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Indigenous knowledge as a key to sustainable architecture: western Africa

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Dissertation

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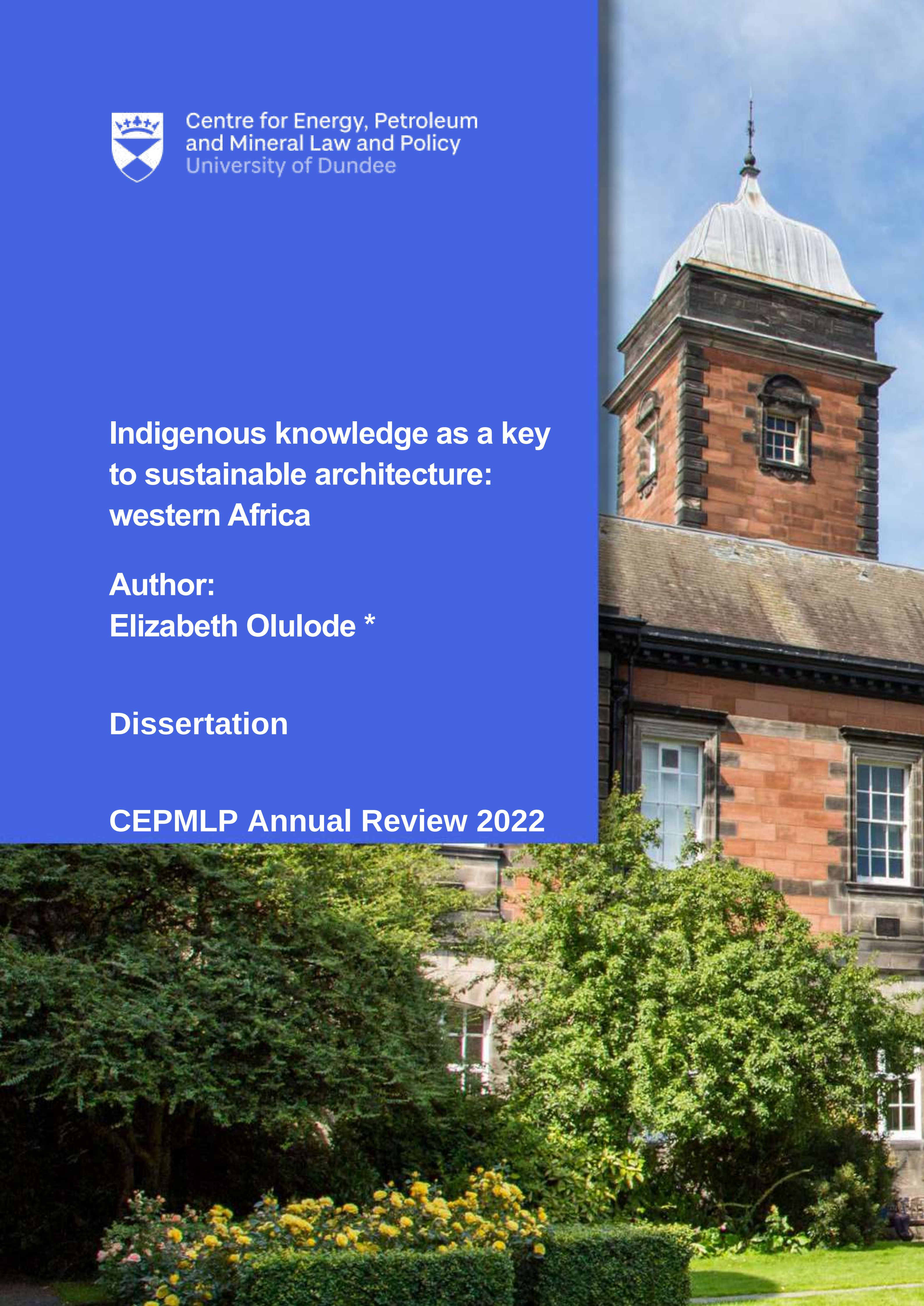

Abstract

A domestic building's fundamental purpose is to provide a comfortable environment, protected from the extremes of the climate, as well as respond to site, setting, and context. However, over the years, the building sector has become one of the largest energy consumption sectors (alongside food, and transportation) that together place a substantial and increasing burden on the environment [1]. The building sector, directly and indirectly, is itself responsible for 40% of the energy use, material use, and greenhouse gas (GHGs) emissions in the world [2].

West Africa, like many other world regions has been facing serious challenges in attempts to meet sustainability goals, and adapt to the changing climate. One of the forms that this challenge takes is to actively threaten the regions current architecture practices. Modern buildings stand against the needs of the environment in which they reside therefore, making the design unfit for its context. Moreover, the increasing influence from Europe in building sector has undermined the prevalence of traditional, environmentally sustainable, structures in the region. However, all is not lost and these traditional forms of architecture still offer benefits, over Modern alternatives.

For this reason, the hypothesis that indigenous architecture practices can be a solution to assist in reducing carbon emissions in the context of West Africa was formed. The results show that some principles that West African indigenous people abide by do indeed reduce the amount of carbon emissions. Although there are limitations such as to the absence of information available for the West Africa region and lack of continuity in cultural practices due to colonisation, it is evident that sourcing materials locally is one of the keys to a sustainable built environment. The study concludes by affirming the hypothesis that West African typical traditional building techniques and design result in less environmental impact vis-à-vis Western architectural modes.

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1. Introduction

1.1 Background

The phrase “sustainable development” can be defined in numerous ways. However, according to the United Nations, it is described as a development that meets the needs of the present without compromising the ability of future generations to meet their needs [4]. Other definitions directly focus on specific aspects such as environmental, socio-cultural, economic and all development policies [4],[6],[7],[8].

Within the architecture practice, a constructed building, particularly a family dwelling, is designed to provide a comfortable living environment that is sustainable and protects the users from the extremes of the climate. As well as this, it must respond to its immediate site, setting, and context [3]. However, over the years, the building sector has become one of the huge consumption sectors which places an increasing burden on the environment [5]. The activities within the building sector in developed nations are responsible for 40% of the energy use, material use, and GHGs emissions in the world [2]. As West African countries continue developing towards the same standards, this can further exacerbate climate issues. In the case that all regions in the developing world increased their energy usage to the 2008 level of the developed world, their energy use would escalate to four times the current amount [9]. This change is incompatible with the sustainability goals written in the 2015 (effective 2016) United Nations climate change treaty, the “Paris Agreement”, and ratified by all 17 countries in West Africa [14]. Although building technological standards continue to evolve over time, the current trajectory in which West Africa is headed, by mimicking European architecture, could cause further environmental consequences.

The current planetary emergency defies humankind with a crisis that is environmental, due to the misuse of resources; social, because of the ascent of inequalities; and economic [15]. By continuing to consume these resources in large quantities, we risk material scarcity and many other threats to humanity [13]. This has not always been the case in the building industry however, vernacular architectural designs were built using indigenous knowledge by adapting to their surroundings and abiding by sustainable principles using local materials and technology [16], offering rational solutions to the harsh climate and human needs.

Within the built environment, it is sufficient to look to the past: instead of envisioning solutions, it can be reimagined through traditional examples [94],[95]. This paper proposes the hypothesis that cultivating sustainability practices in different disciplines does not always have to consist of new present-day solutions, instead we can look to the past, to more traditional examples of sustainable building. Hence the question: Can we use previous indigenous knowledge as a driver to reverse environmental degradation?

This research will focus on three countries in West Africa: Burkina Faso; Ghana; and Nigeria. The criteria for the selection of these countries included their similar policies, European influence, as well as the amount of documented architectural history currently available.

1.2 Challenge

This section depicts the central issue that this dissertation will address. Western Africa, like many other regions of the world, has been facing serious challenges in its attempt to adapt to the changing climate. One of the main contributors to these difficulties is the marginalisation of Africa's traditional architectural knowledge [17]. Research demonstrates that western Africa was rich in traditional architecture, however, in the pursuit of being progressive in development and living standards, their architectural designs as well as other parts of their livelihoods have been increasingly Europeanised [10]. Traditionally, the local cultures within West Africa used sustainable resources for buildings, with construction characterised by cost-effective use of resources, use of easily accessible building materials, and design adapted to the African context [11]. However, the increasing influence from Europe in the building sector has endangered sustainable architecture, thus posing significant harm towards environmental sustainability [12]. In light of the above, should West Africa's building sector continue to adopt practices of more Western and industrialised societies, there will be a further detrimental impact environmentally. Therefore, the present research has been organized to explore the possibility and feasibility of indigenous knowledge restoring sustainable architectural building practices in West Africa.

There is a lack of written data that encompasses the history of West African indigenous dwellings. However, in parts of the western African region, the continuation of vernacular architecture has been passed on through generations.

By isolating, identifying and cherishing the key elements that traditionally allowed for more sustainable dwellings, West African countries will have the ability to then fully incorporate those elements and hence develop their architectural, built environment and construction sector in an environmentally-friendly way that also suits their particular climate, societies, culture, heritage, and economies.

1.3 Aims and objectives

As the title suggests, the following section states the intended outcome of this thesis and the purpose of the investigation.

The aim of the current research is to explore the role and significance of traditional knowledge in promoting sustainability within the building sector of West Africa. This aim is fulfilled through the following objectives, namely to:

I. explore the significance of traditional knowledge for the building sector of West Africa; and
II. compare the traditional and modern buildings through empirical modelling and sustainability indexes to assess their impact on the environment.

The main research question guiding this study is to investigate the characteristics of indigenous architecture, its positive and negative attributes, and how this can support future site-specific sustainable goals. The supporting research questions are stated as follows.

I. what defines west African indigenous architecture?;
II. how does it differ from how architecture has evolved and adapted to the current climate and social needs?;
III. how can indigenous knowledge further improve the built environment sustainability progress in western Africa?; and
IV. what challenges are faced by reverting to indigenous architectural styles?

This dissertation research topic builds on previous literature which defines a sustainable dwelling, indigenous knowledge on vernacular architecture, and refining the link between both concepts. As global goals continue to promote fewer GHG emissions through policy and ratifying the environmental agreements. it is important for communities to take action and adopt creative solutions to meet these targets.

This study's first step is to acknowledge the benefits and weaknesses of indigenous architectural history through identification of the varying building styles which informs the sustainability aspects of the West African built environment practices.

The scope of this paper is limited to the west of Africa, particularly focusing on three countries and domestic constructions within this region. Due to the lack of documented information on historic dwellings, this paper encompasses a broad location with similar values.

2. Methodology

2.1 Introduction

This section addresses the approach taken in this thesis project. It explains the choice of methods used to explore the research questions and the reasoning behind this.

In accordance with the interdisciplinary aspects of my educational path, and the modules I took part in during my degree studies, the strategy used for this research draws on knowledge gained in multiple university modules and independent research. These strategies include evaluating previous literature; reviewing policies; analysing the benefits of materials and design techniques using modelling software tools; and social exploration strategies.

Furthermore, the purpose of this investigation is to address real-life sustainability problems within the built environment using the various methods listed in the upcoming sections. The strategy includes a combination of an overview of the previously published works relevant to the topic and software modelling to compare the energy and environmental performance of chosen dwellings.

2.2 Literary review methodology

A literature review is an extensive summary of written works that exists to strengthen the foundation of knowledge on a particular research topic [19]. This method is reported to facilitate an in-depth study of a topic, concept and idea [18].

In order to understand the previous history regarding the built environment in western Africa the first research phase was included to determine the criteria for what defines indigenous architecture within the chosen countries. This identified key themes in previous literature to identify and evaluate the elements that are included in the design of indigenous dwellings and the ideologies that were implemented to make the constructions sustainable for the particular site and context. Examples of traditional buildings built by locals in the region were explored to further understand the logic behind the design.

The selected literary works were limited to those written in English and available online due to the lack of access to physical libraries during the 2020/21 global pandemic. Material explored particularly focused on villages that have been less subjected to Europeanisation as they are most likely to contain the last of indigenous architecture that remains. The initial stage of the literary review involved online searches of keywords in relation to the topic of indigenous architecture, comparing this to modern architecture. Following this, the abstracts of the texts were used as a deciding factor to ensure their relevance in contributing to the research outcomes.

These literary works chosen were identified using resources from the University of Dundee Library (online), online search engines and journal databases.

2.3 Policy

The policy can be a huge driving force in implementing sustainability practices into various sectors [20]. To acquire knowledge into the legislative issues regarding sustainability in the built environment within the context of west Africa, this study uses a policy review methodology to analyse current actions and future plans in place that are framing the construction activities. The extent of this investigation covers macro to micro levels which includes global, Economic Community of West African States (ECOWAS), and country specific legislations.

In addition to official documents, a revision of media articles and reports are used to gather insight into the public, private and non-profit sectors. Further understanding was achieved by this, especially concerning how the concept of sustainability has been understood and implemented in Burkina Faso, Nigeria, and Ghana.

2.3 Data collection

This section covers the qualitative aspects of the research project. To get a full understanding of how indigenous knowledge can further improve the built environment's sustainability progress in western Africa, it is important to find out what carbon qualities this style of architecture has. As part of this study, embodied carbon was focused on because this is a primary impact of construction.

The information gathered in the literature review provides an insight into the materials used by indigenous tribes in Burkina Faso, Ghana, and Nigeria. An analysis of these materials was conducted using The Bath Inventory of Carbon and Energy (ICE) database to provide statistics used to calculate an estimated level of embodied carbon in a single-family dwelling.

