THE NIGERIAN INSTITUTE OF BUILDING

THEME

ADVANCING TECHNOLOGIES, SYSTEMS AND STANDARDS FOR SUSTAINABLE BUILDING CONSTRUCTION

OUR VISION

Providing professional excellence and leadership for sustainable shelter.

OUR MISSION

To enable members deliver, with relevant stakeholders, sustainable shelter that addresses the housing needs of the Nation through research and development and global best practices.

OUR CORE VALUES

The Nigerian Institute of Building (NIOB) is a value-driven professional organization, thus we have below the core values that drive us:

1. Research and Development

Members are trained through conferences, seminars and workshops with the latest development in the building industry.

2. Sustainable Shelter

We encourage our members to build maintainable, environmentally-friendly and sustainable structures.

3. Professional Excellence

We always strive for professional excellence, encouraging industry best practices and innovations.

THEME

ADVANCING TECHNOLOGIES, SYSTEMS AND STANDARDS FOR SUSTAINABLE BUILDING CONSTRUCTION

SUB -THEMES:

1. The states of the technologies, systems and standard in building construction
2. Understanding sustainability in building construction.
3. Advances and emerging technology options for foundation construction.
4. Advances and emerging technology options for sustainable wall construction
5. Advances and emerging technology options for sustainable construction of structural members.
6. Advances and emerging technology options for sustainable roof construction.
7. Soft and hard technologies for sustainable building project delivery.

OBJECTIVES OF THE CONFERENCE

OBJECTIVES

1. To Retrain Professionals On Modern Technologies, Systems and Standards in Building Constriction Practice.

2. To Understand Concept of Sustainable Practice in Building Construction.

3. To Understand Advanced and Emerging Technology options for Sustainable Construction of Building elements (Foundations, Walls, Roofs and all Structural Elements).

4. To Promote Standardization and Right Technology for Sustainable Building Project Delivery.

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THE NIGERIAN INSTITUTE OF BUILDING

TECHNICAL PAPERS PRESENTED AT THE 51ST CONFERENCE/AGM

Papers Title and Authors List

S/N	Papers Title	Lead Author	Co-Authors	Phone number
1.	Sustainable Construction Practices and Indicators: A Critical Literature Review	Omeife, C. A.	Windapo, A. O. Oboirien, M. O.	08030802444
2	Collaborative Knowledge Management' An Emerging Theme Among Construction Firms in Nigeria	Osuji, E. C.	AbdulAzeez A. D., Mbamali I. M. Ibrahim, A. D.	
3.	Design Principles and Construction Methods of Foundation Systems for High-Rise Buildings	Anejo, J. A.	NIL	08038376343
4.	Understanding The Performance of Expanded Polystyrene (Eps) Towards Sustainable Housing Construction	Mansir, D.[1],	Badamasi A. A. Kabir F. A.	080 6566 6829
5.	Reactive Powder Concrete: A new generation of concrete	Abdullahi, G.	Ibrahim, A.G.	08060907165, 08122567692
6.	Assessment of Lean Construction Tools for Sustainable Building Project Delivery in Nigeria	Adamu, S.	Kawu, L.	08035054717
7.	Confrontations to Sustainable Construction in Nigeria	Akinola, V.O.	Oluyale, J.T.	08065701490
8.	Application of Sustainable Construction Technology for Successful Building Project Delivery in Nigeria	Akinola, V.O.	Oluyale, J.K. Oso, F. A.	08065701490
9.	Understanding Sustainability in Building Construction	Usman, N. D.	Bustani, A. B. Igwe, C. O. Adamu, S	08123505182
10	The Art and Science of Foundations: Some Capsules	Akin Akinrinde		
11	The art and science of foundations: some capsules	Akinola Akinrinde		
12	REALITY CAPTURE - An Indispensable Process for Builders	Donatus Oduopara		08037267237

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FOREWORD

The Annual General Meeting and Conference of the Nigerian Institute of Building has always been momentous and epoch making. In the Annual General Meeting, decisions that positively affect the Institute, the Building profession and indirectly the society with respect to building project delivery are taken. The Annual Conferences also prove highly educative and informative. This year's Conference and Annual General Meeting of the Institute is not an exemption. It promises to be engaging and vivacious.

It is with joy and sense of appreciation that we write the foreword to the proceedings of papers for this year's conference. The NIOB has been systematically addressing project delivery from first principles. We had addressed very lately concepts of building structures and building services. Understanding the essential role of the registered builder in actualising and bringing together, in a whole, the dream of the client and the disparate inputs of the professional stakeholders, the NIOB has deemed it fit to devote this year's conference to address technology options for constructing and installing various elements of the building and consequently the entire building.

It is in this light that the theme of the conference has been chosen as: Advancing Technologies, Systems and Standards for Sustainable Building Construction. The subthemes are meant to address:
1). The State of the Art of Technologies, Systems and Standards in Building Construction.
2) Understanding Sustainability in Building Construction.
3) Advances and Emerging Technology Options for Foundation Construction.
4) Advances and Emerging Technology Options for Sustainable Construction of Structural Members.
5) Advances and Emerging Technology Options for Sustainable Roof Construction.
6) Soft and Hard Technologies for Sustainable Building Project Delivery

The papers in this proceedings address some if not all of the above subthemes. Other keynote papers and industry presentations that are not in this proceedings will add flavour and knowledge. The ultimate aim of this year's conference is to refresh the knowledge of our members and expose them to emerging soft and hard technology options for the delivery of the building starting from the elements thereof. The expected outcome is greater value addition of builders in their services to their clients and the general society. Other stakeholders in the building delivery value chain will also add to their knowledge leading to better appreciation of the interrelatedness of stakeholders and complimentary nature of their services and inputs. It is our expectation and hope that all participants will make the best of the conference.

Our special thanks go to our reviewers and indeed members of the Research and Development Committee of the Institute for the efforts put in despite challenges of time. Our thanks also go to the authors and presenters. Thanks too to all the conference participants. We thank you all and appreciate you very highly

Bldr Kunle Awobodu, FNIOB
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SUSTAINABLE CONSTRUCTION PRACTICES AND INDICATORS: A CRITICAL LITERATURE REVIEW

Sustainable Construction Practices And Indicators: A Critical Literature Review

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ABSTRACT
Presently, the world is transitioning to an irrevocable urban future whose epicentre has moved into African cities, including Nigeria. Also, the considerable deficit in infrastructure and housing in Nigeria means that investment made in construction should be sustainable to meet the growing demands. However, there are many reported incidences of building collapse in Nigeria, which indicates the use of unsustainable construction practices in construction. This study, therefore, aims at understanding sustainability in building construction and whether there are key drivers. A scholarly literature review was adopted for the study employing a manual search of journals and conference proceedings. The study found that sustainability is measured in terms of environmental and socio-economic perspectives. In contrast, the key drivers of sustainability are education, training and awareness, environmental and economic integration, availability of a sustainability assessment system, and the National Building Regulations. It concludes that education and training and developing a system of assessment will improve the uptake of sustainable practices on construction projects. Based on these findings, the study recommends that the government, through its regulatory arm, i.e., the Council of Registered Builders of Nigeria (CORBON), should develop a sustainability assessment system that can measure the sustainability of the methods of construction used on projects as well as the acceptable thresholds. Other recommendations include using economic principles in materials and component installations, consideration of new modes and methods of material sourcing and usage that ensure zero waste generation.

Keywords: Content analysis, Education, Environmental Impact, Sustainability index, Sustainable Development, Sustainable Construction Benefits.

INTRODUCTION
The construction industry is acknowledged to have a severe impact on the environment and is one of the main drivers behind the depletion of natural resources. Awareness of sustainability in the 1970s emerged amidst the oil crises (*the UK, GOV. Department for Business, Energy & Industrial Strategy, 2010)*. It was realized that it is necessary to utilize energy and find alternatives to contemporary energy sources efficiently. Additionally, shortages of other natural resources such as water also raised public attention to the importance of sustainability and conservation (*the UK, GOV. Department for Business, Energy & Industrial Strategy, 2010)*. From the late 1960s, the construction industry began to explore ecological approaches to construction to seek harmony with nature *(Leonard and Bachman, 2008)*.

According to United Nations Environment Programme (UNEP), *the increased construction activities and urbanization will increase waste, eventually destroying natural resources and wildlife habitats and over*

70% of land surface from now up to 2032 (*UNEP, 2002*). Moreover, construction uses around half of the natural resources that humans consume. Production and transport of building materials consume 25 - 50 per cent of all energy used (depending on the country considered) *(Sattary,* 2004). Taking the UK as an example, the construction industry counts for 47% of CO_2 emissions. Manufacturing construction products and materials accounts for the most significant CO_2 emissions within the construction *process (the UK, GOV. Department for Business, Energy & Industrial Strategy, 2010)*.

Precise definitions of sustainable construction vary from place to place and have evolved to encompass varying approaches and priorities. The United States Environmental Protection Agency (EPA) defines sustainable construction as creating structures and using environmentally responsible and resource-efficient processes throughout a building's life cycle. This spans design, construction, operation, maintenance, renovation, and deconstruction (US EPA Basic Information, 1990). Sustainable construction is a way of building that aims at reducing (adverse) health and environmental impacts caused by the buildings or the built-up environment construction process (Luc, 2010). Kibert (1994) described sustainable construction as creating and responsible management of a healthy built environment based on efficient and ecological principles. Sustainable construction can be described as a combination of sustainable building features, including water efficiency, energy and atmosphere, material and resources, indoor environment, sustainable sites, innovation and the construction process.

More comprehensively, sustainability can be considered from three dimensions of the planet, people, and profit (3Ps) across the entire construction supply chain (Solaimani and Sedighi, 2019). Key concepts include protecting the natural environment, choice of non-toxic materials, reduction and increased reuse of resources, minimizing waste, and using life-cycle cost analysis. United Nations Member States, in 2015, after recognizing that action in one area affects outcomes in others and that there is a need for development to balance social, economic, and environmental sustainability, adopted the Sustainable Development Goals (SDGs), also known as the Global Goals. The seventeen SDGs are integrated as a universal call for action to protect the planet.
The introduction of sustainable development into the environmental/economic discourse served as a middle ground for the limits-to-growth theory and earlier pro-growth theories that argued maintaining economic growth would not hinder long-term sustainability (*Hill and Bowen, 1997)*. The term sustainable development was first coined in the Brundtland report of 1987; it is defined as the ability to meet the needs of all people in the present without compromising the ability of future generations to meet their own (*Hill and Bowen, 1997)*. Sustainable development interconnects three socially concerned systems—environment, society, and economy—seeking to achieve a range of goals defined by the United Nations Development Program (UNDP, 2015). As a result, scholars have faulted sustainable development for being too value-laden since applications of its definition vary heavily depending on relevant stakeholders, allowing it to be used in support of both pro-growth and pro-limitation perspectives of development arguments despite their vastly different implications (*Hill and Bowen, 1997)*. For the concept to be effective in real-life applications, several specified frameworks for its use in various fields and industries, including sustainable construction, were developed.

Since 1994, much progress on sustainable construction has been made all over the world. According to the US 2015 Green Building Economic Impact Study of the Green Building Council (USGBC) (*US EPA, 1990),* the Green building industry contributes more than $134.3 billion in labour income to working Americans. The study also found that green construction's growth rate rapidly outpaces conventional construction and will continue to rise (Shutters, 2015). Traditional construction concerns (performance, quality, cost, and time) are added to the new concerns in sustainable construction: resource depletion, environmental degradation, and health impact on the environment. This paper examines sustainability in building construction and whether there are key drivers. To do this, the paper provides an overview of the concepts of sustainability and sustainable construction, followed by the research methods, findings and conclusions, and recommendations.

CONCEPT OF SUSTAINABLE CONSTRUCTION

The concept of sustainable construction was borne out of sustainable development discourse *(Hill and Bowen, 1997).* Additional definitions and frameworks for sustainable construction practices were more rigorously defined in the 1999 Agenda 21 on Sustainable Construction, published by the International Council for Research and Innovation in Building and Construction (CIB) (*Du Plessis et al., 2002)*. The same council also published a different version of the agenda for sustainable construction in developing countries in 2001 to counteract biases present in the original report because most contributors were from the developed world (*Du Plessis et al., 2002)*.

Sustainable construction addresses these criteria through the following principles set by the conference (*Kibert, 1994)*: Minimize resource consumption (Conserve); maximize resource reuse (Reuse); Use renewable or recyclable resources (Renew/Recycle); Protect the natural environment (Protect Nature); Create a healthy, non-toxic environment (Non-Toxics); Pursue quality in creating the built environment (Quality). In a later work, Du Plessis et al. (2007) extend the definition of sustainable construction to encompass the importance of sustainability in social and economic contexts (*Du Plessis et al., 2007)*. This is especially relevant in construction projects in the Global South, where local value systems and social interactions may differ from the western context in which sustainable construction frameworks were developed (*Du Plessis, 2007)*.

Construction Methods, Methodology and Sustainability

Globally, construction industries are attempting to implement sustainable construction principles. For example, the Government in Singapore has developed a Sustainable Construction Master Plan with the hope of transforming the industrial development path from only focusing on the traditional concerns of "cost, time, quality" to construction products and materials to reduce natural resource consumption and minimize waste on-site (Anggadjaja, n.d). The development of efficiency codes has prompted the advancement of new construction technologies and methods, many pioneered by academic departments of construction management that seek to improve efficiency and performance while reducing construction waste.

New techniques of building construction are being researched, made possible by advances in 3D printing technology. In a*dditive building construction*, like the additive manufacturing techniques for manufactured parts, building printing makes it possible to flexibly construct small commercial buildings and private habitations in around 20 hours, with built-in plumbing and electrical facilities, in one continuous build, using large 3D printers. Working versions of 3D-printing building technology are already printing 2 metres (6 ft 7 in) of building material per hour as of January 2013, with the next-generation printers capable of 3.5 metres (11 ft) per hour, sufficient to complete a building in a week (*Diaz, 2013)*. Dutch architect Janjaap Ruijssenaars's performative architecture 3D-printed building was scheduled to be built in 2014 (Hossain, et al. 2020).

New Urbanism and New Classical architecture adoption promote a sustainable approach towards construction that appreciates and develops smart growth, architectural tradition, and classical design. This is in contrast to modernist and short-lived globally uniform architecture and opposing solitary housing estates and suburban sprawl (American Institute of Architects, 2005). Both trends started in the 1980s. Also, timber is being introduced as a feasible material for skyscrapers (nicknamed plyscrapers) thanks to new developments incorporating engineered timber, whose collective name is "mass timber" and includes cross-laminated timber (*Callaghan, 2016)*.

Specific parameters are needed for sustainable construction projects in developing countries. The Council for Scientific and Industrial Research (CSIR) in South Africa defines the following key issues as specific to work in developing countries (*Du Plessis et al., 2002)*: New, non-western frameworks for development; Understanding the connection between urbanization and rural development; Sustainable housing solutions; Education; Innovative materials; Innovative methods of construction; Merging modern and traditional practices; Promoting equity in gender roles; and Development of new financing systems and also, improving

the capacity of the government and the construction industry.

Benefits of Sustainable Construction

Suttell (2006) groups the potential benefits of green buildings according to the different aspects of life affected by them. The benefits of sustainable construction practices include the recycling of construction waste for later use, the use of locally available building materials, controlling pollution (noise, light, and air), protection of natural habitats, limiting stormwater runoff, efficient and low maintenance of buildings, and use of low-emitting materials and less harmful equipment on projects (Cruywagen, 2013) and green buildings. Suttell elaborates that these benefits are dependent on design and construction teams working together in the initial stages of the project. The three classes identified by Suttell (2006) comprise environmental, economic and social benefits.

The environmental benefits of green buildings are: (1) enhancing and protecting biodiversity and ecosystems. Du Plessis et al. (2002) noted that green buildings are concerned about the ecosystem's well-being. Their design and construction incorporate the environment and try to minimize damage or disturbance to it as much as possible; (2) improve air and water quality. Green building projects seek to improve the quality of the air and water involved in the project, and the Green Building Council of South Africa (GBCSA) (2013) acknowledges that one of the nine criteria for achieving a green star rating is improving the quality of air and water; (3) the reduction of waste streams. Components are designed to fit together with less wastage, and therefore designers must ensure that their design has minimal wastage in terms of layout; that is, the design should be efficient enough for most of a tile to be used (GBCSA, 2013); (4) the conservation and restoration of natural resources. At the design stage of a project, the designers specify the material to be used for a project based on the availability of that resource in the area.

The economic benefits of green buildings are: (1) reduced operating costs. This is a significant pull factor for most investors or clients because, for example, the operational cost of a high electrical bill, which would be caused by air conditioning, can be minimized; and (2) the profitable trade in green products and services. There is a relatively short supply of green building products in the market, so they are relatively costly. This has led to less competition and more profits made on green building components and services. The social benefits of green buildings are: (1) the enhancement of occupant comfort and health.

NEED FOR ADOPTION OF SUSTAINABILITY CONCEPT IN THE NIGERIAN

CONSTRUCTION INDUSTRY

The construction industry faces significant challenges in reducing its environmental footprint. Climate change, resource consumption, and water management are all environmental issues that must be carefully considered when working towards sustainability in construction. The industry contributes 11% of the world's greenhouse gas emissions, and its current volume of natural resource utilization is not sustainable and substantially compromises the environment for the sake of growth (Bracco, 2019). Ijigah et al. (2013) discovered that the fast-growing threat of environmental impacts of building construction projects on the ecosystem in Nigeria are pollution, resource use and habitat destruction, which is caused by the destruction of vegetation, desertification, waste disposal, soil erosion and material wastage. Another study by Akinola and Funsho (2012) gave a detailed report highlighting that the average depth of digging at three quarry sites in Ogun State is 6 meters; the average distance of the sites to the nearest building is 9 meters; the average distance of the sites to the nearest stream is 750 meters; the distance of the sites to the nearest road is 18 meters, and the area covered by the dug sites is about 4.6 hectares. The excavation has caused damages to private property and infrastructures such as roads, electricity poles and drainage. According to the authors, it was discovered that excavated sites during the constructions of Lagos- Abeokuta and Ota-Idiroko international highways left some pockets of dug sites with health implications, including the breeding of mosquitoes. The bare surface areas are currently degraded by massive excavation and digging. The typical impact includes a series of environmental problems: soil erosion, loss of cropland, deforestation, ecosystem destruction, and species extinction.

RESEARCH METHODS

A systematic review of the scholarly literature was adopted for the study. Sustainability is a broad concept that includes a large number of related constructs and themes. Therefore, the following search terms were used to match the focus of the study to the literature search: Sustainable Construction, Sustainability indicators, Sustainable Development in North America, Europe, South America, Asia, Australia, Oceania and Africa. Concepts and themes such as 'Green Building', 'Environmental impact', 'Resource Management', and 'life-cycle design' were used to extract information from the selected articles.

The literature search included peer-reviewed articles and conference proceedings; on Google Scholar, Primo and the University of Cape Town's electronic library (https://www.lib.uct.ac.za/&usg=AOvVaw2GdHaMTdj-w9NKfJLgwJpA). Furthermore, as a supplementary search, all articles that have cited articles relevant to the study were reviewed to ensure that the search is comprehensive. Content analysis was used to determine the presence of the search terms within the selected articles and quantify and analyze the concepts' presence and meaning. The results of the analysis are presented in the following sections.

SUSTAINABILITY INDICATORS AND DRIVERS OF SUSTAINABLE CONSTRUCTION

Windapo et al. (2021) established sustainability indicators using the GBCSA (2013) Technical Manual. The manual assessed a complete building and its area; it had to be adjusted, as shown in Figure 1. It is relevant to the study objective, which is focused on establishing the sustainability indicators. Three levels are shown in Figure 1. Level 1 displays the primary components of the sustainability index – Environmental and Social Economic sustainability indicators. The appropriate sustainability indicators - energy, material, and innovative indicators (constituents of the environmental sustainability indicator) are displayed in Level 2 of the Sustainability Framework. The Energy indicator shows the level of minimization of greenhouse gas emissions; the Material indicator shows the level of recyclability or use of recycled materials in the manufacture of the component, Innovation indicator indicates the level of changes in practices or processes required to use the building component as shown in the third level of Figure 1. The Socio-economic indicator acknowledges socio-economic initiatives such as employment creation, growth and development of small-sized enterprises, skills development, and promotion of better safety practices as components for assessing the sustainability index of construction projects. The socio-economic indicator is not broken down further at Level 2 of the Framework used to assess construction projects' sustainability index.

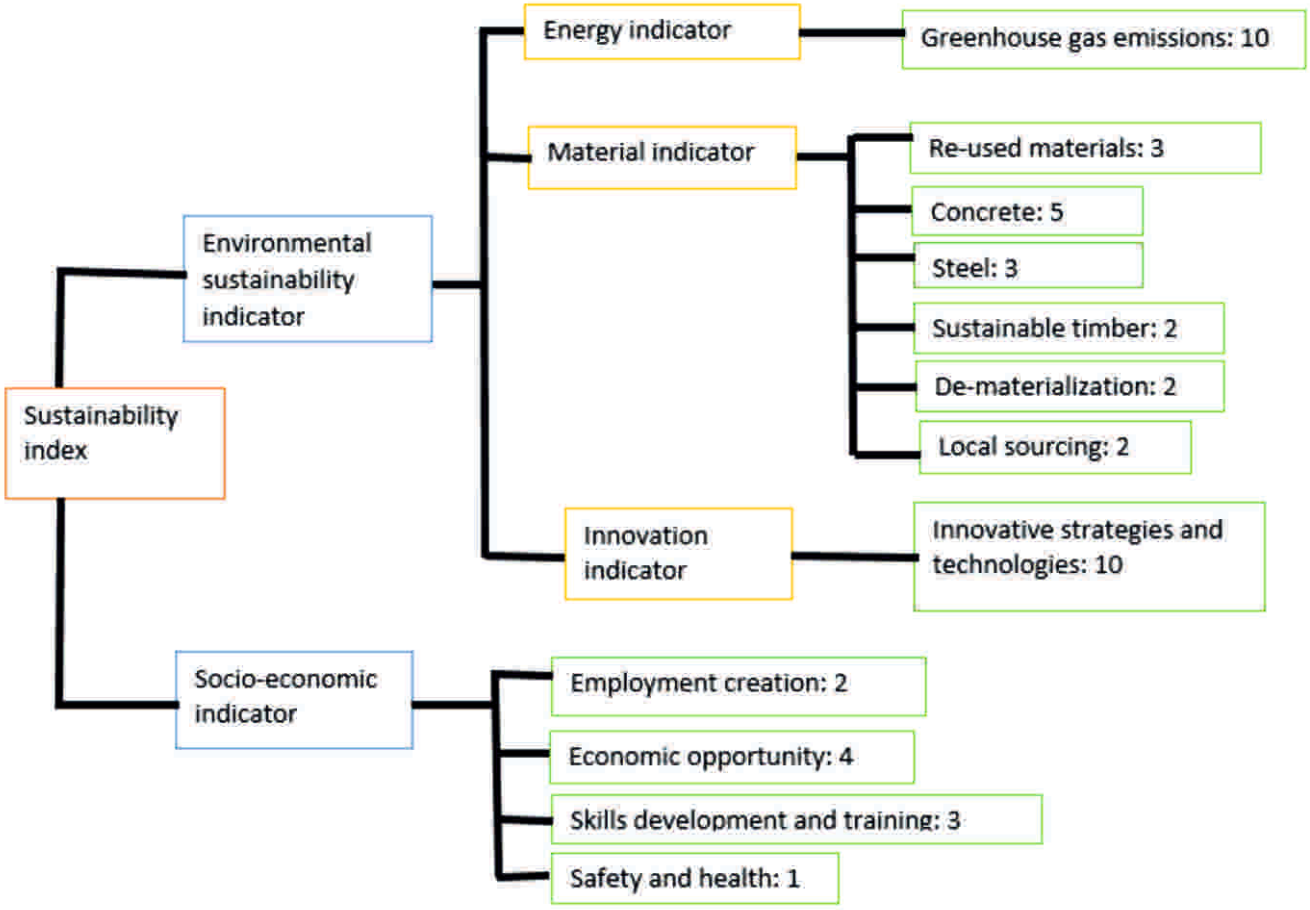

Figure 1: Framework for assessing the sustainability performance of low-income housing (Source: Windapo et al., 2021)

The GBCSA manual indicates that the drivers of sustainability construction are greenhouse gas emissions and innovative strategies and technologies. It can be seen from Figure 1 that these elements for the Framework, which are related to environmental sustainability, are assigned a credit of ten each out of the total Sustainability credit score of 47. The elements presented in the third level of the Framework shown in Table 1 are further discussed in the following sub-sections.

Green House Gas Emissions

This indicator assesses the environmental sustainability of construction components by recognizing components that minimize greenhouse gas emissions in the building. Pertsova (2007) states that greenhouse emission is a generic synonym of carbon dioxide emission.

Materials

The following subcategories of the material indicator – reused materials and sustainable timber serve the same purpose. They are there to reward the reuse of construction materials, concrete, steel and timber. The subcategories for concrete and steel recognize a reduction of embodied energy and resource depletion occurring through the use of concrete and steel, respectively. While the design for disassembly subcategory deals with the recognition of building components that minimize the embodied energy and resources associated with demolitions, the local sourcing is a recognition of the environmental advantages gained, in the form of reduced transportation emissions, by using materials and products that are sourced close to the construction site.

Innovation Strategies and Technologies

This deals with the level of innovation in the building components used in construction. It has a credit score of ten which is awarded in recognition of pioneering initiatives or processes in sustainable building components and in recognition of sustainable design initiatives or processes that are currently outside the

scope of the Green Star SA rating tool but have a substantial environmental benefit. This category is included in the Technical Manual to encourage the use of innovative technologies that positively impact the environment.
There are innovative technologies certified for use by Agrément in South Africa, but they are rarely used. This may be attributed to the lack of skills and knowledge of innovative building technologies and the high cost of constructing low-income houses with sustainable building materials or technologies. This finding is in line with Windapo and Ogunsanmi (2014a) conclusions, which indicated that a lack of skills in the use of innovative building materials is a significant barrier to its use in construction projects. This is further buttressed by a study by Omoparola et al. (2019), which found that Education, training, and awareness are key drivers of sustainable construction followed by environmental and economic integration.
The use of innovative technologies means that the construction process is much shorter than conventional methods. Also, it was found that innovative technologies have higher costs and less environmental impact when compared to conventional methods of construction. Also, innovative building technologies have a higher environmental sustainability level due to the low carbon dioxide emission associated with the manufacturing process. This is aligned with previous studies by Windapo and Ogunsanmi (2014b), who established that innovative building systems have a much lower carbon dioxide emission level than conventional building components.

Socio-Economic Sustainability Indicators
This category involves the acknowledgement of socio-economic initiatives of new or existing buildings, which have been previously assessed by the GBCSA Technical Manual (environmental aspects) (GBCSA, 2013). All the subcategories, Employment creation, Economic opportunity, Skills development and training and Safety and health, complement each other.

Employment Creation
Employment creation recognizes developments/manufacturing of building components and labour-intensive construction methodologies**,** which create employment opportunities for priority groups, who, in South Africa, are the previously disadvantaged people. A labour-intensive activity is one where much labour is required in order to produce the desired output. This subcategory is an important one as, according to Tregenna (2008), employment creation is essential, given the current unemployment crisis, which also contributes to high levels of poverty.

Economic opportunity
Economic opportunity deals with the expansion of small construction firms, and it works in line with employment creation. It recognizes the growth and development of small-sized enterprises through interventions in the design and construction of building components**.** If small firms have more jobs, then they can increase their growth by providing more services.

Skills development and training
Skills development and training is the provision of practical working experiences for all types of labour. This subcategory recognizes that the production of building components should award unskilled, semi-skilled and skilled employees with more knowledge and more skills. According to Ponte et al. (2007), the Broad-Based Black Economic Empowerment (BBBEE) policy was implemented to remedy the effect of apartheid.

Safety and Health
Safety and Health awards one credit score to recognize actions taken to promote better safety practices and understanding in the construction industry.

The above sustainability indicators are useful in determining the sustainability index of a proposed development. Windapo et al. (2021) found that the majority of low-income housing
projects in South Africa are constructed using conventional methods of construction. The study also showed social issues as the low-income communities are opposed to innovative technologies. They believe it is of a lower quality than conventional construction techniques, although innovative technologies are more

sustainable. Following a comparative analysis of the GBCSA sustainability index of innovative building components against conventional building components for three components, namely the floor, external envelope and roof systems, it has been observed that the innovative technology is more sustainable both environmentally and socio-economically. Conventional construction materials are cheaper than innovative construction components, and developers lack the financial incentives to adopt innovative technologies on development programs as their profit margin is higher when conventional construction methods are used.

CONCLUSIONS

It emerged that sustainable construction is an essential practice in the development of the construction industry. Principles through which sustainable construction are addressed were highlighted. Goals of sustainable construction were articulated as well as methods and methodology for ensuring sustainability. The need for sustainable development measures in the Nigerian construction industry where environmental degradations informed by construction materials extractions is also reviewed. The study found that the key sustainability indicators in the construction industry are greenhouse gas emissions and innovative strategies and technologies. It also established that the drivers of sustainable construction practice are education, training and awareness, which is a key driver of sustainable construction followed by environmental and economic integration. Based on these findings, the study concludes that education and training and developing a system of assessment based on the different sustainability indicators shown in Figure 1 will improve the uptake of sustainable construction practices on construction projects.

RECOMMENDATIONS

Based on the conclusions that the construction industry lacks sustainability in terms of environmental degradation management and the low uptake of innovative strategies and technologies on construction projects, the following suggestions are made to ensure sustainability during construction in Nigeria.

i **Reducing Energy Used in Construction**

Energy usage in construction should shift to electrically powered equipment that will improve the overall energy efficiency of the construction site to reduce the negative carbon impact.

ii **Use of Lean Manufacturing Processes**

Lean manufacturing processes in controlled environments is another way to reduce environmental impact. Manufacturing may be completed in a controlled setting like an indoor factory, where waste can be substantially reduced, and materials can be recycled instead of throwing it away. The building components are transported to and assembled on-site; this makes less impact on the surroundings of the building.

iii **Architects' and Engineers' Considerations of Materials**

When constructing new buildings or renovating old ones, it is essential to consider using materials that can be sourced sustainably and recycled after use. The extraction and treatment of these raw materials are taxing for the environment resulting in damage on both local and global scales. Recycling forms a critical element of the circular economy, and it is time for construction to become circular. Designing buildings with the circular economy in mind also sets a high standard for the longevity and robustness of the building elements used. Choosing long-lasting building materials that serve multiple purposes lowers the cost of renovating the buildings over time and ensures consistent performance.

iv **ICT Based Construction Resources Estimating and Control Tool**

Artificial neural network models have a methodology that can provide an economical and rapid means of assessing cost and time overruns on the estimated bills of quantities. Construction programmes for building projects at any stage of the construction process are recommended for built environment professionals and contractors' use.

v **New Construction Methods**

Modes and methods used by typical Nigerian contractors from pre- to post-construction stages vis-a-vis resources estimations, orderings, site receipts, selection, usage generated wastes, and disposals need review and upgrade into new methods.

vi **Consideration of Economic Principles in Building Designs**

The synergy between designers, materials, and component manufacturers with the central objective of ensuring that form and falsework materials and components can be exchanged between construction project sites. Therefore, sizes of forms can be standardized to encourage the evolution of construction activity-based entrepreneurs who deal for examples on items such as concrete moulds for lintel, beams, columns, and slabs.

vii **Economic Principles in Materials and Component Installations and Zero Waste Generation**

Training and retraining of Builders, construction managers, site supervisors and foremen and gang heads in resource management and control (materials and men). This will ensure almost a zero per cent waste minimization as off-cuts generation is reduced and reuse frequencies are increased, market sizes of materials and components are either used wholly or cut into modular sizes for multiple uses.

viii **Construction Companies to Maximize Positive Benefits and Minimize the use of the Negative Components**

Currently, the construction industry is making a profound impact on the environment; thus, it becomes imperative that companies maximize the positive benefits while minimizing the use of components that adversely affect the environment. Construction companies should ensure that both materials and manufacturing processes lead to sustainability in construction. These steps are good for the environment, as well as the company's profile and bottom line.

ix **Development of construction sites sustainability assessment system for the Nigeria construction industry**

Through its' building profession regulatory arm, that is, the Council of Registered Builders of Nigeria (CORBON), the government should develop a sustainability assessment system that can measure the sustainability of the contractor's methods of construction used on projects as well as the acceptable thresholds of sustainability (following the index presented in Figure 1.)

