedented population growth since 1950's due to rural urban migration. Zami (2010) further contends that the cities in developing nations are not planned to accommodate the rapid population growth resulting in the mushrooming of informal settlements. The absence of corresponding increase in affordable housing investment and infrastructure to population growth has led to increased deficit in housing provision, poor sanitation facilities and national resource and environmental depletion (Arnott, 2009; Gandhi, 2012; UNDESA, 2013; Okeyinka, 2014).

Zambia's population stood at 19,610,769 with urbanization rate at 4.3% confirming that Zambia is one of the most urbanised developing countries in Africa (MHID, 2020; ZSA, 2022). Zambia has been struggling with the provision of affordable housing since attainment of its independence in 1964 (Hadjri, et al 2007; UNCAD, 2015; Phiri, 2016). The rapid rural-urban migration population growth coupled with dwindling formal economic activities and increased informal sector economic activities in Zambian urban areas has exerted pressure on the provision of affordable housing delivery and other basic infrastructure. The increase in urban population has led to a corresponding increase in urban poverty (Chibuye, 2011; UKAID, 2015).

Zambia needs to build more than 222,000 housing units annually to reduce a housing backlog currently at more than 2 million formal housing units (ZDA, 2014; Phiri, 2016). Out of the estimated existing housing stock of 2.5 million in 2010, only 36% were formal housing (about 800,000) while 64% were traditional houses (Phiri, 2016). According to ZSA (2016) 43% of the estimated 3,014,965 units in 2015 were formal housing (about 1,296,905) representing an increase of 7% or 406,305 units. However, the annual addition in formal housing over a period of five years from 2010 to 2015 was 81,261 which was less by 140,739 units of the targeted estimate of 222,000 (MHID, 2020) units annually. The Zambian government's desire to provide affordable housing for its citizens is emphasised in the Eighth National

Development Plan (8NDP 2020-2024) which state that “To increase access to decent and affordable housing for all, the Government will facilitate the provision of affordable housing finance, provide incentives for private sector participation, and promote investments in research on alternative building materials and technologies. Consequently, during the Plan period, the housing deficit is expected to reduce from 1,539,000 in 2021 to 1,378,000 housing units in 2026.”

Almost 50% of the population, most of the rural population, and at least 20% of urban and suburban population live in earthen structures (ICS, 2008) as it allows them to reduce the cost of construction whilst building large and durable houses (ZSA, 2012). Earth has always been accepted as a building material to build durable houses in the informal sector as it is the most affordable and sustainable material to provide shelter since earth is an abundant resource (Zami and Lee, 2010).

## **1.2 Problem Statement**

The provision of sustainable and affordable housing has been Zambia’s desire to bridge the gap in the housing deficit (8NDP 2020-2024) since the attainment of its independence in 1964. According to the survey conducted in 2015, earthen structures accounted for 57% of the total housing units in Zambia (ZSA, 2016) confirming earth as the most acceptable alternative building material. There have been some effective attempts at building new housing stocks since 1991 both by the government and the private sector. However, these interventions have yet to have any significant reduction in housing deficit as the majority of the urban dwellers are unable to afford the houses resulting in the increase of unplanned settlements with poor housing units. Though earth is popular as a housing construction material, the perceptions on rammed earth that it has poor compressive strength, high construction cost including poor resistance to weather elements has affected its widespread use as an alternative material to construction of affordable housing units in Zambia despite its advantages over the conventional concrete and sand-cement block construction method.

## **1.3 Aim of the Research**

The aim of the study was to investigate the Perceptions on the suitability of the use of rammed earth in construction of affordable urban housing units in Zambia.

## **1.4 Research Objective**

The following were the objectives of this study: -

- i) To establish public perception on the use of rammed earth in housing construction in Zambia and elsewhere.
- ii) To assess the physical and chemical properties of the soil including suitability of rammed earth for housing construction.
- iii) To assess the cost advantage of stabilised rammed earth construction against other conventional building materials.

### **1.5 Research Questions**

To achieve the specific objectives of this study, the following research questions need to be addressed: -

- i) What is the public perception on the use of rammed earth in housing construction in Zambia and elsewhere?
- ii) How is the suitability of rammed earth for housing construction?
- iii) What is the cost advantage of stabilised rammed earth construction against other conventional building materials.

### **1.6 Scope of the Research**

The increase in population growth without corresponding increase in housing stocks has exerted pressure in the provision of housing in Zambia. Currently the housing stock deficit stands at over 2 million units. In view of the situation, the study analyses the role of stabilised rammed earth in the construction of sustainable and affordable housing. The study evaluated the challenges and perceptions on the use of rammed earth as a building material and conducted laboratory experiments to evaluate the effect of Portland cement as a stabiliser on the compressive strength and resistance to weather elements of rammed earth. Further, the study also involves an analysis of cost comparison of rammed earth structure to that constructed using conventional building materials such as concrete block. The scope of the study was restricted to construction professionals, contractors, and occupants of earthen structures as well as laboratory experiments. Further, the research identified areas of improvement on existing rammed earth construction methods to improve its wide acceptance in the delivery of affordable housing units in Zambia.

### **1.7 Significance of the Study**

The findings of this study affirm the importance of the research. The study highlights the importance of stabilised rammed earth as an alternative and sustainable construction building

material in the provision of housing in Zambia. The importance of this study can further be justified by: -

- i) Identification of challenges associated with existing rammed earth construction methods and techniques.
- ii) Identification of mechanisms for improving the mechanical properties and resistance to weather of stabilised rammed earth.
- iii) The research further highlights the cost advantage of stabilised rammed earth construction against other conventional building materials.
- iv) Further, the findings of this study will increase the knowledge base for construction consultants and professionals, developers, contractors, builders and general public on the unique characteristics and qualities of stabilised rammed earth in housing construction.

## **1.8 Chapter Synthesis**

This dissertation is divided into five chapters, as follows: -

Chapter One introduces the research problem, aim and objectives, research questions, scope and significance of the research and outlines of the research methodology. The chapter ends with the resume of this thesis.

Chapter Two covers the literature review. It examines historical background of earthen structures including their viability and sustainability in the provision of affordable housing in Zambia. It further examines the existing legislation and laws affecting the construction of earthen structures in Zambia.

Chapter Three outlines the methodology adopted for this research as well as research methods and techniques. The research methodology is tailored to the aim and objectives of this research.

Chapter Four presents the findings and data analysis and findings from the interviews and questionnaires administered to targeted population sample. The research results highlight the advantages of stabilised rammed earth over conventional building methods in the provision of affordable housing in Zambia.

Chapter five presents the conclusions and recommendations based on the aim and objectives of the study.

## **1.9 Chapter summary**

This chapter provides an overview of this research by introducing the research problem, highlighting the aim and objectives of the research, outlining research questions, scope and the significance of the research. Further, an outline of the research methodology is presented and the structure of this dissertation. The following chapter explores in greater detail the research problem by examining literature on the characteristics of stabilised rammed earth and its potential benefits in the construction of affordable housing units in Zambia.

## **CHAPTER TWO : LITERATURE REVIEW**

### **2.1 Introduction**

Housing is one of the most important necessities of mankind known to affect human health and wellbeing (Emsley et al., 2008). According to Okeyinka (2014) housing is a basic necessity that holds a singular importance in the general strategy of development for its socio-economic characteristics. Housing is a socio necessity of aesthetic and a second basic need to man after food (Okeyinka, 2014). The Zambian government and its social partners in conformity with this view have placed housing among its top priority (ILO, 2018). The term sustainable in this study according to the 1987 report of the World Commission on Environment and Development (WCED), also known as the Brundtland Commission refers to development that meets the needs of the present without compromising the ability of future generations to meet their own needs (UN - Habitat, 2020). The UN-Habitat (2018) defines sustainable housing as sustainable development which is largely concerned with the location of the house, the design and methods of construction adopted, the integration of the house with economic, cultural, social and the environmental fabric of communities.

Affordable housing on the other hand has largely been viewed with respect to the cost of housing in relation to the income of households which should not exceed 30% of the total income (MHID, 2020). Therefore, sustainable and affordable housing in this study refers to any house rented, purchased or built that is not beyond the financial capacity of a household and built using sustainable construction method based on localised requirements including local building materials (Emsley et al., 2008; Niroumand et al., 2013; GRZ, 2016; UN - Habitat, 2020). Approximately, 41.8% of Zambia's population is in urban areas out of which 70% are unable to adequately afford a decent shelter and hence live in informal and poorly constructed houses (Okeyinka, 2014; MHID, 2020). Figure 2-1 shows some informal and poorly constructed houses.



***Figure 2-1: Informal and poorly constructed houses in Grippies, Lusaka***

Earth as a building material is not strange to the housing construction in Zambia (Hadjri et al. 2007) as can be attested by the existing earthen structures countrywide in all the ten provinces. Earthen structures countrywide in Zambia account for more than 52.9% of households in rural areas. In urban areas 188,051 housing units representing 14.5% of households surveyed in 2015 were made of earthen structures (ZSA, 2016) as can be seen from Table 2-1. The existence of earthen structures country wide makes Zambia an interesting case study in the provision of sustainable and affordable housing using earth (Baiche et al. 2008).

**Table 2-1: Percentage Distribution of Households by type of Housing Unit by Residence, Stratum and Province, in Zambia**

RSP	Type of housing Unit							NS (%)	T1 (%)	T2
	T (%)	IT (%)	D (%)	F (%)	SD (%)	SQ (%)	O (%)			
<b>TOTAL</b>	32.0	21.5	28.5	10.4	5.5	1.3	0.8	-	100	3,014,965
<b>RESIDENCE</b>										
<b>Rural</b>	52.9	29.9	14.2	1.3	1.1	0.1	0.4	-	100	1,718,060
<b>Urban</b>	4.3	10.2	47.4	22.5	11.4	2.8	1.4	-	100	1,296,905
<b>STRATUM</b>										
<b>Small scale</b>	55.1	30.3	13.1	0.4	0.7	0.1	0.3	-	100	1,542,587
<b>Medium Scale</b>	32.9	36.1	28.9	1.2	0.8	-	0.1	-	100	56,974
<b>Large scale</b>	17.9	25.8	53.7	1.7	1.0	-	-	-	100	2,807
<b>NON-AGRIC</b>	35.2	21.8	20.2	13.0	7.2	0.7	1.8	0.1	100	115,692
<b>Low Cost</b>	5.5	12.5	44.0	23.1	11.5	2.3	1.1	-	100	996,975
<b>Medium Cost</b>	0.7	12.5	44.0	23.1	11.5	2.3	1.1	-	100	166,580
<b>High cost</b>	0.3	1.6	56.3	24.6	7.9	6.5	2.8	-	100	133,350
<b>PROVINCE</b>										
<b>Central</b>	36.6	28.1	27.4	4.5	2.8	0.2	0.5	0	100	292,049
<b>Copperbelt</b>	8.6	20.1	47.3	7.6	9.9	4.9	1.6	0	100	450,843
<b>Eastern</b>	45.7	23.5	27.1	1.3	1.2	0.2	1	0	100	342,161
<b>Luapula</b>	45.2	37.8	15.8	0.4	0.3	0.2	0.3	0	100	207,612
<b>Lusaka</b>	2.8	5.1	38.5	38.4	11.9	1.9	1.4	0	100	592,073
<b>Muchinga</b>	48.3	23.4	19.8	4.9	3.4	0.1	0	0	100	174,832
<b>Northern</b>	65.1	18.5	14.3	1.1	0.5	0.2	0.3	0	100	253,779
<b>North Western</b>	42.6	34.9	18.8	1.9	1.5	0.2	0.2	0	100	164,141
<b>Southern</b>	26.3	30.7	28.3	5.1	8.1	0.7	0.9	0	100	164,141
<b>Western</b>	72.8	18.1	6.8	1.1	0.9	0.1	0.3	0	100	199,215

Source: Central Statistics Office 2016

**Legend:** RSP= Residence/Stratum/Province, T = Traditional hut, IT = Improved traditional hut, T1 = Total., T2 = Total number of households, SQ = Servant

quarters, SD = semi-detached house, O = Other, F = Flat/apartment/multi-unit, D = Detached house, NT = Not stated

Table 2-1 shows a comparative analysis of housing types built using earth (traditional/improved traditional huts) and other conventional means in urban and rural areas. According to the numerical data shown in Table 2-1, in urban areas 188,051 housing units representing 14.5% of households were made of earthen structures while the rural areas accounted for 1,422,554 housing units representing 82.8% of households surveyed in 2015.

Therefore, to meet the research objectives, this chapter starts by introducing housing and defining sustainable and affordable housing in general, then it defines rammed earth before discussing construction methods and techniques. Secondly the chapter discusses the public perception on the use of rammed earth in housing construction. And lastly the physical and chemical properties affecting the suitability of stabilised rammed earth in urban housing construction in Zambia.

This research therefore explores the perceptions on the use of rammed earth as an alternative and sustainable material for construction of affordable housing units in Zambia.

## **2.2 Definition of Rammed Earth**

Rammed earth is a construction technique where a well selected and graded mixture of wet soil is compacted between formwork to form a monolithic building structure (Maniatidis and Walker, 2003; Ciancio and Jaquin, 2011; Cheah et al., 2012; Birznieks, 2013; Dabaieh, 2014). According to Beckett and Ciancio (2016) “traditional rammed earth, structures are formed through the compaction of raw material into formwork, which is then removed to allow the material to dry, granting it its considerable strength”. The compaction is done in layers of 100 to 150mm by pneumatic tapper or hand rammers. The density of the soil is altered during mechanical compaction improving soil principal properties such as compressive strength, shearing resistance, shrinkage and swelling (Zerrouk, 2013).

## **2.3 Historical Overview of Rammed Earth**

Rammed earth has been used in construction for millennia throughout many regions of the world (Maniatidis and Walker, 2003; Sonia et al., 2011; Taghiloha, 2013; Juncos, 2016). Currently, 30% of the world population live in earth structures constructed from unbaked earth (ICS, 2008). Major centres of rammed earth construction include North and West Africa, Australasia, regions of North and South America, China, Europe, France Germany and Spain. Initially, the form work was made from wood and ramming, by hands with a ramming pole, is currently practiced in developing countries with cheap labour. Several historical

rammed earth buildings in South America, Himalayan regions and central Europe including North Africa supplement the list world rammed earth treasures (Anroville Earth Insitute, 2011).

In Zambia, rammed earth housing structures have different names with regards to locations where they are found. In Isoka District of Muchinga province, rammed earth is called “Sindile” while in most parts in Eastern Province it is called “Nyumba Yamudindo” and is mostly practiced in rural areas.

## **2.4 Classification and Types of Rammed Earth**

The term rammed earth has been used to describe many different processes involving the dynamic compaction of the soil to form a solid mass (Jaquin, 2008). More than 20 different techniques of earth walling are known of which three predominate – pise’ or rammed earth, adobe and compressed earth bricks (Baiche et al. 2008). The method of building is influenced by prevailing climate, ease of use and locally available materials and the priority given to different factors varies with the socio – cultural structure of the community.

### **2.4.1 Pise’ de terre**

Pise’ de terre (or rammed earth) it’s a building technique for building walls consisting of natural aggregates of earth – gravel, sand, silt, clay, chalk and lime. Rammed earth is a structural wall system built of dump natural mineral soils compacted in thin layers within sturdy and temporal formwork (Jaquin, 2008; Niroumand et al., 2013; Ciancio, 2015). The walls can be reinforced using imbedded timber beams, bamboo grids or steel reinforcement bars. Figure 2-2 gives an illustration of the rammed earth wall construction whilst Figure 2-3 shows a completed two-storey housing unit.



**Figure 2-2: Rammed earth construction of Shipundu Community School, Zambia.**

*(Source: Build It International, 2012)*



**Figure 2-3: Stabilised Rammed Earth House, Western Australia.**

*(Source: Thuysbaert, 2012)*

#### **2.4.2 Adobe Sun Dried Bricks**

Adobe is a mud brick sundried in open air, produced manually in different shapes and sizes using bottomless wooden moulds (Bahar et al., 2004). The stability can be enhanced by the addition of straw, cow dung or even bitumen. According to Smith and Austin, 2019, adobe sun-dried bricks can be made from a variety of local soils, with the most suitable soil being

sandy loam composed of approximately 55–85% sand and 15– 45% finer material. Figure 2-4 shows the Adobe sun-dried brick making process.



**Figure 2-4: Adobe sun-dried bricks making process. (Source: Abundant Edge, 2016)**

### **2.4.3 Compressed Earth Brick**

Compressed earth brick is the modern version of traditional unbaked and moulded earth brick (Ciancio, 2015). Compressed earth brick has several key characteristics with traditional rammed earth and adobe bricks shown in Figure 2-4 which make them an attractive choice of building material. The main ingredient is soil which is cheap and in abundance on most of the building sites or in the remote areas. Building with local soil means significantly reducing the costs of transporting materials to site. Despite compressed earth brick building technique being highly mechanised, only one skilled worker is needed to give instructions about soil mixing and operating the compressing machine or making formwork and the rest of the work can be done by untrained or unskilled workers (Ciancio, 2015). Figure 2-5 shows a classroom block made from compressed earth (hydrafoam) bricks.



**Figure 2-5: Classroom block made from hydrafoam bricks. (Source: Build It International, 2010)**

#### **2.4.4 Perceptions on Rammed Earth**

Rammed earth construction has received a surge in popularity with an increase in earthen structures constructed across many countries in the world (Booth et. al, 2021). However, public perceptions on rammed earth have resulted in dismal contribution to mainstream housing construction. The following paragraphs highlight some of the public perceptions hindering the widespread use of rammed earth as an alternative housing construction material.

##### **A) Primitive material**

According to Hafez et al., (2023) and Dahmen (2011), developer's perception of the material being primitive with poor aesthetics and poor durability, prone to erosion and failure is one of the common barriers inhibiting the widespread use of rammed earth as an alternative building material. Dahmen (2011) contends that the perception that rammed earth is a primitive material and good for the poor people in contracts to conversional materials such as concrete blocks, glass and steel and has partly attributed to a sustained decline in the proportion of rammed earth housing units in Global South countries (Marsh & Kulshreshtha, 2022). Hafez et al.,2023 and Adegun and Adedeji, 2017 argues that the perception on rammed earth being a construction material for the poor is consistent with literature that young women across Africa refuse to marry men who do not own a house constructed from concrete blocks. Hafez further argues that the association between rammed earth construction and poverty does not apply to

wealthy patrons who are environmentally conscious. Dahmen (2011) argues that rammed earth construction, in which supplemental binders are not used has a poor compression strength and poor resistance to weather elements which can be immediate if structures are not detailed correctly.

### **B) Rammed earth suitable for hot and rid regions**

According to Kraus (2012), the perception that rammed earth is a suitable construction material limited to hot, arid climates despite a fertile genealogy occurring in almost every region of the planet is misplaced. Hafez et al., (2023) contends that rammed earth has a wider acceptance in the Global North, which is broadly believed to have more positive associations with earth construction than the Global South for which there is a general association between earth housing and poverty.

### **C) Labour intensive**

The perception that rammed earth is labour-intensive, limited to low-rise applications, and requires significantly more space than conventional wall assemblies is one of inhibitors hindering the widespread use of rammed earth in housing construction (Hafez et al., 2023). Unlike the traditional rammed earth construction techniques which were more labour intensive, the modern rammed earth construction techniques employ advanced manufacturing techniques in the production of either the formwork or the compaction process offering more productivity, higher quality and less labour intensive (Gomaa et al., 2023 and Alhumayani et al., 2020).

## **2.5 Construction Methods and Techniques**

### **2.5.1 Traditional Method**

The traditional building method consists basically of filling a wooden box or cast with superimposed layers of moist soil, successively compacted with a wooden stick until a monolithic structure is formed. The formwork is horizontally displaced until the perimeter is closed. The procedure is repeated putting a new row on top of the other until the desired height is achieved (Jaquin, 2008;Dabaieh, 2014).

