Metropolia University of Applied Sciences

Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

# Utilization of hydraform brick as alternative construction material for sustainable project delivery in the tropic

Master Thesis

International Master of Science in construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin.

from

Valentine Ejidike

Date:

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**Conceptual Formulation**

**Master Thesis for Mr Valentine Ejidike**

**Metropolia Student number: 2007402**

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**Topic: UTILIZATION OF HYDRAFORM BRICK AS AN ALTERNATIVE CONSTRUCTION MATERIAL FOR SUSTAINABLE PROJECT DELIVERY IN THE TROPIC**

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## INTRODUCTION

The need for shelter has progressed, leading to the construction of buildings that enable man's significant activities. Building construction has also evolved to serve different functions; however, its function is to achieve the comfort of the users as its primary objective. The construction industry continues to rise as the population is increasing; the world population is expected to reach 9.8 billion in 2050 (UN, 2017)

The industry continues to play an essential role in achieving employment and socio-economic development. Statistics have shown that the construction industry constitutes over half of total national capital investment, which represents about 10% of G.N.P (Gross National Product) in every country (UNEP, 2002)

The increasing cost of constructing a building has become a concern to most governments, especially in developing countries; a possible cause of the increasing cost of building is the procurement of the building materials, which serves as a more significant percentage of the cost of construction. (P.P Yalley, 2013)

Hussein (2011) opines that materials are the easiest way for architects to begin incorporating sustainable design principles in buildings; consideration for materials and resources should

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focus on health and the productivity consequences of such material selections for building occupants, plus the long-term social, economic, and environmental impacts of the materials used in the design and construction of the building. Heavy materials like masonry and concrete are the common building materials in the tropics. However, Stouter (2008) has recommended using lighter construction materials due to the low diurnal temperature range in most parts of the tropics.

The rate at which resources are being depleted is becoming a global concern which calls for a shift in utilising more renewable resources. The energy put into the production and transportation of building materials is a significant determinant of construction cost, making buildings expensive. Today, the exploitation of non-renewable resources is due to the high demand for conventional building materials, which has become a critical environmental issue; with the increasing world population, this concern will become vital. The utilisation of alternative building materials in construction is an excellent way to address this concern effectively.

Alternative building materials (ABMs) are inexpensive materials. They aim to reduce construction's environmental impact by saving energy and minimising emissions using renewable materials, local resources, recycled content, industrial/agricultural by-products/wastes, etc.

The utilisation of alternative building materials (ABMs) has been supported by the United Nations Commission for Human Settlement (UNCH, 1992) since the early 1990s. It was well-thought-out as a means of enhancing the housing stock for low-income earners by utilising affordable and local materials and methods. Some authors criticised this concept owing to some reasons. (Myers, 1999) considered it contradictory because most low-income earners depend on the existing resources meant to be protected.
More so, the structures erected by the ABMs are considered structurally poor in terms of durability due to the lack of technological know-how during the material manufacturing or construction process (Wells, 1993).

However, the need for alternative building materials has continued to rise with the demand for housing in most countries. It is gaining more favour as research addresses the problems that previous authors highlighted.

## RESEARCH AIM

This research aim is to explore the utilisation of hydraform brick as an alternative construction material for a sustainable and affordable housing in the tropics as concrete is predominantly used as construction material and is expensive with a high embodied energy.

## RESEARCH QUESTIONS

The following questions are to be addressed:

- What challenges the construction industry in utilising Hydraform brick as an alternative construction material?
- What factors can influence the acceptability indices of hydraform brick as an alternative material?
- What risk is involved in using hydraform brick as an alternative construction material?

## RESEARCH METHODOLOGY

In conducting this research, I will adopt pragmatism (an approach that evaluates theories or beliefs in terms of the success of their practical application) to assess the truth and adequately confirm the research questions.

I will use Internet-based research to get information from published academic reports, conference proceedings, journal articles, etc.

A well-structured questionnaire will be administered to critical professionals in different construction companies while also developing correspondence.

The Parameters received will be analysed subsequently and compared to the information in the literature review.

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**Abstract**

This study focuses on using hydraform brick as an alternative construction material for sustainable project delivery in the tropics, with Nigeria, as the study area. Hydraform bricks are cement-stabilised soil blocks that allow for dry stacked interlocked construction.

The study examined what sustainable development entails and the life cycle of building materials; it also evaluated the sustainable development principles that guide a project's achievement through the economic, social, and environmental perspectives.

A case study and interview were conducted to gather relevant information; it was revealed that the hydraform bricks significantly benefited its users and the environment as it uses primarily natural raw materials that are readily available in large quantities.

**Keywords:** Hydraform brick, alternative building material, construction

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# 1.0 Introduction

## 1.1 General Introduction

The circumstances preceding this research are highlighted in this chapter. It starts with a summary of the intended research's background, a problem statement, and a justification for the research. The study's aim and objectives and a brief explanation of the methodology used are further explained. The research is concluded with its structure and content.

## 1.2 Background to the Research

The building construction sector is the highest consumer of raw materials (Jakob, 2021). Materials are essential in constructing a building; they must be sustainable in serving their purpose now and for the future generation (CIB, 2011). The increasing population has brought about high demands for housing; the household number has been predicted to increase over the next 25 years by 300 million (Giddings, 2007). With this realisation, seeking alternative construction materials that are cost-efficient, sustainable, not harmful to health, and lower the environment's carbon footprint while serving the population is imperative.

Over the last 30–40 years, there has been a development of a substantial, sustainable housing movement; the establishment of such initiative and experimenting with new practices has, however, not been broadly dispersed, and the stakeholders who are responsible for the provision of housing lack the knowledge to adapt the lessons from the green builders (Seyfang, 2009; Abisuga & Oyekanmi, 2014). It was also found that there is a low perception by professionals and contractors of the sustainability of building materials. Interest in environmentally friendly building materials has emerged from a global trend toward higher environmental awareness and climate change; developing countries' economic growth and expansion drive global housing demand (Marut, Alaezi & Obeka, 2020).

The cost of housing delivery is escalating, making it challenging to accomplish potential housing. Evaluating what signifies decent or satisfactory housing has consequences for the income groups striving for it (Afolayan & Omirin, 2016). The desire to own a house requires a substantial formation of capital linked to a more significant financial inclusion scheme. The challenge is becoming worrisome, this can be connected to the high price index of materials, and the affordability of housing is extremely limited with the level of earned income. (United Nations Habitat, 2011) gave an insight into housing affordability, defined as Housing that is suitable in terms of quality and location but not so expensive that it prevents residents from paying for other essential living expenses or jeopardises their enjoyment of fundamental human rights. To enable homeowners, a primary strategy is the construction of affordable housing units. (Babatunde, 2017) described various housing costs, such as land values, development fees, regulatory requirements, construction costs, materials, and labour costs.

The United Nations Commission has supported the utilisation of alternative building materials (ABMs) for Human Settlement since the 1990s (United Nations Centre for Human Settlement, 1992); it was well thought out as a means of enhancing the housing stock for low-income earners by the alternate use of local materials and methods that are affordable. It is necessary to comprehend what the term "Alternative Building Materials (ABM)" entails; they are materials developed by the modification of conventional materials, indigenous or traditional materials that are particularly appealing for housing, and they should include an essential component of suitable building materials that do not have any hazardous compounds in their construction that can harm the ecosystem, or human health (Almusaed, Asaad & Raad, 2020)

### 1.3 Statement of Research Problem

As the population grows, the rapid rate of urbanisation will increase the pressure on the limited resource; sustainable interventions are to be put in place as the built environment is being formed, rather than fixing it when it has been developed (Usman, Mohd & Hassan, 2012). As housing demand increases, construction materials' rising cost increases. (International Resource Panel, 2019) as cited by (Paul & Dimitri, 2021) documented the use of resources with its impact on the environment, materials used globally since 1970 have tremendously increased from twenty-seven billion tons to ninetytwo billion tons, and fossil fuels rose from nine billion to twenty-four billion tons. The construction industry contributed a high proportion, from nine billion to forty-three billion tons.

Consequentially, greenhouse gas emission is to be controlled through the embodied energy generated by construction materials. Buildings and construction are responsible for about one-quarter of greenhouse gas emissions through the production of cement, fossil and fuel burning such as coal, oil, and gas for construction. In decades to come, an average of 55 to 75 per cent of the African countries, including Asia, will expect more than half of their building stock to be constructed; the current housing policy on a national scale has emphasised the affordability of building inventory. In contrast, little attention has been placed on environmental sustainability (UNH, 2019).

(UNH, 2019) recognises the sustainability and improvement of building materials that are deployed for the design of households and the introduction of eco-friendly management of utilities, thereby supporting a paradigm shift; it is expected that such activities will produce a significant impact on the reduction of carbon emissions from the construction industry and make the housing stock more resilient to climatic change and sustainability.

The consideration has further developed to include greenhouse gas emission and sustainability; these materials' critical advantages over conventional materials are the embodied energy, simplicity in manufacture, availability, and affordability. In response to corporate responsibility, the construction industry has not been responsive. Still, the regulatory system concerning waste management and carbon emissions is pushing companies to advance their practices, and many customers are starting to call for environmentally friendly construction materials (Marut et al., 2020).

Construction materials should possess the qualities of being sustainable such that it meets the requirement of present and future generations; these materials are the constituent of building construction, which results in the growth and utilisation of alternative materials for the construction of buildings that can meet the requirements of lower energy consumption (Usman et al., 2012). Unfortunately, there seems to be insufficient knowledge and understanding among the designers for sustainability and alternative construction materials; the situation is problematic as there is limited information on the different available materials during the concept design phase. The shared knowledge and information available were the use of concrete and concrete blocks, the most common materials in the tropic. This research project explores the full potential of the hydraform bricks (compressed stabilised earth brick) as an alternative material in the construction industry for delivering sustainable housing stock; it will also investigate the affordability and availability of the constituent materials.

### 1.4 Justification of the Research

There is an apparent demand for suitable and long-lasting housing, particularly in developing countries' urban and semi-urban areas; the lower-income section of the community is disproportionately affected by the housing scarcity since it can least afford construction supplies and skilled labour. While land availability is not an issue in any developing country, providing more lasting houses at a cheaper cost while utilising locally accessible materials is needed. The cost of construction materials makes up a significant amount of the total cost of a building; the building components made with techniques imported from the industrialised world are expensive and energy-consuming, while the use of the traditional method is not fully utilised considering the technology. As technology progressed, more opportunities arose, and the construction of houses was made possible using locally accessible building materials, significantly reducing the cost of housing development.

Hydraform bricks, amongst other materials, contain a significant proportion of soil as the most available local material that can easily be made available and affordable. It is an interlocking brick method that allows for a fast-paced construction of aesthetically pleasing and cost-effective structures. The Bricks have a well-rendered finish depending on their mould; it is possible, at the owner's choice, to leave the walls bare, plastered, or painted. This material is produced with a hydraform brick manufacturing machine or other manual compression equipment that can be made on the construction site; skilled labourers can make it on the site or the location where it will be used, or it can be manufactured for the market, therefore utilising local resources to assist in the development of technologies that are energy-efficient, and environmentally friendly. It helps save time and transportation costs since it can be made wherever needed.

It is crucial for the direct stakeholders, with the support of the government or Non-Governmental Organizations, through the establishment of research grants and industries' participation to promote the awareness of the utilisation of the material. Hydraform brick is becoming increasingly important in tropical regions with other soil-stabilized building materials; their production capabilities and performances still must be investigated in many tropical countries, which necessitates further research and dissemination to the public to address bad housing deficit conditions and affordability issues.

## 1.5 Research Questions

A research question arises when a gap in a particular field of study is identified, and steps are taken to solve it. Consequently, the realisation of this research requires an answer to these questions.

1. What challenges the construction industry in utilising hydraform brick as an alternative construction material?
2. What factors can influence the acceptability indices of hydraform brick as an alternative material?
3. What risk is involved in using hydraform brick as an alternative construction material?

## 1.6 Research Aim and Objectives

In answering the above research questions, this research aims to explore the utilisation of hydraform brick as an alternative construction material for sustainable and affordable project delivery in the tropics as concrete is predominantly used as construction material and is expensive with a high embodied energy.

To achieve the above aim, the objectives are to:

1. Identify the need for a sustainable approach to utilising the hydraform brick.
2. Determine the availability of the constituent materials to produce the hydraform brick.
3. Determine the willingness and acceptance level of using hydraform brick as an alternative to the predominant use of concrete blocks.
4. Determine the cost ratio of hydraform brick to the conventional concrete blocks.

## 1.7 Scope of the Research

The conclusions of this study's research are essential to design and construction stakeholders, and they centre on using hydraform brick as an alternative building material for sustainable project delivery. The scope of the study is limited to the Nigerian context (being a country in a tropical region)

## 1.8 Thesis Structure and Contents

Chapter One: Introduction

In this chapter, the research's introduction is discussed. It has several subtopics, ranging from the study's background to its scope.

Chapter Two: Literature Review

This chapter analyses numerous works peculiar to sustainability and the utilisation of hydraform bricks along with other related literature, journals, publications, etc. It helps clarify the aim of the research expressed in the introductory chapter and gives insight into the research questions.

Chapter Three: Research Methodology

This chapter explains the research methodology used in sourcing answers to the research questions to determine the study's aim.

Chapter Four: Findings and Discussion

This chapter will discuss the case study's research findings.

Chapter Five: Conclusions and Recommendations

This chapter summarises and discusses the conclusions drawn from the methodology, along with supplementary information that may be used to help evaluate the research and future relevant studies.

# 2.0 Literature Review

## 2.1 General Introduction

The research's literary component is crucial for providing the best assessment of its objectives (Blumberg, Cooper & Schindler, 2005). This literature study includes data, information, and other pertinent facts about a research topic that has been identified. This literature was primarily compiled from relevant sources to support the effort done by other researchers in the same field or study area. According to (Fellows & Liu, 2003), the literature body should be scrutinised rather than found and quoted without carefully comprehending what it contains. Every type of data, approach, result, discussion, and theory related to a particular work must be demonstrated in the literature. (Gill & Phil, 2002) drew attention to the benefits of having well-researched literature as:

- Being aware of the relevant field provides a precise comprehension of the research topics.
- It demonstrates how the notions that the research has incorporated into the research effort have been theoretically evaluated.
- Creating a connection between research conducted by other researchers closes a narrow gap while addressing the issue the research is trying to answer.
- It offers understanding and a thorough description of the subject.
- It picks on where the previous researcher left off by meticulously assessing potential solutions, proving the need for the research to be conducted in the first place.

Either primary or secondary sources can be used to find literature. Every source differs in how it conveys the knowledge the researcher has gleaned. A primary literature source can be obtained through empirical investigations or theoretically based publications that present original work. Information compiled from printed or digital secondary sources is also included. The five research methods to follow, according to (Neuman, 2006), are:

- Having a thorough grasp of the topics to research.
- Sharing designs about the search.
- Having access to reports.

- Supporting relevant research papers about the search.
- Noting essential documentation.

