Civil Engineering and Architecture 8(5): 777-791, 2020 http://www.hrpub.org
DOI: 10.13189/cea.2020.080505

# Life Cycle Energy Assessment (LCEA) Approach: A Prospect for Sustainable Architecture in Developing Countries

**Udomiaye Emmanuel[1,*], Chukwuali Basil Chukwuemeka[2], Kalu Cheche Kalu[1]**

[1]Department of Architectural Technology, Akanu Ibiam Federal Polytechnic, Uwana, Nigeria
[2]Department of Architecture, University of Nigeria, Enugu Campus, Nigeria

*Received June 25, 2020; Revised August 14, 2020; Accepted August 28, 2020*

***Cite This Paper in the following Citation Styles***

***(a):** [1] Udomiaye Emmanuel, Chukwuali Basil Chukwuemeka, Kalu Cheche Kalu , "Life Cycle Energy Assessment (LCEA) Approach: A Prospect for Sustainable Architecture in Developing Countries," Civil Engineering and Architecture, Vol. 8, No. 5, pp. 777 - 791, 2020. DOI: 10.13189/cea.2020.080505.*

***(b):** Udomiaye Emmanuel, Chukwuali Basil Chukwuemeka, Kalu Cheche Kalu (2020). Life Cycle Energy Assessment (LCEA) Approach: A Prospect for Sustainable Architecture in Developing Countries. Civil Engineering and Architecture, 8(5), 777 - 791. DOI: 10.13189/cea.2020.080505.*

**Abstract** Sustainable architecture searches for methods to lessen the adverse environmental burdens of buildings by efficiently and moderately using materials, energy and space. Ensuring sustainable development in multiple dimensions requires an essential factor such as sustainable architectural practice that inculcates assessment framework. Life Cycle Energy Assessment (LCEA) is a key component of Life Cycle Assessment (LCA) in which energy use at different life cycle stage of buildings is the only parameter analysed. In developing countries, defining sustainable architecture and environmental sustainability assessment in buildings remains a herculean task. The aim of the study was to examine the theoretical challenges associated with defining what we mean by calling a building "green" or sustainable architectural design and a post-positivism viewpoint on sustainability assessment of architectural design. The objectives are to review the criteria for sustainable architecture and conduct an LCEA of an existing residential apartment building in Abakaliki-Nigeria, using process-based Life Cycle Energy Assessment. The embodied energy intensity was found to be high at 6.10GJ/M$^2$, while cement- based component was 8.8% by mass but accounted for 67.6% of the embodied energy. Consequently, it is imperative to carry out LCEA at the early stage of design and employ strategies to reduce embodied energy instead of focusing only on lessening the operational energy. Environmental and energy efficiency approaches should be prioritized on a life cycle energy basis.

**Keywords** Architecture, Assessment, Energy, Environment, Sustainability

## 1. Introduction

Any professional that is involved in building design, procurement, construction and building maintenance or other activities related to the built environment in recent years would have encountered in one way or another the term sustainability or sustainable architectural design. Sustainable development is the "development that achieve the needs of the present without hindering the ability of the future generations to meet her needs" [1]. Therefore, sustainable architecture advocates ways to lessen the adverse environmental burdens of buildings by efficiently and moderately using materials, energy and space. Arezon, Kalan; Oliveira & Eduardo [2] added that sustainable architecture deals with the use of deliberate technique of ecological and energy management in planning the built environment. Ensuring sustainable development in multiple dimensions requires an essential factor such as sustainable architectural practice that is equipped with an assessment framework. It is the designer's insight and technical knowledge to implement the fundamental features of the practice i.e. to design and build in accord with the environment [3], sociocultural and economic aspects of a community [2]. Therefore, the enhancement of architectural design and 'specifications writing' for an all-encompassing accomplishment of the environment is relevant and crucial for; reducing, costs, lowering energy use/greenhouse gas emissions, and for finding actual resolution that not only accomplishes an improved economy and environmental performance but also as an assessment framework for architects [4]. According to Walker [5] architects have the responsibility to engage in life cycle energy thinking during the design phase through a coherent deliberation about a combination of issues like environmental sustainability, durability, longevity and appropriate materials. One of such environmental assessment tools or framework that enables the architect to ascertain the level sustainability of his design is Life Cycle Energy Assessment (LCEA). Life Cycle Energy Assessment (LCEA) remains a key component of Life Cycle Assessment (LCA) in which energy use at different life cycle stages is the single parameter analysed. According to IPCC -Intergovernmental Panel on Climate Change [6] "LCA is a standardized tool under the International Organisation for Standardisation (ISO) for the measurement of environmental impact of products and processes throughout their life cycle usually from cradle to grave". Life Cycle Assessment (LCA) exemplifies an all-inclusive technique used to estimate the environmental sustainability of a product such as buildings at all stages in its life cycle. Architecture is a significant arena for sustainable innovation. This is because according to the UNEP [7] construction of buildings "accounts for 40% of total energy use, 40% of altogether raw materials use, 30% of solid waste generation, and responsible for about 33% of the global greenhouse gas emissions".

Vision 2050 of the International Union of Architects -IUA is to realize carbon-free and low energy, thus sustainable buildings [8]. Unfortunately, the current practice in most developing countries is far and in opposite direction with regard to the vision. This could be as a result of the fact that sustainability has not be accorded the needed attention in the training of the architect [9]. A recent Nigerian study by [10-11] revealed that carbon emission intensity of buildings in Nigeria is significantly high related to the values obtained from developed countries. Udomiaye et al., [11] added that the high emission intensity was traced to high volume of non-structural concrete elements such as concrete fascia, non-load bearing columns and concrete parapets. Moreover, the paucity of knowledge that exists with respect to what makes sustainable architecture or green design, how emissions from built environments can be mitigated and how to assess environmental sustainability need to be filled. This can be done by involving incorporation of established knowledge, advanced architectural design strategies, application of innovative technologies and development of sustainability assessment guidelines. Environmental sustainability assessment of design is pivotal to understanding sustainable architecture. Thus, the aim of this paper is to bring awareness to a shared practical issue of sustainable architecture and provide parameters for assessing sustainable architectural design with the view to make the buildings more efficient, functional, and sustainable. This was done through literature review and practical Life Cycle Energy Assessment of an existing residential apartment building as a case study.

### 1.1. Sustainable Design and Green Architecture

Sustainable design is a design concept that considerably reduces the adverse influence of construction and operation of buildings on the environment, economy and human health as described in figure 1, thereby enhancing the overall building performance during its Life Cycle. Therefore, Sustainable buildings need to be resistant to climate change and be adaptable, non-rigid and durable so as to enhance a building's service life [12]. Sustainable architecture and environmental sustainability are integral to green building. According to Madhumita [13] the "green" architecture is a conscious effort to protect air, water, and earth by selecting eco-friendly building materials and construction methods. Green Architecture idea, often refers to as "sustainable architectural design" or "green building," is the philosophy, science and building designed approach and constructed in harmony with environmentally responsive principles [14]. The primary aim of green architecture is to mitigate the amount of resources consumed (i.e. economy of resources) during construction, use and operation of buildings as well as curbing the damage inflicted on the environment and sociocultural life through carbon emission, pollution and waste. The basic objectives of sustainable design are to achieve; energy efficiency, renewable energy, zero carbon and application of the 3R rule-Reduce, Reuse, and recycle.

