SUSTAINABLE CONSTRUCTION MATERIALS AND ASSEMBLIES FOR NIGERIAN LOW COST HOUSING PROJECTS

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Specially dedicated to my beloved Wife Hajiya Fatima and my children, Hauwawu, Aishetu, Ahmad & Muhammad for their endless love, support and encouragement.

"Thank you for your sacrifice during this PhD journey".

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ABSTRACT

Sustainable construction is a way to achieve environmental-friendly building design and construction. Construction activity has impact on the environment and users of naturally occurring and synthesized resources. The recent rise in environmental conscious design mandates the development of a new tool for pre-use stage decision-making in the materials and assemblies process. It is crucial in building life-cycle decision making, to integrate environmental issues in the evaluation process. The study developed an evaluation-tool to aid in the pre-use stage decision-making process of low cost housing projects by integrating sustainable construction principles into the materials and assemblies process. The study identified the decision making tool; then investigated the environmental awareness issues in sustainable materials and assemblies at pre-use stage; and finally, evaluated and compared the pre-use stage overall environmental impacts of a building life cycle. An explanatory sequential mixed method research design was adopted. 43.1% of 480 architects and designers in Abuja-Nigeria, through stratified random sampling participated in the survey. Data were analysed using descriptive statistics analysis, relative index analysis and Kendall's Concordance. The findings showed the need for a new materials and assemblies tool for environmental impact evaluation, and designers do have the knowledge and are concerned about environmental issues of sustainable materials and assemblies. Based on the findings, an evaluation system was developed. Two case studies of a traditional construction method (TCM) and a contemporary construction method (CCM) for low cost housing were chosen to test the system. Data were analysed using linear programming coupled with a process life cycle assessment (LCA) framework and international energy and carbon protocols. The findings showed that the environmental performance of the building life-cycle pre-use stage can be improved by up to 126% embodied energy and 165% embodied carbon emissions. Furthermore, it was much easier to compare the environmental performances of whole-building assemblies, instead of separate materials and elements that do not represent the performance of the function of a building. The study has shown that the evaluation system provides design guidelines and criterion to achieve environmental conscious design. Based on the findings from the evaluation system, a decision-making tool, the Optimum Life Cycle Assessment Performance (OLCAP) was developed. This tool can be used to guide local authorities, academicians and stakeholders to develop a structure for effective implementation of pre-use stage sustainable materials and assemblies. The tool developed was validated by the application of REVIT. Furthermore, the tool exposes the true environmental and economic sustainability in materials and assemblies with the help of simple multiplication and REVIT, which is readily available in the market. As a conclusion, OLCAP, the tool developed in this research can reduce the environmental impact of design and construction.

ABSTRAK

Pembinaan lestari adalah satu langkah dalam merealisasikan reka bentuk dan binaan bangunan mesra alam. Aktiviti pembinaan memberi impak terhadap persekitaran dan pengguna sumber yang terjadi samaada secara semula jadi atau dan sumber buatan. Peningkatan kesedaran terhadap reka bentuk mesra alam baru-baru ini mempengaruhi pembangunan kaedah terkini untuk membuat keputusan dipenngkatpra-guna tentang pemilihan bahan dan pemasangan. Adalah penting dalam penentuan keputusan kitaran hidup bangunan untuk mengintegrasikan isu persekitaran dalam proses penilaian. Kajian ini membangunkan alat penilaian untuk membantu proses membuat keputusan di peringkat pra-guna bagi projek perumahan kos rendah dengan menerapkan prinsip kelestarian untuk pemilihan bahan dan proses pemasangan. Kajian ini mengenal pasti alat untuk membuat keputusan, diikuti dengan meng kaji isu-isu persekitaran dalam bahan dan pemasangan lestari pada peringkat pra-guna dan akhirnya menilai dan mem dibandingkan impak keseluruhan pada peringkat pra-guna terhadap kitaran hidup bangunan. Reka bentuk kajian dengan kaedah penerangan berperingkat secara pelbagai telah digunakan. 43.1% daripada 480 arkitek dan jurureka di Abuja-Nigeria telah mengambil bahagian melalui kaedah persampelan secara rawak. Data dianalisis menggunakan analisa statistik deskriptif, analisa perkaitan indeks dan “Kendall’s Concordance”. Dapatan menunjukkan bahawa perlunya alafpenilaran baru bahan dan alat pemasangan untuk menilai kesan persekitaran, dan pereka mempunyai pengetahuan dan adalah prihatin terhadap isu-isu persekitaran bahan dan pemasangan lestari. Berdasarkan dapatan kajian ini, sistem penilaian telah dibangunkan. Dua kajian kes bagi kaedah pembinaan tradisional (TCM) dan kaedah pembinaan masa kini (CCM) bagi perumahan kos rendah telah dipilih untuk menguji sistem penilaian. Data dianalisis menggunakan program segaris bersama proses rangka kerja penilaian kitaran hayat (LCA) dan protokol tenaga dan karbon antarabangsa. Dapatan kajian menunjukkan bahawa perlunya alat bantuan dan pemasangannya untuk penilaian berimpak terhadap persekitaran, Dapatan kajian juga menunjukkan bahawa prestasi persekitaran pada peringkat pra-guna bagi kitaran hayat bangunan boleh ditingkatkan sehingga 126% tenaga dalaman dan 165% pembebasan karbon dalaman. Selain itu, adalah lebin mudah untuk membandingkan prestasi persekitaran terhadap pemasangan keseluruhan bangunan daripada mengasingkan bahan dan elemen yang tidak menerangkan prestasi fungsi bangunan. Kajian ini menunjukkan bahawa sistem penilaian ini menyediakan garis panduan reka bentuk dan kriteria untuk mencapai reka bentuk mesra persekitaran. Berdasarkan hasil dapatan dari sistem penilaian ini, sebuah alat membuat keputusan Penilaian Prestasi Kitaran Hayat Optima (OLCAP) telah dibangunkan. Alat ini mampu akan memberi panduan kepada ahli majlis tempatan, ahli akademik, dan pihak berwajib untuk membangunkan sebuay yangberkesan struktur dalam mengimplimentasi pemilihan bahan dan pemasangan pensykat pra guna lestari. Alat yang dibangunkan telah diuji menggunakan aplikasi REVIT. Tambahan pula sistem ini menunjukkan kelestarian persekitaran dan ekonomi dengan tepat dalam pemilihan dan pemasangan dengan bantuan jalan kira yang mudah dan REVIT yang terdapat di pasaran. Sebagai kesimpulan, OLCAP, alat yang dibangunkan dalam penyelidikan ini dapat mengurangkan kesan terhad ap alam sekitar terhadap dani reka bentuk dan pembinaan.