## 2.2 Study context: Nigerian Construction Industry

### 2.2.1 Geographical location and size


*Figure 1: Map showing the geographical location of Nigeria[1]*

Nigeria is among the tropical regions west of Sub-Saharan Africa, between latitudes $4^0$ and $14^0$ to the North and longitude $3^0$ and $14^0$ East of Greenwich meantime. Nigeria shares borders in the East with Chad and Cameroon, the West with The Republic of

[1] Source: https://www.mapsofworld.com/nigeria/

Benin, the North with Niger, and the Atlantic Ocean (Gulf of Guinea) to the south, as shown in Fig1. She is officially called the Federal Republic of Nigeria after its independence in 1960. The total area of Nigeria is about 923,768 sq. km, with a population of over 206 million (Internet World Stats, 2020)

Nigeria's capital moved from Lagos to Abuja, the Federal Capital Territory, in 1991; the country currently has 36 states and the Federal Capital Territory, with over 274 ethnic groups divided into three major regions and grouped under six geopolitical zones with 774 Local Government Areas. (Ahiakwo, 2014)

### 2.2.2 Climate and topography

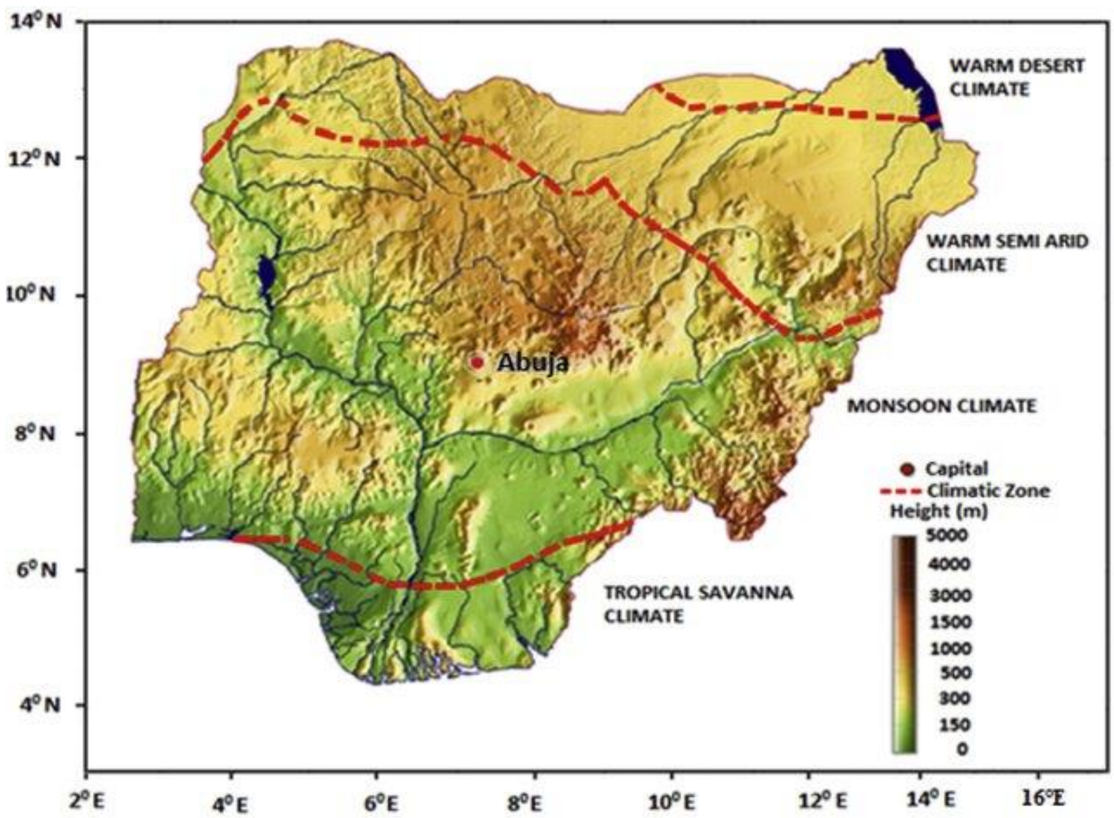


*Figure 2: The topography and climatic zones of Nigeria.*[2]

[2] Source: (Mohammed, 2019)

The climate of Nigeria has been evolving, evident in the temperature rise, irregular rainfall, increase in flooding, and sea level (Ikpe, Sawa & Ejeh, 2017). The climate has four zones: the warm weather, the monsoon climate, the semi-arid climate, and the tropical savanna climate, as shown in Fig 2; the climate is divided into two seasons: from April to October is the rainy season, and from November to March is the dry season. The median rainfall per annum in the country differs from >200mm to >500mm, and the maximum daily temperature ranges from $30^0$C to $37^0$C. The topography of Nigeria is relatively flat in the south, and the north has some elevated areas and mountains; Chappal Waddi has the highest elevation in the northeast at 2419m, while the Atlantic Ocean in the south has the lowest elevation at 0m (Mohammed, Eun-sung, Shamsuddin & Noraliani, 2019).

### 2.2.3 Natural resources

Nigeria is known as the giant of Africa and one of the wealthiest countries in Africa; it is richly blessed with natural resources such as crude oil, iron ore, gas, cocoa, tin, columbite, timber, tantalite, gold, wolfram, lead-zinc, limestone, kaolin, clay, shale, marble, coal, petroleum, natural gas (Jackson, Better & Odubo, 2016). It is proven that the country has an oil reserve of about 35 billion barrels which is the $10^{th}$ oil reserve globally (Oluwakiyesi, 2011). Arable land and coast are abundant in the country.

### 2.2.4 Population and urbanisation growth

According to the world bank, in 2015, about 21% of the tropic's population stayed in low-income nations; the major challenge is managing the cities' fast urbanisation rate. With its economy growing at 20% of the world, there is a high urbanisation and infrastructure boom; many people are attracted to work because of job opportunities (Kuah, 2018). Nigeria is the most populous country in Africa, with the highest population and urbanisation growth rates globally, with an annual growth rate of 5.8% and a national growth rate of 2.8% (Jiboye, 2011).

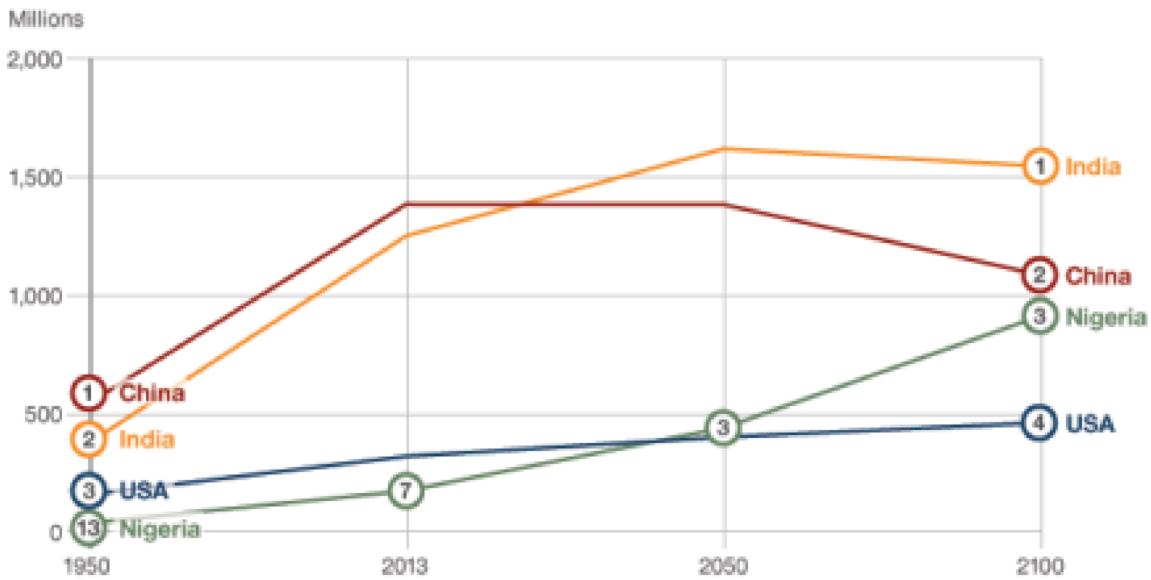


*Figure 3: Global population ranking of Nigeria*[3]

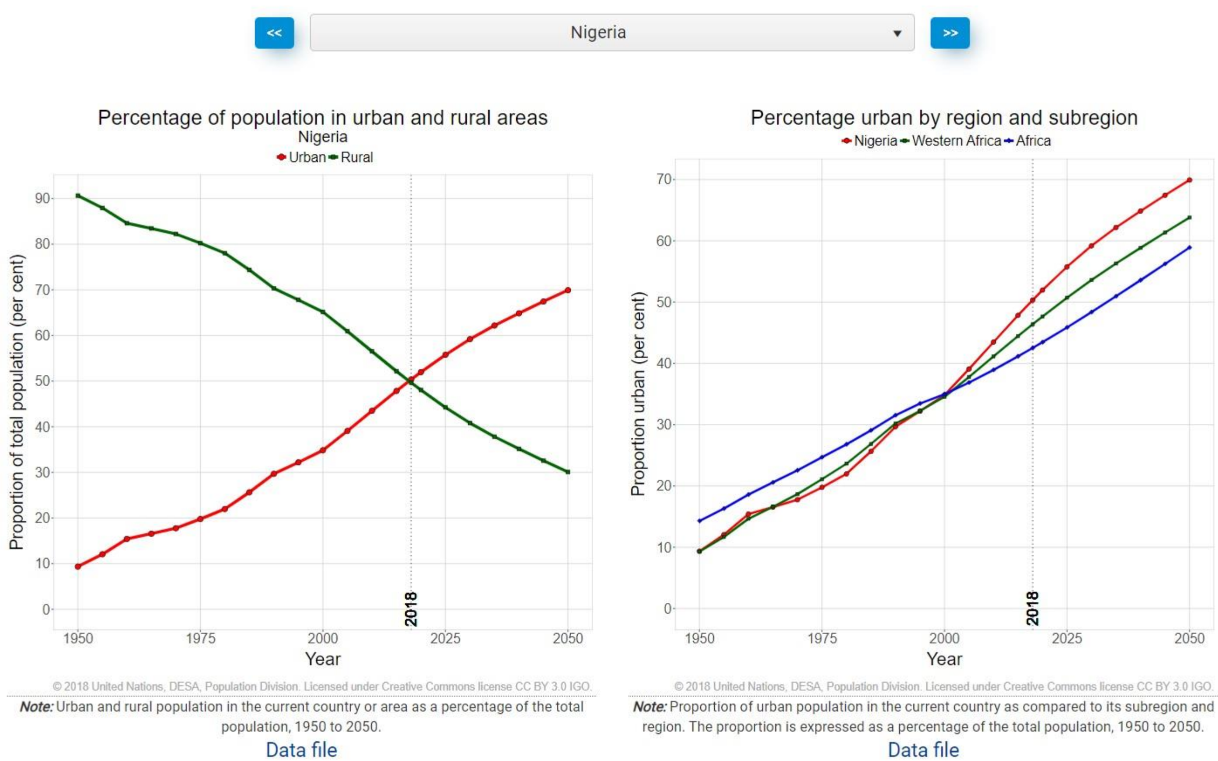


*Figure 4: Percentage Population in Nigeria in 2018*[4]

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[3] Source: https://opinion.premiumtimesng.com/2018/04/10/nigerias-population-predicament-by-chris-ngwodo/
[4] Source: https://population.un.org/wup/Country-Profiles/

According to a published report in 2014 by World Bank, 15% of the population in Africa is represented by Nigeria. Nigeria's population grew from 158.42 million in 2010 to 162.47 million in 2011 and 178.52 million in 2014, as shown in Fig 3, and in 2050, it is expected to double (United Nations, 2012). Nigeria is experiencing rapid growth in urbanisation; it was estimated that by the year 2018, 50% of the population would be living in the urban centres, as shown in Fig 4 (United Nations, 2018). Urbanisation has promoted the economy in areas of production and distribution system, which has aided economic development in states like Abuja, Lagos, and Rivers in Nigeria. (Oluwakiyesi, 2011)

### 2.2.5 Housing demand in Nigeria

In ancient times, housing was never built to last; it was made to solve urgent demand for shelter, which was usually short-term and provided maximum dwellings in a short time as migration was rampant. As settlement began to occur and the population began to increase, the need for appropriate and durable shelter was considered. Many developing countries are experiencing rapid urbanisation and economic growth in the tropics. In the forthcoming decades, many regions have been envisaged encountering the urgent need for new housing. In a recent report by the United Nations (UN), by 2030, there will be a housing deficit across the world because of the addition of three billion people, which translates to about 100,000 houses required per day to be built to meet the pressing demand by 2020 (Hung, 2016). Providing housing for this population is a critical concern.

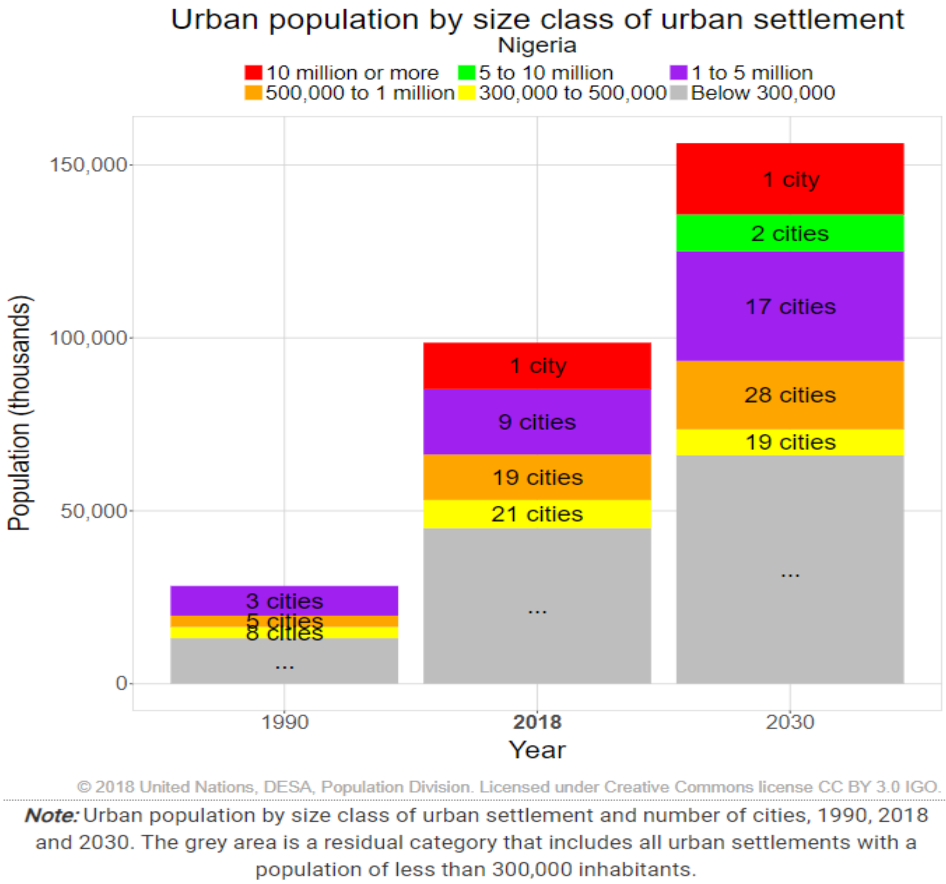


*Figure 5: Urbanization Population and Forecast by Nigerian Cities*[5]

It is predicted that a city, most probably Lagos state, will double its population, as shown in Fig 5, which depicts the forecast of the growth of urbanisation and population in Nigerian cities; it is expected that with the current pace of development in the cities, the housing demand will rise to 800,00 units annually. The formation of urban centres and cities is linked to the need for housing, thereby influencing the city's economy through job creation, businesses, and income generation. Nigeria's housing industry is plagued with underdevelopment and an unstructured institutional quality product; investors have shown interest in states like Port-Harcourt, Lagos, and Abuja that have positive economic growth in the urban market (Dashol, Willy & Florence, 2017). According to (Oxford Business Group, 2011), rapid rural to urban migration, population growth, middle-class

[5] Source: https://population.un.org/wup/Country-Profiles/

expansion, and an expansive macroeconomic will result in a housing deficit estimated to be about 17 million housing units, which affects the demand for housing in Nigeria.

### 2.2.6 The construction industry in Nigeria

The construction industry is a significant asset in generating wealth and improving a nation's life and socio-economic infrastructure, which links to other sectors to provide a multiplier effect on the economic spectrum. (Oladiran, Ogunsemi & Aje, 2012) opines that the construction industry in Nigeria is essential for other industries because of its dependence on the product. (Ahiakwo, 2014; Oluwakiyesi, 2011) believes that the small-scale and medium scaled contractors control the industry. (Oluwakiyesi, 2011) further noted that a robust construction industry indicates a solid national investment that is a foundation and the right step to economic development. According to (International Trade Administration 2021; Muringo 2021), the construction industry in Nigeria is estimated to increase by 3.2% annually between 2021 and 2025; In 2020, the construction industry struggled with a decline of 7.7% due to the COVID-19 pandemic and the lockdown measures in the country. The National Bureau of Statistics (NBS), as cited in (Business Wire, 2021), reported that the construction industry in the year-on-year (YoY) of the second quarter of 2020 contracted by about 31.8% and recovered in the third quarter of 2020 with a growth of 2.8% and expects the industry to grow to 4% in 2021 which will be a sharp improvement in the level of output.

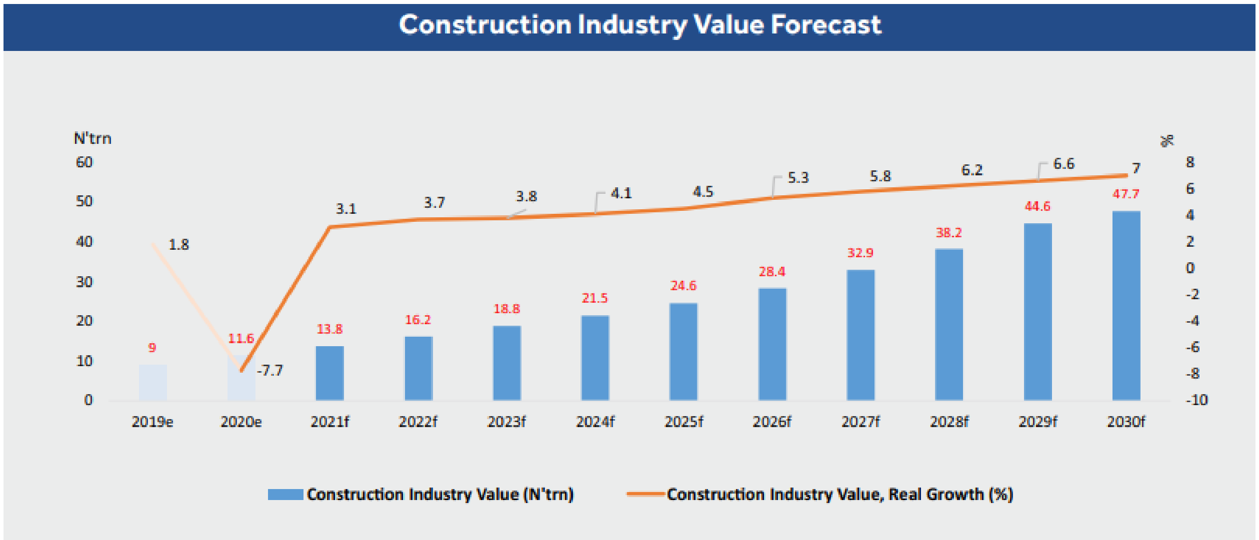


*Figure 6: Figure showing the construction industry value forecast*[6]

As shown in Fig 6, as of 2020, the construction industry in Nigeria had a market size of approximately ₦11.64 trillion; the industry is engaged in a variety of engineering and building activities consisting of foreign and locally owned companies, and the construction services are being demanded by private individuals and mainly by the government as it closes the deficit of infrastructure in the country which amounts to 40% of the Gross Domestic Product (GDP) while trying to attain the 70% Gross Domestic Product (GDP) international benchmark, the private investors are also playing a pivotal role through project development that is aimed at corporate institutes and residential customers in boosting the construction services, the growing population and rapid urbanisation in the country is also a key driver that is expected to boost the construction industry (Corporate Digest, 2021)

[6] Source: (Corporate Digest, 2021)

### 2.2.7 The current trend of housing development in Nigeria

The current housing deficit of Nigeria is between 17million to 22 million housing units (Further Africa, 2021). The current deficit is highly alarming, with a population of about 200 million. To finance this deficit, about ₦21 trillion will be required; as of 1991, the housing deficit in Nigeria was 7 million; in 2007, it rose to 12 million; in 2010, it rose to 14 million, and the price of housing and the rents have gone high above general inflation (Moore, 2019).