This research was then repeated using the data input of a similar house designed with modern materials in West Africa. The results of materials used in indigenous buildings and modern-day buildings were collected and compared to confirm or dispute the hypothesis that reverting to indigenous architectural styles is more effective in combating decarbonisation. Secondary to this, estimations of the operational carbon factors such as transport, construction process, and other aspects relevant to sustainability were also considered.

3. Understanding the role of sustainability in the built environment

Understanding the role of sustainability in the built environment The built environment can be described as "the human-made space in which people live, work and recreate on a day-to-day basis" [21]. The term encompasses a vast range of major divisions such as architecture, engineering, policy, economy, energy networks, transport, urban planning, water supply, public health, sociology, and anthropology, among others [22],[23],[24],[25],[26]. Prominent features that directly affect sustainable development in the built environment include the cost of factors which include homes, buildings, streets, zoning, open spaces, transportation, and more. In other words, this can be defined as man-made elements that are created to support human settlements [27].

3.1 Relationship between: built environment and sustainability

Current literature shows that the built environment is responsible for more than 33% of worldwide energy usage, the industry single-handedly produces almost 40% of worldwide energy related GHG emissions and, has so far depleted up to half of the total global raw material resources [90],[91]. This makes the sector the largest contributor to GHG emissions reducing these statistics is, therefore, a key solution to mitigating climate change.

In spite of these grave statistics, the destructive trend of exploiting the natural reserves continues. Its adverse consequences on the sustainability of the planet are also affected by the need for broader urban areas, increasing the pressure on the built environment sector. The significant drivers for outstanding growth yet to come in the urban communities are the rising total of the world's population, fast-growing cities in developing nations, longer life span of humans which increase the need for residential buildings, and modernised family structures. Therefore, in order to preserve the earth for future generations and tackle the current climate emergency, there is a need to prioritise the shift towards a resilient, inclusive, healthy, sustainable, and zero-emissions built environment. Enforcing better sustainable practices in the built environment sector will provide a healthy community for its inhabitants and contribute towards achieving the global sustainability goals [92].

The knowledge to build sustainably is available. Yet, it is an exemption and not the benchmark criteria in the modern world [93]. There is, however, a lack of emphasis on calculating how buildings perform in relation to carbon emissions generated by material use known as 'embodied carbon' and carbon emissions produced during the use phase of a building which is known as 'operational carbon' [97].

The solution to improve sustainable development depends on design strategies [98]. In the preliminary stages of design, environmental aspects regarding weather inputs are a huge factor in decision making [93]. In the case of West Africa, by mimicking architectural styles of other continents, they risk retrogression as the rest of the world advances in the fight against the climate crisis [9]. Therefore, there is a gap in research to support sustainable architecture in West Africa. The simplicity in passive design solutions, e.g. in indigenous architectural buildings, can greatly reduce the impact on climate. To successfully transition back towards sustainable environments, it is necessary to understand the impact of built environments on climate and sustainability goals. This paper compares the collective use of building-related embodied and operational carbon in Traditional and Modern dwellings.

Aside from societal pressures to implement more sustainable architectural practices, action is still required from manufacturers, constructors, and urban planners within the public and private sectors to advance the rate of change more rapidly. This means that professionals and their clients will consider measures for decarbonization in future development, renovations, and the replacement of materials to reduce their carbon footprint.

3.2 Emboddied carbon

The structural elements of an architectural design can contribute up to 80% of a building's embodied carbon. However, to thoroughly explore this, the origin of the raw materials used is the first point to address, as this important decision affects the entire life cycle from the use-phase of the building to waste and disposal [97]. Making embodied carbon the main focus when designing a building can greatly reduce the extent of emissions caused by the built environment. In the bid to reduce the climatic impacts of the built environment, a few methods have been embraced. These include designing:

- with less material;
- for reduced disposal; and
- to increase the life span of a building.

With this information gathered, it has become clear that buildings can reduce their carbon footprint by up to 10% with the use of recycled materials instead of facilitating extractions of virgin materials [97]. The simplicity of the material composition used by indigenous people in West Africa can be a solution to this issue as it can be easily recycled and features waste upcycling [79],[99]. However, the carbon involved in the collection, transport, and processing of building materials must also be considered when investigating the reduction of the carbon footprint within the building industry.

3.2.1 Circular economy

The concept of a circular economy evolved from the need to reduce embodied carbon. The ideology supports the notion that every material is capable of providing relevant value to a new cause after its current function has ceased. This is how natural elements on earth operate i.e., the infinite nature of energy, meaning if something dies it gives new life to another [100].

'Cradle to grave' is a term used to describe the linear system currently adopted by the modern era; it can be further explained by where humans take resources, make structures that add value to their high standard of living, then dispose of it at the end of the building lifecycle.

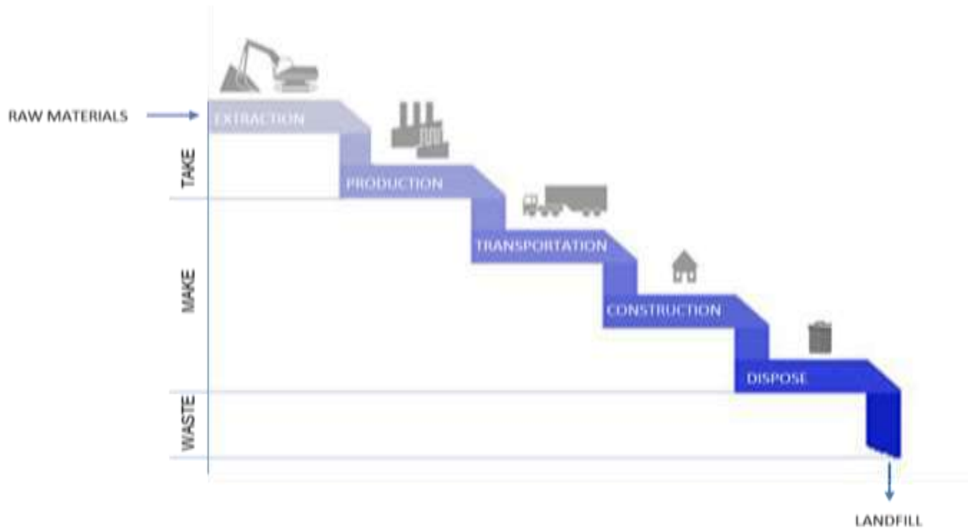

Figure 1 Illustration of take-make-waste. Source: Author

The aim of the circular economy principle is to create a cycle where buildings are designed for their purpose and use-phase in a way that minimises disposal. Therefore, keeping the embodied carbon in a continuous loop.

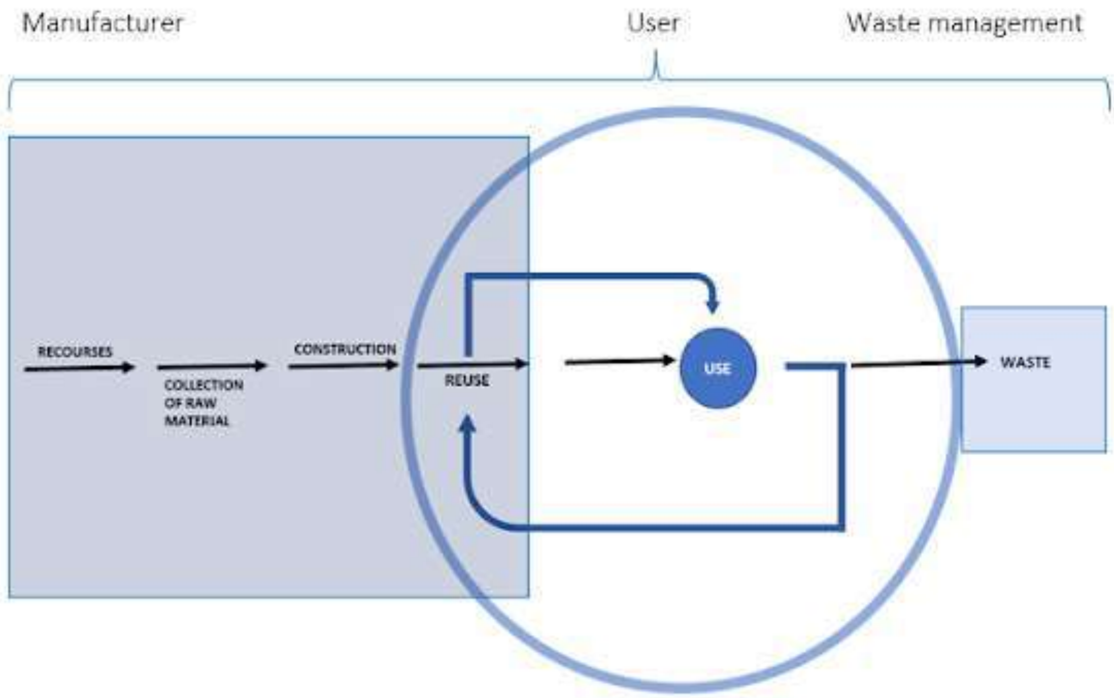

Figure 2 Phases of a CE when transitioning from a linear system. Source: Author

The figure above clearly separates the different key phases of a circular economy when transitioning from a linear system. It also highlights the shift of responsibility from manufacturer to user, and finally waste management. In an ideal circular economy, the use-reuse loop will be constant. Therefore, significantly reducing the amount of carbon produced in the overall lifespan of buildings over several generations [101].

3.3 Operational carbon

Tackling sustainability covers a wide range of factors that are all intertwined and have an effect on one another. The use phase of a building can be affected by the strategy used in the initial design and construction. These impacts include, but are not limited to, the following factors;

- Poorly selected materials affect the thermal qualities of a building. Therefore, increasing the amount of energy used for heating and cooling [106].
- Reduction in biodiversity that naturally encapsulates the planet's carbon and absence of green areas is one of the causes for temperature increase resulting in a rise in electricity usage [107].
- Increased energy for maintenance. For example, a switch from carpet to hardwood flooring can greatly reduce the carbon emissions produced [108].

- Required transportation. The proximity between homes and other key buildings in the community will reduce the need for automobiles which is the second largest cause of carbon emissions [101].

It is evident from reports and studies that materiality and embodied carbon affect the operational carbon in a buildings life cycle as well as other sectors. Responsibility must be taken to optimize decarbonisation in the built environment in order to implement sustainable development as it is one of the core issues currently faced. The aim of this paper Is to add to the research available, particularly in the West African context, to facilitate the change towards a more sustainable built environment.

4. Background history of indigenous West African architecture

4.1 European influences

This section is an introduction to the history of Residential buildings within the region of West Africa. Firstly, the general influence of Europe on West Africa's build environment will be addressed. Following this, as Africa covers a vast number of countries and cultures, the study will highlight important milestones in the development of building practices in Burkina Faso, Ghana, and finally, Nigeria.

Indigenous knowledge can be described as “a historical continuity of resource-use practices often possesses a broad knowledge base of the behaviour of complex ecological systems in their own localities” [37]. This information tends to be gathered through a long series of investigations and inspections passed down from one generation to another, in an effort to cope with their own agroecological and socio-economic environments [38]. Their practices allow for the conservation of techniques and specific skills, through a trial-and-error process over a long period of time thus proving their intimate relationship with their surroundings and expertise in the methods they implement [37]. It also demonstrates sustainability as these practices have successfully met the needs of the communities for multiple lifetimes. It is that the ideologies of West African inhabitants worked well for the community during that previous era and were adaptive to their lifestyles. The information used to establish building methods and materials was chosen due to the specific needs of each region.

New technologies and influences from other parts of the world, however, have resulted in designs that are not fit for purpose in the context of West Africa, and include material combinations that are less environmentally friendly [96]. It has been a deceptive 'improvement' of indigenous knowledge that has progressively distanced architecture from its original purpose - to adapt to the environment and community which it shelters.

In the late 19th and early 20th century, colonization took place in various African countries. During this time in history, Europeans established control over West African territories. As a result, these countries lost major parts of their cultural identities and were forced towards

Europeanisation [28],[34]. This affected different parts of the livelihoods of West African communities including the buildings in which they lived in [35,36]. The figure below shows the stark disparities in between urban settlement plans before and after colonisation. It is apparent that West African stripped of its organic nature to conform with a rigid design that works against nature.