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ARCON	-	Architects Registration Council of Nigeria
Bath ICE	-	Bath Inventory of Carbon and Energy
BEES	-	Building for Environment and Economic Sustainability
BEEC	-	Building Energy Efficiency Code
BREEAM	-	BRE Environmental Assessment Methods
BEAT	-	Building Environment Assessment Tool
BEPAC	-	Building Environmental Performance Assessment Criteria
BRE	-	Building Research Establishment
BIM	-	Building Information Modelling
BPEO	-	Best Practice Environmental Option
BATNEEC	-	Best Available Technique Not Entailing Excessive Cost
CEN	-	European Committee for Standardisation
CRISP	-	Construction Research and Innovation Strategy Panel
CCM		Contemporary Construction Method
DETR	-	Department of the Environment, Transport and the Regions
DMT	-	Decision Making Tool
EE	-	Embodied Energy
EC	-	Embodied Carbon
EN	-	European Standard
ERGP	-	Economic Recovery and Growth Plan
ECD	-	Environmental Conscious Design
EMS	-	Environmental Management System
EPD	-	Environmental Product Declaration
EPM	-	Environmental Performance Management
FIEC	-	European Construction Industry Federation
FMPWH	-	Federal Ministry of Power Works and Housing

GBCN	-	Green Building Council Nigeria
GDP	-	Gross Domestic Product
GHG	-	Greenhouse Gas
HK-BEAM	-	Hong Kong Building Environmental Assessment Method
ISO	-	International Organisation for Standardisation
IPCC	-	Intergovernmental Panel on Climate Change
Bath ICE	-	Bath Inventory of Carbon and Energy
KMO	-	Kaiser-Meyer-Olkin
LCH	-	Low Cost Housing
LCA	-	Life Cycle Assessment
LCIA	-	Life Cycle Impact Assessment
LCI	-	Life Cycle Inventory
MOA	-	Multiobjective Optimisation Analysis
NIA	-	Nigerian Institute of Architects
NBS	-	National Bureau of Statistics
NBC	-	National Building Code
NBRRI	-	Nigerian Building and Road Research Institute
PAS	-	Publicly Available Specification
PCR	-	Product Category Rules
RMRDC	-	Raw Material Research and Development Council
MA	-	Materials and Assemblies
SETAC	-	Society of Environmental Toxicology and Chemistry
SHESTCO	-	SHEDA Science and Technology Complex
SAIC	-	Science Applications International Corporation
SPSS	-	Statistical Package for the Social Sciences
SC	-	Sustainable Construction
SCDC	-	Sustainable Construction for Developing Countries
TC	-	Technical Category
TCM	-	Traditional Construction Method
WBCDI	-	World Bank Collection of Development Indicator
WRAP	-	Waste and Resources Action Programme
WUF	-	World Urban Forum
IISD	-	International Institute of Sustainable Development

LIST OF SYMBOLS

$b_{j,n}$	-	Environmental burden coefficients (kg/kg)
B_j	-	Environmental burden (kg)
$e_{k,j}$	-	Environmental impact coefficients (kg/kg)[5]
E_k	-	Environmental impact (kg)
F	-	Economic objective function (N)
C	-	Cost objective function (N)
f	-	Environmental and economic objective functions
x	-	Continuous variables
y	-	Integer variables
R^n	-	Set of *n* continuous variables (kg); (MJ)
Z^q	-	Set of *q* integer variables (-)
P_l	-	Product output (kg)
$m_n^{(k)}$	-	Mass flow *n* in a subsystem k (kg)
$C_n^{(k)}$	-	Capacity of a process or an operation unit (kg)
GWP		Global warming potential objectivefunction

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CHAPTER 1

INTRODUCTION

1.1 Research Background

This research is based on the assumption that to accomplish sustainability in the construction sector, there is a need for integrating the principle of sustainable construction into Materials And Assemblies (MA) decision-making of Low Cost Housing (LCH) projects pre-use stage. Sustainability in materials and assemblies has grown to be one of the major subjects in the sector. Whilst there are hosts of related research in this domain, but major barriers still persist in integrating low-carbon standards in pre-use stage of low cost housing projects in Nigeria. Furthermore, as energy efficiency has had focus in climate change mitigation in the building sector, the carbon footprint of the construction material is gaining relevance. Therefore, this research attempts to contribute and redress this imbalance.

The speedy population growth, industrialisation and increased living standards, have effect on environment (Udawattha and Halwatura, 2017). More than half of the world's population is urban, and cities emit 75% of all CO_2 from energy consumption (Nordin and Sek, 2018). Therefore, challenge of housing the poor is particularly acute in the urban areas in Nigeria where an explosive expansion of the urban population due to a high population growth rate and massive rural-urban drift has compounded the housing situation (Nwakeze and Okwor, 2017).

The building and natural environment are inextricably linked. The relationship between the built and the natural environments has received an unprecedented level of coverage in the media in recent years as well as driving much new scientific research (Bansal *et al.*, 2015). The construction, fit-out, operation and ultimate demolition of buildings is a huge factor of human impact on the environment both directly (through material and energy consumption and the consequent pollution and waste) and indirectly (through the pressures on often inadequate infrastructure). The built environment also has a crucial impact on the physical and economic health and well-being of individuals, communities and organisations. A good building is a delight, will enhance a community or organisation, and our ability to learn or increase our productivity (Omardin *et al.*, 2015). Where buildings contribute to ill-health and alienation, undermine community and create excessive financial liability, they are undesirable and unsustainable.