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COLLABORATIVE KNOWLEDGE MANAGEMENT' AN EMERGING THEME AMONG CONSTRUCTION FIRMS IN NIGERIA

Collaborative Knowledge Management' An Emerging Theme Among Construction Firms in Nigeria

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Abstract
The increasing pressure of cost and time reduction, delivering better projects and fighting ever-increasing challenges has made the effective use of intellectual capital even more important for construction firms. With these growing complexity comes an increasing need to understand how disciplines relate to each other and the value of collaboration. This research is aimed at assessing the drivers and barriers to collaborative knowledge management' as an emerging theme among construction firms in Nigeria. The research is an investigative study, in which a quantitative research method was used. The research used a purposive sampling technique that considered large building construction firms that captured in its management structure, the responsibilities of the key knowledge professionals at unit and departmental levels. These knowledge professionals were identified as Architects, Quantity Surveyors, Land Surveyors, Builders and Engineers, who are unit/departmental heads. Twenty-eight (28) firms involving the five (5) knowledge professionals in each firm participated in the research, giving 140 respondents. The Cronbach's coefficient alpha was used to check the internal consistency of the data, hence ascertaining the reliability of the instrument (above 0.8), while the content validity was conducted to ascertain the relevance of the research questions as well as the tools. The Kruskal-Wallis test which is the nonparametric equivalent of a one-way ANOVA was used for testing whether samples originate from the same distribution. The availability of Collaborative KM Software was identified as the most significant driver (MS=4.31). The research also classified the barriers of CKM into process and technological barriers, with the lack of awareness of Collaborative KM practices as the most significant process barrier (M=4.21) and Poor Internet Connectivity as the most significant technological barrier (4.26). The research concludes that that all the factors (drivers and barriers) identified have significant effect on the emergence of CKM as agreed by the various professional's groups that all the drivers identified have significant effect on the emergence of CKM. The research recommends the need for a nationwide public and professional awareness of the need for collaboration as well as CKM, which can begin from involvement of professional bodies to the enforcement of construction firms and other relevant key stakeholders. It also recommends that firms should create of a dedicated collaborative knowledge management software/platforms as well as the availability of good internet services as most collaborative activities are executed over the web.
Keywords: Collaboration, Knowledge Management, Construction firms, Professionals, Nigeria

INTRODUCTION

Construction firms has realised that the biggest asset it possess is knowledge and experience associated with its human capital (Kamara, Augenbroe, Anumba, Carrillo, 2002). The increasing pressure of cost and time reduction, delivering better projects and fighting ever increasing environmental challenges has made the effective use of intellectual capital even more important. Construction firms embark on projects that are interdisciplinary and multi-agent in behavioural processes, which continue to access, create knowledge and apply it to practical work to realize the value of knowledge. Most construction projects are unique and fast moving, so work organizations are rather dynamic as they must be restructured again and again with different professionals, management, materials, equipment, and crews (Sauer, Liu and Johnston, 2001). Traditional pattern of construction projects lead to the fragmentation which made communication an obstacle among all the professionals (Xin and Jiming, 2010). In the recent times, construction projects have turned into a more complicated, dynamic and interactive scenario. Construction firms are constantly required to speed-up reflective decision-makings on time. With this growing complexity comes an increasing need to understand how disciplines relate to each other especially with the increased intricacy of projects there is a growing need for collaboration (Bhatla & Leite, 2012; Dvir et al., 2003; Eastman et al., 2011). Knowledge therefore is noted to be one of the most important resources contributing towards managerial decision-making and enhancing the competitive advantage of construction firms in carrying out such projects (Carrillo, 2004 and Nonaka, & Takeuchi, 1995, Almahmoud and Doloi, 2013). To achieve the

construction firm goals of a typical construction project, more than one construction professional is involved (Chinyio and Olomolaiye, 2010). According to Oke, Ogunsemi, Adeeko (2013) in a developing country like Nigeria, it is constant to have architects, engineers, builders, quantity surveyors and land surveyors as primary construction professionals on contracted building projects. It is known that construction professionals commissioned on construction projects are tied to the goal of successful project delivery, especially in terms of cost, time and quality (Idris, 2017). This suggests a shared area of interest among the professionals.

Knowledge has been described as information, which has been used and becomes a part of a person's knowledge-based experience and behavioural patterns (Kaklauskas, Zavadskas, & Gargasaitė 2004, DeTienne, & Jensen, 2001). Individuals as well as professionals have different knowledge-based capacity and experience, thus leading to different problem solving approaches and decision-making. When choosing a construction professional, knowledge and experience are significant (Ogunlana, Siddiqui, Yisa, Olomolaiye, 2001). According to Dave, and Koskela (2009), social interaction/collaboration between workers is one of the most appropriate ways to capture tacit (experiential) knowledge in construction firms. Professional must therefore be capable of knowing how to synchronize, use, manage, and utilize such knowledge in a project.

According to Muntean, (2012), Collaboration on the other hand represents a strategic alternative to the monolithic approach to business development and competition. It involves a different approach to business – focused on managing business relationships between people, within or without groups, and within and between organizations. In the present global economy, strongly influenced by IT (information technology) and information systems evolution, the modern organizations try to face the challenges by adjusting their strategies and restructuring their activities, for aligning them to the new economy requirements. It is certain, that the enterprise's performance will depend on the capacity to sustain collaborative work. It is obvious that, all collaborative environments (workgroups, practice communities, collaborative enterprises) are based on knowledge, and between collaboration and knowledge management (KM) there is a strong interdependence. Collaboration may be seen as the combination of communication, coordination and cooperation at the total life-cycle of construction project (Xin and Jiming, 2010). Communication is related to the exchange of messages and information among people, coordination is related to the management of people their activities and resources, and cooperation is related to the production taking place on a shared space. Collaboration technology typically focuses on collaboration and group processes (cooperation, communication, coordination and coproduction). Knowledge Management (KM) technology typically focuses on content (creation, storage, sharing and use of data, information and knowledge). Yet, to achieve their common goals, teams and organizations need both KM and collaboration technology to make that more effective and efficient. Therefore, collaborative knowledge management (CKM) is considered as a process of collective resolution of problems where it is useful to memorize the process of making collective decision and to structure the group interactions to facilitate problem solving and sharing of ideas (Lewkowicz, 2000). Understanding that collaborative knowledge management deals with the management of both organisational and personal knowledge, there is the need to harness this potential. Wasko and Faraj (2000) suggest that knowledge is a private property that is exchanged in the expectation of a commensurable return. Hall (2003) also argues that knowledge is a private commodity and it is up to the owner to decide whether to share it or not. To entice people to share their knowledge as part of a social exchange transaction, they need to be persuaded it is worth doing so.

Over the last century, the view on the design and implementation of collaborative solutions has shifted from a more technology driven perspective in general to a more sociotechnical perspective used at the turn of the last century (Dix, 2017). This shift moves the focus from the technology to the people and the organizational context in which the technology is implemented in and as such moves towards a more holistic perspective. The sociotechnical system approach focuses on describing and documenting the possible as well as the actual impact of the introduction of a specific tool/system/technology in an organization (Johannesson & Perjons, 2014; Sackey, Tuuli, & Dainty, 2014). This kind of documentation also helps analysing the difficulties that are faced when implementing the tool/system/technology. As communication and collaboration are inherently social activities common in construction and as such become part of a

sociotechnical system (Sackey et al., 2014), this becomes important in the development of tool/system/technology supporting these actions. Chien Wu, & Huang (2014) identified a number of challenges in construction when implementing new tool/system/technology, ranging from financial, management related and personnel related to technical risk factors (Chien et al., 2014). These factors can manifest themselves in expectations from the personnel to challenges in compatibility of the tool/system/technology with regards to current ways of working (Davies & Harty, 2013). The success of implementations of tool/system/technology in construction has mainly been research from a tool/system/technology push view (Hartmann et al., 2012; Xue et al., 2012). tool/system/technology push is defined as the development of new tool/system/technology that offers a business process change from a tool/system/technology perspective in contrast to a demand pull where demand drives the development (Chidamber & Kon, 1994; Hartmann et al., 2012) The sociotechnical system view helps consider not just the implementation of the technology tool/system/technology, but the environment that creates the context for the implementation as well, which is the management of construction firms (Arayici et al., 2011). Therefore this research in developing a framework for collaboration, considers the management, process, people and Technology as an analytical frame.

The assessment, process, challenges etc. of adopting knowledge management in construction management are well documented, as there are a great wealth of existing literature (Anumba, Bouchlaghem, Whyte, Duke (2000), El-Gohary (2008), Lu and Issa (2005), Zhang and Tiong (2003), to list a few). In the emerging knowledge-based economy, the essence of collaboration becomes the exchange and integration of knowledge. Thus, Knowledge management has gone beyond the integration and sharing of data to the integration of people, processes and technology within and between organizations in the implementation of project decisions and hence successful project delivery (Quirchmayr and Tagg 2002).
The research strictly focused on respondents that are knowledge workers in construction firms as described by Egbu, and Robinson, (2005) as being responsible for providing important skills and knowledge in the construction industry. These workers are unit heads in the firm who are expected to be knowledgeable about the strategic choices of their firms with regard to collaboration and hence, competitive advantage as identified by Ibem, Aduwo, Uwakonye, Tunji-Olayeni, Ayo-Vaughan (2018).. A major characteristic of growing cities and city centers is the high demand for infrastructure (Ogunlana, Li and Sukhera, 2003). Hence, the research will cover large building construction firms in Abuja, the Federal Capital Territory of Nigeria, with emphasis on the management of temporary organizational setting (project based).

Literature Review

The Nature of the Construction Industry in Nigeria

The Nigerian construction market is reported to be among the largest construction markets in Africa, (Sunday, Olubola, & Hakeem, 2013). According to forecast by (Global, 2010) Nigeria's construction industry is growing fast and is likely to grow very large over the next decade. According to the Foci Report (2012), the Nigerian construction market is dominated by foreign companies, which is similar to most African Countries. A large number of these major constructing firms in Nigeria are subsidiaries of North American, European and Asian construction firms.
According to Onugu (2005) and AbdulAzeez (2012) firms can be classified into four major categories as seen: Micro Enterprise, Small Enterprise, Medium Enterprise and Large Enterprise.
The word construction project is generally understood to mean a series of tasks and actions by human or machineries which consume not only capital but also firm resources to build building or achieve specific objectives being planned earlier (Hanafi & Nawi, 2016). Construction projects may come in all sizes and shapes from more complex projects to smaller and simple ones. No matter the type or size of project, there are some essential components that a construction firm must get it right in order to accomplish a remarkable result. Whether a project is about enhancing a current item or administration, overseeing change or executing another system, the same essential contemplation are required when overseeing ventures. Several factors are important to be considered in determining the level of success of a project (Hanafi et al., 2016). One of such factors is Overhead costs (Chilipunde, 2010: Ogunde, et al., 2016).

The Construction Professionals

Given the focus on how the construction professionals' roles and identities are formed in construction

projects, the power of position, and interaction between, actors, structures and agencies is viewed through a practice lens (Gheradi, 2009). More so, to achieve the goals of a typical construction project, more than one construction professional is involved (Chinyio and Olomolaiye, 2010). According to Owolabi and Olatunji (2014), the list of the professionals actively involved in the construction industry includes but not limited to, Architects, Builders, Estate surveyors and valuers, Land surveyors, Quantity surveyors, Town planners, Civil, Electrical, Mechanical and Structural Engineers this also agrees with Oke et al (2012).

The Evolution of Knowledge Management to Collaborative Knowledge Management

CKM is considered as a process of collective resolution of problems where it is useful to memorize the process of making collective decision and to structure the group interactions to facilitate problem solving and sharing of ideas (Lewkowicz, 2000).

Table 1: Evolution of Knowledge Management to Collaborative Knowledge Management

Evolution Period: Main Focus	**Key Theme & focused issues**	**Driving Forces**	**Examples of KM Systems**
Development: Within an organization (1960s – 1970s) Know-what	The conceptual foundations of KM - Resource based view of the firm (Penrose, 1959) - Knowledge classification (Polanyi, 1962) - Organizational learning models (Argyris, 1976)	- Increased number of large organizations - Transaction processing systems and manufacturing automation	- Expert systems & knowledge-based systems in research labs (e.g., DENDRAL-1971; MYCIN-1975; HACKER-1975)
Consolidation: Beyond a single organization (1980s – early 1990s) Know-how	Competitive strategic framework - Organizational design and strategic fit (Mintzberg, 1980) - Strategic capability of the firm (Prahalad & Cowin, 1983)	- Globalization - Shift toward service and knowledge based organizations	- Operational uses of DSS and GDSS - Computer Supported Cooperative Work (CSCW) (Kraemer & King, 1998) - Total quality management
Extension: Internet-based (mid 1995s - onwards) Know-where	Internet based applications & systems - Increased attention to knowledge and intellectual capital management - Industry practice and prescriptions for effective KM (Davenport, Long, & Beers, 1998)	- Web applications (Web 1.0) - Business process reengineering - Emergence of information economy	- Business intelligence - Data mining & data warehouse technologies - Workflow management systems
Elaboration: Web 2.0 & collaboration (late 1990s	Collaborative knowledge management - Conversational knowledge management	- Web service platform - People power, social networking, collective	- Internet based KM Services (e.g., www.askme.com, 1999)

onwards)	- Web-based group work management	intelligence (Web 2.0)	- Wikis (1995), Blogs (approximately 1994)
E-Collaboration	- Distributed collaborative design	- Mobile technologies	- Intelligent and mobile agent systems
	- Distributed collaborative authoring		

Kim and Yang, (2010)

Factors Affecting the Adoption of CKM in Construction Firms

According to Abubakar (2012) in the factors affecting the adoption of Building information modeling in Nigeria, identified the following factors which were similarly identified by Ruikar *et al;* (2006) and subsequently adapted in this research. The choice of these factors in this research can be attributed to the relationship between BIM and CKM as emerging themes in the construction industry and their large dependence on technology, despite the fact that BIM seems to be gaining more awareness; the factors under study was divided into two; those that facilitate the adoption called the drivers and others that hinder the adoption called barriers. The barriers were further divided into two: process and technological barrier. These can be seen below as:

Drivers/Facilitators and Barriers

According to Tolga, Attila and Deniz (2008), Innovation is a key to competitive advantage in the construction industry, enabling firms to contend with major changes occurring in the market and to achieve the objectives in a specific project or over a range of projects. Accordingly, innovation studies have become an established part of construction management discipline with respect to the academic research undertaken and to the wide application in practice. However, knowledge base in the discipline is still developing and there is a genuine need to identify the research trends and neglected areas in the literature. This research attempts to overview and organise the many innovation drivers and barriers that have been identified in construction innovation literature and classified them as see below:

The divers are seen as

1. Government support through legislation
2. Company's interest in the involvement of collaborative KM practices in their projects
3. Collaborative KM Software availability
4. Availability of well trained professionals to handle the Collaborative KM process Cooperation and commitment of professional bodies to its implementation
5. Collaborative Procurement methods

The barriers were classified into Process Barriers and technological barriers as identified by Abubakar (2012). The process barriers are seen below as:

1. Lack of Awareness of Collaborative KM practices
2. Lack of knowledgeable and experienced Knowledge professionals
3. High Cost of Training
4. Lack of Enabling Environment (Government policies and legislations) to guide implementation
5. Legal and Contractual Constraints
6. Lack of Trained Professionals to handle the tools
7. Social and Habitual Resistance to Change
8. No proof of financial benefits
9. Firms are not encouraging the use of collaborative KM tools on projects

The Technology Barriers are seen below as:

1. High Cost of Collaborative/Integrated KM software/Models for all professionals
2. Lack of Standards to Guide Implementation
3. Poor Internet Connectivity
4. Frequent Power Failure

Research Methodology

According to Creswell (2003), Fellow and Lui (2015) research methods can be classified into two broad classifications (qualitative and quantitative). Hanson (2008), however, argues that these sociological

approaches have converged. Certainly, one can be integrated within the other (e.g. Haynes et al., 2007) in order to strengthen research design (Patton, 1990). In qualitative research, an exploration of the subject is undertaken, sometimes without prior formulations – the object may be to gain understanding and collect information and data such that theories will emerge and so, tends to be exploratory. On the other hand the quantitative method approaches adopt 'scientific method' in which initial study of theory and literature yields precise aims and objectives with proposition (s) and hypotheses to be tested – conjecture and refutation may be adopted.

Data Collection Techniques

The primary data was obtained through field survey, using a structured questionnaire. According to Joshi Kale, Chandel & Pal (2015), the need to quantify the thing, which cannot be measured through conventional measurement techniques, has necessitated the transformation of an individual's subjectivity into an objective reality. Attitude, perceptions and opinions are such qualitative attributes amenable for quantitative transformation due to above mention reason. Qualitative research techniques do try to compensate, by depicting the complexity of human thoughts, feelings and outlooks through several social science techniques, still the quantification of these traits remains a requirement and that's how psychometric techniques come into picture. The Likert which gives definition to the psychometric techniques, is referred to as an "Evaluative continua" scales as proposed by Fowler, (2002), which are numerical or adjectival scales, where, multiple choice questions should ideally offer five to seven (5-7) response options, ranging from strongly disagree to strongly agree as the case might be. There are two (2) major constructional diversities of a Likert scale as the analytical treatment and interpretation with Likert scale largely depends upon these diversities.-Symmetric versus asymmetric Likert scale- If the position of neutrality (neutral/don't know) lies exactly in between two extremes of strongly disagree (SD) to strongly agree (SA), it provides independence to a participant to choose any response in a balanced and symmetric way in either directions (Joshi and Pal, 2015). This construction is captured in the five (5) point likert scale as a symmetric scale, against the seven (7) and ten (10) point likert scale, which are considered asymmetric.

Population Size

The Population for the study are registered construction firms within the Federal Capital Territory (FCT), this is due to the large concentration of construction firms within the region. The presence of a large volume of construction activities, have driven most construction firms in the country to establish a branch within the FCT. The respondents are the knowledge workers/ in the construction industry such as Engineers, Quantity Surveyors, Architects, Land Surveyors and Builders in those companies, especially those who head a unit where firm policies and decisions are made, as they are expected to know how to respond to the questions being asked and identify most of the facts that lead to reliable conclusions. The population of construction firms were obtained from Corporate Affairs Commission (CAC) as 3,126 registered Construction companies in the FCT of Nigeria, and a further classification was conducted on the basis of the firm's size, specialization and most importantly the availability of unit/departments that captures the knowledge professionals.

Sample Size and Sampling Technique

The sampling is concerned with the selection of a subset of individual, from within a statistical population to estimate characteristic of the whole population. The objective of sampling is to provide a practical means of enabling the data collection and processing components of research to be carried out whilst ensuring that the sample provides a good representation of the population, Fellow and Lui (2015).

According to Priscilla (2005), determination of sample size depends on five factors:

1. Desired degree of precision
2. Statistical power required
3. Ability of the researcher to gain access to the study subjects
4. Degree to which the population can be stratified
5. Selection of the relevant units of analysis

The following are the classification of sampling techniques as identified by Charles and Fen (2007) as: Probability Sampling, Purposive Sampling, Convenience Sampling, Mixed Methods Sampling. The research

The research focused on the purposive sampling technique. The purposive sampling technique, also called judgment sampling, is the deliberate choice of a participant due to the qualities the participant possesses

(Tongco, 2007).
The following are the classifications of purposive sampling techniques: Sampling to Achieve Representativeness or Comparability, Sampling Special or Unique Cases, Sequential Sampling, and Sampling Using Combinations of Purposive Techniques as identified by Charles and Fen (2007): Kuzel (1992), LeCompte and Preissle (1993), Miles and Huberman (1994), and Patton (2002). The research used the Multiple Purposive sampling Techniques, considering the following:

i. **Homogeneous Sampling**: The choice of a homogeneous population consisting of companies with departments/ units for the knowledge professionals such as Builders, quantity surveyors, Architects, Land surveyors and Engineers.
ii. **Reputational Case Sampling**: The firms involved are large construction firms with reputation
iii. **Revelatory Case Sampling**: the nature of the research is to reveal the true state of construction firms with respect to their readiness for the adoption of collaborative knowledge management as well as the need for a framework.
iv. **Confirming and Disconfirming Cases**: The nature of the research is also tied to Confirming and Disconfirming the state of the construction firms

Therefore, considering the population distribution of these construction firms (Large building construction firms) within the study area (Abuja) and the availability of structured units/departments that captures the knowledge professionals in these firms, the research identified a population of thirty two (32) building construction firm. However, the research could only effectively access twenty eight (28) construction firms.

Questionnaire Design
Good questionnaire design is crucial (Bulmer, 2004; Creswell, 2003; de Vaus, 2002; McGuirk and O'Neill, 2005; Oppenheim, 1992; Parfitt, 2005; Patton, 1990; Sarantakos, 2005) in order to generate data conducive to the goals of the research. Questionnaire format, sequence and wording, the inclusion of classification, behavioural, knowledge and perception questions, and questionnaire length and output, was considered to ensure reliability, validity and sustained engagement of the participant. The principal requirement of questionnaire format is that questions are sequenced in a logical order, allowing a smooth transition from one topic to the next (Sarantakos, 2005). This will ensure that participants understand the purpose of the research and they will carefully answer questions to the end of the survey (McGuirk and O'Neill, 2005).
The nature of the questionnaire as shown in figure 3.1 showed that the questionnaires were both open ended and close ended. Every section had provision for both closed and open ended questions. The close ended questions were multiple choiced questions, reflected in the five point likert scale from section two, the multiple choiced questions in the likert scale provides determined choices from previous literatures.

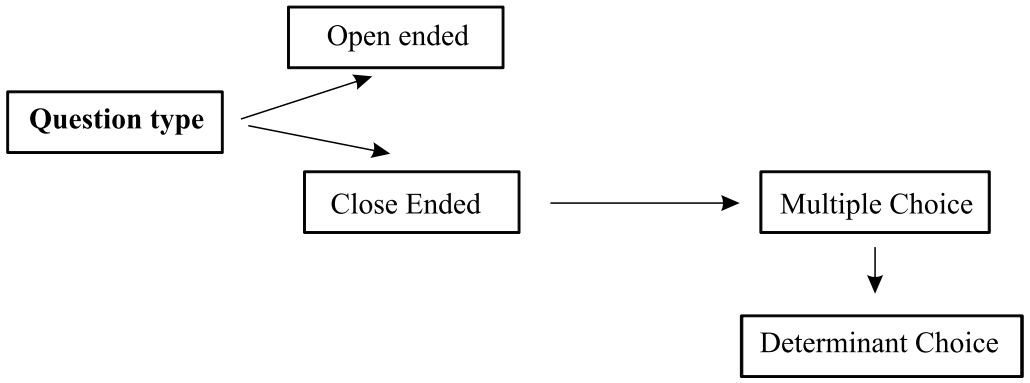


Figure 1: Questionnaire Design
The questionnaire is designed in such a way that the knowledge workers can properly articulate and respond accordingly for their firms. The questions are coined, and adapted from existing literatures that are of relevance to this research. The research implored an "Evaluative continua" scales as proposed by Fowler, (2002), which are numerical or adjectival scales, where, multiple-choice questions should ideally offer five to seven (5-7) response options, ranging from strongly disagree to strongly agree as the case might be.

Reliability test

The most fundamental requirement of a research instrument is that it be reliable in the sense that it would yield consistent results if used repeatedly under the same conditions to test the same participants and is therefore relatively unaffected by errors of measurement. Most researchers have focused on internal consistency, as measured by Cronbach's coefficient alpha (Cronbach, 1951). By conventional psychometric criteria, any values of coefficient alpha below .6 are regarded as poor, even for relatively heterogeneous constructs (e.g., Robinson et al., 1991). Indeed, for measures of individual differences in cognitive processing, more stringent standards of internal consistency are expected (Childers et al., 1985; McKelvie, 1994). Administering these questionnaires on a single occasion is obviously much less arduous than locating the same individuals for testing on two separate occasions. It is therefore not surprising that fewer researchers have directly evaluated the test–retest reliability of these instruments.

Therefore the research implored the use of the internal consistency method using the Cronbach's coefficient alpha (Clarke, 1986; Entwistle and Ramsden, 1983; Watkins and Hattie, 1980). The internal consistency of the constituent scales of the questionnaire appears to as 0.853 indicating that the data is internally consistent thereby reliable for the study as seen in figure 3.2

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Fugre 2: Cronbach's coefficient alpha
Source: Cronbach, (1951)

Validity test

The other fundamental requirement of a research instrument is that it be valid in the sense that it measures the trait or traits that it purports to measure (Biggs *et al*., 2001, Richardson, 2004). Validity is arguably the most important criteria for the quality of a test. The research focused on the content validity, where the questions were subjected to professionals in both the academia and practice to validate the appropriateness of the questions as well as the tools for the research.

Data Analysis Procedure and Presentation

The analyses of data and discussion of results were based on the categories of data. Analysis of the drivers and barriers was done using descriptive statistics such as Means Score (MS) and Standard Deviation, a non-parametric Kruskal-Wallis test.

The choice of the Kruskal-Wallis test (Kruskal and Wallis 1952, 1953) which is the nonparametric equivalent of a one-way ANOVA is as a result of its use for testing whether samples originate from the same distribution. The Kruskal-Wallis test does not make assumptions about normality. However, it assumes that the observations in each group come from populations with the same shape of distribution and that the samples are random and independent. This test is a more flexible, convenient, easy to use and powerful technique similar to a parametric one-way ANOVA. For ease, Statistical Package for Social Sciences (SPSS) computer package will be used in conducting the analysis.

Nonparametric methods require less stringent assumptions than do their parametric counterparts; on the other hand, they also use less information from the data. When the assumptions of the parametric tests are not met, the nonparametric tests are the ones to be used.

The Kruskal-Wallis test is useful as a general nonparametric test for comparing more than two independent samples. It can be used to test whether such samples come from the same distribution. This test is powerful alternative to the one-way analysis of variance. Nonparametric ANOVA has no assumption of normality of

random error but the independence of random error is required. If the Kruskal-Wallis statistic is significant, the nonparametric multiple comparison tests are useful methods for further analysis.

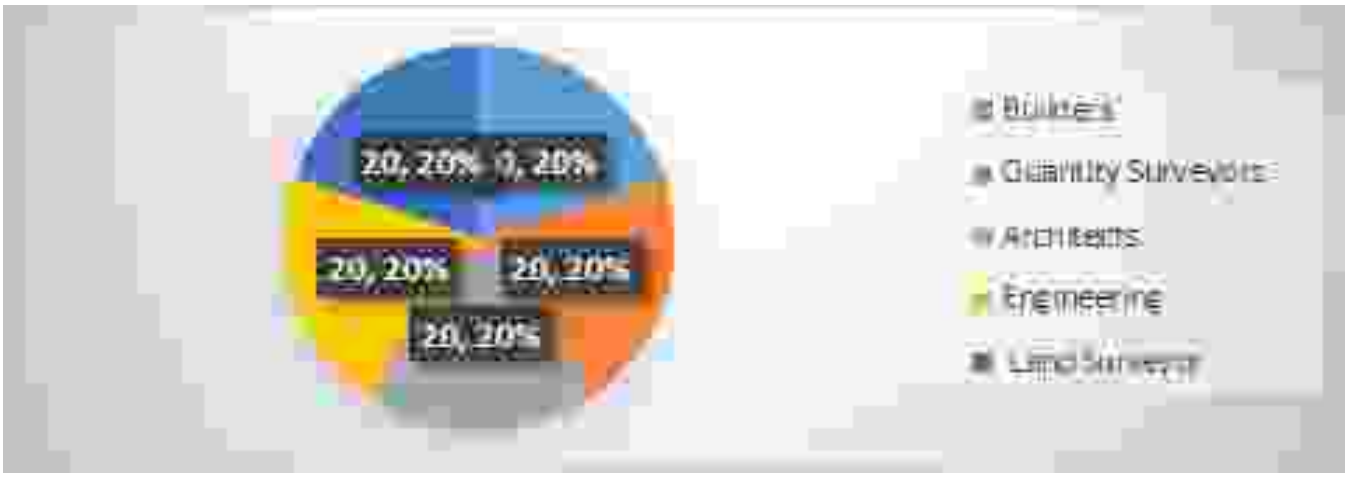
DATA PRESENTATION, ANALYSIS, AND DISCUSSIONS

Preliminary Research Data

As earlier mentioned in the chapter three (3), a total of twenty eight (28) construction firms were selected for the study with the knowledge professionals as a critical criteria for their selection as identified by Egbu, and Robinson, (2005) and Oke *et al*. (2013). The results of the findings are presented in the subsections below.
The data were collected from Abuja, focusing on the various construction firms within the region and the following construction knowledge professionals as the respondents: Engineers, Quantity Surveyors, Land surveyors, Architects and Builders.

Distribution of respondents according to Profession

From figure 3, it can be seen that all the five (5) knowledge professionals in the twenty eight (28) construction firms were evenly distributed. One professional each from the construction firm, thereby forming a 20% even distribution of the population for each of the professionals.
Figure 3: Distribution of respondents according to Profession



Source: Field survey (2019)

Factors Affecting the Implementation of CKM in Construction Firms

The section B of the questionnaire sought the opinion of the respondents as regards the existence of factors that affect the implementation of CKM in construction firms. The factors identified from literature were of two categories; those that facilitate the adoption called the drivers and others that hinder the adoption called barriers. The responses are as follows:

Drivers/Facilitators of CKM Adoption in Construction firms

The Kruskal Wallis result for the test of significant difference within and between the groups of professionals in the firms on the existence of drivers/facilitators of CKM adoption in the construction firms is presented in Table 2.
Table 2: Kruskal Wallis Test result on the Drivers/Facilitators of CKM adoption

Professionals	N	Mean Rank	Test	
Builder	28	72.32	Kruskal-Wallis H	0.106
Engineer	28	70.59	Df	4
Land Surveyor	28	68.86	P-value	0.999
Architect	28	70.36		
Quantity Surveyor	28	70.38		
Total	140			

Source: Field survey (2019)

The mean rank ranged between 72.38 and 68.86 and the Chi-square value (Kruskal-Wallis H) was obtained to be 0.106 which is less than the critical value (7.779) and the p-value (0.999) is greater than 0.05. The overall results indicated no significant difference within and between all groups of knowledge professionals in the construction firms in terms of agreement with the existence of drivers/facilitators of CKM adoption in the construction firms. However, this is not to say that they are all at the same level of agreement, some variations still exist, but they are not statistically significant.

Table 3 Descriptive Statistics of the Drivers of CKM Adoption

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Government support through legislation	140	4	1	5	4.00	.080	.945	.892
Company's interest in the involvement of collaborative KM practices in their projects	140	4	1	5	4.14	.080	.949	.900
Collaborative KM Software availability	140	4	1	5	4.31	.075	.890	.793
Availability of well trained professionals to handle the Collaborative KM process	140	4	1	5	4.11	.084	.997	.994
Cooperation and commitment of professional bodies to its implementation	140	4	1	5	4.19	.074	.872	.761
Collaborative Procurement methods	140	4	1	5	3.92	.090	1.060	1.123

Source: Field survey (2019)

Considering the drivers individually, from the table of descriptive statistics results (shown in Table 3) revealed 'Collaborative KM Software availability' and 'cooperation and commitment of professional bodies to its implementation' as the most important drivers of CKM adoption in the Nigerian construction industry with mean scores of 4.31 and 4.19 respectively. 'Company's interest in the involvement of collaborative KM practices in their projects' and 'Availability of well trained professionals to handle the Collaborative KM process' also stands out as important drivers with mean score of 4.14 and 4.11 respectively.' Collaborative Procurement methods' was least with mean score of 3.92, but also considered an important driver.

It can be resolved here that the subjects of Collaborative KM Software availability and the cooperation and commitment of professional bodies the implementation of CKM are the most important drivers of CKM adoption as opined by the respondents. This reflects the idea propagated in the Rethinking Construction document of the United Kingdom in 2008 about software development for the transformation of the UK construction industry.

Moreover, the company's interest in the adoption is another major facilitator since the company are the executors of construction projects and their support for any innovation in the construction process has a far reaching effect to the successful implementation of such innovation. The government as the regulator of affairs has a vital role also to play by enacting legislations that mandate or govern the implementation of initiatives such as the use of CKM in construction.

Barriers of CKM Adoption in Construction Firms

The barriers to the adoption of CKM in the Nigerian construction industry are considered under two headings as classified by Eastman *et al*; (2011) i.e. process and technology barriers.

Table 4: Kruskal Wallis Test result on the Barriers of CKM adoption

	Professionals	N	Mean Rank	Test	Process Barriers
Process Barriers	Builder	28	66.55	Kruskal-Wallis H	1.840
	Engineer	28	64.09	df	4
	Land Surveyor	28	76.36	Asymp. Sig.	.765
	Architect	28	73.86		
	Quantity Surveyor	28	71.64		
	Total	140			

Source: Field survey (2019)

The mean rank ranged between 71.64 and 66.55 and the Chi-square value (Kruskal-Wallis H) was obtained to be 1.840 which is less than the critical value (7.779) and the p-value(0.765) is greater than 0.05. The overall results indicated no significant difference within and between all groups of knowledge professionals in the construction firms in terms of agreement with the existence of process barriers to CKM adoption in the construction firms. However, this is not to say that they are all at the same level of agreement, some variations still exist, but they are not statistically significant.