### **2.5.2 Modern method**

Rammed earth construction methods have evolved with time (Jaquin, 2008). The difference from the old and the new way of building rammed earth has been the strength and durability factors. They have been increased through the addition of additives and binders, rebar, and the compaction method, which has changed from manually to pneumatically. In some places

manually compressing the soil is still being used (D'Ambra, 2016). The construction process basically follows the following steps:

- To begin with the process, the use of recently excavated soil is important, so the material still maintains its natural moisture.
- The soil is thoroughly sieved to get rid of any rocks or lumps bigger than a walnut.
- The earth walls are built on top of a foundation made of rock or brick that rises at least 40 to 80 centimetres above ground level to protect the bottom wall from moisture.
- On top of the foundation walls, the formwork is settled and firmly put in place, commencing at one corner of the building and checking horizontal and plumb levels of all sides.
- The top of the foundation walls is levelled with mortar to avoid soil spilling out the joints when tamping.
- The workers pour the soil in the formwork and evenly spread it and start to tamp or compact the layers of soil of about 150 to 200 millimetres thick.
- Tamping starts from the edges of the wall moving towards the centre.
- The operation is repeated until the cast is complete then the formwork is removed.

Table 2-2 gives guidance on suitability of various strata for rammed earth foundations. It can be deduced from Table 2-2 that no foundation footing is required where the base is rocky and rammed earth foundation footing should not be constructed in loose sandy, soft silt and very soft clay soils.

**Table 2-2: Minimum width of strip foundation in rammed earth.**

Type of subsoil	Condition of subsoil	Field test applicable	Foundation width	Foundation thickness
Rock	Not inferior to sandstone, limestone or firm chalk	Requires at least mechanically operated pick for excavation	Equal to width of wall	Not applicable (N/A)
Gravel	Dense	Requires pick for excavation. Wooden peg 50mm square	Equal to width of wall	N/A
Sand	Dense	Hard to drive beyond 150mm		
Clay	Stiff	Cannot be moulded with the fingers and requires a pick or mechanically operated spade for the removal	400 mm	$\frac{F-W}{2}$ or wall width whichever is larger
Sandy clay	Stiff			
Clay	Firm	Cannot be moulded by firm pressure with the fingers and cannot be excavated with spade	500mm	$\frac{F-W}{2}$ or wall width whichever is larger
Sandy clay	Firm			
Sand	Loose	Can be excavated with a spade. Wooden peg 50 mm square can be easily driven	So better to dig deeper to firmer subsoil then apply width needed for that soil type	
<b>Silty sand</b>	Loose			
Clayey sand	Loose			
Silt	Soft	Fairly easily moulded in the fingers and readily excavated	So dig deeper to firmer subsoil	
Clay	Soft			
(and sandy/silty clays)	soft			
Silt	Very soft	Natural sample in rainy season exudes between fingers when squeezed in fist	So dig deeper to firmer subsoil	
Clay	Very soft			

Source: SADCSTAN, 2014

Note: 1. F is the foundation width, W is the wall width,  
2. An engineering foundation design may be used.

### 2.5.3 Soil Identification and Preliminary Site Testing

According to Dabaieh (2014), soil identification and preliminary soil site tests should be conducted using a sample taken from the site at a minimum depth of one meter (1.0m) to ensure that the surface materials are excluded. Various scholars have done extensive research on soil suitability assessment for rammed earth construction (Walker et al. 2005; Jiminez et al., 2007; Ciancio, 2011; Maniatidis and Walker, 2013). According to Walker et al., 2003, the

most ideal soils for cement stabilisation should have a Plasticity Index between 5 to 15. Walker et al., (2002) summarise the grading and plasticity properties of soils suitable for rammed earth in Table 2-3.

**Table 2-3: Recommendations for soil suitability**

	% by mass	
	Minimum	Maximum
<b>Sand + gravel content</b>	45	75
<b>Silt Content</b>	10	30
<b>Clay Content</b>	0	20
<b>Cement Content</b>	4	12
<b>Liquid Limit</b>	35	45
<b>Plasticity Index</b>	1	15

**Source: Ciancio, 2011**

The location of site, available tools and experience determines which testing method to be used (Schildkamp, 2009). The following are some of the simple site tests to analyse the soil: -

**A) The drop test**

According to Ávila, Puerta and Gallego (2022) drop test is a simple test method that is used to test the approximate moisture content of the soil. A cohesive ball is made on the palm using a moisten handful of soil without stabilizer, left to dry for a few minutes and then dropped to the floor from a height of about 1 metre. According to Taghiloha (2013) if the ball is broken into 4-5 lumps when it is dropped, the moisture content is satisfactory. The soil sample is too dry or contain a lot of sand if the ball crumbles away and if it remains intact the moisture content is excessive or the clay content in it is high.

**B) The jar test “Particle size test”**

The test is used to get preliminary assessment of the proportions of different particle sizes or ratio of coarse to fine particles in the soil. Two thirds of a bottle are filled with soil from the preferred site, and water added to fill the bottle. The bottle is shaken till all the soil particles are suspended then it is left to settle for a few hours. Different soil layers are formed separated by distinct visible lines. The sand layer normally settles at the bottom as its particles are heavier, then layers of silt and clay stays on top (Maniatidis, 2003).

### C) Ribbon test

A moist soil sample large enough to form a ribbon 150 – 200mm in the size of a cigar is threaded between the thumb and index finger until its diameter is reduced to between 3 and 6mm thick. If no ribbon is formed using the soil sample the soil contains very little clay or even no clay. When a short ribbon between 5 to 10 cm is formed the soil contains a low to medium amount of clay while when a long ribbon is made without any problem, even up to 25 to 30 cm the soil has a very high clay content (Maniatidis, 2003). Interpretations of the ribbon test as proposed by various authors are presented in Table 2-4.

**Table 2-4: Ribbon test evaluation.**

Soil Classification	Ribbon Length (mm)				
	Easton, 1996	Standards Australia, 2002	Houben and Guillaud, 1994	Keable, 1996	Norton, 1997
Soil, unsuitable due to excessive shrinkage	>200	>80	250-300	>120	>150
Low-strength soil	<100	<40	50-100	<80	<80

Source: DTi, 2003

### D) Smell test

A few drops of water are added to a sample of recently excavated soil to enhance the odour of the sample. A damp and musty or even rotten smell indicates the soil contains a lot of organic matter. The smell of organic matter comes from decaying plant and animal matter and no further tests should be done on the soil if the smell of organic matter is detected (Maniatidis, 2003).

### 2.5.4 Laboratory Testing

According to DTi (2003) the laboratory test for determining comprehensive strength of rammed earth is similar to the ones used for concrete, bricks and blocks. A summary of the required specifications for compressive strength of rammed earth from various standards around the world is presented in Table 2-5. According to Mulenga, 2018 Standardization is a means by which regional and international agreements, trade and collaboration can be boosted to achieve a sustainable built environment.

**Table 2-5: Compressive Strength test specimen details.**

Reference	Specimen details					Minimum number of specimens required
	Cylinder		Prism			
	Diameter (mm)	Height (mm)	Height (mm)	Length (mm)	Width (mm)	
<b>Bulletin 5; Earth-Wall Construction, CSIRO</b>	150	110	150	150	1.3 x h	5
<b>Standards Australia HB195, 2002</b>	150	300	N/A	N/A	N/A	1 sample for every 25-100m <sup>2</sup>
<b>(Tibbets, 2001)</b>	N/A	N/A	102 (4'')	102 (4'')	102 (4'')	N/S
<b>NZS 4298:2020</b>	N/A	N/A	N/S	N/S	2 x h	5

*Source: DTi (2003)*

The recommended design values for rammed earth as proposed in Table 5 including other codes are summarized in Table 2-6.

The ACI Materials, Journal Committee, 1990, has a wide range of rammed earth compressive strength based on the type of soil mixture rammed. Sandy soils with pebbles 2.76-6.89 MPa, Silty soils 2.07-6.21 MPa, and Clayey soils 1.72-4.14 MPa.

Unlike the codes mentioned in Table 2.6, the Zimbabwe Standard Code of Practice for Rammed Earth Structures (SAZS 724, 2001) specifies 1.5 – 2.0 MPa compressive strength for a single storey wall of up to 400mm thick and 2.0 MPa for two storey walls, respectively, for erected walls. The procedure for obtaining the strength is based on interpretation of indirect surface hardness testing of the built wall. The test utilises a spring capable of applying the required stress to a rammed earth surface (Maniatidis, 2003).

**Table 2-6: Recommended design values for characteristic Unconfined Compressive Strength**

Reference	Unconfined Compressive Strength (MPa)
Bulletin 5; (Middleton, 1992)	0.7
Standards Australia HB195, 2002	0.4 – 0.6
NZS 4298:2020	0.5
SADC ZW HS 983:2014 and SAZS 724, 2001	1.5-2.0
Tibbet, 2001	2.07
ACI Materials, Journal Commitee (1990)	1-6.89

### A) Formwork

According to Dabaieh (2014), formwork is a temporary construction support member during compaction of rammed earth. Doat et al., 1991 highlight the importance of formwork in rammed earth construction both in material usage and determining the cost of the building. Dubaier (2014) explains that like concrete, formwork is required to have sufficient strength, stiffness and stability to resist pressures subjected to during assembly, pouring the soil mix, ramming and dismantling. However, unlike concrete, rammed earth formwork can be removed after compaction, enabling much faster re-use efficient organization of formwork which is essential to efficient rammed earth construction.

### 2.6 Stabilised Rammed Earth

Stabilization of soil is the process of modifying the soil properties in relation to its strength, texture, voids and water resisting properties, to obtain permanent properties compatible with a particular application (Zieve and Yalley, 2016). There are three techniques for stabilising soil namely Mechanical, Physical and Chemical (ICS - UNIDO, 2008; Houben, 2014; Hopkins, 2015). Mechanical stabilisation refers to compaction of the soil which changes its density, mechanical strength, compressibility, permeability, and porosity (Amu, 2008). Physical stabilisation is where the texture of the soil is altered through the control of the grain fraction mix, heat treatment, drying, freezing or electrical treatment while the addition of chemicals to alter the properties of the soil is referred to as chemical stabilisation. This happens via a physical-chemical reaction between the grains of the soil and the materials added, or through the addition of a matrix that binds or coats the grains (Hopkins, 1995; Amu et al., 2008).

### **2.6.1 Benefits of Stabilised Rammed Earth Construction**

Stabilisation fulfils several objectives that are necessary to achieve a lasting structure from locally available soil, including better mechanical characteristics (improved wet and dry compressive strength); better cohesion between particles (reducing porosity which reduces changes in volume due to moisture fluctuations); and improved resistance to wind and rain erosion (Beckett and Ciancio, 2016; Damme et al., 2018). The application of any or a combination of the three stabilisation techniques listed above will achieve these objectives. Optimum methods depend on the type of soil; therefore, careful soil analysis is needed to identify the most effective method of stabilisation. The main categories of binders used for earth construction are Portland cement, lime, bitumen, natural fibre and chemical solutions such as silicates and as approved by the building supervisor (Houben, 1994; SAZS-724, 2001; Standards Australia HB195, 2002; Keable, 2014; SADC ZWHS 983, 2014).

### **2.6.2 Aesthetics**

According to Schroeder (2011), Hoppe (2022) and Spennemann (2022) there has been a resurgence in popularity of rammed earth due to its unique materiality, fascinating and individual surface aesthetics that come with ageing of the surface due to natural erosion or design patterns during construction. Strazzeri and Karrech (2023) asserts that rammed earth architecture integrates well in the local natural landscape and that the material responds to the aesthetic criteria of contemporary architecture.

### **2.6.3 Lifespan**

According to Pritchard (2023), the lifespan of rammed earth walls varies depending on several factors, such as soil type and degree of compaction, curing, and the type of stabiliser used. Generally, rammed earth walls can last anywhere from 20 to more than 1,000 years (ibid). According to Arrigoni, Ciancio and Beckett (2016) stabilisers such as lime or cement can increase the lifespan of rammed earth walls as well as a proper maintenance of rammed earth structures.



**Figure 2-6: The Great Mosque of Djenne built between 1200 and 1330. (Source Ruud Zwart)**

Figure 2-6 shows the Great mosque of Djenné which was built between 1200 and 1330, proving that earthen rammed earth can stand the test of time (Rodríguez, 2023)

#### **2.6.4 Improved compression strength**

According to Crowley (1997), Walker (2000), DTi (2013) and SADC ZW HS 983(2014) cement stabilises the soil samples by improving strength, resistance to water and reduces shrinkage of the rammed walls. Numerous studies have been conducted on the strength, durability and shrinkage characteristics of stabilised soils which indicate a strong linear correlation between compression strength and cement content as can be seen in Table 2.7. The values proposed by different authors, as presented in Table 2.7, tend to be much higher than the ones proposed for un-stabilized soils.

**Table 2-7: Cement-stabilised rammed earth Compressive Strength.**

Reference	Compressive Strength (MPa)
Bulletin 5; (Middleton, 1992)	.....
Standards Australia HB195, 2002	1-15
NZS 4298:2020	>1.5
SADC ZW HS 983:2014	1.5- 2.0
Tibbets, 2001	2.07 (minimum)
Houben and Guillaud, 1994	2-5
ASTM International E2392 / E2392M - 10e1 (2010)	2.068

The advantages of using cement in stabilised rammed earth should be weighed against some of the notable advantages such as the reduction in permeability of most soils (ACI Materials Journal Committee, 1990), environmental impact of cement production and reduced ability for recycling of rammed earth (Salas *et al.*, 2016; Habert *et al.*, 2020; Mohamad *et al.*, 2021).

#### A) Soil Cement Mix Ratios

Literature recommends the proportion of cement in stabilised soils to be between 4% and 15%, with the range 6% to 10% being the most specified (Bryan, 1988; Walker, 2000; Burroughs, 2008). This range results in the compressive strength between 1to 15MPa (Standards Australia HB195, 2002). The amount of cement required is determined by the type and grading of the soil. Soils ideal for cement stabilisation should have minimal clay to produce desired results (Paikiey and Rabbani, 2017).

#### B) Plasticity and Shrinkage

According to Taghiloha (2013), Linear Shrinkage (LS) is the percentage decrease in the length of a bar of soil dried from the liquid limit, and it is assessed on a distribution sample. The Plasticity Index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the Liquid Limit and the Plastic Limit ( $PI = LL-PL$ ). According to Gooding 1993, a soil suitable for cement stabilization should have a low PI.

The test results shows that the saturated strength and durability of cement stabilized soil blocks are improved by increased cement content and impaired by clay content and the most ideal soils for cement soil block production have a plasticity index between 5 and 15 above 20-25 are not suited to cement stabilization using manual presses, due to problems with

excessive drying shrinkage, inadequate durability and low compressive strength (Walker, 1995).

The results of the study conducted by Veena, Kumar and Sakaria (2014) indicates that the most ideal soil for cement stabilisation should have a PI between 5 to 15% while soils with PI above 20-25% are not ideal for cement stabilisation when using manual rammers. Shrinkage or tensile cracking is dependent on the proportion and type of clay selected and can cause the weakening of earth walls if not controlled (Taghiloha, 2013). Natural or un-stabilised clay types can shrink as little as 4% or as much as 25%. The stabilizer content, soil type, water content, degree of rammers as well as curing speed affect the extent of shrinkage. Table 2-8 gives the minimum permissible linear shrinkage according to the various standards with a range of 0.05% to 3%.

**Table 2-8: Rammed earth Permissible linear shrinkage to various codes and standards.**

<b>Code/ Standard</b>	<b>Standards Australia HB195, 2002</b>	<b>New Zealand Standards, NSZ:4299:2020</b>	<b>Scotland Scottish Executive, 2001</b>
<b>Minimum permissible linear shrinkage (%)</b>	<2.5	0.05	3

**Source: Tanghiloha, 2013**

### **2.6.5 Microclimate regulation and thermal comfort**

The ability of earth to regulate indoor air humidity is significant in creating a healthy indoor climate. Natural rammed earth walls balance humidity faster and to a greater extent than any other building material enabling it to balance indoor climate (Richter et al., 2014). However, the addition of chemical stabilisers compromises earth's ability to regulate indoor air humidity (Saidi et al., 2018). Earth has excellent abilities to maintain stable interior air humidity levels and thermal mass potential superior to that of most alternative building materials (Gupta et al., 2020).

The wall thickness of 300mm retains heat for a long time compared to other conventional building materials making rammed earth an ideal construction material for passive solar construction housing construction (Taylor and Luther, 2004; Hall and Allinson, 2009; Hall, 2009). Earth has a low rate of thermal conductivity. Earth construction provides excellent heat insulation making the interior spaces being cooler than the exterior making earth an ideal

construction material in the tropical and sub-tropical regions (Zami and Lee, 2010). Standards Australia HB195, 2002 specifies thermal characteristics of different construction methods as stated in Table 2-9.

**Table 2-9: Typical thermal characteristics of walls of different construction materials**

Method	Rammed Earth	Mud Brick	Concrete
Wall Thickness (mm)	250	300	300
Thermal Resistance (m <sup>2</sup> K/W)	0.25 to 0.60	0.35 to 0.7	0.15 to 0.33

**Source: Standards Australia HB195, 2002**

### **2.6.6 Sound Insulation**

Rammed earth is a good sound insulator, and it is used as a sound isolative material in facilities with increased sound intercity such as concert halls and recording studios. It has also excellent sound reverberation characteristics. It does not generate the harsh echoes characteristic of many conversational wall materials (Birznieks, 2013).

### **2.6.7 Self Job Creation**

According to Salami (2019) rammed earth housing construction is affordable and regarded as a local job creating opportunity by utilising the availability of local labour force: and local resources within the vicinity of the building area.

### **2.6.8 Fire proofing**

Rammed earth is a good fireproofing material. A typical solid rammed earth wall can achieve 90 minutes resistance in fire, adequate for most applications (Zami and Lee, 2010).

### **2.6.9 Economic Benefits of Rammed Earth Construction in Sustainable Urban Housing**

According to Zami and Lee (2010), the appropriate use of rammed earth in housing construction has a significant reduction on the construction cost as local soils can be excavated from the site; hence reducing transportation cost. Rammed earth wall is 40% cheaper than a conventional concrete block wall including labour. The appropriate use of rammed earth, leads to job creation as it allows unskilled and unemployed to learn a skill, get a job and rise in the social scale (Khadka, 2020).

### **2.6.10 Environmental Benefits of Stabilised Rammed Earth Construction**

Rammed earth is a sustainable construction material with significant environmental benefits (Niroumand, Zain and Jamil, 2013). Rammed earth has the lowest environmental cost and its

embodied energy compared to other conventional building materials is significantly lower (Zami and Lee, 2010; Birznieks, 2013; Marais, Littlewood and Karani, 2015) as can be seen from Tables 2-10 and Table 2-11.

**Table 2-10: A comparative analysis of energy consumption and carbon dioxide emission of four types of building materials**

<b>Product and thickness</b>	<b>A</b>	<b>B</b>	<b>C</b>
<b>CSEB- 24cm</b>	40	110	16
<b>Wire Cut Bricks – 22cm</b>	87	539	39
<b>Country Fired Bricks -22cm</b>	112	1657	126
<b>Concrete blocks – 20cm</b>	20	235	26

*Source: Zami and Lee, 2010*

**Legend:** A= Number of Units (per square metre),  
 B = Energy consumption (MJ per square metre),  
 C = Carbon dioxide emission (kg per square metre)

Table 2-10 gives a comparative analysis of energy consumption and carbon dioxide emission of four types of building materials. According to the numerical data shown in Table 2-10, CSEB consume lowest energy and lowest carbon dioxide emission if compared with wire cut bricks, country fired bricks and the concrete blocks. Table 2-11 shows a comparative analysis of Carbon dioxide emissions of four types of foundations. According to the numerical data shown in Table 2-11, concrete strip foundation emits 3.75 times of carbon dioxide per cubic metre as compared to a 2% cement stabilised foundation.