*Table 1: Housing deficit of selected countries in Africa*[7]

| S/N | Country | Year | Estimated population (2016-2019) | Estimated housing deficit |
|---|---|---|---|---|
| 1 | Nigeria | 2016-2019 | 185-200 million | 18-22 million unit |
| 2 | Ghana | 2016-2019 | 28-30 million | 1.76-2.6 million unit |
| 3 | Kenya | 2016-2019 | 45-52 million | 2 million unit |
| 4 | Uganda | 2016-2019 | 37-43 million | 1.7-2 million unit |
| 5 | South Africa | 2016-2019 | 56-58 million | 2.5 million unit |
| 6 | Ethiopia | 2016-2019 | 56-58 million | 1.2 million unit |

From the table above, it is essential to develop a strategy to improve the housing deficit in Nigeria; the deficit has kept increasing since 1991; the table below shows the estimation and causes.

According to the world bank, cited by (Moore, 2019) from projections, bridging the 20 million housing deficit will cost about ₦59 trillion, indicating a substantial potential investment in Nigeria's construction and real estate. Many Nigerians desire to own a decent home, but the issue of affordability contributes to the deficit housing situation in the country, evident in Table 2.

[7] Source. (Moore, 2019).

*Table 2: Nigeria's housing deficit*[8]

| Year | Housing deficit | Population | Cause |
|---|---|---|---|
| 1991-1993 | 4-7 million | 104 million | Mortgage inefficiency. |
| 2007 | 8-10 million | 145 million | Slum demolition and urban migration. |
| 2013-2015 | 16-17 million | 178 million | Overpopulation, urban expansion, and increased poverty. |
| 2017-2019 | 18-22 million | 184 million | Increased poverty, overpopulation, and urban migration. |

The materials used in building construction play a significant role in housing development, and the cost of materials substantially impacts the construction industry and potential homeowners. The construction industry faces challenges with the high inflation rate, low working capital, and high cost of development (Umar, 2017). Materials prices rose by over 300% (Gbonegun, 2021). In place of this, the Nigerian Building and Road Research Institute (NBRRI) was established to create a strategy for utilising alternative building materials that is sustainable and affordable.

## 2.3 Sustainable Housing Development

To proceed with sustainability, it is first essential to understand the term and concept of 'sustainable development. Brundtland's report from 1987 explains sustainable development as a growth that allows the current generation to meet their needs without compromising on the future generation meeting theirs (Brundtland et al., 1987). Although this concept had different contributions since its introduction and has experienced various assessments over time, it is being accepted in multiple aspects of human activities (Klarin, 2018).

The UK defines sustainable development as the assurance of the quality of life for everyone in the present and the future generation. (Du Plessis & Landman, 2002) has a contrary opinion on the popular belief of sustainable development, which is not a

[8] Source. (Moore, 2019).

development that is to be sustained but a development that needs to be monitored to retain the state of sustainability; sustainability is not the goal but rather a means to maintain equilibrium between what is ecologically possible and the people's demands for quality of life and prosperity, it further explained that development should not be seen in its myopic meaning of growth, but instead as growth during evolution and improvement.

In addition, the definition of sustainability has been founded on various principles; which fundamental principle is the underlying and integration of social, economic, and environmental concerns as the core and the intergenerational justice, which acknowledges a futuristic scale of maintaining order in addressing the future generation's needs (Mensah & Casadevall, 2019)

The cities are rapidly growing, and the series of challenges associated with environmental, social, and economic growth has necessitated the need to reshape and transform the urban spaces to realise a sustainable development that is understood in a different dimensional process that harmonises social, economic, and environmental dimension (UNH, 2011). In 2018, about 4 billion people lived in cities; it is expected that by 2050, this number will rise to 6.5 billion people amounting to 90% of the world's population, thereby expanding the urban spaces. It is also essential to investigate housing, an essential component of the built environment; it is also a necessary constituent of social and economic development; it is an entity that uses natural resources while producing energy and waste. An enormous quantity of power utilised in conjunction with greenhouse gasses is connected to the construction building industry. To effect a change in the approach to sustainable development, the primary stakeholders in the construction industry must change the concept of architecture, spatial planning, and construction to erect buildings that have carbon footprints and are energy efficient. Efficient housing is built to respect the proper utilisation of resources that achieve a low carbon footprint and provide a sustainable environment.

## 2.4 Sustainable Development Principles

The core principle of sustainable development is incorporating social, economic, and environmental affairs into all decision considerations. However, the sustainable development goal is stability over a long time.

### 2.4.1 Economic perspective

From the economic perspective, questions arose on how sustainability validates financial concepts; this was a question that the economist faced in the 19th century; it is a focus on the current trade consumption for future consumption as noticed by Malthus, who saw population growth that outpaced the development of food, though Malthusian forecast wasn’t actualised because of the technological intervention through innovations, some economist believes that the current consumption rate can be maintained. In contrast, technological innovation will cater to future generations’ needs (Elliott, 2005). A sustainable economy utilises economic tools that help create policies that promote innovation, thereby transforming into profit generation. Economists simplify the identification of maximum human welfare (clothing, food, transportation, housing, education, and health) by maximising the utility derived from its consumption. Economic sustainability refers to a production system that meets current consumption levels without jeopardising future requirements (Lobo, Pietriga & Appert, 2015). Traditionally, economists have put too much importance on the market's ability to apportion resources effectively, presuming that the availability of natural resources is limitless (Du & Kang, 2016). It is also argued that economic development can be complemented with technical development to replace natural resources depleted during the manufacturing procedure (Cooper & Vargas, 2004). On the other hand, natural resources are limited, and not all the materials can be renewed or renewable. The expanding range of the financial system has been overstressed by the natural supply base, necessitating a reassessment of some basic economic postulates (Du & Kang, 2016). Production, distribution, and consumption are the three significant events conducted in an economy. However, accounting standards that govern and appraise the economy in these areas severely distort values, which is terrible news for the environment and society (Cao & Emission, 2017). Human necessities such as food, clothes, and housing rise because of the increasing population, but the world's means and resources cannot keep up with the demands indefinitely (Dernbach, 2003). Further to that, (Retchless & Brewer, 2016) asserts that because economic expansion appears to have been the primary concern, important financial components such as the effect of exhaustion and adulteration are ignored, while the growing request for goods and services tries to push markets and invade the environment's destructive effects. Thus, economic sustainability necessitates making choices in the fairest and most economically sound manner achievable while also considering the other components of sustainability (Zhai & Chang, 2019).

### 2.4.2 Environmental perspective

The ability of the natural environment to remain beneficial and durable to sustain life is called environmental sustainability. Environmental sustainability correlates to the ecological system's reliability and carrying ability in the natural ecosystem. (Brodhag & Taliere, 2006). It necessitates the long-term use of natural capital as an indicator of financial inputs and disposal systems. (Goodland & Daly, 1996). As a result, natural resources should be extracted as soon as they can be replenished. As soon as the environment can process waste, it should be discharged (Diesendorf, 2000; Evers, 2018). The earth’s ecosystems must maintain equilibrium within their limits or bounds.

However, because technical innovation may not maintain exponential expansion, the pursuit of uncontrolled development puts more considerable demands on the earth’s system and strains these boundaries. There is growing evidence to back up concerns about the environment's long-term viability (Griggs, Nilsson, Steavance & McCollum, 2017). The consequences of climate change, for example, present a compelling case for the sustainability of the environment. Climatic change is an essential, extended period of climatic system variations resulting from environmental-climate variability or human factors (Coomer, 1979). This process heats the climate and oceans, shrinking ice sheets, rising sea levels, rising ocean acidity, and rising greenhouse gas concentrations (Du & Kang, 2016).

The changing climate already has started to have an impact on biodiversity. (Kumar, Raizada & Biswas, 2014) found that high temperatures alter the planning of procreation in plants and animals, the migration pattern of animals, distributions of species, and the population level. While catastrophic predictions abound, (Ukaga, Maser & Reinchenbach 2011) suggests that the real impact of global warming is unknown. According to (Campagnolo et al., 2018), it is apparent that, for sustainability, all civilisations must react to the new reality in handling the natural growth constraints and the ecosystems.

The present rate of biodiversity damage is faster than the natural extinction rate. With climate change, the world's biomes boundaries are predicted to alter as species migrate to greater latitudes and altitudes and large-scale vegetation cover shifts (Peters & Lovejoy, 1992), quoted in (Kappelle, Van Vuurem & Baas, 1999). Species' chances of survival are diminished if they cannot adapt to new geographical distributions. By 2080, roughly 25% of coastline wetlands will have vanished because of the rising sea level. All the significant environmental challenges, as previously said, have ramifications on how the natural ecosystem remains effectively stable and robust to maintain development and human life.

### 2.4.3 Social perspective

Equity, accessibility, empowerment, participation, institutional stability, and cultural identity are all values that should be prioritised for social sustainability (Daly, 1992). Development being about people, the term suggests that people are more concerned (Benaim & Raftis, 2008). (Littig & Grießler, 2005) define social sustainability as the structure of cooperative association that relieves impoverishment. However, social sustainability fundamentally links socioeconomic situations such as environmental devastation and poverty (Farazmand, 2016). With this perception, a notion of social sustainability asserts that mitigation of poverty should not be accompanied by unjustified environmental degradation or economic uncertainty; there should be an attempt to reduce poverty while working within the society's prevailing natural resource base and economy (Kumar et al., 2014; Scopelliti et al., 2018)

At the social level, according to (Saith, 2006), sustainability means promoting the growth of individuals, cultures, and communities to attain meaningful life, taking on appropriate healthcare, peace, gender equality, and firmness worldwide. According to (Benaim & Raftis, 2008), social sustainability is difficult to attain since the social dimension appears to be complex and overpowering. The social structure dynamics are immaterial and cannot be represented, unlike the ecological and financial systems, where streams and cycles are easily visible (Benaim & Raftis, 2008; Saner, Yiu, & Nguyen, 2019). "The concept of accomplishment within the societal system is that persons are not endangered to circumstances that weaken their capability to meet their needs," as (Everest-Phillips, 2014) puts it.

According to (Kolk, 2016), guaranteeing that everyone's needs are addressed is not the goal of social sustainability. Instead, it attempts to create the conditions necessary for everyone to be able to meet their own needs if they so wish. Any impediment to this capacity is a barrier that must be overcome for people, organisations, or communities to develop toward social sustainability (Brodhag & Taliere, 2006; Pierobon, 2018). Comprehending the kind of societal dynamics and how they develop from the perception of a system is crucial for social sustainability (Zhongme Lv, 2018). Above all, according to (Gray, 2010; Guo, 2017), social sustainability incorporates several concerns such as human rights, gender equity and equality, public involvement, and the rule of law, supporting social sustainability.

## 2.5 Sustainable Construction and Materials

Ecologically friendly building materials are required for sustainable construction (Sarah, 2020). This also entails utilising materials and resources that are renewable and easily accessible from a wide range of sources. As cited by (Marut et al., 2020), the Building and Construction Authority (BCA) of Singapore 2007, described sustainable construction in the aspect of the usage of products and materials for construction which utilises few mineral deposits and promotes the ability of such materials to be reused for the same or comparable purposes while minimising waste. Sustainable construction aims to improve the flexibility of the construction industry, such that sustainable materials should be made available in the market with their utilisation; it is necessary to share information and skills in the use of the materials to achieve sustainability. Compressed stabilised brick, which can replace the use of conventional brick and substantially reduces energy consumption, $CO_2$ emissions, and waste generation, is an ideal prototype for building materials that are sustainable building (Gunnell, Du Plessis & Gibberd, 2009) also described sustainable construction as considering the social, economic, and ecological problems of a building within the framework of its location.

Additionally, sustainable building materials are simply resources that are created locally such that it reduces the cost of transportation and the emission of $CO_2$; they could also be reused materials that have minimal or no environmental effect, with thermal efficiency, and consumes less energy compared to conventional materials, they are sustainable economically by making use of renewable resources (Sharma, 2020). Sustainable construction aims to prevent the exhaustion of water, energy, raw materials, and ecological deterioration triggered by the amenities and infrastructure during its usage (Sarah, 2020). Consequently, the emphasis of the environmental policy is on the efficiency of materials, where waste prevention and recycling or reuse of materials perform an essential function in delivering water, material, and energy savings.

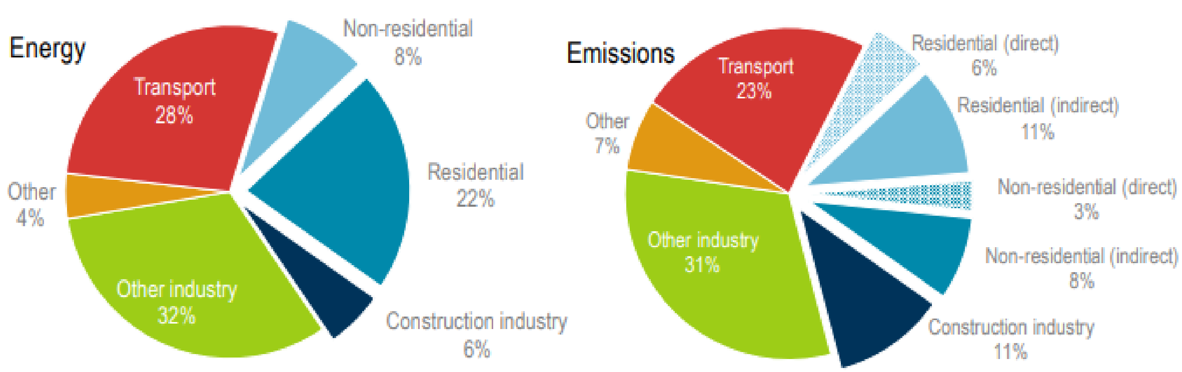


*Figure 7: Global share of buildings and construction final energy and emissions, 2018*[9]

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[9] Source: (UNEP, 2019)

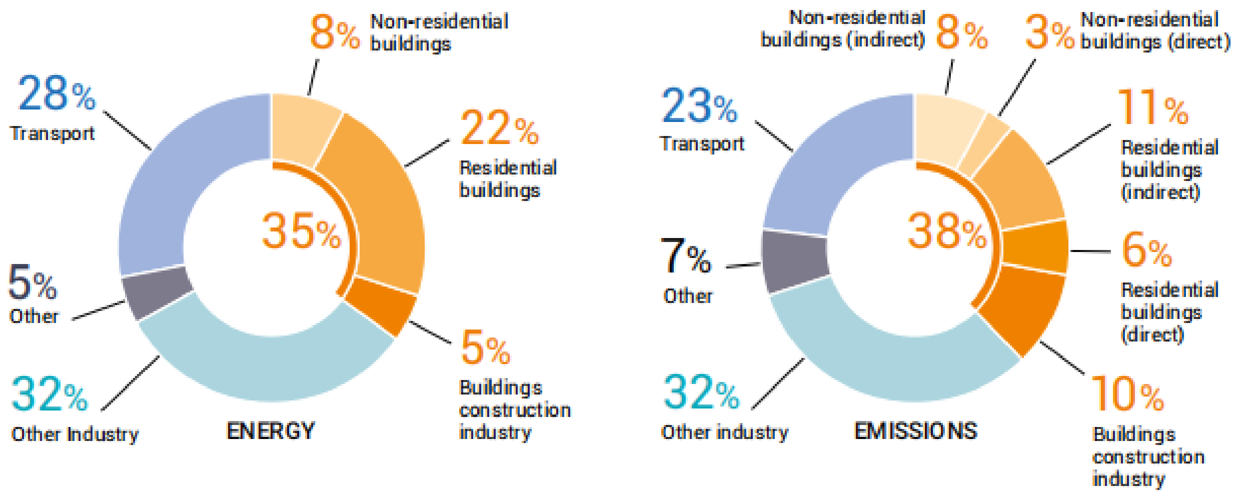


*Figure 8: Global share of buildings and construction final energy and emissions, 2019*[10]

The emission of $CO_2$ from the construction industry is the greatest, the global building sector's final energy consumption was unchanged in 2019 from Fig 8 compared to the previous year as shown in Fig 7, and building-related $CO_2$ emissions have yet risen to their most significant level, accounting for roughly 30% of total global $CO_2$ emissions, when the emissions from the building construction industry are factored in, this figure rises to 38% of total world energy-related $CO_2$ emissions, the increase in transportation and other industrial emissions related to buildings resulted in a somewhat lower share of buildings emissions, compared to 39% in 2018, the upsurge in emissions from the building construction industry is attributable to the ongoing usage of oil, coal, and natural gas for cooking and heating purposes, as well as increasing activity levels in places where electricity is still carbon-intensive, which results to a stable direct emissions, the usage of power in building activities accounts for about 55% of global electricity consumption, this emphasizes the significance of a three-pronged approach to aggressively decrease energy consumption in the built environment, while also decarbonizing the power sector and applying materials processes that reduce lifecycle carbon emissions, all of which will cut both energy demand and emissions (UNEP, 2019).