Table 5: Descriptive Statistics of Process barriers to the adoption of CKM in construction firms

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Lack of Awareness of Collaborative KM practices	140	4	1	5	4.21	.075	.886	.784
Lack of knowledgeable and experienced Knowledge professionals.	140	4	1	5	4.11	.079	.935	.873
High Cost of Training	140	4	1	5	4.11	.077	.914	.836
Lack of Enabling Environment (Government policies and legislations) to guide implementation	140	4	1	5	4.15	.072	.848	.718
Legal and Contractual Constraints	140	4	1	5	4.17	.066	.777	.603
Lack of Trained Professionals to handle the tools	140	4	1	5	4.16	.078	.926	.858
Social and Habitual Resistance to Change	140	4.00	1.00	5.00	3.96	.07779	.92036	.847
No proof of financial benefits	140	3.00	2.00	5.00	4.10	.06515	.77087	.594
Firms are not encouraging the use of collaborative KM tools on projects	140	4.00	1.00	5.00	4.04	.07910	.93587	.876
Valid N (listwise)	140							

Source: Field survey (2019)

Considering the process barriers individually, from the table of descriptive statistics results (shown in Table 5) revealed 'Lack of Awareness of Collaborative KM practices', 'Legal and Contractual Constraints' and 'Lack of Trained Professionals to handle the tools' as the most important process barriers to CKM adoption in the Nigerian construction industry with mean scores of 4.21, 4.17 and 4.16 respectively. 'Lack of Enabling Environment (Government policies and legislations) to guide implementation', 'Lack of knowledgeable and experienced Knowledge professionals' and 'High Cost of Training' also stands out as important process barriers with mean score of 4.15, 4.11 and 4.11 respectively.' Social and Habitual Resistance to Change' was least with mean score of 3.96, but also considered an important process barrier.

Table 6: Kruskal-Wallis Test of Technological barriers to the adoption of CKM in construction firms

	Professionals	N	Mean Rank	Test	
Technological Barriers	Builder	28	62.45	Kruskal-Wallis H	1.620
	Engineer	28	74.88	df	4
	Land Surveyor	28	71.82	Asymp. Sig.	.805
	Architect	28	71.02		
	Quantity Surveyor	28	72.34		
	Total	140			

Source: Field survey (2019)

Considering the process barriers individually, from the table of descriptive statistics results (shown in Table 4.4) revealed 'Lack of Awareness of Collaborative KM practices', 'Legal and Contractual Constraints' and 'Lack of Trained Professionals to handle the tools' as the most important process barriers to CKM adoption in the Nigerian construction industry with mean scores of 4.21, 4.17 and 4.16 respectively. 'Lack of Enabling Environment (Government policies and legislations) to guide implementation', 'Lack of knowledgeable and experienced Knowledge professionals' and 'High Cost of Training' also stands out as important process barriers with mean score of 4.15, 4.11 and 4.11 respectively.' Social and Habitual Resistance to Change' was least with mean score of 3.96, but also considered an important process barrier.

Table 7: Descriptive Statistics of Technological barriers to the adoption of CKM in construction firms

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
High Cost of Collaborative/Integrated KM software/Models for all professionals	140	4	1	5	4.14	.083	.983	.967
Lack of Standards to Guide Implementation	140	4	1	5	4.13	.082	.973	.947
Poor Internet Connectivity	140	4	1	5	4.26	.067	.790	.624
Frequent Power Failure	140	4	1	5	4.05	.077	.908	.825
Valid N (listwise)	140							

Source: Field survey (2019)

Considering the technological barriers individually, from the table of descriptive statistics results (shown in Table 7) revealed 'Poor Internet Connectivity' is the most important process barriers to CKM adoption in the Nigerian construction industry with mean scores of 4.26. 'High Cost of Collaborative/Integrated KM software/Models for all professionals and 'Lack of Standards to Guide Implementation' also stand out as important Process barriers with mean score of 4.14 and 4.13 respectively. 'Frequent Power Failure' was least with mean score of 4.05, but also considered an important technological barrier.

It is important to identify the general agreement of the professionals on the subject matter, as each professional might tend to have a perspective based on the uniqueness of professional specialization, which agrees with Abubakar (2012), Idris (2017). From the six (6) drivers identified, it is obvious that all of them work towards the Facilitation of CKM Adoption in Construction firm. However, the availability of Collaborative KM Software is considered the most significant, which agrees with Stefano, Giovanna, Gobbi and Nancy (2011) who identified the need for a dedicated CKM software that is unique to a specific field. On the other hand, the lack of awareness of CKM practices has posed a major process barrier to application of CKM as also identified by Kim and Yan (2010). Poor Internet Connectivity was identified as a major technological barrier and according to Adomi (2005), it has served as a major drawback to technological adoption and adaptation in Nigeria and Africa at large.

Conclusion and Recommendation

The research concludes based on the agreement of the various professional's groups that all the drivers identified have significant effect on the emergence of CKM, with the availability of Collaborative KM

Software as the most significant driver. The research in identifying the barriers to CKM adoption as identified by the various professional groups of the firms indicated that all the elemental factors captured under the process and technological barriers were significant. The lack of awareness of Collaborative KM practices is the most significant process barrier and Poor Internet Connectivity is the most significant technological barrier.

It is important to note that the world is gradually migrating from the traditional concept of knowledge management to integrated knowledge management and hence, collaborative knowledge management. Therefore, the need for a nationwide public and professional awareness of the need for collaboration as well as CKM, which can begin from involvement of professional bodies to the enforcement of construction firms and other relevant key stakeholders. One major role construction firms will also play will be to provide good internet services to their staffs to encourage collaborative knowledge shearing and building as the world as we know it is consistently evolving. Construction firms as well as the built industry should employ the services of web based professionals to design and aid in the application of a dedicated and flexible web based collaborative knowledge management system/platform for knowledge professionals in construction firms to boost knowledge integration and hence collaboration.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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DESIGN PRINCIPLES AND CONSTRUCTION METHODS OF FOUNDATION SYSTEMS FOR HIGH-RISE BUILDINGS

Design Principles and Construction Methods of Foundation Systems for High-Rise Buildings

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ABSTRACT

Foundation is an important part of a structure and functions to transmit the load from a structure ultimately to the soil or underlying bedrock. The choice of foundation depends on many factors among which is the type and nature of the building. High-rise buildings, by their nature and size, are heavy and complex and therefore require special consideration in design and construction. The construction of high-rise buildings has evolved, with increasing heights and sizes. It was projected that there would be 200 buildings all over the world exceeding 300 m in height by 2020. These factors, among others, present new challenges to practitioners in the construction industry with respect to, choice, designs (structural and geotechnic) and construction of the requisite foundations. This paper presents the foundation types that are suitable for high-rise buildings, their design principles and briefly describes the methods used in their construction. The paper concludes that since both structural and geotechnical loads are necessary for the foundation design and construction, detailed geotechnical investigation for foundation design in high rise buildings is indispensable. Also, in suitable soil types, the piled raft foundation is shown to offer better economy as foundation system for high rise buildings. It has been recommended, among others, that detailed geotechnical investigation should precede the design and construction of high-rise buildings. This is because the foundation soil parameters are very important factors considered in the design and construction of the foundations.

Key Words: Construction, design, foundation systems, high-rise buildings, geotechnic investigation.

INTRODUCTION

Foundation is a very crucial component of any physical structure (buildings, bridges, transmission masts etc.). It consists of the substructure footing and the surrounding soil within its zone of influence according to Das (2009). Foundation links the structure to the earth and functions to transmit the various loads acting on the structure ultimately to the soil or the underlying bedrock (Dey and Reddy, 2014). In performing this function, it should not fail or cause excessive settlement of the structure. For structures in the built environment, it is important to construct a firm base which supports the superstructure safely under envisaged service conditions without decay or collapse. It is therefore very important to ascertain the type of foundation, the type of materials for the foundation as well as the design method for any particular structure. The wrong choice of foundation, use of inappropriate material, wrong assumptions in design and unsuitable construction methods in foundation expose the structure to high risk of failure (Magar, Kudtarkar, Pachpohe and Nagargoje, 2020).

The past few decades have witnessed a significant increase in the rate of construction of high-rise buildings. The construction of high-rise buildings has evolved over the years, with many of them in recent times reaching hundreds of metres in height. CTBUH (2011) projected that by 2020, there would be about 200 buildings that have heights exceeding 300 metres. This has been due to space constraints in some places and higher population density (Katzenbach, Leppla, and Choudhury, 2016) that will make the developer to want to have more usable space within the available area; while some build them for prestige. Some of these structures are also located in areas where the subsoil is comparatively soft. These factors, therefore, present new challenges to practitioners in the construction industry with respect to designs (structural and geotechnic) and construction of the requisite foundations. There are different types of foundation used in different types of structures, with designs and configurations specific to each one of them that will make the structure to be safe and durable. This implies that there are different types of foundation that are used for bungalows with low-rise buildings, and high-rise buildings. With the increase in the number of high-rise buildings, as well as the necessity to construct these buildings in difficult terrains, it is important to examine

the possible options available in the choice, design and construction of foundations for this class of buildings. The aim of this paper is to present the foundation types that are suitable for high-rise buildings, the design principles and describe the methods used in their construction. This with the view to aiding practitioners in the building profession in making knowledgeable choices with respect to foundation types, design procedures and construction methods in high-rise buildings. After all, the number of high-rise buildings is increasing in Nigeria, and there may be the need too, to internationalise one's practice.

HIGH-RISE BUILDINGS

A tall building is a multistorey structure in which most of the users depend on elevators (lifts) to reach their destinations (Elsevier, 2009). The most prominent tall buildings are referred to as high-rise buildings in most countries. They are sometimes referred to as tower blocks in Britain and some European countries. Generally speaking, a high-rise building is considered to be one that has at least seven storeys; and in terms of linear height, it has a height of at least 23 m (Hall Jr, 2005 and Konke, 2006). There are many high-rise buildings in Nigeria. An example of these is NECOM House in Lagos, which is 158.50 m in height consisting of 32 floors, constructed in 1979. Others include Union Bank Headquarters in Lagos, World Trade Centre Towers in Abuja, Central Bank of Nigeria Headquarters in Abuja. Many of the high-rise buildings are found in the Middle East and China. The tallest building in the world for now is the Burj Khalifa in Dubai, which is 828 m in height. In Jeddah, Saudi Arabia, the Kingdom Tower is under construction currently, and will be about 1000 m in height after completion.

Characteristics of High-Rise Buildings

High-rise buildings, because of their size, have some significant effects on the choice, design and construction of the foundation. These characteristics, according to Poulos (2016), include the following:

1. The weight of the building, and consequently, the vertical load that comes on the foundation can be very large. Also, the weight of the building does not increase linearly with the height. Therefore, the ultimate bearing capacity and settlement need to be carefully considered.
2. Most times, a high-rise building is surrounded by low-rise level structures with consequent lower loads. Therefore, differential settlements between the high-rise and low-rise level sections need to be controlled.
3. Lateral forces resulting from wind loading, and the resulting moment on the foundation could be substantial. The increased moment could increase the vertical loads on the foundation, especially on the outer piles in the foundation system. The strength design of the piles should take into account these increased loads which act together with lateral forces and moments.
4. The lateral loads and moments resulting from the wind effect are cyclic in nature. Consideration should therefore be given to the influence of cyclic vertical and lateral loading on the foundation system. This is because cyclic loading has the ability to degrade the capacity of the foundation and cause increased settlements.
5. Additional lateral forces and moments can be induced by seismic action in the ground housing the foundation. This is also possible in Nigeria (Danjuma and Ajoge, 2021).
6. The loads induced by the wind and seismic actions are dynamic in nature and therefore can give rise to resonance within the structure which needs to be assessed.
7. The dynamic response of tall buildings presents some notable structural and foundation design challenges.

TYPES OF FOUNDATION AND AREAS OF APPLICATION

BS 8004 (2015) broadly categorises foundations into two major types, viz: shallow foundations and deep foundations. It defines shallow foundations are those that transfer loads to depths not exceeding three metres below the natural ground level. The adoption of the three-metre depth is arbitral. Examples of these include strip foundation, pad foundation (isolated or combined), mat or raft foundation. On the other hand, deep foundation is provided to transfer structural loads to depths of more than three metres below the natural ground level. They are provided often to transfer the load from the superstructure to soil layer of adequate bearing capacity located far below the natural ground level. It serves the purpose of anchoring the

superstructure as in high rise buildings to the ground and prevent the resulting collapse from inadequate anchorage to the earth. Also, there are buildings where some levels are located below the natural ground level. This will therefore necessitate the location of the foundation at a depth more than three metres. An example of this type of foundation is the piled foundation in its different forms.

FACTORS AFFECTING FOUNDATION CHOICE FOR HIGH-RISE BUILDINGS

The choice of foundation for a high-rise building is dependent on many factors. These factors, according to Poulos (2016), include the following:

1. Location and type of structure.
2. Size and distribution of the loadings
3. Ground conditions
4. Access for construction equipment
5. Durability requirements
6. Effects of the construction on adjacent foundations, structures, and people
7. Comparative cost
8. Local construction practices.

THE FOUNDATION DESIGN PROCESS

Design Stages

Basically, there are three broad stages in foundation design. These according to Amornfa, Phienwej and Kitpayuck (2012) and Poulos (2016), are

1. A preliminary design: provides an initial basis for the development of foundation concept and casting.
2. A detailed design stage: the selected foundation concept is analysed and progressive refinements made to the layout and details of the foundation system.
3. A final design stage: both the analysis and the parameters used in the analysis are finalized.

It is important to note that the geotechnical parameters used for each stage may change as more information of the ground conditions, and the results of in situ and laboratory tests are made available. The parameters for the final design stage will have to include the results of foundation load tests.

Design Considerations

Some very important issues have to be addressed in the design of foundations for high-rise buildings. These according to Poulos (2011) and Poulos (2016) include the following:

1. Ultimate capacity of the foundation when subjected to vertical, lateral and moment loading combinations.
2. Effect of the cyclic nature of wind, earthquakes and wave (if applicable) loadings on the foundation capacity and movements.
3. Overall settlements.
4. Differential settlements, both within the high-rise area and between the high-rise and low-rise areas.
5. Possible effects of ground movement on the foundation system, resulting from extraneous sources like excavations for pile caps or adjacent facilities.
6. Dynamic response of the structure-foundation system to forces resulting from wind and wave effect.
7. Earthquakes effects, which includes the response of the structure-foundation system to earthquake excitation, and possible liquefaction in the soil surrounding and/or supporting the foundation.
8. Structural design of the foundation system, including the load sharing among the various components of the system (e.g., the piles and the supporting raft) and the distribution of loads within the piles.

STRUCTURAL DESIGN REQUIREMENTS

Most structural design requirements use the limit state theory. In high-rise buildings, the design criteria for the ultimate limit state are two; structural and geotechnical. It is required that the design structural strength and the design geotechnical strength should be equal to or greater than the design action effect (i.e., factored load combinations) for each case. The two criteria are applied to the entire foundation system while the

structural strength criterion is applied to individual pile within the pile group (Poulos, 1999).
The geotechnical strength criterion will however, be satisfied if the foundation system with the reduced strength does not collapse under the ultimate limit state design action effects (i.e., factored load combinations).

Load Combinations
The desired load combinations that the structure and the foundation system will have to be designed for will usually be specified by an appropriate structural loading code.

Cyclic Loading Considerations
In addition to taking into consideration the usual design criteria for the structural strength and geotechnical strength, it might be necessary to impose another criterion for the whole foundation of a high-rise building to cater for the effect of repetitive loading resulting from wind and wave action.
Serviceability – Settlement and Differential Settlement
The design criteria for the serviceability limit state are that, the maximum computed settlement of the foundation should not exceed the allowable foundation settlement and; the maximum computed local angular distortion should not exceed the allowable value.

Ground Movements Consideration
The design of the foundation has traditionally focused on loads applied by the structure. It should be noted that significant loads can also be applied to the foundation system because of ground movements, sources of such movements include the following:

1. Ground settlement resulting from site filling, reclamation or dewatering
2. Ground heave due to excavation of the site for basement construction
3. Lateral and vertical movements arising from the installation of piles close to piles already installed
4. Dynamic ground movements due to seismic activity.

Dynamic Loading
The natural frequency of the foundation system should be greater than that of the structure it supports to avoid potential resonance. The natural frequency depends basically on the stiffness of the foundation system and its mass. The amplitude of dynamic motions of the structure-foundation system should be within acceptable limits.

Earthquake Loading
In foundation design, consideration must be given to possible reductions in soil strength arising from build-up of excess pore pressures during and after an earthquake. In extreme cases, the generation of pore pressure may lead to the liquefaction of relatively loose sandy and silky soil.
Soil deposits in earthquakes prone locations may be subjected to the following effects during an earthquake.

1. Pore pressure increases
2. Vertical ground movement which are time-dependent, during and after the earthquake
3. Lateral movements which are time-dependent, during the earthquake.

For these reasons, consideration should therefore be given to earthquake loading, especially in regions where this is common.

FOUDATION OPTIONS FOR HIGH-RISE BUILDINGS
Generally, the foundation type adopted for any structure depends on the type, size and nature of load as well as the depth to the earth stratum of adequate bearing capacity (Magar, Kudtarkar, Pachpohe and Nagargoje, 2020). For high-rise buildings, the foundation options available to choose from as suggested by Poulos (2016) are as follows:

Raft or Mat Foundation
Raft or mat foundation is one of the foundation types referred to as spread foundation. The foundation

components transfer their loads to the underlying soil by normal stresses and shear stresses. Raft foundation covers the whole area on which a structure is constructed. In high-rise buildings that have basement at multiple levels, the base of the structure may be constructed close to or embedded into a rock of adequate strength. If height of the structure is moderate, a raft foundation to support the whole structure may be feasible. For very tall buildings, however, this type of foundation may be too shallow to develop adequate resistance to horizontal and moment loadings. However, Davies, Lui, Pappin, Yin and Law (2004) reported that it was used for International Finance Centre II in Hong Kong, which is an 88-storey high building, and is performing well. The principle here is to locate the foundation far below the ground surface. Katzenbach, Leppla and Choudhury (2016) also reported that it was used for some structures in Germany among which is Silver Tower in Frankfurt, Germany. It is a 166 m high structure; the raft foundation has an average thickness of three and half metres and located fourteen metres below the ground surface.

Construction Method

Raft or mat foundation is constructed by removing the entire area to be covered by the structure. It is constructed using reinforced concrete; usually there is no provision for shear reinforcement. The shear is taken care of by arranging haunches where there will be concentrated loads or increasing the slab thickness. A raft foundation under construction is shown in Figure 1.

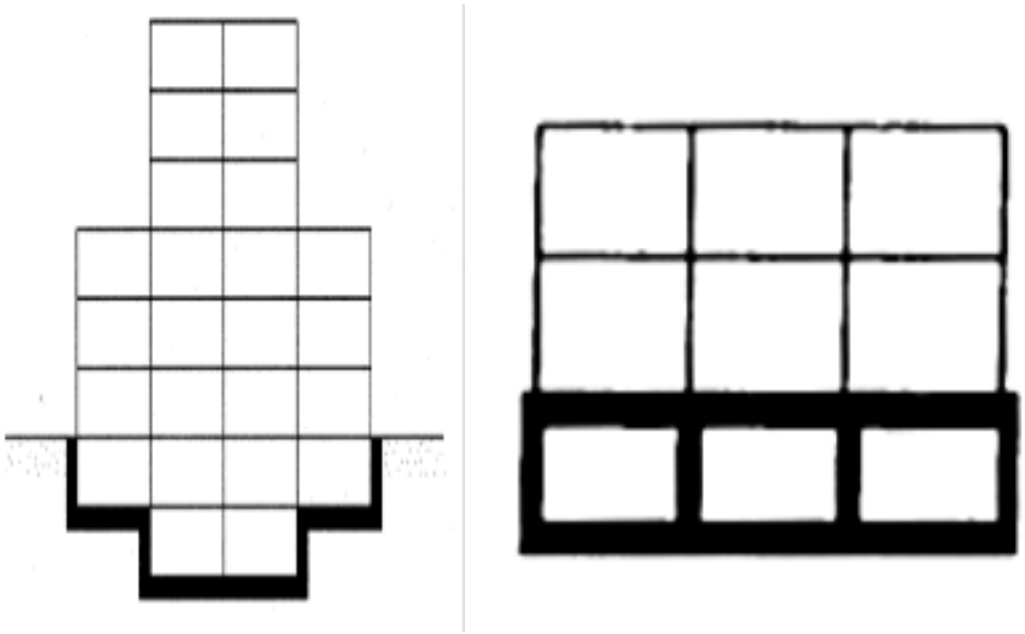
Figure 1 Raft foundation under construction

Depending on the magnitude of loads, slab thicknesses for the raft in high-rise buildings sometimes exceed three meters. It is important to prevent ground water influx or to exclude external weather conditions. This is achieved by limiting the crack width of the concrete. However, the installation of the construction joints and settlement joints has to be planned carefully and closely supervised during construction (Katzenbach, Leppla and Choudhury, 2016).

Compensated Raft Foundation

Compensated raft foundation is used where it is necessary to support heavily loaded structures constructed on soft and low-permeable soils (Dey and Reddy, 2014) like clay or loose sand (Poulos, 2016). It is a special category of raft foundation where the net pressure on the foundation soil is reduced due to higher depth embedment of the foundation with simultaneous construction of a basement wall. Very often, tall buildings have one or more level basements that may be used as car park or for commercial and retail space. In situations like this the construction of the raft involves excavation of the soil before construction of the foundation and superstructure. The excavated soil is no longer used as backfill, thereby reducing the overburden pressure significantly. The weight of the structure is partially or fully compensated by the weight of the excavated soil, which provides a reduction in the subsequent settlement. For this reason, the net increase in ground stress because of the structure will be reduced, therefore it may be expected that the settlement and differential settlement will also be reduced (Poulos, 2016). Where the structural load is fully

compensated, the foundation is called a buoyancy raft as shown in Figure 2 (Dey and Reddy, 2014; and Poulos, 2016).



(a) Compensated raft (b) Buoyancy raft

Figure 2 Compensated raft foundation

Construction Method

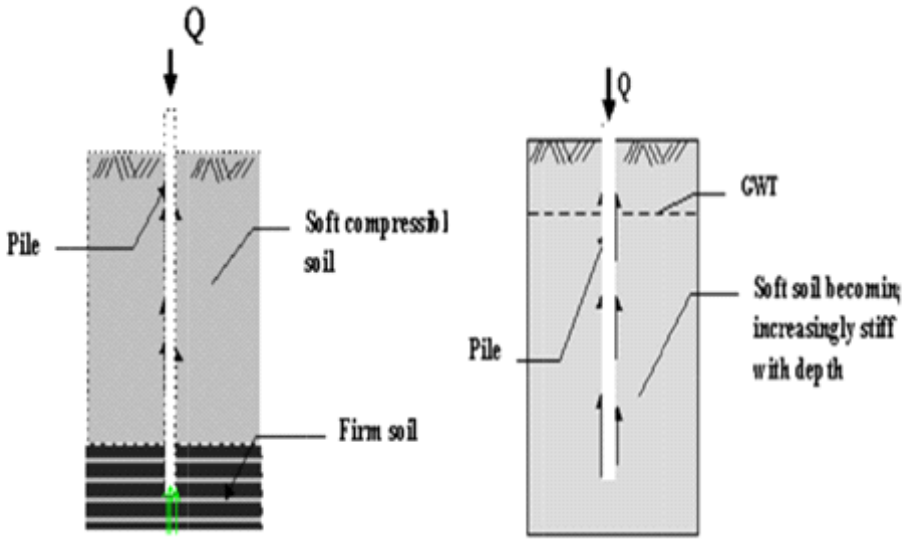
The process of construction for *compensated raft foundation* is similar to that of the normal raft foundation. However, the volume of excavation is more. Therefore, the amount and type of equipment deployed will be much. It is also constructed using reinforced concrete with attention being paid to details to prevent water ingress into the foundation system.

Figure 3: Compensated raft foundation under construction

Piled Foundation

Sometimes, the ground conditions at a proposed building site are unsuitable for a shallow raft/mat foundation. This is so especially for high-rise buildings where the vertical and lateral loads coming on the foundation are substantial. In this kind of situations, it is necessary to support the loads from the building on

piles. These are either single piles or pile groups, usually placed below the columns or load bearing walls. According to Shedbal (2016), piled foundation are deep foundations formed by relatively long columnar elements. Pile foundation consists of two components: pile cap and single or group of piles. Piles are classified on the basis of load carrying characteristics (end bearing or friction piles, Fig.1), pile material (wooden, steel, concrete, or composite), effect on the soil (displacement or non-displacement) and method of installation (driven or bored piles) (Adejumo, 2013).



(a) End bearing pile (b) Friction or cohesion pile

Figure 4 Pile Foundations

For high-rise structures, piled foundation most times comprises a large number of piles. The challenge in the design therefore is how to capture the effects of pile group interaction. This is because of the common knowledge that the settlement of a pile group can differ greatly from that of a single pile at the same average load level as a result of group effects. In addition to this, is the fact that the ultimate load that can be supported by a group of piles may be different from the sum of the ultimate load that can be supported by each pile within the group. Consideration therefore has to be given to pile group efficiency.

Construction Method

P*iled foundations* for high-rise buildings can be a couple of tens of meters in length to be able to reach the desired depth. Also, the pile diameters are large, ranging between 0.3 to 3 m. The specific method used in pile installation according to Bilfinger and Berger (2012), depends on the condition of the soil, ground water levels, site conditions and the pile length. Pile installation methods are broadly classified into two; driven piles installation and bored piles installation methods. One method of driving pile is by the use of dropping weight. A hammer with a weight approximately equal to the weight of the pile is raised to a suitable height and released to strike the pile head. In the vibration method, the equipment is used to induce vibration into the pile thereby forcing it into the ground. This is most suitable for sandy and gravelly soil. On the other hand, the boring method include the bored stabilisation process, casing installation method and the excavation method. The excavation is done by using grab excavation, rotary drilling, flush boring methods. Sometimes, the piles for high rise buildings are required to be taken to very large depths in tens of metres. Therefore, piles used in this kind of situations are not driven but bored piles. Suitable equipment for this purpose include the Reverse Circulation Drills (RCD) (Davies, Lui, Pappin, Yin and Law, 2004) and the Continuous Flight Auger (CFA) (Adejumo, 2013) to take the boring on to the desired depth. The columns cannot rest directly on the piles, pile caps are provided to transfer the column loads to the piles.

To ensure stability of the piled foundation system, the pile caps are linked together with ground beams. Where driven piles are used, it is better to start with the inner piles. This will prevent the soil from becoming

compact when the external piles have been driven earlier, making the driving of the inner piles difficult.

Piled Raft Foundation

High-rise buildings are often constructed with basements having thick slabs. When piles are used in foundations to such buildings, the general assumption is that the basement slab does not carry any foundation loads. There are cases where it is possible to utilise the basement slab, acting together with piles, to have a foundation which satisfies both bearing capacity and settlement criteria. This kind of arrangement is referred to as a piled raft foundation, with the basement slab acting as a raft. Piled raft foundation has been adopted in the design of tall buildings in many parts of the world (Katzenbach, Arslan and Moormann, 2000; Poulos, 2001; and de Sanctis and Mandolini, 2006). This is because it has potential cost saving and better control of differential settlement, according to Amornfe, Phienwej and Kitpayuck (2012). Poulos (2011) reported that it was proposed for the Incheon Tower in Songdo, Korea and it was adopted for the Burj Khalifa in Dubai (El Gendy and El Gendy, 2018).

Piled raft foundation is a composite system in which both piles and the raft act together to carry the applied structural loadings. This will significantly reduce the number of piles compared to the number required in the conventional pile foundation. In this kind of arrangement, the piles provide the higher proportion of the foundation stiffness while the raft provides reserve load carrying capacity. Also, in situations where raft foundation alone might be used, and does not satisfy certain design requirements (particularly the total and differential settlement requirements) it may be possible to increase the performance of the raft foundation by the addition of piles. In such cases, using a limited number of piles, which are strategically located, can improve both the capacity as well as the differential settlement performance of the raft, thereby allowing the design requirements to be met (Horikoshi and Randolph, 1998).

According to Poulos (2016), adopting a piled raft foundation have the following advantages:

1. Since piles need not be designed to carry all load, there is the possibility of substantial savings in cost
2. Locating the piles strategically beneath the raft helps to control differential settlements
3. Piles of different sizes (length and/or diameter) can be used at different locations to optimise the foundation design.
4. Raft thickness can also be varied at different locations also to optimise foundation design.
5. Piles can be designed to carry a load almost equal to their ultimate geotechnical load, provided the raft can develop an adequate proportion of the required ultimate load capacity.

Piled raft is most effective when the raft can provide adequate load capacity but the settlement and/or differential settlements of the raft alone exceed the allowable limits. According to Poulos (2001) piled raft is suitable for:

1. Soil profiles consisting of relatively stiff clays.
2. Soil profiles consisting of relatively dense sands.

This foundation type does not provide any advantage over conventional piled foundations in the following types of soil profiles:

1. Very soft clays at or close to the surface of the raft, because the raft can contribute only small proportion of the foundation load capacity.
2. Profiles that may be subject to long term consolidation settlement, the reason is that the soil may lose contact with the raft and all the load will be transferred to the piles.
3. Profiles that may be subjected to expansive (upward) movements: the soil movements will increase contact pressure on the raft which result in tensile forces in the piles.

Construction Method

In the *piled raft foundation* system, the piles are first of all bored and cast in place. The raft foundation of the desired capacity is cast over the piles that were earlier installed. Since the raft and piles act monolithically, the use of pile caps as well as the ground beams used as ties in the conventional piled foundation is eliminated. The precaution taken in the construction of the two separate types of foundation (pile and raft) is adopted in this system as well.

Compensated Piled Raft Foundation

Compensated piled raft foundation entails the use of piles together with compensated raft to provide a foundation system for a high-rise building. As the total piled-raft stiffness is directly related to the pile capacity, the overall behaviour of a compensated piled raft will depend on the sequence of excavation (Poulos, 2016). That is, whether the pile holes will be drilled before the excavation for the compensated raft or the other way round.

Construction Method

The process involved in constructing the compensated raft foundation and piled foundation are adopted. The excavation is carried out to the desired level for the raft. From that level, the piles are then bored into the soil layer of desired depth. In this case also, the pile caps for each group of piles as well as the connecting beams are eliminated.

Generally speaking, construction of foundations for high-rise buildings requires high level of expertise and heavy equipment. For this reason, most of the foundation works for high-rise buildings are undertaken by specialist contractors.

Conclusion

The use of high-rise buildings is becoming more and more prevalent, with most of the very tall ones found in Asia, and more predominantly in the Middle East. foundation is a very important part of the building. The sheer size of the buildings with the consequent size of the structural loads, coupled with the fact that the designs also should be made economical, makes a critical look at the foundation an imperative. The paper has presented a review of some of the foundation options available for high-rise buildings. The design considerations for the foundations as well as the construction methods have been highlighted. For this type of structure, consideration is not only given to structural loads but also to the geotechnical loads in the foundation design. The geotechnical parameters of the foundation soil are important for the final design. Therefore, the design and construction of foundation for any high-rise building is preceded by a detailed soil investigation. For most of the soil conditions that are available, it is seen that piled raft foundation offers a very economic option.

Recommendations

1. Construction practitioners should make effort to acquaint themselves with evolving construction practices as it relates to high-rise buildings especially as it relates to their foundation design and construction processes.
2. Since this kind of structures are not very common in Nigeria, effort should be made by those who have directly participated in any of such projects to document their experiences for others to learn from.
3. Everyone engaging in the design and construction of the foundation of this kind of buildings should ensure that a detailed soil investigation, undertaken by a reputable geotechnical engineer, be carried out.
4. Effort should be made by development control departments in all development approving agencies that soil investigation reports submitted for approval purposes are genuine. This because, cases abound where existing reports for other projects are doctored and submitted for new projects and approvals are still given on the basis of the doctored report.