Earth is a nature’s product and therefore requires no energy to produce. Earth is readily available in large quantities in most regions (Lal, 1995; Easton, 1996; Morris, 2000; Adam, 2001; Alagbe, 2011). Earth construction products have a potential to reduce energy used in production by 80-90% (Zami, 2010). Half of the global CO<sub>2</sub> emissions can be attributed to construction and more especially the operation of buildings. Rammed earth construction decreases the reliance on unsustainable resources. Scholars have long recognised the interdependence of economic, environmental and social factors as a triangle relationship as outlined in the Brundtland Commission report which states sustainable development as “development that meets the needs of the present without compromising the needs of the future generation to meet their own needs (WCED, 2017).

**Table 2-11: Comparison of foundation types carbon dioxide emissions.**

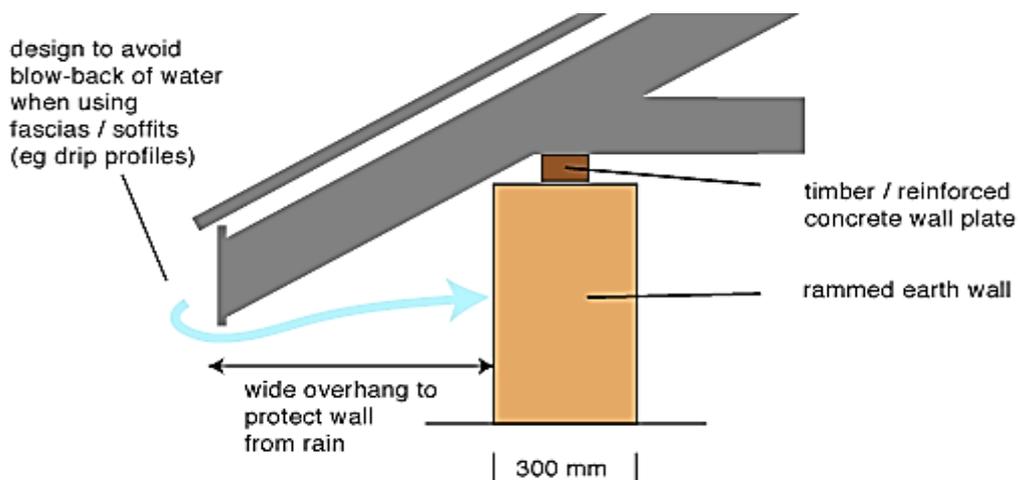
Foundation type	KgCO <sub>2</sub> /m <sup>3</sup> of material	Foundation width (mm)	Foundation depth (mm)	Foundation area (m <sup>2</sup> )	kgCO <sub>2</sub> /linear m of foundation	% CO <sub>2</sub> used	% CO <sub>2</sub> saved
Concrete strip	150	800	600	0.48	72	100	0
2% cement stabilise	40	700	1050	0.735	29.4	41	59
5% polymer	30	700	450	0.315	9.45	13	87
2% cement with 5% polymer above	70	700	1500	1.05	38.85	54	46

Source: Paul et al., 2015

## 2.7 Challenges Associated with Rammed Earth Construction

### 2.7.1 Water Abrasion

According to Alagbe (2009) exposed areas of rammed earth walls such as the gable end and plinth are affected by rainfall, hence they must be regularly maintained and houses face significant deterioration due to rains and require frequent re-plastering. Poorly constructed foundation and inadequate protection against rainfall result in structural weakening of the earthen walls leading to their collapse.



**Figure 2-7: Rammed earth roof eave detail**

Figure 2.7 shows projected roof covering as a means of protecting the walls from rain.

### **2.7.2 Low Resistance to Abrasion**

Alagbe (2011) further states that natural rammed earth has low resistance to abrasion and impact especially in the event of earthquake as compared to other conventional building materials.

### **2.7.3 Poor Tensile and Compression Strengths**

The tensile and compression strength of natural rammed earth are equally low hence having poor resistance to bending moments making it effective only in load bearing walls, domes and vaults (Adam and Agib, 2001). According to Zami and Lee (2010), structural failure in natural rammed earth structures is common due to high moisture absorption ratio and high shrinkage/ swelling ratio.

### **2.7.4 Lack of Building Codes**

Zami and Lee (2010), contends that earth as a building material lacks institutional acceptability in most countries especially in Africa, Zambia inclusive and as a result building codes and performance standards have not been fully developed.

### **2.7.5 Not all soil types are appropriate.**

Preliminary soil identification and tests should be conducted on the soil sample to be used for the construction of rammed earth buildings to ascertain the durability of the structure and correct stabilisers for the particular soil (Zami et al.2010; Dabaieh, 2014). Stabilisation of rammed earth addresses the above-mentioned disadvantages.

## **2.8 Building Regulations in Zambia**

The **building regulations** are a set of rules that specify the minimum standards for the design, construction, alterations and occupancy of buildings in the interest of health, safety and welfare of the public (McGibbney and Kumar, 2013; Denman, Crockett and Groves-Kirkby, 2018).

Despite Zambia having progressive laws and regulations, none of the existing legislation and regulations addresses the use of earth as a building material. The building regulations are enshrined in the Public Health Act Chapter 295 relating mainly to sanitation and housing. The regulations are biased towards the use of conventional materials such as concrete and no specifications for earthen structures are explained therein. They apply mainly in formal housing areas, areas classified as Statutory Areas under the Urban and Regional Planning Act, 2015.

According to UN-Habitat (2012), the building standards in existing regulations are inappropriate to the majority and hence reducing the housing construction activities. The absence of regulations promoting the use of earth as a building material and restrictive construction requirements has further hampered activities in the housing sector, to narrow the housing deficit.

## **2.9 Summary**

The literature reviewed in this chapter reveals that housing delivery deficit is increasing annually in urban cities especially in the Sub-Saharan region due to massive urbanisation, low investment in housing and costly conventional building materials. The promotion of conventional building materials has made housing affordability beyond most of the urban dwellers. The chapter recognises that the promotion of stabilised rammed earth bridges the gap in housing. The improved compression strength, tensile strength, shear and resistance to erosion, makes stabilised rammed earth acceptable and comparable to concrete blocks widely used in urban areas. This chapter further, recognises the challenges faced by construction professionals, contractors and developers due to the absence of legislation and guidelines governing rammed earth construction.

## **CHAPTER THREE : METHODOLOGY**

### **3.1 Introduction**

This chapter outlines the research methodology used to achieve the aims of the study. It demands articulating the problem to be investigated, selection of a suitable research design, appropriate procedures for the data collection, findings and analysis. This study was conducted in two parts. Part A involved a survey which contained the administration of a questionnaire to purposively selected construction professionals, contractors, and end users of rammed earth structures. The survey aimed at establishing respondents' perceptions on the use of rammed earth in the building construction.

Whereas Part B involved laboratory experiments aimed at assessing the soil physical, chemical properties and suitability of rammed earth for use in housing construction. The following tests were conducted Sieve analysis, optimum moisture content and maximum dry density to ascertain the ideal moisture content of the soil samples. Further tests were conducted on the compressive strength of the samples with varying mixture of Portland cement to ascertain the suitable soil cement mix proportions for desirable compressive strength.

The sample of the questionnaire and laboratory results are attached to Appendix 2 and 3 respectively.

### **3.2 Research Design**

Research design is the plan for addressing a research question including the specification for enhancing the integrity of the study (Polit and Hungler, 1999). This research study was a descriptive cross-sectional study, both qualitative and quantitative in nature. This study design was chosen because it helped to investigate perceptions on the suitability of rammed earth in the construction of affordable housing units in Zambia.

#### **3.2.1 Research Approach**

According to Creswell and reswell (2018), research approaches comprise strategies and methods for research that extend the decisions from general assumptions to thorough methods of data gathering and reasoning. Bean, Mustapa and Mustapa, 2019 defines research approach as the data collection and analysis strategy which is applied in research informed by the research design and research methods. There are three types of research approaches namely, deductive research approach, inductive research approach and abductive research

approach. An abductive research approach seemed most suitable given the nature of the research objective.

According to Timmermans & Tavory (2012) abductive research approach is a continuous process of conjecturing about the world that is shaped by the solutions based on the researcher's cultivated position. Abduction research approach is a 'pure' form of inference for analysing and organizing reasoning from factual premises to explanatory conclusions within the research community (Råholm, 2010). By having a thorough theoretical basis and good knowledge of the field of research, the researcher will be capable of thinking in new ways and thus explore the vagueness and clarity of the phenomena within the study.

### **3.3 Methodological choice**

Kothari (2004) refers to Research methods as all the methods or techniques that the researcher employs in studying his research problem. In this research study, a mixed method approach was adopted. Quantitative research is regarded as the organized inquiry about phenomenon through collection of numerical data and execution of statistical, mathematical, or computational techniques. The source of quantitative research is positivism paradigm that advocates for approaches embedded in statistical breakdown that involves other strategies like inferential statistics, testing of hypothesis, mathematical exposition, experimental and quasi-experimental design randomization, blinding, structured protocols, and questionnaires with restricted variety of prearranged answers (Slevitch, 2011).

### **3.4 Research Strategy**

Research strategy refers to the overall direction of the research and the methodical process by which the research is concluded to solve an inquiry problem. The research strategy is applied so that suitable research methods are identified to ensure the attainment of research goals and objectives as well as the validity of the results (Vosloo, 2014; Saunders, Lewis and Thornhill, 2009).

There are various strategies used in research namely archival research, experiment; survey; case study; action research; grounded theory; as well as ethnography (Cohen et al., 2007; Saunders, Lewis and Thornhill, 2009). However, for the purpose of this study, survey and experiments (laboratory tests) were employed after considering and analysing the research questions and objectives, literature review, the amount of time and necessary resources, as follows:

### **3.4.1 Part A - Survey**

According to Senam and Akpan (2014) a survey strategy is a research strategy which investigates, examines, assesses, or evaluates the issues that constitute a research problem. Survey, as a research tool is used to measure, describe and explain attitudes, salient issues, human behaviour and other observable phenomena in realistic settings. Surveys allow for the collection of a large amount of data from a sizeable population in a highly economical way (Saunders, Lewis and Thornhill, 2009; Vanderstoep and Johnston, 2022). The data is often obtained by using a questionnaire administered to a sample resulting in a standardised data allowing easy comparison.

### **3.4.2 Part B – Laboratory Experiments**

Experimental research is a type of research design conducted under highly controlled conditions in which the study is carried out utilising a scientific approach and two sets of variables. According to Cohen et al., (2007) the main purpose of experimental research is to study the effect that a factor or independent variable has on a dependent variable which determine the events in which they are interested, introduce an intervention, and measure the difference that it makes. An independent variable is the input variable, whereas the dependent variable is the outcome variable. Experimentation is used in quantitative research methodologies namely exploratory and explanatory research. Most times experiments are conducted in laboratories rather than in the field. This means that the researcher has greater control over aspects of the research process such as sample selection and the context within which the experiment occurs. In this study, soil samples without cement additives were employed as dependable variables while Portland cement as an independent variable was added to soil samples at 3%, 6% and 10%. Detailed laboratory tests are attached under Appendix 3.

## **3.5 Target population**

Creswell (2012) defines a target population (or the sampling frame) as ‘a group of individuals (or a group of organizations) with some common defining characteristic that the researcher can identify and study’. The following sections present aspects on the target population.

### **3.5.1 Survey**

In this study, participants were selected from the Zambia Institute of Architects (ZIA), Engineering Institution of Zambia (EIZ), Zambia Institute of Planners (ZIP), Surveyors Institute of Zambia (SIZ) based on their specialised expertise and close involvement in the

Zambian construction sector, contractors registered with National Council for Construction (NCC) Grade 4 Category B as well as occupants of earthen structures as the target population of the proposed research. The population comprised of 68 practicing Architects, 704 Civil and structural practicing Engineers, 115 practicing Planners, 362 contractors registered with NCC and 10 occupants of earthen structures from the three urban towns (Lusaka, Kitwe and Chipata). Table 3.1 categorizes the target population and justifies the sampling method.

**Table 3-1: Categories of target population**

<b>Population Category</b>	<b>Sampling method</b>	<b>Justification</b>
Architects (68)	Stratified Random	Design and recommend specifications of the proposed buildings to developers
Engineers (704)	Stratified Random	Design and recommend structural, electrical and plumbing specifications of the proposed buildings to developers
Contractors (Grade 4B) (362)	Stratified Random	Bring to reality by translating architectural and engineering drawings into built infrastructure
Planners	Stratified Random	Enforce Regional and Planners act
Earthen House Occupants (10)	Stratified Random	End users of built infrastructure

### 3.5.2 Sample

A sample, according to Marczyk et al., (2005) is a representative subgroup of the target population that the researcher plans to study for generalizing about the target population. A sample is a subgroup of people from the target population participating in the research (Vanderstoep, 2009). The sample was selected from the three urban towns Lusaka, Kitwe and Chipata. Lusaka and Kitwe urban towns were selected because of the high demand for housing in both provinces with a high number of densely populated areas while Chipata has most of the housing units constructed from burnt clay bricks. Table 3-2 gives a breakdown of the populations and sample sizes. Though Muchinga Province was not sampled, during the survey, there are several unstabilised rammed earth houses in Kampumbu Village of Isoka District.

### 3.5.3 Sample size

Cochrane single proportion formula was used to determine the sample size (Equation 1). This was based on the total number of practicing Architects, Structural and Civil Engineers, Urban and Regional Planners, registered contractors in grade 4B, and earthen house occupants that were available on the study sites during the time of the survey as explained in 3.5.1. Equation 3.1 was used to determine the sample sizes.

$$n_{\infty} = \frac{z^2 p(1-p)}{e^2} \quad \text{Equation 3-1}$$

where:

- Z is the critical score of 1.96,
- P is the proportion (0.113), 'e' is the margin of error at 0.05, and
- n is the sample size.

Therefore, the population size was 154.

The correction of the sample size due to the small population size was determined by using Equation 3.2

$$n = \frac{n_{\infty}}{1 + (n_{\infty} - 1) / N} \quad \text{Equation 3-2}$$

where:

- n is the corrected population sample size,
- $n_{\infty}$  is the sample size derived from Equation 1 and,
- N is the known population.

For example the sample size for Architects with a population of 68 was determined to be 47. Table 3-2 summarises the sample sizes.

$$n = \frac{154}{1 + (154 - 1) / 68} = 47$$

**Table 3-2: Sample size justification**

<b>Population Category</b>	<b>Population</b>	<b>Sample Size</b>
Architects	68	47
Engineers	704	131
Contractors (Grade 4B)	362	108
Planners	115	66
Earthen House Occupants	10	10
Total	1259	362

From Table 3-2, a total number of 362 questionnaires were administered.

### **3.6 Data collection**

Bhattacharjee (2012) define data collection as “the precise and a systematic gathering of information relevant to the research sub-problems....” There are various methods of collecting primary data in qualitative and quantitative studies such as: (i) interviews, (ii) observations (laboratory observation), (iii) questionnaires, and (iv) schedules (Kothari, 2004; Marczyk et al., 2005; Chisumbe, 2016). According to Marczyk et al., (2005) these tools have established reliability and validity thereby eliminating the need to develop and validate an instrument from scratch. Data collection is cardinal in research because it verifies research questions or hypothesis (Chisumbe, 2016). For this study being a mixed method research and in order to address the research problem and objectives, the following primary data collection instruments were used: (i) questionnaires and (ii) laboratory experiments.

#### **3.6.1 Primary Data Collection**

According to Kothari (2004), primary data is data collected afresh and for the first time or original. To facilitate collection of primary data in this research both structured questionnaires and laboratory experiments were used.

#### **3.6.2 Secondary Data**

Secondary data is the data which has already been collected and put through statistical process by researchers (Kothari, 2004). Unlike primary data, there are numerous sources of secondary data, both published and unpublished. The following are some of the sources of published secondary data; Government publications, technical and trade journals, books, magazines, newspapers, reports prepared by research scholars, universities, economists, in various fields, historical documents and other sources of published information. The source

of unpublished data include internet, unpublished biographies, unpublished work by scholars and researchers. Secondary data sources with information like this study were used to review the literature.

### **3.7 Survey**

#### **3.7.1 Questionnaire**

Chisumbe (2016) defines a questionnaire as ‘any written instruments that present respondents with a series of questions or statements to which they are to react either by writing out their answers or selecting from among existing answers.’ One of the characteristics of a questionnaire, according to Wellington (2000) is that it begins with straight forward, closed questions and leaving the open-ended questions at the end. Mohammad (2013) stated that a questionnaire is one of the cardinal primary sources of obtaining data in research and that it must be valid, reliable, and unambiguous. Generally, there are three types of questionnaires:

- i. Structured (closed-ended) questionnaires.
- ii. Unstructured (Open-ended) questionnaires
- iii. A mixture structured and unstructured (closed-ended and open-ended) questionnaires.

According to Mohammad (2013) Structured questionnaires provide the researcher with quantitative or numerical data and unstructured questionnaires with qualitative or text information. This research being a mixed design research, structured and unstructured questions were combined in one questionnaire and administered to respondents. The questionnaire was prepared in the following format: -

- i. Rammed earth construction specifications and technics
- ii. Advantages and disadvantages of earthen structures
- iii. Construction cost and financial providers

#### **3.7.2 Laboratory Experiments**

Laboratory tests were conducted to establish the characteristics of the soil for stabilised rammed earth, ideal soil mixing methods, compression strength and residual strength in accordance with BS1377-2, 2022. The tests included moisture content, curing and compression strength. Cubes measuring 150mm x 150mm x 150mm were made from the sample soils with various mixing proportions. The cubes were cured in accordance with Standards Australia HB195, 2002; Walker et al, 2005 and subjected to compression tests at various stages. The results from the laboratory experiments were used to clarify some of the

perceptions on durability and compression strength of stabilised rammed earth from the respondents during the survey.

## **A) Data collection procedures**

### **i) Material selection**

Soil samples were selected for laboratory experiments using stratified random assignment based on their physical and chemical characteristics as recommended in the literature. Suitable sites were selected, and sample soils collected at a depth of 1m to 1.5m to avoid vegetative matter in the soil. The following suitable sites were identified, and soil samples collected per site. Soloborn Compound in Kafue, Kalingalinga along Kamloops Road in Lusaka, Kaunda Square Primary School and Meanwood Kwamwena Phase1. Soloborn Compound in Kafue was selected because most of the houses were constructed from sun dried clay bricks. Kalingalinga and Kaunda Square were chosen because of high-density areas and some structures are made from sun dried bricks.

The preferred sub-soils were first subjected to smells test and elimination of soil samples with humus or decomposed matter in the field and further classified by performing laboratory tests to ultimately determine their suitability as a material for the manufacture of Rammed Earth cubes. The results of these tests, which led to the selection of the ideal soil sample for Rammed Earth, are laid out and discussed in Chapter 4. The water content was determined by moisture content test and by performing a “ball test” according to Walker et al., 2005. Portland cement was added to the mix in varying ratios of 3%, 6% and 10% by dry weight of soil sample. The material for all test samples was compacted using a 2.5kg tapping cylindrical rammer in three layers of 50mm in accordance with BS 1377-2, 2022.

### **ii) Determination of particle size distribution**

Mechanical analysis of the ideal soil sample was conducted using sieve analysis. Sieve analysis is a laboratory test procedure used to determine the percentage of particle size distribution in the soil sample by allowing the material to pass through a series of sieves of progressively smaller mesh size and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass. Sieve analysis was conducted in compliance with BS 1377-2:2022. Among the different types of sieve analysis are the throw-action, horizontal, tapping, air circular jet and wet sieve analysis. This study implored the wet sieve analysis in the determination of particle size distribution. Figures 3-1 and Figure 3-2 show sieving of the material in readiness for oven drying.



*Figure 3-1: Water spraying of the sieve material*



*Figure 3-2: Sieve material in readiness for drying*

The sieve stack is clamped onto the sieve shaker and the sample is placed on the top sieve. A water-spray nozzle was placed above the sieve to support the sieving process in addition to the sieving motion. The rinsing is carried out until the liquid which is discharged through the receiver is clear. Samples residues on the sieves were weighed then dried in the oven at 100 degrees Celsius for how long, cooled for 24 hours thereafter weighed again and results recorded.