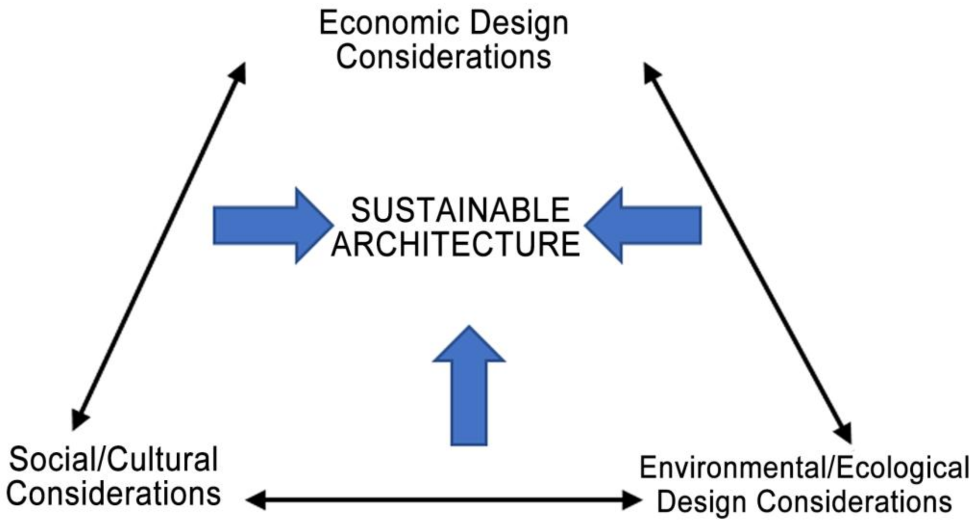


**Figure 1.** Sustainable design concept. Source: Author

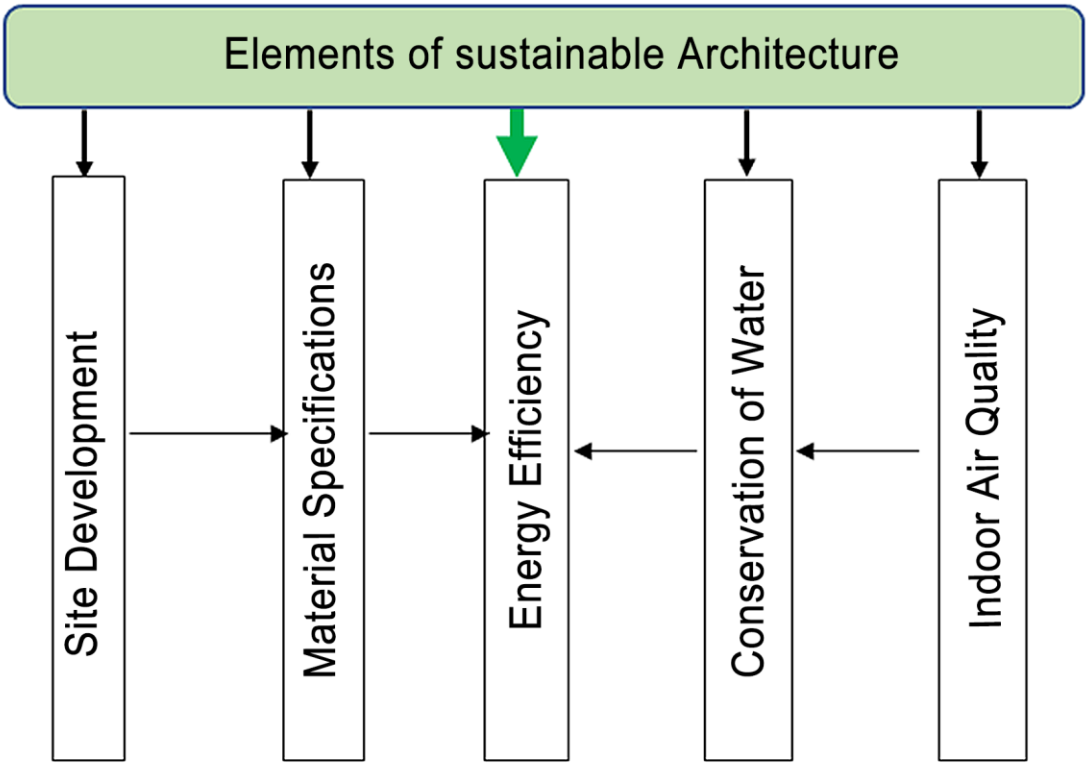


**Figure 2.** Basic Elements of sustainable Architectural Design

### 1.2. Relevance of Sustainable Architecture

Many developing countries are going through speedy development because of the huge infrastructural evolution from formal and informal sectors. The process of embarking on infrastructural development to meet the housing need of the ever-increasing urban population has raised environmental sustainability concerns. Currently, due to an increasing understanding of human interface with nature, it is extensively acknowledged by the scientific community that consuming energy from non-renewable sources has caused significant environmental damage [15]. The principles of green design can effectively blend aesthetic and functionality to save planet earth. The design and sustainable construction, or "Green Building" is an opportunity to use our resources more efficiently, while creating more energy efficient and healthy homes [16]. Effective green building or sustainable architecture is relevant based on the need to;

I) Reduce embodied and operational energy and emission

II) Minimize operating cost by increasing productivity and less energy and water.
III) Improve occupant health as a result of improved indoor air quality.
IV) Reduce environmental impacts, climate change migration and adaptation

### 1.3. Main Criteria for Sustainable Architecture

Sustainable architecture is more than just energy-efficient buildings. However, Vujozevic [17] posited that energy efficiency is the most significant approach that gives an opportunity to address the three current issues: environmental damage, climate change and energy security. In practice, sustainable architecture or green design involves five main design considerations or principles as presented in figure 2. These are site development, material specifications, energy efficiency, conservation of water and indoor air quality [14]. Pursuing these principles requires organizing a vast range of practices, procedures, skills to lessen or mitigate the environmental burdens and impact on human health, It frequently highlights the advantages of renewable resources, e.g. using sunlight through passive/active solar, photovoltaic equipment as well as using plants, green roofs, reduction of rainwater run-off, rain gardens, and other techniques are used such as using energy efficient building materials [18]. However, the practices or technologies adopted in green design or sustainable architecture are continuously developing and might actually vary based on regional differences, but the central philosophies are constant from which the technique is derived. Energy efficiency of building is a key factor in the search for sustainability in architecture [19]. Hence, understanding energy use in building could as well be a panacea for sustainable architecture.

## 2. Material and Methods

### 2.1. Energy Use in Buildings and Assessment

As earlier mentioned, the knowledge of energy use in buildings and its assessment framework are fundamental to understanding sustainable or green architecture. The rising fears around the preservation of the eco-system from late 1980s has made energy use of buildings to be closely monitored than previously, principally with regards to resource depletion, local/regional pollution and global warming, [20]. According to Ezema et al., [10] and Dixit [21] these forms of energy are consumed either directly or indirectly in a primary or delivered form. For example, in Nigerian scenario, the residential sector accounts for most of the final energy consumption with 57.8% [22]. Energy consumption throughout the life cycle of buildings consists of embodied energy, operating energy and demolition or decommissioning energy. Thus, the framework creates the fundamentals for energy efficiency procedures in the building industry, this underscores the relevance of LCEA in architecture and the built environment in general.