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UNDERSTANDING THE PERFORMANCE OF EXPANDED POLYSTYRENE (EPS) TOWARDS SUSTAINABLE HOUSING CONSTRUCTION

Understanding The Performance of Expanded Polystyrene (Eps) Towards Sustainable Housing Construction

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ABSTRACT

Goal 11 of the Sustainable Development Goal (SDG) mandates delivering buildings utilising sustainable materials. An emerging material used to fulfil this goal is Expanded Polystyrene (EPS), a thermo- plastic material whose end-product is a meshed panel that can be moulded into different shapes and sizes used in constructing buildings. Although the use of EPS is relatively new in construction (as against its use in industrial packaging), it is attributed to having commendable sustainable properties. Despite its commendable characteristics, studies on EPS predominantly cover its technical and mechanical aspects (from the views of professionals/experts). In a bid to enhance the appreciation of the material, this study seeks to investigate the performance of EPS in Citec Mbora Mount Pleasant Estate Abuja relative to occupant's satisfaction. A total of 57 occupants were identified from Citec Construction Ltd to being involved in constructing the houses they occupy and thus have some experience on the use of EPS. While data is collected using a survey with the aid of a questionnaire, data is analysed both descriptively and inferentially using IBM SPSS Statistics 23 and M.S. Excel using frequencies, Mean Score and Relative Satisfaction Index (RSI). Results reveal that majority of the respondents are adults over 26 years of age and have lived in the houses for over 3 years. Furthermore, out of the 6 factors studied, while maintainability is the only factor that leans towards occupants being satisfied with the performance of EPS (with a Mean Score of 3.56), hot weather insulation is also the only factor that leans towards occupants being dissatisfied with the performance of EPS (with a Mean Score of 2.47). The other factors leaned towards occupants being 'unsure'. It was found that the satisfaction of occupants residing in Citec Mbora Estate in terms of the physical performance of EPS (maintainability and aesthetics) is more than the satisfaction in terms of general insulation performance (heat, cold and sound). Future research can look deeper into other factors that cause satisfaction (such as cost, frequency, and culture of maintenance of EPS) of the houses built with EPS in Citec Mbora Mount Pleasant Estate. Also, environmental factors that affect insulation can be covered in future studies However, those who know about EPS confirms its flexibility, quick construction time, and its environmental friendliness all herald a great future for the applications of these advanced building products in the Nigerian construction industry, but EPS is not readily available like other conventional materials which makes its application challenging to professionals of the built environment.

Keywords: Citec Mbora Estate, Expanded Polystyrene (EPS), Housing construction, Occupant's satisfaction

INTRODUCTION

Among other mandates of Goal 11 of the Sustainable Development Goal (SDG), it is determined to support sustainable and resilient buildings utilising sustainable materials (SDG, 2015). This mandate arose from the several challenges prevailing in housing provision (availability, affordability and accessibility), which persists in developing countries. In a bid to improve these challenges, researchers have made efforts to identify the factors retarding effective housing delivery particularly in developing countries. For instance, Ede, Alegiuno, & Aawoyera (2014) link the challenge facing effective housing delivery to rural-urban drift, a general increase in living cost, high cost of urban land with the consequent high cost of housing schemes, the presence of excessive demands and shortage of housing facilities. Also, Ngugi, Kaluli, & Gairy (2017) and Kageni (2014) attribute cost of construction materials, rising population, and low income, among other factors causing challenges of effective housing delivery. While it is evident that these underlying factors

driving challenges faced by ineffective housing delivery differ, there is unanimous agreement that optimising these challenges largely depends on sustainable construction practices which includes the use of sustainable construction materials.

Although there exists an array of sustainable building materials adaptable to countries, regions and locations, Ibrahim, Bankole, Maaji, Ohize, & Abdul (2013), Ede et al. (2014) and also Ngugi et al. (2017) all approve Expanded Polystyrene (EPS) to being a building material suitable for the construction of affordable and sustainable housing in developing countries. Expanded Polystyrene (EPS) used in construction is a thermo- plastic material whose end-product is a meshed panel that can be moulded into different shapes and sizes. The works of Paolella & Grifoni (2013), Ede et al. (2014), Ngugi et al. (2017) and also Mansir et al. (2019) all showcase building elements produced with EPS and used in housing construction (which include walls, roofs, staircase, ceiling and floor slabs). Although EPS is relatively new in construction (as against its use in industrial packaging), EPS has exhibited commendable characteristics, which makes it suitable for use as a sustainable building material. The commendation of its use across authors can be contextualised into its physical properties, which include availability, lightness, simplicity in use (Paolella & Grifoni, 2013); it's sustainably economical in terms of both initial and operating costs (Doroudiani & Omidian, 2010; Kageni, 2014; Ngugi et al., 2017); it's environmentally friendly in terms of energy efficiency and insulation property (Doroudiani & Omidian, 2010; Kageni, 2014; Ngugi et al., 2017); and also it is flexible in production into different shapes and sizes (Doroudiani & Omidian, 2010; Ngugi et al., 2017).

Even though the commendable characteristics of EPS is alluded to making it a sustainable construction material, its (EPS) application in building construction in Nigeria is posed with challenges. For instance, Ibrahim et al. (2013), Ede et al. (2014) and also Mansir et al. (2019) all claim that there are not so many construction firms using EPS in Nigeria. Likewise, Ede et al. (2014) attribute low patronage in using EPS in construction to relatively scarce knowledge in the innovative methods of construction using EPS and poor access to the material. Furthermore, Mansir et al. (2019) assert that a low level of awareness of the building professionals and the general public and its non-availability has hampered the diffusion of EPS in Nigeria. Irrespective of these challenges, however, researchers are continuously improving the patronage in using EPS, which implies proffering solutions to sustainable building delivery. For instance, Ibrahim et al. (2013) assessed the properties of EPS used in building construction in Citec Mbora Mount Pleasant Estate in Mbora District Abuja relative to mechanical performance (compressive strength specifically). Similarly, Mansir et al. (2019) investigated the factors affecting the use of EPS among professionals of Citec Construction Limited. While these studies somewhat covered the technical performance of EPS used in housing construction based on professionals' opinions, (Ishiyaku 2016) believes that the full evaluation of a sustainable material used in construction should also entail liaising with users to get their opinions. As such, this study seeks to advance the understanding of EPS in Citec Mbora Mount Pleasant Estate relative to occupant's satisfaction with its performance.

The use of EPS material technology seems to be highly appealing to the major players in the construction industry. Clients, designers, contractors, and end-users are frequently at odds over the key construction industry issues of cost, quality, and time. Construction of a facility of the greatest quality while keeping costs and construction time to a bare minimum is the goal of every customer (Aina and Wahab, 2011). Customers are drawn to high-quality homes that are within their budgetary constraints. Building materials that are appropriate and carefully chosen are the most appropriate means of accomplishing this. Expanded Polystyrene is one product that may help achieve high quality, low cost, and quick construction product completion (Omolola, 2014). Houses built in Citec Mbora Mount Pleasant Estate by Citec Construction Limited are classical cases of buildings built with EPS in Nigeria. As such, EPS has performed well in its application in Nigeria.

LITERATURE REVIEW

The subsequent sub sections review the literature on EPS, its use in housing construction and its performance requirements in general. Also, the use of EPS in Citec Estate is discussed.

Sustainable Building Construction Using Expanded Polystyrene

Sustainable Development Goal 11 (SDG 11 or Global Goal 11) is one of 17 Sustainable Development Goals adopted by the United Nations General Assembly in 2015. It is about "sustainable cities and communities." Goal 11 of the Sustainable Development Goals aims to "Make cities more inclusive, safe, resilient, and sustainable" (U.N., 2017). As a result, the 17 SDGs recognise the importance of balancing social, economic, and environmental sustainability (UNDP, 2021). Investment in public transportation, the creation of green public spaces, and participatory and inclusive urban planning and administration are among the SDG 11 priorities (SDG, 2015). The achievement of Goal 11 of the SDG is being tracked through the use of fifteen indicator metrics. Safe and affordable housing, affordable and sustainable transportation systems; inclusive and sustainable urbanisation; protection of the world's cultural and natural heritage; reduction of the negative effects of natural disasters; reduction of city environmental impacts; and provide access to safe and inclusive green, and public spaces are among the seven "outcome targets" (SDG, 2015). Strong national and regional development planning; adopt policies for inclusiveness, resource efficiency, and disaster risk reduction; and help least developed nations develop sustainable and resilient infrastructure are among the three "ways of accomplishing" goals (U.N., 2017; Africa UNDP, 2021).

For the construction industry, the sustainability of buildings is a critical issue. Sustainable buildings are characterised by lower construction costs for energy consumption and operations, are environmentally friendly, are capable of conserving natural resources while also being comfortable and healthy for their occupants (Mesaros et al. 2016). The availability of secure and inexpensive housing gives personal, social, and economic advantages to individuals while also contributing to the health and safety of those who live there (Shi et al., 2015). According to Yüksek (2014), energy is one of the most important factors in economic growth and social development in all countries, and as urbanisation continues to grow at a rapid pace, the construction of residential areas is being carried out intensively at the same time that the world is experiencing a scarcity of energy resources. As a result, modifications to housing design and construction technologies are required to reduce the cost, gas emissions, and other environmental impacts Raj et al. (2014) and mitigates the impact of depleting energy supplies, which is a danger to humanity's present and future (Ogundiran, 2014).

Because of this, other insulating materials such as EPS or other kinds of combustible materials should be taken into account. According to Ogundiran (2014), both the customer and the residents of the EPS were pleased with the building's excellent recyclability, dependability, flexibility, and moisture resistance. They made a further assertion: EPS applications in the Nigerian construction sector has an excellent future. According to Raj et al. (2014), the usage of pre-reinforced EPS sheets will minimise total building costs by reducing construction time and, therefore, labour expenses. Because the dead weight of the superstructure is relatively low compared to that of traditional reinforced concrete, it may also be built where the soil carrying capacity is limited. As a result of its lightweight, energy-absorbing, and heat-preserving properties, EPS is used in many specific construction industries, including high-rise buildings, floating marine platforms, and large-sized and long-span concrete (Shi et al. 2015; Kumm, 2013). As a result, it should be considered for use as an alternative building material.

Expanded Polystyrene Used in Housing Construction and its Performance Requirement

The drive towards sustainable housing delivery (as championed by Goal 11 of SDG, 2015)) has yielded the use of diverse materials believed to fulfil the economic, social and environmental paradigms attributed to sustainable development. Among other materials believed to be sustainable for housing construction, EPS is gradually gaining the limelight. EPS is a thermo- plastic material formed by the union of so many

polystyrene beads produced during a modelling process with the supply of heat and water steam until the full formation of the desired properties is attained(Ede et al., 2014;Ngugi et al., 2017). Although the use of EPS is relatively new in construction (as Kageni, 2014 and Ngugi et al., 2017) claimed, its use in industrial packaging has been much longer. While EPS used in packaging is usually monolithic, EPS used in the design and construction of buildings usually has steel mesh reinforcement embedded in it (Ibrahim et al., 2013; Ngugi et al., 2017). Detailed procedure for the assemblage of EPS elements used in housing construction can be found(Ministry of Housing and Urban Poverty Alleviation Government of India 2017). The polystyrene material is depicted in Figure 1.

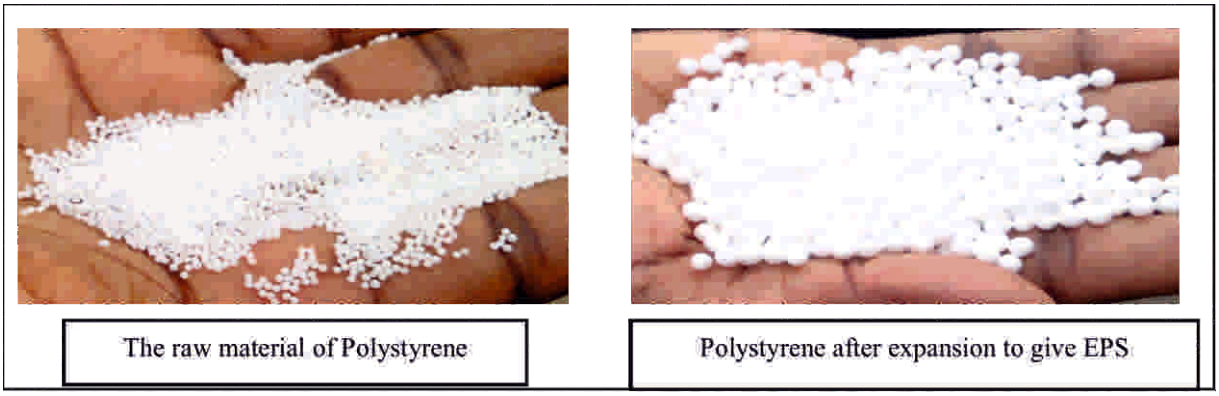

Figure 1: Polystyrene Material
Source: (Mansir et al. 2019)

Pre-expansion, intermediate conditioning and stabilisation, moulding, shape, and post-production operations are among the five platforms of polystyrene manufacturing (Saint-Goban, 2009). The EPS beads (figure. 1) are heated to around 800 and 1000 degrees using a steam boiler during the pre-expansion step. To expand the beads holding a sequence of non-interconnected closed cells pentane re-agent is added. As the beads cool, the air is induced into them, lowering the bulk density from 630kg/m3 to 10 and 35kg/m3. The EPS is cooled in the intermediate conditioning and stabilisation step before being transported to an aerated storage silo for development. The EPS cools in the silo, and air diffuses into the gap/pores, progressively replacing the other components until the beads encapsulate over 90% of the air. At this point, the beads have regained their mechanical elasticity and their expansion capability. Moulding is the third stage in EPS manufacture. The pre-expanded beads are moulded into boards, blocks, or unique product designs. During the moulding process, the steam forced each bead to fuse to its neighbour, resulting in a consistent product. The shaping step is the fourth in the process. The moulding block is allowed to cool once it has been withdrawn from the moulding machine. The block is subsequently chopped or shaped using a hot wire or other suitable processes. The completed material (EPS) is laminated with foils, plastics, roofing felt, and wall cladding materials in the final post-production phase.

The growth in EPS use can be attributed to some of its commendable properties when used as a sustainable building material. For instance, Paolella & Grifoni (2013) characterise EPS as being readily available, light in weight, resistance, insulating properties, cheapness and simplicity in use. Also, Ngugi et al. (2017) indicated EPS used in construction to exhibiting lower construction costs for energy consumption and operations; environmentally friendly; able to save natural resources; comfortable and healthy for users; and flexibility of being manufactured in multitude shapes and for multiple applications. Furthermore, Doroudiani & Omidian (2010) reported that EPS in construction proffers low material usage and installation costs, good performance, resistance to biodegradation, resistance to moisture penetration and availability in a wide range of sizes and densities. Also, EPS is cost effective for thermal and sound insulation (Kageni, 2014). All these commendable characteristics of EPS buttress the claim of its passing for sustainable construction material.

Several pieces of research have been conducted to ascertain the potentials of EPS in fulfilling its functional requirement as a sustainable material in housing construction. Findings from conducted researches have informed on its potentials to be used for sustainable housing construction. Table 1 depicts authors' works that covered specific functional requirements of EPS relative to varying scopes in studying EPS used in construction.

Table 1: Performance Requirement Factors of EPS Used in Construction

S/No	Factor	Authors
1	Aesthetics	Ibrahim et al. (2013) ; Ministry of Housing and Urban Poverty Alleviation Government of India (2017)
2	Hot weather resistance	EUMEPS (2013); Lakatos & Kalmár (2013) ; Alam et al. (2013); Briga-Sá et al. (2013)
3	Fire resistance	EUMEPS (2013) ; Alam et al. (2013) ; Briga-Sá et al. (2013); Ministry of Housing and Urban Poverty Alleviation Government of India (2017) ; Ngugi et al. (2017)
4	Cold weather resistance	Daouas et al. (2009) ; Kageni (2014) ; Raj et al. (2014) ; Ngugi et al. (2017)
5	Maintainability	EUMEPS (2013); Lakatos & Kalmár (2013) ; Alam et al. (2013); Paolella & Grifoni (2013) ; Ministry of Housing and Urban Poverty Alleviation Government of Ind ia (2017)
6	Resistance to the impact of sound	Raj et al. (2014) ; Ngugi et al. (2017) ; Briga-Sá et al. (2013); Ministry of Housing and Urban Poverty Alleviation Government of India, (2017)

Source: (Mansir et al. 2019)

Specific to housing construction, EPS has been reported by several authors to be used for wall panels, floor slabs and roof, among other building elements. Table 2 captures some works researched on EPS relative to building elements used in housing construction.

Table 2: Building Elements Made with EPS

S/No	Element	Authors
1	Wall	Daouas et al. (2009) ; Paolella & Grifoni (2013) ; Ede et al. (2014); Ngugi et al. (2017)
2	Floor (lightweight)	Paolella & Grifoni (2013); Ede et al. (2014); Ngugi et al. (2017)
3	Roof (insulation)	Paolella & Grifoni (2013); Ngugi et al. (2017)
4	Staircase	Ibrahim et al. (2013) ; Ministry of Housing and Urban Poverty Alleviation Government of India (2017)
5	Ceiling	Paolella & Grifoni (2013); Ngugi et al. (2017)

Source: (Mansir et al. 2019)

These studies were conducted in several countries. While the works of Kageni (2014) and also Ngugi et al. (2017) illustrates the use of EPS in housing construction in Kenya, the work of Daouas et al. (2009) discussed the use of EPS in Tunisia. Similarly, Doroudiani & Omidian (2010) demonstrates the use of EPS in Canada.

In Nigeria, the works of Ibrahim et al. (2013), Ede et al. (2014) and also Mansir et al. (2019) equally covered the use of EPS as a material used in housing construction. Although these studies differ in scope, they all concluded that EPS is indeed sustainable for housing construction.

The Use of Expanded Polystyrene in Citec Estate

According to Ibrahim et al. (2013), Ede et al. (2014) and also Mansir et al. (2019), there are not so many construction firms using EPS in Nigeria. Citec Construction Limited is one among such limited firms that use EPS in construction. This is evident in its housing construction project at Citec Estate Mount Pleasant at Mbora District Abuja. The project is a proposed 3,000 unit mass housing estate whereby thousands of housing units using EPS have been completed and occupied since the project commenced in 2003. As at the time of collecting data for this study, others units in the Estate are under construction. Within the estate, there is a workshop for the production of building elements using EPS. Some elements produced using EPS in the workshop are depicted in Figure 2.

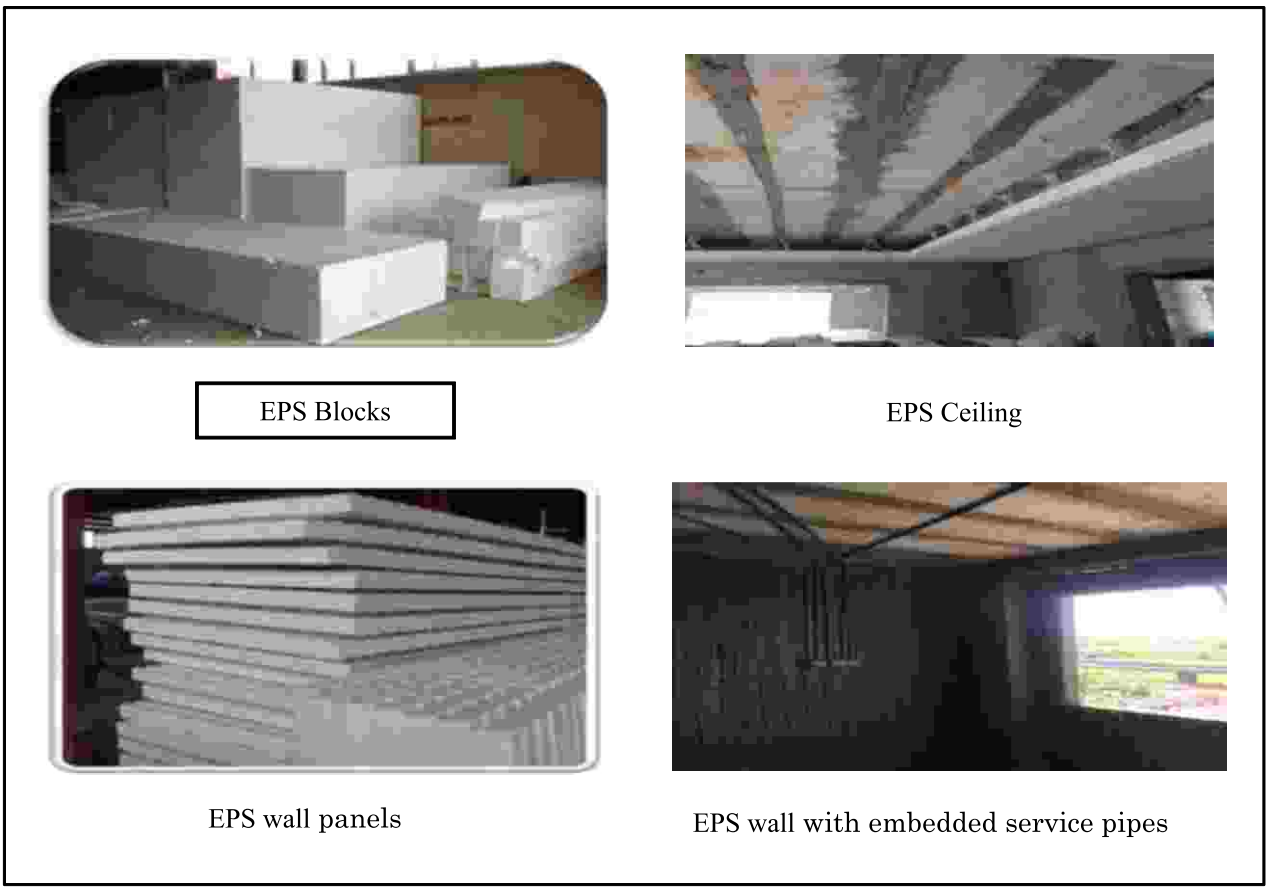

Figure 2: EPS Elements Produced in the Workshop at Citec Mbora Mount Pleasant Estate Abuja
Source: (Field Survey, 2019; Mansir et al. 2019)

In construction, polystyrene blocks are used as permanent insulation in structures and serve as thermal insulation, as seen in Figure 2. They are energy efficient and provide optimum insulation for building walls and roofs, and floors. Electrical wiring and plumbing pipes can be put into the polystyrene material, which makes it suitable for use in various applications. Constructing with EPS blocks is similar to building with toy blocks in that it is straightforward. Stability is achieved as soon as the concrete is cast into the blocks (EPS), and after the blocks are in position and situ, they create a structural framework. Although the fabrication of EPS elements of variable size, shape or colour can be done off-site, their assembling and subsequent finishing are done on-site. As is shown in Figure 2, service pipes are also embedded in the EPS element.

METHODOLOGY

This study seeks to investigate the performance of EPS through occupant's satisfaction. Several studies have assessed the performance of buildings through occupants/users satisfaction (such as Salleh & Ahmad (2008), Bilau & Witt (2015), Ishiyaku (2016) and also Nkpite & Wokekoro (2017). Adopting the data collection technique of these studies, data for this study is collected using a survey technique with the aid of a structured questionnaire. Each question consists of a 5-point Likert-type response item with categories as: Very Satisfied (5); Satisfied (4); Unsure (3); Dissatisfied (2); and Very Dissatisfied (1). Specific to assessing EPS used in buildings in Nigeria, this scale is recommended for use by (Ede et al. 2014).

Judgmental sampling is used in selecting the respondents. The claim informs the choice of such non-probability sampling of Fellows & Liu (2008), where they recommend its use when a researcher intends to use some informed judgement to determine the population and or sample of a study. Similarly, Saunders, Lewis, & Thornhill (2009) recommend judgemental sampling when a researcher wishes to select respondents that are particularly informative in fulfilling the research objectives. Since the respondents of this study cover occupants of the houses built with EPS in Citec Estate Mount Pleasant, Mbora District Abuja, information was obtained on respondents knowing that the houses they occupy were built with EPS. Based on such informed judgement, the researcher found that 57 occupants (which forms the sample of the study) residing in the estate acquired their houses when construction work was ongoing and are somewhat informed that EPS was used in the construction of the houses based on their involvement in some activities during the construction process. On the other hand, many occupants occupied the houses after construction in various capacities (owner-occupier or tenant). This information was obtained from Citec Construction Limited, the construction company that used EPS in building houses in Citec Estate Mount Pleasant, Mbora District Abuja since 2003.

Data will be analysed both descriptively and inferentially using IBM SPSS Statistics 23 to compute the frequencies. Furthermore, MS Excel will be used to compute the Mean Score. This measure has been used in construction management researches whereby John & Itodo (2013), Samuel & Eziyi (2014), Chan & Hou (2015) and also Ejohwomu et al. (2017) express it as:

$$\bar{X} = \frac{\sum X_i}{n}$$

where: $\bar{X}$ denotes the Mean Score

$\sum X_i$ is the sum of the number of responses and score awarded a variable (V_i; for $5 \geq V_i \geq 1$)

n denotes the total number of responses

The Mean Score obtained will be used as a basis to ascertain where each factor studied leans towards in the 5 point scale used (supported by Holt, 2014; Samuel & Eziyi, 2014; and also John & Itodo, 2013). Additionally, MS Excel will be used to compute the Relative Satisfaction Index (RSI), which will serve as a basis to rank the satisfaction level (by the occupants) of the performance requirements of EPS studied. The suitability in using RSI is obtained from the works of Aigbavboa & Thwala (2010) and also Olusola (2012), where they express RSI as:

$$RSI = \frac{1n_1 + 2n_2 + \ldots . An_A}{AN} \quad (0 \leq RSI \leq 1)$$

Where:

$n_1, n_2, \ldots, n_A$ = number of respondents scoring response stem integers 1 to Amax (5), respectively.

A = largest integer on the response item (5 for this research)

N = total number of respondents

Furthermore, the respondent proportion scoring above or below the median value will be calculated. Such analysis helps draw inferences from the scoring profiles for each factor studied (refer to Holt, 2014; Joshi, Kale, Chandel, & Pal, 2015; Bishop & Herron, 2015; Carifio & Perla, 2007; and Harpe, 2015).

DISCUSSION OF RESULTS

All 57 questionnaires distributed were not only successfully retrieved, but all questions were answered. The demographics of the respondents are presented in Table 3.

Table 3: Demographics of respondents

Demography	Number of respondents	Percentage
Age (years)		
18-25	5	8.77
26-50	31	54.39
Above 50	21	36.84
Total	**57**	**100**
Period of occupancy (years)		
1-3	12	21.05
4-6	35	61.40
7-9	10	17.54
10 and above	0	0
Total	**57**	**100**

The age range of the respondents in ascending order are: 5 respondents are aged between 18-25 years; 21 respondents are aged over 50 years, and 31 respondents are aged between 18-25 years. From these results, most of the respondents (91.23 percent) are adults, which adds reliability to the opinions obtained on the performance requirement of EPS in the houses at Citec Mbora Estate Abuja. Also, while 21.05 percent of the respondents have lived in the houses between 1-3 years, 61.40 percent of the respondents have lived in the houses between 4-6 years. Similarly, while 17.54 percent of the respondents have lived in the houses between 7-9 years, none of the respondents have lived in the estate 10 years and above. From these results, over three-quarters of the respondents (78.94 percent) have lived in the houses for over 3 years. This duration of stay by the respondents in the estate is deemed to add reliability in the opinions obtained on the performance requirement of EPS based on their experience living in the houses at the estate.

Table 4 depicts the results of the 6 performance requirement factors of EPS studied. While maintainability of EPS ranked 1st (with a mean value of 3.56; RSI of 0.71), aesthetics ranked 2nd (with a mean value of 3.23; RSI of 0.65). Also, while fire resistance of EPS ranked 3rd (with a mean value of 3.14; RSI of 0.63), cold weather insulation ranked 4th (with a mean value of 2.81; RSI of 0.56). Furthermore, while Sound insulation of EPS ranked 5th (with a mean value of 2.54; RSI of 0.51), hot weather insulation ranked 6th (with a mean value of 2.47; RSI of 0.49).

Table 4: Satisfaction of the performance requirement of EPS in housing construction

Factor	Frequency of responses					Total	Scores below median	Scores above median	Mean Score	RSI	Rank
	5 VS	4 S	3 U	2 D	1 V. D.						
Maintainability	9	14	34	0	0	57	0	23	3.56	0.71	1st
Aesthetics	0	19	32	6	0	57	6	19	3.23	0.65	2nd
Fire resistance	5	5	40	7	0	57	7	10	3.14	0.63	3rd

Cold weather insulation	3	5	28	20	1	57	21	8	2.81	0.56	4th
Sound insulation	2	4	19	30	2	57	32	6	2.54	0.51	5th
Hot weather insulation	2	3	18	31	3	57	34	5	2.47	0.49	6th

Legend: 5- Very Satisfied, 4- Satisfied, 3- Unsure, 2- Dissatisfied, 1- Very Dissatisfied

From these results, although more respondents are satisfied with the 'maintainability' of EPS (23) followed by its 'aesthetics' (19), these numbers do not add up to half of the respondents studied. Also, while more respondents are dissatisfied with the 'hot weather insulation' of EPS (34) followed by its 'sound insulation (32), these numbers exceed half of the respondents studied.

While the Mean Score of maintainability (3.56) is the only result that leans towards occupants being satisfied with the performance of EPS, the Mean Score of hot weather insulation (2.47) is also the only result that leans towards occupants being dissatisfied with the performance of EPS. The Mean Score of aesthetics (3.23), fire resistance (3.14), cold weather insulation (2.81) and also sound insulation (2.54) all lean towards occupants being unsure with the performance of EPS.

Although the maintainability of EPS ranked 1st, it recorded the second largest number of respondents (34) that are unsure of its performance. Also, although fire resistance of EPS ranked 3rd, it recorded the largest number (40) of respondents that are unsure of its performance. These large numbers (constituting over half of the respondents studied in each factor) could result from a large number of respondents never experiencing any damage to the EPS from fire or any agent during their stay in the estate.

FINDINGS

Overall, occupants of Citec Mbora Estate are more satisfied with the maintainability of EPS and least satisfied with the hot weather insulation of EPS. Similarly, occupants of Citec Mbora Estate are more dissatisfied with its performance in hot weather insulation and sound insulation (more than half of the respondents are dissatisfied with each) than they are satisfied with its maintainability and aesthetics (less than half of the respondents are satisfied with each).

Furthermore, occupants of Citec Mbora Estate are more satisfied with the performance of EPS in cold weather insulation than they are with its performance in hot weather insulation. This is, however, contrary to the findings ofMansir et al. (2019), whereby professionals rated the performance of EPS used in constructing houses in Citec Mbora Estate to be better in heat insulation than in cold insulation. This is also contrary to the findings ofIbrahim et al. (2013) and also Ede et al. (2014) that rated the performance of EPS to be better in heat insulation than in cold insulation. A probable reason for this could be attributed to the active ventilation (fan, air conditioning) often used in the houses due to the annual climatic variation in Abuja, whereby hot weather lasts longer than cold weather.

Also, occupants of Citec Mbora Estate are more satisfied with the performance of EPS in terms of its aesthetic appeal than in its sound insulation. This supports the findings in Mansir et al. (2019), whereby professionals rated the performance of EPS used in constructing houses in Citec Mbora Estate to be better in aesthetics appeal than in sound insulation.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDY

The satisfaction of occupants residing in Citec Mbora Estate in terms of the physical performance of EPS (maintainability and aesthetics) is more than the satisfaction in terms of general insulation performance (heat, cold and sound). While this may be commendable, particularly regarding obsolescence costs, more

efforts should be made regarding improving the insulation property of EPS used in constructing houses during manufacturing. Future research can look deeper into other factors that cause satisfaction with the factors studied in this research (factors such as cost, frequency, and culture of maintenance of EPS). Also, environmental factors that affect insulation can be covered in future studies of the houses built with EPS in Citec Mbora Mount Pleasant Estate.

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REACTIVE POWDER CONCRETE: A NEW GENERATION OF CONCRETE

REACTIVE POWDER CONCRETE: A new generation of concrete

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Abstract

Concrete is the most widely used construction materials and its production began in the early 1900s. Since then, the concrete has been in use due to its versatility (despite its heterogeneous and porous nature). There is no clear demarcation between normal strength concrete (NSC) and high strength concrete (HSC), any time a concrete with superior strength is produced, it is referred to as HSC. However, a concrete with strength from 41 N/mm^2 and above is acceptably regarded as HSC. Due to its brittleness, low tensile strength and durability problem associated with HSC, a high-performance concrete (HPC) was innovated. It is made up of cement, aggregates, pozzolans, low water to binder ratio (0.3-0.4) and superplasticizer. High-performance concrete has the ability and efficiency to perform its designed purpose with little or no maintenance and is characterized by high strength (up to 120N/mm^2). In 1995, an ultra-high-performance concrete (UHPC) known as reactive powder concrete (RPC) was developed. Reactive powder concrete is a special coarse aggregate-free cement -based material with superior properties than HPC. It made up of powdered materials, fiber and high dosage of superplasticizer. Reactive powder concrete is characterized by high strength of between 57.3 to 800 N/mm^2, high flexural strength (30-60 N/mm^2) and ductility of about 25 times that of conventional concrete. Metakaolin and gear inner wire were locally used in the production of first RPC in Nigeria with a maximum compressive strength of 72.5 N/mm^2, tensile strength of 7.1 N/mm^2 and flexural strength of 22.3 N/mm^2.

Introduction

Concrete is the most widely used construction material, second to water as the most utilized material on the planet (Gambhir 2006, Mehta & Mantero 2007). It is made by mixing cementitious materials, aggregates, water and sometimes admixtures in the required proportions.