### **iii) Compaction test (Proctors test)**

To assess the amount of compaction of soil and water content required in the field, compaction tests were done on the soil samples in the laboratory using Proctor's test to determine compaction characteristics of the soil samples with change in moisture content. The optimal moisture content at which a given soil type becomes most dense and achieve its maximum dry density by removal of air voids was recorded. Dry density is related to the degree of compaction of soil mass. The higher the degree of compaction the higher is the dry density of the soil mass under consideration. The dry weigh of soil per unit volume or bulk density was further investigated. Bulky density is an indicator of soil compaction. It takes into consideration both the solids and pore space. Bulk Density is calculated as the dry weight of soil divided by its volume (Mishra, 2019) as shown in Equation 3-3.

#### iv) Dry Density

The dry density of earth material in general and especially of the rammed earth depends on the soil type, the water content during compacting and the mode of compaction. The maximum dry density gives an indication of the strength of the earthen material. The dry density is one of the factors influencing the compressive strength obtained. The compression strength of rammed earth is proportional to its dry density as shown in Chapter 4 including the relationship between the compressive strength and the dry density achieved in compaction as shown mathematically by Equation 3.3.

$$pd = \frac{p}{1+w} \quad \text{Equation 3-3}$$

Where:

- (pd) is Dry density,
- w is water content and p= bulky density

#### v) Bulk Density

Bulky density is defined as the dry weight of soil per unit volume of soil. It is an indicator of soil compaction. It takes into consideration both the solids and pore space. Bulk density is calculated as the dry weight of soil divided by its volume as shown mathematically by Equation 3.4. It is typically expressed in kg/m<sup>3</sup>.

$$p = \frac{ws}{v} \quad \text{Equation 3-4}$$

- where  $p$  is Bulky density,
- $ws$  is dry weight of compacted soil in grams(g) and,
- $v$  is volume of soil

#### vi) Moisture Content test

Moisture content or water content in soil is an important parameter for building construction. There are several ways of determining moisture content such as oven drying method, calcium carbide method, torsion balance method, pycnometer method, sand bath method, radiation method and alcohol method. In this study oven drying method in accordance with BS 1377-2:2022 was adopted as it is the most common and accurate method. Soil samples were weighed and put in an oven and dried at 110 degrees  $\pm$  5 degrees Celsius. The difference between the wet and dry masses was noted as the mass of the moisture in the soil.

### **vii) Optimum Moisture Content**

The Optimum Moisture Content (OMC) or Optimum Water Content (OWC) is the moisture content at which the soil attains maximum dry density. This is determined from the compactions test. The amount of water added to the cement stabilised rammed earth is cardinal for good compaction during moulding and for achieving the densest block yielding the greatest strength. In this study OMC method in accordance with NZS 4297:2020 was adopted.

### **viii) Casting of Rammed Earth Test Cubes**

Only one soil sample out of the four soil samples collected in the field met the parameter for ideal rammed earth soils after undergoing laboratory soil grading analysis. Cubes were made with varying cement soil mixture and rammed in a steel measuring 150mm x 150mm x 150mm internally using a 4.5kg cylindrical steel control rammer with 27 blows per layer of 50mm high. A total of 64 rammed earth cubes measuring 150x150x150mm were made following recommendations of Walker et al. (2005) cited in Thuysbaert (2012). Table 3-3 shows the computed number of rammed earth cubes with 0%, 3%, 6% and 10% cement stabilization ratios.

**Table 3-3: Number of stabilised and unsterilized cubes**

<b>Soil Sample</b>	<b>Percentage of Cement Stabiliser</b>	<b>No. of cubes cast</b>
<b>A1</b>	<b>0%</b>	16
<b>A2</b>	<b>3%</b>	16
<b>A3</b>	<b>6%</b>	16
<b>A4</b>	<b>10%</b>	16
	<b>Total</b>	<b>64</b>

The following instruments and materials were used during sample preparation: -

- A 4.5 kg cylindrical control rammer
- Polythene sheet
- 150mm x 150mm x 150mm high internal dimensions metal moulds
- Lubricating oil
- A straight edge
- 10kg Electronic scale

- Beaker /Calibrated cylinder
- Drying ovens capable of maintaining uniform temperatures of 110 and 1000 degrees Celsius, respectively.

#### **ix) Curing procedures**

Curing methods affect the strength of the test specimens. The stabilised specimens after the completion of moulding were tightly wrapped in polyethene sheeting for 7 days to enhance hydration in accordance with Walker et al., (2005), Thuysbaert (2012) and Narloch and Woyciechowski (2020). The chemical reaction between water and cement results in a calcium silicate hydrate an interlocking skeleton which gives the material its strength. The stabilised specimens were further exposed to air for 7, 14 and 28 to 56 days to dry while the un-stabilised rammed earth cubes were immediately exposed to air after demoulding. All specimens were left to dry in shaded environment. Cubes were weighed and measured immediately after demoulding to establish the material bulk densities.

#### **x) Moisture absorption by immersion**

Durability tests were conducted to determine the effect of water absorption by immersion on specimens with and without cement stabiliser. This was a useful test in determining whether cement was an effective binder at reducing water ingress. Moisture absorption tests for Rammed Earth were performed according to recommendations of Standards Australia HB 195:2002. The test involved immersing oven dried stabilised and un-stabilised rammed earth cubes in water for 24 hours and increase in mass was determined and expressed as a percentage of the specimen's initial dry mass.

Four nominally identical specimens of 150mm x150mm x 150mm with various cement mix ratios (0%, 3%, w% and 10%) were used for the test. The specimens were tested at 7,14 , 28 and 56 days after manufacture. Curing of all specimens was followed as mentioned in this chapter. Cubes were weighed before testing to establish material bulk densities.

### **3.8 Data Analysis and Presentation**

Data analysis converts data into information and knowledge and explores the relationship between variables. According to Sharma (2018), “data Analysis is the process of systematically applying statistical and/or logical techniques to describe and illustrate, condense and recap, and evaluate data.” The purpose of data analysis is to obtain usable and useful information by describing and summarizing the data, categorizing, testing, identify relationships between variables, comparing variables, identify the difference between

variables and forecast outcomes or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study (Chisumbe, 2017). For this study the quantitative data collected was analysed using descriptive statistics and qualitative data was analysed synthetically.

### **3.8.1 Descriptive statistics**

Descriptive statistics summarize and organize characteristics of a data set. A data set is a collection of responses or observations from a sample or entire population. In quantitative research such as this one, after collecting data, statistical analysis involved describing characteristics of the responses, such as the average of variables (Bhandari, 2022).

### **3.8.2 Reliability and validity**

According to Kimberlin and Winterstein (2008) the integrity and quality of a measurement instrument is assured by the evidence of reliability and validity. Reliability and validity are two of the most important technical criteria for measuring devices in research (Oluwatayo, 2012). Mohajan (2017) citing Singh (2014) asserts that validity and reliability increase transparency in research by diminishing the researcher's opportunity to insert bias in qualitative research. According to Marczyk et al., 2005 'reliability refers to the consistency of the measure while validity focuses on what the test or measurement strategy measures and how well it does so.'

#### **A) Survey**

To ensure reliability and validity of the survey data the pilot study was conducted among the Structural and Civil Engineers and Architects who were not previously included during survey to check if the instrument (questionnaire) was able to collect the anticipated data. Furthermore, the questionnaire development was informed by the comprehensive literature review. A copy of the questionnaire for this study is attached under Appendix 2.

#### **B) Laboratory Experiments**

To ensure reliability of the experimental study, the experiments were done in a controlled environment with clearly outlined stages of experiments thereby making it easier for replication. Validity of the experimental research was achieved by use of laboratory instruments at the University of Zambia School of Engineering laboratory which are calibrated by the Zambia Bureau of Standards and by following the procedures outlined in this chapter.

### **3.9 Ethical consideration**

Ethics in research defines guidelines for conducting professional research. Ethics were achieved in this study by respecting the respondents' rights, disclosing the intention of the research to respondents and maintaining the objectivity during data collection. The copy of the ethical clearance letter for this study is attached under Appendix 1.

### **3.10 Summary**

In this chapter the methodology adopted for this research has been discussed by outlining the appropriate research approaches, methods of data collection and instruments and target population, thereafter, the sample size, sampling process as well as its reasonable justification. This was important in ensuring reliability and validity of the study is achieved.

## **CHAPTER FOUR : FINDINGS AND DISCUSSION**

### **4.1 Introduction**

This chapter presents the findings and discussion of the Survey (Part A) and the laboratory experimental results (Part B). It draws vital perceptions and understanding of the respondents, how the materials behaved and why. The main focus was on the survey responses and the impact of cement additives to rammed earth on the compressive strength, surface strength and material quality of rammed earth.

The first part of the study presents the background information and perceptions on rammed earth by the respondents. The main objective of the study was to establish the perceptions on the suitability of the use of rammed earth in construction of affordable urban housing units in Zambia.

In the second phase, laboratory tests were conducted on the four soil samples collected to establish the optimal soil cement mixing ratios for stabilised rammed earth wall construction. The findings are contextualised for use in practice and optimal soil-cement combinations that give the most advantageous set of physical and mechanical engineering properties for load bearing and non-load bearing applications.

### **4.2 Background to the Findings**

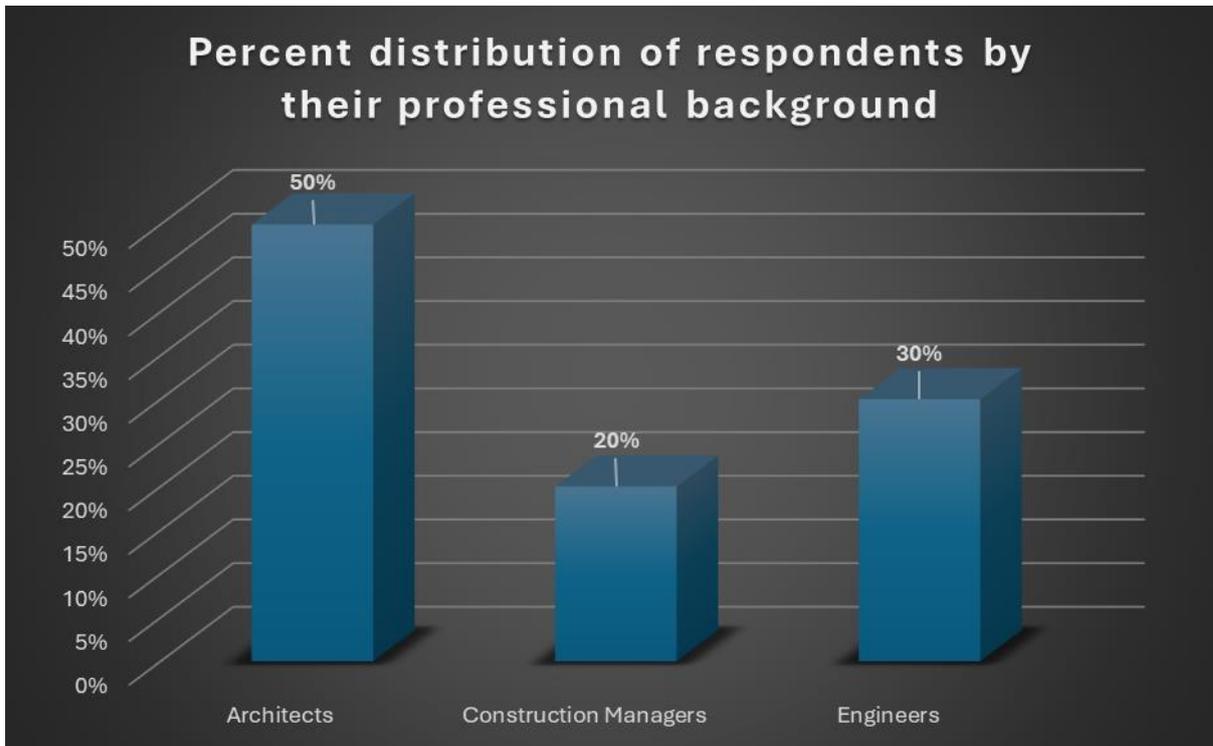
The information that was obtained from respondents during the survey including laboratory research is presented and analysed to draw conclusions and recommendations for the research. The presentation of findings was aimed at meeting the overall objective as indicated in Section 4.1.

### **4.3 Survey Research**

To establish the application of rammed earth in the housing construction and its widespread use in housing construction in Zambia perceptions on rammed earth was collected from the design and construction professionals including earth structure occupants. The instrument used in the collection of the information from respondents were the semi-structured questionnaires.

#### **4.3.1 Sample Sizes and Response Rate**

The findings as shown in Figure 4-1, revealed that half (50%) of the respondents were Architects whilst 30% and 20% of the respondents were Engineers and Construction Managers, respectively.



**Figure 4-1: Professional background of respondents.**

Table 4-1 shows that only 104 responses were received out of the total number of 362 questionnaires administered indicating a response rate of 29% mathematically calculated using Equation 4-1 (Saunders et al., 2009). Table 4-1 further revealed that 87% of the respondents were Architects whilst 60%, 21%, 18% and 17% of the respondents were earthen house occupants, Engineers, Planners and Contractors respectively.

**Table 4-1: Summary of population sizes, sample sizes and response rates**

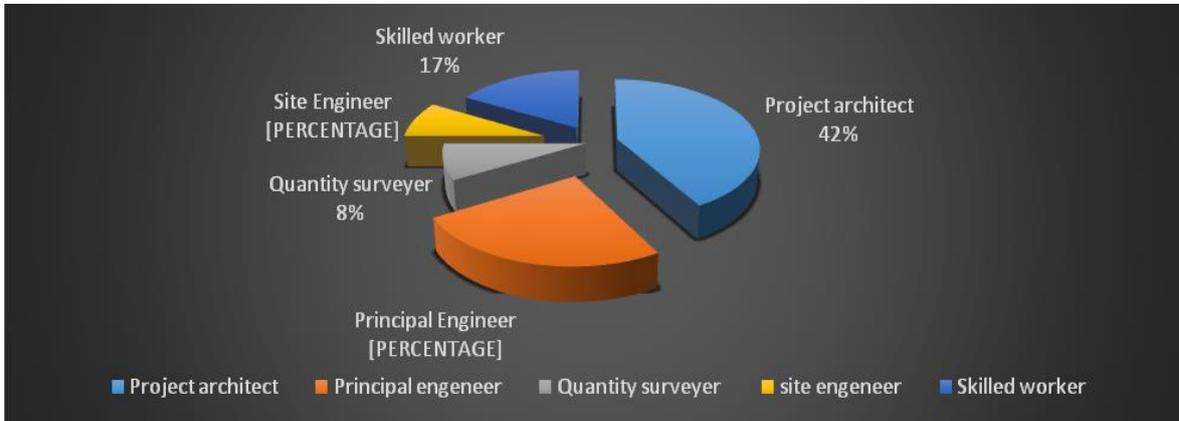
Population Category	Population Size	Sample Size	Successful Response	Response Rate
Architects	68	47	41	87.0%
Engineers	704	131	27	21%
Contractors (Grade 4B)	362	108	18	17%
Planners	115	66	12	18%
Earthen House Occupants	10	10	6	60%
Total	1259	362	104	29%

$$\text{Response rate} = \frac{\text{Total successful response}}{\text{Total sample size}} \times 100$$

Equation 4-1

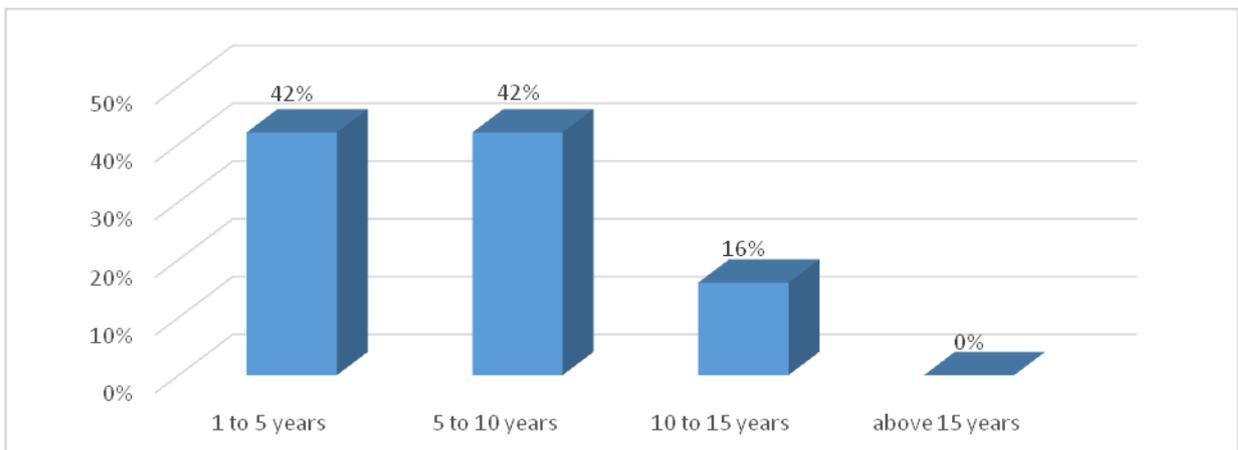
$$\text{Response rate} = \frac{104}{362} \times 100 = 29\%$$

Therefore, the response rate was 29% of the circulated questionnaires.



**Figure 4-2: Respondents' position in the firm or organisation**

Figure 4-2 shows the percentage distribution of respondents by their positions in their firms or organizations. The findings showed that the respondents were Project Architects (42%) Principal Engineers (25%), skilled workers (17%) and Quantity Surveyors and Site Engineers (8%).



**Figure 4-3: Respondent's experience in the Construction sector**

Likewise, Figure 4-3, shows the percentage distribution of respondents by their level of experience. The figure shows that 42% of the respondents had between 1 to 5 and 5 to 10 years of experience in the construction sector while 16% of the respondents had 10 to 15 years of experience in the construction sector. None of the respondents had more than 15 years of experience in the construction industry.

#### 4.4 Perceptions on the use of Rammed Earth for Housing Construction

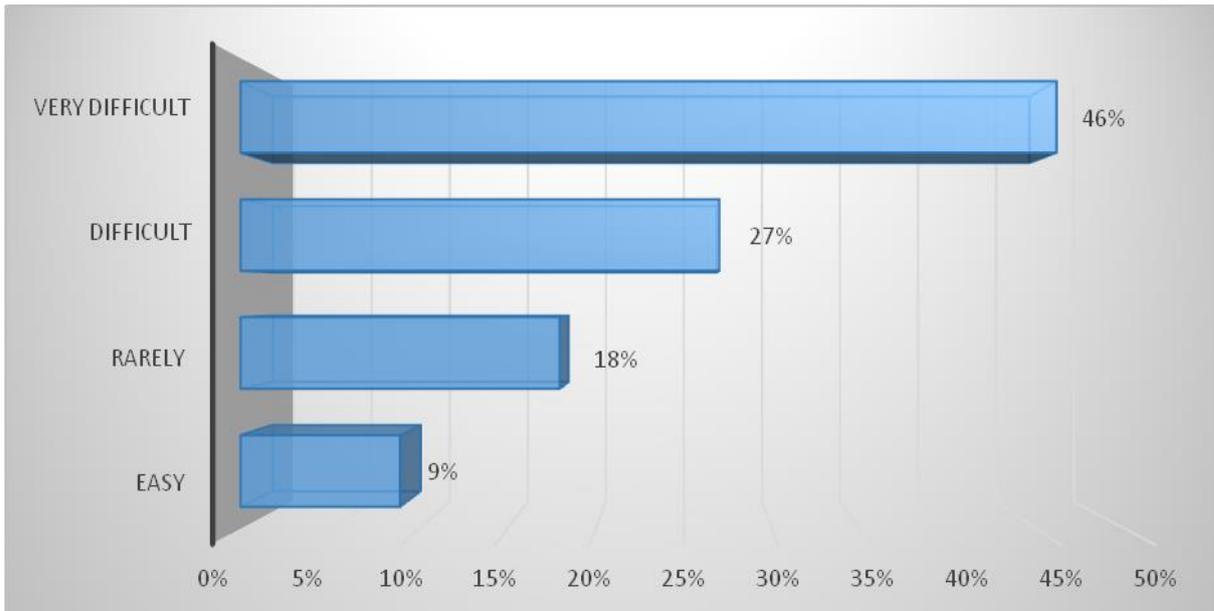
This section of the study presents findings on the perceptions of the use of rammed earth in housing construction. The findings are summarised in Table 4-2.