[10] Source: (UNEP, 2020)

As a result, to reach these ambitious goals, an evaluation of the many alternative building materials for sustainable building construction is required to fulfil sustainable development goals and meet housing needs; it is necessary to establish the case for looking at alternate building materials for sustainable development, the knowledge gap and insufficient experience can be bridged toward sustainable development through studying the alternative building materials for sustainable construction.

## 2.6 Conceptual Framework for Alternative Construction Materials

A concept, according to (Cohen, Lawrence, & Morrison, 2000), is a link between a word and an idea or rather a conception. A framework is a research instrument designed to help researchers understand and comprehend the studied topic and convey this information. (Smyth, 2004). A conceptual framework is a network of interconnected concepts that collectively offer a thorough knowledge of the subject (Jabareen, 2009). The independent but connected theories form the foundation of the conceptual framework of the inclusive process by using alternative building materials. Materials used for building can be categorised into three groups: conventional or modern, innovative, and traditional building materials; traditional materials includes bamboo, laterite, and thatch, which are utilised with basic technology and are categorised by low-quality performance; this low-quality performance has necessitated its development to the conventional building materials that consist of steel, blocks, cement, glass, rod, and various roofing materials, these materials are scarce and expensive as a result of importation, the innovative group is a category where the traditional and conventional building material are improved on through research development which is aimed at providing alternatives to imported materials, the development of the traditional building materials can help in solving housing deficit problems (Aliyu, Rozilah & David, 2011). This problem, according to (Opara, 2003) as cited by (Abdulakeem, Hadiza & Yusuf, 2021), varies from the rising cost of building materials and the building construction industry facing various challenges because of the deregulation in the economy, the dependency on imported materials, and inadequate local building materials which have caused an increase in construction cost because of the high transportation cost, exchange rate, amid other problems.

(Arayela 2002), Opined that it is imperative to seek ways to reduce the construction cost and make it attractive. He further added that stabilised laterite bricks are currently being used to reduce the cost of construction. (Opara, 2003) further asserted that intensifying research and development of locally sourced building materials would go a long way in solving the problem of the rising cost of building materials.

According to a survey of various construction materials studies, the development of alternative building materials follows some distinct paths, either conventional construction materials are transformed with the primary goal of lowering their cost, or unconventional materials make up the category of alternative materials that are explored and their qualities are investigated to incorporate them into current construction practice. The primary means of modifying the original materials is the fractional replacement and replacement of specific elements, stability, compression, and reinforcements, as shown in Fig 9. Most research tries to reduce the construction cost of materials. Instead, it starts and stops with strength testing and other attributes of the materials produced, with no relevant assessments of the discoveries' economic ramifications (Marut et al., 2020).

Materials can be used for the following:

- Substructure: When adequately handled and stabilised with lime, cement, reeds, and bitumen, earthen laterite can create a good foundation.
- Flooring: Laterite reinforced with coconut palm or bamboo, or when mixed with desirable workability and reinforced with reeds, can be rammed as oversite on a well-compacted hardcore, and when mixed adequately with clay screening, produces a solid and attractive floor.
- Wall and structural frames: A desirable construction wall is made of brick with laterite, baked brick, stone jointed with laterite mortar or lime stabilised mortar, bamboo, coconut palm, and lumber treated as stakes inside the earth.
- Roofing: When treated, coconut palm, pale, and stake may be used as roof trusses. Alternative Building Materials such as rice husk ash, soil bitumen brick, and micro concrete roofing tiles can be used in the building. (Marut et al., 2020).

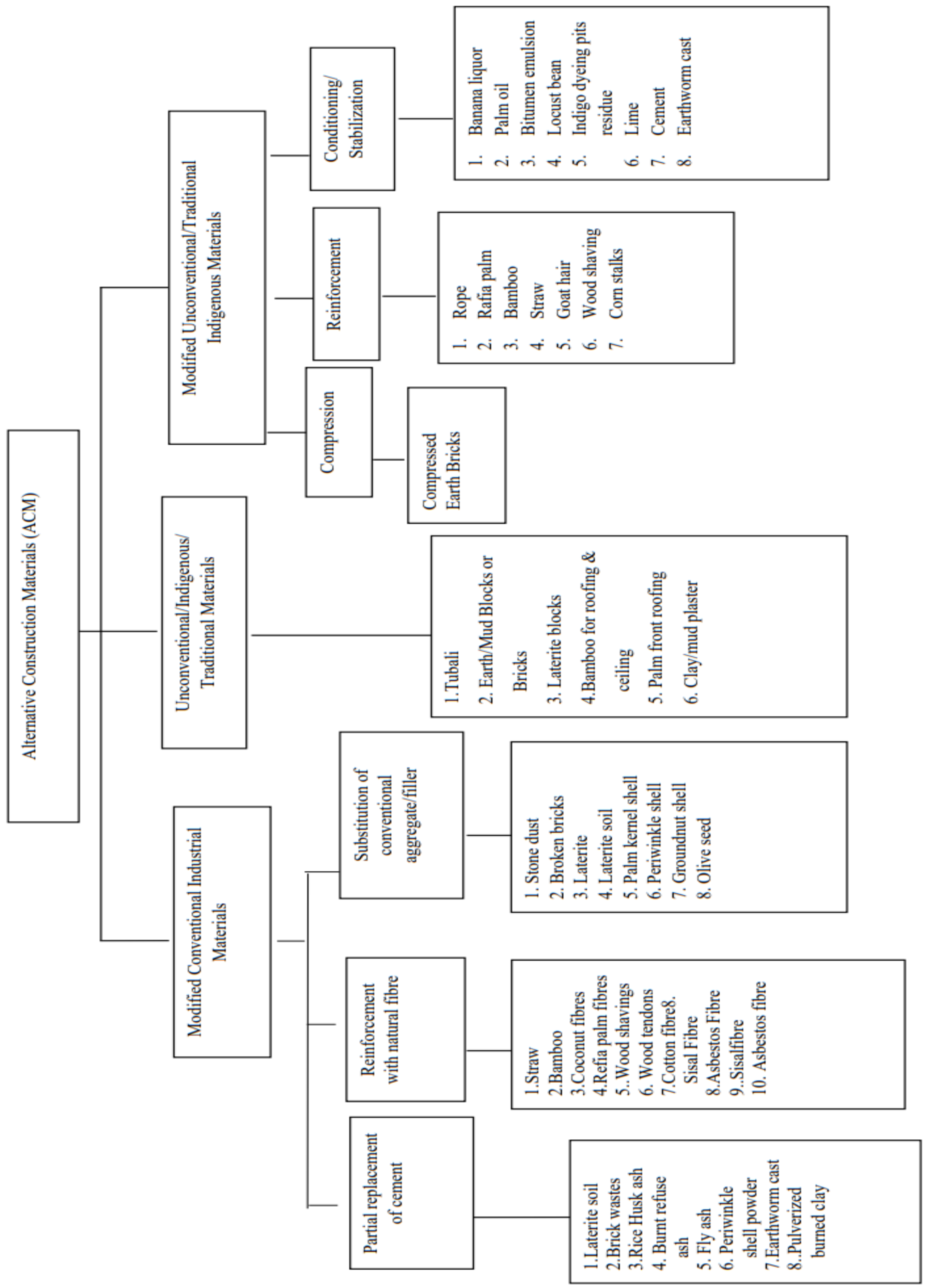


*Figure 9: Classes of sustainable alternative construction materials*[11]

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[11] Source: (Marut et al., 2020).

Researchers have discovered several alternative building construction materials that can be utilised to achieve sustainable construction and development. It's worth noting that, as shown in Fig 9, several of these materials are currently undergoing scientific testing to determine their mechanical properties (Marut et al., 2020).

The construction industry contributes to the change of the built environment by constructing infrastructure and facilities that will decide our freedom and flexibility over the next century. Sustainable construction entails lowering a building's environmental effect while increasing its economic viability over time (Ali, Shukri, Patel, & Ahad, 2020). On the other hand, developing and maintaining the built environment through efficiently utilising resources and ecological principles is considered sustainable building. (Baba & Anas, 2018).

Studies on sustainable materials' environmental, social, and economic benefits are increasing (Antoli & Matteo, 2019). Sustainable material is believed to be integrated into sustainable development (Sheth, 2016). Sustainable building materials have two ecological and economic features; the ecological features include contamination, recyclability, thermal conductivity, and insulation, while the economic features include manufacturing and price, flexibility, availability, and lifetime expectancy (Danso, 2018). It was explained by (Sheth, 2016) that the consideration of building material being sustainable was by an acid test, which satisfies the following criteria: The material ought to be resource-efficient and renewable, as well as beneficial to the environment. Similarly, there are three indicators for sustainable building materials which include ecological indicators that comprise climate change, human, solid waste, and toxicity; social indicators that comprise thermal comfort, adaptability, housing, and local resources; economic indicators that comprise operational cost, maintenance cost, initial cost, life span and long-term savings (Sunke & Schultman, 2019).

According to (Smaranda, Liliana, & Radu, 2019), some characteristics of sustainable building construction materials include: being healthy and hygienic for users, it should consume less energy for transportation while avoiding pollution, it should consume less energy during fabrication, it should possess insulation qualities to avoid high energy usage, and materials should possess favourable environmental effects.

## 2.7 Sustainable Building Materials Life Cycles

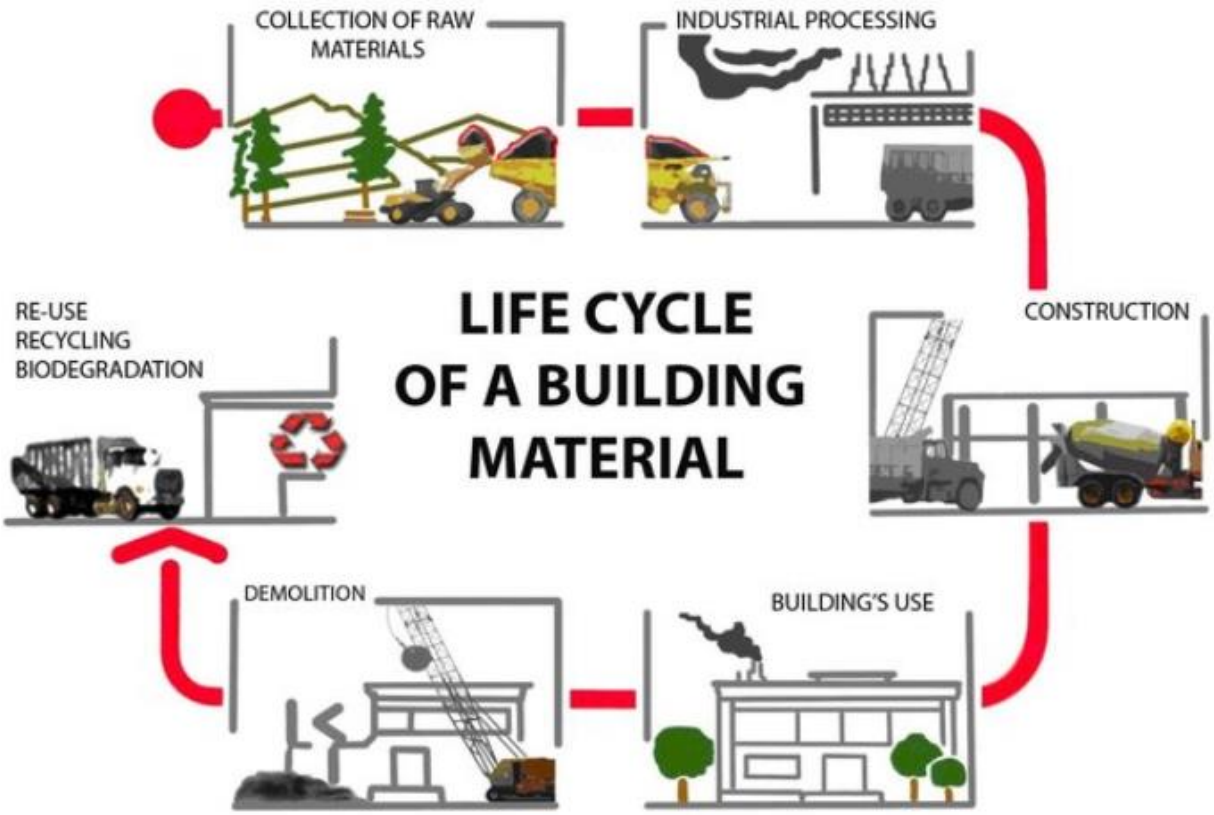


*Figure 10: Building material life cycle*[12]

The precepts of life cycle analysis deliver a crucial framework for the assessment of materials used in the construction industry, starting from the assemblage of the raw materials to their proper removal or disposal, giving a better insight into the long-term materials' cost; the client does not only pay these costs, but it is also paid by the owner, the environment, and the occupants. Every step of the production process is reviewed for environmental impact, from sourcing raw materials to its production, dissemination, installation, and final disposal. According to (Najjar et al., 2022), the life cycle of a material can be divided into three phases: Pre-Building, Building, and Post-Building. Similarly, (Fivos et al., 2019) explained the life cycle of construction materials, as shown in Fig 10,

[12] Source: (Fivos et al, 2019)

into the following stages: Extraction, Production, Building construction process, Usage and Dismantling. These phases correspond to the stages of the building's life cycle; instead of just accounting for initial construction expenses, assessing building materials' impact on the environment at each phase allows for a cost-effective analysis across the project’s life.

### 2.7.1 Pre-Building phase

The manufacturing and supply of materials up to but excluding the installation stage are described in the Pre-Building Stage. This stage involves sourcing the raw materials, gathering them, producing them, packing them, and delivering them to a construction site. The potential for environmental harm is most significant during this stage. Still, it will be possible to choose suitable building materials by understanding the effects during the pre-construction stage. The techniques used to get raw materials, the manufacturing procedure, and the distance between the manufacturing facility and the construction site impact the environment. When a building's active environmental impact is identified, it is essential to understand the origin of the materials used to construct it. (Najjar et al., 2022).

### 2.7.2 Building phase

The building phase describes the duration of a building material's usable life; it starts with the assembly of the material into a structure, involves maintenance and repair and lasts throughout the material's existence or as a component of the building. A substantial amount of material waste may be produced on a construction site. Choosing building materials that reduce construction waste and waste that can be recycled is crucial at this point of the building life cycle. The inhabitants' health could be harmed by prolonged exposure to certain building materials. Reality rarely focuses on choosing materials based on their potential to outgas harmful chemicals, which requires regular maintenance with such chemicals or frequent replacements that prolong the exposure cycle, despite growing awareness of the health risks associated with exposure to various products (Najjar et al., 2022).

### 2.7.3 Post Building phase

The building materials that have reached the end of their useful life in a structure are referred to as the post-building phase. At this point, a material may be recycled completely, have some of its components used again in new products, or it may just be thrown away. According to the designer, the end of a structure or material's usable life is when the building life cycle is least measured and recognised. There are significant environmental costs associated with demolition and garbage clearance. Biodegradable materials can produce hazardous waste when combined with other materials or used alone. Waste products eventually fill up limited landfill space. The energy used in the materials and construction of an existing structure is sustained by its adaptive recycling. If these resources are not used efficiently, the energy used in building construction alone and producing these materials would be wasted (Najjar et al., 2022).

## 2.8 Hydraform Brick as an Alternative Construction Material

### 2.8.1 Background history of Hydraform brick

In ancient times, soil blocks were traditionally used in construction; they were constructed using hands to mould into blocks and sometimes reinforced using straw as the binder. The blocks were laid with mud as mortar for binding, and mud was also used in the wall's finishing and was usually maintained with the addition of mud on the new layer susceptible to high rainfall. In comparison, there is another traditional method of construction known as adobe, where wooden strips known as wattle are laced with sticky materials made from a combination of sand, clay, straw, and animal dung.

The machine used in compressing soil dates to the 18th century with mechanisation. Francois Cointeraux, a promoter of 'new pise' and an inventor, created the 'crecise', a piece of equipment developed from a winepress that moulded earth materials. Not until the early 20$^{th}$ century was the first mechanical press designed using heavy caps forced into moulds. Some presses were motor-driven; the industry proceeded with using a static compression press where the earthen material is being compressed between plates. 1952 was a turning point in the use of the machine press and the mode for construction, with the invention of the CINVA-RAM press, designed in the CINVA centre at Bogota, Columbia, by Raul Ramirez. (Vincent, 1985).

It is comprehensible that the buildings built with conventional materials were not easily affordable in some developing countries. (Aldeek, 2020). More so, their maintenance and sustainability were questioned as regards the greenhouse gas emissions, which has made the energy crisis pave the way for the utilisation of other building materials and has necessitated the interest in earth materials for construction; this was because of the low thermal mass and the embodied energy earthen materials produced.