There is an increasing use of carbon footprinting and Environmental Product Declaration (EPD) for communicating the environmental performance of construction products (Finkbeiner *et al.*, 2014). This can be related to increasing concerns regarding Greenhouse Gas (GHG) emissions from human activities and associated climate change (Stechemesser and Guenther 2012). Greenhouse gas emissions result when fossil fuels are produced and consumed and these emissions contribute to climate change (Akuru et al., 2015). In Nigeria, the total GHG emissions is 301010 kit of CO_2 equivalent and the total GHG emissions percentage change from 1990 is 84.36% (WBCDI, 2014). Product carbon footprint accounts the total amount of greenhouse gas emitted during the life cycle of goods and services, based on Life Cycle Assessment (LCA). Thus, this is based on a different approach than the greenhouse gas assessments at the level of projects, corporations, nations and individuals which mostly account for direct greenhouse gas emissions, not addressing indirect emissions from upstream and downstream activities (Tellnes *et al.*, 2017).

Modern buildings are responsible for 40% of energy consumption and contribute up to 30% of greenhouse emission (UN-Habitat, 2018). Mandatory energy and resource efficiency codes have been identified as suitable policies measures that contribute to lower energy consumption and carbon footprint. Meeting the target of the 2015 Paris climate agreement to keep heating well below 2° C above pre-industrial levels requires staying within a ‘carbon budget’ and emitting no more than around 800 gigatonnes of CO_2 in total after 2017. Yet bringing the rest of the world up to the same infrastructure level as developed countries (those listed as Annex 1 to the Kyoto Protocol) by 2050 could take up to 350 gigatonnes of the remaining global carbon budget (Bai *et al.*, 2018).

A commitment to maintain the environment can be linked with Sustainable Design. Maduka *et al.* (2016) states that “in addition to cost, time and quality objectives, sustainable designs add to it the criteria of resource delpletion minimization and negative environmental impacts and enhance a healthy living environment”. The substitution of other construction materials, which often have a higher carbon footprint, brings additional benefits (Escamilla *et al.*, 2016; Fouquet *et al.*, 2015; Peñaloza *et al.*, 2016) like the protection of the environment and job opportunities.

As awareness of the potential environmental impacts of building construction has grown, efforts are being made to avoid these adverse effects and to work towards impact mitigation. There is a growing consensus that appropriate strategies and actions are needed to make buildings and construction activities more sustainable (Omardin, *et al.*, 2015) With respect to such significant influence of the construction sector, the sustainable construction approach has a high potential to make a valuable contribution to sustainable development. The sustainability of a building depends on the decisions taken by a number of actors in the construction process: owners, managers, designers, firms, etc. The pace of actions towards sustainable application depends on the awareness, knowledge as well as an understanding of the consequences of individual actions (Ghafourian *et al.*, 2017). Among these is the environmentally responsible approach to the selection of building materials (Bansal, *et al.*, 2015). The selection of building materials is one of several factors that can impact the sustainability of a project (Ansah *et al.*, 2015). An appropriate choice of materials for a design process plays an important role during the life cycle of a building (Flórez *et al.*, 2010). Understanding the environmental issues surrounding the extraction of raw materials, the manufacture of construction materials, and their effects in use, is important to ensure sustainability (Al-Geelawee and Mohsin, 2018a). Thus, these have given an incentive for the quantity of enterprises to ensure sustainability strategies production. Also, awareness is enhanced as society advances in profitable chances bringing about productivity through sustainable-local technology.

Presently, energy consumption is based on fossil fuels despite advances in natural resources and renewable energy technology. It is doubtful whether such demand can be satisfied in an environmentally sustainable way (Schmidt and Crawford, 2018). Also, the demand for world energy is expected to be more by up to 71% between 2003 and 2030 (Hussain *et al.*, 2017). The only way to avert minimization is to achieved a magnitude improvement in energy-efficiency, which is defined as the ratio between the provided energy services and energy used (Derrick *et al.*, 2017).

The Buildings Energy Data Book, by U.S. Department of Energy, approximates an average life of 75-80 years for buildings in most developing countries such as Nigeria. This implies that buildings will have long-term effect on its structural performance and also on the environment. Impacts of buildings and its construction need not be always negative. Structures that are well-planned and built with sustainable materials and methods can be very beneficial to both community and workers as well. However, buildings have more impacts on environment than on other impact categories and the consequences can be both direct and indirect (Nirmal, 2012). In addition, Isnin and Ahmad (2012) affirmed that "encouraging usage of greener building materials and environmental-friendly products for a sustainable future as the way forward".

To achieve these sustainable design principles, decision has to be made at every building's life cycle stage. Before making such decisions, the decision-makers need to evaluate the short-term, medium and long-term impacts on the environment. Therefore, the construction process needs development and separation in naming their environmental implications.

However, any architectural energy use assessment ought to look at the entire building life-cycle which is divided into three (3) phases: Cradle-to-gate and construction phase (embodied energy phase), operational phase and deconstruction phase. But, this study focused on only the pre-use stage. Why the focus? Because the energy consumption intensity for the buildings production and components has raised with the development of construction sector in Nigeria.

Traditionally, buildings were built from local materials with low energy use and environmental impacts but in new buildings, materials such as concrete, PVC, glass, cement, alumimium and so on are utilized, which raise energy use and environmental impact (Bribián *et al.*, 2009). Hong *et al.* (2015) convey that "the greenhouse gas emissions that are linked with the construction and material production are acquiring major significance when buildings are turning more energy-efficient". Therefore, environmental footprint minimization of the building needs view of the whole-building life time rather than operational use only. The heightened awareness of the environmental protection importance and impacts of construction, have raised the concern in the development of a tools to better realise and address these impacts.

In addition to the impact caused by different material choices, building component assemblies also effect the environment in various ways. The term "Building Component Assembly" in this research refers to the way a building is built i.e., the method used to construct foundations, floors, walls, roofs, windows, doors and finishes. Different building component assemblies use different amounts of energy in the production or transport and they are also responsible for producing harmful gas emissions. Some component assemblies can be re-used or re-cycled and some are responsible for producing more waste than others. Building component assemblies can be combined with use of different construction materials to get the benefits of each (Nirmal, 2012). For example, you can have a lightweight wall and a heavy weight wall on different sides of a house, depending upon the degree of insulation required based on the orientation of the building. Therefore, to ensure a successful combination of different building component assemblies and construction materials a competent design advice is required.