### 2.2. Embodied Energy

Embodied energy is the total energy expended in raw material extraction, manufacturing as well as energy used for the construction, maintenance of the building and haulage of raw and finished materials. Embodied energy consists of two parts: initial and recurring embodied energy [23-24]. The energy used in producing a building - materials production, haulage of materials and site construction (Manual and Machine) is referred to as initial embodied energy, while the energy used in maintaining building over its active life is known as recurring or maintenance. In mathematical expression, embodied energy is the sum total of initial embodied energy and recurring energy, whereas initial embodied energy is the sum total of material embodied energy, site construction energy and transportation as represented by equation

$$EE_i = EE_M + EE_T + EE_C \qquad \text{(Equation 1)}$$

Where; $EE_i$ = initial embodied energy, $EE_M$ = embodied energy of material (cradle – to – gate), $EE_T$ = embodied energy of transportation (gate – to – site), EEC = site construction energy.

### 2.3. Operation Energy

Operation energy is one of the parameters for assessing sustainable buildings. The energy used in keeping the indoor environment within the acceptable range and other human activities is referred to as Operating energy [20]. Through the operational phase, that is when the building is fully occupied, energy sources such as electricity for appliances, air-conditioning, lighting; LNG (cooking gas); kerosene, PMS (petrol) and diesel for powering electricity generators constitute the segment of energy called operating energy. Data for computations are often obtained using questionnaire and the questionnaire are distributed to occupants. Operations energy can vary depending on the level of luxury essential to occupants, the predominant climatic environments as well as the operational plan [10]. This underscores the much effort to improved building energy efficiency through lowering of operational energy. In the case study area, metering of energy is at the point of entry to the building. The energy expended by the occupants is referred to as delivered energy [25], while the energy that is embodied in resources as they are found in nature: chemical energy embodied in fossil fuels (coal, oil, and natural gas) is known as Primary energy. However, energy used during the operation of buildings is generally stated in primary energy terms which integrates the source of the energy being expended in its delivered state. Energy and Treloar [23] added that in computing operational energy, primary energy is a suitable measure of the environmental consequences of energy- use. Its equivalence is gotten by the multiplication delivered energy with the primary energy factor (PEF). The primary energy translation factors are determined by the electrical energy mix of the study area.

### 2.4. Demolition Energy

Whenever a building's life span or service life comes to a close, the structure is decommissioned and carried to landfill sites [10] and some demolition procedures are often employed, these are; mechanical demolition, deconstruction and hybrid demolition. Decommissioning energy is energy required to demolish a structure at the expiration of its life time. In most cases, the outcome is not dependent on material choice [26]. There is the possibility that some materials at the demolition stage could be recycled into the materials fabrication stage. This results to some level of ambiguity at the demolition phase with regards to the outcome of building materials in the future [27]. Nevertheless, existing studies indicated that energy needed for demolition is about one percent (1%) of the whole life cycle energy [27-28].

### 2.5. Life Cycle Energy Assessment (LCEA) in Buildings

Assessing environmental sustainability in buildings is multifaceted. Reliable number of research work has gone into developing framework for assessing the environmental performance of buildings over its life [29]. Life-cycle energy analysis includes the operational energy of the building, initial and recurrent (maintenance) embodied energy throughout its life cycle [25]. Life-cycle energy analysis is express in equation 2:

$$\text{LCEA} = \text{EEi} + (\text{EErec} + \text{OE}) \times \text{Service Life} \quad \text{equation (2)}$$

where: LCEA = the life-cycle energy assessment;

EEi = the initial embodied energy;

EErec = the annual recurrent (maintenance) embodied energy; and

OE = the annual operational energy (air- cooling appliances, light fittings and domestic energy uses).

Haapio and Viitaniemi [30] stated that the period of time after installation, in the course of which all the properties surpass the least satisfactory level is known as service life. Existing studies revealed that the service life of a building is determined by Life Cycle Assessment goals. According to Holmess and Hudson [31] environmental sustainability assessment in buildings has developed as one of the key subjects in sustainable architectural design and building construction. Nevertheless, in the developing countries, measuring the environmental sustainability of buildings is comparatively new and it is largely based on the statements or sustainability declaration presented by the manufacturers [32]. Ding [29] added that these tools are fundamentally in two groups: Assessment Tools and Rating tools.

Sustainability assessment measures (environmental or performance-based) are continuously developing in order to overcome their several restrictions [33]. Nevertheless, two key assessment approaches that are notable: quantitative approach and qualitative assessment approach [34-35].

### 2.6. Application of LCEA in Buildings

LCEA is well-positioned to deliver quantitative data to building professionals because it holistically assesses the environmental impacts of a product [36]. The main aim of LCEA is to inspire teamwork involving professionals in the built environment and construction process. There are methods that have been developed to compute life cycle energy in buildings as fully and exactly as possible: process -based; input - output; and hybrid [25]. Process-based method was adopted for the case study and the unit of measurement are megajoule (MJ), gigajoule (GJ) or in tonnes of oil equivalent (toe).

Process-based assessment **-** This is carried out in four (4) stages namely: goal and scope definition; inventory analysis; impact assessment and interpretation. During the process indirect/direct upstream energy flows of a product or process is evaluated and quantified [10]. The material upstream energy flow consists of extraction, manufacturing, transportation, construction and use flows (use and maintenance), while the downstream flow includes deconstruction [37].

Input - Output Assessment **-** Makes use of national statistical information such as gross domestic product (GDP) and economic growth per-capita compiled by government agencies or ministries for assessing national economic growth and flows amongst sectors. According to Optis [38] the system boundary of the technique is more comprehensive than process-based LCA because it accommodates the various economic influences within the economy. Nevertheless, the accuracy level is far lower than the process-based technique because of the level aggregation of industry classification lacks regional variances [39].

Hybrid Assessment **-** This is a combination of the merits of process-based analysis (dependable energy consumption figures for specific processes) and that of input-output analysis (theoretically complete system framework) while removing their characteristic weaknesses - incompleteness and mistakes. A study by [40- 41] in an Australian building revealed that hybrid assessment can be employed to advance the correctness of embodied energy assessment.

### 2.7. Application of LCEA and Architectural Design Process

LCEA can be applied at the various stages of design process; Pre-design stage, schematic design stage and detailed design or design development.

### 2.7.1. Pre-design stage

This implies choosing the right systems and setting the right environmental goals [36]. LCEA is critical at this stage to guarantee energy efficiency, since it governs how the building is properly incorporated with the immediate environment [9]. Interpretation of the results of an LCEA entails the design team to prioritize which environmental impacts categories are most significant to discourse. For instance, does the design team want to reduce carbon emissions through the use of carbon-sequestering products? And what is the cost implication? LCEA could be used to make decisions regarding selecting a structural system and the building footprint among numerous possibilities. Bayer, Gentry; Joshi & Gamble [42] added that at this stage operational phases can also be evaluated to decide assembly types. Passive design strategies such as building positioning and building forms are determined in this stage and could meaningfully influence the energy performance of buildings especially at the use stage. The outcome of LCEA at this stage will help the design team to consider “daylighting, natural ventilation and passive design solutions for heating and cooling, using mass, landscaping and design to work with topography and climate” [43- 44].