**Table 4-2: Perception on the use of Rammed Earth for Housing Construction**

Description	Ratings by the respondents					Total
	Very poor	Poor	Average	Good	Very good	
<b>Thermal</b>	16.6%	0%	0%	41.7%	41.7%	100%
<b>Fire residual strength</b>	9%	0%	9%	18.0%	64%	100%
<b>Microclimate</b>	0%	9%	28%	45%	18%	100%
<b>Economically</b>	9%	0%	36.4%	36.4%	18.2%	100%
<b>Availability</b>	0%	8.3%	33.3%	16.7%	41.7%	100%
<b>Sustainability</b>	9%	18.2%	0%	36.4%	36.4%	100%
<b>Structural strength</b>	45.7%	22.7%	17.7%	10.2%	3.7%	100%
<b>Labour intensive</b>	0%	16.7%	16.7%	41.7%	25%	100%
<b>Construction knowledge by the professionals and developers</b>	0%	41.7%	50%	8.3%	0%	100%
<b>Housing for the poor</b>	0%	8.3%	16.7%	25%	41.7%	100%
<b>Maintenance costs</b>	0%	9%	18.0%	27%	46%	100%
<b>Lack of legislation</b>	46%	36%	9%	9%	0%	100%

From Table 4-2, the respondents had to rate the characteristics on a 5 Likert scale. The findings showed the perception that rammed earth had good to very good fire residual strength (82%), good maintenance costs (73%), thermal (83%), availability of low materials (58%), housing for the poor (68%), sustainability (73%), poor structural strength (68.4%) but lacked legislation (45%) as one of its draw backs.

On how marketable housing units built with rammed earth were compared with those built with other materials, it was found that the perception of the majority (73%) of the respondents was that it was very difficult to sell or resale a house or structure constructed using rammed earth methods compared to conventional construction methods. It was also found that only 9% of the respondents indicated that it was easy to sell or resale a structure constructed using rammed earth methods and 18% of the respondents indicated that it was rarely manageable, as shown in Figure 4-4.



**Figure 4-4: Comparison on marketability.**

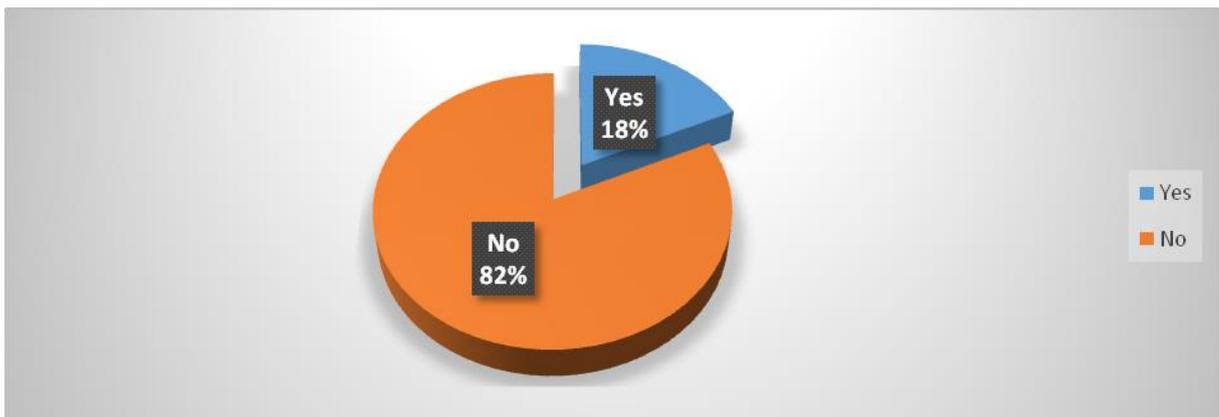
#### **4.4.1 Specification of Rammed Earth as a Construction Material in Urban Housing**

The widespread use of rammed earth in the construction of urban housing as specified by the design and construction professionals in comparison to other building material in housing construction was investigated. The findings showed that the most popular material among constructional professionals was adobe sundried bricks (100%), rammed earth was the least popular building material (18%). The findings also showed that 90%, 70%, 65% and 33 % used adobe compressed blocks, wattle, adobe burnt bricks and sandbag, respectively, as shown in Table 4-3.

**Table 4-3: Comparison of specification and usage of construction material during design and construction**

Construction materials	Have used the material	Not used the material	Total
<b>Rammed earth</b>	18%	82%	100%
<b>Wattle</b>	70%	30%	100%
<b>Adobe (clay) sun dried bricks</b>	100%	0%	100%
<b>Adobe (clay) burnt bricks</b>	65%	35%	100%
<b>Adobe (clay) compressed blocks</b>	90%	10%	100%
<b>Sandbag</b>	33%	67%	100%

Regarding the use of rammed earth, Figure 4-5 shows the percentage distribution of the respondents by their use of rammed earth construction technique. The figure shows that the majority (82%) do not use this technique and only a few (18%) have used it.



**Figure 4-5: Percentage distribution on the use of rammed earth in construction**

The popularity of rammed earth among professionals and how often they recommended it to the clients against other options (materials) was established. The study revealed that the most rarely recommended building material by design and construction specialists is rammed earth (60%) followed by sandbag, wattle, adobe clay bricks and burnt adobe clay bricks with 55%, 50%, 10% and 9%, respectively. The findings also showed that the most often recommended technique to clients was adobe clay bricks with 73% while the least recommended technique was rammed earth with only 10% of respondents who indicated that they recommended it to their clients very often, as shown in Table 4-4.

**Table 4-4: Recommendation of Rammed earth and other building materials to developers by Design professionals**

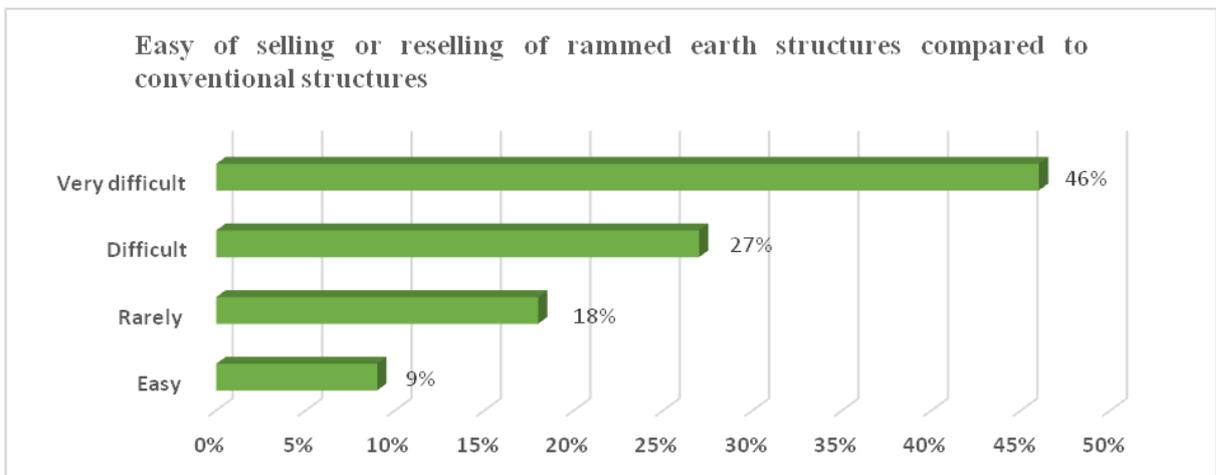
Type	Always	Often	Sometimes	Rarely	Never	Total
<b>Rammed earth</b>	0%	10%	30%	0%	60%	100%
<b>Adobe (clay) bricks</b>	30%	30%	10%	20%	10%	100%
<b>Wattle</b>	0%	0%	30%	20%	50%	100%
<b>Burnt clay bricks</b>	37%	36%	9%	9%	9%	100%
<b>Sandbag</b>	9%	0%	18%	18%	55%	100%

Table 4-5 shows that concrete structures were more expensive compared to rammed earth as well as other structures. It was found that 66% of the respondents said that concrete structures were expensive to build or construct. The findings also showed that concrete blocks were also expensive while the cheapest was steel followed by rammed earth, adobe burnt bricks, wattle, adobe sun dried bricks, being represented by 83.3%, 75%, 58.4% and 58.3%, respectively.

**Table 4-5: Comparison of the cost of rammed earth to other conventional building materials**

	Very cheap	Cheap	Average	Expensive	Very expensive	Total
<b>Rammed earth</b>	26%	57.3%	9.9%	6.8%	0%	100%
<b>Adobe sun dried bricks</b>	41.7%	16.7%	33.3%	0%	8.3%	100%
<b>Adobe burnt bricks</b>	8.3%	58.3%	16.7%	8.3%	8.3%	100%
<b>Concrete blocks</b>	16.7%	8.3%	16.7%	41.7%	16.7%	100%
<b>Concrete</b>	25%	0%	8.3%	16.7%	50%	100%
<b>Timber structure</b>	9%	9%	46%	36%	0%	100%
<b>Sandbag</b>	9%	36%	55%	0%	0%	100%
<b>Wattle</b>	36%	28%	36%	0%	0%	100%
<b>Steel</b>	27%	73%	0%	0%	0%	100%

Figure 4-6 shows the percentage distribution of the marketability of rammed earth structures as compared to conventional structures. The results reveal that the perception of the majority (73%) of the respondents was that it is exceedingly difficult to sell or resale a rammed earth house compared to a house constructed using conventional building materials. The results further revealed that only 9% of the respondents said that it was easy to sell or resale a rammed earth house and 18% of the respondents said that it was rarely manageable.



**Figure 4-6: Marketability of rammed earth housing units against conventional housing units**

#### 4.5 Suitability of rammed earth for housing construction

The second objective of the study was to find out the suitability of rammed earth for housing construction. To meet this objective laboratory tests were done to attest its suitability.

##### 4.5.1. Material selection

The preferred sub-soils were first subjected to smells test and elimination of soil samples with humus or decomposed matter in the field and further classified by performing laboratory tests to ultimately determine their mineralogy and suitability as a material for the manufacture of Rammed Earth cubes. The results of these tests, which included sieve analysis, bulk and dry density led to the selection of the four sub-soils as Rammed Earth materials. The percentage of particle size in the soil samples using wet sieve analysis satisfied the recommended proportions according to BS1377-2:2022, ASTM D2487-17, SANS 201- 2008 and Walker et al.,2005, for the samples to be considered for further analysis as shown in Table 4-6.

**Table 4-6: Test soil composition**

Sample	Gravel	Sand	Silt/ Clay
A	35	12	53
B	4	16	80
C	1	12	87
D	1	21	78

The results indicated that sample A, fell within the recommended rammed earth soil composition by Walker et al., 2005 and the Proctor test was conducted on the soil Samples A, B, C and D.

#### 4.5.1.1 Moisture Content test

Likewise, the moisture content was conducted in accordance with BS 1377-2:2022. Soil samples were weighed and put in an oven and dried at 110 degrees  $\pm$  5 degrees Celsius. The difference between the wet and dry masses was noted as the mass of the moisture in the soil. Figure 4-7 and Figure 4-8 shows the material being prepared for drying in the oven and the dried sample respectively.



*Figure 4-7: Drying of samples in the oven*



*Figure 4-8: Dried sample ready for further tests*

**Table 4-7: Moisture content Determination**

Sample No.	1	2	3	4	5
Moisture can No.	28F	82	57	110	90
Weight of can+wet soil	30.40	30.60	30.80	31.00	31.20
Weight of can+dry soil	28.10	27.40	26.90	26.40	26.00
Weight of water	2.30	3.20	3.90	4.60	5.20
Weight of Can	6.70	6.60	6.70	6.40	6.60
Weight of Soil	21.40	20.80	20.20	20.00	19.40
Water Content, w (%)	10.75	15.38	19.31	23.00	26.80

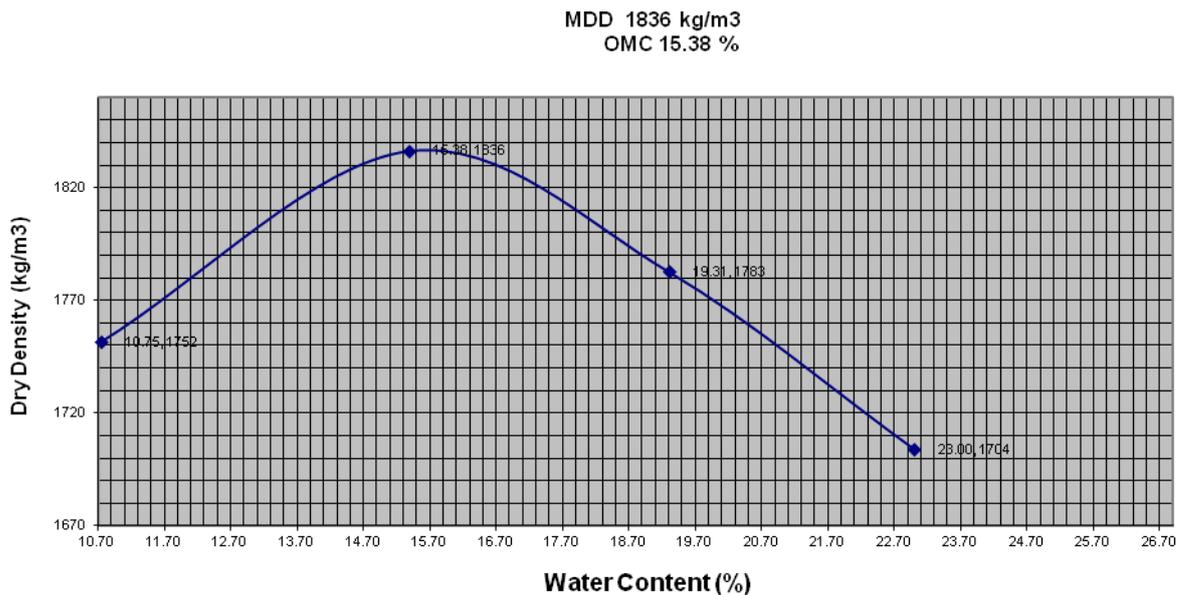
The results in Table 4-7 indicated that sample A, had a moisture content of 15.38% and further tests were conducted.

#### 4.5.2. Compaction test (Proctors test)

Likewise, the Proctor tests were conducted to ascertain/confirm the moisture content required for each sample at which the compacted sample achieved the greatest dry density. Table 4-8 presents the Proctor Test results.

**Table 4-8: Optimum Moisture Content and Maximum Dry Density**

ID	Soil Sample	Optimum Moisture Content(%)	Maximum Dry Density (Kg/m <sup>3</sup> )
1	Sample A	15.38	1836
2	Sample B	17.48	1700
3	Sample C	18.81	1684
4	Sample D	16.75	1714



**Figure 4-9: Relationship between Maximum Dry density and Moisture content for sample A**

The results indicated that only sample A (Gravel 35%, Sand 12% and silt/clay 53%) fell within the recommended threshold for rammed earth soil composition as shown in Table 4-8. The OMC (15.38%) and MDD (1836kg/m<sup>3</sup>) for Sample A is as shown in Figure 4-9.

#### 4.5.3 Curing procedures

Curing methods were conducted in accordance with Walker et al., (2005), Thuysbaert (2012) and Narloch and Woyciechowski (2020). The stabilised specimens were wrapped in

polythene sheets for 7 days after demoulding and further exposed to air for 7, 14 and 28 to 56 days to dry while the un-stabilised rammed earth cubes were immediately exposed to air after demoulding. All specimens were left to dry in shaded environment. Cubes were weighed and measured immediately after demoulding to establish the material bulk densities. Figure 4-10 and 4-11 shows the curing of cubes wrapped in the polythene sheet (Figure 4-10) and the weighing of the rammed earth cube immediately after unwrapping the polythene sheet (Figure 4-11).



*Figure 4-10: Curing of rammed earth cubes wrapped in polythene sheets*



*Figure 4-11: Weighing of rammed earth Cubes*

#### **4.5.3 Unconfined Compressive Strength**

The specimens were tested for compressive strength using the compressive testing machine at the University of Zambia School of Engineering laboratory. The specimens were put through the same machine concrete samples is tested in accordance with BS 1377-2:2022 and SADC ZW HS 983- 2014 standards in determining the unconfined compressive strength of the rammed earth samples. Tests were conducted on sixty-four (64) cubes, similar to concrete specimens recommendation from previous researchers as indicated in section 2.5.3 (E). This machine gave an accurate reading to the test specimens and ultimately decided their compressive strength and results recorded. Figure 4-12 and Figure 4-13 shows rammed earth cubes being tested for compressive strength. The aim of this test series was to check the observation from the non-destructive tests shown earlier in this study and compare them with the standard testing methods for determining the compressive strength of a material. The results revealed that samples A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub> satisfied the minimum desired standard of 1.5MPa

as shown in Table 4-9, whilst sample 1 fell below the recommended SADC ZW HS 983: 2014 standard.



*Figure 4-12: Compressive strength test after curing at various test days*

*Figure 4-13: Cured sample undergoing compressive strength test*

Unconfined Compression Strength ( $\sigma_c$ ) = Ultimate Load ( $P_u$ ) divided by plan Area of the cube as shown mathematically by Equation 4-2

$$\sigma_c = P_u/A$$

Equation 4-2

**Table 4-9: Compression strength results at 7, 14, 28 and 56 days**

ID	Days	Compression Strength (MPa)			
		7	14	28	56
A1	0%	0.35	1.22	1.4	1.6
A2	3%	1	1.57	2.2	2.9
A3	6%	1.2	1.65	2.96	3.1
A4	10%	1.3	2.96	3.12	3.7

#### 4.5.4 Moisture absorption by immersion

Durability tests were conducted by studying the effect of water absorption by immersion on specimens with and without cement stabiliser. This was a useful test in determining whether cement was an effective binder at reducing water ingress as explained in Section 3.7.6. The

test involved immersing four nominally identical oven dried cubes. Three stabilised and one un-stabilised rammed earth cubes in water for 24 hours. The increase in mass was determined and expressed as a percentage of the specimen's initial dry mass. The un-stabilised rammed earth cube crumbled in water after being immersed for 24 hours and no further tests were done on it. Further tests were done on the stabilised cubes, the results revealed that the samples which contained a higher percentage of cement gained less weight (+9.8%) than the samples with less cement content (+16.8%) as shown in Table 4-10.

**Table 4-10: Moisture absorption by immersion**

<i>Sample weight before and after immersion in water</i>					
<b>Specimen</b>	<b>Treatment</b>	<b>Before</b>	<b>After</b>	<b>Variance</b>	<b>Moisture absorption (%)</b>
<b>A<sub>1</sub></b>	0%	6602	-	-	-
<b>A<sub>2</sub></b>	3%	6538	7563	1025	16.8
<b>A<sub>3</sub></b>	6%	6506	7361	855	14
<b>A<sub>4</sub></b>	10%	6690	7358	668	9.8

Table 4-10 shows that the specimens with a lower cement content had a higher rate of moisture loss compared with specimens with higher cement content which had a lower loss of moisture due to chemical reaction between cement and water resulting in a calcium silicate hydrate an interlocking skeleton which gives the material its strength.



**Figure 4-14: Weighing of the specimen before emersion in water.**



**Figure 4-15: Water absorption by immersion in water**

Figures 4-14 and Figure 4-15 show the weighting of cubes before and after being immersed in water for 24 hours. The un-stabilised specimen disintegrated under water immersion as shown in Figure 4-15 confirming that un-stabilised Rammed Earth walls, unless protected, were not durable in the presence of water.