Since then, hydraform brick has been a potential alternative in sustainable construction, attracting awareness and consideration from the movement of sustainable building construction within developed nations to find more ecological and nature-friendly building materials (Donkor, 2014).

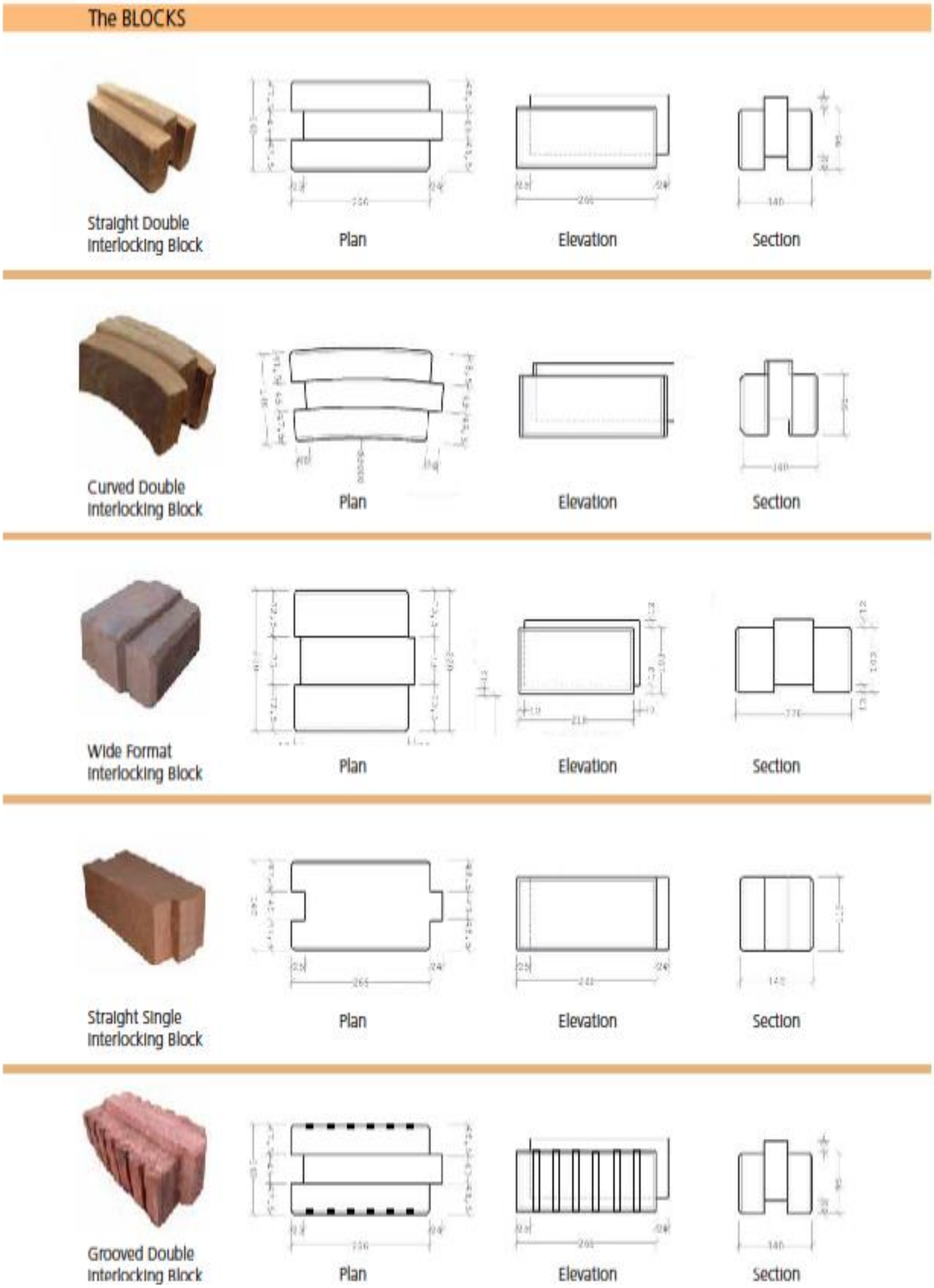


*Figure 11: Types of hydraform brick*[13]

[13] Source: (Adongo, 2017)

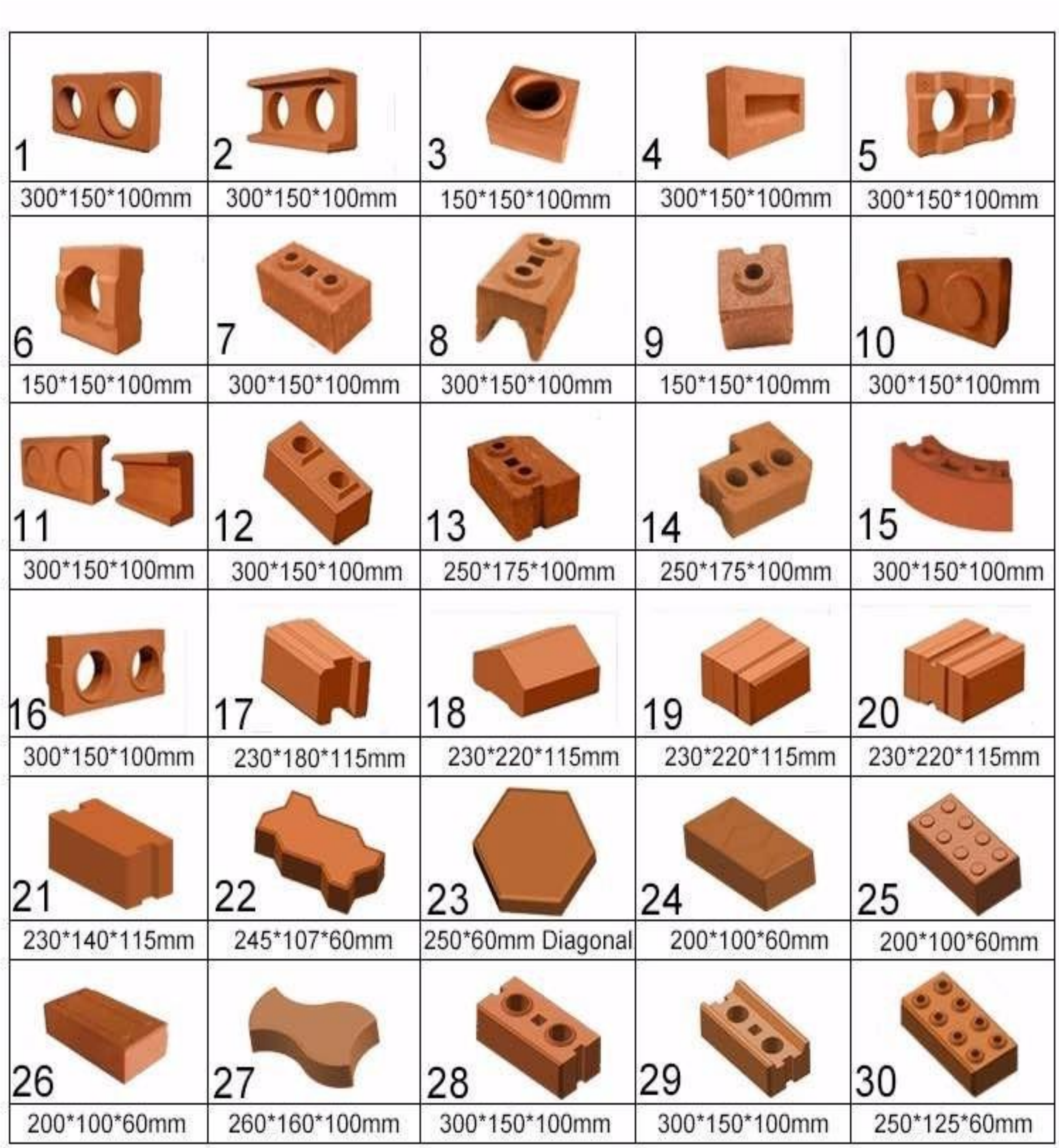


*Figure 12: Types of hydraform bricks with sizes*[14]

[14] https://m.yfbrickmachine.com/detail-193-yf210hydraforminterlockingblockmakingmachine

## 2.9 Materials for hydraform production

### 2.9.1 Soil

The main constituent of hydraform brick is the soil; there are various types, qualities, and dispositions of soil, dependent on its location; the soil should be subjected to testing to determine its appropriateness before using it for the production of the bricks; the soil must possess the correct constituent, after which it is being mixed with water and cement, the appropriateness of the soil is dependent on the chemical, plasticity, composition, and the gradation. The suitable conditions for soil used in the production of hydraform brick will be described in section 2.11**.** The soil's fine particle contributes immensely to the brick not disintegrating. It is important to note that soil having hummus is not to be utilised as it resists cement; therefore, it is expedient that the topsoil (30-40 cm) is not to be used; another factor to consider is the PH level, a PH level that is less than 4.5 or above 10 should be disregarded or soils with above 2% of sodium and potassium salts (Raheem, 2010).

### 2.9.2 Cement

Cement is a stabilising agent that prevents brick from decomposing when it is in contact with water; the addition of cement helps in the improvement of strength, volume stability, and durability as an outcome of the reactions taking place chemically between the constituents of the cement and soil, the impacts will be proportional to the amount of cement used. The block's strength will grow with the amount of cement used, but at a different rate with different soil. due to the high cost of cement, there is no need to add more than is required for brick production; depending on the type of soil, a cement rate of 4-16 per cent is usually advised (Habtemariam, 2012)

### 2.9.3 Lime

The first documentation of lime used in construction as a stabiliser was under the Roman Empire when it was employed in Egypt for the construction of pyramids around 4000 B.C. lime has been proven for its performance and has made a significant impact on masonry construction that has endured for centuries, the Great Wall of China is a typical example, this document was authored by Marcus Vitruvius Pollio (80 BC – 15 BC), who was an engineer, architect, and a writer, and was known globally as the first engineer (Fetra, Ismail & Ahmad, 2011). In treating soil, lime can be used in the form of quicklime (calcium oxide – CaO), lime slurry, or hydrated lime (calcium hydroxide – Ca (OH)2), quicklime is made with the conversion of calcium carbonate (limestone - CaCO3) to calcium oxide using a chemical process, hydrated lime can be produced by quicklime reacting chemically with water, hydrated lime combines and reacts with clay particles to generate a solid cementitious matrix that lasts (Raheem, 2010). Quicklime and hydrated lime for soil stabilisation should have the following chemical composition, according to (ASTM C977, 2002):

- Calcium and Magnesium Oxides (on a non-volatile basis, minimum %) ……….90.0
- Carbon Dioxide (taken at point of manufacture, maximum %) …………………..5.0
- Free Moisture (taken at point of manufacture, maximum %) ……………………2.0

The term "lime" is frequently applied to by-products of the lime manufacturing process, which, while containing some reactive lime, have just a fraction of the oxide or hydroxide content of the finished product. (National Lime Association, 2004)

### 2.9.4 Water

The pores in the soil that are air-filled and with water are lowered during the process of compaction, and the addition of more water in the mixture will lubricate the grains and replace air voids, making it more straightforward for grains to mix; water is also required for the stabiliser’s hydration process, along with the silt and clay, it will prevent the freshly pressed brick from falling apart, the amount of water required varies based on the soil's dryness. (Afkari, 2010)

## 2.10 Properties of soil for hydraform brick

### 2.10.1 General properties

Soil is the outcome of physical, chemical, and biological processes from the weathering of rock which is influenced by natural and climatic factors; it is typically deposited on the earth's surface and can come in a variety of forms, the variation present in soils can be ascribed to a series of natural phenomena working over a period, upon the soil surface, materials with a high concentration of organic compounds are usually expected, which is inappropriate for brick production and can be differentiated through a musty smell when heating. The materials that are beneath the organic layer are better preferred as it comprises the various size of particles and also a fraction of soil particles called “fines”, which are described as particles passing through a mesh of 75μm and containing silt and clay, clay is required in brick production because it improves the mixture's workability, increases consolidation, and improves green strength, there is a proportion of air and water that fills the holes amidst connecting elements in the soil, which gives natural soil a nonhomogeneous nature (Abdulkader, 2015)

With so many diverse qualities a soil sample can have, it would be absurd to uncover them in every circumstance where hydraform bricks are made. Only a few properties are fundamental to the scientific testing of the soil. Once the absence of unstable chemicals and organic matter has been confirmed, the chemical composition of the soil becomes less critical; physical properties are of more interest for making compressed stabilised earth because these will help to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength, and bulk density, among other things. To make compressed stabilised earth, it is necessary to control or monitor the clay fraction; too much clay causes unacceptably high expansion when wet, necessitating the use of extra cement to compensate; too little clay promotes low particle adhesion, resulting in high breakage rates when the compressed stabilised earth is removed from the mould. However, soil with minimal silt and clay to facilitate cohesion must produce compressed, stabilised earth (Afkari, 2010). Chemical properties can also be of interest, mainly when a chemical additive is applied; the composition, mineral concentration, metallic oxides, PH levels, and sulfates in the soil are all chemical properties. The following are the benefits of using suitable soil to produce hydraform bricks (Waziri, Lawan & Mustapha, 2013):

- Better quality of bricks with high compressive strength and resistance to erosion.
- The ability to be handled immediately after moulding without breakage
- The bricks retain their shape and size during curing.
- The ability to retain its form when drying and to wet cycles.

On the other hand, according to (Jean-Claude, 2007), the soils that are not suitable to produce hydraform bricks are:

- soil containing high organic impurity.
- Highly expansive soil.
- Soil that contains too many soluble salts.

### 2.10.2 Classification of soil

Soil is categorised in various ways, including its intended purpose, origin, size, texture, colour, and density. A particle size distribution analysis and a plasticity index can characterise soil for building purposes. The particle size analysis will reveal the soil's potential to create a complex structure and the number of fines present, while the plasticity index will show the fines' cohesiveness (Abdulkader, 2015).

### 2.10.3 Classification by grain size

Disintegrated rock, degraded organic matter, and soluble mineral salts make up all soils. A technique of categorisation extensively used in civil engineering is used to grade soil types according to particle size. According to ASTM, the variety of soils based on grain size is summarised as follows.

*Table 3: Classification of grain size according to ASTMD standards*[15]

| Pebbles | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| 200 to 20mm | 20 to 2mm | 2 to 0.006mm | 0.06 to 0,002mm | 0.002 to 0mm |

Gravel is rarely utilised in manufacturing soil cement because of its large particle size, which might result in a rough surface finish. Silt, sand, and clay-sized particles should be present in suitable soil. The attributes of these three fractions impact the block's properties; the soil utilised must be "well-graded" if the dense block is produced. However, a natural soil with a uniform particle size distribution is considered for compressed stabilised earth blocks; the value of a well-graded soil is that it produces a compact structure with such a low surface area due to the size distribution. A dense structure is essential for a variety of reasons. More contacting particles will be tightly packed, resulting in a robust load-bearing framework. The number of connected spaces and inter-particle voids will be decreased, lowering the soil's porosity and thus its permeability, minimising water penetration. Because the interlocking calcium silicate matrix spreads over the soil voids, a more compressed void system would require less cement to provide an equal-efficiency matrix. Similarly, suppose a chemical stabiliser (cement or lime) coats the surfaces of soil particles. In that case, blinding will require a significant amount of chemical stabiliser in soil with a large specific surface area. A lower specific surface area soil, on the other hand, will take less stabiliser to get the same particle surface coverage and, as a result, the same strength and durability. A coarse soil with no particles is non-plastic and will not hold its shape when ejected from the mould or transported to the curing location. Due to the lack of fines, the coarse soil could be compared to a sand-cement mixture with huge voids (due to lack of fines). Huge holes will enhance the brick's permeability, reverting to the classic sand-cement problem of quick dryness before cement can cure properly. Even if the soil were correctly graded, it would be inappropriate to manufacture soil-cement blocks (Tadege, 2007)

A well-graded fine soil with minimal sand but a high clay component, on the other hand, would have a large specific surface area and expansive behaviour. The high clay

[15] Source: (ASTM D, 2008)

component will offer cohesiveness when the soil is ejected from the mould. Still, the enormous specific surface area would necessitate a considerable amount of cement to ensure adequate particle coverage. As a result, proper soil will be highly graded, but there should be some other constraints: the greatest particle size present should not be large enough to cause a poor surface finish (Tadege, 2007).