### 2.7.2. Schematic Design Stage

At the schematic stage the design proposal approved by the client is now taken to a more serious and detailed level. LCEA can help design team make choices regarding building products and optimize structural systems by selecting the most environmentally friendly options [45]. Energy conservation procedures such as active approaches for cooling and heating systems, motorized by renewable resources are evaluated for their environmental loads, and a well-versed decision can be enhanced by the use of LCEA [9,36,46]. Buffaloe and Rebecca 2014 stated that at the schematic design phase, LCEA reminds the design teams to ask the questions: How much material does the project actually need? And what is the spatial arrangement of structural systems that hugely minimize the environmental impact of the project?

### 2.7.3. Detailed Design or Design Development Stage

At this stage, the schematic design is worked through in detail, detailed working drawings are produced for co-coordinating structure, services, and professional installation. LCEA can shed light on the environmental trade-offs of various product choices during specification writing. For example, if the architect chose a steel panel door over wooden panel doors during pre-design and adopted steel panel doors needed during schematic design, LCEA can assist the architect to compare the pros and cons of different door material selections. Material finishes and water fixtures choices could impact potable water conservation, hence, can also be compared with the help of LCEA results [9].

## 2.8. Examples of Life Cycle Energy Assessments

An appraisal of existing studies on LCEA of buildings shows that the outcomes were dependent on Life Cycle Assessment goals and these goals significantly influenced the boundary, approach and methodology.

In Scotland, Asif, Muneer & Kelley [47] assessed a semi-detached three (3) bedroom residential building. LCEA was employed to evaluate the material embodied energy and the consequences on the environments. In the study, 65% (227.46GJ) of the embodied energy of the referenced building and up to 99 % of the resultant environmental burden was attributed to concrete components. Chang, Reis &Wang [48] undertook an LCEA study using residential buildings in China. Interestingly, the study discovered that energy consumed by rural house units were much lower than total energy use by urban house units. For both cases, the percentage of operational energy was higher ranging between 75% - 86% of total life cycle energy separately. Moreover, an Australian study, Myers, Fuller & Crawford [49] revealed that embodied energy can be reduced by 28% (7.5GJ/m$^2$ to 5.4GJ/m$^2$) by simply replacing conventional materials with renewable building materials. Mithraratne & Vale [50] carried out LCEA using a New Zealand residential building as a case study with the aim of assessing its energy-use under different conditions adopting 100 years as service life. The study shown that operational energy varied from 57% to 74% of total life cycle energy and using extra insulation decreased the life cycle energy by 31%. The above study concluded that concrete elements though has the highest initial embodied energy component possibly will possess a lengthier valuable life that might result to lower embodied energy at the long run.

## 2.9. Case Study

For easiness and understanding of the discussion, Life-Cycle Energy Assessment (Process-Based) is demonstrated using a residential building project located in Abakaliki, south eastern Nigeria. The residential building analyzed for a service life of 60 years is a block one-bedroom apartment building containing five (5) units designed by EDT/GEMEX architects and engineers in 1997 and built by Ebonyi state Housing development Corporation (EBSHDC), Abakaliki, Nigeria. A total of one hundred and sixty-five (165) house units were used as sample size each building has a gross floor area of 355.68m$^2$ as shown in figure 3 with details in appendix 1, 2 and 3.

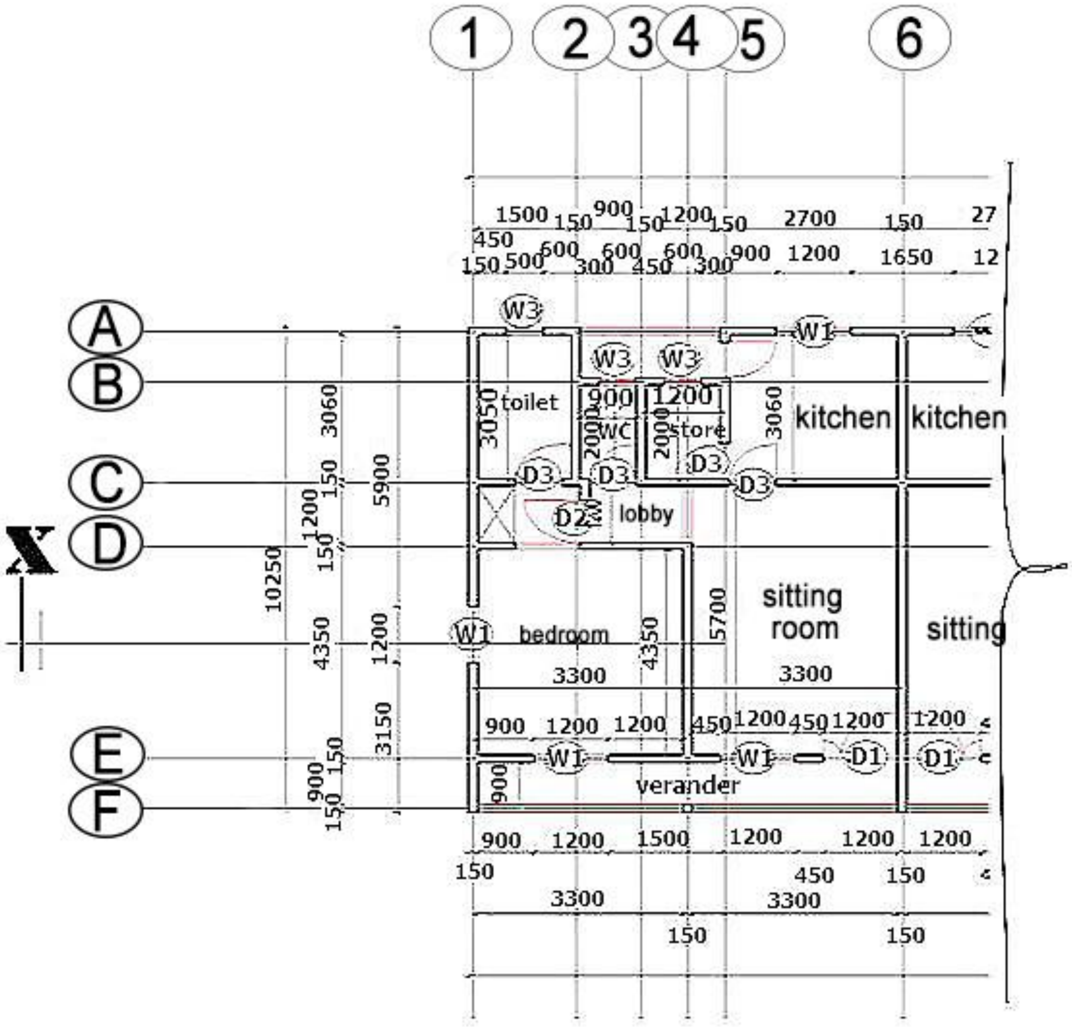


**Figure 3.** Typical Floor Plan of one (1) Bedroom house unit (details in appendix 1, 2 and 3) Source: ESHDC

## 3. Case Study Results

Results obtained for the intensity for embodied energy, operational energy and total life-cycle energy are stated in square meters ($M^2$) rate founded on the livable area of $355.68m^{2,}$ also referred to as energy intensity. This is to enable comparison with other results having different sizes and in this type of climate as obtained from other studies.