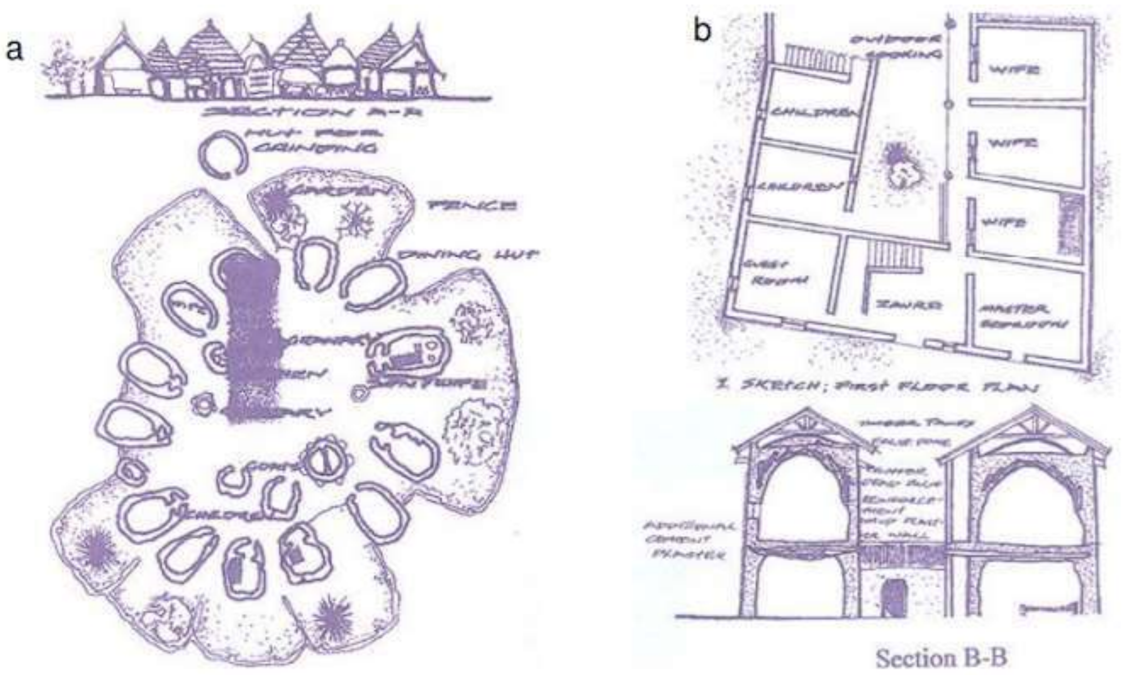

Figure 3 Typical housing layouts in Jos, Plateau State. (a) Typical Berom compound layout in Jos; (b)Typical Miango compound layout in Jos. Source: Rikko and Gwatau, 2011. [102]

Urbanization, change in social construct, and the introduction to western education have made imported concepts part of West Africa's history. This clarifies the reason behind the disappearance of the indigenous social construct, Cultural expression through architecture, and urban planning [102]. The overall experience of colonisation created a major dependency on Europeanised influences which does not suit the African context - therefore, unsustainable. The disparity between traditional and modern structures is much larger where industrialization and cultural impositions have taken place.

In addition to many of these post-colonial, modern structures in west Africa being unable to adapt to individualised climate needs. These countries are suffering from natural disasters such as desertification in Burkina Faso; flood and population growth in Ghana and Nigeria; amongst other issues such as health problems, loss of biodiversity, and increasing economic debt [29,30,31,32,33]. This information highlights the urgency of the current research into the re-visitation of indigenous knowledge in order to gain insight into methods that were previously successful in adapting to the West African climate. By expanding on the traditional approach to sustainability, this will in turn challenge the influence of Europeanisation in this journey, restoration of a healthier environment, society and economy.

To gain a full understanding of West African Architectural history, A country-specific literary review follows which elaborates on the specifications that can be used to define the vast variety of indigenous West African architecture.

4.2 Burkina Faso

Figure 4Map of Burkina Faso. Source: Britannica.com [41]

A previous French province, Burkina Faso acquired independence and was named as 'Upper Volta' in 1960. The name Burkina Faso, which signifies "Land of Incorruptible People'' was embraced in 1984 [40]. Burkina Faso is a particularly unique country to explore as 70% of its residential buildings are traditional earthen constructions in rural areas [39]. Situated in the Sahel area, Burkina Faso encounters a portion of the world's most revolutionary climatic changes, from outrageous dry spells to extreme flooding [42]. This shows that immediate action is imperative, there is a necessity for research to identify an architecture style which is responsive, and adaptive in relation to the surrounding context.

Gaining information from the sustainable attributes of vernacular architecture in Burkina Faso is important to improve the current ecological crisis we face; it appears to be more challenging in societies where a cultural dissimulation has occurred. Prior to European exploration, various cultures lived within this region. Although they lived in close proximity which resulted in access to the same natural resources and climatic demands, factors such as social systems, language structure, religious beliefs and political views differed. These individualities were evident in the development procedures, building typologies and social gathering frameworks within the country [43].

Different investigations have been conducted to further understand the selection of building materials and strategies utilized while constructing different kinds of structures in Burkina Faso. Previous research has indicated that two kinds of building materials were used primarily by the indigenous people of Burkina Faso, for hundreds of years [63]. These materials consisted of clay, cow compost, and other organic elements.

4.2.1 Clay buildings

The region of Tiébélé in Burkina Faso was occupied by the Kassena tribe, of the more noteworthy Gurunsi ethnic group from both Ghana and Burkina Faso. There, hand-painted houses date as far back as the fifteenth century. These basic yet elaborate constructions, called 'Sukhala', are found in the community leader's compound and were painted by Gurunsi ladies, while the men typically constructed the structural parts of the building [70]. Materials like mud, chalk, earth, coal, and an enamel, produced using beans, were utilized to make the dark, white, beige, and red designs. (See figure 5 below)

Figure 5 Painted clay building in Burkina Faso. Source: [70]

This style is unique to this particular area, however, It is not capable of achieving as much diversity in style as a building designed with modern strategies. Further research is required in this area as indigenous architecture may no longer be accepted by the locals due to its lack of aesthetic variance.

Although the building may not meet the standard of the modern-day person in Burkina Faso, the main building material, clay, may not be as outdated. Clay is used in many countries as an architectural medium particularly for its thermal qualities [64]. The general simplicity of which earth can be easily sourced in West Africa suggests that utilizing locally available material may reduce transport emissions significantly. Clay, therefore, should be considered as a sustainable choice of material in the context of Burkina Faso. (This theory will be further developed in quantitative research section of this paper).

4.2.2 Compressed earth blocks

In Ouagadougou village, Burkina Faso, houses made of formed earth blocks represent around 24% of dwellings [68]. The earth material needed for making these structures are sourced from local quarries which drastically reduces carbon emissions in the life cycle analysis of the material. The blocks are produced using the mix of clay, water and sometimes, straw is included in the composite material to increase durability. It is commonly modelled into a block using wooden frames [65].

Occasionally, cow compost is used for its binding qualities, insulation properties, and ability to create a smooth finish. As an added bonus, it also possesses antifungal and antiseptic properties which positively impacts the health of locals [66]. It is evident that these practices have been tried and tested by indigenous people in efforts to upcycle a waste product (cow compost). This is knowledge is an archaic practice that has been explored for many years and can be of great benefit in the present day.

Figure 6 Moulded earth houses. Source: Hema, 2017 [68]

A more recent approach to building with clay can be seen in the use of compressed earth blocks for building (CEB). This compost material which consists of earth mixed with water and an organic material such as straw or dung can also be referred to as adobe blocks in literature [67]. The guidelines for strategies to compact the organic material and optimal particle size to produce good quality construction of CEB structures are provided by CRAterre research laboratory [68].

Regular dimensions of adobe blocks are typically either 11.5 cm3 or 9 cm3. These measurements provide optimal strength to wall thickness ratio. Moreover, the varying thickness of blocks also depends upon the apparatus used. These walls are usually not cladded. Elements of the structure such as the roofs are inspired by modern architectural styles [68,72]. This is an example of a hybrid construction that includes organic materials sourced sustainably however, factors such as the need for cement and steel which are unsustainable materials, to enhance the load bearing properties if CEB, bearing reduces the positive environmental qualities of the architectural style [69].

Figure 7 CEB house. Source: Forke, 2017 [69]

This indigenous building style therefore challenges the hypothesis that indigenous knowledge can be the sole answer to sustainability in the built environment because issues such as strength to weight ratio; lack of ability to achieve multiple storey housing; wall span capacity and building maintenance can be easily resolved using modern techniques. However, it could also be argued that these attributes are not required by locals in West Africa and that more hybrid sustainable methods have not yet been trialled.

4.3 Ghana

Although this paper addresses West Africa as a whole, this is a vast region which represents many subgroups that encompass varying, despite, similar practices. This is evident arcross the traditional development styles typically found in these areas.

Figure 8 Map of Ghana Source: Britannica.com [71]

Ghana is located on the coast of the Gulf of Guinea. It is important to note that it occupies a smaller area and a lower population of 31,508,000 inhabitants in comparison to Burkina Faso and Nigeria. Ghana is one of the main nations of Africa, mostly because of its extensive wealth and its achievement to become the first black African country of the Sahara to achieve independence from colonial leadership. Ghana is additionally celebrated for its rich history—its residence dating from 10,000 BCE—and as an extemporary repository of cultural heritage [71].

The historical background of vernacular structures which are unique to the Ghanaian context can be partitioned into two areas. The principal factor is the materials that were available to the locals within the area. This set a boundary regarding the material qualities and the kinds of construction that could be achieved. The primary factor includes the traditional construction methods used to execute the elaborate architectural designs.

4.3.2 Materiality

The building materials utilised in indigenous Ghanaian architecture include the following;

Bamboo is one of the most generally accessible materials that have a low environmental impact in comparison to modern material choices of materials [73]. It was commonly used in Northern Ghanian architecture due to its hollow tubular structure that provides a great strength to weight ratio which is a beneficial attribute in the built environment sector. In addition to this, bamboo is an economically efficient product due to its locality, quick growth and harvesting period. [74].

Timber is another broadly accessible material in Ghana and has been utilized in sustainable development for many years [83]. It is used for aesthetic, non-structural elements such as cladding, floor finishes, roof construction, as well as load bearing walls. Evidence from previous literature suggests that timber is one of the few materials that can sequester carbon [93] and it is more resilient to harsh climates in comparison to other buildings constructed through conventional materials; however, its fire-resistant qualities are a con. [75],[76].

Similarly to Burkina Faso, **Clay and earth** is a material that has been used by indigenous tribes in Ghana [77]. The organic construction material consists of clay blocks, laterite, clay soil, and rammed earth [78]. Although this can be sustainably sourced and have a natural ability to absorb and release moisture from the air and regulate humidity, it is susceptible to deterioration when exposed to direct moisture. In order to stabilise this material to prolong its life span, cement is required [69]. This fact challenges the ideology of returning to indigenous knowledge for all aspects of design and construction, as it is evident that it structures require utilisation of modern day materials, such as cement, in order to maximise their lifespan.

Thatch is a tightly intermingled layer of living and dead stems, leaves, water reed, sedge, rushes, heather, or palm branches, which accumulates between the layer of actively growing grass and the soil underneath. It is a traditional material used for roofing in West Africa.

Particularly Ghana and Nigeria due to its ability to utilise a waste material and shelter inhabitants from rainwater [79],[80].

Figure 9 Thatched roofs construction. Source: Danja, 2017 [87]

The building materials that were used in traditional buildings in post-colonial Ghana were sourced and constructed sustainably. This is more efficient than more modern Europeanised architecture particularly in the context of West Africa that does not meet Ghana's social and climate needs. It is important to note that traditional materials are not as durable as modern materials which increases demolition rates, meaning that the indigenous architecture fails to be a cost effective and long-term sustainable solution.

4.2.3 Construction methods

As seen in Burkina Faso, adobe construction is a method also used in Ghana. This is an efficient method for construction in developing countries that suffer from economic and labour hardship [80]. Its cost effectiveness is fundamentally credited to the wide accessibility of material in the local area. less distance to travel equates to less carbon emissions [115]. Furthermore, this method is advantageous to the built environment as it does not involve any elaborate processes.

Figure 10 Adobe construction in Ghana. Source: Agyekum, 2020 [80]

Using the Adobe method, the building's foundation and later, its walls, take a circular shape as this is easier to achieve. [81].

Wattle and Daub is another building technique used in olden day, Southern Ghana. Using this method, the layout of the structure is planned out, followed by vertical props inserted into the base and secured with stones. Then, the composite earth material is added. Although African indigenous knowledge can be viewed as unsophisticated [81], This method shows the ingenuity in their practices as this method creates a structure that has a low carbon impression, as well as protects it is well suited for earthquake prone areas [82]. It is evident from the visual's provided that the locals are experts in their environment and tackle sustainability and climate adaptation through their architectural designs.

Figure 11: Wattle and Daub in Ghana. Source: Agyekum, 2020 [80]

Rammed earth, as its name suggests, is a construction method that adapts the strategy of compacting in different layers of material. In the local language, this method is known as 'Atakpame' and this name is given to this construction method because of its association with the Ewe ethnic group who live in the west African countries - Benin, Togo, and Ghana. This method possesses low embodied energy, minimal waste, and great thermal quality attributes [80].

Figure 12 Rammed earth construction in Ghana. Source: Azure magazine (2019) [110]

Common themes across these three countries studied are locally sourced materials and similar construction methods which can be simply easily applied by local builders to construct new dwellings. These structures naturally possess sustainable traits. Further study is required to determine the overall environmental impact of traditional buildings from resource mining to the end of its served purpose as a construction material.

4.4 Nigeria

Figure 13 Map of Nigeria. Source: Britannica.com [85]

Nigeria is a country made up of many tribes that originally did not share the same language or culture. It was created as a result of European imperialism [83], established as one single British colony in 1914 from the union of two smaller ones, gaining its independence on October 1st, 1960. For this reason, Indigenous designs vary in the region. The main tribes include Yoruba, Igbo, Fula, Hausa, Edo, and Ibibio, but this is to name just a few from the hundreds of tribes present in the modern day country [85].