### 2.10.4 Classification by plasticity

Soil cohesion is determined by the amount of silt and clay in the soil, and these fines give new blocks their handling capacity. The degree of cohesiveness produced by the block is determined by the particles present and the degree of compression used in its formation. A low-pressure moulding technique, in general, necessitates a more extensive fines content than a high-pressure moulding process. Higher compaction forces soil particles into closer contact, resulting in a more substantial new compact. The particles also affect the wetting expansion of the final cured block. To reduce the expansion and contraction of the cured block during reported wetting and drying, the clay fraction's expansions must be primarily restricted by the calcium silicate matrix. (Tadege, 2007)

As a result, the clay percentage should be as little as possible to achieve the lowest cement concentration. The considerable disparity in specific surface area between the three clay varieties stated above may be since various clays have drastically varied expansion characteristics when wet. In general, as the surface area of the clay percentage increases, so does the amount it will expand when wet. As a result, the clay type and quantity will impact the block. The fine fraction appears to be beneficial to the block-making process, but it has a negative effect on the final cured block's wet strength and durability. As a result, the amount and type of clay used should be carefully considered. The Atterburg tests specifying liquid limit, plastic limit, and plasticity index are utilised to quantify the fluidity of a soil's finer fraction. These tests determine the percentage of moisture content at which the soil transitions from a liquid to a plastic state (liquid limit) and from a plastic to a solid-state (plastic limit) (plastic limit). The plasticity index is the numerical difference between the liquid and plastic limits, indicating the range of water content at which the soil can be deemed plastic. Because soil cohesion affects plasticity, this index has been discovered to reflect the soil's cohesive qualities. Furthermore, because the particles' particular surface area determines cohesion, these plasticity limits reflect the soil's expansiveness. A soil that has a low plasticity index will have low cohesiveness and typically low expansion when wetted, whereas a soil with a high index will have the opposite effect (Abdulkader, 2015)

## 2.11 Suitable Soil for hydraform brick

Organic matter and excessive soluble salts should be avoided in suitable soil to avoid interfering with the chemical stabiliser’s setting. The sand’s percentage should be well sorted to deliver a densely packed load-bearing framework for the brick, and its greatest particle size should be small to give a good surface finish. The fine portion should be adequate to provide the new brick with good cohesiveness to prevent damage during discharge from the mould. A high fines concentration will either necessitate a high cement content for proper stabilisation or impair the final cured block's durability and wet strength. The new block's cohesiveness is determined by the compaction pressure applied and the kind and quantity of clay included in the fines. From the preceding, it should be clear what role each soil component fraction has in a stabilised compressed earth block and the importance of choosing the suitable soil. If the soil on site looks unsuitable, consider that natural soil is divided into strata with different compositions. If the various strata have been thoroughly examined, mixing suitable quantities of two or more strata to generate good soil is relatively straightforward (Abdulkader, 2015).

### 2.11.1 Available criteria for soil suitability

The selection of an appropriate type of earth can be made in the field using factors that have been developed via practical experience. If there is any uncertainty, laboratory identification tests should be performed. We require clay in a compacted stabilised soil block, and it's impossible to prevent moisture differentials in humid locations. Therefore, the only properties we can try to lower are porosity and permeability.

The particle size distribution of a soil sample should be determined before deciding if it is acceptable for compressed stabilised soil block manufacture. One can acquire an indication of the compatibility of the soil sample in issue based on such test findings and previous practical experiences. The following is a more usable range of particle sizes suited for earth block construction (David, 2002)

- Sand/fine gravel: 40 - 75%
- Silt: 10 - 30%
- Clay: 15 - 30%

### 2.12 Production of hydraform brick

Hydraform brick is a construction material that consists of laterite (earth) mixed with a stabiliser (either lime or cement) into a compressed block (Noorbaya, Temple, & Tengku, 2014). The production of hydraform brick starts by carefully contemplating the factors for the usage of the brick; non-load-bearing or load-bearing, the placement within the structure; either internal or external, the building code of the region, the climatic condition of the area, the available type of soil, etc. the above factors are the consideration of the kind of stabiliser to be used, the level of its compaction, and the application of external render to the brick.

Production on a large or small scale or on-site production of hydraform brick starts with the appropriate extraction of soil, making sure it’s dry soil, also screening the soil to remove unwanted debris, and selecting the right stabiliser, after which proportioning is done, followed by mixing the soil with stabiliser, water, then compacting the mix with an appropriate press, afterwards demoulding the bricks, curing them and stockpile the bricks. The type of soil must be evaluated to determine the technique for stabilisation.

From the above description, the production requires a moderately low-skilled worker since the method is simple and takes only a three-phase process: the preparation of soil, compression of the mix, and curing. A remarkable distinction between the hydraform brick and the conventional brick is the amount of energy consumed during their respective production process and their carbon emission. The hydraform brick creates about 20kg

$CO_2$ per ton compared with a concrete block which produces about 140kg $CO_2$ per ton, an aerated concrete block which has about 280kg- 370kg $CO_2$ per ton and fired clay brick which produces about 200kg $CO_2$ per ton during production (Morton, 2008).

The stabiliser used in the production of hydraform brick plays a vital role in forming a bond between the mix of soil-stabilizer, the primary work of the stabiliser is to lower the bulging properties of the soil by creating a rigid framework with the soil mass while enhancing its durability and strength, the most widely used stabiliser for hydraform brick is the Portland cement, (Walker, 1995; Guettala, Houari, & Bouzidi, 2002). The addition of lime to the mix enhances the stabilisation process, and the lime to soil ratio is increased with the existing lime present in the cement, which helps in plasticity reduction; lime fixation is then achieved when the lime is added to the soil and has been absorbed by the soil mineral.

*Figure 13: A typical compressing machine*[16]

[16] http://www.giantlinblockmachine.com/JD1-30-Manual-Soil-Cement-interlocking-Hydraform-Block-Making-Machine-18-36-1.html

## 2.13 Performance of Hydraform brick

### 2.13.1 Strength

Compressive strength is usually a universally accepted value in determining the quality of bricks; it is related intensely to the soil type and the content of the stabiliser; the compressive strength determination is usually the weakest value when the brick is still in its wet condition. Factors that could affect compressive strength are usually the soil type when looking at its plasticity, the cement content, and the type of compaction it undergoes. The compressive strength of hydraform brick can be increased by adding natural fibres such as sisal fibres to enhance the ductility in stiffness; the enhancement is typically by retarding the tensile crack after initial formation (Mahmoud, 2004). Another method for improving the compressive strength of hydraform brick, according to (Beneyam, 2021), is to increase the cement content, which fills the pores of the soil through hydration; the result showed a high compressive strength of 4.6MPa at a curing time of 28 days with a cement content of 12%. Compared with the result from (Noorbaya et al., 2014), the compressive strength of 3.78MPa was achieved with 12% cement stabilisation after 28 days of curing. (Raheem, 2010) compressive strength result reported 2.78 MPa after 28 days of curing, with a cement content of 15%.

### 2.13.2 Density

The density of hydraform brick, according to (Oti, John & Jiping, 2009) as cited by (Zaidi, Fetra & Ismail, 2010), is within the range of 1500 to 2000kg/m$^3$; it is related to the compaction force and compressive strength during production; the density is primarily a function of the moisture content during the pressing, the material’s characteristics and the degree of compaction load applied, the density can be affected depending on the type of compaction application either Vibro, static or dynamic compaction. Hydraform bricks are usually denser in comparison to other concrete masonry blocks; as shown in Table 4, the density when high is considered a disadvantage as a result of the dead weight it imposes on the structure, and also during transportation, the low density is deemed to be advantageous as a result of its thermal properties which is preferred in regions with hot, dry climatic conditions where the temperature of the internal space of the building is moderated (Adam & Agip, 2001).

*Table 4: Properties of Hydraform blocks versus other walling materials*[17]

| Property materials | Hydraform bricks | Fired clay bricks | Calcium silicate bricks | Dense concrete blocks | Aerated concrete blocks | Lightweight concrete blocks |
|---|---|---|---|---|---|---|
| Wet compressive strength (MPa) | 1-40 | 5-60 | 10-55 | 7-50 | 2-6 | 2-20 |
| Moisture content in (%) | 0.02-0.2 | 0.00-0.02 | 0.01-0.035 | 0.02-0.5 | 0.05-0.10 | 0.04-0.08 |
| Density in (Kg/m³) | 1700-2200 | 1400-2400 | 1600-2100 | 1700-2200 | 400-950 | 600-1600 |
| Thermal conductivity (W/m⁰C) | 0.81-1.04 | 0.70-1.30 | 0.10-1.60 | 1.00-1.70 | 0.10-0.20 | 0.15-0.70 |
| Durability against rain | Good to very poor | Excellent to very poor | Good to moderate | Good to poor | Good to moderate | Good to poor |

### 2.13.3 Water absorption and Moisture content

The water absorption level usually causes the deterioration of brick; a high absorption rate triggers a rapid decline. (Freidin & Evyatar, 1995) attempted reducing water absorption with the addition of siloxane-polymethyl hydrogen-siloxane, a hydrophobic material which was made by a German company (Merck), and Siloxane CS, combined with slag and fly ash (highly absorbent), and the result revealed that the addition of siloxane had a 50% water intake than fly ash slag.  Bricks with clay content have an increasing porosity and water absorption. In contrast, cement content has a decreasing absorption, as observed by (Walker, 2004) and confirmed by (Guettala et al., 2006), where a comparison was carried out between lime, cement, cement-resin, and cement-

[17] Source: (Adam & Agip, 2001)

lime content, the mixture with cement content had the lowest possible absorption rate in capillarity. Where there is a high-water absorption rate, swelling occurs, which usually leads to a loss of strength over a period (Zaidi et al., 2010).

The moisture content can affect strength development, significantly impacting the material's performance over a period. The type of compaction influences the moisture content of the mix; the dynamic compaction reduces the 12% moisture content to 10% while the compressive strength is increased to about 50%, for the static compression, the moisture content is about 10-13% (Adam & Agip, 2001)

### 2.13.4 Shrinkage

Materials containing earthen construction material react to water by swelling and shrinking when dry; the extent of shrinkage depends on the type and amount of soil present; only an experiment could predict the expected percentage of shrinking (Chijioke & Okoronkwo, 2015). The loss of water contributes to shrinkage, the shrinkage of brick is regulated by its cement content and plasticity index; the plasticity index for a low clay mineral content is below 20%, and for an index above 25-30%, shrinkage increases quickly, cement stabilisation is suitable for a plasticity index less than 20% with its cement content at 10% (Walker, 1999). Several techniques to control shrinking can be utilised depending on the requirement of the building. However, the assimilation of humidity from the environment has no impact on its physical changes (Becky & Tom, 2001).

### 2.13.5 Durability

The durability of earth blocks is mainly affected by water absorption. The basic principle of stabilisation is to prevent water attacks from obtaining a durable material. Earth blocks are durable when it is not saturated. The durability problems arise when the brick material is exposed to saturation and wet conditions. The deterioration of earth blocks occurs rapidly with the high-water absorption value (Kerali, 2000). For example, to increase durability, the problem of rain penetration in buildings must be solved. The durability of earth blocks can be improved by using suitable soil and reducing water absorption in the material by a suitable stabilisation method.

Fair-faced walling can be made of bricks of exact size that are of adequately good quality with a high-quality finish; their appearance is dependent on the soil colours, particle size, and degree of compaction used; with high-quality blocks, external or even internal rendering should not be necessary; a whitewash finishes directly applied to the bricks as a render covering could be used to reduce solar gain. It should be emphasised that, like other blocks and bricks, Hydraform bricks would require enough steel reinforcement if utilised in places prone to earthquakes, cyclones, and other natural disasters. Hydraform blocks are not particularly vulnerable to termites, bacteria, fungi, or fire. On the other hand, organic soil material may diminish the block's strength (Adam & Agip, 2001).

### 2.13.6 Thermal Value

Since building standards today place a greater emphasis on a structure's thermal performance than in the past, thermal comfort in building materials is an important consideration that garners a lot of attention in the developing energy-conscious and ecological consciousness. Brick has an excellent thermal conductivity for building material. Thermal conductivity, as observed by (Oti et al., 2009), depends on the material's density and moisture content. As a result, both theoretical and experimental methods can be used to estimate the design value for thermal conductivity. Compared to burnt clay bricks, hydraform bricks have a higher thermal conductivity value.

- Lime: $0.2545 \pm 0.0350\ Wm^{-1}k^{-1}$
- Cement: $0.2612 \pm 0.0350\ Wm^{-1}k^{-1}$
- Fired clay bricks: $0.4007 \pm 0.0350\ Wm^{-1}k^{-1}$

According to (Bahar, Benazzoug & Kenai, 2004) adding cement and sand can marginally reduce the conductivity of brick. The benefit of low thermal conductivity is that it promotes energy efficiency and is environmentally beneficial. Clay bricks that have been fired have a higher conductivity rating because heating transforms the clay into a semi-glossy product that gives their strength and durability.

Table 5: Summary of relevant literature relating to the performance of hydraform brick[18]

| Research work | Stabilisers & Types of soil | Method | Findings | Remarks |
|---|---|---|---|---|
| Walker, P.J., 1995 Strength, durability, and shrinkage characteristics of cement stabilised soil blocks. | OPC & Clay soil | Manual compaction. Compaction pressure 2-4 MN/mm$^2$. Dimension 295 x 140 x 130 mm-BSI 6073 (drying shrinkage)-AS 2733-ASTM D559 (resistance to water erosion). | Dry density. Dry/saturated compressive strength. Modulus of rupture. Drying Shrinkage-Resistance to water erosion. | Propose empirical relationship that modulus of rupture shall equal at least one-sixth of compressive strength as a simple mean of field assessment |
| Walker & Stace, 1996 Properties of some cement stabilised compressed earth blocks and mortars | OPC & Clay soil | Manual/constant volume pressure. Compaction pressure 2 MN/mm- Dimension 295 x 140 x 125 mm$^2$. AS 2701 (wet mixing). AS1289 (optimum moisture content). AS2733 (compressive strength, drying shrinkage, initial rate of absorption). ASTM D 559 (durability). | Compressive strength. Drying Shrinkage. Durability. Water absorption. | Soil with mineral content less than 15% to 30% most suitable with cement stabilization between 5% and 10% |
| Guettala et al, 2002 Durability of lime stabilised earth blocks. | Lime & Clay soil, sand | -ASTM D 559-57 (durability)-ASTM D 560 (freeze-thaw test) | Compressive strength. Water absorption. Durability. | Compressive strength increases with increasing compacting stress. Water absorption and weight loss decrease with increasing |

[18] Source: (Zaidi et al., 2010)

| | | | | |
|---|---|---|---|---|
| | | | | compacting stress and lime content. |
| Bahar et al, 2004 Performance of compacted cement-stabilised soil | OPC & Clay soil, sand | Static compaction. Vibro-static compaction. Dynamic compaction. | Splitting tensile strength. Compressive strength. Shrinkage. Water permeability. Conductivity. Durability. | Mechanical stabilization by dynamic compaction is better than static or Vibro-static compaction. Chemical stabilization with cement content higher than 8% resulted in better compressive strength. |
| Mesbah et al, 2004 Development of a direct tensile test for compacted earth blocks | Sisal fibres & Sandy silty soil | Dimension 295 x 140 x 100 mm. Direct tensile test method. | Tensile strength. | The use of natural fibre reinforcement can improve ductility in tension, inhibition of tensile crack propagation after initial formation, and inhibition of shrinkage cracking. |
| Morel et al, 2005 Compressive strength testing of compressed earth blocks. | OPC & Soil | Dimension* UK 215 x 102.5 x 65 mm* AS 230 x 110 x 76 mm-Compressive strength testing. Direct unit strength. RILEM test. Indirect test. | Density. Compressive strength. Moisture content. Flexural strength (three-point bending test) | The most recommended test for compressive strength is a direct, confined test on a single unit-RILEM test dependent on mortar quality since blocks are tested together with a mortar joint in a prism. |

| | | | | |
|---|---|---|---|---|
| | | | | Indirect testing (three-point bending test) can provide an indication of relative strength |
| Billong et al, 2008<br>Properties of compressed lateritic soil stabilized with a burnt clay-lime binder: Effect of mixture components. | Calcined kaolinitic clay, industrial slaked lime & laterite soil | Hydraulic press.<br>Force applied 10 kN.<br>Pressed surface 115.4 x 80mm. | Pozzolanic properties.<br>Compressive strength.<br>Water absorption.<br>Density. | Increasing the percentage of lime increases compressive strength.<br>An increase in the laterite-binder ratio decreases compressive strength and water absorption but increases apparent density. |
| Jayasinghe, C. & Mallawaarachchi, R.S., 2009<br>Flexural strength of compressed stabilized earth masonry materials. | OPC & Laterite soil | Dimension*brick 230 x 110 x 75 mm. block 225 c 225 x 115mm.<br>BS 5629: Part 1: 1992 (testing procedure). | Flexural strength parallel/perpendicular to bed joints of the brick panel, block panel and rammed earth. | Flexural strength of brick or block panel about 0.25N/mm$^2$<br>And comparable with burnt clay bricks having water absorption above 12%. |
| Oti et al, 2009<br>Compressive strength and microstructural analysis of unfired clay masonry bricks. | Quicklime, Hydraulic lime, GGBS, OPC &<br>Lower Oxford Clay (LOC). | BS 1924-2:1990 (compressive strength).<br>BS EN 771-1:2003 (compressive strength).<br>SEM, SBD/EDX (microstructure). | Compressive strength.<br>Swelling/shrinkage.<br>SEM. | Compressive strength results showed bricks made of industrial by-products are strong and volumetrically stable.<br>The effect of swelling/shrinkage on the unfired clay bricks is negligible, |

| | | | | |
|---|---|---|---|---|
| | | | | suggesting good durability |

## 2.14 Prospect of Hydraform brick

The utmost attribute of hydraform is the availability of its constituents in quantum; the materials required in its production are locally sourced and, if not directly on building sites, thereby reducing the cost of transportation and the gaseous emissions that could have been associated with transportation. Its use and production do not require highly specified equipment.