In Nigeria, government has ascertained the practices of construction and designing as technical aspects of encouraging and delivering a sustainable built environment (Akinbami and Akinbami, 2017). The government has indicated its allegiance by convening awareness campaigns and conferences (FMPWH, 2008). In 2012, the Green Building Council Nigeria was conceived and Professional bodies are taking acute interest (Akadiri and Olomolaiye, 2012), it was signed into law in 2017 but implementation and establishment has been the problem. Nigeria is rich in various cultures, it is possible to integrate its social and cultural systems thereby contribute to increasing growth (Mullings and Mahabir, 2015). Local buildings had their sustainable features noted in their eco-friendly elements. However, almost in all parts of Nigeria regions, used environmental-friendly building materials like bamboo, thatch or palm leaves/fronds, stones, wood, straw, and red clay as major elements in their building features.

The Nigerian construction sector is robust and with its rapid growth in population, resulted to overcrowding in the nation’s capital, Abuja, causing a construction spill-over to other councils such as Kuje. Construction in Kuje needs longer transportation distances from Abuja, thereby increasing energy usage. The CO_2 emission from manufacturing industries and construction in Nigeria is about 43.2million metric tons (WBCDI, 2014). The climate harshness also affects energy use. By and large, planning and design follow standard practices, and special adjustment to local conditions is the exception rather than the rule (Huberman *et al.*, 2015). The distribution of Nigeria’s energy use is an example of industrialized countries, where buildings account for a bigger percentage. But in the United State of America, the mixed residential and commercial buildings account for about 40% (Güneralp *et al.*, 2017). But the share of energy utilized by buildings gains when energy used in their production is admitted.

The Nigerian government commitment to sustainable construction is set out in 'Architecture and the Nigerian Development Agenda – Sustainable built environment' (Architects Colloquium, 2006). Future focus were highlighted in the first progress review (Architects Colloquium, 2010). Although the 2010 progress which was the third since inception, is a continuation of what they had done in the past years. The 2012 edition of Architects Colloquium has thus identified the "Sustainable Built Environment" as an issue to be brought forth to the front burner within the context of "Architecture and National Development Agenda" and their match toward the Nigeria vision and focus. The theme of the 2012 Architects Colloquium was therefore "Architecture and the National Development Agenda V: Sustainable Built Environment II". In turn, construction development in Nigeria can impact on each of the themes as outlined below (Afolami *et al.*, 2016).

i. Provide effective protection of the environment,
ii. Encourage social progress that meets the needs of everyone,
iii. Ensure prudent use of natural resources, and
iv. Maintain stable economic growth and employment.

Construction is an interesting area to test the government's ability to implement its strategy, as there is a clear potential for conflict between the four (4) theme(Afolami, *et al.*, 2016). At the risk of over-simplifying the argument, to grow the economy, provide jobs and encourage social progress would seem to require more construction activity. However, to protect the environment and reduce the consumption of natural resources might require less construction. The task then, for a sustainable construction strategy, is to find ways for the four themes to complement each other. Ever since its publication, the sustainable construction agenda has been taken forward through a dynamic partnership between the government and sector. As a result, there have been several developments, namely (i) regulations, planning and energy; (ii) encourage awareness, capacity building and reporting mechanisms; and (iii) research agencies. Sustainable construction has gained significant momentum, but still faced with great importance challenges (Ghafourian, *et al.*, 2017).

Regardless of the outcomes achieved by the previously software like BEES, ECO Calculator, Envest, LISA, SEDA, BEE 1.0 used in modelling a sustainable materials chioce design aid tool, there is need to improve current practices in Nigerian sector and grow the activities and impact into Africa, where real change in needed in terms of how buildings are delivered in order to keep up with the current pace of development on the continent. Furthermore, need for a procedure that will enable the designer to select sustainable materials and assemblies for low cost housing in the context of no real-system database. Thus, there is need for a selection-tool for analyzing and evaluating the material and assembly impacts from environmental perspective.

1.2 Problem Statement

The housing situation of the urban poor is a source of deep concern in Nigeria. However, as shown in the previous studies, the problem of housing is a universal one, as virtually all countries are faced with the problem of providing adequate accommodation for their citizens. According to Nwakeze and Okwor (2017), in the urban centres in Nigeria it has reached an alarming state, as almost 75% of the urban dwellers live in slums and in conditions that are degrading to human dignity. The challenge of housing the poor is particularly acute in the urban areas of Nigeria where an explosive expansion of the urban population has compounded the housing situation.

The quality of the environment in most urban centres in Nigeria is not so much dependent on the material characteristics of buildings (Olajuyigbe, 2016) but on their organization as spatial units. Buildings are poorly laid out with inadequate infrastructures likes roads, drainage, provision for refuse evacuation and other basic services to address the need for the urban population; more energy and resources will be needed. Urban poverty finds expression in an environment characterized by high densities of buildings, the crowding of large numbers of people into those buildings, lack of space for open air living between houses, poor health, substandard housing, and acute environmental and sanitary problems (Adedayo and Zubairu, 2016). This is the environment in which the Nigerian urban poor live. Therefore, in view of the fundamental role of housing in the overall well-being and productivity of man, this research asserts that the plight of the urban poor, who are the least able to afford decent housing, deserves special attention if they are to contribute meaningfully to the economies of Nigerian cities in particular and the national economy in general.

In addition, Nigeria as a country is highly vulnerable to the impacts of climate change because its economy is mainly dependent on income generated from the production, processing, export and/or consumption of fossil fuels and its associated energy-intensive products (Akuru *et al.*, 2015).