### 3.1. Embodied Energy

As presented in table 1, material embodied energy (cradle to gate) for the case study was calculated to be 1095.48 GJ and energy intensity of 3.08 $GJ/m^2$, with superstructure having the highest energy intensity of $0.88GJ/m^2$. For transportation energy the estimated quantity of fuel consumption of 3,408.72 liters of diesel, multiplied by the 35.94 being the default heating value, the energy for materials transportation was computed as 122.51GJ with energy intensity of $0.34GJ/m^2$. In computing the construction (Manual and Machine) it was observed that majority the construction events were carried out manually and few contractors had machine/equipment. Hence, contract sum /labour cost were obtained and manual energy computed using human energy coefficient of 0.75 MJ/hour with day-to-day working period of 8 hours. The human energy factor was obtained from the Nigerian Agricultural sector's settings and effectively used in industrial situations by Odigboh [51] and Ohunakin, Leramo, Odunfa & Bafuwa [52]. Quantity of diesel, petrol and lubricant were obtained and the value was multiplied by their energy coefficient. The construction energy (manual and machine) was calculated to be 60.16GJ with construction energy intensity value of $0.169GJ/m^2$.

The initial embodied energy was calculated to be 1278GJ with energy intensity value of $3.60GJ/m^2$. Recurring energy was estimated using 60 years as service life and the estimated value is 892.3GJ while the recurring energy intensity was estimated as 2.51GJ/m$^2$. Using equation 1, the total embodied was calculated as 2,170.45GJ as presented in table 2. The embodied energy intensity is calculated as 6.10 GJ/m$^2$.

**Table 1.** Cradle – to – Gate Embodied Energy Computation. Source: Author

| **No** | ***Bldg Component*** | **Embodied Energy (MJ)** | **Intensity (MJ/m$^2$)** | ***(%)*** |
|---|---|---|---|---|
| 1 | Substructure | 314,574.91 | 884.43 | 28.72 |
| 2 | Walls | 236,701.30 | 665.48 | 21.61 |
| 3 | Roof Structure | 205,298.86 | 577.20 | 18.74 |
| 4 | Doors and Windows | 58,158.72 | 163.51 | 5.31 |
| 5 | Wall Finishes | 57,253.31 | 160.97 | 5.23 |
| 6 | Floor Finishes | 38, 699.08 | 108.80 | 3.53 |
| 7 | Ceiling Finishes | 35,550.38 | 99.95 | 3.25 |
| 8 | Painting and Decorations | 64,453.80 | 181.21 | 5.88 |
| 9 | Plumbing Installation | 63,826.78 | 179.45 | 5.83 |
| 10 | Electrical installations | 20,958.67 | 59.93 | 1.91 |
| | ***TOTAL*** | ***1,095,475.8(1095.48GJ)*** | | ***100*** |

**Table 2.** Total Embodied Energy of the referenced building. Source: Author

| No | Embodied Energy Category | Embodied Energy (MJ) | Intensity (GJ/m$^2$) | (%) |
|---|---|---|---|---|
| 1 | Cradle-to-Gate | 1,095,475.81 | 3.08 | 50.3 |
| 2 | Transportation(surface) | 122,509.36 | 0.34 | 5.6 |
| 3 | Site Construction | 60,160.82 | 0.17 | 2.8 |
| 4 | Recurring Embodied Energy | 892,318.41 | 2.51 | 41.0 |
| | **TOTAL** | **2,170,450 (2,170.5GJ)** | **6.10** | **100** |

**Table 3.** Operational energy (Annual) of house unit of the case study building. Author

| No | Energy Source | Monthly Consumption | Annual Consumption | Lower Heating Value/Primary Energy factor | Total Primary Energy (MJ) |
|---|---|---|---|---|---|
| 1 | LNG | 2Kg | 24Kg | 47.3 | 1,135.20 |
| 2 | Petrol | 24.36liters | 292.32liters | 32.7 | 9,558.86 |
| 3 | Kerosene | 20.15liters | 241.8liters | 35.24 | 8,521.03 |
| 4 | Diesel | 0 | 0 | 35.94 | 0 |
| 5 | Electricity | 188.7kwh | 2264.6kwh | 2.83(3.6MJ) | 23,071.59 |
| | **Total** | | | | **42,286.69(42.29GJ)** |

### 3.2. Operation Energy

Data for identified energy source (quantity of Petrol, Kerosene, Diesel and LNG) for calculating the operation energy were obtained from the questionnaire. The values obtained were multiplied by the respective heating values and primary energy factor in line with Intergovernmental Panel on Climate Change (IPCC) protocol. The annual operational energy was calculated as 42.29GJ, with annual operational energy intensity as 0.59 GJ/m$^2$/year. Over 60 years (Service Life) the operational energy was estimated as 2,537GJ with operational energy intensity as 35.67GJ/m$^2$ for a house unit.

### 3.3. Total Life Cycle Energy Assessment (LCEA)

Equation 2 was used to calculate the total LCE. Since the operation energy was computed based on house unit the value for embodied energy per house unit was calculated by dividing the total embodied energy value by five (5) being the number of house unit per block. The total embodied energy per house unit is calculated as 434.1GJ, while the operational energy is 2,537GJ. Thus, the Life Cycle Energy for the case study house unit is 2,971GJ. The embodied energy accounted for 15%, while operational accounted for 85% of the total Life Cycle Energy Assessment as shown in figure 4, and the LCEA intensity is given as 41.84GJ/m$^2$ for a house unit.

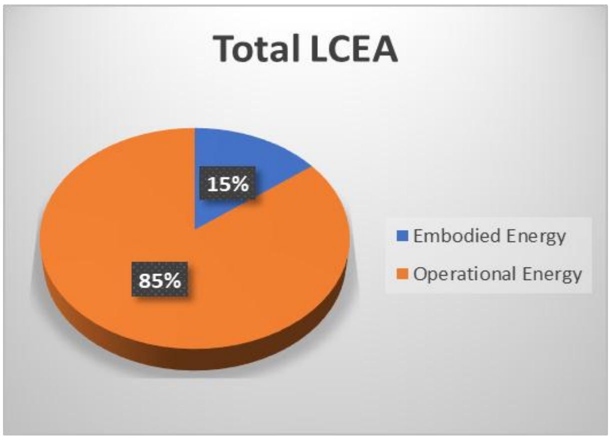


**Figure 4.** Total Life Cycle Energy percentage distribution. Source: Author

## 4. Discussion

The values obtained from the case study is comparable with the existing studies. The Life Cycle Energy Assessment was computed as 2,971GJ. It was observed that cement base materials accounted for just 8.8% by mass of total concrete used, however, it contributed 67.6% of the total embodied energy. This is slightly higher than the value from the Scottish study – 65% [47]. The study is on the view that reducing concrete based element in buildings is a panacea for the reduction of embodied energy. The embodied energy intensity value of 6.10GJ/m$^2$ for the study area is high in comparison with the mean of 0.663GJ/m$^2$ in a study by Ghattas, Gregory, Olivetti & Greene [53]. An earlier Nigerian study reported 7.38GJ/m$^2$ for a similar building in Lagos [10]. The value of embodied energy intensity of the study area and that reported by Ezema [10] are of great concern with regards to sustainable housing and hence requires urgent actions. With regards to operational energy, the value of 41.84GJ/m$^2$ obtained in the study is higher than 27.3GJ/m$^2$ – 31.68 GJ/m$^2$ reported in a foremost LCA by Adalberth [54]. However, the value is lower than a similar Australian and Nigerian (Lagos) study which also adopted direct calculation from electricity bills, the studies reported operational energy intensity values of 86GJ [41] and 51.8 GJ [10]. Similarly, the value falls within the range values range of 37.3 GJ – 66.85 GJ/m$^2$ presented by Ramesh, Prakash, Shukla [55]. The operational energy accounting for 85.4% for the study is higher than the values (57% - 74%) reported by Mithraratne and Vale [50]. In line with the study objectives, using energy intensity as a parameter and based on the values obtained from the study, it is evident that more enlightenment is urgently needed with regards to sustainable architecture and development of sustainability assessment framework that integrate local data instead of relying only on international data. Especially now that the developing countries are racing to mitigate the housing deficit. It is imperative to adopt more sustainable measures in design process and renewable energy alternatives in order to reduce operational energy in the housing sector. Also, integration of passive design styles at the early stages of the design process is one of the effective methods of reducing operational energy in buildings.