### 2.14.1 Advantages of hydraform brick

Using the hydraform brick system in construction has several advantages; the brick reduces the use of mortar and construction time when compared to the conventional concrete blocks, and by constructing load-bearing walls without the need for timber formwork, it also contributes to reduced construction costs by lowering the cost of walls, the advantage of hydraform brick construction system according to (Nurul et al., 2018) can be summarised as:

- No formwork required.
- High rigidity.
- Construction cost is cheaper by 20% when compared with the conventional concrete block.
- Flexibility in design and planning.
- Resistance to an earthquake.
- Very eco-friendly

The ease of creating hydraform brick is the most significant advantage; according to (Zami & Lee, 2011), the adaptability and ease of the knowledge transfer between various stakeholders in the building construction industry are made possible by the flexibility and simplicity of the technology incorporated in the production of the hydraform brick, enabling both individuals and communities to easily take part in the construction of their own homes on a budget.

According to (Hadjri et al., 2007), most metropolitan locations in Africa cannot afford to construct homes using conventional materials since transportation costs account for about 40% of the overall material cost; utilising hydraform bricks lowers the material cost because transportation expenses are much decreased, making it a far more practical choice for underprivileged populations.

The Hydraform building method has the advantage of saving money on both construction and transportation costs. Additionally, using these blocks doesn't require high technical knowledge, and anyone can pick them up quickly. It is also kind to the environment and makes an excellent insulating material. The blocks are faster to build with and offer a high level of polish and aesthetics. (NBRRI, 2020)

According to (Godwin, 2020), the following advantages of using hydraform were noted.

- The use of hydraform brick leads to faster construction.
- Rendering of the external wall is not required.
- There is little consumption of cement.
- Professional masons are not required.
- When compared with the conventional concrete block, the hydraform brick has better thermal properties.
- The hydraform brick has an attractive finish with the possibility of using other colours, which is dependent on the soil used.

(Waziri, Kadai & Biu, 2014) further contributed to the numerous advantages of the hydraform building system as follows:

- The constituent materials to produce the brick are usually available locally in most regions.
- The materials are suitable for most weather conditions.
- The materials can easily be recycled.
- The usage of the brick results to free maintenance.

- Its production can be on-site or in a centralised production unit on a very large scale.
- Its cost-effectiveness reduces its life cycle cost.
- It can be produced manually or mechanically.

### 2.14.2 Disadvantages of hydraform brick

Acceptability is one of the biggest obstacles preventing hydraform brick from becoming the preferred option of building materials among experts, lawmakers, decision-makers, and the client. The unfavourable attitude about building with hydraform brick will be changed through raising knowledge and understanding of environmental issues such as air pollution, deforestation, land degradation, energy access, and affordability (Zami & Lee, 2011)

According to (Alagbe, 2009), due to the area being impacted by medium and heavy rainfall, the durability of hydraform brick in exposed sections like the gable end will be diminished; as such, it must be routinely maintained and adequately covered. Additionally, it is claimed that hydraform brick has a low resistance to impact and abrasion, particularly during earthquakes.

According to (Adam & Agip, 2001), hydraform brick should only be utilised in compression, such as bearing walls, domes, and vaults, since its low tensile strength makes it ineffective at resisting bending forces.

According to (Godwin, 2020), the following disadvantages of using hydraform were noted.

- Locating the correct type of soil that is expected to contain 5-20% clay is challenging.
- There is poor control of the quality when produced on site.
- The technology depends on the construction site's location for high-cost savings.
- There may be a need to render the wall to minimise water penetration because of erosion over a period.

(Waziri et al., 2014) also highlighted some dissatisfaction with the usage of the hydraform brick as:

- The delay encountered in the production of the brick when it requires a large volume of work invariably distorts the construction schedule.
- The absence of quality control which may lead to poor quality bricks
- The lack of trained and qualified personnel handling the brick production.

## 2.15 Comparative cost analysis of hydraform brick

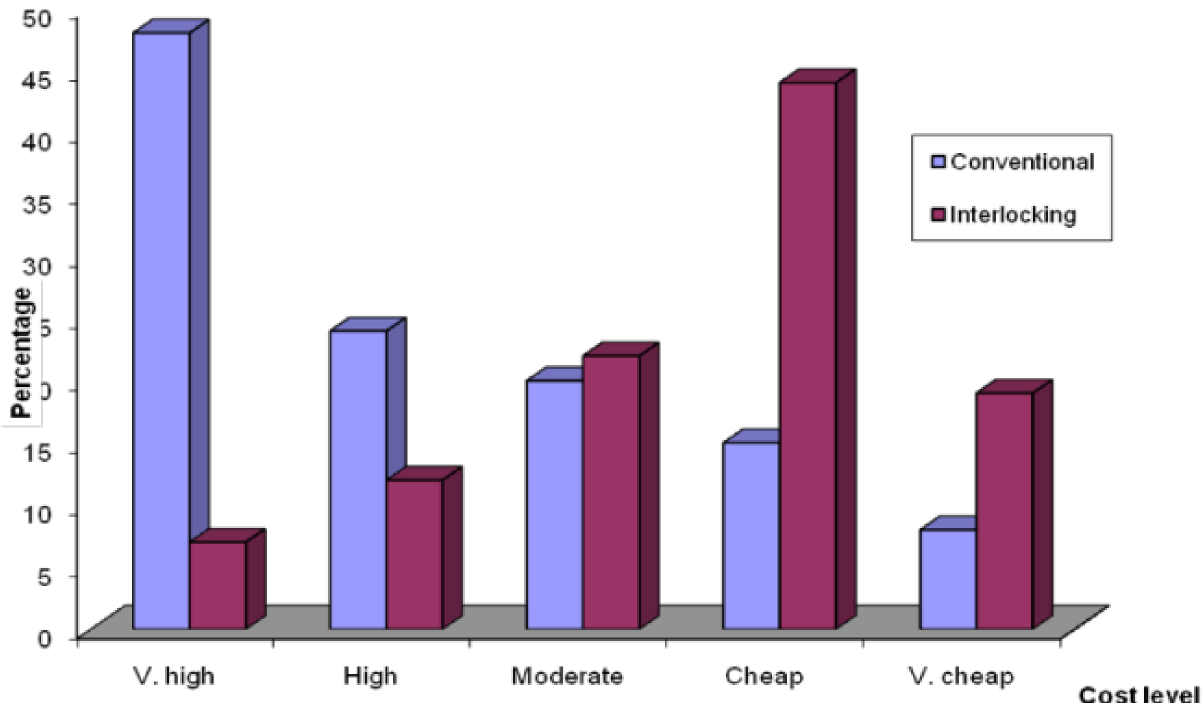


*Figure 14: Comparative cost of conventional concrete block and hydraform brick*[19]

(Adedeji & Fasakin, 2011), sampled the opinions of respondents to seek and assess the relationship between the costs of materials and affordability as shown in Fig 14, it revealed that hydraform bricks (interlocking) with its high content of local material that is

[19] Source: (Adedeji & Fasakin, 2011)

available in large quantities is cheaper compared to the conventional concrete blocks, which is essentially a product of cement.

(Adejumo & Ade, 2016) sourced data from Osun state in Nigeria through the Osun State Property Development Corporation (OSPDC), a government agency for property development; it was gathered that a meter square of the conventional concrete block cost ₦6,500. In contrast, a meter square of hydraform brick cost ₦5875; it was concluded that the cost for the hydraform brick could still be reduced if there were more producers of the brick, as that would create competition; the report further noted that the difference in price cost could be attributed to the absence of mortar while setting the bricks and also does not require plastering and painting as the surface could be left bear with its aesthetic qualities.

A comparative production cost analysis was carried out by (Aligamhe, Alao, & Dania 2020) between the conventional concrete block and the hydraform brick; the materials were sourced from the Auchi and Agbede area of Estako in Edo State, Nigeria. The production cost for a unit of the conventional concrete block cost ₦168.57, while the production cost for the hydraform brick cost ₦57.85. The report explained that besides the base mortar, which is needed to connect the first course of the hydra form brick wall to the floor, no mortar is needed for the remaining courses of the hydraform walling system. Compared to the conventional concrete block, the amount of mortar used was significantly reduced due to the absence of mortar bedding and jointing in the hydraform brick walling method. The findings showed that applying finishes to concrete block walls is more expensive than applying finishes to the hydraform brick wall; the concrete block walls need to be rendered or plastered, which involves applying a smooth coat of material to the walls to give them a smooth, joint-free surface that is hygienic and easy to decorate, it also hides any unevenness in the block wall. On the other hand, hydraform brick walls save a lot of plastering costs because they don't need to be rendered or plastered. Concrete block walls and hydraform brick walls can be painted, but hydraform bricks are also aesthetically beautiful and might not need to be painted. The study recommends:

- Using hydraform bricks to create affordable housing will help with the housing need.

- Government to provide mass housing schemes using the hydraform brick for affordable housing.
- The technology involved in the production of the hydraform brick to be commercialised by the construction industry

(Olusola & Deborah, 2020) further detailed a cost comparison between the hydraform brick and the conventional concrete block from a three-bedroom floor plan using the market survey of Akure, Ondo state in Nigeria. The cost estimation was based on the measured floor area of 116.89m$^2$, with a wall estimate of 303m$^2$. The report gave the cost per unit for hydraform brick as ₦80.08 while the conventional concrete block was at ₦347.20; it further estimated the material cost as ₦1,214,232.64 for hydraform and ₦2,080,516.15 for the conventional concrete block which translates to ₦10,378.06 per meter square (m$^2$) for hydraform and ₦17,782.19 per meter square (m$^2$) for conventional concrete block, which implies there are 41.6% savings in the procurement of materials. It was estimated that the laying of the hydraform brick would be for 32 days while the conventional concrete block was for 40 days; with the same gang of workers, laying the hydraform brick will cost ₦120,000.00 while the concrete blocks cost ₦200,000.00, which implies 40% savings on labour cost.

From the comparative cost analysis done by (Nasiru & Umar, 2021), the hydraform brick was compared to the conventional concrete block through the extract in a bill of quantities of the superstructural works of a proposed two-bedroom bungalow. Below is the summary:

**Summary using the conventional concrete blocks**

| | |
|---|---|
| Super structural works: | ₦1,180,788.00 |
| Add 10% contingency: | ₦118,078.80 |
| | ₦1,298,866.80 |
| Add Profit and overhead at 25%: | ₦324,716.67 |
| | ₦1,623,583.50 |
| Add V.A.T (5%): | ₦81,179.175 |

Grand Total **<u>₦1,704,762.68</u>**

**Summary using the hydraform bricks**

| | |
|---|---|
| Super structural works: | ₦327,638.00 |
| Add 10% contingency: | ₦32,763.80 |
| | <u>₦360,401.80</u> |
| Add Profit and overhead at 25%: | ₦90,100.45 |
| | <u>₦450,502.25</u> |
| Add V.A.T (5%): | ₦ 22,525.11 |
| Grand total | **<u>₦473,027.36</u>** |

From the summary above, the conventional concrete block and the hydraform bricks have a cost of ₦1,704,762.68 and ₦473,027.36, respectively; the result showed that the use of hydraform brick saves cost as against the conventional concrete block. From the study, households built with hydraform bricks were few compared to the conventional concrete blocks in the Kaduna metropolis of Nigeria. Despite its cost implications, it was observed that there was low awareness of using hydraform bricks in the study area (Nasiru & Umar, 2021). It was recommended from the study that:

- Building industry experts should promote using hydraform interlocking blocks as a substitute material for constructing low-cost dwellings.
- There should be sensitisation with sustainable alternative materials for building construction.
- The federal government should apply relevant regulations to regulate the building industry's output and enforce contractors to use quality assurance professionals when working with sufficiently large contractors.
- Construction industry specialists should transfer their knowledge to develop advanced approaches to guarantee effective quality control.

## 2.16 Acceptability index for hydraform bricks

It has long been introduced in the most industrialised nations that the old and conventional technologies used for building construction and maintenance are ineffective and resource-wasting due to the significant resources required. As a result, there is an increasing need for their technology to be developed further (Ghosh, 2002). The utilisation of hydraform is expanding; a 60-unit housing estate in 1991 at the University of Lagos, Lagos State, was the first known use of the hydraform brick in Nigeria (Olusanya & Deborah, 2001). As a strategic approach to housing distribution and an engine of growth in a booming Nigerian economy, it has developed into a prototype for urban housing. The Nigerian Building and Road Research Institute (NBRRI) demonstrated how to use the hydraform brick in Nigeria's largest cities, including Lagos and Abuja.

(Adedeji & Fasakin, 2011), discovered from his study and analysis, as shown in Fig 15, that the high rate of acceptability of hydraform by the building construction stakeholders was a result of the cost-effectiveness, accessibility, suitability, and adaptiveness to the tropical climate.

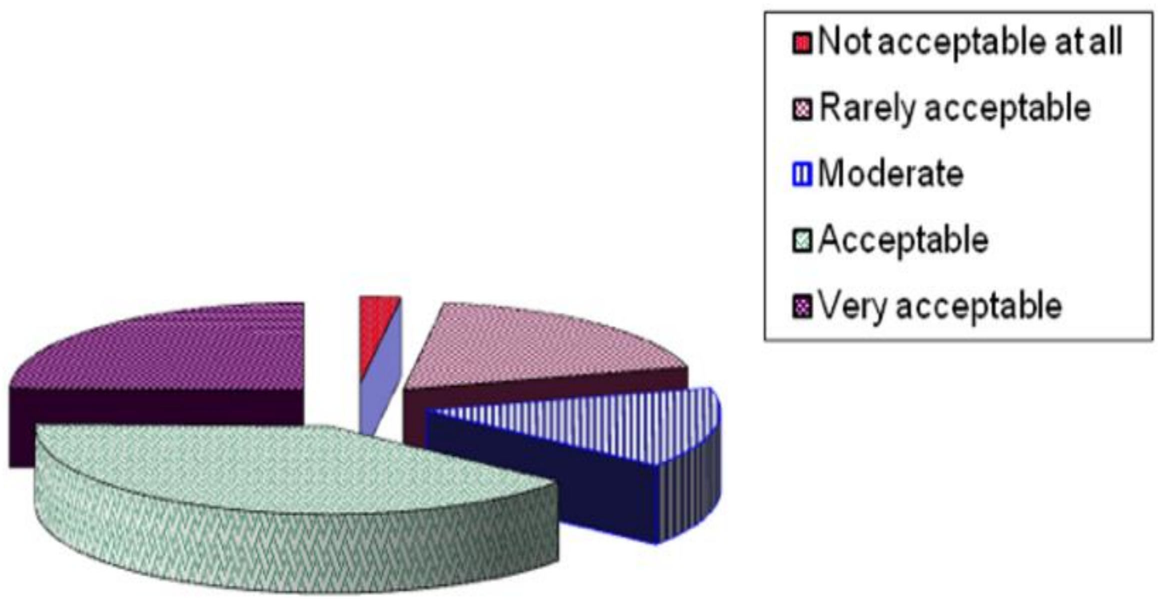


*Figure 15: Rate of hydraform brick acceptance*[20]

[20] Source: (Adedeji & Fasakin, 2011)

The growing use of interlocking blocks in both private and public construction projects can help further to strengthen their suitability for use in construction projects. Hydraform brick can quickly replace the conventional concrete blocks in the delivery of homes due to their high compatibility and acceptability for construction. As Nigerian society gains more advantages from the material compared to traditional varieties, the level of acceptance is sure to rise. Hydraform bricks have recently seen increased demand in the building industry due to the time, labour, and cost savings that have been seen. Due to the removal of vertical joints and improved alignment made possible by the hydraform brick characteristic, thin-jointed and mortar-bedded cases were found to be constructed more quickly than the conventional concrete blocks; when assessing the opinions of respondents regarding their desire to use these materials, the tendency toward the preference for the usage of both interlocking-block masonry is further investigated. Most respondents preferred interlocking blocks (83.4%), as depicted in Fig 16, because they speed up the construction of walls, save time, require less labour, and are more affordable. As new improvements are made, and user confidence levels rise, the degree of liking for using the material will also rise. Therefore, using the material in place of traditional concrete blocks is highly advised (Adedeji & Fasakin, 2011).

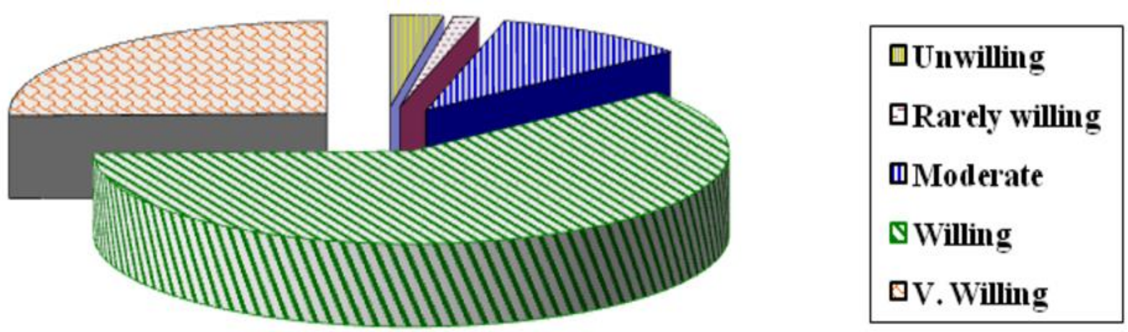


*Figure 16: Rate of willingness to utilise hydraform brick*[21]

[21] Source: (Adedeji & Fasakin, 2011)

## 2.17 Carbon Emission in Hydraform brick Construction

The building construction industry contributes to the increase in carbon with its high carbon emissions that are produced by the buildings and influence climate change; the hydraform bricks technology is an upgrade over the conventional concrete block production, which fabricates bricks using a compressed process (without firing), hence lowering carbon emissions (Asman et al., 2019). When a building is designed, specified, and built, embodied energy and carbon emission are typically not considered; the hydraform brick technology reduces the carbon emissions because they are not fired (Razali et al., 2017). The energy used during production and the carbon emissions produced distinguish between hydraform brick and conventional concrete blocks. In comparison, concrete blocks create (143 kg CO2/tonne), conventional fired clay bricks create (200 kg CO2/tonne), aerated concrete blocks create (280–375 kg CO2/tonne), and hydraform brick produces 22 kg CO2/tonne during production (Nasly & Yassin, 2010). Compared to similar fired clay and concrete masonry units, hydraform bricks required less than 10% of the input energy (Abidin, 2009).