4.4.2 Defining feature

The northern part of Nigeria is mainly inhabited by the Fula and Hausa tribes. The indigenous architecture in this region is unique for its engravings and elaborated symbols. This is one of the most defining features of Nigerian dwellings and elements of this remain in modern designs.

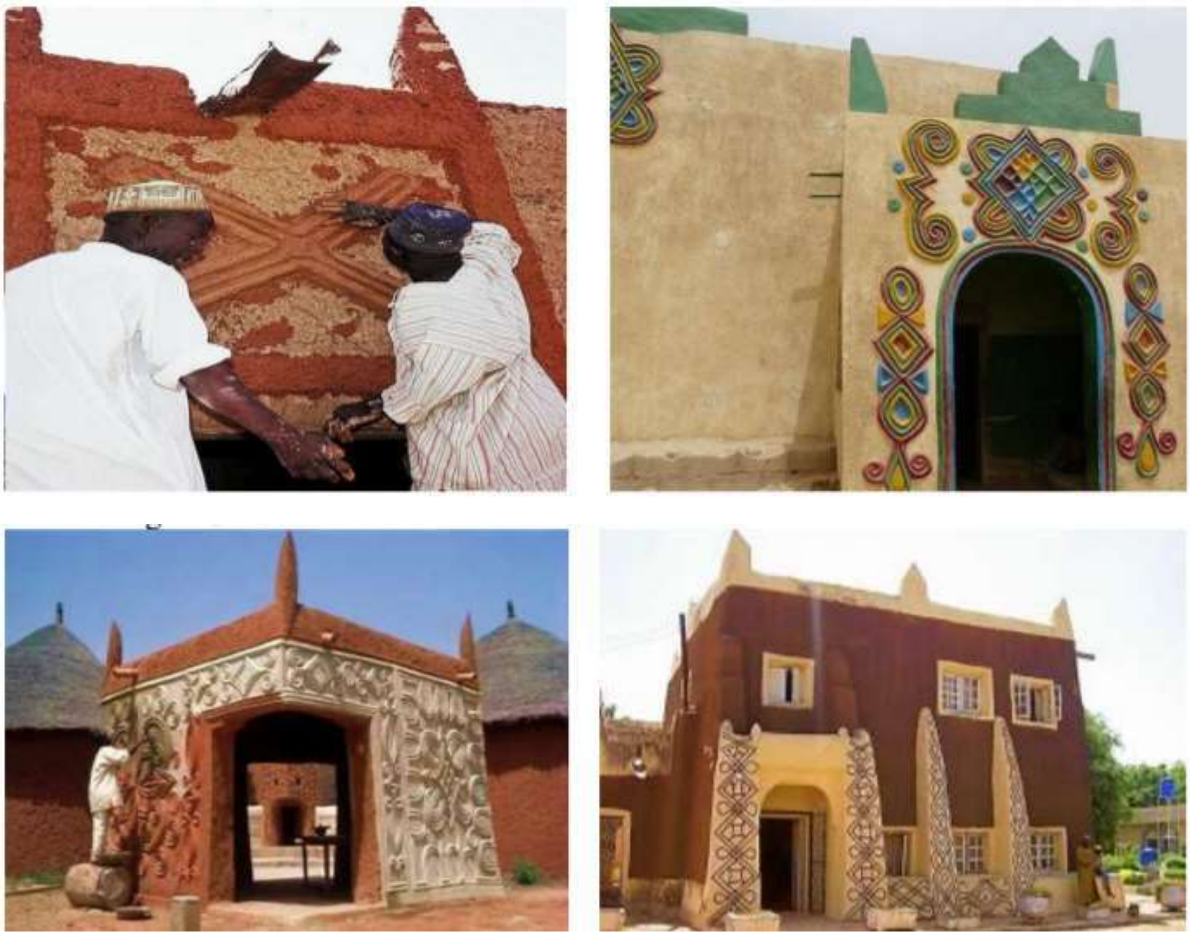

Figure 14 Engravings on Nigerian architectures. Source: Agboola, 2014 [86]

Engravings are one of the oldest features of Nigerian buildings. Tools are used to create slitting artistic expressions across the hard and flat surfaces by making grooves into it. These engravings require skilled traditional builders who have acquired mastery through apprenticeship from elders in the community – passing on from one generation to another [86]. This information is relevant to depict features that identify indigenous buildings.

4.4.3 Materiality

The materials used in Nigeria are similar to the rest of West Africa. These consist primarily of earth, reeds, grasses, stones, and timber which shows that there is a similarity in the built environment sector across the region [87],[90]. The indigenous knowledge of sustainable practices was utilized in all aspects of traditional architecture however, in modern day Nigeria, buildings resemble neo-classical European architecture. This can be characterized by the geometric configuration, grandeur of scale, symmetry, and materials used. Unfortunately, the previous sustainable options have been replaced with cement, sand, glass, and concrete, that are jeopardizing the quality of life and sustainable development progression within the country [88].

Figure 15 European-influenced architecture in Ibadan, Nigeria. Source: Sijuwade 2020 [89]

Aside from a few mosques and temples, the majority of buildings made up of earth material including mud and bricks have been destroyed in an attempt to be more modern and resemble more western architecture. The figure below shows the practice of Wattle and Daub construction in Nigeria. This seems to be a popular construction type in all 3 countries explored, the method remains favourable throughout West Africa due to its environmentally friendly nature, and durability.

Figure 16 Wattle and Daub construction. Source: Auwalu, 2019 [88]

Previous literature has shown that the approach of modern architecture and its use of materials such as steel, aluminium, zinc, glass, and composite material have largely replaced the use of traditional building materials within Nigeria. Studies have attributed the discontinuation of vernacular building design and materials used to the following factors; human ignorance, modernization, improved socioeconomic conditions, changing weather and climatic conditions, and increased maintenance of traditional architecture. Although more archaic building methods are not favoured in this region, in order to improve the quality of life, and tend to the climate emergency, revival of traditional architecture is necessary [87]. This paper also recommends that the remaining remnants of traditional architecture should be conserved as this can be used as a tool for further education.

5. Policy

Legislatures in all nations contribute to the foundations of cultivating sustainable development within a country, which includes activity from all parts of society and the economy. This section investigates public and private engagements on the implementation of sustainability as a whole and within the built environment. The Abidjan-based West Africa Sub Regional Office (Office) was set up in 2015 to reinforce The UN Environment's key role in the districts, which was prompted by the UN Conference on Sustainable Development (Rio+20). This command related to strengthening and updating UN Environment as the worldwide environmental authority.

The Office serves as an addition to UN Environment commitment with Member States to improve the arrangement of intelligible support in propelling their national environmental agenda, especially by integrating the three pillars of sustainable development i.e., people, planet, and profit - with regards to the United Nations 2030 Agenda for Sustainable Development and related Goals. [58],[59].

Figure 17 SDG goals. Source: https://www.un.org/development/desa/dspd/2030agenda-sdgs.html [59]

The sub-regional Office covers a block of sixteen countries which also include those which have been analysed to complete this study; Burkina Faso, Ghana and Nigeria. The function of the UN Environment West Africa Office is to work intimately with other United Nations organizations just as key accomplices in West Africa including the African Development Bank, the Economic Community of West African States (ECOWAS), West African Economic and Monetary Union (WAEMU), the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS) and the common society [58].

The core functions of the West Africa Sub Regional Office Communication and outreach is to promote visibility of sustainability in West Africa; mobilizing resources; leveraging strategic and programmatic partnerships; supporting an organised delivery of UN Environment work in West Africa; and, with policy through sharing of quality information, investigations and making informed suggestions. The image below shows the UN sustainability goals against the progress of achievement within West Africa for each goal. (Red: Poor, Orange: Fair, Yellow: Good, Green: Excellent)

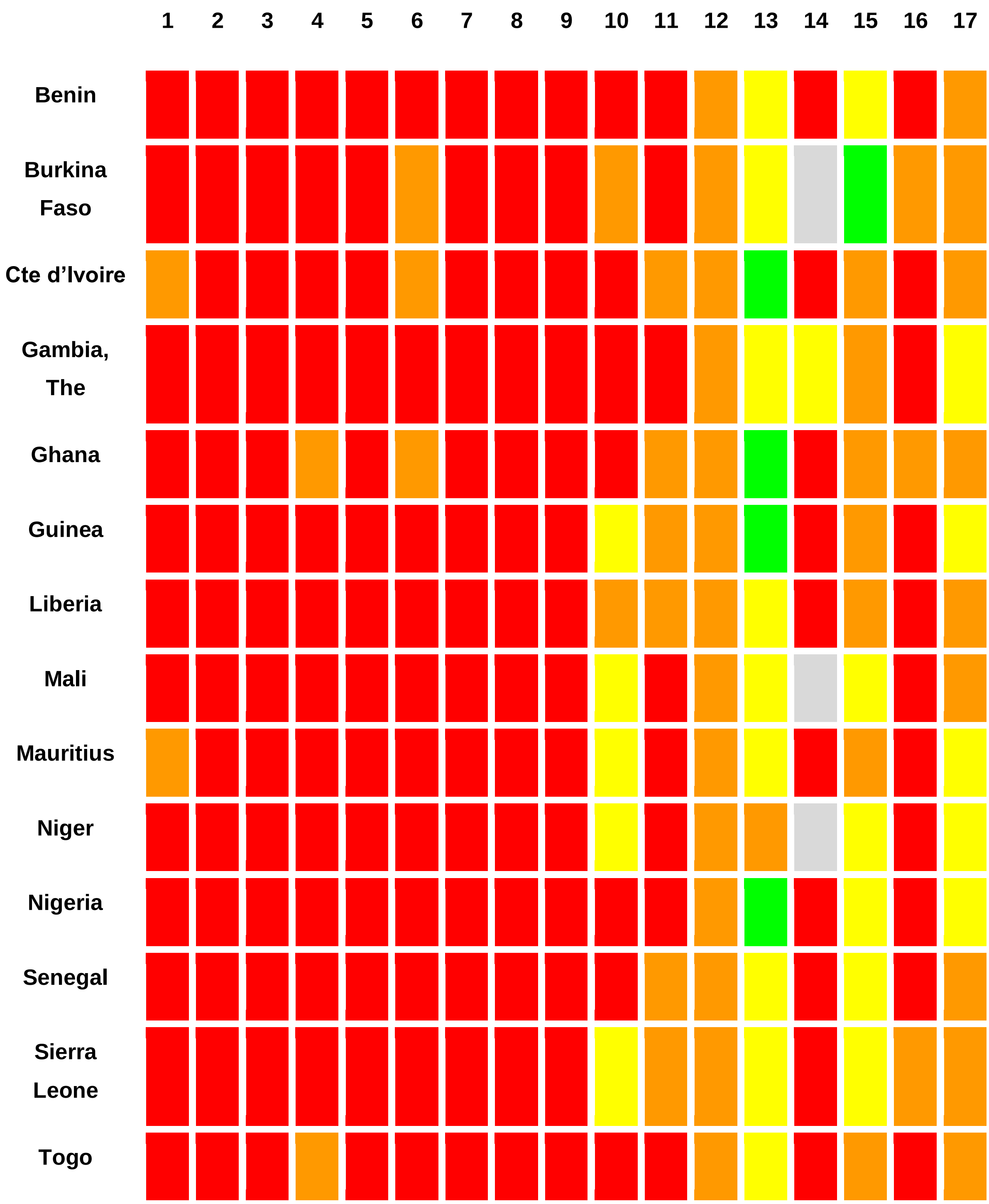

Figure 18 Progress of sustainable development in West Africa 2019 Source: ISNAD-Africa [104]

An additional organization created to prompt in support of sustainability development is The African Ministerial Conference on the Environment (AMCEN) which was set up in December 1985, following a meeting of African ministers of environment. The conference was held in Cairo, Egypt. Its main principles are to give support to ecological assurance in Africa; to guarantee that essential human requirements are met satisfactorily and in a reasonable way; to guarantee that social and financial advancement is acknowledged at all levels; and to ensure that rural practices meet the food security and biodiversity needs of the district.

Finally, Burkina Faso (2016), Ghana (2016) and Nigeria (2017) all ratified the Paris agreement treaty which encompasses the target of reaching net zero carbon emissions by 2050 [60]. In response to this, policy requirements to reduce carbon emissions in the built environment are now considered when making applications for planning permissions as well as secondary impacts found in other sectors.

Due to lack of resources, the ability to follow the guidelines in all investigated countries could not be explored thoroughly. In the case of Nigeria, however, its policies are currently in line with contribution towards the Paris agreement's biggest goal, which is to limit global warming to 1.5°C. However, their actions are contrasted with their previous commitment [61]. The climate action tracker website estimates that Nigeria's greenhouse gas emissions would reach 25-45% above 2010 levels if no changes are made to their current practices. Indigenous knowledge used as a method to achieve sustainability could drastically reduce the high GHG emission forecasted by making changes to different factors such as embodied carbon, waste reduction, water efficiency and energy efficiency [111],[116],[117].

The Government of the Federal Republic of Nigeria recognises the importance of tradition and cultural heritage particularly within the built environment. In 2006, they distinguished indigenous heritage as an essential component for tourism advancement which positively impacts the Nigerian economy [62].

It is evident that West African countries have made attempts to solve the world crisis however their scope has been limited to greenhouse gas emissions during the era of indigenous norms. Although the developing world has made great efforts to have a similar living standard to European nations, the proposed policies need to be more holistic and personalised in order to truly develop a more achievable, sustainable development that is unique to the region.