Moreover, it is important to note that in the study area, kerosene and petrol consumption contributed significantly to operational energy in comparison with developed countries, with 20.15% and 22.60% respectively. This is as a result of inadequate grid electricity supply in the study area (this is very common in the developing countries) resulting to the use of electricity generators and kerosene lamps/cooking stoves by the occupants. This underlines the need to improve grid electricity supply in Nigeria as a way of aligning with the global quest for sustainable built environment.

### 4.1. Implications of the Findings

Understanding the energy-use consequences of architectural design is key to sustainable architecture and climate change mitigation/ adaptation strategy in the housing sector. Life Cycle Energy Assessment (LCEA) of the referenced building provided an opportunity to identify the implications of architectural design decisions and the various dimensions of sustainable architecture in practice.

There are policy implications of the research findings with regards to energy -use and energy intensity regulations in the national building code especially for new buildings. According to Okonjo-Iweala [56] the Federal Mortgage Bank of Nigeria put the country's present housing deficit at 17-22 million, as a result, the Federal Government is currently constructing affordable homes in 34 states of the federation. Thus, in order to lessen the energy intensity resulting from mass housing, it is imperative that the climaxes in their embodied energy and operational energy are addressed. Cement based building materials accounting for 67.6% is of great concern, therefore, at research and development level, more research intended at finding alternative materials and substitute for cement in building construction needs to be encouraged. Moreover, GHG emissions and energy-use in the housing sector should be given thoughtful deliberation in energy and $CO_2$eq lessening plans, instead of focusing only on oil, gas and agricultural sector, especially now that efforts to reduce the housing deficit is gaining momentum from the informal and formal investors.

At the level of architectural education and practice, there is need to include environmental sustainability assessment protocol in school curriculum and workout synergy with appropriate regulatory institutions to regulate and certify alternative materials to enhance their specification by architects. This will make the vision 2050 of the International Union of Architect realizable.

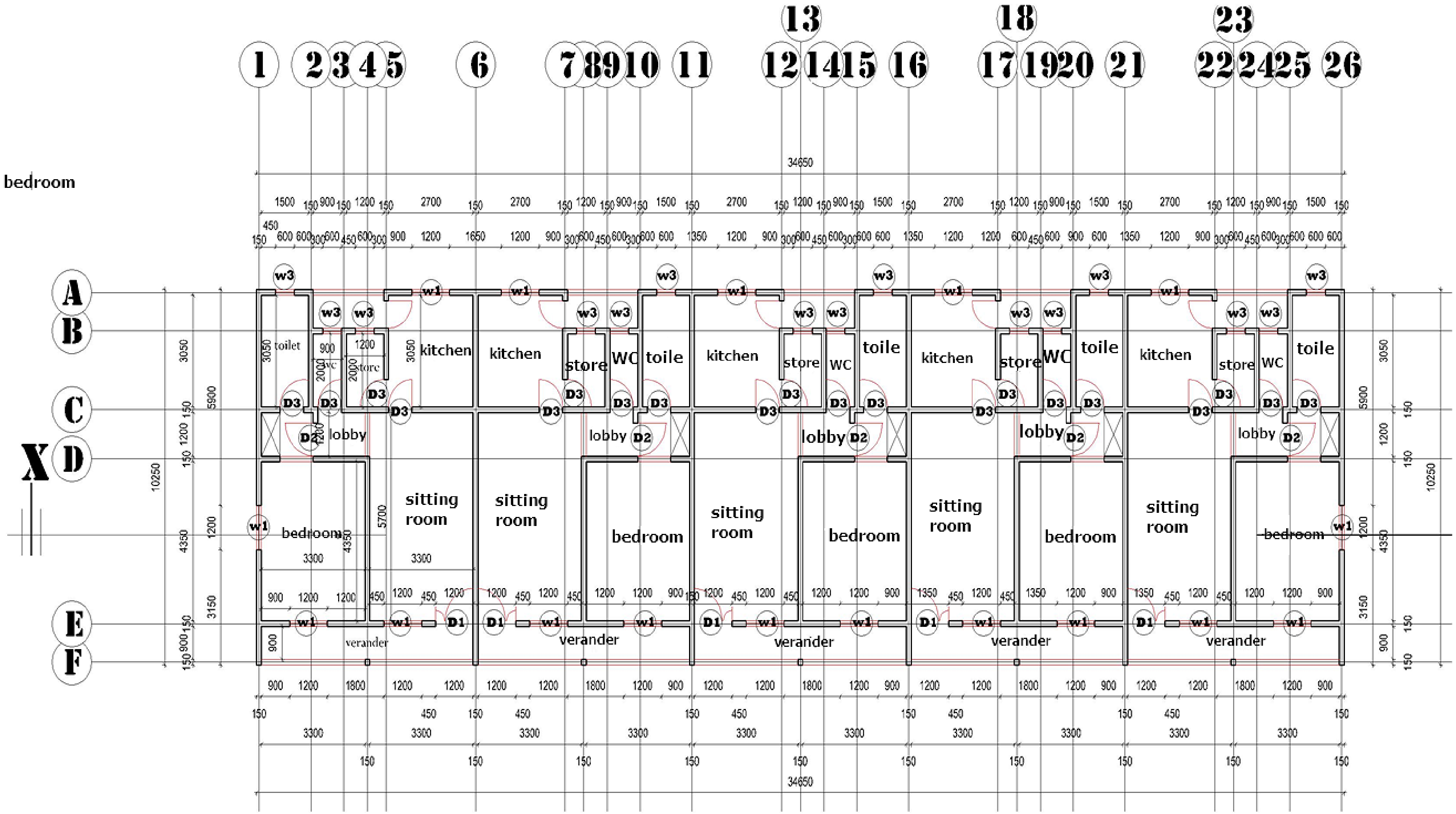
One of the ways to reduce the operational energy in the study area is the adoption of renewable energy technology. Thus, policy should focus on how collections of housing units or housing estates can be stimulated to install integrated Photo Voltic (PV) retrofits including micro-grid renewable installations.

## 5. Conclusions

According to Guy and Farmer [57] sustainable architecture is not a 'prescription', but it's an approach, practice and an attitude. The study reviewed the theoretical challenges associated in defining what we mean by calling a building "green" or sustainable architectural design and provides a summary of a post-positivism viewpoint on the development of sustainable architecture by using a case study. The imperative of an architect having an all-inclusive knowledge of all aspects of sustainability in order to be able to engage with a variety of professionals and specialists underscores the significance of this paper. From sustainable architecture perspective, buildings and infrastructures should become producers of energy rather than being just consumers of energy, directing our attention to imagining a future where we give more than we take. From the values obtained from the study and existing Nigerian study shows that the embodied energy intensity of the Nigerian housing sector is high.