**Table 4-11: Relationship between moisture content, time and stabiliser**

		Days after manufacture				
		0	7	14	28	56
Specimen	Treatment	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
A1	0%	7588	7302	7208	6302	6210.4
A2	3%	(7585)	7500	7200	6538	6446.3
A3	6%	(7445)	7405	7168	6534.6	6506
A4	10%	(7553)	7492	7236	6758.4	6690

#### 4.5.5 Residual strength

Furthermore, the fire residual strength of rammed earth as a building material was tested using stabilised and un-stabilised rammed earth cubes which were heated in an oven at 1000 degrees Celsius for 4 hours and cooled for a further 24 hours before being subjected to compression strength test. The aim of these tests was to observe the effect of fire on a rammed earth material. All the cubes remained intact, and further compression strength tests were conducted on them. The results revealed were interesting in that all the samples met the SADC recommended standard of a minimum for of 1.5MPa. However, it was found that un-stabilized sample yielded a higher compressive strength of 7.8MPa, compared to the stabilized sample (10% stabilized) which yielded a result of 3.2MPa as shown in Table 4-12. Figure 4-16 shows placing of cubes in the oven and Figure 4-17 shows rammed earth cubes being heat at 1000 degrees Celsius.

**Table 4-12: Compression Strength results after fire tests**

Specimen	% Cement Stabilization in Soil Mix	Compression Strength (MPa) before Fire @ 28days	Compression Strength (MPa) After fire
A <sub>1</sub>	0	1.4	7.8
A <sub>2</sub>	3	2.2	4.6
A <sub>3</sub>	6	2.96	3.5
A <sub>4</sub>	10	3.12	3.2



**Figure 4-16: Placing of rammed earth cubes in an oven**



**Figure 4-17: Fired rammed earth cubes**

#### 4.5.6 Rate of Drying

The rate at which samples dried when exposed to air during curing was measured to ascertain the amount of time a Rammed Earth wall is likely to take to lose its moisture. To explore this relationship between moisture content and time, the masses of the samples were measured at the 1, 7, 14, 28 and 56 days, after casting and unwrapping from the polyethylene sheet. This established a rate of drying for the soil type under consideration. The results revealed that the samples with less cement had a higher loss of mass compared to samples with a higher cement mix ratio as shown in Table 4-13.

**Table 4-13: Rate of Drying**

		Days after manufacture					
		0	7	14	28	56	Variance
Sample	Treatment	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	
A1	0%	7588.0	7302.0	7208.0	6302.0	6210.4	1,377.6
A2	3%	(7585.0)	7500.0	7200.0	6538.0	6446.3	1,053.7
A3	6%	(7445.0)	7405.0	7168.0	6506.0	6534.6	870.4
A4	10%	(7553.0)	7492.0	7236.0	6758.4	6690.0	863.0

#### 4.6 Exploring the cost comparisons of rammed earth to conventional building materials.

With respect to the cost comparison of rammed earth to conventional building materials or structures, Table 4-14 shows that concrete structures were more expensive than rammed earth as well as other structures.

**Table 4-14: Cost comparison of rammed earth to other construction building materials.**

Description	Very cheap	Cheap	Average	Expensive	Very expensive	Total
Rammed Earth	26%	57.3%	9.9%	6.8%	0%	100%
Adobe sun dried bricks	41.7%	16.7%	33.3%	0%	8.3%	100%
Adobe burnt bricks	8.3%	58.3%	16.7%	8.3%	8.3%	100%
Concrete blocks	16.7%	8.3%	16.7%	41.7%	16.7%	100%
Concrete	25%	0%	8.3%	16.7%	50%	100%
Timber structure	9%	9%	46%	36%	0%	100%
Sand bag	9%	36%	55%	0%	0%	100%
Wattle	36%	28%	36%	0%	0%	100%
Steel	27%	73%	0%	0%	0%	100%

It was found that 80% of the respondents said that rammed earth structures were cheap to build while 66% of the respondents said that concrete structures were expensive to build or construct. The findings also showed that concrete blocks were also expensive while the cheapest was steel followed by adobe burnt bricks, wattle, adobe sun dried bricks, being represented by 75%, 58.4% and 58.3%, respectively.

##### 4.6.1 Comparing Unit Rate Cost for rammed earth against concrete block for wall construction.

The initial costs of constructing a wall per square meter were compared for concrete blockwork against stabilised rammed earth. The house plan with a total floor area of 101.5m<sup>2</sup> was used both for rammed earth and concrete blocks construction with the unit prices derived as shown in Tables 4-15 to 4-16. The house plans and detailed material schedule are attached under Appendix 4.

The other information which guided the rate build-up included the following:

- 8” concrete block =ZMW7.0
- 6” concrete block =ZMW 7.0

- Cement = ZMW135/50kg bag
- Building Sand = ZMW3500/25tn
- Gravel = ZMW2500/25tn
- Clay soil = ZMW2500/25tn
- Volume of stabilised rammed earth x 1.3 = volume of stabilised loose soil

Considering that 1m<sup>2</sup> requires 12.5 concrete blocks the unit rate was arrived at was ZMW117/m<sup>2</sup> of concrete block work by dividing the cost of superstructure with the total wall surface area of block work under superstructure ZMW24,430/ 209.18m<sup>2</sup> as shown in Table 4-15.

**Table 4-15: Summary of Construction cost for a 101.5m<sup>2</sup> concrete block house**

	SUMMARY	TOTAL (ZMW)
1	Substructure	49,842.00
2	Concrete works (Ring beam, Lintels, Slab)	25,000.00
3	Block work in Superstructure	36,700.00
4	Wall finish	15,030.00
	Sub-total	<b>126,572.00</b>
	TOTAL MATERIAL COST	<b>126,572.00</b>
	Add FOR	
5	Labour & Equipment 20% of total cost	25,314.40
6	Transport costs @ 10% of total cost	12,657.20
	TOTAL ESTIMATE COST	<b>164,543.60</b>

From Table 4-16 the average construction cost of a concrete grey housing unit can be estimated at ZMW1,621.12/m<sup>2</sup> by considering the cost of construction of the concrete grey structure of ZMW164,543.60 for the total floor area of 101.5m<sup>2</sup>

Similarly, the unit cost of ZMW258.00/m<sup>2</sup> for stabilised rammed earth wall was calculated by considering the cost of stabilised rammed earth superstructure cost at ZMW53,965.00 for the total wall surface area of 209.16m<sup>2</sup> (62.75m<sup>3</sup> /0.3m) as shown in Table 4-16.

**Table 4-16: Summary of Construction cost for a 101.5m<sup>2</sup> stabilised rammed earth house.**

	SUMMARY	TOTAL
1	Substructure	33,670.00
2	Concrete works in lintols	10,000.00
3	Superstructure	53,965.00
4	Wall finish	0.00
5	Paint work	0.00
	Sub-total	97,635.00
	TOTAL MATERIAL COST	97,635.00
	Add	
6	Labour & Equipment at 20% of total cost	19,527.00
7	Transport costs at 10% of total cost	9,763.50
	TOTAL ESTIMATE COST	126,925.50

From Table 4-16 the average construction cost of a stabilised rammed earth housing unit can be estimated at ZMW1,250.50/m<sup>2</sup> by considering the cost of stabilised rammed earth of ZMW126,925.50 for the total floor area of 101.5m<sup>2</sup>. Detailed cost comparison of concrete and Rammed earth construction cost is included under Appendix 4

## 4.7 Discussion

### 4.7.1 Perception on the use of Rammed Earth

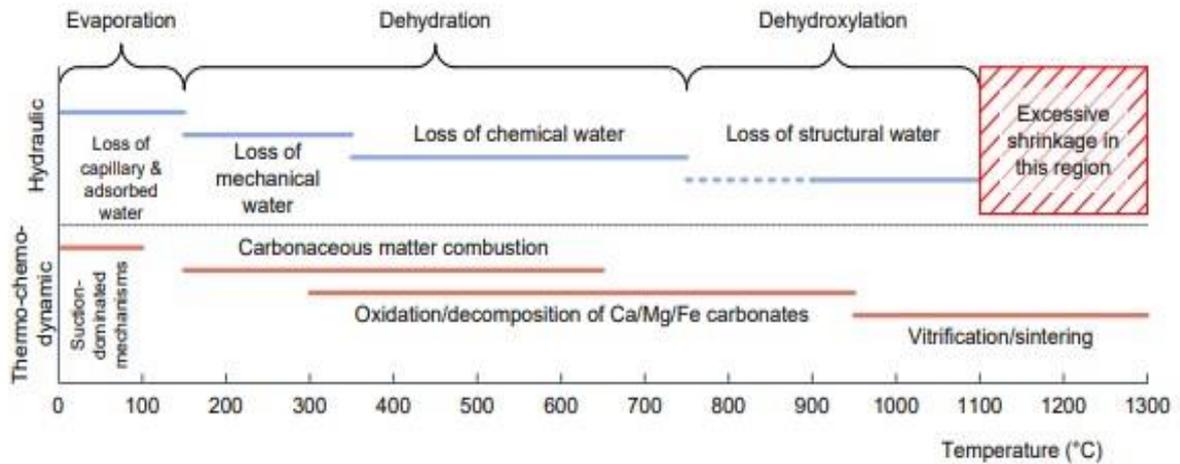
On the perception towards the use of rammed earth, the respondents indicated that rammed earth had good thermal and fire residual strength. This agrees with Kraus, 2012 who stated that among the most perceived favourable attributes of rammed earth is that it has good thermal resistance, good fire resistance, as well as low life cycle costs. Likewise, the results agree with literature that among the factors considered to be least favourable consequently hindering the adoption of rammed earth material for housing construction include challenges to do with constructability, as well as perceived high initial costs of investment (Maini, 2005, Hadjri et al., 2007). The use of this construction material in remote regions or under-

developed countries is suggested as a viable alternative to conventional building techniques like concrete and steel.

With regards to knowledge among professional, the study revealed that there is lack of knowledge among architectural professionals. This agrees with literature that there is a lack of knowledge, skills, and understanding among professionals, government, donors and users which is affecting the widespread use of stabilised rammed earth. Lack of information regarding the accepted chemical composition of soils as a construction product, as well as lack of skilled labour in stabilised earthen construction, are some of the factors hindering the adoption of rammed earth in construction of housing (Castells and Laperal, 2007; Houben et al., 2007; Jagadish, 2007). Similarly, on non-availability of legislation, the results agree with literature that lack of building codes, standards, quality control criteria, and policies guiding usage of stabilised rammed earth as a building construction material hinders the adoption of rammed earth for construction of urban housing (Eisenberg, 2005; Hadjri et al. 2007; Morton, 2007). This aligns with Mulenga (2018) who affirms that lack of standards and code of practice has negatively affected sustainable construction methods.

#### **4.7.2 Properties of Rammed Earth**

Unconfined compressive strength results revealed that the stabilised rammed earth cubes satisfy the desired minimum threshold of minimum of 1.5 MPa in accordance with international standards such as SADC ZW HS 983: 2014 at 1.5 – 2MPa, NZS 4298:1998 at 1.5MPa and ASTM International E2392 / E2392M - 10e1 (2010) at 2.06MPa if stabilized with a minimum of 3% cement. This agrees with literature that cement stabilization of rammed soil samples improves strength, resistance to water and reduces shrinkage of the rammed earth walls. Numerous studies have been conducted on the strength, durability and shrinkage characteristics of stabilised soils which indicate a strong linear correlation between compression strength and cement content (Crowley, 1997; Walker, 2000; DTi, 2003; SADC ZW HS 983, 2014). On fire residual strength, the results revealed that rammed earth retained the desired strength. This aligns with Nshimiyimana et al., 2022 who affirmed that rammed earth could withstand relatively high temperature without risking the loss of their mechanical performance. However, after exposing the rammed earth to fire, the samples with less or no cement content yielded even more strength than those with more cement content. This aligns and with Beckett, Kazamias and Law (2019) and Johari et al., (2010) who affirm that unstabilised rammed earth cubes gain strength when exposed to elevated temperatures above 100 °C due to loss of water and thermos chemo-dynamic as shown in Figure 4-18 and Table 4-18.



**Figure 4-18: Key hydraulic and thermo - chemo process and associated temperature ranges during typical clay brick firing. (Source: Beckett, Kazamias and Law ,2019)**

Figure 4-18 shows the changes in the chemical composition of rammed earth which are similar to clay bricks when exposed to elevated temperatures while Table 4-18 gives an explanation of the two main stages of chemical changes in rammed earth when exposed to elevated temperatures.

**Table 4-17: Hydraulic and thermo-chemo dynamic processes associated with clay brick firing.**

Hydraulic processes	Evaporation: temperatures are sufficient to remove pore water menisci suspended between soil particles.
	Dehydration: removal of water that is chemically bonded to the clay particles. Here, the process is separated into loss of mechanical water, being that which is loosely bound to the particles or adsorbed between platelet stacks, and chemical water, being that which is part of the hydrous clay minerals.
	Dehydroxylation: removal of hydroxyl ions from clay crystal structure
Thermo- chemo dynamic processes	Suction-dominated: changes in pore water pressure due to moisture migration result in material shrinkage and aggregate rearrangement.
	Carbonaceous matter combustion: breaking down of the carbonaceous matter and carbonates forming hydrocarbons and carbonaceous residue.

	Oxidation: carbonates of Ca, Mg and Fe thermally decompose into their oxides, producing carbon dioxide and/or monoxide, depending on the oxygen availability within the kiln.
	Vitrification/sintering: clay materials partially melt and coat the remaining solid particles, bonding them together and developing the fired brick's strength.

(Source: Beckett, Kazamias and Law ,2019)

According to Schneider (1988), Naus (2005), Shen and Xu (2019) the decrease in compressive strength of the cement stabilised rammed earth samples with increase in elevated temperature is due to changes in porosity and pore structure of the calcium silicate hydrate due to loss of water.

Furthermore, regarding moisture absorption, the study revealed that the un-stabilised samples tend to disintegrate when exposed to water compared to cement-stabilized samples. This supports the assertion by Hall and Djerbib (2004) that stabilised rammed earth generally absorbs much less water due to capillary suction, and at a slower rate, than conventional masonry building materials such as bricks and concrete. More so, that moisture ingress in rammed earth, due to capillary suction, increases linearly per unit inflow surface area against the square root of elapsed time. The particle-size distribution of the soil is critical in determining the rate at which moisture may ingress.

#### **4.7.3 Cost comparison of stabilised rammed earth against concrete blocks**

In comparing the unit cost per square meter (m<sup>2</sup>) of constructing a wall in a housing unit using stabilised rammed earth against concrete block work, this study built a rate and found that the cost of using stabilised rammed earth is lower compared to that of using concrete block work by 30%.

These results agree with Bui et al., (2009) that the cost effectiveness and durability of houses made of rammed earth may provide a solution to the problem of expensive housing, advancing that soil can be sourced on-site at zero or almost zero cost. The transportation cost of the construction materials when the main bulk component (earth) is sourced on-site is significantly reduced. More so, that rammed earth walls do not require painting or other wall treatments, resulting in minimum on-going maintenance cost (ibid).

However, it is important to note that even though the forming systems for the two materials are similar and take the same man-hours to erect, layering and compacting rammed earth into

the form takes considerably more labour and equipment than pouring and vibrating concrete, or laying of concrete blocks. The only savings possible are a reduction in aggregate and cement costs. To achieve these savings, a mix design must be developed that utilizes a major portion of either on-site or other free mineral soil and a minimum rate of stabilization.

The results confirm the assertion that the *Zambian housing sector* is associated with numerous challenges in the provision of affordable and sustainable housing units thereby impacting negatively on access to affordable housing. Further, the findings showed that if stabilised, rammed earth can be employed in the construction of sustainable and affordable housing units thereby improving the delivery of affordable housing. A list of recommendations for further research and evaluations are presented in Chapter 5.

## **CHAPTER FIVE : CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS**

### **5.1 Introduction**

This chapter outlines the conclusions from the research carried out and makes appropriate recommendations on the use of rammed earth as an alternative building material in construction of urban housing. The conclusions are based on research objectives. The chapter also gives recommendations with regards to the problems identified based on the research findings. It also gives limitations and suggestions on areas for further research.

### **5.2 Conclusions**

#### **5.2.1 To establish public perception on the use of rammed earth in housing construction.**

The public perception on the use of rammed was mixed, with some considerable level of agreement on its advantages associated with lower cost, thermal, fire as well as moisture resistance. On the other hand, the respondents were of the view that the market value for a house constructed with rammed earth is lower compared to one constructed with concrete; housing constructed with rammed earth was aimed at the poor and those who were not doing well economically. Furthermore, another factor perceived to be a drawback in the adoption of rammed earth was the lack of legislation as well as standardization. A further factor was the perceived challenges or difficulties associated with constructability.

#### **5.2.2 To assess the properties and suitability of rammed earth for housing construction.**

The test results for compressive strength, fire residual strength as well as moisture resistance all fell within the recommended thresholds by various standards, suggesting that stabilized rammed earth material is suitable for construction of walls in housing.

#### **5.2.3 To compare the cost of wall construction using rammed earth and conventional concrete block work.**

The study found that the construction cost of rammed earth was cheaper in Lusaka compared to that of concrete blocks. However, it was observed that even though the forming systems for the two materials were similar and took more or less the same man-hours to erect, layering and compacting, rammed earth into the form takes considerably more labor and equipment than laying of concrete block. The identified cost savings were in terms of aggregates, formwork, and cement costs including a significant less impact on the embodied energy and embodied carbon dioxide emission of a building as compared to conventional concrete block (Venkatarama Reddy and Prasanna Kumar, 2010).

### **5.3 Limitations of the Study**

As with most studies, this study has three major limitations that could be addressed in future research. First, limited funding meant that sample size both during survey and during laboratory tests was limited mostly to Lusaka and not countrywide hence the small geographical coverage translated into a small sample size of the targeted population. Second, due to Covid-19, interviews were limited and the response rate from questionnaires was low and third, limitation of the survey instruments that are distributed with time constraint has been noted in that some respondents struggled to submit within the stipulated time frame because of their busy schedules and questionnaires were not interactive unlike interviews where respondents could ask clarifying questions, respondents were limited to the text in the questionnaires thereby limiting the range of responses.

### **5.4 Recommendations**

The recommendations based on the research findings are as follows:

1. The research revealed that a legal framework is an important prerequisite for promoting the use of rammed earth as a building material. On this basis, the Government aligned ministries and the construction regulatory bodies should formulate policies and guidelines guiding the usage of stabilised rammed earth as a building material.
2. The research revealed that un-stabilised rammed earth cubes fired at 1000 degrees Celsius for four hours gained more than twice the strength compared to the stabilised samples. Higher learning institutions offering building construction should research further in the use of sustainable clean energy for baking un-stabilised adobe earth blocks for construction.
3. The research revealed that there is lack of construction standards governing the usage of rammed earth in Zambia. The Government, construction industry and institutions of higher learning offering building construction should develop rammed earth building standards and incorporate them in the building regulations.
4. The research revealed that lack of knowledge on rammed earth has affected the widespread use of rammed earth as a building material. Modules on rammed earth

construction should be introduced in universities and tertiary education institutions offering building construction.

5. Institution such as National Council for Construction, and National Housing Authority should carry out sensitizations on the use and benefits of rammed earth as an alternative building material.