6. Indicators

Evaluation guidelines and certification promotes regulation of environmentally friendly infrastructure. This section reviews the literature available to highlight the influence of environmental certification systems used in West Africa. The importance of this knowledge is to gain an understanding about how energy, waste and materials used in architectural practices are measured and how this information can be used to determine which methods and practices are most sustainable. Certification through any relevant evaluating framework/ index gives confirmation of eco-friendly qualities and can be a useful marketing tool to promote architectural practices. Ecological verification in the built environment can be used to motivate customers, architects, and clients to create, promote and strongly consider highly sustainable solutions in construction practices [57].

Green building indices and verification frameworks require a plan incorporated with sustainability to make projects that are naturally eco-friendly and use minimal resources all through a structure's life cycle: from the initial to plan, development, activity, upkeep, remodel, and destruction [57] They must ensure transparency and the use of science-based evidence for the examination. The certification body must also not be biased, and finally, their sustainable standard levels should advance industry practices.

Examples of these verification systems can be seen in Europe and Europeanised nations. Some examples include the following organisations such as ; Building Research Establishment's Environmental Assessment Method (BREEAM) – Great Britain; Green Building Tool (GBTool) - Canada; Leadership in Energy and Environmental Design (LEED) – United States of America; EcoProfile – Norway; and Environmental Status - Sweden [50],[51],[52],[53],[54]. These measurement tools assess elements such as materiality, energy consumption, water usage, transportation etc. Although these certification systems have individual limitations, and are not mandatory to achieve, they contribute to governance information when required in the built environment sector. The guidelines within rating systems also help to identify more sustainable alternatives for clients. Although these indexes and organisations which are available to evaluate sustainable practices exist in more western countries, in West Africa, there is currently no specific database that provides the same information [55]. Particularly in the built environment sector, none of these certification systems are one-size-fits all. This is due to the uniqueness of architectural designs which must comply with its immediate context [56].

Comparing the sustainability needs of other parts of the world to West Africa, there is a clear difference in terms of its application observed between the Northern and Southern hemispheres [55]. There are many factors which inhibit the adoption of sustainable solutions in the built environment within West Africa. The lack of indicators ie; environmental certifications systems utilized in West Africa has consequences on the implementation of sustainability in the built environment. It is evident that sustainability within this sector must comply with its context [56].

Therefore, Indigenous knowledge which has been cultivated by locals over centuries could be a useful method in improving environmental challenges. Combined with this, it would be beneficial to fill the research gap by developing a tool which assesses material and energy use that supports the climate, context and style of architecture as seen in other parts of the world.

7. Quantitative research method

In order to compare the construction carbon footprint of houses built following modern and traditional West African architectural styles, the Royal Institution of Chartered Surveyor's (RICS) Whole Life Carbon Assessment for the Built Environment 1st edition guidance (LCA) [118] was used.

The typical carbon emission was calculated for a simple family dwelling built using modern materials, and another built using the proposed traditional west African design, of the same size. Uniformity in both subjects creates a research parameter and allows for a fair comparison between both styles; it was thereby used as a criterion for analysis. No one indigenous west African building style was analysed in its entirety, however, key materials from different techniques in the countries highlighted were chosen, combined and finally, used as a basis to form a hybrid traditional west African home.

This study will focus on the impact of construction on carbon emissions and will therefore cover phases A1 to A5 of the methodology with A1-A3 referring to the product stage (embodied carbon), A4 to transport to project site and A5 to construction and installation process. Due to the limited scope of this study and the information available, several key assumptions have been made for modelling purposes.

7.1 A1 to A3 (embodied carbon)

These calculations were determined using the following formula: (A1 to A3) = Material or system mass × carbon conversion factor.

The units for the Embodied carbon factors were taken from ICE 2.0 this can be found in appendix 1.

7.1.2 Determining building size

In order to create a data prototype for an average dwelling in West Africa, the first step was to determine the size of the building. The table below shows the average number of inhabitants in a single residence in Burkina Faso, Ghana, and Nigeria. This information was collected from the United Nations Household Size and Composition around the world data booklet (2017) [119].

Country	Average household size (number of members)
Burkina Faso	5.7
Ghana	3.5
Nigeria	4.6
	Total average = 3

Table 1 Average household size. Source: Author

The result of these statistics enables further research in concluding the area an average building would cover. Due to the lack of evidence that reveals the average square meter per person in West Africa, the statistics derive from measurements determined for UK environments. The choice of the United Kingdom was selected as the study will be comparing West Africa and another European country's fundamental principles of the built environment - in this case, the United Kingdom data was easily accessible. The average number between all the countries above equates to 3. Studies reveal that the average size of a three-bedroom family dwelling in the UK is 1033 sq. ft. [112]. This figure will be used to create an estimate on material input into a traditional and modern building.

7.1.3 Determining the quantity of building materials

At this stage, key structural materials were chosen for traditional and modern model homes with the following quantities assumed. Four materials were selected from the literature review section of this paper based on the most commonly used materials.

The following data is a calculation of the estimated quantity of materials used in the construction phase of a traditional house. As described in section 4 of this paper, the materials used for indigenous architecture in West Africa include bamboo, clay, thatch, and timber. Due to a lack of information on indigenous buildings, the figures below are estimated extrapolating from published literature and using the same units as modern building substitutes to ensure comparability.

Material	Amount needed per 1000 sq. ft	Amount needed per 1033 sq. ft
Bamboo	2100 kgs	2169 kg
Clay	20,000 kg	20,660 kg
Thatch	12,00 sq. Ft	12,396 sq. Ft
Timber	2100 kgs	2169 kg

Table 2 Quantity of materials needed for traditional house. Source: Author

This information was gathered using a series of sources that show the amount of material needed per 1000 sq. Ft. i.e. the amount of:

- Bamboo was calculated by estimating the amount of structural beams used in modern materials and using the same amount in the substitute material which is Bamboo [73],[113],[120],[121];
- Clay was determined using the measurements of its substitute material which is cement [113],[121]; and
- Thatch was particularly difficult to estimate due to its rare use in modern buildings; however, it was estimated that 1200 sq ft of thatch would be necessary to cover the amount of roof area needed. The varying styles of laying thatch also add variances to this estimation as some designs require less amount of material [122].

As described in section 4, the materials used in Modern buildings include cement, steel, sand, glass, and concrete. The embodied carbon accumulated by these materials will be measured using estimated figures gathered from the ICE database to provide statistics. Unfortunately, this database is based on UK statistics and is used due to the lack of data available for the West African context. In order to do so, the amount of each material must be established. This is done by collecting data that shows the amount needed for 1000 sq. ft from industry sources [113]. The gathered information is then converted into the amount needed for the average UK house size - 1033 sq. ft. The table below shows an estimate of the materials needed for a modern house.

Material	Amount needed per 1000 sq. ft	Amount needed per 1033 sq. ft
Concrete	50 kg bags x 400	20,660 kg
Steel	2100 kgs	2169 kg
Sand	1800 cubic ft	1,859.4 cubic ft
Brick	25000	25,825

Table 3Quanity of materials needed for modern house Source: Author

The gathered estimation on the quantity of materials used enables further research into the embodied carbon accumulated by each building style. These calculations set a preliminary base for the embodied carbon to be calculated.

The following formula was used to calculate the embodied carbon units: *(A1 to A3) = Material or system mass × carbon conversion factor*

Mass being the ‘amount of material needed by sq. Ft’, and carbon factor was determined using RICS LCA.

7.1.4 Results

Traditional buildings

Category	Default Emission Factor	Material Amount (kg)	Total Emissions ($kgCO_2e$)	Emissions Intensity ($kgCO_2e/m^2$ GIA)
Bamboo	0.3100	2,100	651	8.14
Timber	0.2400	20,000	4,800	60.00
Clay	0.2400	20,000	4,800	60.00
Thatch	not available	12,000	321	not available

Table 4 embodied carbon of traditional building Source: Author

Modern buildings

Category	Default Emission Factor	Material Amount (kg)	Total Emissions ($kgCO_2e$)	Emissions Intensity ($kgCO_2e/m^2$ GIA)
Concrete	0.1070	2,100	2,211	27.63
Steel	2.0300	20,660	4,263	53.29
Sand	0.0051	117,941	602	7.52
Bricks	0.0240	5,863	1,407	17.59

Table 5 embodied carbon of modern building. Source: Author

7.2 A4 - Transport to project site

To assess the impact of transporting building materials to the project site on the environment, this was calculated to inform the analysis within the study. The calculation was based on the recommended assumptions in section 3.5.2 of RICS LCA these assumptions were based on UK and EU specific data due to the limited information available for West Africa. Carbon emissions were calculated using the formula: [A4] = Material or system mass × transport distance × carbon conversion factor.

Where: Material or system mass was same quantities assumed for A1 to A3 (see section 6.1.4)

Transport distance (in line with section 3.5.2 of RICS LCA) was assumed to be 50 km by land for all traditional materials – this assumption was made on the premise that traditional architecture is centred around materials available in the local area; 300 km by land for sand and bricks; 1,500 km by land for concrete; and 10,000 km by sea and 200 km by land for steel.

For Land transportation, All HGVs factor was collected from UK Government GHG Conversion Factors for Company Reporting 2021 - Freighting Goods section [123]
For data regarding the sea, Average Bulk Carrier Cargo Ship factor from UK Government GHG Conversion Factors for Company Reporting 2021 - Freighting Goods section [123].

7.3 A5 - Construction and installation process

This calculation was assumed to be similar between traditional and modern architecture and therefore not included in the model.

8. Results

This study suggests two areas where a traditional house may be more carbon-efficient than a modern house. The first area is Materials Embodied Carbon where the traditional house has advantages due to not relying on carbon-intensive steel for its structural elements and instead, utilizing wooden materials for construction. The second and most impactful area is the Emissions from Deliveries made as due to the local nature of traditional architecture most materials are sourced locally while many of the materials required for modern houses i.e., limestone, clinker, and cement [109] would need to be transported nationally, regionally, or even internationally. This significantly increased transport distance results in a highly inflated carbon footprint for modern houses.

Stage	Emission source	Modern house	Traditional house	Reduction %
A1-A3	Materials embodied carbon	8.48	5.87	31%
A4	Emissions from deliveries made	7.44	0.13	98%
A1-A4	Total embodied carbon	15.93	6.00	62%

Table 6 Construction impacts of Modern and Traditional House. Source: Author

The results in table 6 show the output of the methodology research. Findings, therefore, support the hypothesis that overall, the comparison shows that there is a reduction of embodied and operational carbon. The numbers used in this study were estimated due to lack of resources from the West Africa context however, this gives an overview that implies that indigenous architecture is more sustainable as it requires fewer carbon emissions to construct.

9. Discussion

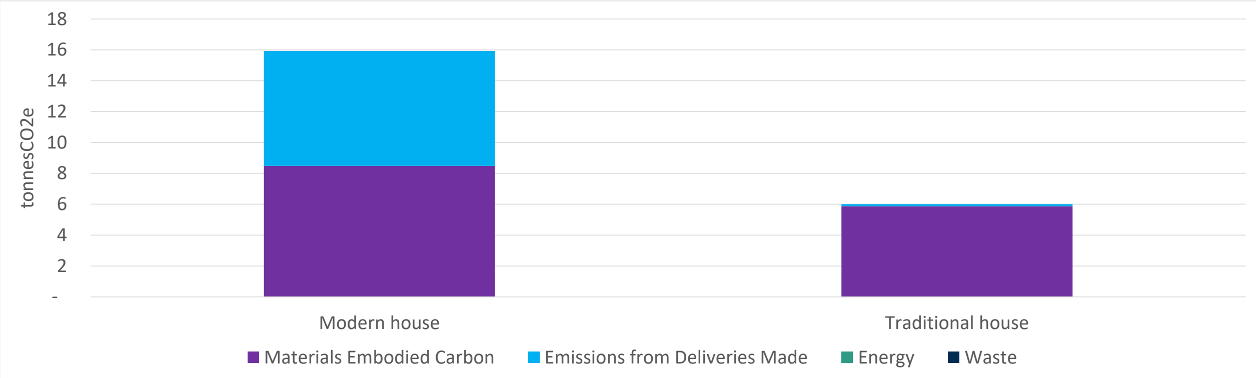

Figure 1 Carbon comparison between modern and traditional house. Source: Author

The findings of the study confirm that utilising indigenous knowledge in the built environment is indeed a method that can reduce carbon footprint, thereby making the building industry, particularly in western Africa more sustainable. In agreeance with the initial hypothesis, the research shows that by simply using materials and resources that are locally accessible during construction, allows for more sustainable developments i.e, weather-resistant, low environmental impact, low-carbon and energy-proficient structures, traditions and cultures, to ensure access to resources and a cooler climate for future generations [114].

There are a variety of elements that can be considered to upgrade sustainability in building planning, construction, development, and operations processes [111]. This can be understood from the information presented in the literary review and is more evident in the quantitative analysis of embodied and operational carbon.

Although this paper mainly focused on materiality, the quantitative methodology highlights that there are miscellaneous factors that should be further examined as they cross over to other sectors. For example, transport – the amount of miles travelled to reach the destination where the material will be used, can greatly influence the amount of carbon emissions calculated over the life cycle of a material resource.

This information can be seen in the qualitative method results below.