Normal strength concrete (NSC) was first made in the early 1900's. It is still a material of choice due to its versatility, low cost and excellent resistance to water (Mehta, 1999), but it has some shortcomings. Hardened Portland cement concrete is heterogonous and porous in nature (Buitelaar, 2004). This is the reason why the concrete becomes affected when exposed to aggressive media, resulting to durability problems. Since strength was used as the only index of determining the quality of concrete at that time, a high strength concrete was developed.

American Concrete Institute (ACI363-1984) defined high strength concrete (HSC) as a concrete having special attributes such as high workability, good strength (41 N/mm^2 or greater) and high durability. Mehrotra, (2009) stated that HSC should have strength of between 75 and 100 N/mm^2 at 28 days with improved impermeability and durability over the NSC. This opinion seems to be more appropriate considering the new innovations, improved technology and materials in concrete production. The HSC is however, associated with some challenges such as brittleness, low tensile strength and strain capacities (Mehrotra, 2009). Because of these problems, a High-Performance Concrete (HPC) was developed in the 1950s (Aıtcin, 2003).

Mehrotra (2009) and Gambhir (2006) defined HPC as follows:

A concrete in which certain characteristics are developed for a particular application and environment so that it will give excellent performance in the structure in which it will be placed, in the environment in which it will be exposed, and with the load to which it will be subjected during its design life.

High performance concrete is made up by the addition of pozzolanic materials with low water-binder ratio (between 0.30-0.40), high strength of up to 120 N/mm^2 which is more durable than normal concrete and its capillary and pore networks are somewhat disconnected due to the development of self-desiccation (Chan *et al.,* 2000; Agharde & Bhalchandra, 2015). The continuous search for high performance concrete for construction in advanced civil engineering and building structures such as long span bridges, skyscrapers,

nuclear stations, etc. has led to the discovery of Ultra-High-performance concrete (UHPC) also known as Reactive Powder Concrete (RPC) with better properties than the HPC.
Reactive powder concrete is a special cement-based material with excellent properties than the HPC that could solve the shortcomings of concrete today (Al-hassani, Khalil & Danha, 2014). It was first produced by Richard and Cheyrezy (1995) in Bouygues laboratory, France. It was made possible by optimizing the packing density of the concrete with precise gradation of all the mix particles (cement, sand, quarts, pozzolans, superplasticizer and steel fiber). RPC has a high strength of up to 800 N/mm^2, high ductility (about 250 times that of conventional concrete) and high flexural strength (30 -60 N/mm^2) (Maroliya, 2012, Sujatha & Basanthi, 2014).

An overview of Advances in Concrete Technology

Normal Strength Concrete

Development in concrete technology has been ongoing since 1900s. With each successive development and corresponding strength increase, the definition of strength was revised. Chan, Peng and Chan (1996) described concrete with strength between 28-47 N/mm^2 as NSC. Historically, concrete with 25 N/mm^2 was considered HSC in the middle of the 20th century (Wu, Sofi & Mendis 2010). In the 1980s, 50 N/mm^2 concrete was considered HSC. Moreover, there is no exact point of separation between NSC and HSC (ACI363-84). Thus, HSC is defined as that concrete which has compressive strength from 41 N/mm^2 and above. This value was adopted by ACI 363 in 1984, but is not yet hard and fast, because ACI recognizes that the definition of high strength varies on a geographical basis. Another classification of concrete was given in Table 2.1 by Prof. Francis Young of the University of Illinois (Farny & Panarese 1994):

Table 1.: Strength classification of concrete

	Conventional concrete	High strength concrete	Very high strength concrete	Ultra-high strength concrete
Strength, MPa	< 50 (7250)	50-100 (7250-14,500)	100-150 (14,500-21,750)	> 150 (21,750)
Water-cement ratio	> 0.45	0.45-0.30	0.30-0.25	< 0.25
Chemical admixtures	Not necessary	WRA/HRWR	HRWR	HRWR
Mineral admixtures	Not necessary	Fly ash	Silica fume	Silica fume
Permeability coefficient (cm/s)	> 10^{-10}	10^{-11}	10^{-12}	<10^{-13}
Freeze-thaw protection	Needs air entrainment	Needs air entrainment	Needs air entrainment	No freezable water

Source: Farny and Panarese (1994)

So, because ACI is one of the world leading research institutes, their definition has been considered in this paper to be more appropriate. Therefore, it can be said that any concrete with strength below 41 N/mm^2 can be regarded as NSC.

High Strength Concrete

High strength concrete (HSC) is a concrete that has improved properties more over NSC particularly strength. The ACI defined it as a concrete with designed 28 days strength of 41 N/mm^2 and above. HSC is a concrete with compressive strength of 70 N/mm^2 or above (Kosmatka & Wilson 2012). Nayak and Jain (2012) describe HSC as a concrete of strength between 65 and 100 N/mm^2. However, looking at the lowest

and highest figure stated above, it can be concluded that any concrete with strength between 41 and 100 N/mm^2 can be regarded as HSC. Kosmatka and Wilson (2012) were of the view that the production of HSC does not require special materials; only the designer should know the factors affecting compressive strength and vary them for better results. Moreover, many were of the opinion that the use of HSC depends economically on the availability of high-quality materials for use in the concrete (Nayak & Jain 2012, Mehrotra, 2009). It can be argued that factors affecting compressive strength could be materials (source and method of processing the material) or the way they are used in concrete production. Therefore, HSC depends greatly on the optimization of the concrete and its constituent materials. When producing HSC, the designer should optimize the following according to Mehrotra, (2009):

a. Cementitious paste: the water-cement ratio of the paste should be adequate to give the required consistency and workability without segregation.
b. Aggregates: the fine and coarse aggregates should have the required grading as specified by the relevant standard taking into consideration the optimum cement content.
c. Paste Aggregates Bond: the bond between paste and aggregates is a weak one; attention should be paid to improve its contribution to the overall concrete strength. Attention should also be paid to materials, mix design, handling, placing, compaction and finishing.

The use of HSC has advantages in the precast and prestressed construction which include the rapid output of component and reduction in damage during transportation and handling. It allows the use of thinner concrete sections, longer beams spans which results in overall dead load reduction of the structure (Mehrotra, 2009). The permeability is low, HSC may be used in aggressive environment like the marine environment, etc. However, HSC is believed to be a concrete with limited application such as construction of columns in high rise buildings or off-shore platforms which are critical components of the structure exposed to aggressive environment (Nayak & Jain 2012).

Conclusively, HSC is characterized by superior strength, high stiffness and better durability compared to NSC. On the other hand, high brittleness, low tensile strength and strain capacities were identified as the shortcoming of HSC (Mehrotra, 2009).

High Performance Concrete

Advancement in concrete technology including the use of improved materials led to the use of HSC for modern infrastructure development. However, the use of concrete has been extended to aggressive environment and strength or high strength alone is no longer the index used in determining the performance of concrete. Performance or high performance is defined as the ability and efficiency of a concrete to perform its designed purpose for and or above the specified period of time with little or no maintenance (Mehrotra, 2009). A performance enhance concrete or HPC is a specialized concrete designed to obtain some benefits that are not obtainable from NSC (Gambhir, 2006). In addition to this, HPC is a concrete with superior properties than those of NSC and HSC. Any concrete fulfilling certain criteria aimed at overcoming the shortcomings of NSC and HSC may be called HPC. This is a concrete with improved resistance to environmental factors, high strength, reduced construction time without compromising long term serviceability and other requirements. American concrete institute also defined HPC as concrete meeting special combination requirements that cannot always be achieved routinely when using conventional constituents and normal mixing, placing and curing practices. The HPC is characterized by low water-cement ratio (0.2-0.45) (but super plasticizers are used to make the concrete flowable and workable), it has greater durability in mild, moderate or severe environment than other types of concrete (Kosmatka & Wilson 2012). Table 2.2 shows the list of some materials often used in HPC and their selection criteria and Table 2.3 shows some the selected properties of HPC.

Table 2: Materials used in high performance concrete

Material	Primary contribution/ desired property
Portland cement	Cementing material
Blended cement	Cementing material/durability/high strength
Fly ash	Cementing material/durability/high strength
Slag cement	Cementing material/durability/high strength
Silica fume	Cementing material/durability/high strength
Metakaolin	Cementing material/durability/high strength
Calcined shale	Cementing material/durability/high strength
Expanded shale, clay, and/or slate	Lightweight
Superplasticizers	Flowability
High-range water reducers	Reduce water to cement ratio
Hydration control admixtures	Control setting
Retarders	Control setting
Accelerators	Accelerate setting
Corrosion inhibitors	Control steel corrosion
Water reducers	Reduce cement and water content
Shrinkage reducers	Reduce shrinkage
ASR inhibitors	Control alkali-silica reactivity
Polymer/latex modifiers	Durability
Optimally graded aggregate	Improve workability and reduce paste demand

Source: Kosmatka and Wilson (2012)

Table 3: Selected properties of high-performance concrete

Properties	Test method	Criteria that may be specified
High compressive strength	ASTM C39 (AASHTO T22	55 to 140 MPa (8000 to 20,000psi) at 28 to 91 days
High-early compressive strength	ASTM C39 (AASHTO T22	20 to 41 MPa (3000 to 6000psi) at 3 to 18 hours, or 1 to 3 days
High-early tensile strength	ASTM C78 (AASHTO T97	2 to 4 MPa (300 to 600 psi) at 3 to 12 hours, or 1 to 3 days
Abrasion resistance	ASTM C944	0 less than 2mm depth of wear
Low permeability	ASTM C1202 (AASHTO T277)	500 to 2500 coulombs
Reduced chloride penetration	ASTM C1543 (AASHTO T259 and AASHTO T 260)	Less than 0.07%Cl at 6 months
High resistivity	ASTM G59	
Low absorption	ASTM C642	2% to 5%
Low diffusion coefficient	ASTM C1556	$100x10^{-13}$m/s
Resistance to chemical attack	Expose concrete to saturated solution in wet/dry environment	No deterioration after 1 year

Resistance to sulfate attack	ASTM C1012	Mild exposure:0.10% max expansion at 6 months; moderate exposure: 0.10% max expansion at 12 months; severe exposure: 0.10% max expansion at 18 months
High modulus of elasticity	ASTM C469	34 to more than 48 GPa (5 to more than 7 million psi)
High resistance to freezing and thawing damage	ASTM C666, Procedure A(AASHTO T161)	Relative dynamic modulus of elasticity after 300 cycles of 70% to more than 90%
High resistance to deicer scaling	ASTM C672	Visual rating of the surface after 50 cycles of 0 to 3
Low shrinkage	ASTM C157	Less than 800 millionth (microstrain) to less than 400 millionths (microstrain)
Low creep	ASTM C512	70 microstrain/MPa to less than 30 microstrain/MPa (0.52 microstrain/psi to less than 0.21 microstrain/psi)
Increased workability	ASTM C143 (AASHTO T119)	Slump more than 190mm (7.5in)
Increased workability for SCC	ASTM C1611	Slump flow =600mm (24 in)
Resistance to alkali silica reactivity	ASTM C441	Expansion at 56 days of 0.20% to less than 0.10%
Resistance to delayed	Maximum internal	Less than 70 ^{0}C (158 ^{0}F)

Source: Kosmatka and Wilson (2012)

The life span of HPC is between 75 to 120 years (about 2-times longer than conventional concrete (Mehrotra, 2009). Therefore, according to (Nayak & Jain 2012), for a concrete to be recognized as HPC it must comply with the requirements of impermeability and dimensional stability.

a. Impermeability: the movement of moisture and harmful chemical ions into concrete can greatly affect the performance of concrete leading to corrosion of steel or expansive reaction within the concrete that affect its service life.
b. Dimensional or volume stability: this depends on high elastic modulus, low thermal strain, low drying shrinkage and low creep. If these are not taken care of, undesirable stress effects can result in volume changes under restrained conditions. Improved elastic modulus can be achieved through proper selection of materials in concrete proportions. When this is done, the creep and drying shrinkage at 90 days can be reduced to less than 0.04% as against 0.08% common to normal concrete. Volume stability can therefore be achieved by limiting the total volume of the cement paste in concrete and by using coarse aggregate which has high strength and elastic modulus.

Benefits of using HPC

The following are some of the benefits according to Mehrotra (2009) that can be derived from using HPC:

i. Using thinner section (leads to dead load reduction) and reduction in the overall cost of the structure
ii. Early removal of formwork
iii. HPC members have greater stiffness and are relatively lighter
iv. Concrete can be put into service much earlier; for example, an HPC pavement or heavy-duty platform can be opened for use in 4-5 days
v. Bridge deck made of HPC are more durable and require minimum maintenance
vi. HPC members have higher axial strength that allow use of smaller columns

Applications of HPC

Some of the areas of applications of HPC are as follows:

i. The common use of HPC is in the construction of high-rise buildings, bridge decks and columns structures, use of reduced column size, increase usable space in high rise buildings with smaller foundations.
ii. The HPC can be used to satisfy special needs like high compressive strength, high flexural strength, etc. in areas like dams, roads pavements, airport runways, etc.
iii. It can be used to build long-span bridges components like piers and pier columns abutments, decks, rails, etc. Because of its longer life-span, HPC can cut down significantly maintenance repairs and even replacement needs over the entire life of the bridge.
iv. The HPC reduces construction time.

Reactive Powder Concrete

There is growing interest in the emerging of new cementitious materials with better properties than NSC, HSC and HPC. Reactive powder concrete (RPC) has been recognized as a revolutionary material that provides ultra-high strength, excellent ductility and excellent durability (Tam, Tam & Ng, 2010). The RPC is a mixture of very fine powders (cement, sand, quartz powder and silica fume), steel fibers (optional) and super plasticizer (Song & Liu, 2016). It was first produced in 1995 by Richard and Chereyzy in the Bouygues laboratory, France. It is regarded as a promising material for special precast industries members such as those used in industrial and nuclear waste storage facilities (Yazici *et al.,* 2010). RPC is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits and build structures that are strong, durable and sensitive to the environment (Maroliya, 2010).

Composition of reactive powder concrete

Reactive powder concrete is composed of cement, sand, quartz sand or powder, silica fume, steel fibers (optional) and super plasticizer (Song & Liu, 2016). The use of super plasticizer is at optimal dosage which leads to reduction in water cement ratio while improving the workability of the concrete. Silica fume, as the major ingredient of RPC, is an excellent pozzalanic material that has proven benefits on the properties of concrete (Srivastava, Agarwal & Kumar2012). Its major influence is that of filler which fill the spaces between the cement particles.

Properties of reactive powder concrete

The properties of the RPC are highlighted as follows:

Fresh properties

At the beginning of the 20th century, the concrete industry deemed it necessary to monitor the workability of concrete to ensure that the concrete can be properly placed and achieve adequate strength (Koehler & Fowler 2003). The workability of fresh concrete influences micro structural development as well as the ultimate hardened properties of the concrete. Moreover, the main function of any fresh concrete is that it should be consistent in such a way that it is readily consolidated in forms and around reinforcement without excessive bleeding or segregation (Roussel 2007). Therefore, fresh concrete with sufficient workability shall have good hardened properties. The strength of concrete depends upon hydration reaction in which water plays an important role (Tam, Tam & Ng, 2010).

The quantity of water required for chemical combination with cement and occupying gel pores is instrumental for hydration process. Shetty (2015) stated that the theoretical water/cement ratio required is 0.38. Use of water/cement ratio more than this will result in capillary cavities; less than this, will result in incomplete hydration and also lack of space in the system for the development of gel. The use of good water to binder ratio is significant in achieving concrete with required strength. Tam *et al*. (2010) noted that the strength of concrete largely depends on hydration reaction. However, there is different water to binder ratio used by many researchers across the globe to achieve maximum compressive strength. For RPC, the amount of water-binder ratio is lower than the theoretical (0.38). Richard and Cheyrezy (1995) as pioneer researchers of RPC, used water/binder ratio of between 0.15 to 0.19. Subsequent researchers on RPC used

between 0.17 to 0.3 (Al-Hassani, Khalil & Danha 2014; Sujatha & Basanthi 2014; Tam *et al.* 2010; Cwirzen *et al.* 2008, Ibrahim *et al*. 2020).

Hardened properties of RPC

RPC is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits and build structures that are strong, durable and sensitive to the environment. It was developed by Richard and Cheyrezy (1995) and since then, there have been a lot of researches in this field trying to explain the properties of the RPC particularly the hardened ones. It was stated that the RPC was made possible by the application of certain number of basic principles relating to the composition, mixing and post-set heat curing of the concrete. It is now possible to produce concrete with strength of between 170 to 200 N/mm^{2}as R200 and between 650 to 810 N/mm^2 denoted R800. But R800 is obtained with a mixture incorporating steel aggregates. Moreover, R800 has flexural strength of between 30 to 60 N/mm^2, young modulus of between 50 to 60 N/mm^2. R800 on the other hand has flexural strength of between 45 to 141 N/mm^2. RPC is tested in terms of strength, uniaxial compressive stress-strain relation and flexural load deflection relation.

After the discovery of the RPC in 1995, researches have been continued to date. Chang *et al.* (2006) evaluated the performance of RPC used as a retrofitting material. Results showed that the flow of fresh RPC was between 155 to 205%, the average compressive strength was 110.7 N/mm^{2}and 157.9 N/mm^2 for 7 and 28 days respectively under normal moist curing. Moreover, there was an increase in strength of between 28.7% to 40% when steam cured.

Most of the researches that came after the discovery of RPC achieved the same or similar mechanical properties to those of the pioneer researchers. Another break through is that of using other pozzolanic materials to partially replaced one of the constituent materials of RPC. In 2010, Yazici *et al.* replaced up to 60% Portland cement with ground granulated blast furnace slag (GGBFS) and achieved a compressive strength of over 250 N/mm^2, after autoclaving (using granite aggregates), 400 N/mm^2 was achieved with external pressure application during setting and hardening stage (using bauxite aggregate). There was also reduction in cement content; 564 and 376 kg/m^3 were used for the two mixes as against 800-1000 kg/m^3 for conventional RPC (Yazici *et al.,* 2009). Reduction of cement led to reduction in heat of hydration. RPC without quartz powder was produced by replacing up to 15% of cement with fly ash and GGBFS (Kumar, Rao & Sabhahit, 2013). The results indicated improvement in compressive strength and modulus of elasticity. More recently, Kushartomo, Bali and Sulaiman (2015) used glass powder of up to 30% of cement by weight to replace quartz in the production of RPC. With 20%, a compressive strength of up to 136 N/mm^2, average split tensile strength of 17.8 N/mm^2 and flexural strength of 23.2 N/mm^2 were achieved.

Reduction of cement content using class-C fly ash up to 60% was targeted under standard curing, autoclave curing and steam curing using bauxite and granite aggregates (Yigiter *et al*. 2012). Test results show that compressive strength of 200 N/mm^{2}was achieved when cured in water. Thermally treated specimens show compressive strength beyond 250 N/mm^2, when external pressure was applied, a compressive strength of up to 400 N/mm^{2}was achieved. Furthermore, split tensile and flexural strengths greater than 20 N/mm^{2}and 25 N/mm^{2}respectively were achieved. The results obtained by Yigiter *et al*. (2012) and Yazici *et al*. (2010) are in agreement although different materials were used to reduce the cement content in the conventional RPC.

Yazici *et al*. (2009) studied the mechanical properties of RPC containing class-C fly ash and GGBFS under different curing regimes with the results indicate that strength of above 100 N/mm^{2}were possible when cured in water. Moreover, strength of over 234 N/mm^2 and 250 N/mm^2 were achieved using steam and autoclave curing respectively. Decreasing cement content led to reduction in heat of hydration and shrinkage which are problems associated with conventional RPC.

Abbas, Soliman and Nehdi (2015) studied a number of UHPC mixtures with varying steel fibres lengths (8 mm, 12 mm and 16 mm) and dosages (1%, 3% and 6%) by volume. Results show an increase in mechanical properties (up to 173 N/mm^2 of strength) as the fibre dosage increase. UHPC mixtures incorporating short steel fibres exhibited enhanced flexural properties compared to that of mixtures with similar volume of longer steel fibre.

Table 4: Summary of hardened properties of RPC

S/No.	Author	Curing method	Hardened properties		
			Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Flexural strength (N/mm^2)
1.	Richard & Cheyrezy (1995)	Water Pressure	(170-200) R200 (650-810) R800	(50-60) R200 (65-75) R800	(30-60) R200 (45-141) R800
2.	Cheng *et al.* (2006)	Water	110.7-157.9		
3.	Yazici *et al.* (2009)	Water Steam Autoclaving	?100 234 250		
4.	Yazici *et al.* (2010)	Autoclaving Pressure	250 400		
5.	Yigiter *et al.* (2012)	Water Steam & pressure	200 400	?20	?25
6.	Abbas, Soliman & Nehdi (2015)		173		
7.	Kushartomo *et al.* (2015)		136	17.8	23.2
8.	Asteray, Oyawa & Shitote (2017)		57.3		
	Average	Depending on the condition & Material	57.3-800	=17.8	=23.2

Types of RPC

There are basically two types of RPC designated as R200 and R800 (Richard & Cheyrezy, 1995) but for the purpose of this paper, only R200 was considered because RPC is at its infancy stage in Nigeria and no availability of instrument for pressure application as shown in Table 2.6.

Table 5: RPC 200 and its properties

RPC 200	Range of values
Pre-setting pressurization	None
Heat-treating	20^oC to 90^oC
Compressive strength	170 to 200 N/mm^2
Flexural strength	30 to 60 N/mm^2
Fracture energy	20, 000 to 40, 000 $J.m^{-2}$
Ultimate elongation	5, 000x10^{-6} to 7, 000x10^{-6} $m.m^{-1}$
Young's modulus	50 to 60 KN/mm^2

Richard and Cheyrezy, (1995)

Application of Reactive Powder Concrete

Reactive powder concrete has been recognized as a new construction material for precast prestressed concrete highway bridges due to its reduced maintenance cost compared to steel and conventional concrete bridge girders (Nematollah *et al.,* 2012) like the repairs and retrofitting on concrete element under compressive and flexural strength (Lee, Wang & Chiu, 2007). The reduction in porosity and the improved impermeability of RPC also lead to significant durability and strength development that enables the casting of slender elements.

The RPC was first used in the construction of a footbridge in Canada known as Sherbrooke in 1997 and a footbridge spanning 120 m was constructed in Seoul, South Korea in 2002 (Nematollahi, Saifulnaz, Jaafar & Voo 2012). Currently, there are thousands of RPC structures (bridges, buildings, nuclear stations, etc.) standing across the globe.

Researches on the use of RPC or UHPC in China are on top gear. The present five completed bridges (made up of RPC/UHPC) in China indicate a significant milestone in this regard (Chen *et. al* 2016). These bridges comprise two railway bridges, one highway bridge and two pedestrian bridges in China.

Because of its fire resistance and large residual strength when exposed to high temperature, RPC can be used as building materials particularly in areas where high temperature is expected (Liu & Huang 2009).

Reactive Powder Concrete in Nigeria

Reactive powder concrete was first produced in Nigeria using metakaolin (MK) and gear inner wire (GIW) as alternatives to silica fume and steel fibre (Ibrahim *et al.* 2020). Results showed that

i. A compressive strength of 72.5 N/mm^2, tensile strength of 7.1 N/mm^2 and flexural strength of 22.3 N/mm^2 was obtained using 20%MK and 0.25% GIW
ii. Reactive powder concrete with 20% MK has better performance in terms of residual strength, water absorption capacity and ultrasonic pulse velocity (UPV) when exposed to elevated temperatures compared with control made with silica fume.

Conclusions

Normal strength, high strength and high-performance concretes are still in use and will continue to be in used for certain purposes. Reactive powder concrete is a special coarse aggregate-free concrete material with superior properties than the other types of concretes. It is stronger and more durable than the other types of concretes. The advantage of RPC is that it enables the concrete industries to produce concrete materials that are strong, durable and sensitive to the environment with long slimmer sections. The use of the unrefined MK and GIW can lead to production of strong, durable, cheaper and sustainable RPC by cutting down importation cost of both silica fume and fibre materials.

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ASSESSMENT OF LEAN CONSTRUCTION TOOLS FOR SUSTAINABLE BUILDING PROJECT DELIVERY IN NIGERIA

Assessment Of Lean Construction Tools For Sustainable Building Project Delivery In Nigeria

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ABSTRACT

The poor image of the Nigerian construction industry arising from suboptimal performance in project delivery due to colossal wastes generation in project delivery is well documented in existing literature. However, effort to proffer solutions to the problems of waste on site in Nigeria has been marginal. Lean construction has been adopted to address problem of waste, non-value adding activities and improved productivity in the advanced economies. This study, therefore, adopted an action research to assess lean construction tools implementation in building project delivery. A pragmatic phenomenological approach was used to collect data related to benefits of lean construction implementation. The study assessed six lean construction tools via two case studies in Yobe State University, Damaturu and Federal Polytechnic Damaturu all in Yobe State. Data was collected through observation, interview, questionnaire, and site diary, and were analysed thematically using content analysis. The results were validated using methodological triangulation. The study found that the application of lean construction techniques in Nigerian construction sites could address the problem of waste and non-value adding activities and improve productivity. The study identifies several challenges and barriers that could impede the application of lean construction, including lack of knowledge on lean approach, cultural issues, misconception by participants, and lack of involvement of designers in the implementation process. In view of these findings, the study recognises training, enlightenment on the benefits of lean, involvement of designers in the implementation process, simplifying the process, trust between the project participants and collaborative planning as strategies for addressing the problems.

Keywords: Building delivery, Lean construction techniques, Non-value adding activity, Traditional approach, Waste.

INTRODUCTION

The Nigerian construction industry as a major sector of the economy requires attention to achieve successful sustainable housing delivery. Nigeria, just like any other developing country in line with her Vision, recognized the need to use infrastructural development as a means of firing the Nigerian economy and uplifting the wellbeing of its citizenry. The need for the use of best practice in the provision of these infrastructures is necessary. In this respect, it has been recognised that lean construction made colossal impact to the construction industry of developed nations, such as USA, UK, Denmark, Chile, Finland, Brazil, Japan (Ballard and Howell, 2003). Scholars as Salem *et al.* (2005), Gonzalez *et al.* (2010), Ballard *et al.* (2009), Adamu *et al,* (2012) investigated the application of lean construction tools. Their results showed substantial improvement in the project delivery in the countries applied. This research aims at assessing the implementation of lean construction technique in the Nigerian construction sites as tool for achieving sustainable construction project delivery.

Pragmatic research approach was adopted. Phenomenological approach used in construction environment for inquiry offers opportunity to spawn a description of everyday experience to achieve an understanding of the essential structure (Malagon-Maldonado, 2014). Extant literature on implementation of lean construction was reviewed to understand how the tools are being implemented on the developed economies. Case study data and semi structured interview methods were used. Data collection instruments included Site diary, minutes of meeting, interview, pictures, questionnaire survey and other documentations. The data were analysed thematically using content analysis for the interview, descriptive and inferential statistics for the questionnaire. The lean projects are compared with non-lean implemented projects to identify the benefit of the lean construction implementation.

LITERATURE REVIEW

Lean construction developed on production management method of project delivery, is a new technique of that can be adopted to any type of construction, especially for quick, uncertain, and complex project. Production management philosophy is the basis of lean construction. Lean construction is different from the traditional construction practice but places more emphasis on the objective of meeting customers' needs with the use of minimum of resources. Lean management in production has made a great revolution to the manufacturing industry, from design stage, supply chain and assembling. When adapted from manufacturing to construction, it changes the method of the work through project delivery processes. The pull concept of scheduling in lean management approach makes it differs from the push concept of traditional management. Lean construction emerges from the objectives of lean production systems, focusing on waste minimization and maximization of end value using specific approaches.

Based on the criteria, the delivery process of a facility and the definition of the facility were designed collectively to better meet the user's expectation and support client's purposes. Negative iterations are reduced in the process while positive iterations are amplified and supported. Work is planned all through the process to reduce waste and increase value at the project delivery level. Effort for improvement of performance and the management are targeted towards improving general project performance which is better than increasing the speed of an activity or reduction of cost. Control is redefined from the results which are monitored to ensure effects. Thus, planning and control of systems performance are measured and improved in the process. However, recently the lean construction community outlined that research should be centred on developing practical solutions to explicitly solve problems not only for identifications (Alschaimi and Koskela, 2018). In that wise, solving the prevailing problems within the Nigerian construction industry, a novel research approach that can go beyond the normal traditional research of descriptive or explanatory research should be adopted to address the persistent practical construction management snags, and contribute to construction management knowledge. Scholars like Azhar, *et al.* (2010), Voordijk (2009), Jang *et al.* (2010) have therefore suggested action, constructive and design science research to be the best suitable model. It was enunciated that adopting lean construction approach in project delivery could address the occurrences of waste and non-value adding activities (Howell and Ballard, 1999; Saurin *et al.,* 2002; Thomas *et al.,* 2005; Salem *et al.* 2007; Schafer *et al,* 2008; Mossman, 2009).

The lean construction concept has been adopted by some developed nations in their construction industry at the project sites, and prodigious benefits were achieved at the projects levels (Nahmens and Ikuma, 2009; Koranda *et al.,* 2012). Lean construction tools have been used in many countries to improve co-ordination, planning, control, productivity, communication, collaboration, teamwork, learning and project performance successfully (Fiallo and Revelo, 2002; Ballard *et al,* 2009; Gonzalez *et al,* 2010; Mossman, 2012). Nevertheless, there is not any empirical evidence that relays the implementation of lean construction concepts in the Nigerian construction sites.

Lean design and construction are the adoption of lean approach, technique, or tools to the entire project delivery process, which is designing the project and at construction stages to gain the benefits clearly achieved in manufacturing operations. These includes reducing cost, minimum delay, less uncertainty, minimum waste, efficient building and facilities and high satisfaction of users. Adoption of lean approach has resulted in best resources utilization, particularly labour and material. It improves construction quality of completed projects, achieves client/owner satisfaction, attain high safety level, ultimately greater profitability for client, builder, contractor, design consultants, (Forbes and Ahmed, 2011). Lean construction technique/tool have been developed and tested in many countries in different projects and have improved the project delivery process as compared to traditional approach. The most common lean construction tools tested include Last Planner System, First Run Studies, Increase Visualization, 5S, Huddle Meetings, and Fail Safe for Safety and Quality.

The International Group for Lean Construction (IGLC) makes a substantial contribution towards formulating the theoretical foundation of lean construction through the application of lean production

concept in managing construction process. The implementation of lean construction principles by developed nations and emerging economy proved to improve project delivery process in terms of project performance and variability from planning to execution. As mentioned earlier, the application of lean construction approach has achieved some benefits in UK, USA, Japan, Korea, Germany, Brazil, Finland, Singapore, Canada, Chile, Sweden and Demark (Abdullahi et al, 2009; Johansen and Walter, 2007; Kim and Jang, 2005; Ballad and Howell, 2004; Chen et al, 2004; Walsh et al, 2003; Bartelsen, 2002; Gabriel, 1997; Meiling et al, 2012). Such benefits include delivery of custom products instantly without waste, well informed business case design in all project level, delivery of product and services on time and within budget, minimisation of conflict which may affect the schedule and budget.

The building industry was identified as the principal actor in application of lean construction approach (Sacks & Goldin, 2007), the application by some countries in specific building projects has improved project reliability and labour flow, better productivity through reliable planning and project performance (Gonzalez *et al.,* 2010; Ballad, 1999), and reduced waste with increasing value to the product. Specific project benefits and improvements achieved using lean construction in some countries include high customer satisfaction, improvement of workers safety, increase value and reduce cost drastically, Improved planning and workflow reliability.

Lean construction was identified as a tool that develop the skill of employees by encouraging active contribution of workers through the job understanding and is configured and structured to give value (Joegensen, 2006). Moreover, Gabriel (1997) established that lean project management approach has been successful in the management of difficult projects which had high level of risk and tight budgets. The technique proves to be the transformation tool in many countries at various levels of project delivery process. Studies have revealed features that lead to its successful application. These studies are categorised into six in a construction organization. In this research, case studies were selected for investigations along such factors - Management, Finance, Education, Government Policy, Technical Factor, Human Attitude.

THE CASE STUDIES

Two (2) pilot case studies were selected. Various implementation documentation forms were developed for easy understanding and assessment of the process. Such forms include WWP and PPC, SWLA schedule, 5S checklist and production control checklists The study was planned by selecting the activities, date for sitework based on schedules, review of drawings. The procedures were practically detailed. This involved step by step laying by the trades men at first run. A small portion of the job was inspected and discussed with the workers, on requirement of the job and how it can be done better and faster. All workers and the project manager were involved in the discussion in which ideas for improvement were given. The ideas were evaluated by the Project manager for possible adoptions. The workers spoke freely based on working experience on how to do the work better and on schedule. The suggestions were formalized in meetings and added to subsequent area of work for improvements. Based on observations a standard crew for the work and sequence of the activities was established. The projects implemented six lean construction tools - last planner, increase visualization, fail safe for safety and quality, 5S, huddle meetings and first run studies via action research as follows.