## 3.0 Research Methodology

### 3.1 Introduction

This chapter outlines the methodology deployed for the research, which uses case studies and interviews.

The goal of the thesis is to explore the utilisation of hydraform bricks as an alternative to the predominant use of concrete blocks. The relevance of the case study and interview will be described in this section.

### 3.2 Research strategy and Methodology

Different scholars have defined the word “Research”. According to the Oxford English Dictionary, research is analysing and examining materials to determine facts or achieve a reasonable conclusion. According to the Longman Dictionary, it is a careful examination of a study designed to find more facts or test ideas.  (Neuman, 2006) described the research as a method for generating solutions from a collection of inferences to solve a specific problem. Research doesn't just happen; it must capture the researcher's attention to find a remedy to such an issue to define a fact and improve the users' condition. (Kerlinger, 1873) defines research as a systematic, empirical, controlled, and critical examination of hypothetical claims about natural phenomena's putative relationships. Research is incomplete Without identifying and describing the approach, techniques, and tools. Research methodology is described by (Easterby-Smith, Thorpe, & Lowe, 2002) as a set of methods or procedures for investigating an issue. (Crotty, 1998) defined 'Methods' as the strategies or processes used to collect and analyse data connected to a research question or hypotheses in a more detailed and particular manner.

(Love, Holt, & LI, 2002) proposed two strategies: interpretivism (also known as the phenomenological approach) and positivism (also known as the phenomenological method). The first strategy is drawing inferences from qualitative research that has generated a conclusion that can contribute to knowledge. (Blumberg et al., 2005), advanced the second method by defining positivism as knowledge gained through quantitative study to demonstrate a fact.

To maximise the use of the research knowledge gathered, fundamental models for driving a specific field of study in relativity should be followed.

- **Bias**

This effect may impact the nature, access, and analysis of data gathered for the study (Leedy & Ormrod, 2001). (Neuman, 2006) emphasised how self-belief and personal convictions can permeate research, influencing the findings or preventing data collection. The behaviour may happen at any time while the data is being collected, and it would subsequently be analysed to generate an output that contains personal data (Fellows & Liu, 2003). A good researcher should be impartial toward the topic under investigation and prepared to identify any biases in the data that have been provided.

- **Validity**

This describes the feasibility of the study in connection to the data acquired in the researcher's thinking (Fellows & Liu, 2003). According to (Yin, 2003), validity should be correlated with every ounce of correlation to the project's intended objectives, which include obtaining adequate knowledge accessible. Also, ensuring that the improvements made during the research contest fill the gap in change that was intended to be filled.

- **Reliability**

It is stated that the study and relative results should have a consistent outcome using established testing methods (Yin, 2003). The concept of reliability should lead to an understanding that the outcome should be consistent at the end of the testing process so that it may be scrutinised further.

### 3.3 Interviews

Interviews are one of the most significant bases of case study information (Yin, 2003). The interview was designed to target people directly involved with using the hydraform brick in building construction which is the cause of concern for this research. This case study research focused on the performance of the organisations or companies that used the bricks but on how they utilised the bricks in their constructions.

### 3.4 Case study

According to (Fellows & Liu, 2018), the case study research approach offers significant knowledge and a clear comprehension of the subject to be researched, as well as insight and ideas to validate the events. This research method is proven effective in conducting in-depth investigations and helps in offering a strategy that can be valuable for upcoming projects. Using the case study approach, one can assess the realisation of the focused solution through an existing sample.

### 3.5 Procedure for case study

The procedures to gather the data used to present the conclusions in this chapter include.

#### 3.5.1 Planning the interviews

Before field research began, a collection of unstructured questions for most topics covered by hydraform brick were developed in advance. A company in the construction industry in Nigeria which had recently completed a project using hydraform brick was contacted. The project research background and a brief synopsis were provided to the company, after which the interview was planned to take place virtually through the Zoom application.

### 3.5.2 Conducting interviews

The interviewees were the owners of the company, who had directly specified and utilised the hydraform bricks. They were knowledgeable about the use of the brick as they had researched its uses. The interview was recorded through the Zoom application with the express permission of the participants.

### 3.5.3 Presentation of the interview data

The responses from the interview on using hydraform bricks as an alternative construction material were compiled, which will be discussed in the next chapter. However, while checking the suitable presentation method of the qualitative data, the coverage of the responses converged with technical, economic, social, and environmental themes.

### 3.5.4 Analysis of the results

The interview analysis will be interpreted to get the intrinsic value of the subject matter.

# 4.0 Findings and Discussion

## 4.1 Case Study (An Event Centre built with hydraform brick)


*Figure 17: Completed project with hydraform brick*[22]

The building chosen as the case study is a completed project located in Ilesa, Osun State, Nigeria. It is an Event Centre with the ground floor plan shown in Fig 18. The completed project is shown in Fig 17. The event centre has a capacity of 500 seats, with a gallery on the first floor; the building occupies a gross floor area of 427.151m$^2$. The event centre has supporting spaces like a store, kitchenette, conveniences, and an office. The structure was built with a frame structure system, where the columns and beams were made with reinforced concrete. This chapter is dedicated to analysing the project through the company's use of the hydraform brick. The study explores the use of the hydraform brick and its affordability. Most projects in Nigeria adopt the conventional concrete block system to construct their building; it is known from literature and practice that this conventional block system consumes a high embodied energy in its production and contributes to high carbon emissions. The case study was chosen based on its utilisation of the hydraform bricks and the willingness to solve the menace of the rising cost of construction and create affordable housing units for the low-income in society.

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[22] Author

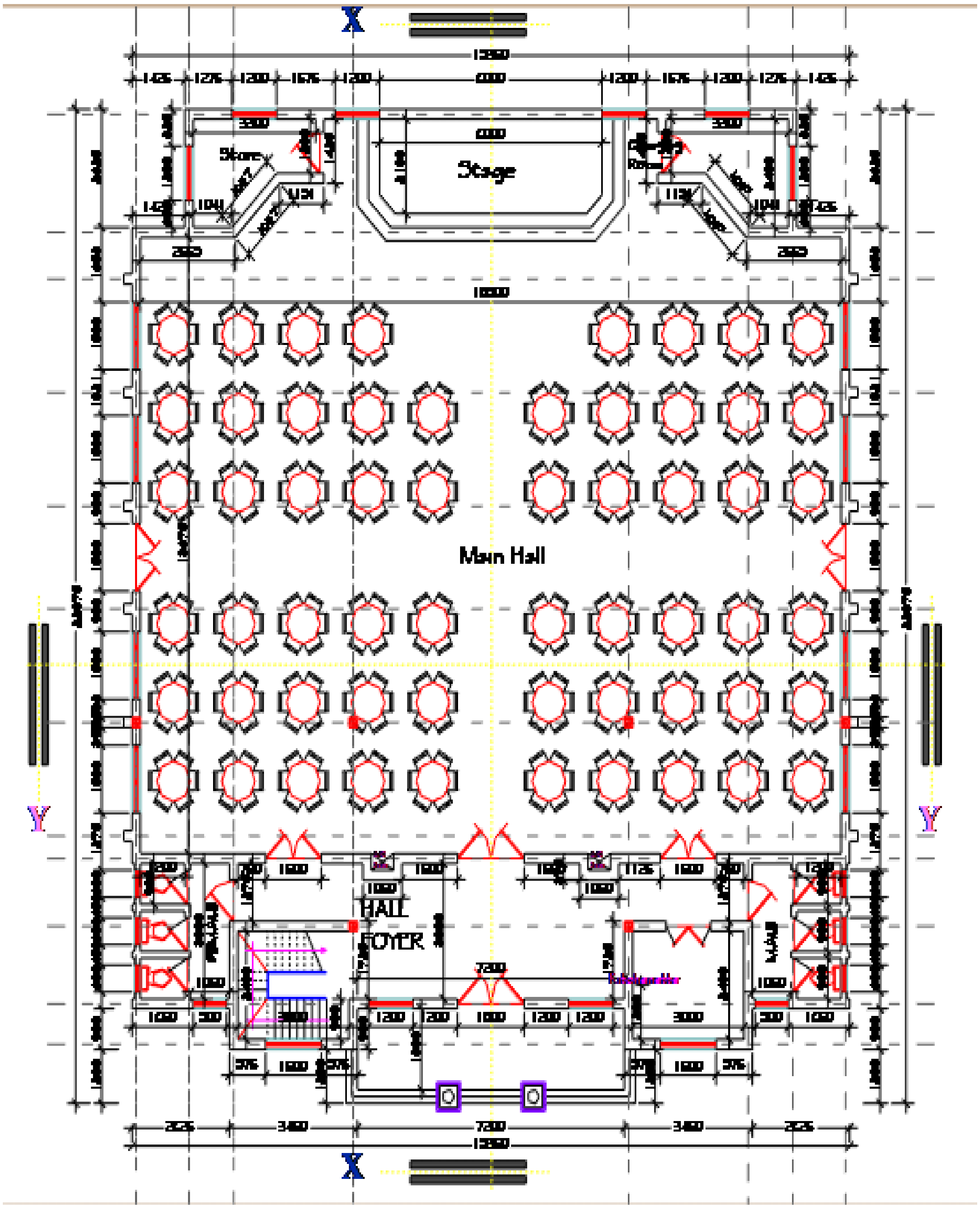


*Figure 18: Ground floor plan of the event centre*[23]

[23] Author

## 4.2 Company Organisation Structure

The company was founded by a couple, a Civil engineer and an Architect. It is an indigenous company whose services include the construction of buildings and other civil engineering infrastructure, with the prospect of creating a niche in the construction industry through research and development.

## 4.3 Data Collection

The summary of the data collected is described in Table 6

*Table 6: Data summary for case study*[24]

| S/No | Description | Data |
|---|---|---|
| 1 | Type of project | Event centre |
| 2 | Project category | Commercial development |
| 3 | Project location | Ilesa, Osun State, Nigeria<br>7°38'48.1"N 4°44'16.9"E |
| 4 | Project commencement | November 2020 |
| 5 | Project completion date | 30th September 2021 |
| 6 | Project duration | Ten months |
| 7 | Project cost | ₦25,000,000.00 |

**Challenges with using hydraform bricks.**

The challenges encountered in this case study with the use of the bricks are:

- New method of construction.
- Insufficient lateritic soil on site.
- Prolonged timing to source for the material.

**Approach to solving the problems**

It is crucial to have plans in place to handle the difficulties that will arise during construction; there is no construction work without its peculiar challenges, the challenges

[24] Author

could either be major or minor and the combination of little solutions, and attention to the minor details may be the key to resolving complex building flaws.

The company adopted the hydraform brick method for their construction project as a new approach because they had not used it before. This was necessitated because they researched the performance of the hydraform brick as an alternative to the conventional concrete block, which was at the time scarce and expensive. The client was intimated about the plans to change the scope of the project with the introduction of the bricks, which fortunately was approved due to its uniqueness in that community. However, the lateritic soil present on site was insufficient to produce the brick as many bricks would be needed; it had to be outsourced to cover for the deficit, which due to logistics, took time to get sorted. The outsourced bricks were brought to the site and stacked ready to be used, as shown in Fig 19.

*Figure 19: Stacked hydraform bricks*[25]

[25] Author

*Figure 20: Lintel made with steel*[26]

The hydraform bricks were mainly used for walling and, in this case, do not require plastering or rendering as the client appreciated the inherent aesthetics of the brick. Lintel made with steel was used to reduce the project's concrete volume, as shown in Fig 20 and Fig 21.

[26] Author

*Figure 21: Lintel positioning*[27]

The reinforced concrete column and beams in the project were plastered, rendered, and painted to enhance the aesthetics of the building further, as shown in Fig 22

*Figure 22: Rendered columns and beams*[28]

[27] Author
[28] Author

## 4.4 Research questions and answer

The results of all the work put into this study will be used to answer the research questions that were previously outlined. In other words, the answers will be obtained from the research of relevant sources, the case study, and the interview.

### 4.4.1 What challenges the construction industry in utilising Hydraform brick as an alternative construction material?

The construction industry is a high-risk and capital-intensive industry, therefore must be sensitive to the nature of its development. Despite the enormous advantages of the hydraform bricks in the construction of buildings, the level of utilisation is alarmingly low compared to the conventional concrete blocks. Concerning the interview, it was deduced that breaking a trend in the housing sector is challenging and at a slower pace; before the advent of the conventional concrete blocks, houses were built with mud, which later transcended to mud bricks and then to the conventional concrete blocks; this has been the sequence. The advent of concrete blocks took over the market, making them readily available when needed, and the prices were going higher as the demand continued to increase.

Due to sustainability, carbon footprint and embodied energy, materials are being modified to meet the current standards and requirements of eco-friendliness. Mud bricks have been modified by stabilising them with various constituents such as lime, cement, etc., thereby reducing their carbon footprint, and it involves little or no embodied energy in their production. Therefore, returning to the modified mud brick, now known as hydraform brick because of its production with a hydraulic press, will be challenging and require proper awareness and sensitisation.

(Waziri, 2014) also noted some challenges that the construction industry is facing with utilising the hydraform bricks, which are due to issues with its production, such as production delays, lack of quality control, unskilled machine operators, and untrained personnel handling the production, as well as issues with construction, such as the lack of trained masons for wall construction.

(Alagbe, 2011; Ng‘ang‘a, 2013) noted other challenges to the use of hydraform brick as a critical material in building construction, such as lower durability of structures built with the brick if not routinely maintained and appropriately protected, particularly in places impacted by medium to high rainfall, limited resistance to abrasion and impact if not sufficiently reinforced or protected. Minimal acceptability amongst most social groups and the material is presumed to belong to the second class, termed poor people.

### 4.4.2 What factors can influence the acceptability indices of hydraform brick as an alternative material?

Several factors can be responsible for enhancing the acceptability of hydraform.

- **Aesthetic value:**

This refers to the outlook of the structure; hydraform bricks generally have a monotonous appearance as they display their interlocking pattern with a single colour; these colours depend on the nature of the soil used and can also depend on the client’s choice to apply a different colour paint. However, its appealing nature can improve the willingness and acceptance level of the public.

- **Cost-effectiveness:**

This is a significant factor in accepting to use the of hydraform bricks. The construction industry is capital-intensive and requires a considerable amount of investment. However, effective cost management while achieving a sound output will gear towards a high acceptable index.

- **Awareness:**

Proper sensitisation of the hydraform bricks with its benefits can help increase acceptability. The professionals in the building industry are in the best position to help the awareness of the materials. At the same time, the government could instil laws to regulate the building industry such that materials with high embodied energy and high carbon emissions are discouraged from being used.

- **Availability:**

This could enhance acceptability when the needed constituents are easily accessible without delay or compromise.

- **Low maintenance:**

This is an attribute that encourages house owners, the ability for a property to demand less attention after it's been built or not tending to cause problems that could require extra time and finances.

### 4.4.3 What risk is involved in using hydraform brick as an alternative construction material?

The only significant risk involved when using hydraform bricks, as it was gathered from the interview that algae could grow on the bricks if not adequately treated. This situation was treated by adding stone dust (a finer granite particle) and lime to the mixture during production.

## 5.0 Conclusion

The entire thesis's concept and supporting data are covered in this chapter. It starts with a summary of the research's findings and is followed by conclusions drawn from the findings. This part and the fundamental research are concluded with recommendations for possible actions or additional study.

This study concludes that using the hydraform bricks in construction can significantly benefit its users and the environment as it uses primarily natural raw materials readily available in large quantities; it was deduced that its utilisation is cost-effective with an average savings of 40% against the conventional concrete blocks.

There is willingness and acceptance of using the hydraform brick as an alternative construction material because of its performance and attributes when specified for construction. As more of it is made accessible on the market and more homes are constructed using it, its popularity will increase.

This development can help reduce the estimated housing deficit in the country through its cost-effectiveness and faster construction method, thereby improving the people's standard of living, particularly the middle-income earners.

## 5.1 Recommendations

Following the findings of this research, it has instigated some measures on utilising the hydraform brick for sustainable project delivery. However, some recommendations are expressed:

Governments should demonstrate an essential role by utilising the hydraform bricks in executing public projects, thereby enabling a favourable market for firms to take up inventive approaches to alternative construction materials. This aligns with the report of (Hampson, Kraatz, & Sanchez, 2014) that governments in many nations provide a range of incentives for private companies to make the most of their Research and Development (R&D) expenditures, from direct subsidies to Research and Development tax concessions, also incentives to promote the use of efficient building materials.

Building professionals are recommended to adopt the usage of the bricks by specifying them for the construction of houses.

**Declaration of Authorship**

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Location, Date

Signature of the student

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