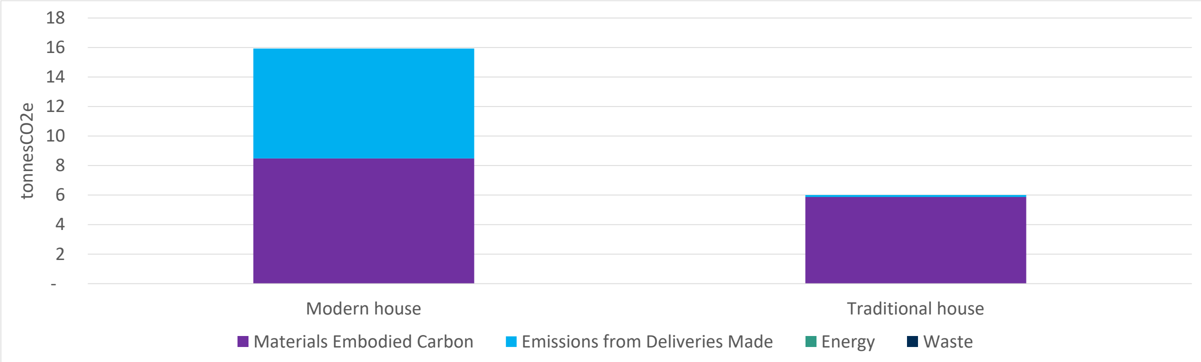

Figure 2 Quantitative method results. Source: Author

A significant difference is apparent when comparing the traditional house that sources its materials locally, to modern houses that require a substantial amount of travelled miles to deliver the material on site. Due to this fact, cement supplier companies such as Dangote Industries Limited in Nigeria, are attempting to address the issue regarding the climate impact of 'export to import' strategy to obtain cement in West and Central Africa [109]. This practice is efficient in Nigeria which has an abundance in the key ingredient of the composite material which is limestone. Particularly in the southern regions in close proximity to demand centres and export facilities. Nigeria has an overall bounty of value limestone particularly in key southern districts close to request focuses and trade offices. Limestone is not available in more coastal areas of West and Central Africa however. The lack of limestone mining in the rest of West Africa and Central has driven a large portion of consumers to import large amounts of cement or a derivative of limestone called clinker, generally from outside of the African continent [109]. Although the company produces a less sustainable product, the new system of local accessibility proposed, if correctly executed, can have a drastic effect of the amount of carbon produced.

Figure 19 Dangote cement action plan. Source: Dangote cement [109]

The image above shows Dangote's sustainability goals relating to its built environment products. This confirms that there are many factors that affect carbon emissions and modern materials that are not sustainable in the context of West Africa can be made more sustainable if communities are self-sufficient and focus on local production as opposed to imported materials.

In the initial stages of this research, the hypothesis was supported by claims that the type of material was the main contributor of carbon emissions. However, the results following the comparison between traditional and modern dwellings make it clear that although the building material is an important factor to tackle. However, it is now overwhelmingly clear that the more significant cause of emissions in the life cycle of a material resource is requirement for transportation.

9.1 Limitations

Due to the absence of data specific to the West African region, many of the calculations above were based on UK or EU-centred emission factors and assumptions ICE, RICS LCA and UK Government GHG Conversion Factors for Company Reporting 2021[118],[123],[103] . These factors are not country, or region-specific and therefore the accuracy of this study could be improved by using information specific to the region explored in the research.

There was very limited information available on the quantities of materials used for a typical model of a traditional and modern house in West Africa and therefore the assumptions used in this study could be improved in follow up research. While this limitation is important to note, it does not significantly affect the outcome of this paper, as the purpose of this study was to identify a broad sustainability benefit of certain aspects of traditional architecture when compared to modern architecture in West Africa, which it successfully demonstrates. The exact quantitative benefits, however, would need to be established in future research.

It is important to note that traditional construction materials may be less suitable for achieving tall structures and may be less applicable to densely populated urban areas. However, it is possible to significantly reduce the carbon footprint of modern houses by applying learnings from traditional architecture to modern houses – most notably, the use of local materials as that can have a very large impact on the carbon footprint of construction.

9.2 Future Research

Supportability is an issue of developing importance in the built environment sector. According to the review presented, there is limited data that has focused on sustainability in the context of West Africa. The construction industry in West Africa would benefit from data collection to form a database similar to ICE. This would allow for professionals in construction to conduct more accurate assessments on indigenous architecture, particularly its materials and practices thus supporting them to make informed decisions when building new structures.

In addition to this, further research can assist in creating a green/ sustainable building index and verification framework that particularly cater to the needs of West Africa as seen in other parts of the world, discussed above, such as; BREEAM – Great Britain; GBTool - Canada;LEED – United States of America; EcoProfile – Norway; and Environmental Status – Sweden.

The availability of site-specific material carbon emission units and a tool which considers all aspects of design, construction and demolition of buildings can pave the way for architects and other building professionals to revert to or at least adopt indigenous methods as they can better prove the benefit of their chosen materials and processes. Future research should also focus on establishing data that can be utilised in making progress on measuring embodied carbon of buildings for waste minimization, management, and regulation.

10. Conclusions

In the case that all regions in the developing world increased their energy usage to the 2008 level of the developed world, their energy use would escalate to four times the current amount which does not align with future goals in place [9]. Decarbonisation of the built environment to promote sustainable development projects is a wide issue that encompasses deeper social issues such as decolonisation and population increase; economic issues such as cost of materials and accessibility; and environmental issues such as increase in natural disasters, rising global temperatures and increase in energy usage in maintenance. These factors all contribute to the ability to make an urban settlement 'sustainable'.

It is important to note that traditional construction materials may be less suitable for achieving tall structures and may be less applicable to densely populated urban areas. However, it is possible to significantly reduce the carbon footprint of modern houses by applying learnings from traditional architecture to modern houses – most notably, the use of local materials as that can have a very large impact on the carbon footprint of construction. Although modern building materials for example, cement, is also useful in construction generally, as its application could to maximise the lifespan of a building, there is a demand for new sustainable alternatives and recycling facilities when it reaches the end of its life cycle.

Vernacular shelters have evolved alongside indigenous humans over centuries. It is evident that the key solution to reduce carbon emissions using the knowledge gained of centuries is to utilise materials available locally. In West Africa and beyond, indigenous peoples have studied their lands and learnt how to build in a way that is beneficial to their environment, economy, and societal needs [110]. This study confirms the hypothesis that the fundamental aspects i.e., the principles of a typical traditional building is consistent with lower energy consumption as compared to those constructed to Western templates, using more modern materials.

11. References

1. Ghosh, I., 2020. A Global Breakdown of Greenhouse Gas Emissions by Sector. [online] Visual Capitalist. Available at: <https://www.visualcapitalist.com/a-global-breakdown-of-greenhouse-gas-emissions-by-sector/> [Accessed 15 May 2021].
2. Wang T, Seo S, Liao PC, Fang D. GHG emission reduction performance of state-of-the-art green buildings: Review of two case studies. Renewable and Sustainable Energy Reviews. 2016 Apr 1;56:484-93.
3. Farrelly, L., 2012. The fundamentals of architecture. Lausanne: bloomsbury publishing, p.chapter 1.
4. UNDESA. 1987."Sustainable Development for Africa". The World Commission on Environment and Development, Our Common Future/UN Department of Economic and Social Affairs; Division for Sustainable Development. The Brundtland Report
5. Li, D., Huang, G., Zhu, S., Chen, L. and Wang, J., 2021. How to peak carbon emissions of provincial construction industry? Scenario analysis of Jiangsu Province. Renewable and Sustainable Energy Reviews, 144, p.110953.
6. Ott, K. 2003. "The Case for Strong Sustainability." In: Ott, K. & P. Thapa (eds.) Greifswald's Environmental Ethics. Greifswald: Steinbecker Verlag Ulrich Rose.
7. Braimoh A., Osaki M.. 2010.Land-Use Change and Environmental Sustainability. Sustainability Science 5: 5–7. DOI 10.1007/s11625-009-0092-2.
8. 5. Odebiyi O. Sustainable Housing Development in Africa: Nigerian Perspective [Internet]. Dx.doi.org. 2021 [cited 19 September 2021]. Available from: http://dx.doi.org/10.3968/j.ibm.1923842820100101.005
9. Wolfram C, Shelef O, Gertler P. How Will Energy Demand Develop in the Developing World?. Journal of Economic Perspectives. 2012;26(1):119-138.
10. Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU), 2016,'Sustainable buildings and construction in Africa', BMU

11. Gbatu,N.J., and Li,H., 2019, 'The Transformations of Vernacular / Traditional Architecture to Modern Architecture in West Africa, Liberia', Advances in Social Science, Education and Humanities Research, vol.324
12. Mazzocchi,F., 2020, 'A deeper meaning of sustainability: Insights from indigenous knowledge', The Anthropocene Review
13. Sameh S. Promoting earth architecture as a sustainable construction technique in Egypt. Journal of Cleaner Production. 2014;65:362-373.
14. UNTC [Internet]. Treaties.un.org. 2021 [cited 22 September 2021]. Available from: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en
15. Clift C. What are the impacts of climate change? [Internet]. Imperial College London. [cited 17 June 2020]. Available from: https://www.imperial.ac.uk/grantham/publications/climate-change-faqs/what-are-the-impacts-of-climate-change/
16. Keshtkaran P. Harmonization Between

7. Climate and Architecture in Vernacular Heritage: A Case Study in Yazd, Iran. Procedia Engineering. 2011;21:428-438.

17. Cajete,A.G., 2020, 'Indigenous Science, Climate Change, and Indigenous Community Building: A Framework of Foundational Perspectives for Indigenous Community Resilience and Revitalization', Sustainability
18. Snyder, H. , Lite ratu re rev iew as a research methodology: An over vie w and gu ide li ne s. Journal of Business Re search, 2019 , 10 4, p. 333-339 .
19. Paul J, Criado A. The art of writing literature review: What do we know and what do we need to know?. International Business Review. 2020;29(4):101717.
20. Waheed B, Khan F, Veitch B. Linkage-Based Frameworks for Sustainability Assessment: Making a Case for Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) Frameworks. Sustainability. 2009;1(3):441-463.
21. Roof, K; Oleru N. (2008). "Public Health: Seattle and King County's Push for the Built Environment". J Environ Health. 75: 24–27.

22. Sussman, Ann (2014). Cognitive architecture : designing for how we respond to the built environment. Taylor & Francis. ISBN 978-0-367-46860-6. OCLC 1224041975.
23. Handy, Susan L.; Boarnet, Marlon G.; Ewing, Reid; Killingsworth, Richard E. (2002-08-01). "How the built environment affects physical activity: Views from urban planning". American Journal of Preventive Medicine. 23 (2): 64–73. doi:10.1016/S0749-3797(02)00475-0. ISSN 0749-3797. PMID 12133739.
24. Sallis, James F.; Floyd, Myron F.; Rodriguez, Daniel A.; Saelens, Brian E. (February 2012). "The Role of Built Environments in Physical Activity, Obesity, and CVD". Circulation. 125 (5): 729–37. doi:10.1161/CIRCULATIONAHA.110.969022. PMC 3315587. PMID 22311885.
25. Galster, George; Sharkey (2017). "Spatial Foundations of Inequality: A Conceptual Model and Empirical Overview". RSF: The Russell Sage Foundation Journal of the Social Sciences. 3 (2): 1. doi:10.7758/rsf.2017.3.2.01. ISSN 2377-8253. S2CID 131768289.
26. Lawrence, Denise L.; Low, Setha M. (1990). "The Built Environment and Spatial Form". Annual Review of Anthropology. 19: 453–505. doi:10.1146/annurev.an.19.100190.002321.
27. Lamprecht,M.(2016). The Role of the Built Environment in Human Life. Selected Issues. European Spatial Research and Policy. 23(2).
28. Conklin A. Colonialism and Human Rights, A Contradiction in Terms? The Case of France and West Africa, 1895-1914. The American Historical Review. 1998;103(2):419.
29. Lindqvist S, Tengberg A. New Evidence of Desertification from Case Studies in Northern Burkina Faso. Geografiska Annaler: Series A, Physical Geography. 1993;75(3):127-135.
30. Gyampoh BA, Amisah S, Idinoba M, Nkem J. Using traditional knowledge to cope with climate change in rural Ghana. Unasylva. 2009;60(281/232):70-4.
31. Aboagye DD, Dari T, Koomson J. Risk perception and disaster management in the savannah region of Ghana.

32. Adeagbo A, Daramola A, Carim-Sanni A, Akujobi C, Ukpong C. Effects of natural disasters on social and economic well being: A study in Nigeria. International journal of disaster risk reduction. 2016 Aug 1;17:1-2.

33. Daramola AY, Oni OT, Ogundele O, Adesanya A. Adaptive capacity and coping response strategies to natural disasters: a study in Nigeria. International Journal of Disaster Risk Reduction. 2016 Mar 1;15:132-47.

34. Conway, M.; Patel, K.K. (Eds.) Europeanization in the Twentieth Century: Historical Approaches; Palgrave Macmillan: London, UK, 2010; ISBN 978-1-349-31307-5.

35. Whyte, W. Modernism, Modernization and Europeanization in West African Architecture, 1944-94. In Europeanization in the Twentieth Century: Historical Approaches; Conway, M., Patel, K.K., Eds.; Palgrave Macmillan: London, UK, 2010; pp. 210–228. 7.