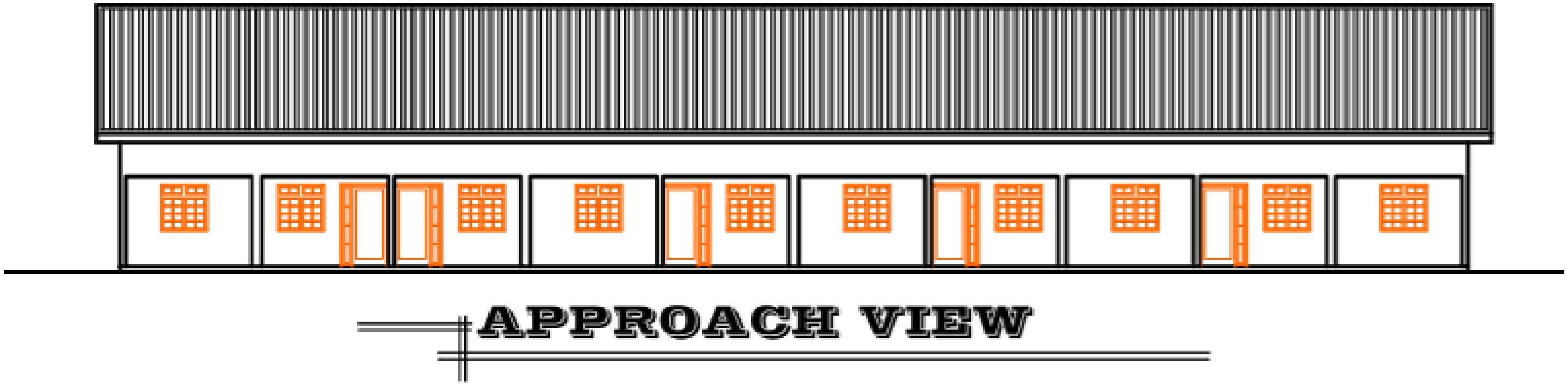
Architects need to take responsibility at the early stage of building design by carrying environmental sustainability assessment of their design. This is because no one can claim that his building design is sustainable until a Life Cycle Assessment is carried out. This calls for more enlightenment among architects in practice with regards to Life Cycle Energy Assessment and the use of architectural design strategies for climate change migration and adaptations.

**Appendix 1: Floor Plan of one bedroom apartment at Udensi Estate, Abakaliki. Source: EBSHDC**



**Appendix 2: Section X-X of One (1) bedroom apartment at Udensi Estate, Abakaliki. Source: EBSHDC**

**Appendix 3: Approach View of One (1) bedroom apartment at Udensi Estate, Abakaliki. Source: EBSHDC**



# REFERENCES

[1] World Commission on Environment and Development. *Our Common Future.* Brundtland, Oxford: Oxford Uni. Press, 1987.

[2] Arezon, Kalan and Oliveira, Eduardo. A Sustainable Architecture Approach to Economic and Social Aspect of Bazaar of Tabriz. *Munich Personal RePEC Archive. Paper no 53245.* [Online] January 28, 2014. http://www.mpra.ub.uni-murnchenide/53245 {Accessed: 4/06/2020}.

[3] Ghani, Fatima. *Issues in Sustainable Architecture and Possible Solutions.* International Journals of Civil and Environmental Engineering. Vol12(1). 2012

[4] Yao, Jian. *A Multi-Objective (Energy, Economic and Environmental Performance) Life Cycle Analysis for Better Building Design.* Journal of Sustainability 6(2), pp. 602-614,2014

[5] Walker, S.B. *Sustainable Design Exploration in Theory and Practice.* s.l.: EarthScan, 2006.

[6] IPCC -Intergovernmental Panel on Climate Change. *Climate change 2007: Mitigation of climate change.* London: Cambridge university press, 2007.

[7] UNEP. *Sustainable building and construction: Facts and figures.* Paris: s.n., Industry and Environment. Vol.26(2-3), pp. 9-12.2003.

[8] Ezema, Isidore, Olutuah, A and Fagbenle, O I *Estimating Embodied Energy in Residential Buildings in Nigeria Context.* Inter journal of Applied Engineering .2015

[9] Margarida, Feria and Amado, Miguel *Architectural Design: Sustainability in the Decision-Making Process.* Buildings, 2019 http://www.mdpi.com.

[10] Ezema, Opoko, A and Oluwatayo, A. De-carbonizing the Nigeria Housing Sector: The Role of Life Cycle CO2 Assessment. *Research India Publications ISSN 0973-6077 Vol 11.* [Online] 2016. http://www.ripublication.com {accessed 14-02-18}.

[11] Udomiaye, E. and Chukwuali, B.C. *Climate Change Mitigation Strategies in The Nigerian Housing Sector: The Role of Life Cylce Co2eq Assessment.* International Journal Architecture, Engineering and Construction, pp. 54-69. 2018, http://dx.doi.org/10.7492/IJAEC.20.

[12] Grierson, David and Moultrie, Carolyn. *Architectural Design Principle and Processes for Sustainable: towards a topology of Sustainable Building Design.* Design Principle & Practices Journal Vol.4, 2011. www.Design-Journal.com.

[13] Madhumita, Roy. *Importance of Green Architecture Today.* Kolkata, India: Dept. of architecture, Jadavpur University, 2008.

[14] Ragheb, Amany, Hishan, El-Shiny and Ragheb, Ghada. *Green Architecture: a concept of sustainability.* Procedia - Social and Behavioral Sciences Vol 216, pp. 778-787, 2016. doi.org/10.1016/j-sbspro.2015.12.075.

[15] Marques, Bruno and Loureiro, Carlos Rafael. *Sustainable Architecture: Practice and Methods to Achieve Sustainability in Construction.* International Journal of Engineering and Technology 5(2).2013

[16] Gourgel, Mario Alcino Pio. *The Importance of Sustainable Architecture in Tropical Climate Countries: case study in luanda city.* Lisboa: unpublish thesis, univesidade Tecnica de lisboa, 2012.

[17] Vujozevic, Milica. *About Sustrainable Architecture - a definition* Thessalonik, Greece: PREConf. Protection and restoration of the Environment.2012

[18] Arun, Solanki and Nayyar, Anand. *Green Building Management and Smart Automation.* Hershey PA, USA: IGI Global, 2020.

[19] Bodart, M and Evard, A. *Architecture and Sustainable Development.* Louvain-la-Neuve: Presses universitaires de louvain .2012. doi:10.7763/IJET.2013.Vs.547.

[20] Chen, Tingyao, Burnett, J and Chau, C. *Analysis of Embodied Use in the Residential Building of Honkong.* Energy 24(4), pp. 323-340. 2000. doi :10.1016/S0360-5442(01)00006-8.

[21] Dixit, Manish Kumar. *Embodied Energy Calculation Method and Guildlines for a Building amd its Constituent Materials.* Dept of Architecture, Texas A&M University: Unpublished PHD Thesis, 2013.

[22] IEA. *Tracking Clean Energy Progress.* Paris: Energy Tech. Perspectives, 2012.

[23] Treloar, G.J. *A comprehensive embodied energy analysis framework.* Victoria. Australia.: Ph.D. Thesis, Deakin University, 1998.

[24] Hegner, S. *Embodied energy for energy efficiency measures, an assessment of embodied energy's relevance for energy saving in the Swiss residential building sector.* Zurish: Diploma Thesis, Department of Environment Science, ETH, Zurich, Switzerland., 2007.