To achieve the objective of eliminating waste and non-value adding activities a functional two-way communication was provided. The traditional scheduling method was replaced with Last Planner System (LPS) pull scheduling technique which offers good team planning without complications. The Master schedule developed by the project manager based on time given to execute the projects was redesigned using Reverse Phase Schedule (RPS). The master schedule, drawings, chart, quality and safety plan and construction methodology were all distributed to the team members before the RPS meeting. The LPS concept's objective and the procedure was explained to the project team prior to the RPS meeting. All team members participated in developing the RPS activity program. The logic of the activities is identified, and the sequence was adjusted to fit requirement. Activities that dominate the critical path were identified; floats were added to activities with uncertainty in the critical path. The master schedule was the guide for RPS

production plan. Finally, a detail schedule was produced with constrains appearing. The process was observed and adjusted resulting in new detail schedule.

The Six Weeks Look-Ahead (SWLA) schedule was replaced with Four Weeks Look-Ahead (FWLA) for convenience. The FWLA was developed by the project manager based on the result of RPS and master schedule. The main reason for this is because the contractors usually get their payments monthly. Constraints were identified, recorded, and analysed. FWLA schedule was distributed to Weekly Work Program (WWP) meetings. All members of the project team participate in WWP meeting including the contractor. The WWP is compiled from the submission made by different trades before the meeting. The meetings discussed the planning process such as schedules, manpower requirement, quality and safety procedure, construction work requirements in terms of tools, equipment, and material. Early warning chart for supplies were designed, and all anticipated problems are presented. The meeting opened and integrated two-way communications.

Every week the project manager compiled the actual schedule of activities executed, and updates the WWP schedule, a variance control table was developed and analysed. Percentage Program Completed (PPC) was calculated based on start and finished time of activity and circulated to members.
Visual signs on target completion period were placed on workplace in the site. PPC charts were also pasted according to trades, by sighting, each trade knows when her attention is needed. For safety reasons, signs are posted in dangerous places to acquaint the workers on the dangers involve in the areas or operations.
The site supervisors strictly adhered to quality and safety plans which are part of project documents. The project manager selected the casting of isolated columns and beams due to the potential quality for a study to prevent the occurrence of the defects. The defects noticed in other projects was suspected to be due to poor material, but after the study and quality screening of the materials, quality control measures were introduced in the casting of the columns. Another option for the casting was considered, size of aggregate was changed, and poker vibrator was provided to replace manual vibrating. Vibrating using machine was found to be most efficient alternative. All materials were inspected before placements, to sure that only quality materials were delivered to site. Concerning safety, all relevant items were reviewed using safety plans.

The foremen were charged with defining the actions that were implemented for housekeeping. Material and tools layout were designed at the beginning of the project and adopted as job site standardization. It assisted in reducing waiting time in locating material, tools and it enhanced accessibility. The foreman emphasizes on 5S implementation in meetings. Foremen demanded all trades to wash and clean all tools used and keep in designated positions for easy location. Finally, the outcomes were impressive.

At the beginning a weekly meeting was conducted for foremen after weekly work plan meeting. The foremen lead the daily huddle meetings with the workers to review the work required to be accomplished. Three meetings were conducted with the foremen and subcontractors. A five-minute start up meeting for workers was conducted daily after project commencement. At the end the benefits of the meeting were assessed in an interview.
The first run study was conducted on arrangement of tension bar in reinforcement on beams and slabs, casting of beams and slab in expansion joints. The Plan-Do-Check-Act (PDCA) cycle was used as a tool of First Run Studies (FRS).

RESULTS AND DISCUSSIONS

Data collected through observations, interviews, questionnaire, and documents study were analyzed. These were based on the implementation details outlined earlier, the construction processes were observed. Each tool (Last Planner System, First Run Studies, Increase Visualization, 5S, Huddle Meetings, and Fail Safe for Safety and Quality) was observed based on factors already outlined to achieve the project objectives.

Case study A was divided into four phases and case study B divided into three phases as presented in Table 3. All members contributed to the production of the RPS.

Table 1: Phases scheduling for case studies A and B

Phase Scheduling	Case Study A	Case Study B
Phase 1	Substructure	Substructure
Phase 2	Wall with First floor Slab	Wall with Roofing
Phase 3	Upper floor walls with Roofing	Finishing's
Phase 4	Finishing's	

The project manager for case study A indicated that, even though the client recognized the master schedule than the phase schedule, because it is the basis for claiming LAD due to delay in completion and is one of contractual requirement. The phase schedule was later appreciated by client, and they monitor the project progress base on the RPS. This encourages the PM on the project phase completion to use the RPS. The project manager of case study B uses the RPS details as is derived from master schedule only to guide on schedule of work package in the phases. This is in consistent with Ballad (2000) which needed no detail plan (front-end planning) at this stage. The contractor encourages the workers with financial incentives at completion of phase work package at RPS period. The financial incentives provided by the contractor improved the worker morale to complete tasks with the RPS time. Still in case study B, the monthly plan was updated once as the completed phase package was considered. The plan was distributed a day before WWP meeting to the project team members.

The WWP meeting was adopted and maintained in both case study projects. The meetings were held on Wednesdays and Thursdays for case study A and case study B respectively. The project managers collect the work schedule of each trade a day before the meeting. This include manpower requirement, quality and safety requirements, construction methodology, material delivery schedules, 5S requirements (issues of clean-up and placement of materials in right place) and any other problems encountered on the job site that need to be discussed in the meeting. In case study A, the subcontractors did not attend the WWP meeting at the initial stage; they thought is wasting of time, because their schedule task starts at week five. It was insisted that the suppliers shall attend the WWP meeting to ensure prompt supply of material. Just In Time (JIT) was adopted in the supply of materials with co-ordination of first-in-first-out at the project level. This saved the inventory cost. As the work progress, the meeting was adjusted to two weeks for convenience, but the project managers meet weekly informally with the foremen and supervisors to discuss on what was accomplished and what they need to be accomplishing in coming week. It was affirmed that the experience of the planner is the principal source of WWP success. In case study B, the WWP meetings are conducted weekly, and the main agenda of the meeting was.

- An overview of completed task in past week
- Overview of task need to be completed in the coming week.
- Analysing the root cause of schedule delay and subsequent measure to curb it.

The meeting key success factor is the two-way communication, and a consensus among the parties was achieved on result of the agenda. The researcher attends the WWP meeting to monitor how the meeting was conducted. PPC is the matrix used to measure and monitor variation in WWP (Ballad, 2000). Therefore, the PPC was used to monitor the schedule reliability in both case studies. The form developed makes it easy to monitor the PPC by the project managers and prepare the constrain analysis. The PPC for case study A was calculated for 24 weeks and only 20% of the PPC falls below 80% completion, and the remaining 80% of the PPC scored from 80% upward. The PPC chart is presented in Figure 1.

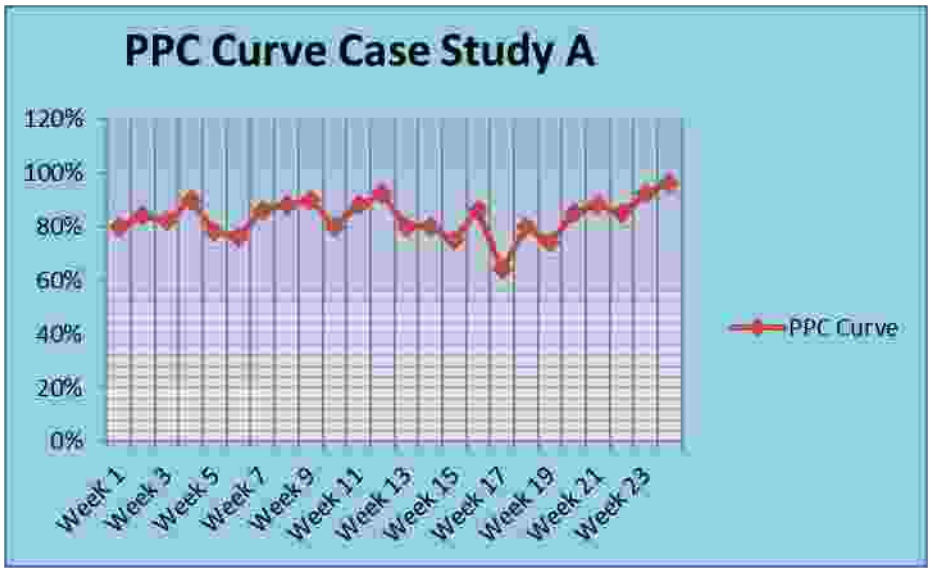


Figure 1: PPC Chart Case Study A

The main reason for delay in completion of the schedule was due to insecurity. Which make the workers to close early to reach their home before imposed curfew time of 5pm. The benchmark of 80% completion was targeted as successful PPC result. The daily working period varies between six hours to seven hours instead of daily eight hours. The LCI affirms that over 80% PPC result is considered successful implementation. The major constraints that affect the PPC were the security situation and Friday congregation's break. One hour thirty minutes was always lost, because some Muslim workers need to go to the mosque to attend the Friday congregation. The good PPC value achieved was due to the effort and commitment of project manager and the foremen, for developing teamwork and cooperation in shaping workflow and optimizing the workflow capacity. The established two-way communication and solving all problems as they erupt, was the success factor of the PPC result. The problems were solved by foremen on site are ratified in WWP meeting. The complete LPS implementation sequence is presented in Figure 2.

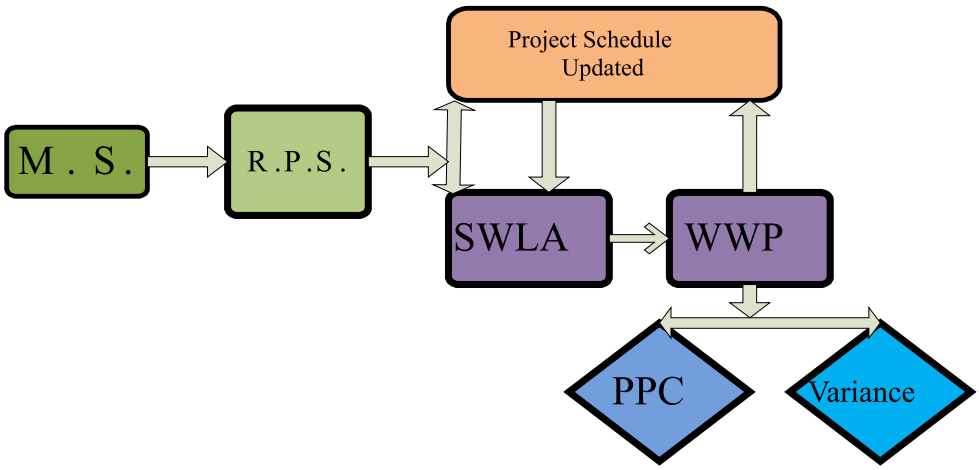
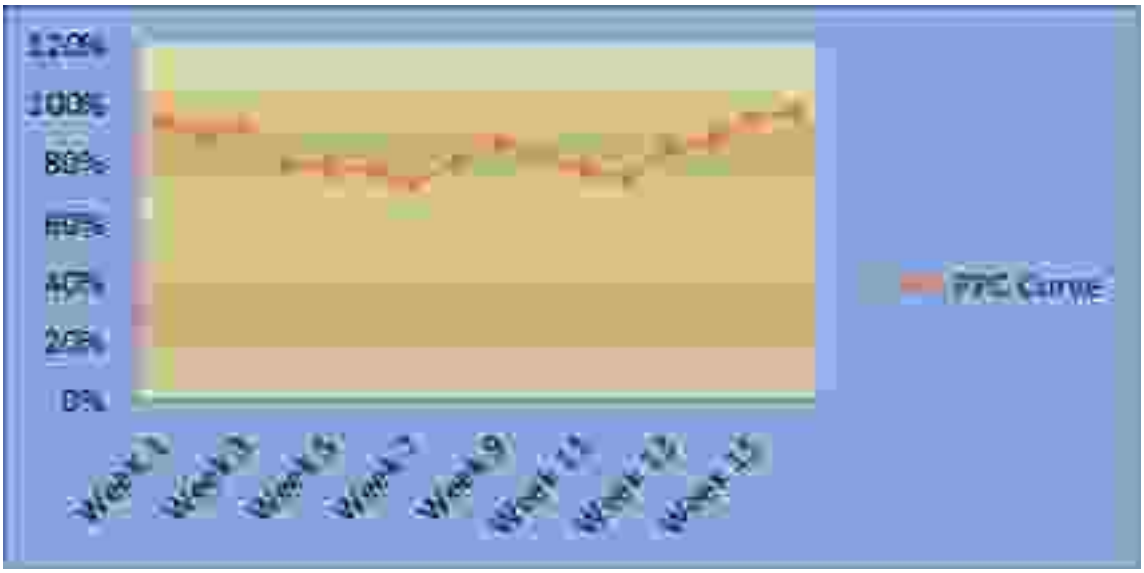


Figure 2: Sequence of Last Planner Implementation

In case study B, the targeted value of the PPC by the project manager was to exceed 80%, but 31% of PPC value was below 80%. The subcontractors managed their schedule effectively, because of the improved co-ordination between different trades. They mobilised to site before their actual schedule date to lay down the soil pipes with assurance that the pipe will be protected by subsequent trade. The PPC results are presented in Figure 3.



The major constraints in the PPC completion for this case study was the insecurity, which delayed the make ready activities and weather (rain fall). The inaccuracy of schedules submitted by subcontractors was among the factors that affect the PPC results The variance of the root causes analysis was conducted. Insecurity and inaccuracy of schedule require the adjustment of the gang size to remove the constraints. The plumbing subcontractor in case study B delays the casting processes of oversite concrete by one day since the pre-requisite work was not completed.

Rain disrupted the completion of week-17 in case A. The cause for failure in case studies A and B, is presented in Table 4. Matching capacity of work force was adjusted to meet up to acceptable PPC values.

Table 2: Root cause for failure

Root Cause	Case Study Project
Insecurity	A & B
Make ready	A & B
Schedule accuracy	A & B
Weather (rainfall)	A

For gradual adoption of the new approach, this meeting was not conducted daily, but three times in a week with interval of one day between the meetings in case study A, while in case study B is twice in a week. When the workers become used to it and realized its benefits the meeting was conducted daily. In both case studies the site foremen participated actively. The meetings were conducted at the beginning of the week with aim to convey the daily targets established during the WWP meeting to entire workforce. The workers ask for clarifications on areas that were not clear, they also give suggestions on the best way to achieve the targets. All pending issues brought forward from the previous week were discussed and addressed. At middle of the week one meeting was conducted to assess the week's progress, and any potential problem that will affect any trade's completion time will be addressed. At the end of the week a similar meeting was also held to review the progress achieved within the week and discuss reasons for failure to complete assignments. All potential constraints the workers may encounter in the following week schedule will be discussed and addressed. The meeting was usually brief about 15 to 20 minutes. The workers contribute to the meeting at different capacity. The foremen included briefing on the issue of clean-up (5S) to the workers in the agenda of the meeting, and the workers accepted it with contentment. The key success of this meeting is two-way communication. The workers solve problem among themselves, they communicate with foremen regularly. The meeting was evaluated at the end during the interview. This is the key instruments of the other tools implementation. It is continues learning process.

The targeted completion dates for some critical activities with uncertainty were placed on the board base on RPS and WWP. The worker can watch and know what is required from them without asking the foremen or project manager. Warning signs placed in dangerous areas, so that the workers will know the dangerous and safety areas. Safety compliance sign was fixed at the entrance gate of the project site, as compulsory and prerequisite for working in the site. This makes the site as accident-free site and helps in achieving high PPC values.

The 5S housekeeping was resisted by workers initially. The project manager and the foremen enforced some basic clean-up assessment checklist that is usually highlighted to the workers in huddle meeting as criteria for working in the site. The workers must wash all working tools and equipment before leaving the site. And all subcontractors are responsible for clearing debris of their work. Material layout plan become continues effort involving all trades. As workers are used to traditional working environment, the foremen continue to shout at them. Implementing the 5S process save the workers time and improved their output.

As quality and safety plan are mandatory and form part of contract document, this projects are not exceptional. The documents were studied in the WWP meeting and strictly adhered to. Preliminary hazard analyses are incorporated in the look-ahead planning meeting and the constraints are identified and removed. The performance of this tool was tracked through the safe working site recorded; this is an indicator achieving proportion of safe work. Lean manufacturing tool was implemented in these projects, which is checking quality at source (QAS). A checklist was used to immediately detect quality problems. This practice improved the quality of these projects compare to the similar projects not using lean. The similar projects not using lean recorded a series of reworks, as the supervisor rejected the columns casted and instructed for their re-cast. The lean projects have not recorded any reworks. The non-lean project in case study A recorded some reworks due to poor quality, while the lean project was moving without reworks. The achieved quality was satisfactory.

The study of site situation was conducted, and a brief meeting was convened on how to improve productivity. The foremen and their team were asked to give suggestions. It was realized that without any additional cost expended productivity will be improved, by improving the method of work, placing material closer to workplace, allocating standard crew to execute an activity. The team makes a first run study of the site features and decided to place concrete material closer to the operations place and blocks were placed around the wall perimeters and designing standard crew to manage the concrete mixer and the pouring operation; an increase in productivity was recorded. JIT was used in supply of filling material. This cut down double handling of materials and improved productivity by cutting down waste tremendously. The quantified value of improvements was analyzed in documents analysis (site diary). filling materials are supplied using JIT blocks were placed around the walls perimeter. These improved the productivity in the site operations and unnecessary movement of workers on site.

Strengths of lean construction

From the interview results of the two projects studied, some strengths of lean construction were observed and summarised as follows:

- As compared to traditional CPM the pull schedule gives more reliable schedules.
- Lean approach improves planning and coordination by involving project participants.
- Lean approach gives fast and reasonable feedback to track causes of failure.
- It recorded an improvement of communication and coordination between the project participants than non-lean projects.
- Matching labour force to material and equipment.
- The lean planning meetings give a better relationship between project participants by sharing their goals and comments.
- Lean has a good documentation to identify constraints and remove them before the project starts.
- It has a control mechanism for managing projects to be completed within cost and schedule, with increase in budgeted profit margin.

Weaknesses of lean construction

Some weaknesses were also identified and summarised as follows:

- Many meetings and repetitive that usually deterred participants at initial stage.
- A lot of documentation, filling of many forms.
- The measurement of PPC weekly was criticized by a subcontractor, when they finished their work before the weekend, it was considered as not completed.
- Some subcontractors miss the training because of late engagement.

Challenges of lean construction

The major challenges required to be addressed before the implementation of lean approach as emphasis by the interviewees includes:

- Knowledge: it is important to train the project team on benefits of lean approach and the application of the lean tools.
- Involvement of project designer in WWP is also considered important.
- Effort to get good result at the initial stage is important to encourage team.
- Trust among the project participants is also important.

Project delivery improvement

The field assessment of the case studies A and B shows a tremendous improvement of the project delivery process using lean concept than the project not using lean. The projects using lean construction approach were completed within the project schedule and cost. The case study A project was estimated at the cost of N96,151,140:75, and budgeted construction cost was at N76,920,913:55, and the project finally completed at N74,324,813:80. The project schedule as per master plan was 24 weeks, RPS was 22 weeks, and the project was completed at 23.6 weeks. While the similar projects not using lean extended beyond their schedule and budgeted cost. The lean tools were used to improve planning, coordinating, and controlling the project delivery process. Figures 4 and 5 are charts comparing materials and time wastes for case studies A and B respectively. Reliability of the projects were thus improved using lean construction tools.

Figure 4: Chart Showing Material Waste for Lean and Non Lean Projects in Case Study

The tools like 5S, increase visualization and huddle meeting are still not fully developed as last planner for full implementation in construction as extensively used in manufacturing. They are used together with last planner to improve communication, knowledge, control of time spends, relationship between different trades and monitoring of action plan. Thus, this tools improved the site operation by reducing waste occurrences in the project delivery process. They helped to improve last planner success in operation planning, co-ordination, and control. Case studies of projects using lean and the other project not using lean were shown in Table 4. The lean project was 100% completed, and the similar project not using lean exceeds their project schedule.

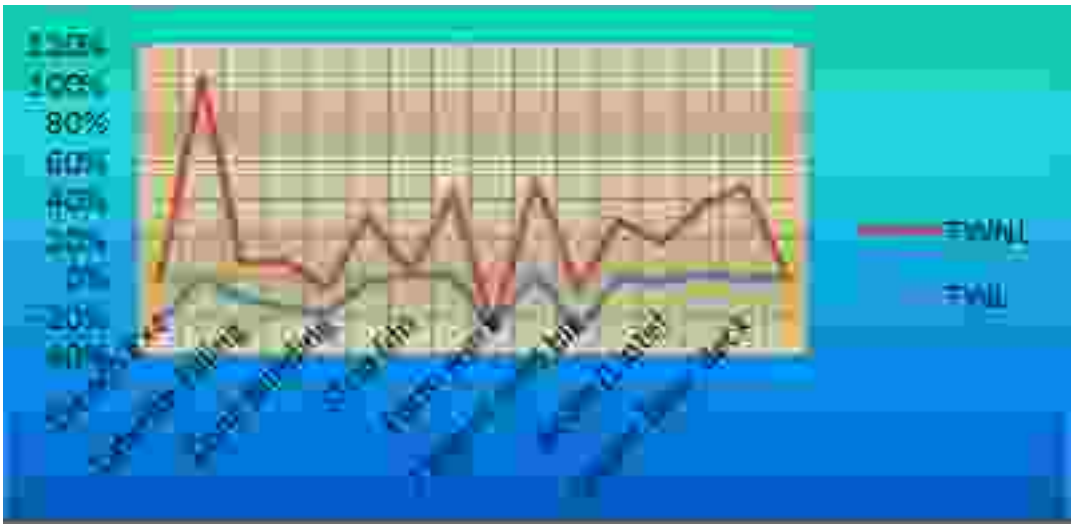


Figure 5: Chart Showing Time Waste for Lean and Non Lean Projects in Case Study A

The apex management of every organisation has an important responsibility to achieve an effective implementation process of any innovative approaches (Salem *et al.,* 2005; Hudson, 2007). The success of lean concept implementation depends on the management commitment, to develop and run a good plan with adequate provision of the resources needs and effective management and support of any change that arose in the process of implementation. Nevertheless, challenges faced towards implementation and barriers recognised in different studies seem to be management related issues. An in-depth appraisal of study by (Common *et al.,* 2000; Alarcon *et al.,* 2002; Forbes and Ahmed 2004; Olatunji 2008 and Alinaitwe 2009) established that slow in making a decision, lack of support by apex management and less commitment in obligations, wrong project definition, late materials delivery, lack of equipment, scarcity of materials, inappropriate organizational structure, weakness of administration, unintegrated supply chain, wrong channel of communication, using inferior devices, unsteady engagement of work, extended period of implementation, poor pre-planning, wrong selection of procurement approaches, insufficient resources, wrong planning, wrong client-supplier participation, poor customer focus and poor long term planning are the main challenges faced and considered as barriers of lean concept successful implementation. However, some of the challenges and barriers seem to be easily overcome, The most important point is for an organization to overcoming these challenges and barriers at the initial stage before the implementation process starts across organisations.

The availability of fund to finance a new and innovative strategy in construction environment, such as lean construction is essential. Workers can be motivated with passable funding, the lean coaching by specialist in lean, provision of appropriate equipment for the site operations and employment lean specialist to guide management and their employees on the process of implementation requires funds. Funding problems are part of some common challenges and barriers faced, and hinder successful implementation of lean concept by many organisations in many countries. Though, the challenges and the nature of barriers differs across certain countries. Studies conducted by Common *et al.,* (2000); Olatunji (2008) and Mossman (2009) reveals that part of these challenges and barriers were contextual, such as corruption, insufficient funds for project funding, professional wages, high rising inflation, pilot implementation cost, and poor incentives and motivation plan, and risk aversion. Failure to adequately overcome these challenges and barriers, will discourage many organisations from implementing lean concepts in their practice.

With all the intensified efforts of knowledge dissemination globally, educational challenge seems to be a strong barrier to lean implementation. There was established efforts to offer guide and awareness on lean knowledge relating to benefits and implementation process in construction site by scholars and practitioner's professional bodies, such as Lean Construction Institutes, Construction Excellence (CE), Lean

Implementation Programme (LIP) and British Research Establishment (BRE). However, their operations remain limited, they only operate in few locations within few countries. Even with the large number of published research, educational problems remained the most common challenge and barriers to lean implementation many countries such developing countries. This may be associated with the fact that lean principle erupted and initiated in the manufacturing industry. Some of these barriers are identified as lack of skills to understanding and comprehend the process and technical knowledge, illiteracy, lack of coaching, lack of holistic implementation, poor knowledge, poor team skills, level of exposure to lean implementation requirement, lack program for awareness, poor understanding and poor shearing of information (Common *et al.* 2000; Cua *et al.* 2001; Alarcon *et al.* 2002; Castka *et al.* 2004; Olatunji 2008; Jorgensen and Emmitt, 2008; Alinaitwe, 2009; Abdullah *et al.,* 2009; and Mossman 2009). Therefore, it can be concluded that educational challenges and barriers stance to be a great threat for successful implementation of lean concept.

Despite the economic stance of construction industry and its contribution made to growth in different countries different levels, still faces many problems that relates to policies made by government. Many studies revealed that, some challenges, and barriers for adopting modern tools and concepts are related to government attitudes towards industry in many locations and countries. A comprehensive investigation by Olatunji (2008) and Alinaitwe (2009) discloses that challenges and barriers such as bureaucracy, inconsistent policies by government, deficiency of infrastructure and social amenities, materials scarcity and unstable commodity price affects the progress of construction industry. Also, some identified challenges and barriers in finance, such as corruption, inflation and wages of professional are also identified to relate to government.

The successful implementation of lean concept faces challenges that are purely technical. These technical challenges are referred to as technical barriers due to direct effect the application of some lean construction tools and techniques. These technical barriers include simplicity, consistency, flexibility, and bench marking. Other identified technical barriers different scholars include constructability and buildability design, poor implementation method, uncertain supply chain, uncompleted design, inaccurate design, lack of good performance measurement method (Koskela, 1999 and Alinaitwe, 2009). The fragmented nature of construction industry poised a great challenge to collaboration and teamwork, these are considered as barriers to partnering and lean implementation (Mossman, 2009). However, these identified challenges are related to some tools and techniques, which will affect the holistic application of the lean construction concept. A disorganised application will never harvest the complete anticipated lean construction benefits.

It was affirmed that, human attitudes towards change poised a major challenge that affects a successful lean implementation in many constructions industry. Scholars have also found that lack of teamwork, cultural change, transparency, self-critics, cooperation, leadership, good housekeeping policy, team spirit, reliable client needs and presence of leadership conflict, misconception on lean, fear of new practice and over enthusiasm are barriers to lean implementation in construction industry (Common *et al.,* 2000; Cua *et al.,* 2001; Castka et al., 2004; Forbes and Ahmed, 2004; Alinaitwe, 2009 and Mossman, 2009).

The case study B project was estimated at the cost of N60,571,872:66, and budgeted construction cost was at N46,640,341:95, and the project finally completed at N45,792,335:73. The project schedule as per master plan was 18 weeks, RPS was 16.4 weeks, and the project was completed at 16.2 weeks. While the similar projects not using lean extended beyond their schedule and budgeted cost.

CONCLUSIONS

The Nigeria construction industry records suboptimal performance in project delivery due to huge wastes generation in project delivery. This study adopted an action research to assess lean construction tools implementation in building project delivery to address problem of waste, non-value adding activities and improved productivity as obtained in the advanced economies. It was observed that the training conducted to the project team was the key success factor for the successful implementation of the lean tools. The project managers' commitment contributed to the implementation success. They contributed to convince the

contractors to employ the lean in their projects, because they have interest in lean approach, and want to be among the pioneers for using the lean tools. The contractors and the subcontractors initially questioned the practicability of the application, but at the end they appreciated the success recorded by the application. Waste and non-value adding activities occurrence was drastically reduced in the lean project. The project team feel proud to complete the project on schedule, without reworks that similar projects not using lean construction experience.

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ASSESSMENT OF CONFRONTATIONS TO SUSTAINABLE CONSTRUCTION PRACTICE IN NIGERIA

Assessment of Confrontations to Sustainable Construction Practice in Nigeria

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Abstract

The United Nations adopted the Sustainable Development Goals (SDGs), thus the seventeen SDGs adopted globally considered the essentials to the flourishing of the planet (earth) and its inhabitants. To achieve this SDGs, the construction sector continues to seek and adopt new policies, better materials, new technologies and sustainable methodologies in the entire construction value chain. Although sustainable construction continues to gain relevance globally, while developing countries like Nigeria are still struggling to adopt sustainability in its construction sector. This paper therefore explores the plethora of confrontations to sustainable construction in Nigeria through literature, investors, community, contractors and construction engineers, the paper opined that the current construction practices in Nigeria should explore the sustainability options available and the challenges dragging sustainable construction in Nigeria. The findings revealed factors inhibiting sustainable construction in Nigeria ranks poverty, corruption, legal policies, high cost materials, limited awareness on climate realities, and limited technical expertise. The paper recommends adoption of traditional sustainability, awareness to the public, government intervention in economy, technology adoption for policies, monitoring and implementation.

Keywords: Climate change, Design, Sustainable Construction, Sustainable Development Goal, Technology

Introduction

According to the report of the 1987 Bruntland commission, sustainability development can be defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Daniel (2003) stated that the Construction industry is all about who plan, develop, produce, design, build, alter, or maintain the built environment and includes manufacturers and suppliers of construction materials, clients, contractors, consultants, and end users of facilities.

When sustainability measures are neglected, construction activities, is likely to have detrimental effects on both man and the environment, emit some greenhouse gases that is unhealthy to the environment. There are some activities, policy in the construction industry that poses serious threat to the environment. The development in the construction sector, contributes to the climate change in either positive way or negative way. Therefore, sustainable construction is a key to the development of Nigeria. Sustainable construction is also key to achieving the SDGs 9 (Industry, Innovation and Infrastructure), SDGs 11 (Sustainable Cities and Communication) and SDGs 13 (Climate Action). When considering sustainability, it is necessary to consider forms after function, such that the properties or characteristics of any construction material, should be highly considered before any construction work.

Figure 1: SDGs (Source: United Nations, 2015)

Construction industry has been found to cause damaging effects to the environment by means of waste generation, energy and water depletion and several other forms of damage to the environment (Aigbavboa., *et al*, 2017). With growing concerns for the environment and climate change, there has been a focus on the way new structures are commissioned and built; particularly in their use of energy and resources (Hayles, 2008).

Sustainable construction (SC) can be seen as a subdivision of sustainable development applied to the construction industry, which can be viewed as "the creation and liable administration of a healthy built environment based on resource efficient and ecological principles" (Kibert, 2016).

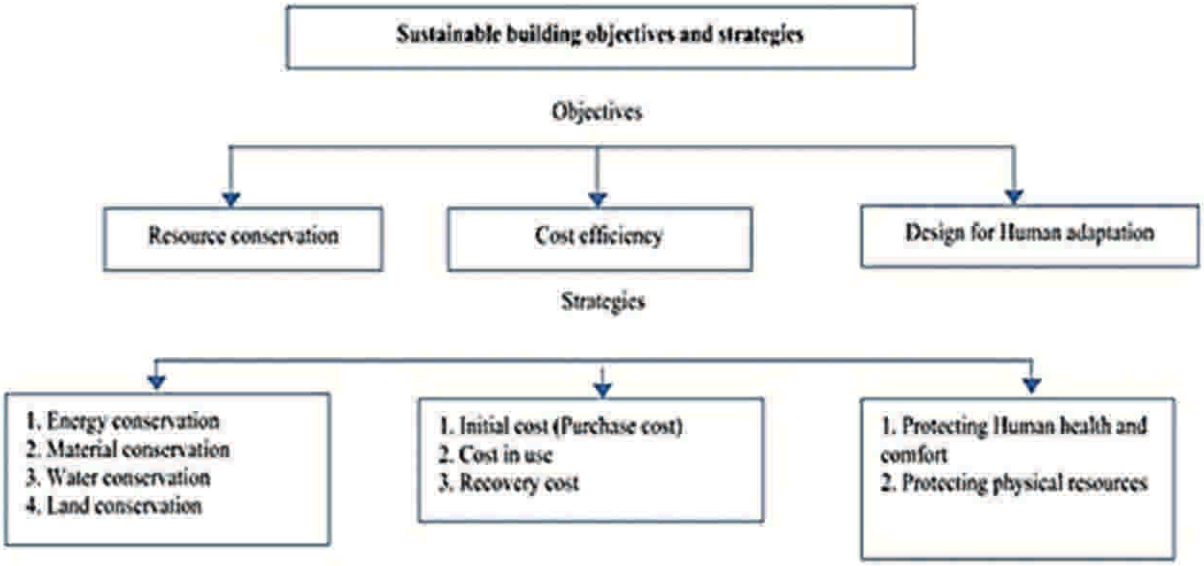


Figure 2: Flow chart of sustainability in construction (Hammadi, and Al-Geelawe,, 2019).