Nigerian government has viewed planning and construction practices as the significant process to promote and deliver a sustainable built environment. Different government offices, firms of registered professionals in built environment sector and professional services firms are leading the programmes for the creation of sustainable communities, minimise energy use, ensure the use of sustainable materials and methods as well as encourage private sector interest in sustainable construction (Architect Colloquium, 2012). Isnin *et al.* (2012) reported that “in lieu with the current efforts to shift towards greener building practices, improvements are required in the development of building material management during construction, occupancy and operation of building adaptation projects”. But many new building developments in Nigeria still incorporate few sustainability features despite the high level of awareness (Ezema *et al.*, 2015). In review of sustainable building activity, Ezema, *et* *al.* (2015) found that "very small ratio of Nigeria's building stock claim to be sustainable, whether judged on sustainable construction, design or performance in use". The question then arise. Why? Given such policy drive, what is stopping sustainability from being realised in practice?

In contrast to traditional practices based on local raw materials and human energy, contemporary practices have allowed fuel energy to be harnessed in the manufacture of standardized, quality controlled building products. In addition, materials are rarely used in their completely natural state. Some preparation or manufacturing is generally necessary to create a usable building product. The high-temperature used in manufacturing of materials such as glass, plastics, foam insulation, steel and so on, has impacts associated with manufacturing which could include pollution to air, water and ground. It also generally requires energy, which is mainly derived from fossil fuel and is associated with global warming and pollution. At the same time, technologies like super-insulated walls have added to operational energy efficiency through high embodied energy materials exploitation. The building materials and assemblies can have multiple effects on a building's energy use over the stages of its life cycle, which can be contradictory. The question is: how can carbon storage benefit be measured and reported in the calculation of the carbon footprint of products using Life Cycle Assessment (LCA)? Carbon accounting refers to processes used to measure and track the flows of carbon atoms through technological systems and how these interact with the environment.

In addition, an increment in new houses construction would have substantial implications for the Nigeria's national energy and CO_2 budget, in which the magnitude of this impact will depend on the way these houses are built. Nigeria is committed to providing new houses, as the housing deficit approximated between 12 – 14 million in 2007 had increased to about 17 million in 2012, and Abuja accounts for 10% of the 17 million housing deficit in Nigeria, due to the demographic nature of the territory and mass influx into the capital city, leading to substantial increase in energy consumption intensity of the existing housing stock (Fatusin and Aribigbola, 2014). At the Federal Capital Territory level, the Federal Capital Development

Authority established under Edict No. 1 1972 to allow for low-cost and housing capable of being sustained to low and medium income earners stands out, due to urbanisation. In terms of procurement process of low cost housing pre-use stage, the present contemporary construction methods dominate, that impact negatively on environment, in spite of opportunities for innovations towards sustainable development in the process of building design and construction process.

According to Ali (2014), the current practice on sustainable construction does not take into consideration integrated design process, acoustic and visual comfort in the planning and construction of sustainable projects. Therefore, government should improve existing laws to enhance quality of working life, education, training as well as knowledge management for all stakeholders in sustainable construction. This has instigated, the promotion of the principles of sustainable construction is crucial for the achievement of sustainability in Nigerian construction sector, and the following questions were considered: which sustainable materials and assemblies can lead towards sustainable construction looking at the indicators of sustainable development? How possible to get stakeholders in the building construction sector to apply sustainable materials and assemblies? How can architects and designers improve their decision-making processes for sustainable materials and assemblies during the low cost housing design stage? These study is therefore attempts to redress this questions in low cost housing projects that looked at the evaluation of environmental impacts during the pre-use stage of building life-cycle in Nigeria, and analysing whether the practical ecodesign road map utilzed in Abuja of Nigeria strongly depend on climate conditions.

1.3 Research gap

As previous studies depict environmental conditions and energy consumption for housing in developed and developing countries, there are no comparable studies in the literature from Nigeria (Ezema *et al.*, 2015). This study attempt to establishes an evaluation method that can minimize the environmental impact and raise sustainability in low cost housing of generations yet unborn. This would be a way to "test the generalisability and applicability of multi-criteria decision support system" as affirmed by Yang and Ogunkah (2013). According to Loh *et al.* (2010), "exercising caution in selection of construction materials and building layout could minimize CO_2 emissions from the built environment". However, no doubt in implementing sustainable materilas and assemblies within the low cost housing sector is important in achieving sustainability. Thus, there are no comparison design tool to assess the needs of sustainable construction principles integration and implementation in materials and assemblies of low cost housing pre-use stage.

The carbon footprint of construction materials can vary greatly from one type to another, the building sector is consequently demanding documentation of the carbon footprint of the materials used (Tellnes, *et al.*, 2017). Using an Environmental Product Declaration is an objective and standardised solution for communicating the environmental impacts of construction products and especially their carbon footprint. At the CEN/TC 350 plenary meeting took place the 10th November 2016 in Berlin, Liaison experts reported the developments of a new standards related to the activity of CEN/TC 350, in particular: Integration of Environmental Product Declaration information in Building Information Modelling (BIM).

Advances in research and development encourage a more reliable pre-use stage sustainable materials and assemblies. That is, there is no index to assess sustainability integration and implementation in materials and assemblies pre-use stage (Yang and ogunkah, 2013). Meanwhile it was recommended by Nirmal (2012) that "projects begin integrating the materials and assemblies, using life cycle assessment (LCA) in order to begin setting benchmarks for the sector". This would translate the way the sector performs environmental assessment and enhance research in simplified tools and methods to evaluate sustainable materials and assemblies.

The LCA examples indicate few African examples and proposes an insufficient study within Nigeria. There was also limited attempt to inquire human energy of the cases reviewed, most studies undertaken on sustainable materials and components combinations choice relied on international databases rather than location-specific data, some degree of doubt came with the results (Ezema *et al.*, 2015). Above all, there is existance of knowledge gap in mitigating and adapting to urban climate change in area of harnessing disruptive technologies (Bai, *et al.*, 2018). Low-cost materials and technologies that can minimize the carbon intensity of future infrastructure in Nigeria should be developed and commercialized.

Finally, to address this gap about comparing the impacts of the materials and assemblies, there is a need for a comparison-tool capable of comparing the environmental impacts of the materials and assemblies that play an important role in decision-making, for the effective achieving of sustainable construction in Nigeria. This would enhance research in simplified way, with valuable and affordable tools in the absence of real-system database.