[25] Fay, Roger, Treloar, Graham and Iyer-Raniga, Usha. *Life Cycle Energy Analysis of Buildings: a case study.* 2000, Building, Research and Information. Vol. 28(1), pp. 31-41.2000

[26] Koezjakov, A, et al. *The Relationship Between Operational Energy Demand and Embodied Energy in Dutch Residential Buildings.* Energy & Buildings 165, pp. 233-445.2018

[27] Stephan, A, De Myttenare, k and Crawford, H. *Multi-Scale Life Cycle Energy Analysis of a Low-density Suburban neighbourhood in Melbourne.* Built Environ 68(0), pp. 35-49.2013

[28] Crowther, P. *Design for Disassembly to recover Embodied Energy.* Melbourne: QUT, Proceedings of Passive and Low Energy Architecture.1999

[29] Ding, G. *Construction-The role of environmental assessment tools.* Journal of Environmental Management, pp. 86)451-464.2008

[30] Haapio, A and Viitaniemi, P. *A Critical Review of Building Environmental Assessment Tools.* Environmental Impact Assessment Review Vol.39(3), pp. pp 234-55.2008

[31] Holmess, J. and Hudson, G**.** *An evaluation of the objectives of the BREEAM scheme for offices: a local case study.* London: RICS-Research Foundation., Proceedings of cutting Edge2000.2000

[32] Giwa and Peng, C. Environmental Profiling as an approach for quantifying the environmental sustainability of residential buildings in Nigeria. *ASCE Library web site.* [Online] 2012. http://www.ascelibrary.org/doi/abs.

[33] Udomiaye, E. and Chukwuali, B.C. *Advances in Building Environmental Sustainability Assessment Tools/Methods and the Nigeria Context:* International Journal of Civil Engineering, Construction and Estate Management.Vol.7, No.2, pp. pp.30-41.2019

[34] Reijinder and Roekel. *comprehensiveness and adequacy of tool for the environmental improvement of buildings.* Journal of cleaner Production. Vol. 7(3), pp. 221-225.1999

[35] Forsberg, A and Malmberg, Von. *Tools for Environmental Assessment of the Built Environment.* Building and Environment, pp. vol.39) pp 223-228.2004

[36] Buffaloe, Sarah and Rebecca, Lioyd. Integrating life Cycle Assessment (LCA) into the building design & Construction process. *USGBC.* [Online] 2014. http://gocms.hanleywoodexhibitions.com/Gal/shows/greenbuild/2014.

[37] Ragheb, A. *Towards Environmental Profiling for office building. Using Life Cycle assessment.* University of Michigan: Unpublished PHD dissertation, University of Michigan, 2011.

[38] Optis, M., Incorporating Life Cycle Assessment into the LEED Green Building Rating System. Master of Applied Science Thesis, Department of Mechanical Engineering, University of Victoria**.** *Incorporating Life Cycle Assessment into the LEED Green Building Rating System.* s.l.: Master of Applied Science Thesis, Department of Mechanical Engineering, University of Victoria, 2008.

[39] Suh, S. and Huppes, G**.** *Methods for Life Cycle Inventory of a Product.* Journal of Cleaner Production, 13(7), pp. 687-697. 2005

[40] Crawford, R.H and Treloar, G.J. *Validation of the use of Australian input output data for building embodied energy simulation.* Eindhoven, Netherlands: IBPSA, Eighth international IBPSA conference, August 11th-14th.2003

[41] Crawford, Robert. *An as occupied life cycle energy assessment of a residential building.* SE Queensland-Australia: Griffith University. Annual Conf. of the Architectural Science Association. 2012. www.anzasca.net/wp-content/ {accessed :17/7/18},

[42] Bayer, Charlene, et al. *Guide to Building Life Cycle Assessment Practice.* NY.USA: AIA.http://www.aia.org/practicing, 2010.

[43] Olygway, V. *Design with Climate: Bioclimatic Approach to Architectural Regionalism.* NJ, USA: Princeton University Press, 2015.

[44] Akadiri, Peter O., Chinyio, Ezekiel A. and Olomolaiye, Paul. O. *Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector.* Buildings 2, pp. 126-152;. 2012doi:10.3390/buildings2020126.

[45] Morbitizer, C., et al. *Integration of Building Simulation into the Design process of an Architecture Practice.* Rio. Brazil: IBPSA, IBPSA Conference. p. 8.2001

[46] Veira, N., Amado, M and Pinho, F. *Prefabricated Solution to Modular Construction in Cape Verde.* Paris: AIP Conf. Proceedings. Technologies and Material for Renewable Energy, Environment and Sustainability. 2016, doi.org/10.1063/1.497290,

[47] Asif, M., Muneer, T and Kelley, R. *Lifecycle Assessment: A Case Study of a Dwelling Home in Scotland.* journal of Building and Environment, 42., pp. 1391-2394.2007

[48] Chang, Y., Reis, R.J and Wang, Y. Life Cycle Energy of Residential Buildings in China. *Sciencedirect.* [Online] 2013. http://www.sciencedirect.com/journal/energy-policy/vol/57 {Accessed:13/08/18}.

[49] Myers, F., Fuller, R and Crawford, H R. *The Potential to Reduce the Embodied Energy in Construction Through the use of Renewable Materials.* Queensland, Australia, 1- 8.: ASA 2012: Building on knowledge, Theory and Practice: Proceedings of the 46th Annual Conference of the Architectural Science Association.2012

[50] Mithraratne, Nalanie and Vale, Brenda. *Life Cycle Analysis Model of New Zealand Houses.* Building and Environment, pp. 483-492 2004. doi:10.1016/j.buildenv.2003.09.008.

[51] Odigboh, E. U. Machines for Crop Production. [book auth.] B. A. (Ed) Stout. *Odigboh, E. U. (1997), Machines for Crop Production. In Stout, B. A. (Ed.), Handbook of Agricultural Engineering.* s.l.: American Society of Agricultural Engineering, 1997.

[52] Ohunakin, O.S, et al. *Energy and Cost Analysis of Cement Production Using the Wet and Dry Process in Nigeria.* 2013, Energy and Power Engineering, Vol.5, pp. 537-550. 2013 doi: 10.4236/epe.2013.59059.

[53] Ghattas, R., et al. Life Cycle Assessment for Sustainability Hub. *mit.edu.* [Online] 2013. Http://www.mit.edu/cshub/news/pdf/LCAfor ResidentialBuildings.pdf DOI: 10.13140/RG.2.2.10238.38722 {Accessed: 03/01/2019}.

[54] Adalberth, K**.** *Energy Use during the Life Cycle of Single Unit Dwellings: Examples.* Building and Environment, 32(4), pp. 321- 329. 1997.

[55] Ramesh, T., Prakash, R and Shukla, K K. *Life Cycle Energy Analysis of a Multifamily Residential House: A case study in Indian Context.***.** Journal of Energy Efficiency 2, pp. 34-41.2013 http://dx.doi.org/ 10.4236/ojee.2013.21006.

[56] Okonjo-Iweala, N. Unleashing the Housing Sector in Nigeria and in Africa, Keynote Paper, 6th Global Housing Finance Conference, World Bank HQ, Washington DC, USA.2014.

[57] Guy, S and Farmer, G. *Reinterpreting Sustainable Architecture: the place of technology*. Journal of Architectural Education 54(3), pp. 140-488.2001