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## APPENDICES

### Appendix 1 – Ethical Clearance



## THE UNIVERSITY OF ZAMBIA DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777  
Fax: (+260)-211-290 258/253 952 | E-mail: [director.drgs@unza.zm](mailto:director.drgs@unza.zm) | Website: [www.unza.zm](http://www.unza.zm)

### APPROVAL OF STUDY

***IORG No. 0005376***  
***NASRECREC IRB No. 00006465***

31<sup>st</sup> March, 2023

**REF NO. NASREC-2023- MAR – 015**

Mr. Raphael Simbeye,  
The University of Zambia,  
School of Engineering,  
P.O. Box 32379,  
**LUSAKA.**

Dear, Mr Simbeye,

**RE: “AN INVESTIGATION OF PERCEPTIONS ON THE SUITABILITY OF  
RAMMED EARTH IN THE CONSTRUCTION OF AFFORDABLE HOUSING UNITS  
IN ZAMBIA”**

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	ORDINARY REVIEW	APPROVAL NO.
Approval and Expiry Date	Approval Date:	NASREC-2023 MAR - 015
		Expiry Date:

	31 <sup>st</sup> March, 2023	30 <sup>th</sup> March, 2024
Protocol Version and Date	Version - Nil.	30 <sup>th</sup> March, 2024
Information Sheet, Consent Forms and Dates	<ul style="list-style-type: none"> <li>English.</li> </ul>	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

### **CONDITIONS OF APPROVAL**

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled “late submissions” and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO), both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have

any direct or indirect contact with the research participants or animals for the study.

- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.
- A reprint of this letter shall be done at a fee.
- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,



*Dr. Mususu Kaonda*

**VICE-CHAIRPERSON  
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH  
ETHICS COMMITTEE - IRB**

CC: Director, Directorate of Research and Graduate Studies  
Assistant Director (Research), Directorate of Research and Graduate Studies  
Assistant Registrar (Research), Directorate of Research and Graduate Studies

## Appendix 2 –Questionnaire



### THE UNIVERSITY OF ZAMBIA

School of Engineering

Department of Civil and Environmental Engineering

P.O Box 32379, Lusaka.

CELL: +260977675427, Email: [simbeyeraphael@yahoo.com](mailto:simbeyeraphael@yahoo.com)

26<sup>th</sup> May, 2017

Dear Sir or Madam,

### **QUESTIONNAIRE SURVEY ON INFLUENCE OF STABILISED RAMMED EARTH CONSTRUCTION ON SUSTAINABLE HOUSING IN ZAMBIA**

I am currently undertaking a Master of Engineering degree in Construction Management at the University of Zambia. My topic of research is “*An Investigation of Perceptions on the Suitability of Rammed Earth in the Construction of Affordable Housing Units in Zambia.*” This study undertakes to disseminate knowledge on stabilised rammed earth and to examine its potential in the provision of affordable urban housing in Zambia.

Attached is a questionnaire, and based on your experience in using earth as a construction material., kindly take part in this survey by completing it. Please answer all questions where possible. All the information gathered will be treated as confidential and will be used only for the purpose of this research.

Should there be queries, please get in touch with the undersigned using the address provided.

Thank you in advance for your time and assistance.

**Yours Faithfully,**

**Simbeye Raphael** (*Master of Engineering Student at the University of Zambia*)

---

### **SECTION A: GENERAL INFORMATION ON RESPONDENTS' BACKGROUND**

1. Kindly indicate your professional background by ticking below?

Architecture	Quantity Surveyor	Construction Manager	Engineer	Land Economy	Business Managers	Others (specify)

Any other

.....

2. What is your position in your firm/ organisation?

Project Architect	Principal Engineer	Quantity Surveyor	Site Engineer	Site Foreman	Skilled worker	Others (specify)
----------------------	-----------------------	----------------------	------------------	-----------------	-------------------	---------------------

3. To which profession body are you affiliated with?

Firm	ZIA	EIZ	SIZ	PAZ
Architectural				
Engineering(Civil, Structural., Mechanical., Electrical etc)				
Cost Estimator( Quantity Surveying)				
Building Works				
Road works				
Planner				

4. If you are a contractor, kindly tick below in the table the category of your company registration with National Council for Construction?

National Construction Council (NCC)						
Firm	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Tick						

5. Experience in the Construction sector?

	1 to 5 years	5 to 10 years	10 to 15 years	Above 15 years
Tick				

## SECTION B: RAMMED EARTH CONSTRUCTION

*Note: Rammed earth is a construction technique where a well selected and graded mixture of wet soil is compacted between formwork to form a monolithic building structure. Various stabilisers and binders can be added to the mixture in order to vary the characteristics of the mixture to achieve a desired structural effect.*

1. Have you used any of these materials in construction?

Rammed earth( Pise' de terre),	Yes	No √
Wattle		
Adobe (clay) sun dried bricks		
Adobe (clay) burnt bricks		
Adobe (clay) compressed blocks		
Sand bag		

Would you recommend any of the above to your clients? (Yes) √ / (No).

Please explain .....Readily available, cheap and found almost in all places

2. What type of materials would you recommend for the following structural members in a rammed earth wall construction? Please tick (√)

	Foundation	Walls	Opening( door/window)	Roof	Floor
Rammed earth					
Adobe sun dried					
Burnt adobe bricks					
Wattle					
Concrete block/ brick					
Stones					
Metal sheets					
Sand bag					

Concrete					
Timber					

Any other please explain

.....

3. How often have you specified or recommended rammed earth to your clients? Kindly tick in the table below using the five point Likert scale where; 1 = very often, 2 = often, 3 = slightly, 4 = rare and 5 = rarely)

	Very often	often	Slightly	Rare	Rarely
Rammed earth					
Adobe (clay) bricks					
Wattle					
Burnt clay bricks					
Sand bag					
tick(√)					

4. On the five point Likert scale where; 1= very important, 2= slightly important, 3= important, 4= less important and 5= not important, kindly tick in the table below on the importance of mixing ratios on the strength of rammed earth walls?

	1	2	3	4	5
Rammed earth strength	Very important	Slightly Important	important	Less important	Not important
tick(√)					

Any other please explain

.....

5. What proportion of the following materials in rammed earth wall construction would you specify in a construction project compared to conventional concrete construction?

	>50%	30-50%	20-30%	10-20%	<10%

Water					
Clay					
Cement					
< 20mm lime stone aggregates					
Lime					
Sand					
Gravel					

6. What rammed wall thickness would you specify as a consultant to your client?

	100mm	150mm	200mm	250mm	>250mm
Tick					

Any other please explain

.....

7. In your opinion as a consultant or contractor which of the following would you recommend to be on site during construction of a rammed earth wall?

	1	2	3	4	5
Architect/Engineer/Quantity Surveyor					
Bricklayers					
Carpenters					
Steel fixers					
Unskilled labourers					

Any other please explain

.....

8. On the five point Likert scale where; 1 = very high 2= high, 3 = average, 4= poor and 5= very poor, kindly rate the use of the following tools on a rammed earth construction site?

	1	2	3	4	5
Mechanical/ handy rammers					

Wood trowel					
Steel trowel					
Shovel					
Formwork (wooden or steel)					

Any other, please explain:

.....

**SECTION C: ADVANTAGES AND DISADVANTAGES OF EARTHERN STRUCTURES**

- Using a scale of 1 to 5, where 1 means very poor and 5 very good how would you rate the characteristics of rammed earth in housing constructions.

	1	2	3	4	5
Thermal					
Fire resistance					
Sound					
Durability					
Micro climate					
Economically					
Availability					
Sustainability					
Structural strength					

Any other please explain

.....

- Using a five point Likert scale where; 1 = very poor, 2 = poor, 3= average, 4= good and 5 = very good how would you rate the following in terms of rammed earth housing construction.

	1	2	3	4	5
Labour intensive					
Construction knowledge by					

professionals and developers					
Resistance to weather elements					
Housing for the poor					
Maintenance costs					
Water resistance					
Sustainability					
Lack of legislation					
Structural strength					

Any other please  
 explain.....

3. Using a five point Likert scale where; 1 = very poor, 2 = poor, 3 = average, 4= good and 5= very good which stabilisers would you recommend to improve the down side qualities of rammed earth?

	1	2	3	4	5
Cement					√
Lime					
Gypsum					
Molasses					
Bitumen					
Saw dust					

Any other  
 .....

**SECTION D: COST AND FINANCIAL PROVIDERS**

4. Using a five point Likert scale where; 1 = very cheap, 2= cheap, 3= average, 4= expensive, and 5 = very expensive how would you compare the cost of a house constructed using rammed earth to the following construction methods?

	1	2	3	4	5
Adobe sun dried bricks					
Adobe bunt bricks					
Concrete Blocks					
Concrete					
Timber structure					
Sand bag					
Wattle					
Steel					

Any other, please explain:

.....

5. On the five point Likert scale where; 1 = very supportive, supportive, 3 = average supportive, 4 = less supportive, and 5 not supportive, which institutions would be supportive to fund the construction of rammed earth structures?

	1	2	3	4	5
Mortgage Providers					
Insurance providers					
Private developers					
Public developers					

Any other, please explain:

.....

6. Using a five point Likert scale where; 1 means very easy 2= easy, 3= rarely, 4= difficult, and 5 very difficult, how would you compare the rate of re-selling of rammed earth structures (residential and commercial) from conventional (Concrete and steel) construction methods?

	1	2	3	4	5
Tick					

Any other information

- a. ....  
.....
- b. ....  
.....
- c. ....  
.....
- d. ....  
.....

Thank you very much

### Appendix 3 - Laboratory Experiments

Soil identification

Sample	Gravel	Sand	Silt/ Clay
A	35	12	53
B	4	16	80
C	1	12	87
D	1	21	78

Sample No. A

#### Water Content

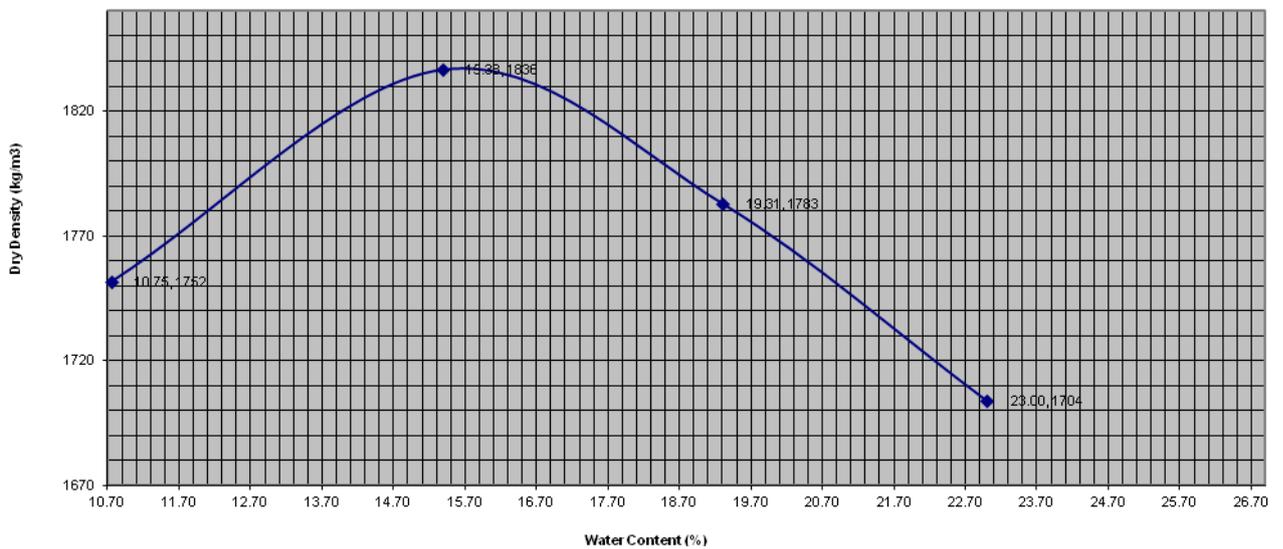
#### Determinations

Sample No.	1	2	3	4	5
Moisture can No.	28F	82	57	110	90
Wt of can+wet soil	30.40	30.60	30.80	31.00	31.20
Wt of can+dry soil	28.10	27.40	26.90	26.40	26.00
Wt. of water	2.30	3.20	3.90	4.60	5.20
Wt. of Can	6.70	6.60	6.70	6.40	6.60
Wt. of Soil	21.40	20.80	20.20	20.00	19.40
Water Content, w (%)	10.75	15.38	19.31	23.00	26.80

## Density Determination

<b>Assumed water content (%)</b>					
<b>Water Content, w (%)</b>	10.75	15.38	19.31	23.00	26.80
<b>Wt. of soil+mould</b>	6561	6740	6748	6717	6684
<b>Wt. of mould</b>	4621	4621	4621	4621	4621
<b>Wt of soil in mould</b>	1940	2119	2127	2096	2063
<b>Wet density (kg/m<sup>3</sup>)</b>	1940	2119	2127	2096	2063
<b>Dry density (kg/m<sup>3</sup>)</b>	1752	1836	1783	1704	1627

**MDD 1836 kg/m<sup>3</sup>**  
**OMC 15.38 %**



**Relationship between moisture content, time and stabiliser.**

		Days after casting			
		7	14	28	56
Specimen	Treatment	Weight in g	Weight in g	Weight in g	Weight in g
A1	0%	7301.6	6102	5992	5924
A2	3%	7199.7	6128	6102	6146
A3	6%	7168.4	6538	6128	6128
A4	10%	7035.6	6876	6776	6302

Compression strength results at 7, 14, 28 and 56 days

ID	Days	Average Compression Strength (MPa)			
		7	14	28	56
A <sub>1</sub>	0%	0.35	1.22	1.2	1.22
A <sub>2</sub>	3%	1	1.57	2.2	2.9
A <sub>3</sub>	6%	1.2	1.65	2.96	3.1
A <sub>4</sub>	10%	1.3	2.96	3.12	3.7

Moisture absorption by immersion results

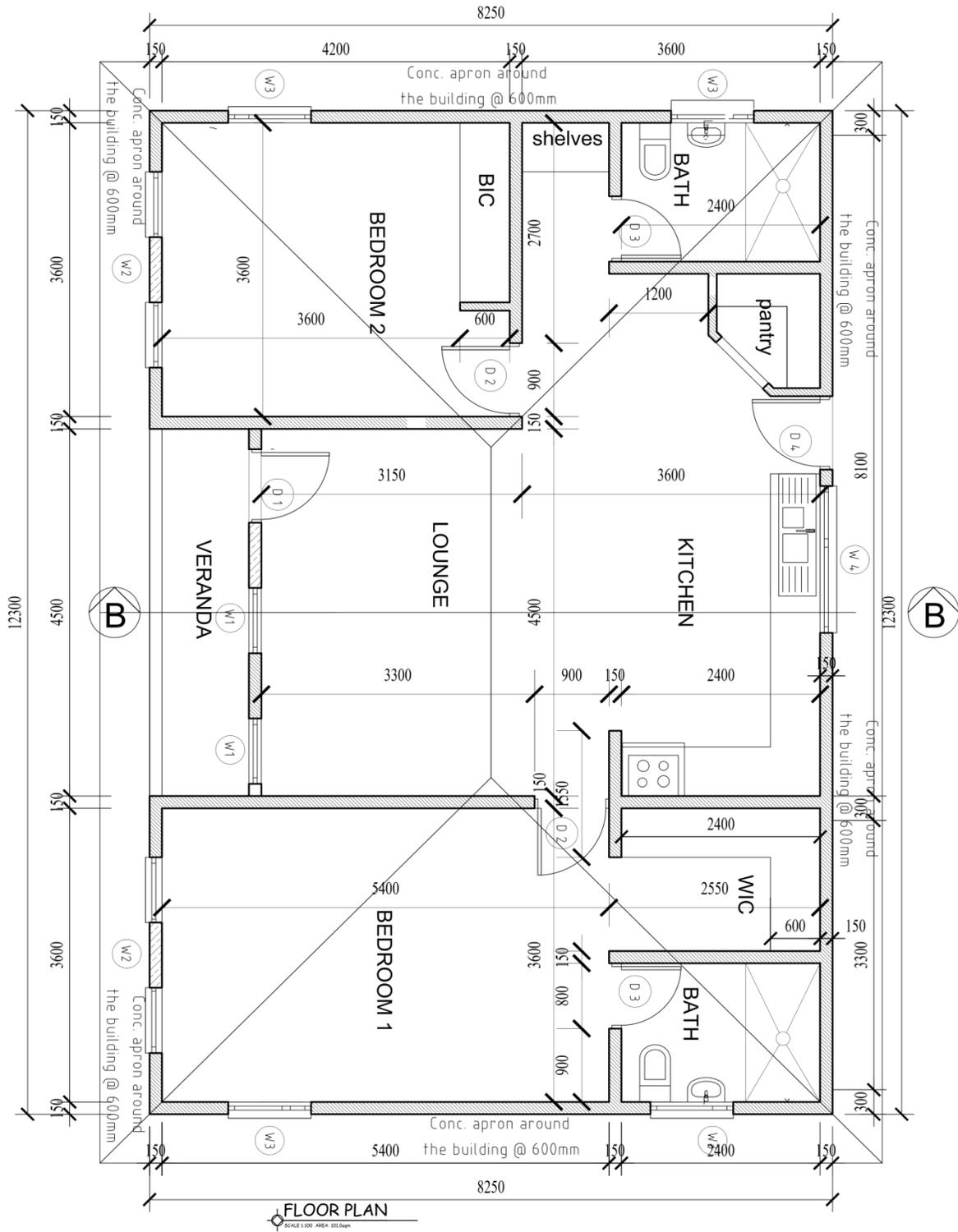
<i>Sample weight before and after immersion in water</i>					
Specimen	Treatment	Before	After	Variance	Moisture absorption (%)
A <sub>1</sub>	0%	5992	-	-	-
A <sub>2</sub>	3%	6102	7127	1025	16.8
A <sub>3</sub>	6%	6128	6983	855	14
A <sub>4</sub>	10%	6776	7444	668	9.8

Rate of Drying

		Days after manufacture				Variation
		<i>7</i>	<i>14</i>	<i>28</i>	<i>56</i>	
<b>Specimen</b>	<b>Treatment</b>	<b>Weight in g</b>	<b>Weight in g</b>	<b>Weight in g</b>	<b>Weight in g</b>	
<b>A<sub>1</sub></b>	0%	7301.6	6102	5992	5924	1,377.6
<b>A<sub>2</sub></b>	3%	7199.7	6128	6102	6146	1,053.7
<b>A<sub>3</sub></b>	6%	7168.4	6538	6298	6128	870.4
<b>A<sub>4</sub></b>	10%	7035.6	6776	6776	6302	733.6

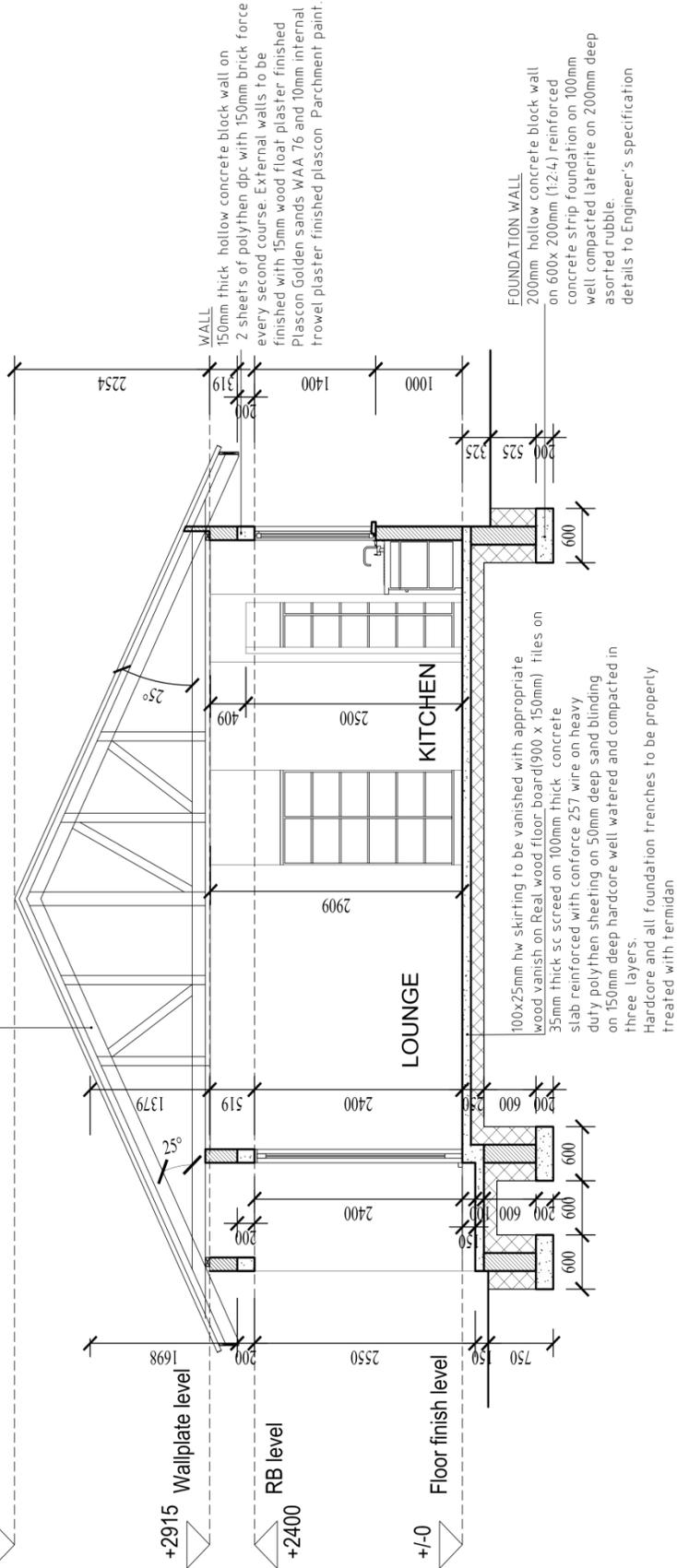
# Appendix 4 – Comparison of Concrete and Rammed Earth Construction Cost

## A. Concrete block construction



R/WUF  
Pitch 25°  
IBR coated roofing sheets on 75 x 50mm sw purlins spaced at 1200mm c/c on 50 x 150mm S/w timber rafters spaced at 1200mm to rest on 100 x 50mm sw wall plate securely strapped to the wall with 10 gauge wire 3 course below.  
All timber to be treated with creosote.