1.4 Aim

The aim is to develop an evaluation tool for the integration and implementation of sustainable construction principles into low cost housing project that can assist the decision makers in the selection of materials and assemblies from an environmental perspective. A decision-making tool was developed to aid the the architects and designers and building stakeholders. The tool was applied to select alternative options for the improvement of process. The study will advance economic and environmental sustainability in the Nigerian low cost housing projects. In an attempt to achieve this goal, this study recognises the following objectives along with associated research questions:

1.5 Objectives

i. To identify the decision making tool used for environmental impact of construction activities at pre-use stage.

ii. To investigate the environmental impact awareness issues and sustainable construction principles at pre-use stage.

iii. To evaluate and compare the overall environmental impacts of building life cycle pre-use stage.

1.6 Research Questions

Four (4) main research questions covers the study context of developing framework for the environmental performance assessment of sustainable materials and assemblies for low cost housing pre-use stage in Abuja-Nigeria. The following questions were asked;

i. What is the gap in present decision-making practice and pre-use stage sustainable materials and assemblies assessment method, and how can it be improved?

ii. What is the environmental awareness level and sustainable materials and assemblies practices and how does it affect the design decisions?

iii. How can the environmental impacts of pre-use stage sustainable materials and assemblies be quantified and compared?

1.7 Research Significance

New technology could make an extreme impact contributions towards sustainable development. The local resources are essential constituent in development processes in Nigeria, thereby minimizing the costs of construction, sustaining the local materials, propagate indigenous technology, employment generation, increase local economy and income growth, minimizes costs (transportation), and more accountable to stakeholders and environment. Adedeji (2010), noted that “about 60% of the total house construction cost goes towards the purchase of construction materials”. Nigeria is endowed with abundant indigenous building materials, that have the lowest energy demand (Olaoye and Kamang, 1999). However, it still suffers from scarcity and import dependence. Examples of such natural resources include: timber, stone, adobe, bamboo and so on, crucial to these facts is the strengthening of domestic technological capability to produce indigenous building materials.

The materials and assemblies can have effects on a building’s energy consumption over the pre-use stage, as some properties like high insulation value may yield high costs of embodied energy. The balance of these factors is important. Why? Because building’s external structure and envelope account for the greatest parts of its embodied energy (Qarout, 2017).

This study has placed a trend in declining traditional perception of culture and configuration due to rapid culture in the urban environments. Priority is on developing sustainable materials and assemblies through a procedure that looks at people and social interaction with environment. Therefore, no doubt that implementing sustainable sustainable materials and assemblies within the low cost housing sector can be very important in achieving sustainability. The evaluation tool will encourage the evaluation analysis and check the construction life cycle. Government of Nigeria should focus on building sustainable materials and assemblies with sustainable attributes to mitigate the negative impacts of low cost housing pre-use stage. Evaluation measurements based on building life-cycle can produce significant long-term gains for clients and occupants (Cole and Kernan, 1996). Life-cycle analysis takes into account all costs of a building system. This is useful when project alternatives that satisfy the same performance demands, but disagree with initial and operating costs, have to be compared to choose the one that maximizes net savings.

However, energy efficiency and government energy regulations had focused on buildings operational energy as it constitutes the bulk of a building's energy profile (Pacheco-Torgal *et al.*, 2013; Waldron *et al.*, 2013; Wallbaum *et al.*, 2013). But, with the mainstreaming of energy efficiency measures through energy regulations and the evolution of zero-energy buildings, the importance of environmental impacts is coming to the fore. Amongst is the building construction impact, which is the latent impacts of building linked with the materials, construction process and maintenance.

The National Building Code has been signed into law. This can be better accomplish through modelling of a design-aid tool for pre-use stage sustainable sustainable materials and assemblies that can determine and minimize the environmental burdens from a product and construction, which is the focused of this study. According to Solid Green company in Johannesburg of South Africa, in August, 2017 (a technical consultant and Director) commissioned for policy development of Building Energy Efficient Code (BEEC) in Nigeria acknowledge that "With the energy scarcity that is common in Africa, energy efficiency becomes very important in allowing and maintaining development", and in "Nigeria, it has been found that it is easier to build a building to consume 30% - 40% less energy than to pay to add renewable technology onto an inefficient building. In other words, it means buildings that perform well from a first principles point of view". Its primary merit over other site-specific methods for environmental analysis, like environmental impact assessment and environmental auditing lies in broadening the system boundaries to include all products or process burdens and impacts in the life-cycle. Gibberd (2005), stated that sustainable development in developing countries should address economic and social consequences as a priority; he proposed, that environmental sustainable development objectives should be acknowledged and handled in interventions designed to treat urgent economic and social priorities. Also, Ali and Al Nsairat (2009), believed that "nations of the developing world, cannot afford to be looking at environmental performance only". The economic and social problems are top of these countries' agendas. The development of building assessment and evaluation method is a necessity in Nigeria to determine the nature of the building-stock's performance and to encourage the housing sector into sustainable track that support social and economic aspects.

Evidence emerging from tropical climates and from low-income housing scenarios where operational energy demands are lower but proposes that embodied energy is important to energy efficiency and carbon mitigation (Henry *et al.*, 2014). As a result, studies are needed to comprehend the residential buildings embodied energy profile in areas where operational energy profile is comparatively lower than in developed countries. Therefore, it is important to broaden the research to the residential buildings embodied energy profile in Nigeria, a tropical country characterised by low electrical energy use and where modern building materials and less innovative construction methods are prevalent.

Carbon accounting is an essential element of carbon trading schemes, such as the European Union Emissions Trading System. The emission trading scheme sets a limit on total amount of emissions allowed by participating installations in the European Union and then the allowances of emitting greenhouse gas can be traded. The aim is to give market incentives for emission mitigations. Carbon accounting is also needed in order to report on national greenhouse gas inventories required under the United Nations Framework Convention on Climate Change, Kyoto protocol and

Paris Agreement (Tellnes, *et al.*, 2017). Carbon footprinting of products can also be used as a means of supporting informed decisions about products and processes, using Life Cycle Assessment (LCA) approaches.