Sustainable Building

Sustainable construction is a strategy that look into reducing the impact of the building activities on the environment. Sustainable development has been defined as the development that meets the needs of the present without compromising the ability of the future generations to meet their needs (Bruntland, 1987).

Mena (2015) opined that, sustainable construction involves issues such as the design and management of buildings, materials performance, construction technology and processes, energy and resource efficiency in building, operation and maintenance, robust products and technologies, socially-viable environments, stakeholder participation, occupational health and safety and working conditions, innovative financing models, improvement to existing contextual conditions.

It is known that on a global scale, construction industry has a variable impact on the depletion of natural resources, air, water pollutions, deforestation and global warming (Wang *et al*, 2018).

Durdyev, *et al* (2018) opined that, for effective implementation of sustainable construction, it is important to identify possible drivers and constraini factors at the beginning, so that frontline industry professionals (government authorities, contractors and project managers) can successively act upon the professionalism

Traditional Building

The traditional method of project delivery imposes a contractual and organisational separation between design and construction whereas in the integrated method, the design and construction are under the same contractual and organisational umbrella thus contractual arrangement and organisational deployment of project participants for the realisation of the building project are important processes (Dada, 2012). According to Bima *et al.* (2015) projects are affected by the procurement method adopted for project delivery and that performance of projects could be improved using alternative or hybrid procurement methods. The traditional system does not create a unified team in which experience, feedback, and new ideas are shared, resulting to client' s needs not fully achieved, caused by the separation of design and construction (Kong and Gray, 2006). The alternatives of project delivery methods that are available today resulted from the need to improve construction project delivery (Babatunde *et al.*, 2010).

Traditional method of project delivery has been widely criticized as an ineffective procurement method yet is the most often used by the stakeholders (Bima *et al.*, 2015). The major criticism of the traditional contract was that, construction activities were getting more complex and hence there was need to integrate design and construction for a better solution. Thus, separation of design and construction phase of building projects created more rooms for ineffective management of building projects, which often result in conflict between the design team and the building contractors. The traditional system generally, has also been continuously identified as the slowest method of procuring building projects. Kong and Gray (2006) pointed out the major criticisms of the traditional system identified in the literature include, time consuming aspects of the development processes, the effect of cost uncertainty, the effect on buildability, and fragmentation of organizational interface. According to Amal Gambo Muazu *et al* (2017), traditional building materials can be used as:

a). Structural materials – Load bearing construction (wood, stone, rammed earth, straw bales, clay bricks, etc.)

b). Insulation materials- Sheep wool, fibers- hemp, cork, etc.,

c). Complementary materials- realization of plastering, painting, flooring (clay, cork, etc.).

Traditional construction materials are highly sustainable, affordable and available for different purposes. Adopting the use of this traditional materials, is another way to sustainable construction.

Building Regulation In Relation To Sustainable Development

Regulations are rules or norms adopted by government and backed up by some threat or consequences, usually negative ones in the form of penalties (Ruya Fadason, Chitumu Danladi, and Jatau , 2017).

According to the Nigerian Institute of Quantity Surveyors (NIQS), regulatory framework is the due process of regulation surrounding a single topic that entails all of the relevant legislative documents (acts, regulations, annexes) and describes the agency or body responsible for administering the framework. The Building Regulation finds it necessary to identify the factors that promote and determine the future regulation process of the building regulation process and associated standards and guidance in the next 20 years in relation to sustainable construction issues (Architect and Quantity Surveyors Act, 2010). The factors are based on emerging scenarios relating to physical, social and economic changes that are taking place in the country and globally like international requirements, human needs and responsibilities and technological changes (Ruya Fadason, Chitumu Danladi, and Jatau Sharon, 2017; Architect and Quantity Surveyors Act, 2010).

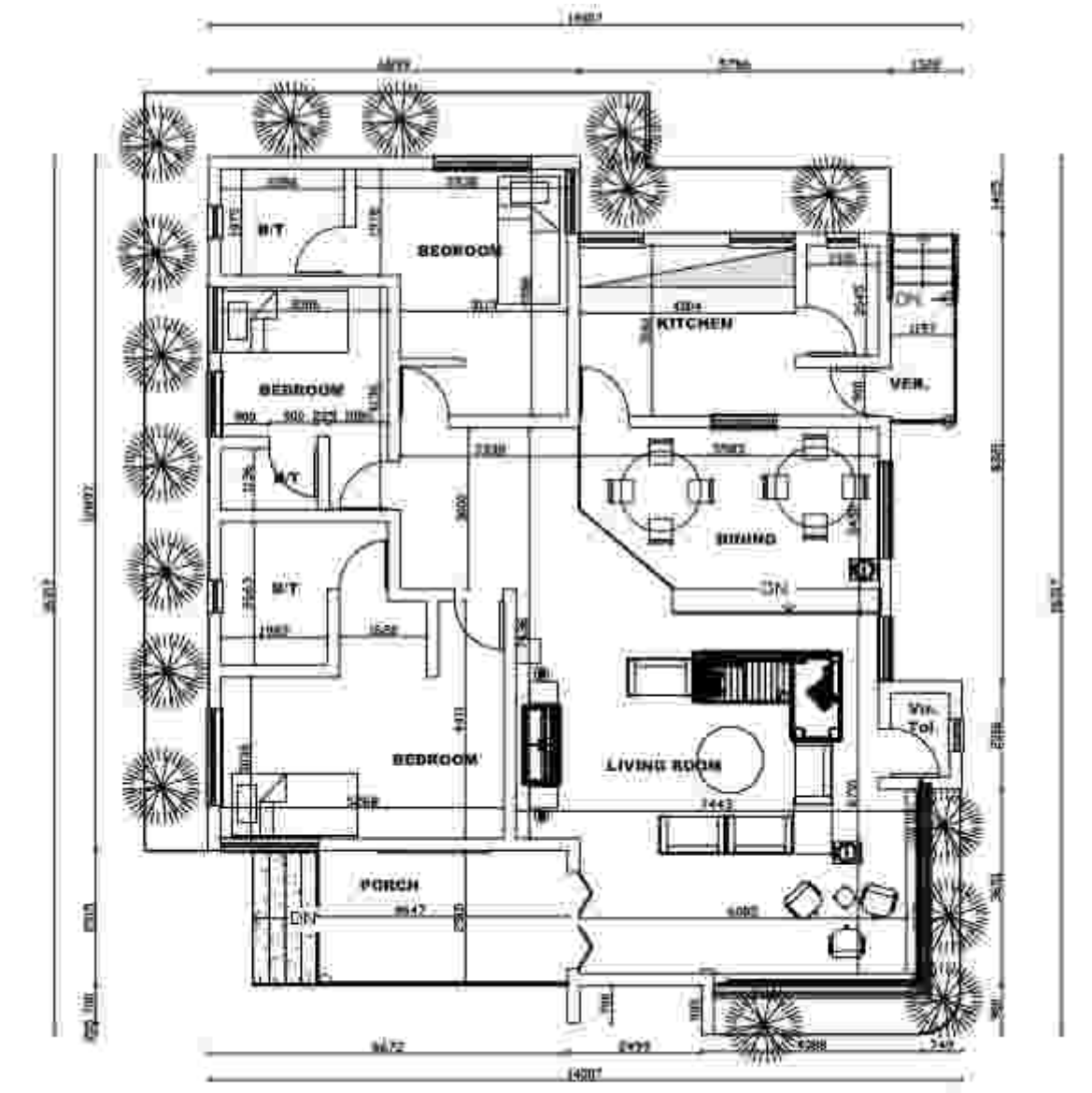
Edinburgh (2003) indicated that some of the factors include climate changes, resource conservation, waste minimization, biodiversity and health and well-being of individuals and communities in and around building.

Comparative Analysis of a Sustainable Residential Building in Ibadan

This section compares a conventional three-bedroom residential building to a sustainable residential building, both in Ibadan. The basis of comparison includes; design method, energy efficiency and management, water management, construction materials, and waste generation and management. The results of the comparison are represented in the table below.

	CONVENTIONAL PROTOTYPE	SUSTAINABLE PROTOTYPE
Building TYPE	**Three-Bedroom flat**	**Three-Bedroom flat**
Design Method	Any orientation Conventional three-bedroom design	Calculated orientation to fit solar yield, and season currents. Includes tree shades, garden, natural ventilation ducts, solar-integrated roof. Designed to accommodate sustainable technology solutions
Materials used	Cement blocks, steel, concrete, roofing sheet (zinc), asbestos ceiling,	Modern customized bricks, wood, steel, PVC ceiling, porcelain tile, wall insulation materials

Energy System	Petrol-powered plant, firewood, kerosene stove, energy consuming appliances used.	Solar-powered plant, biogas plant, gas plant and energy saving appliances used.
Water management system	Water well and borehole system	Rainwater harvesting and conservation system, water purification system, and borehole system
Waste management system	Waste burning, and reliance on municipal waste disposal system	Selected household wastes used to feed the biogas plant, waste-water recycling system, and municipal waste system



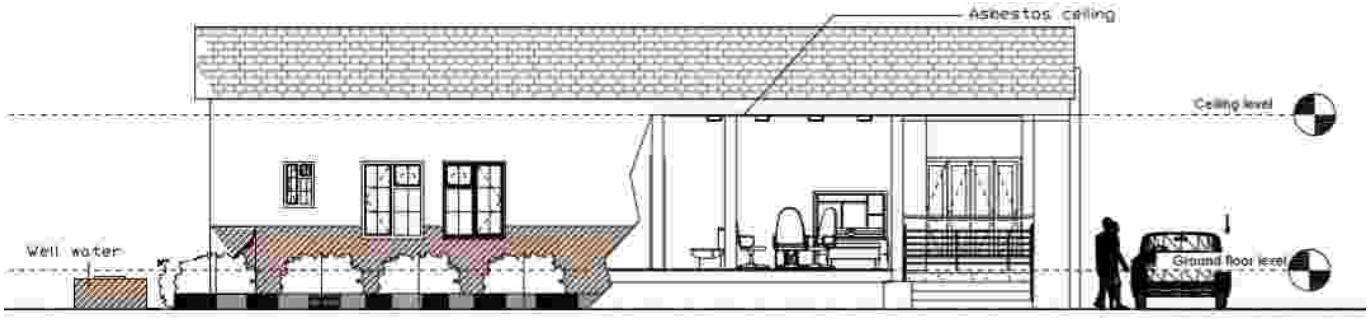


Fig. 3: Showing the Plan, Elevation and 3D of a three-bedroom bungalow of a conventional building design

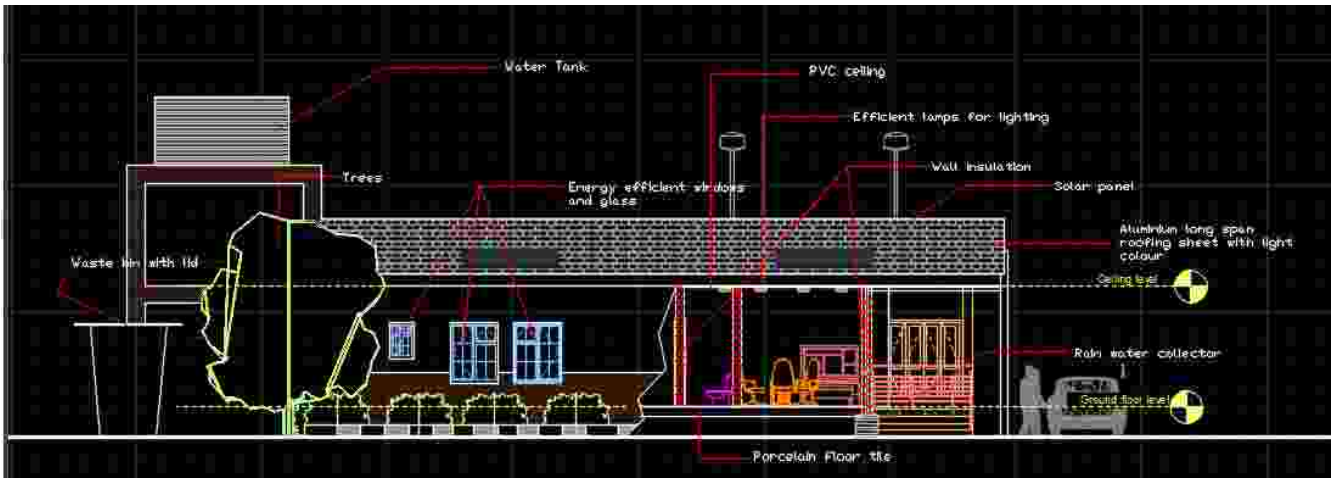


Fig. 4: Showing the design model of a sustainable residential building

Timber

Bricks

Thatches

Bamboo

Fig. 5: Showing traditional building materials that may be used for construction materials (Source: google)

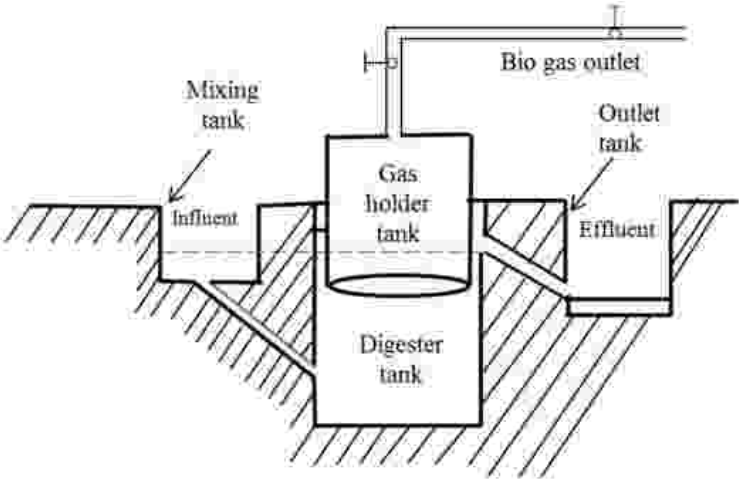


Fig. 6: Showing a Biogas plant
(Md Mizanur Rahman *et al*, 2017)

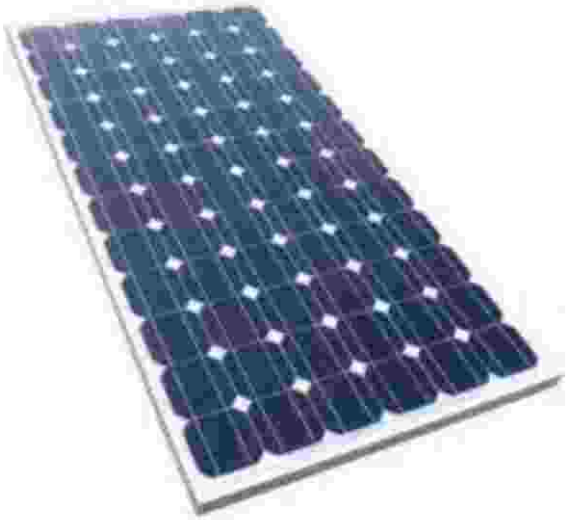


Fig. 7: Solar (source: google)

It can be observed that the sustainable three-bedroom flat building in ***Table 1 and Fig. 3*** above, has many features which are missing in the conventional three-bedroom building. Also, the initial total cost of the sustainable three-bedroom would be higher than the conventional three-bedroom. It is worth noting that the marginal cost of the sustainable three-bedroom is relatively lower in the long run. Seeing the benefits of the sustainable building in the case study in table 1, it will be expected that many Nigerians will embrace such sustainable option. Sadly, there are many confrontations limited the popularity of such option.

Confrontation to Sustainable Building

There are various confrontations to the goal of construction sustainability in Nigeria. Construction in this regard covers projects like; buildings, bridges, roads, dams, and other edifices

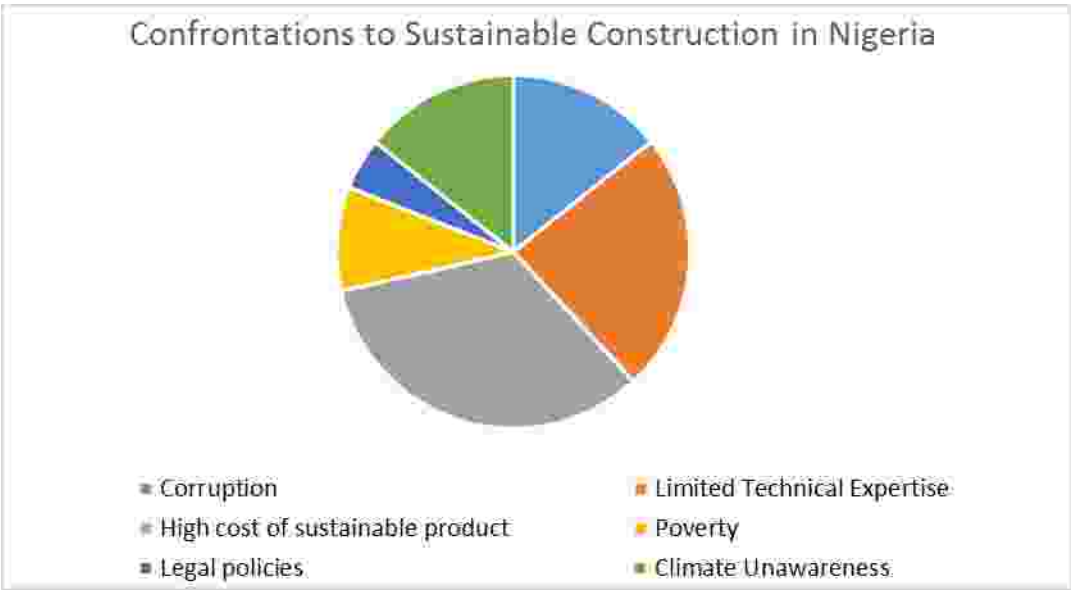


Figure 8: Confrontations to sustainable construction in Nigeria

As seen in the chart (fig. 3) developed in this work, the confrontations to sustainable construction in Nigeria are discussed below.

Corruption

In a developing country like Nigeria, majority of the public construction activities are funded by the government. It is common to hear of public fund embezzlement. The Vanguard newspaper published an article on January 28, 2021 that, on the global corruption index, Nigeria ranks as a highly corrupt nation. Nigeria ranks 149 out of 183 countries assessed by Transparency International (www.transparency.org). Infact, a former Nigeria president had to set up an agency (EFCC) to curtail the issue of economic and financial crimes. Many public office holders continue to divert public funds allocated for sustainable construction and infrastructure in Nigeria.

Poverty

According to the United Nations multidimensional poverty index (MPI), more than 49% of the Nigerian population live below the poverty line. As published on www.worldbank.org, in 2020, the Nigeria National Bureau of Statistics (NBS) confirmed that 40% of Nigeria's total population live below the country's poverty line of 137,430 naira (381.75) per year. Many Nigerians go any length to provide shelter for their family. In the quest to get any form of shelter, they use poor designs, unsustainable materials, and engage quack builders. The cost of building a standard modern structure is very challenging for many Nigerian who live below the poverty line.

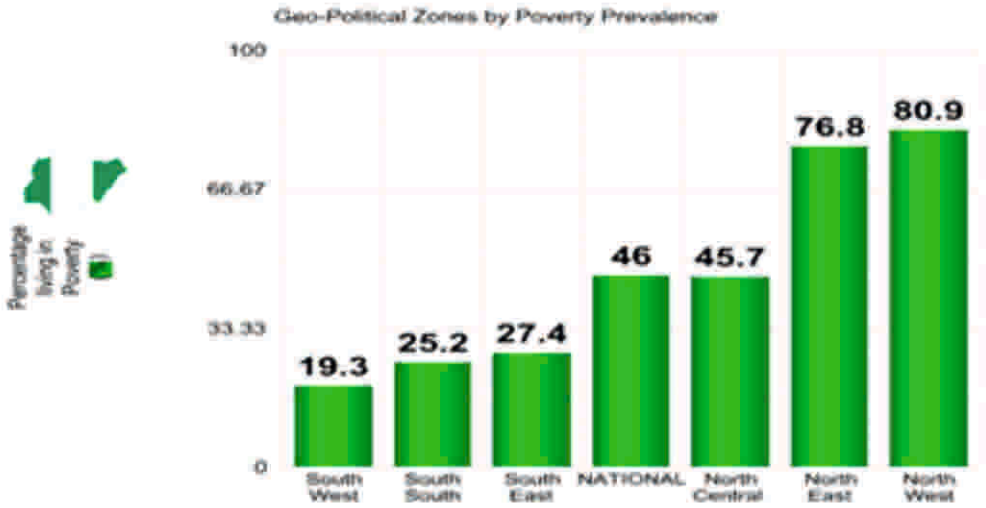


Figure 9: Poverty index in Nigeria (Source: google)

Inadequate awareness on climate change realities

The building industry grossly contribute to greenhouse gas emission. The BBC news (www.bbc.com) reported on 17th December 2018, that cement is the source of *5 of the world's carbon dioxide (CO2) emission. Many material users are unaware of some sustainable product, improved technology etc. Several Nigerian communities have no clue about climate change and sustainability. Odjugo A.O, (2018), conducted an analysis of climate change awareness in Nigeria and reported that majority of Nigerians are not aware of the impact of climate change. More awareness programs should be initiated and vigorously implemented locally across the country. Awareness on sustainable materials, sustainable energy consumption during and after construction processes. Builders, contractors, and communities need to know how all their actions and construction decisions affect the climate. Global warming is real; that information needs to sink to the grassroots level.

Inadequate technical expertise

Emerging field of sustainable construction comes with the adoption of new building designs, new construction methods and models and it comes with the integration of technology. In Nigeria, majority of construction works (especially building) are handled by people who are not trained to integrate all aspects of sustainability. In an interview which was published by the guardian newspaper on 7th September 2020, the

president of the Nigeria Institute of Building (NIOB) stated that there I need for capacity development in green building. To increase professional expertise, the Nigeria government should pay more attention to building technology schools and programmes.

High cost of sustainable products

This is also one of the factors and challenges faced when aiming at the goal of sustainability in the Country. Over a decade, there has been a dramatic increase in the costs of building materials in Nigeria, and this development threatens the performance of the construction industry (Akanni P.O *et al*, 2014). Not everyone can afford every product. Because of the high cost in constructing green buildings, the client and builders, looks for an alternative and cheaper product that is not sustainable. Majority of the materials are imported and it makes the materials costly. Locally producing sustainable materials will do a lot to the issue of costly materials.

Legal policy

Some policy pertaining to sustainability in Nigeria are not properly enforced and followed, and this makes people to do whatever they like, not minding whether the environment is endangered or not. It is common to see construction activities being carried out without obtaining necessary approval and regulatory documents.

Adebiyi (2013) believes that in most developing countries, government policies tend to favour the urban areas, because a large percentage of government budgets are devoted to the provision of urban infrastructure at the expense of the rural areas. It is necessary to radically improve the capacity of government at all levels to play an active role so as to have sustainable construction (Plessis, 2002).

Conclusion and Recommendation

This research has identified and discussed the various confrontations to sustainable construction in Nigeria. Some of the issues identified include: poverty, corruption, legal policy, high cost of sustainable products, limited awareness on climate realities, and limited technical expertise. To address the various confrontations, the government need to take economic measure to alleviate poverty. There is also need to encourage local innovation and production of sustainable building materials. Both the public and private sector must be deliberate in creating more awareness on climate change and sustainability. Furthermore, the government need to re-evaluate its approach in legal policy implementation. Both government and private sectors should leverage the power of 21st century technology to achieve sustainable construction agendas in Nigeria. In addition, proactive measures must be taken to eradicate corruption in public infrastructural sector. Sustainable construction will foster a flourishing economy and a healthy environment. We need to build right, so as not to endanger humans and the environment.

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APPLICATION OF SUSTAINABLE CONSTRUCTION TECHNOLOGY FOR SUCCESSFUL BUILDING PROJECT DELIVERY IN NIGERIA

Application of Sustainable Construction Technology for Successful Building Project Delivery in Nigeria

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ABSTRACT

Construction industry has the highest demand when it comes to sustainable buildings and it is committed to deliver a sustainable built environment. The research opined that, the construction sector has the largest consumption of raw materials and generates between 25 to 40 percent of the world's carbon emissions. The major problem associating with sustainable project delivery is not the energy waste and pollution but a problem of obtaining and utilizing sustainable design. Because if humans could spend intelligent effort in inventing plants, tools and products from the on-set, there would be a reduced or no challenge of pollution, waste and materials that reduces the ecological impact of commercial and residential structures. In construction industry there are numerous problems that diminishes the efficiency of sustainable design; therefore, this problem are tackled and solved with practical principles that needs to be monitored. As we are in the modern world of technology, the construction industry, especially in developing countries is currently faced with the challenge of difficulties in gaining approval of new technologies serving as a barrier to the adoption of technologies in achieving a standard sustainability goal. Various research study was done to back up this paper, therefore, this study aims to identify the various principles of sustainable development and its application to the construction industry.

Keywords: Construction industry, Sustainable Design, Construction Technology, Sustainable Built environment, Energy Waste and Pollution

Introduction

Sustainability is composed of three pillars such as economic, environmental and social that are regarded informally as profits, planet and people; focusing on meeting the needs of the present without compromising the ability to meet the needs of future generations (Adnan *et al*, 2008). Sustainable construction is a means of innovating efficient methods and materials to reduce the ecological impact of commercial and residential structures.

Companies are making progress in public commitments to sustainability through actions such as reducing waste, investing in renewable energy and supporting organizations that works toward achieving a more sustainable future (Price *et al*, 2005). Construction companies achieve their sustainable goal by including proper insulation to prevent heat loss, solar panels for lowering energy usage and building materials with a long life span. Sustainable construction is a continuous process, an ongoing development for life and does not end when the construction of a building is completed. The building should have a reduced negative impact on the environment throughout its lifespan.

According to Yates (2014), the global construction industry produces 36% of worldwide energy usage and 40% greenhouse gas emissions (Carbon dioxide). Too much of these atmospheric CO_2 pollutes the air, water and soil, making the environment uncomfortable and unfit to the human health. In most cases, it is not always about the carbon pollution but how we utilize and manage some of these resources (Yates, 2014).

REVIEW OF LITERATURE

Sustainable Construction

Sustainable construction is the adoption of renewable and recyclable materials when constructing new structures, as well as focusing on the energy consumed and waste Guidry (2004). This principle is to ensure quality of life for the future generations.

Sustainable construction is very crucial for the purpose of developments for the benefit of ourselves, future generations and the environment as a whole. Sustainable construction deals with developing buildings; houses, offices and other commercial properties that uses renewable and recyclable resources with a primary goal of reducing the impact on the environment (Kibert, 2005). Therefore, there must be efforts in changing

ways of developing, maintaining and disposing buildings. Sustainable development goals also known as global goals are to end poverty, protect the planet and to ensure that the future generations enjoy peace and comfortability in their environment (Olanipekun, 2015).
We have eight types of sustainable developments which are wind energy, solar energy, sustainable construction, crop rotation, water conservation, green space, sustainable forestry and hydropower (Patrick, 2020).

The Three Pillars of Sustainability

Sustainable development practices are broken down into what is known as the three pillars of sustainability which are the environmental, social and economic sustainability which has an impact one way or the other; to people, profit and the planet as a whole (Adnan *et al*, 2008).

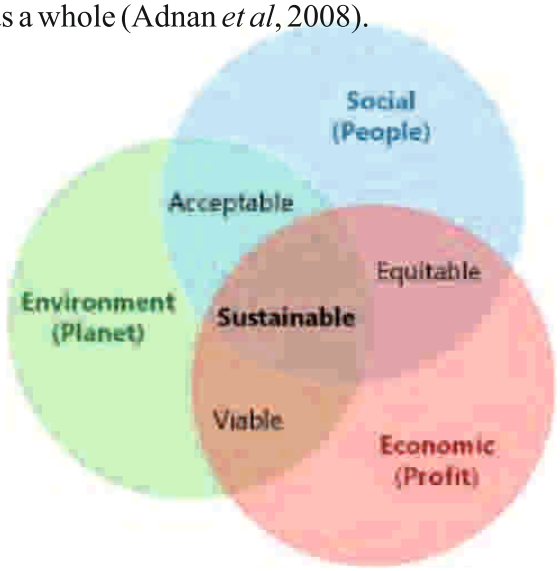


Figure 1: The three pillars of sustainability
Source: Luis (2015)

Environmental pillar is known as the planet pillar and involves minimizing the impact on the environment for the benefit of future generations. The three fundamentals of being environmentally sustainable lies firstly on the principles of renewable resources which indicates that the rate of harvest must not surpass the rate of regeneration. Secondly, pollution which recognizes the fact that the rates of waste generated from a construction project should not exceed the capacity of the environment and the third fundamental principle states that the depletion of non-renewable resources should require comparable development of renewable resources (Blandford, 2008).

The social pillar of sustainable development focuses on people having the support of the employees, customers, stakeholders and the community in which they operate. Social pillar of sustainable development can be categorized into equity, awareness and participation. Equity refers to the accessibility and distribution of goods. Awareness involves making perceptive change of sustainable practices in order to achieve a sustainable future while participation involves including social groups in order to make the buildings more susceptible to design (Kevin, 2012).

The functions of the social pillar of sustainable development is firstly engaging in hiring practices that focuses on learning and development opportunities and flexible work arrangements, also involving the community through community outreach initiatives, scholarship programs and mentoring (Adnan *et al*, 2008).

Most businesses are familiar with the economic pillar of sustainability which is also known as the profit pillar (Bauer, 2015). There is more to the economic pillar of sustainable development than just ensuring a business

remains profitable. Aside from gaining profit, economic pillar of sustainable development practices proper governance, risk management and compliance for economic development. For a business to succeed in the economic pillar, its management must align with the interests of both shareholders and stakeholders as a whole (Ochieng, 2014). Some key considerations to be considered in the economic sustainability development are ensuring accurate and transparent accounting, providing means for shareholders to vote for company directors and leadership, avoiding conflicts of interests, illegal practices through political means and the assessment of business operations and the economic risks to society as a whole (Ojo *et al*, 2014).

Benefits of Sustainable Approaches to Design and Construction

Sustainable design and construction is the approach to creating buildings that have considered the environmental, social and economic impacts from the initial phase through to the lifespan of the building (Olanipekun, 2015).

According to Kevin (2012), the benefit of sustainable construction is divided into three main categories which are environmental benefits, financial benefits and social benefits which are then broken down into smaller units which are benefits of: cost reduction, increased productivity, improved health, waste minimization, better use of materials, environmental protection, noise avoidance, better quality of life, a new market emerging and room for experimentation.

Integrating Sustainable Principles

Sustainable development balances social, economic and environmental goal, making vital contributions to them effectively. Though the built environment has an impact on the environment and provides basic living conditions for the sustainability and development of human life (Tarila, 2014). To ensure the correct application of sustainable development, construction industries must consider the integration of sustainable principles into construction project and sufficient trainings from respective construction industry bodies such as the Nigerian Institute of Building (NIOB). (Opeyemi, 2017).

Miyakate (1996) proposes the six principles for sustainable construction which are:

- Minimization of resource consumption
- Maximization of resource reuse
- Use of renewable and recyclable resources
- Protection of the natural environment
- Create a healthy and non-toxic environment
- Pursue quality in creating the built environment

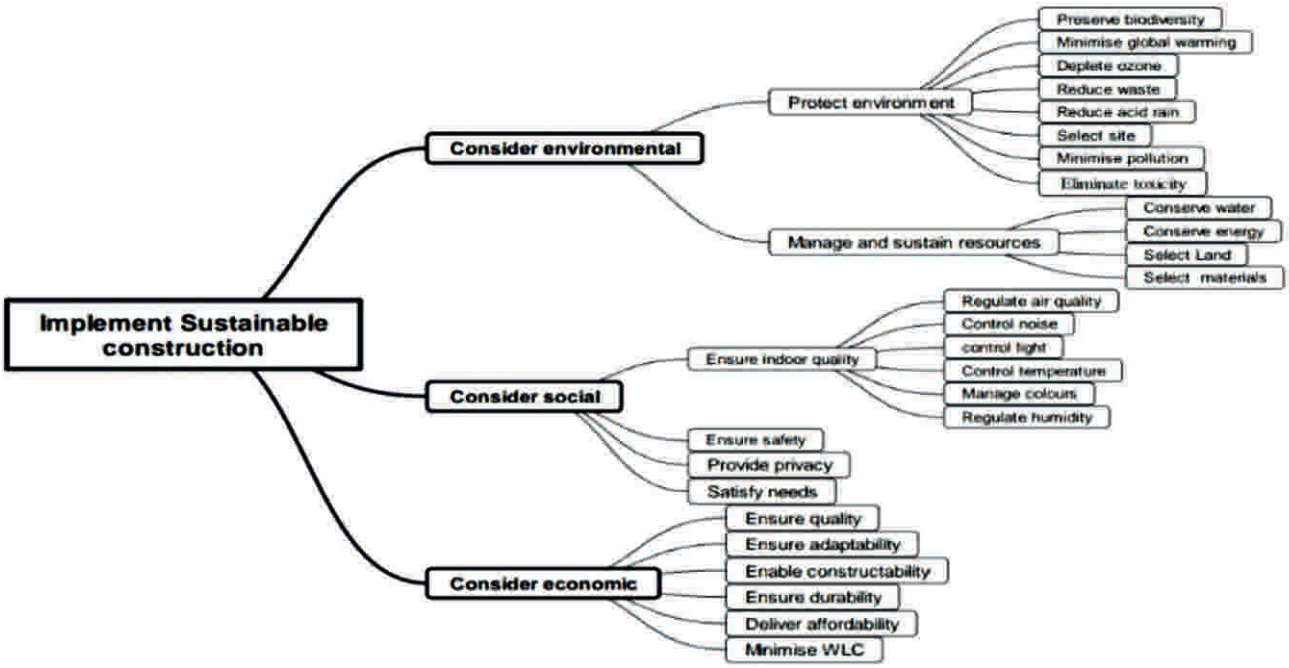


Figure 2: Integration of Sustainable Construction
Source: Price (2006).