+5195 Roof apex



WALL  
150mm thick hollow concrete block wall on 2 sheets of polythen dpc with 150mm brick force every second course. External walls to be finished with 15mm wood float plaster finished Plascon Golden sands WAA 76 and 10mm internal trowel plaster finished plascon Parchment paint.

FOUNDATION WALL  
200mm hollow concrete block wall on 600x 200mm (12.4) reinforced concrete strip foundation on 100mm well compacted laterite on 200mm deep assorted rubble.  
details to Engineer's specification

100x25mm hw skirting to be varnished with appropriate wood varnish on Real wood floor board(900 x 150mm) tiles on 35mm thick sc screed on 100mm thick concrete slab reinforced with conforce 257 wire on heavy duty polythen sheeting on 50mm deep sand blinding on 150mm deep hardcore well watered and compacted in three layers.  
Hardcore and all foundation trenches to be properly treated with fermidan

SECTION B - B

Material Schedule

	SUMMARY	TOTAL (ZMW)
1	Substructure	49,842.00
2	Concrete works (Ring beam, Lintels, Slab)	25,000.00
3	Block work in Superstructure	36,700.00
4	Wall finish	15,030.00
	Sub-total	<b>126,572.00</b>
	TOTAL MATERIAL COST	126,572.00
	Add FOR	
5	Labour & Equipment 20% of total cost	25,314.40
6	Transport costs @ 10% of total cost	12,657.20
	TOTAL ESTIMATE COST	<b>164,543.60</b>

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
	<b>SUBSTRUCTURE</b>					
1	Concrete Blinding (Grade 15) to trenches	2.16	m3			
a	Cement, 50kg/bag	7.57	bag	135.00	1,080.00	
b	River sand	1.01	ton	160.00	320.00	
c	Stone	3.90	ton	160.00	640.00	2,040.00
2	Strip Foundations Concrete (Grade 25).	8.66	m3			
a	Cement, 50kg/bag	61.20	bag	135.00	8,370.00	
b	River sand	7.55	ton	160.00	1,280.00	
c	Stones	15.74	ton	160.00	2,560.00	
					-	12,210.00

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
	SUBSTRUCTURE					
3	Laterite	18.27	ton	60.00	1,140.00	1,140.00
4	Slab + Thickening (Grade 25) 100mm	10.15	m3			
a	Cement, 50kg/bag	71.76	bag	135.00	9,720.00	
b	River sand	8.86	ton	160.00	1,440.00	
c	Stone	18.45	ton	160.00	3,040.00	
d	Ant termite/2ltr	2.00	litres	45.00	90.00	
e	Conforce wire 257, 48m x 2.2m/roll	0.96	roll	3,700.00	3,700.00	
f	250 microfin Polythen sheet membrane, 30m*2m/roll	1.69	roll	730.00	1,460.00	
g	Form work timber 5M length, 150 x 50mm	9.00	No.	250.00	2,250.00	
h	4" wire nails	25.00	kg	20.00	500.00	
j	4" steel nails	20.00	boxes	35.00	700.00	
k	50 x 75 timber (5m)	15.00	No.	120.00	1,800.00	
L	Scaffolds (from substructure & superstructure)	1	item	12,000.00	12,000.00	36,700.00

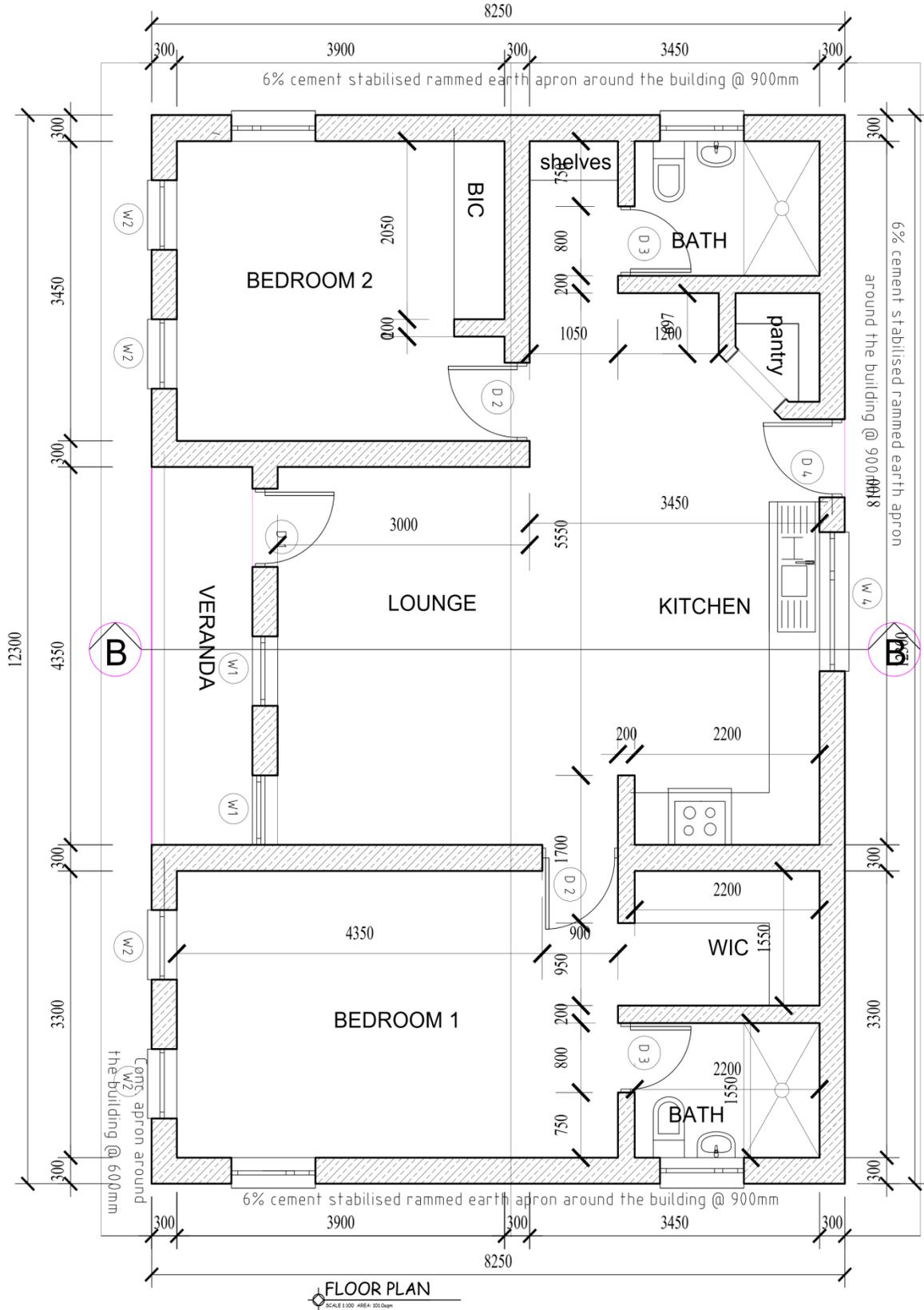
ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
	SUBSTRUCTURE					
5	Block work in foundation 200 mm	43.28	m2			
a	Cement, 50kg/bag	13.52	bag	135.00	1,890.00	
b	Building sand	1.95	tonne	160.00	320.00	
c	8" Hollow block	540.98	No.	7.00	3,787.00	
d	8" Brick force wire, 20m/roll	5.00	roll	17.00	85.00	6,082.00
6	Mortar filling blocks, 1:4 ratio	5.30	m3			
a	Cement, 50kg/bag	4.24	bag	135.00	675.00	
b	Building sand	4.24	ton	160.00	800.00	1,475.00
7	19 mm Plaster to block work in foundation	32.88	m2			
a	Cement, 50kg/bag	8.55	bag	135.00	1,215.00	
b	Building sand	1.66	ton	160.00	320.00	1,535.00
8	Painting to fdn external walls	32.88	m2			
a	Gloss Black bituminous paint - 5 LITRE	2.88	5ltrs	220.00	660.00	660.00
	SUBSTRUCTURE TOTAL					49,842.00

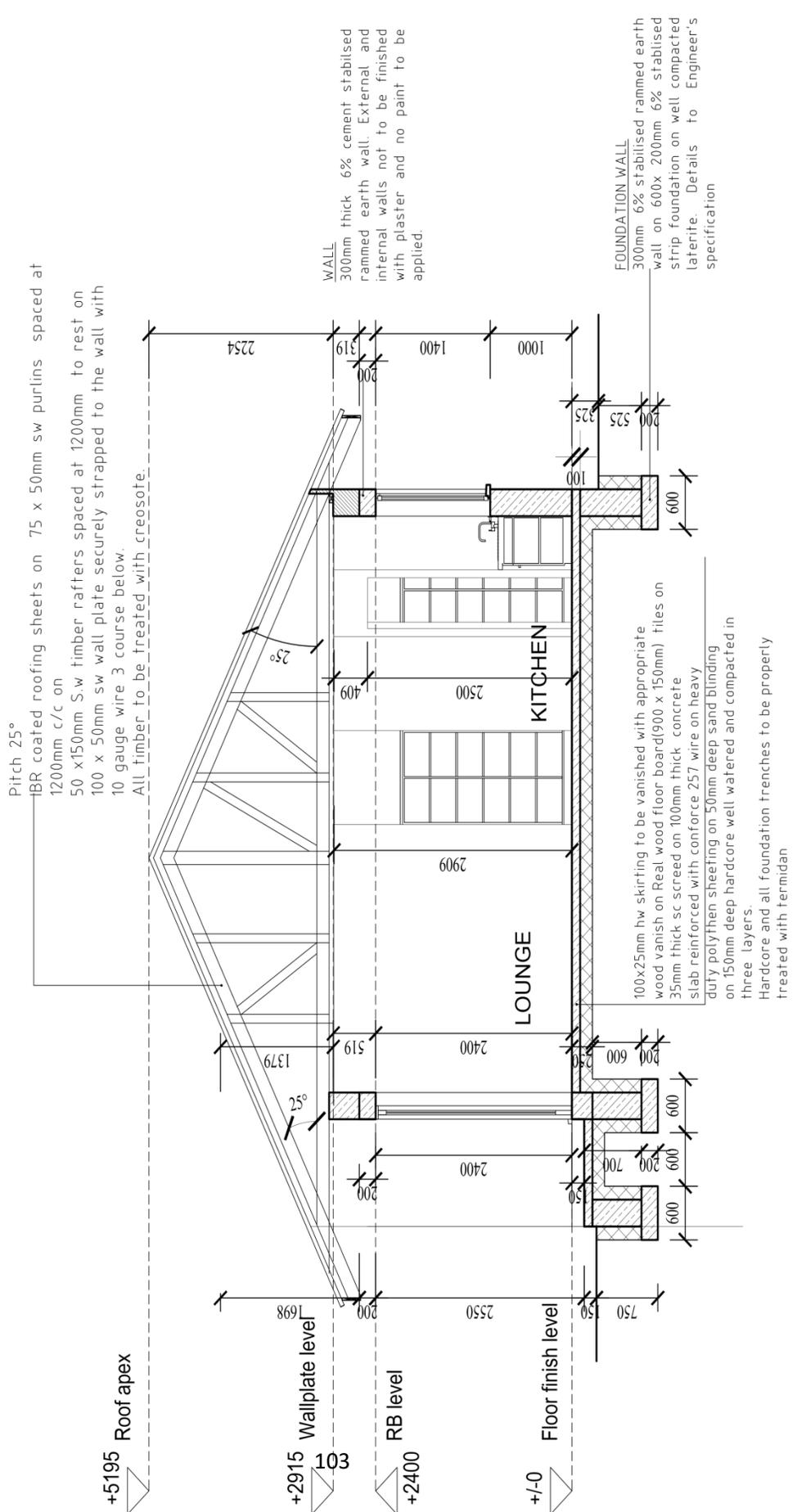
ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
10	<b>BLOCK WORK</b>					
	150 mm thick walls	209.18	m2			
a	Cement, 50kg/bag	25.10	bag	135.00	3,510.00	
b	Building sand	10.54	ton	160.00	1,760.00	
c	6" Hollow block	2,614.71	No.	7.00	18,305.00	
d	8" Damp proof course, 20m/roll	3.61	roll	120.00	480.00	
e	6" Brick force wire, 20m/roll	14.43	roll	25.00	375.00	
						24,430.00
	<b>BLOCKWORK TOTAL</b>					<b>24,430.00</b>

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
17	<b>INTERNALLY</b>					
	19mm cement and sand (1:4) plaster	179.97	m2			
a	Cement, 50kg/bag	46.79	bag	125.00	5,875.00	
b	Building sand	19.44	ton	160.00	3,200.00	9,075.00
18	<b>EXTERNALLY</b>					
	19mm cement and sand (1:4) plaster	119.19	m2			
a	Cement, 50kg/bag	30.99	bag	125.00	3,875.00	
b	Building sand	12.87	ton	160.00	2,080.00	5,955.00
	<b>WALL FINISHINGS</b>					<b>15,030.00</b>

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
	<b>PAINTING AND DECORATING (Excluded from summery)</b>					
21	Painting to walls internal Walls	179.97	m2			
a	Undercoat - 20 Litres	1.50	20 litre	1,050.00	2,100.00	
b	PVA acrylic paint - 20 Litres	2.57	20 litre	680.00	2,040.00	
c	Gloss paint to wet areas - 20 Litres	1.33	20 litre	2,050.00	4,100.00	
22	Painting to walls external Walls	119.19	m2			
a	Undercoat - 20 Litre	0.99	20 litre	1,050.00	1,050.00	
b	Weather guard paint external walls -20 Litre	1.70	20 litre	680.00	1,360.00	
25	Painting necessities					
a	Thinners	5.00	5 litre	250.00	1,250.00	
b	Wall crack filler	10.00	Kg	15.00	150.00	
c	Wall sand paper 300x300mm	10.00	No	20.00	200.00	
d	3" Scraper	3.00	No	35.00	105.00	
e	2" Paint brush	3.00	No	25.00	75.00	
f	4" Paint brush	2.00	No	35.00	70.00	
g	Roller brush and tray Gloss	2.00	No	65.00	130.00	
h	Roller brush and tray_PVA	2.00	No	65.00	130.00	
j	Mutton cloth	5.00	kg	11.00	55.00	
	<b>TOTAL FOR PAINTING</b>					<b>12,815.00</b>

## B. Stabilised Rammed Earth House Construction





Pitch 25°  
 FBR coated roofing sheets on 75 x 50mm sw purlins spaced at 1200mm c/c on 50 x 150mm S.w timber rafters spaced at 1200mm to rest on 100 x 50mm sw wall plate securely strapped to the wall with 10 gauge wire 3 course below.  
 All timber to be treated with creosote.

WALL  
 300mm thick 6% cement stabilised rammed earth wall. External and internal walls not to be finished with plaster and no paint to be applied.

FOUNDATION WALL  
 300mm 6% stabilised rammed earth wall on 600x 200mm 6% stabilised strip foundation on well compacted laterite. Details to Engineer's specification

100x25mm hw skirting to be varnished with appropriate wood varnish on Real wood floor board(900 x 150mm) tiles on 35mm thick sc screed on 100mm thick concrete slab reinforced with conforce 257 wire on heavy duty polythen sheering on 50mm deep sand blinding on 150mm deep hardcore well watered and compacted in three layers.  
 Hardcore and all foundation trenches to be properly treated with termidan

SECTION B - B

Material schedule

	SUMMARY	TOTAL
1	Substructure	33,670.00
2	Concrete works in lintols	10,000.00
3	Superstructure	53,965.00
	Sub-total	97,635.00
	<b>TOTAL MATERIAL COST</b>	97,635.00
	Add FOR	
13	Labour & Equipment at 20% of total cost	19,527.00
14	Transport costs at 10% of total cost	9,763.50
	<b>TOTAL ESTIMATE COST</b>	<b>126,925.50</b>

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
	<b>SUBSTRUCTURE</b>					
1	Strip Foundations rammed earth	12.98	m3			
a	Cement, 50kg/bag	29.00	bag	135.00	3,915.00	
b	Building soil	17.27	ton	84.00	1,512.00	
c	50 x 75 timber (5m)	15.00	No	120.00	1,800.00	
d	4" wire nails	10.00	kg	20.00	200.00	7,427.00
e	4" steel nails					
2	Laterite	18.64	ton	60.00	1,140.00	1,140.00
3	Slab					
	100mm thick 6% stabilised rammed earth	10.15	m3			
a	Cement, 50kg/bag	23.00	bag	135.00	3,105.00	
b	Well graded soil	4.23	ton	84.00	2,100.00	
d	Ant termite/2ltr	2.00	litres	45.00	90.00	
e	Conforce wire 257, 48m x 2.2m/roll	0.96	roll	3,700.00	3,700.00	
f	250 microfin Polythen sheet membrane, 30m*2m/roll	1.69	roll	730.00	1,460.00	
						10,455.00
4	Walls in Foundations rammed earth	12.98	m3			
a	Cement, 50kg/bag	29	bag	135.00	3,915.00	
b	Building soil	31.03	ton	84.00	2,688.00	
c	50 x 75 timber (5m)	50.00	No	120.00	6,000.00	
d	4" wire nails	20.00	kg	20.00	400.00	
e	4" steel nails	20.00	boxes	35.00	700.00	
						13,703.00
	<b>SUBSTRUCTURE TOTAL</b>					<b>32,725.00</b>

ITEM	DESCRIPTION	QTY	UNIT	PRICE	AMOUNT	TOTAL
5	Stabilised rammed earth wall 300 mm	62.75	m3			
a	Cement, 50kg/bag	139.00	bag	135.00	18,765.00	
b	Building Soil	149.78	ton	84.00	12,600.00	
c	Form work boards 12mm thick, 1220*2440 and scaffolds (from substructure & superstructure)	1.00	No	20,000.00	20,000.00	
d	50 x 75 timber (5m)	20.00	No	120.00	2,400.00	
e	4" wire nails	10.00	kg	20.00	200.00	
	Superstructure total					<b>53,965.00</b>