With respect to buildings, the carbon minimization schemes or strategies target emissions from materials and construction methods and emissions from operation (Chirisa *et al.*, 2015; Ezema *et al.*, 2016). In distinction from others, low carbon strategies in building and construction focused on less utilization of carbon intensive materials and minimized operational energy use in buildings through energy efficient design strategies, use of energy efficient appliances and resort to renewable energy especially solar energy (Chirisa, *et al.*, 2015; Ezema, *et al.*, 2016). Hence energy and carbon emission along the buildings' whole value chain is important to recognise target areas for mitigation.

Finally, the results add to apprehension of the energy and carbon emissions from low cost housing pre-use stage that are often neglected. Also, the study has allowed for an insight of information model as affirmed by Isnin *et al.* (2014) that "visible and accessible information on possible negative effects from building materials may assist decision making that could avoid and reduce potential deficiencies that may lead to increased adverse effects to health, safety or unforeseen death". The study could add to the body of knowledge and assist in choosing energy efficient building construction systems, and transportation carbon emission thereby minimizing CO_2 into atmosphere.

1.8 Research Scope

This research focuses on the environmental impacts performance evaluation of pre-use stage sustainable materials and assemblies for low cost housing projects in Abuja of Nigeria. The study seeks to explain the experience of sustainable materials and assemblies assessment for low cost housing pre-use stage. This study was conducted in the city of Abuja-Nigeria, and the chosen district for the site case studies is in Kuje which represents the predominant sampled population. Climatic classifications of Abuja features a tropical wet and dry climate. According to the United Nation (2010) Abuja grew at 139.7% rate between 2000 and 2010. As of 2015, the city record an annual growth of 35%, making it among the fastest growing city in the world. The public housing in Kuje of Abuja, Nigeria are case studies of low cost housing projects, situated in the southwest region of Abuja, sharing boundaries with Nassarawa state, Kwali and Municipal area council that provide enabling environment for the study, namely: Kuje Federal Housing Authority and Kuje Housing Scheme. Abuja, the nation’s capital, situated at central geographical region of Nigeria, sharing boundaries with 4 states in the region and comprises of six (6) are councils as shown in Figure 1.1.

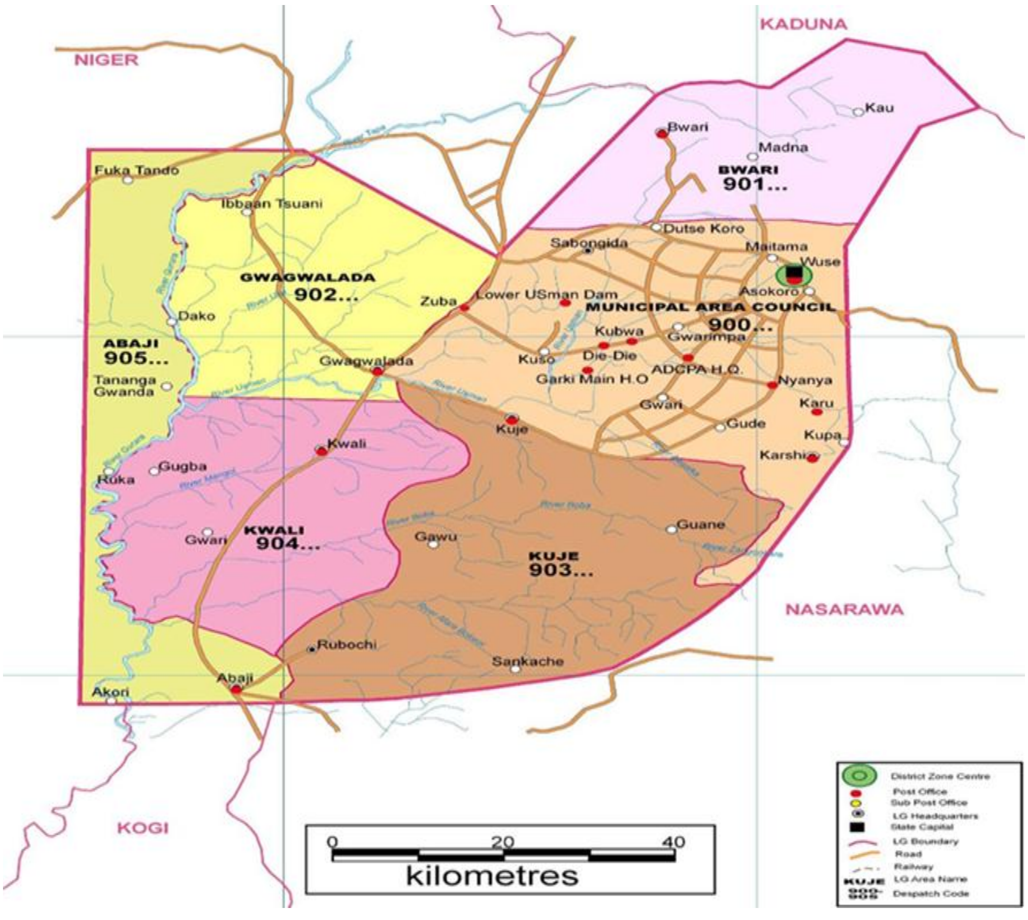

Figure 1.1 The map of Abuja showing the Councils distribution

The building life cycle stage considered is the pre-use stage. Why? It has increased with development of industry in Nigeria and crucial to buildings development. Moreover, embodied energy account for between 10% and 60% of the overall energy used throughout the building's lifetime (Stapleton *et al.*, 2004; Thormark, 2002). In addition, some studies have shown that this is indeed the case, 80% operational energy to 20% embodied energy. However, as operational energy consumption becomes lower, the role of embodied energy in minimizing overall energy use becomes high (Fay and Treloar).

1.9 Thesis Structure

This thesis comprises of seven (7) interconnected chapters organised in a systematic way. The thesis begins with the preliminary pages that include abstract, acknowledgement, table of contents, dedication, certification, list of tables and figures, list of appendices and the glossary.