36. Low, I. Architecture in Africa: Situated Modern and the Production of Locality in Africa. In A Critical History of Contemporary Architecture: 1960–2010; Haddad, E.G., Rifkind, D., Eds.; Ashgate Publishing: Burlington, VM, USA, 2014; pp. 291–310.

37. Gadgil M, Berkes F, Folke C. Indigenous knowledge for biodiversity conservation. Ambio. 1993 May 1:151-6.

38. Fernandez, M.E. (1994) Gender and indigenous knowledge. Indigenous Knowledge & Development Monitor 2: 6-7.

39. Institut National de la Statistique et de la Démographie (INSD). Annuaire Statistique 2018; INSD: Ouagadougou, Burkina Faso, 2019.

40. Williamson BJ. From Upper Volta to Burkina Faso: A Study of the Politics of Reaction and Reform in a Post-Colonial African Nation-state, 1960-1987.

41. Burkina Faso | Facts, Map, Capital, Flag, Religion, People, Geography, & History [Internet]. Encyclopedia Britannica. 2021 [cited 14 September 2021]. Available from: https://www.britannica.com/place/Burkina-Faso

42. 4. Rethinking History: New Architecture in Burkina Faso [Internet]. ArchDaily. 2021 [cited 14 September 2021]. Available from: https://www.archdaily.com/924516/rethinking-history-new-architecture-in-burkina-faso

43. Kéré, B. Architecture et Cultures Constructives du Burkina Faso; CRATerre-EAG: Villefontaine, France, 1995.

44. Sweeney, T.D. (2016) Convergent parallel mixed methods investigation into the role of mindfulness in moderate to severe, persistent depression. PhD Thesis. University of Nottingham. Available at: http://eprints.nottingham.ac.uk/37603/
45. Mertens, D. (2019) Research and evaluation in education and psychology: integrating diversity with quantitative, qualitative and mix methods. 5th ed. Newbury Park, CA: SAGE Publications, Inc.
46. Foddy, W. (1993): Constructing Questions for Interviews and Questionnaires: Theory and Practice in Social Research. Cambridge: Cambridge University Press
47. Artino A, La Rochelle J, Dezee K, Gehlbach H. Developing questionnaires for educational research: AMEE Guide No. 87. Medical Teacher. 2014;36(6):463-474.
48. Lazarsfeld, P.F. (1944): The controversy over detailed interviews - an offer for negotiation. Public Opinion Quarterly, 8, 38-60.
49. Roseland M. Sustainable community development: integrating environmental, economic, and social objectives. Progress in Planning. 2000;54(2):73-132.
50. Assefa G, Glaumann M, Malmqvist T, Kindembe B, Hult M, Myhr U, et al. Environmental assessment of real estates – where natural and social sciences meet: the case of ecoeffect. In: Proceedings of the 2005 world sustainable building conference (SB05Tokyo), 2005 Sep 27–29. Tokyo: 2005. p. 2055–62.
51. Comprehensive assessment system for building environmental efficiency. CASBEE for new construction: technical manual 2004 edition. Available from: http://www.ibec.or.jp/CASBEE
52. Close comprehensive environmental performance assessment scheme for buildings (CEPAS) assessment manual buildings Department, Hong Kong Special Administrative Region (HKSAR) Government (2006) Available from: http://www.bd.gov.hk/
53. LEED for homes green building rating system – U.S. green building council, version 1.11a (2007) Available from: http://www.usgbc.org/leed/homes
54. About us - BRE Group [Internet]. BRE Group. 2021 [cited 24 October 2021]. Available from: https://www.bregroup.com/about-us

55. GhaffarianHoseini A, Tookey J, GhaffarianHoseini A, Naismith N, Rotimi JO. Integrating alternative technologies to improve built environment sustainability in Africa: nexus of energy and water. Smart and Sustainable Built Environment. 2016 Sep 5.
56. Moore S, Karvonen A. Sustainable Architecture in Context. Science & Technology Studies. 2008;21(1):29-44.
57. Green Building Standards and Certification Systems | WBDG - Whole Building Design Guide [Internet]. Wbdg.org. 2019 [cited 25 September 2021]. Available from: https://www.wbdg.org/resources/green-building-standards-and-certification-systems
58. 7. [Internet]. [cited 26 September 2021]. Available from: https://www.unep.org/regions/africa/our-work-africa/un-environment-west-africa
59. THE 17 GOALS | Sustainable Development [Internet]. Sdgs.un.org. [cited 26 October 2021]. Available from: https://sdgs.un.org/goals
60. Pye, S., Li, F., Price, J. and Fais, B., 2017. Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era. Nature Energy, 2(3).
61. Nigeria [Internet]. Climateactiontracker.org. [cited 26 September 2021]. Available from: https://climateactiontracker.org/countries/nigeria/
62. Oluigbo S. CULTURAL EXPRESSION AND SUSTAINABLEDESIGN OF RESORTS IN NIGERIA. [Internet]. 2019;. Available from: https://scholar.googleusercontent.com/scholar?q=cache:xbUDryfIhS0J:scholar.google.com/+%22%23express+culture%22+diversity+%22+west+africa%22&hl=en&as_sdt=0,5
63. Bamogo,H. Ouedraogo,M. Sanou,I. Ouedraogo,J.A.K. Dao,K. Aubert,E.J. and Millogo,Y. (2020). Improvement of water resistance and thermal comfort of earth renders by cow dung: an ancestral practice of Burkina Faso. Journal of Cultural Heritage
64. El Fgaier F, Lafhaj Z, Brachelet F, Antczak E, Chapiseau C. Thermal performance of unfired clay bricks used in construction in the north of France: Case study. Case studies in construction materials. 2015 Dec 1;3:102-11.

65. Wolfram C, Shelef O, Gertler P. How Will Energy Demand Develop in the Developing World?. Journal of Economic Perspectives. 2012;26(1):119-138.
66. Gupta, K.K., Aneja, K.R. & Rana, D. Current status of cow dung as a bioresource for sustainable development. Bioresour. Bioprocess. 3, 28 (2016). https://doi.org/10.1186/s40643-016-0105-9
67. Craven J. Adobe Is the Mud Brick You'll Learn to Love [Internet]. ThoughtCo. 2019 [cited 27 October 2021]. Available from: https://www.thoughtco.com/what-is-adobe-sustainable-energy-efficient-177943
68. Hema,M.C. Moeseke,V.G. Evrad,A. Courard,L. and Messan,A. (2017). Vernacular building practices in Burkina Faso: representatives' models of construction in Ouagadougou and walls hygrothermal efficiency. Energy Procedia.
69. Forke K. Compressed Earth Blocks | EMI [Internet]. Emiworld.org. 2017 [cited 27 October 2021]. Available from: https://emiworld.org/emi-tech/compressed-earth-blocks
70. Bresler A. 54 structures that prove African architecture is widely underrated [Internet]. Matador Network. 2020 [cited 27September 2021]. Available from: https://matadornetwork.com/read/best-african-architecture/
71. Davies O. Ghana | History, Flag, Map, Population, Language, Currency, & Facts [Internet]. Encyclopedia Britannica. 2021 [cited 27 September 2021]. Available from: https://www.britannica.com/place/Ghana
72. Nzdl.org. n.d. Compressed Earth blocks: Manual of design and construction: Introduction: A building tradition. [online] Available at: <http://www.nzdl.org/cgi-bin/library?e=d-00000-00---off-0hdl--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0-0-11----0-0-&a=d&c=hdl&cl=CL1.3&d=HASH01564539ee308f58c8424cbb.3.6#HASH01564539ee308f58c8424cbb.3.6> [Accessed 27 September 2021].
73. Zea Escamilla E, Habert G, Correal Daza J, Archilla H, Echeverry Fernández J, Trujillo D. ami Comparative Life Cycle Assessment (LCA) of Bamboo-Based Buildings. Sustainability. 2018;10(9):3096.
74. Van der Lugt, P., Vogtländer, J., van der Vegte, J. H., & Brezet, H. (2015). Environmental Assessment of Industrial Bamboo Products: Life Cycle

Assessment and Carbon Sequestration. In Proceedings of the 10th World Bamboo Congress (pp. 1-16). World Bamboo Organization.

75. Nyman JF. Equivalent fire resistance ratings of construction elements exposed to realistic fires.

76. Rashid,M. and Ara,R.D.(2015). Modernity in tradition: Reflections on building design and technology in the Asian vernacular. Frontiers of Architectural Research

77. Sameh,H.S. (2017). Promoting earth architecture as a sustainable construction technique in Egypt. Journal of Cleaner Production. Pp.362-373

78. Oyelami, C.A. and Rooy,V.J.L.(2016). A review of the use of lateritic soils in the construction/development of sustainable housing in Africa: A geological perspective. Journal of African Earth Science

79. Uba B, Aghogho O. Rainwater quality from different roof catchments in the Port Harcourt district, Rivers State, Nigeria. Journal of Water Supply: Research and Technology-Aqua. 2000;49(5):281-288.

80. Agyekum,K, Kissi,E. and Danku,C.J. (2020). Professionals' views of vernacular building materials and techniques for green building delivery in Ghana. Scientific African

81. McSmith A. What's in an African hut? [Internet]. Linkedin.com. 2017 [cited 1 October 2021]. Available from: https://www.linkedin.com/pulse/whats-african-hut-alan-mcsmith

82. LALC. (2021). Wattle and Daub. [online] Available at: https://www.bamboo-earth-architecture-construction.com/wattle-daub/ (Accessed at 5th oct 2021).

83. Vision Development. (2021). Timber frame buildings and environment. [online] Available at: https://www.timber-frame-suppliers.co.uk/2014/timber-frame-buildings-environment/ Accessed at 5th Oct, 2021)

84. Birth of the Nigerian Colony - The Centenary Project - Google Arts & Culture [Internet]. Google Arts & Culture. 2014 [cited 7th October 2021]. Available from: https://artsandculture.google.com/exhibit/birth-of-the-nigerian-colony-pan-atlantic-university/ARi_MKdz?hl=en

85. Nigeria - Climate [Internet]. Encyclopedia Britannica. [cited 7th October 2021]. Available from: https://www.britannica.com/place/Nigeria/Climate

86. Agboola,P.O. and M.S. Zango,S.M. (2014) Development of traditional architecture of Northern Nigeria; A Case Study of Hausa house form. International Journal of African Society Culture and Traditions.1(1) pp 61-74
87. Danja,I.I. (2017). Vernacular Architecture of Northern Nigeria in the Light of Sustainability. 2017 International Conference on Environmental and Energy Engineering
88. Auwalu, Koko,F. (2019). Exploring the different vernacular architecture in Nigeria. International Journal of African Society, Cultures and Traditions. 7(1). Pp. 1-7
89. Sijuwade A. A new master's house: The architect decolonising Nigerian design. aljazeera [Internet]. 2020 [cited 9 October 2021];. Available from: https://www.aljazeera.com/features/2020/8/10/a-new-masters-house-the-architect-decolonising-nigerian-designEjiga, O. Paul, O. and Cordelia,O.O. (2012). Sustainability in traditional African architecture: a springboard for sustainable urban cities. Sustainable futures: architecture and urbanism in global south Kampala, Uganda
90. Gibberd,J. (2013). Sustainable African built environments. African Journal of Science, Technology, Innovation, and Development. 5(4). pp.313-318
91. Gibberd,J. (2013). Sustainable African built environments. African Journal of Science, Technology, Innovation, and Development. 5(4). pp.313-318
92. Samuel, L.D.G. Darmasastha,K. Nagendra,S.S.M. and Maiya, P.M.(2017). Thermal comfort in traditional buildings composed of local and modern construction materials. International Journal of Sustainable built Environment
93. Xuereb M. How architecture can fight climate change. https://www.youtube.com/watch?v=tHMLhm3hc5c&ab_channel=TEDxTalks: TEDxToronto; 2020.
94. Correia, M.; Dipasquale, L.; Mecca, S. (Eds.) VERSUS. Heritage for Tomorrow. Vernacular Knowledge for Sustainble Architecture; Firenze University Press: Florence, Italy, 2014; ISBN 978-88-6655-741-8. 2.
95. Whelan, D. Habitat: Vernacular Architecture for a Changing World; Piesik, S., Ed.; Thames & Hudson: London, UK, 2017; pp. 226–240. ISBN 978-0-500-34324-1.