Chapter One: This chapter introduces the research background that determines and support the theoretical framework. The issue and problem intends to cover is set to show the research representation that is made by the research aim. This proceeded by the research gap followed by research objectives which translate into the research questions. Next is the research significance and followed by the research scope and then the research design. The chapter ends with structure of the thesis.

Chapter Two: The literature review focuses on the economic growth and environment and construction sector activities impacts on environment. It builds a theoretical base by reviewing previous research. It also focuses on the relationship between environmental issues, materials and assemblies issues and optimisation couple with Life Cycle Assessment (LCA).

Chapter Three: It examines the impact of construction activities on environment and looks at schemes that can aid to minimize the impact and enhance sustainable goals in the low cost housing sector through building's life cycle. It calls for the information and argument for the importance of incorporating and implementing sustainable construction principles in materials and assemblies that are environmentally and economically equilibrated. It reviews the selection models assisting in pre-use stage decision-making for materials and assemblies evaluation and the environmental assessment methods currently used when evaluating whole-building system performance. A multi-dimensional approches to the evaluation of sustainable materials and assemblies of building lifecycle was discussed.

Chapter Four: It comprehends the research methodology, where the research planning and process and the analytic process are talked about, which contained research paradigm, research planning and design, data collection and analysis mthods. It responds to the research problems and questions by detailing how the research was carried out. It also depicts the process followed in trustworthiness followed to proof the methods and instruments applied.

Chapter Five: This chapter presents the research findings. It describes and organises the findings to indicate the view on sustainable construction principles and environmental awareness issues in materials and assemblies for low cost housing pre-use stage outcome by relating it with the aim and objectives. It depicts the way the results address the research questions. It gave an interpretive account of the deductions from findings through theoretical model and arguments in developing final research outcome.

Chapter Six: This chapter presents the research findings. It describes and organises the findings to indicate the view on environmental impact performance of materials and assemblies for low cost housing pre-use stage outcome by relating it with the aim and objectives. It also focuses on the strategies for application and validation of the evaluation tool for sustainable materials and assemblies of low cost housing pre-use stage.

Chapter Seven: As the concluding chapter it covers the conclusion made on the results and findings. Here the share is clearly stated and made recommendations for further research. In sum, this is indicated in Figure 1.2.

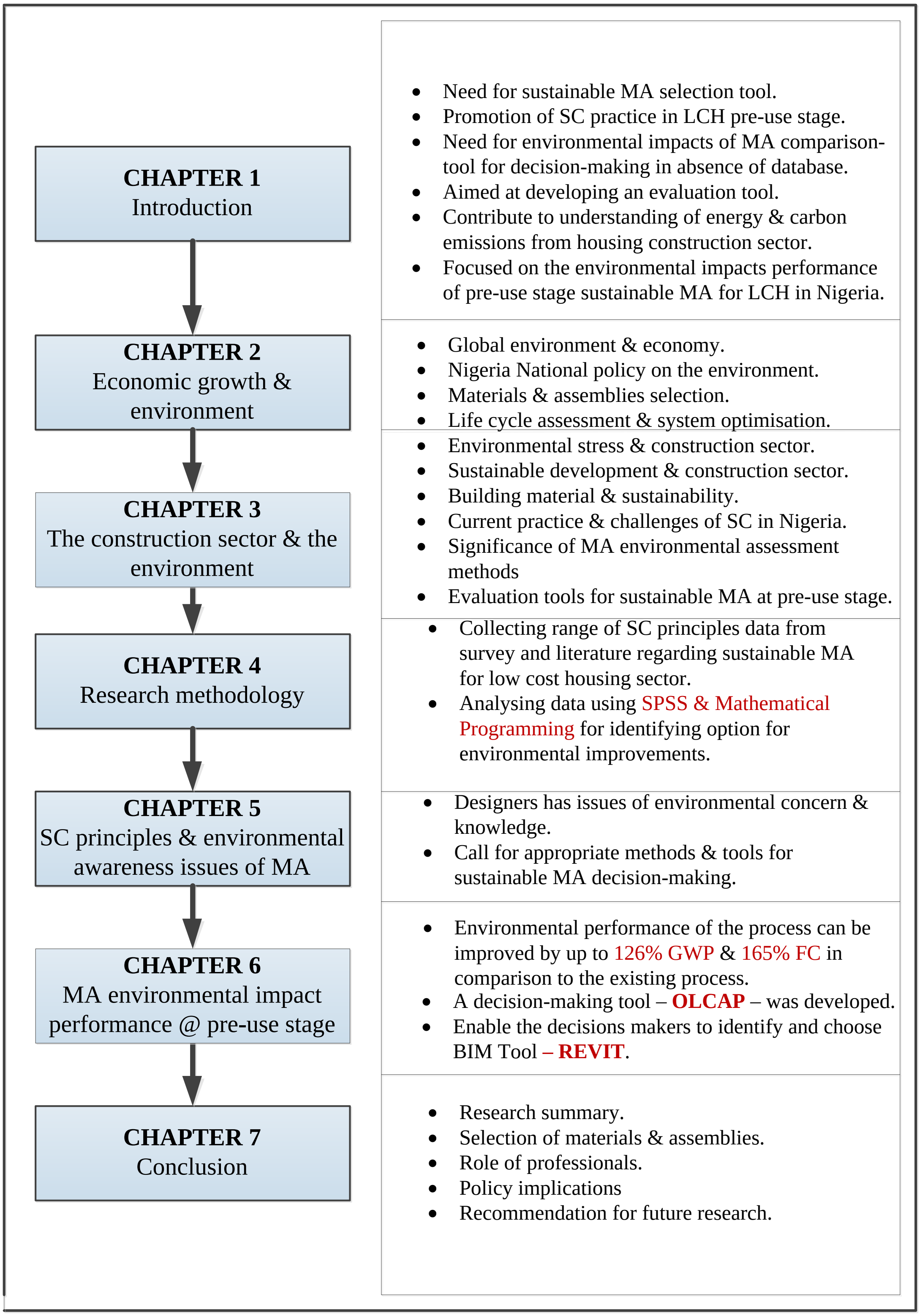

Figure 1.2 Thesis structure

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