96. Sinamai, A. We are Still Here: African Heritage, Diversity and the Global Heritage Knowledge Templates. Archaeologies 2020, 16, 57–71. [CrossRef]
97. Embodied vs Operational Carbon - SPOT - Blog [Internet]. SPOT - Blog. 2020 [cited 28 October 2021]. Available from: https://spot.ul.com/blog/embodied-vs-operational-carbon/#:~:text=Embodied%20Carbon%3A%20The%20amount%20of,the%20making%20of%20a%20building.&text=Operational%20Carbon%3A%20The%20amount%20of,for%2028%25%20of%20global%20GHG.
98. Hub I. Guest Article: The Contribution of Design to Sustainable Development | SDG Knowledge Hub | IISD [Internet]. Sdg.iisd.org. 2011 [cited 28 October 2021]. Available from: https://sdg.iisd.org/commentary/guest-articles/the-contribution-of-design-to-sustainable-development/
99. Amin AM. Recycle of Wastes of Clay Brick Industry for Producing Eco-cement.
100. Braungart, M. and McDonough, W., 2009. Cradle to cradle. Vintage; First Edition Fifth Printing.
101. Braungart, M. and McDonough, W., 2009. Cradle to cradle. Vintage; First Edition Fifth Printing.
102. Rikko L, Gwatau D. The Nigerian architecture: The trend in housing development. Journal of Geography and Regional Planning [Internet]. 2011 [cited 7 October 2021];4 (5):273-278. Available from: https://academicjournals.org/JGRP
103. . Embodied Carbon Footprint Database - Circular Ecology [Internet]. Circular Ecology. 2020 [cited 18 June 2020]. Available from: https://circularecology.com/embodied-carbon-footprint-database.html
104. How is Africa doing in achieving the UN Sustainable Development Goal #7? [Internet]. isnad-africa.org. [cited 11 October 2021]. Available from: https://isnad-africa.org/2019/02/20/how-is-africa-doing-in-achieving-the-un-sustainable-development-goal-7/
105. Crunden E. How Useful Is Recycling, Really? [Internet]. The Atlantic. [cited 9 October 2021]. Available from: https://www.theatlantic.com/science/archive/2021/01/recycling-wont-solve-climate-change/617851/

106. Balter J, Ganem C, Discoli C. On high-rise residential buildings in an oasis-city: Thermal and energy assessment of different envelope materiality above and below tree canopy. Energy and Buildings. 2016 Feb 1;113:61-73.
107. Popescu,A.L. and Luca,O.(2017).Built environment and climate change. Theoretical and Empirical Research in Urban Management
108. Petersen, A.K., Solberg, B. Greenhouse Gas Emissions and Costs over the Life Cycle of Wood and Alternative Flooring Materials. Climatic Change 64, 143–167 (2004). https://doi.org/10.1023/B:CLIM.0000024689.70143.79
109. Sustainability – Welcome to Dangote Cement Plc [Internet]. Dangotecement.com. [cited 10 October 2021]. Available from: https://dangotecement.com/sustainability
110. Rammed Earth Housing from eco-friendly construction company Hive Earth [Internet]. Azure Magazine. 2019 [cited 13 October 2021]. Available from: https://www.azuremagazine.com/article/rammed-earth-housing-ghana/
111. Aminu Umar U, Shafiq N, Malakahmad A, Fadhil Nuruddin M, Farha S, Salihi I. ISSN 0973-4562. International Journal of Applied Engineering Research [Internet]. 2016 [cited 1 October 2021];11(2):1523-1532. Available from: https://www.researchgate.net/profile/Ibrahim-Salihi/publication/296746152_Application_of_Structural_Building_Information_Modeling_S-BIM_for_Sustainable_Buildings_Design_and_Waste_Reduction_A_Review/links/56da64ae08aebe4638bba369/Application-of-Structural-Building-Information-Modeling-S-BIM-for-Sustainable-Buildings-Design-and-Waste-Reduction-A-Review.pdf
112. The Average House Sizes & Average Square Footage in the UK [Internet]. David Wilson Homes. [cited 29 October 2021]. Available from: https://www.dwh.co.uk/advice-and-inspiration/average-house-sizes-uk/
113. Building Material Quantities for House Construction [Internet]. Buildersmart.in. [cited 10 October 2021]. Available from: https://www.buildersmart.in/blogs/building-material-quantities/
114. The Nubian Vault – Better Building in Burkina Faso – Equator Initiative [Internet]. Equatorinitiative.org. [cited 13 October 2021]. Available from:

https://www.equatorinitiative.org/2017/06/05/the-nubian-vault-better-building-in-burkina-faso/

115. Hertwich EG, Ali S, Ciacci L, Fishman T, Heeren N, Masanet E, Asghari FN, Olivetti E, Pauliuk S, Tu Q, Wolfram P. Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Environmental Research Letters. 2019 Apr 16;14(4):043004.
116. Bamogo H, Ouedraogo M, Sanou I, Ouedraogo K, Dao K, Aubert J et al. Improvement of water resistance and thermal comfort of earth renders by cow dung: an ancestral practice of Burkina Faso. Journal of Cultural Heritage. 2020;46:42-51.
117. Ede AN, Olofinnade OM, Edwin EA, Bamigboye G. Implications of construction materials on energy efficiency of buildings in tropical regions. International Journal of Applied Engineering Research. 2017 Oct 3;12(18):7873-83.
118. Whole life carbon assessment for the built environment [Internet]. 2017 [cited 21 October 2021]. Available from: https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf
119. United Nations. the United Nations Household Size and Composition around the world data booklet [Internet]. Un.org. 2017 [cited 7 October 2021]. Available from: https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_around_the_world_2017_data_booklet.pdf
120. How do we calculate the amount of carbon bamboo can absorb? - Bamboo Village Uganda [Internet]. Bamboo Village Uganda. [cited 11 October 2021]. Available from: https://bamboovillageuganda.com/how-do-we-calculate-the-amount-of-carbon-bamboo-can-absorb/
121. Embodied Carbon Footprint Database - Circular Ecology [Internet]. Circular Ecology. [cited 2 October 2021]. Available from: https://circularecology.com/embodied-carbon-footprint-database.html
122. Thatched Roofing Costs: Complete 2021 Guide [Internet]. Householdquotes.co.uk. 2021 [cited 11 October 2021]. Available from: https://householdquotes.co.uk/thatched-roofing/

123. Greenhouse gas reporting: conversion factors 2021 [Internet]. GOV.UK. 2021 [cited 11 October 2021]. Available from: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021

Appendix 1

ICE reference tables

CATEGORY	TYPE	SUB-TYPE	UNIT	EMISSION TYPE	FACTOR
Cement	General (UK weighted average)	-	Kg	KgCO2e	0.74
Cement	Average CEM I Portland Cement, 94% Clinker	-	Kg	KgCO2e	0.95
Cement	6-20% Fly ash (CEM II/A-V)	-	Kg	KgCO2e	0.825
Cement	21-35% Fly ash (CEM II/B-V)	-	Kg	KgCO2e	0.685
Cement	21-35% Fly ash GGBS (CEM II/B-S)	-	Kg	KgCO2e	0.71
Cement	36-65% Fly ash GGBS (CEM II/A)	-	Kg	KgCO2e	0.515
Cement	66-80% GGBS (CEM II/B)	-	Kg	KgCO2e	0.32
Cement	Fibre Cement Panels - Uncoated	-	Kg	KgCO2e	1.09
Cement	Fibre Cement Panels - (colour) coated	-	Kg	KgCO2e	1.28
Cement	Mortar (1:3 cement:sandmix)	-	Kg	KgCO2e	0.221
Cement	Mortar (1:4)	-	Kg	KgCO2e	0.82
Cement	Mortar (1:5)	-	Kg	KgCO2e	0.156
Cement	Mortar (1:6)	-	Kg	KgCO2e	0.136
Cement	Mortar (1:½:4 ½ Cement:Lime:Sand mix)	-	Kg	KgCO2e	0.213
Cement	Mortar (1:1:6 Cement:Lime:Sand mix)	-	Kg	KgCO2e	0.174
Cement	Mortar (1:2:9 Cement:Lime:Sand mix)	-	Kg	KgCO2e	0.155
Cement	Cement stabilised soil @5%	-	Kg	KgCO2e	0.61
Cement	Cement stabilised soil @8%	-	Kg	KgCO2e	0.084
Clay	General (Simple Baked Products)	-	Kg	KgCO2e	0.24
Clay	Tile	-	Kg	KgCO2e	0.48
Clay	Vitrified clay pipe DN 100 & DN 150	-	Kg	KgCO2e	0.46
Clay	Vitrified clay pipe DN 200 & DN 300	-	Kg	KgCO2e	0.5
Clay	Vitrified clay pipe DN 500	-	Kg	KgCO2e	0.55
Steel	General - UK (EU)	Average	Kg	KgCO2e	1.46
Steel	General - UK (EU)	Virgin	Kg	KgCO2e	2.89
Steel	General - UK (EU)	Recycled	Kg	KgCO2e	0.47
Steel	Bar & rod - UK (EU)	Average	Kg	KgCO2e	1.4
Steel	Bar & rod - UK (EU)	Virgin	Kg	KgCO2e	2.77
Steel	Bar & rod - UK (EU)	Recycled	Kg	KgCO2e	0.45
Steel	Coil (sheet) - UK (EU)	Average	Kg	KgCO2e	1.38
Steel	Coil (sheet) - UK (EU)	Virgin	Kg	KgCO2e	2.74
Steel	Coil (sheet) - UK (EU)	Recycled	Kg	KgCO2e	Not typical
Steel	Coil (sheet), Galvanised	Average	Kg	KgCO2e	1.54
Steel	Coil (sheet), Galvanised	Virgin	Kg	KgCO2e	3.01
Steel	Engineering steel	Recycled	Kg	KgCO2e	0.72
Steel	Pipe - UK (EU)	Average	Kg	KgCO2e	1.45
Steel	Pipe - UK (EU)	Virgin	Kg	KgCO2e	2.87
Steel	Pipe - UK (EU)	Recycled	Kg	KgCO2e	Not typical

CATEGORY	TYPE	SUB-TYPE	UNIT	EMISSION TYPE	FACTOR
Steel	Pipe - UK (EU)	Average	Kg	KgCO2e	1.66
Steel	Pipe - UK (EU)	Virgin	Kg	KgCO2e	3.27
Steel	Pipe - UK (EU)	Recycled	Kg	KgCO2e	Not typical
Steel	Section - UK (EU)	Average	Kg	KgCO2e	1.53
Steel	Section - UK (EU)	Virgin	Kg	KgCO2e	3.03
Steel	Section - UK (EU)	Recycled	Kg	KgCO2e	0.47
Steel	Wire	Virgin	Kg	KgCO2e	3.02
Steel	Stainless	-	Kg	KgCO2e	6.5137
Steel	General - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	2.03
Steel	General - World Avg. Recy.cont.	-	Kg	KgCO2e	1.95
Steel	Bar & rod - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	1.95
Steel	Bar & rod - World Avg. Recy.cont.	-	Kg	KgCO2e	1.86
Steel	Coil - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	1.92
Steel	Coil - World Avg. Recy.cont.	-	Kg	KgCO2e	1.85
Steel	Coil, Galvanised - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	2.12
Steel	Coil, Galvanised - World Avg. Recy.cont.	-	Kg	KgCO2e	2.03
Steel	Pipe - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	2.01
Steel	Pipe - World Avg. Recy.cont.	-	Kg	KgCO2e	1.94
Steel	Plate - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	2.31
Steel	Plate - World Avg. Recy.cont.	-	Kg	KgCO2e	2.21
Steel	Section - R.O.W. Avg. Recy.cont.	-	Kg	KgCO2e	2.12
Steel	Section - World Avg. Recy.cont.	-	Kg	KgCO2e	2.03
Stone	General	-	Kg	KgCO2e	0.079
Stone	Granite	-	Kg	KgCO2e	0.7
Stone	Limestone	-	Kg	KgCO2e	0.09
Stone	Marble	-	Kg	KgCO2e	0.13
Stone	Marble tile	-	Kg	KgCO2e	0.21
Stone	Sandstone	-	Kg	KgCO2e	0.06
Stone	Shale	-	Kg	KgCO2e	0.002
Stone	Slate	-	Kg	KgCO2e	0.035
Timber	General	Not Responsibly sourced	Kg	KgCO2e	0.72
Timber	General	Responsibly sourced	Kg	KgCO2e	0.31
Timber	Glue Laminated	Not Responsibly sourced	Kg	KgCO2e	0.87
Timber	Glue Laminated	Responsibly sourced	Kg	KgCO2e	0.42
Timber	Hardboard	Not Responsibly sourced	Kg	KgCO2e	1.09
Timber	Hardboard	Responsibly sourced	Kg	KgCO2e	0.58

CATEGORY	TYPE	SUB-TYPE	UNIT	EMISSION TYPE	FACTOR
Timber	Laminated Veneer lumber	Not Responsibly sourced	Kg	KgCO2e	0.65
Timber	Laminated Veneer lumber	Responsibly sourced	Kg	KgCO2e	0.33
Timber	MDF	Not Responsibly sourced	Kg	KgCO2e	0.74
Timber	MDF	Responsibly sourced	Kg	KgCO2e	0.39
Timber	Oriented Strand board	Not Responsibly sourced	Kg	KgCO2e	0.99
Timber	Oriented Strand board	Responsibly sourced	Kg	KgCO2e	0.45
Timber	Particle Board	Not Responsibly sourced	Kg	KgCO2e	0.86
Timber	Particle Board	Responsibly sourced	Kg	KgCO2e	0.54
Timber	Plywood	Not Responsibly sourced	Kg	KgCO2e	1.1
Timber	Plywood	Responsibly sourced	Kg	KgCO2e	0.45
Timber	Sawin Hard wood	Not Responsibly sourced	Kg	KgCO2e	0.87
Timber	Sawin Hard wood	Responsibly sourced	Kg	KgCO2e	0.24
Timber	Sawin Hard wood	Not Responsibly sourced	Kg	KgCO2e	0.59
Timber	Sawin Hard wood	Responsibly sourced	Kg	KgCO2e	0.2
Timber	Veneer Particle board	Not Responsibly sourced	Kg	KgCO2e	NA
Timber	Veneer Particle board	Responsibly sourced	Kg	KgCO2e	NA

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