From the figure above, the social, economic and environmental factors need to be considered for the successful application of sustainable, ensuring sustainable improvements in the construction project. The integration of sustainable principles into construction project can lead towards sustainable construction and improve project delivery as it was found that it is significant to manage the current environmental issue and attain significant improvement in performance. (Ximing, 2014).

Sustainable Tools and Technologies Used in Green Construction

Green building makes use of natural resources that include efficient use of energy (renewable energy such as solar energy and water energy), pollution and waste reduction measures, enabling of re-use and recycling, good environmental air quality indoor, use of non-toxic and sustainable materials, the environment-friendly design, construction and operation design that allows adapting to changing environment and the quality of life of occupants (Price *et al*, 2005).

The Nigerian construction is a large industry and contributes to the economic growth of the nation but diminishes in the area of sustainable materials and technology. The available sustainable tools and technologies used in green construction are solar power, biodegradable materials, green insulation, cool roofs, electrochromic smart glass, water efficiency technologies, rammed earth brick, prefabrication/modular construction and BIM tools.

Solar Power

Solar power is a clean green electricity sourced from sunlight or from heat from the sun. Solar power can be utilized in either active solar power or passive solar power in which the former utilizes functional solar systems that absorb the radiation of the sun to use for heating and electricity provision and reduces the need for electricity or gas while the latter, passive solar power uses the sun rays to warm homes through the placement of windows strategically and the use of heat-absorbing surfaces (Kibert, 2005).

Installing solar energy makes it sustainable and totally inexhaustible unlike fossil fuels that are finite and emit greenhouse gases. But for solar energy power, it does not emit any greenhouse gases when producing electricity. Using solar energy in a particular building reduces electricity bills and saves money and in addition, it adds value to the building or home (Ahadzie, 2011).

Figure 3: Solar photovoltaic (PV) power
Source: David (2015)

Biodegradable Materials

This is a means of making construction sustainable by limiting the negative impacts on the environment and breaks down without the emission of toxins. The biodegradable materials that is used for constructing the foundation, walls and incorporating insulators, forms part of sustainable construction

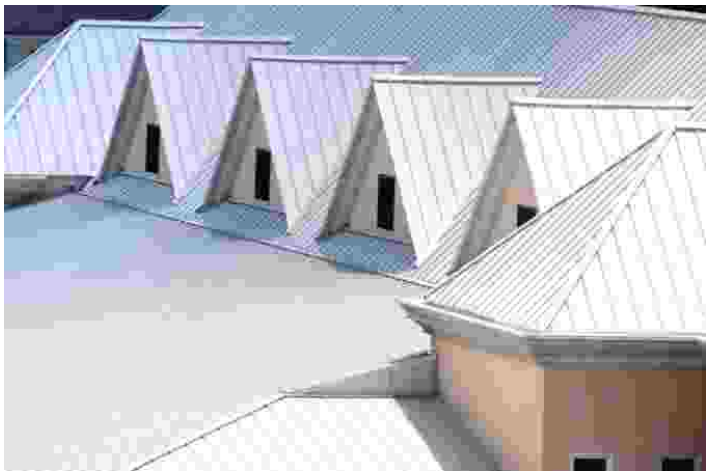
technologies. Readily made biodegradable materials such as sustainable sourced bamboo, timber and organic paints do not have to end up in a landfill (Blandford, 2008). Most of the traditional construction materials that are not sustainable to the environment lead to the accumulation of waste products and toxic chemicals and most of it takes hundeds of years to break down in which when they degrade, it causes harm to the environment (Opeyemi,2017).

Figure 4: Biodegradable materials
Source: Teacho (2020).

Green Insulation

The green insulation is a sustainable construction technology that is adopted to eliminate the need for high-end finishes made from non-renewable materials. Green insulation utilizes recycled materials that are old and being used such as newspaper to line the walls. Green insulations are wall filters that can be gotten cheap and not necessary from highly finished materials.

Figure 5: Green insulation
Source: Ashley (2014)



Cool Roofs

Cool roofs are sustainable green design technologies that helps in keeping the building at the standard room temperature by lowering the heat absorption and thermal emittance. This aims at reflecting sunlight and heat away from the building. Cool roof benefits a building by decreasing the need of air conditioning; thereby reducing energy bills. Another benefit is that it improves indoor comfort and decreases roof temperature which can extend roof service life (Kibert, 2005).

Figure 6: Cool roof
Source: Dezeen (2020)

2.5.5 Electrochromic Smart Glass

This is a sustainable technique that works in hot season to shut out the heat of solar radiation. It uses tiny electric signals to slightly charge the windows to alter the amount of solar radiation it reflects. This can save a lot of heating, ventilating and air conditioning costs.

Figure 7: Smart glass
Source: Marietta Daily Journal (2020)

Water Efficiency Technologies

Dual plumbing lowers sewer traffic and improves the potential of re-using water on-site. Also, rain water harvesting provides water for multi-purpose usage and can be stored for future use. The use of this technique ensures that water is well managed and recycled

Figure 8: A traditional brick and mortar wastewater treatment plant
Source: *US department of energy (2020).*

Rammed Earth Brick/ Compressed earth block

This is an ancient construction technology that is sustainable and in this modern-age, it is getting to be re-introduced which makes it ideal for sustainability and lessons environmental impacts.

Figure 9: A typical compressed earth block building
Source*: Kaitlin (2017).*

Prefabrication/ Modular Construction

Prefabrication is the practice of assembling components of a structure offsite in a controlled environment. This construction needs fewer workers and helps to lessen waste both financially and environmentally (Kibert, 2005).

Figure 10: Image showing an ongoing prefabrication construction process
Source: Farid (2019)

2.5.9 BIM Tools

Zixiang (2017) defines Building Information Modelling (BIM) as an integrated process platform built on coordinated, reliable information of a project from the design stage to the construction stage. BIM is a platform that enables faster, safer, less wasteful construction and more cost-effective, sustainable operation, maintenance and eventual decommissioning (Ochieng, 2014).

Building Information Modelling (BIM) is a set of policies, processes and technologies that, together generate a methodology for the process of designing a building or facility, testing its performance and managing its information and data using digital (based) platforms (Kibert, 2005).

Figure 11: Integration of building design under the concept of sustainable development
Source: TMD Studio Ltd (2018).

Sustainable Construction Barriers and Challenges in Nigeria (Case Study)

Nigeria has a large population of about 201 million people with three tier of subnational government system made of 36 states, one federal capital territory and 774 local governments and has various infrastructures. Nigeria today still struggle with utilizing sustainable designs, digital technology in terms of Building Information Modelling or BIM and the integrated project delivery methods because of some challenges prevailing in the country.

Opeyemi & Michael (2017) gave some trending challenges the country face as regards to building sustainability. One of them is the fact that the socio-economic development in the country is low as well as the standard of living. If the local quality of life in the country is improved, Nigeria will yield to increased sustainability.

Another challenge being faced in the country is the construction team. The construction team is a large contributor to sustainable project delivery and are expected to understand and respond to the sustainability requirements, demonstrating good environmental and social performance.

Also, the rate of corruption in Nigeria is intensively high and unbearable for effective construction development. Another major challenge faced in the country is the dependent on foreign material and labour which makes construction materials constitute the major part of the construction in terms of cost. According to research, Construction materials constitutes over 50% of the total cost of construction. The high cost of

construction materials affects the performance of construction industry.
Key barriers to sustainable construction are higher initial cost, lack of consideration from client and stakeholders, insufficient knowledge and skills about sustainability, insufficient regulations by government, resistance to change and fragmentation (Ochieng *et al*, 2014).

One of the main potential barriers for the implementation of sustainable construction is cost. The high initial cost is a major barrier for owners in pursuing sustainable building objectives, but this can be overcome by changing the view of stakeholders from cost to value and from short term to long term (Olanipekun *et al*, 2015). More so, the critical barrier to sustainable construction is the lack of capacity of the construction sector to implement sustainable practices even though it is a known fact that sustainable practices in construction are estimated to increase initial capital cost generally in the range of 1-25% (Opeyemi, 2017).
Also, the insufficient knowledge and skills about sustainability also constitutes a great barrier to sustainable construction and if left unconsidered, sustainability can be hindered by ignorance or a lack of common understanding about sustainability. Professionals in the built environment needs to be fully acquainted with sustainable construction principles (Olanipekun, 2015). The policies, regulations, incentives and commitment by leadership may not be sufficient enough to move towards attaining realization of sustainability development (Ximing *et al*, 2014). Addressing the term sustainability requires new ways of thinking, practices and attitude, therefore, requires change (Ochieng *et al*, 2014).

Another barrier to promote sustainable construction is the industry's size and fragmentation which has both strength and weaknesses. On the positive view, it deals with highly variable workloads and in the negative view, the extensive use of subcontracting brought about contractual relations to the front and prevented continuity contract to work as a team (McGraw, 2014).

Figure 12: Sustainable Development and its challenges in developing countries
Source: Olga (2018)

METHOD AND MATERIALS

A qualitative empirical study was carried out in this research and previous research and articles as regards to sustainable construction were reviewed while from this study, the integration of sustainable principles were being drawn out explicitly as well as the sustainable tools and technologies used in green construction with their prevailing performances and barriers in Nigeria as a case study.

CONCLUSION AND RECOMMENDATION

This paper has explored the need for the application of construction technologies and their associated barriers in a developing economy, Nigeria as a case study. It is obvious that sustainability in the built environment is a global concern and is being achieved through team work and cooperation. It is required therefore that the contractors, suppliers, tradesmen, architects and engineers must team together in ensuring that every stages of the project meets the performance and safety standards as well as supporting the environment. All stakeholders in the construction industry must join hands together by innovating new ideas, planning and implementation on how to develop sustainable construction technologies that will help in successful building project delivery.

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UNDERSTANDING SUSTAINABILITY IN BUILDING CONSTRUCTION

Understanding Sustainability in Building Construction

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ABSTRACT
Construction industry makes a significant contribution to the growth and development of every economy by providing infrastructure for productive ventures, shelter to the citizens and generating employment to people at different levels of knowledge and skills. It is the backbone of economic development globally. The construction industry can be vibrant when technologies, systems, materials and the processes are of quality standards. Issues of energy consumption, wastage, water and air pollution threatens the health and safety of the people as well as the built environment. The sustainability will not be feasible when the Construction industry have performed below expectations evident by high rate of building collapses, non-compliance of health and safety, loss of lives and properties as well as lack of standards and quality infrastructure for economic development. This has greatly affected the living standards of an average Nigerian. Therefore, understanding sustainable building construction is hinge to pivot development in the construction sector. The method used for the research is exploratory based on relevant literature survey for better understanding of the sustainable building construction. The study concludes that maximizing the use of efficient building material and construction practices, optimizes the use of onsite resources and use of renewable sources of energy, use efficient waste management practices and provide comfortable and hygienic indoor working conditions.

KEWORDS: Buildings, Construction, Standards, Sustainability, Systems, Technologies.

INTRODUCTION
Construction industry makes a significant contribution to the growth and development of every economy by providing infrastructure for productive ventures, shelter to the citizens and generating employment to people at different levels of knowledge and skills. It is the backbone of economic development globally. Construction industry play an important role in developed economies such as job creation, product innovation, research and advancing technologies as well as employment and poverty reduction (Usman & Alaezi, 2016; Chris & Usman, 2019). The Construction industry is recognized globally because of its role in economic development.

Construction industry globally contribute to the economic development of any nation. Economic development can be determined by Gross Domestic Product (GDP). Construction is enhanced by gross domestic product (GDP). For instance, the construction industry accounts for about 5% in Nigeria as compared to South Africa 19%, Mexico 17.7% and Ghana 8% (Usman, 2014, Usman & Alaezi, 2016). This shows that Nigeria is lagging behind in terms of economic development. Studies have shown that the Nigerian economy is dwindling especially in joblessness (Usman, 2014). Evidently, 65% of Nigerian youths are unemployed (Usman, 2014). With the emerging technologies and skills development, the issue of poverty will be a thing of the pass. The construction industry can be vibrant when technologies, systems, materials and the processes are of quality standards. Therefore, understanding sustainable building construction is hinge to pivot development in the construction sector.

Fig.1: Sustainable Construction

Sustainable construction is a way of using renewable energy `and recycling materials as well as reducing energy consumption and waste (Yilmaz & Bakis, 2015. This can also be referred to as green buildings. Sustainable construction is a compound of building that concerns design, economy, utility, durability and comfort. It uses less water and optimizes energy efficiency and consumes natural resources. Although sustainable building construction generates waste but provides health and safety compared to other conventional buildings.

Sustainable buildings are environmentally friendly and resource efficient throughout the life cycle of the building (Usman, 2014). Design can minimize resource and maximize reuse, recycling and utilization of renewable resources. So also maximizing efficient and construction practices by employing skills and quality product. In global arena, optimization of the use of onsite resources and waste management will enhance building sustainability. By this, it provides comfortable and hygienic indoor working conditions thereby minimizing the impact of the natural environment (Didel et al., 2017). Reduces energy and water usage promotes health and safety and increase productivity.

Although the construction industry is a big user of resources, the concern is the climate change and infinite nature of these resources. Construction firm's activities adversely affects and degrade the environment (Geelani et al., 2012). So, increasing pressure will reduce their environmental impact. It should be noted that sustainable construction does not end when the building is completed. The building should have a reduce impact on the environment over time (British Assessment Bureau, 2019). This means that the building design should include elements that can influence the built environment.

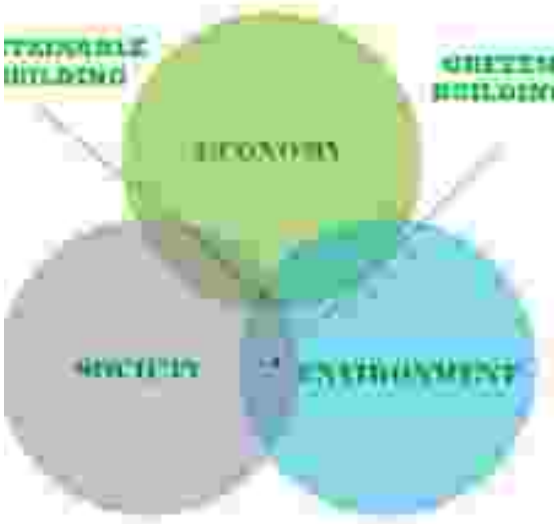

Fig. 2: Environmental Factors

STATEMENT OF THE PROBLEM

Studies by Usman and Alaezi (2016) have shown that the Construction industry have performed below expectations evident by high rate of building collapses, non-compliance of health and safety, loss of lives and properties as well as lack of standards and quality infrastructure for economic development. This has greatly affected the living standards of an average Nigerian. There are several issues that pose challenges to construction industry such as the technologies, systems, skills, insecurity, politics and processes as well standards for sustainable building construction (Chris & Usman, 2019). In addition, high inflation rate has limited economic growth which affects the sustainability of the construction industry. Several efforts geared towards making the construction industry meet its requirements for sustainable economic development have failed. This study therefore, seeks to examine the sustainability in building construction by exploring the advances in technologies, systems and standards for sustainability based on global standards. This can be achieved by minimizing resources, maximizing the reuse, recycling and utilization of renewable resources.

METHODOLOGY

This research used exploratory approach. McNabb (2009) in Usman (2014) advocates that exploratory design is carried out for either one or two purposes, namely; a preparatory examination of an issue for gaining knowledge or for collecting data for immediate application to an administrative or a management problem especially averting building collapses through enhancing sustainable building construction. Exploratory design can be used as a stand – alone design because of its limited scope; in the same vein, it could be used as a stand – alone design when it is used to provide information for management decision (Inuwa & Kunya, 2015). Hence, exploratory design was employed as a stand – alone to provide information for understanding sustainability in building construction. McNabb (2009) advised the use of Literature review as one of the most effective methods for data collection in exploratory design. Hence, the exploratory design examines sustainable building construction.

WHY SUSTAINABLE BUILDING CONSTRUCTION

Buildings are supposed to provide comfort and healthy living. However, the construction industry is faced with numerous challenges such as construction processes, operation and maintenance. Buildings consume a lot of energy and natural resources with adverse effect on the climate change thereby affecting the quality of air and water in the built environment (Didel et al., 2017; British Standard Bureau, 2019). Studies has shown that 40% of the world energy, 50% water used by buildings grossly affects the sustainability of the built environment (British Standard Bureau, 2019). For instance, 23% air pollution, 50% greenhouse gas production, 40% water pollution as well, 40% solid waste decrease biological diversity (World Green Building Trends, 2018). Besides, forestry destruction is a clear indicator of global warming.

The use of unskilled workers, substandard materials and quackery has led to building failures that has advert effect on the economy. The waste in terms of materials and professional indiscipline as well as obsolete construction materials is a signal that sustainable construction is obvious. The consumption of energy is very high in energy emission. The heavy machinery and equipment used in construction relied so much on fossil fuels which results to pollution. It may interest you to know that the construction industry accounts for 36% energy and 40% Carbon dioxide emissions (British Standard Bureau, 2019, Geelani et al., 2012). In the same vein, fabrication and shipping of materials also have impact on carbon emission. Mining raw materials results to pollution of the local water table. Studies revealed that Concreate manufacture increased from 2.8bn tonnes of carbon dioxide to 4bn tonnes annually. Construction is threatened from hazard especially improper disposal of waste. This posed threat to the environmental safety of the built environment.

What Are the Salient Features of Sustainable Building Construction?

A. Sustainable Site Design
B. Indoor Environment Quality
C. Energy and Environment
D. Materials and Resources
E. Water Quality and Conservation

According to Gatley (2020), the following are features for sustainable building construction:

1. There is the need to consider sustainability in all facets of building design and planning.
2. It must be health and safety compliance

3. It must be efficient
4. Its construction and systems must be easy to maintain
5. It is aesthetic and quality standards
6. The materials must be effective and efficient
7. Must be water efficient
8. It must reduce waste and toxics
9. It must be structurally efficient, thus minimizing the environmental impact associated to the life cycle of the building
10. It must be energy efficiency by reducing the operating energy cost. Thus, using renewable energy e.g solar power, wind power, hydro power, biogas etc.

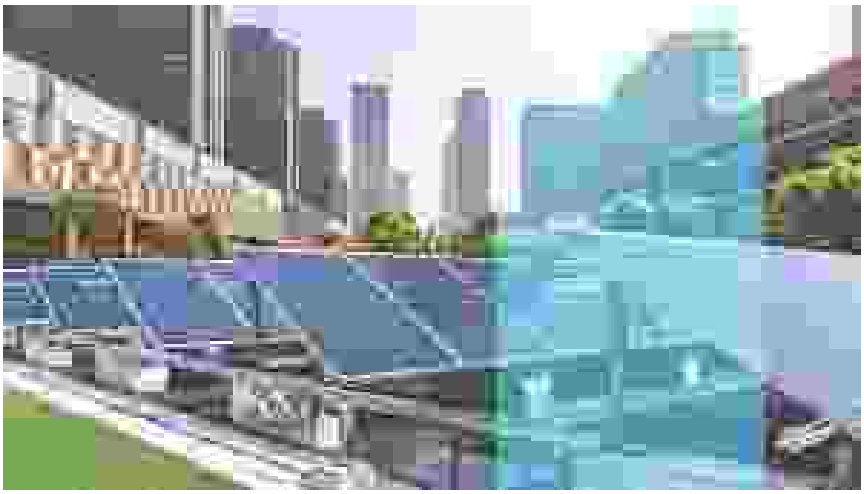

Fig 3: Energy Efficiency

Construction Sustainability

1. Imbibe renewable energy: A modular battery system that can be deployed on-site and recharge by solar panels. This can power electrical tools and vehicles as well as security equipment. With this, it can offset 1ton of carbon dioxide per week and 400 liters of diesel.
2. Sustainable materials: Although wood is a common building material, but also provides habitat for wildlife.
3. Sustainable concrete; alternatives with plastics and recyclables can reduce carbon dioxide by 50%.
4. Alternative materials such as bricks, mud, wool, cigarette butts can be used as binders that can strengthens the material without firing from the kiln that results in harmful emissions.
5. Plastics: Plastic does not degrade but gives maximum strength especially when used in construction. A key issue in building sustainability is to produce a building with longer life span. Since plastic does degrade, it might not need maintenance.

CHALLENGES OF SUSTAINABLE BUILDING CONSTRUCTION

According to the World Green Building Trends (2018), reveals 40% of UK firms are short changed in adopting sustainable construction practices; and 50% indicated that it is costly although 345 clients demand for green building for the sustainability of the built environment. Despite the cost, sustainable building construction can never be overemphasized. The benefits are erroneous for example, sustainable construction methods reduce impact on the environment. It demonstrates sustainable construction beyond environmental concerns. Statistics show that green buildings account for 7% increase in volume when compared with traditional buildings (World Green Building Trends, 2018).

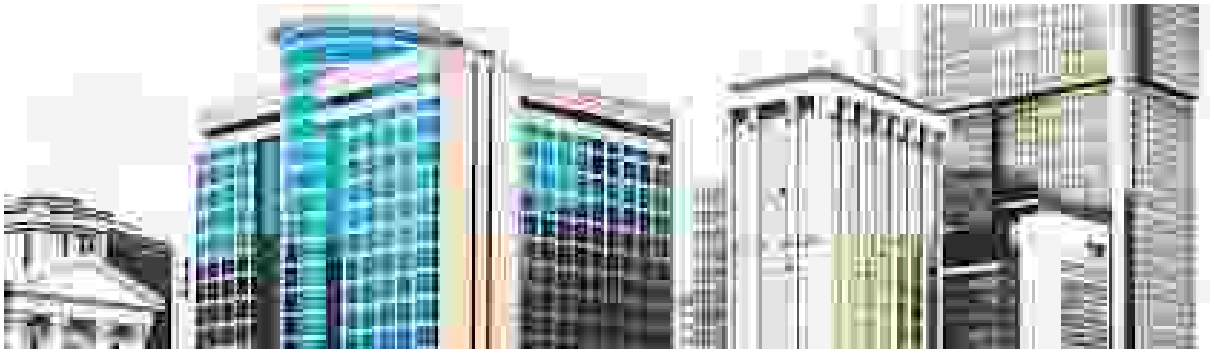

Fig. 4: Adopting Sustainable Construction

CONCLUSION

Buildings have great effect on the environment, human health and the economy. Therefore, embracing sustainable construction can minimize both economy and the environment performance of buildings. So, the reduction of water and operating energy costs during the life cycle of the building will have great impact on the built environment.

Therefore, sustainable construction is a dynamic environment that respond to the peoples changing needs and lifestyle. Sustainable construction can be addressed by imbibing intelligent technologies, systems and standardization especially with the convergence of urbanization, globalization and rapidly changing increasing economy. Consequently, sustainable construction will prevent environmental degradation.

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THE ART AND SCIENCE OF FOUNDATIONS: SOME CAPSULES

The Art and Science of Foundations: Some Capsules

By

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Just like most other professions in the Built Environment, Geotechnical Engineering is considered both an Art and a Science.

Over the years, the Art of Foundations had developed from the stone age era to the modern-day sophisticated way of living. The science aspect of foundation, which enables a geotechnical engineer to design and predict the behavior of the foundation of a structure in a particular ground, has been greatly influenced by collation of experience and technology in recent times.

The construction of buildings likewise, has become more complex in terms of size, shapes and locations where they need to be constructed. The journey for any construction project - as a natural course – starts with the foundation.

1. Soil Investigation: In modern times, the story of any foundation starts with a soil investigation exercise. This seemingly insignificant aspect (in terms of cost) should never be over looked for any project – whether big or small.

The soil investigation exercise is to know the nature of the soil at a particular location. Its suitability at different depths to carry the intended load to be imposed and determine the most appropriate foundation type to be used – considering the environment and available technology to install such foundation. The scope of investigation can range from shallow trial pits to deep boreholes – depending on the size of building.

2. Foundation Types: There are different types of foundation available to be used for building construction depending on the various variable factors to be considered in the selection of such foundation type. The application of the principles and science of soil mechanics in present day techniques of investigation and construction has led to more economic design of foundations for various building types – be they commercial, institutional, industrial or residential. Simply put we can classify foundation into two main categories:

a. Near Surface Foundations – for small, medium or light buildings in fairly good soil. Within this category we have
   - Normal strip "traditional" foundations.
   - Wide strip reinforcement concrete foundations.
   - Different forms of raft foundation - to mention a few.

b. Deep foundations – for large, tall, heavy or sometimes even medium buildings in fairly good or poor soil.

Within this category of deep foundations, we have:

- Micro piles of different sizes & make
- Small and medium diameter piles of different sizes & make.
- Large diameter piles of different sizes & make.

3. The adoption and use of any selected types of foundation is also influenced by other factors outside the normal "Art and Science" as described above. These could vary from economic consideration to environmental or social considerations.

The geotechnical engineer has responsibility to navigate his design between the structural engineer's requirements and the various other considerations to arrive at the most preferred safe solution for any given building project - using available data and experience. The most apparent option may not necessarily be the most economic, feasible or long-term safe solution to a foundation problem. Therefore, the knowledge and experience of the geotechnical engineer in this respect becomes very necessary in the selection of foundation types and method of installation.

4. As in any venture in human endeavor a wrong decision or poor installation technique or construction of a

foundation can have very serious and expensive consequences. These errors could be due to various factors among which but not limited to:
a. Lack of or poor soil investigation exercise.
b. Wrong decision due to inadequate information or lack of experience of the decision maker.
c. Wrong analysis of available right information,
d. Wrong installation method by the contractor – either due to use of poor materials or inexperienced labour etc. This could be due to the contractor not using the right professional, the registered builder, who is the expert trained and licenced in the technology and management of the processes for building construction works

Evidences of these failures abound and are more common in recent times as we see rampant building collapses or tilting. But not all building collapse is due to wrong foundation. There could be other structural or geotechnical factors responsible.
In conclusion the importance of good foundations can never be over emphasized but is more often grossly underestimated and not valued by most people, however at the risk of life and investment. There are is a costly price to pay when there are challenges in foundation design and construction. Like a loop, the structural engineer uses the output and results of geotechnical investigation for his design works while the professional builder uses the output of structural design from the structural engineer during the actual construction of the foundation. Obviously, the builder considers appropriate methodology for the construction works. The implication is that in the successful delivery of foundations, inputs of various professionals at investigation, design and construction stages remain relevant and the professional roles should not be short circuited.

SUB-THEME – THE STATE OF THE ART TECHNOLOGIES, SYSTEMS AND STANDARDS IN BUILDING CONSTRUCTION.

SUB-THEME – THE STATE OF THE ART TECHNOLOGIES, SYSTEMS AND STANDARDS IN BUILDING CONSTRUCTION.

REALITY CAPTURE – An Indispensable Process for Builders

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Abstract
Data is key to all technical professionals in general. Builders, in particular need data for planning, coordination, and evaluation of projects, among others. Such data range from simple linear measurement to complex digital terrain model of a city. It is important to emphasize that the outcome of any structural engineering activity largely depends on the quality of the input data.

What is Reality Capture?

Reality Capture is the process of producing a digital 3D model of an object, building or site by scanning it with a lidar or a photo scanner. Lidar is a method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor, whereas photogrammetry uses photos of the real site and can then be used to make a fully 3D, visual model of the real-world object. Builders can do so much with Reality Capture process.

Reality Capture Equipment and Tools

Reality capture can either be by lidar or photogrammetry. Lidar uses laser light while photogrammetry uses photo images. The output for both options is the same – 3D photo image + point cloud. However, lidar has an edge over photogrammetry because it can map the ground covered with denser foliage better than photogrammetry. Lidar equipment are generally more expensive than photogrammetry equipment. In terms of operation, both lidar and photogrammetry have terrestrial, mobile and aerial options. The choice of option depends on the nature of the work. For instance, while drone mounted photogrammetric camera or lidar is preferred for external mapping of open site, terrestrial photogrammetric camera or lidar will be most suitable for internal mapping of spaces within a building. Mobile photogrammetric camera or lidar, on the other hand, may be preferred to drone for mapping of city infrastructure where there are concerns of obstructions due to roofs and vegetations. Majority of the times, cost dictates what is being used because they can be quite expensive.

Comparing Reality Capture with Traditional Methods of Measurement

TRADITIONAL METHODS (Meter rule, theodolite, total station, engineer's level)	REALITY CAPTURE (Lidar or photo scanners)
Only as many points as may be decided by the operator.	Enormous number of points (up to 2 million point per second) are collected. These cover the entire surface of the object.
The surface generated is not accompanied by any photo image. If you need information about a point that was not captured, you must go back to site	Detailed photo image is available. It can be relied upon to provide any information needed about the site without going back to the site

Slow and full of errors	Fast and accurate
High risk exposure	Absolutely safe
Great limitations	Versatile
Not BIM compliant	Fully BIM compliant. It is the foundation of BIM.

Reality capture for Planning
With the 3D model output of Reality Capture, Builders can plan more efficiently, considering all site constraints. It is interesting to note that Reality Capture gives full information about the surrounding environment. For instance, Builders will be able to evaluate the impact of a tower crane to the surrounding.

Reality capture for infrastructure projects
At the start of an infrastructure project, reality capture tools enable large areas of land to be digitally recorded and modelled simply and quickly – saving huge amounts of surveying time. The range of tools, from UAVs and mobile mapping to wearable devices, means that all types of terrain, including hazardous and hard to reach areas, can be accessed to create a complete digital picture, providing a digitalised working environment that helps to identify possibilities, limitations, and challenges. There are further benefits to the earthworks process, which enables efficient cost management of materials by understanding the quantities and location of stockpiles. Data captured in the initial reality capture stages provides informed insight of the location of underground utility assets. This data can be seamlessly shared between the various stakeholders and used when laying or replacing utilities. The data is easily exchanged onto machines, such as excavators, to specify where and how deep to dig, thus preventing devastating and costly utility strikes. An updated record of utility works can be digitally recorded, documented, shared, and stored in line with BIM process.

As-Built modelling
In situations where existing plans are outdated or inaccurate, utilising the point cloud data is beneficial as the point cloud provides a 3D framework to create a new 3D design model. This provides a true reflection of reality and reduces the risk of potential costly errors downstream.

Site awareness and visualisation
The progress of a project can continue without having to constantly visit the site. Utilising a point cloud alone, inside a viewing solution, gives users a comprehensive 3D picture of their asset from the comfort of their office. Visual checks and digital measurements can be extracted and used to make informed decisions, and the data is shared and easily viewed by the project team.

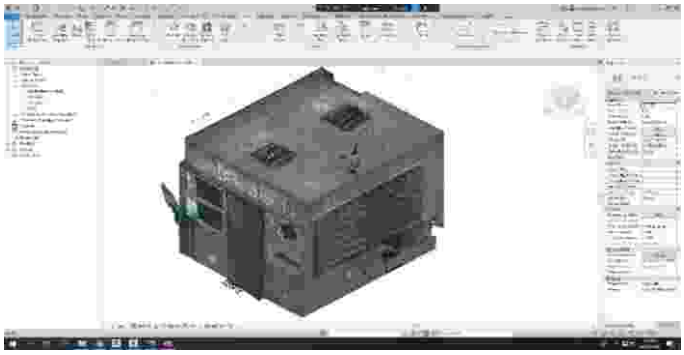
Clash detection
A common occurrence, in new-build or renovation projects, is components not fitting into their intended location. This could be through errors in the design process or oversights where someone has strayed from the plan. Point cloud data can be used, inside coordination software, to clash against design models - this is an automated process which indicates potential conflicts. This information is used to either make alterations to the design model or to highlight required changes.

Construction verification
During construction, it is not unusual that time, effort and money are lost due to errors and rework. This could be due to components being installed incorrectly and creating differences between planned and actual construction. The consequences of these differences are the inevitable rework created downstream as components installed in the future will not fit. Utilising reality capture technologies to record actual site conditions on a continuous basis creates a series of 3D verified pictures – snapshots in time that can be compared against the design model. Any irregularities can be spotted, assessed and corrective action taken before costly rework is required.

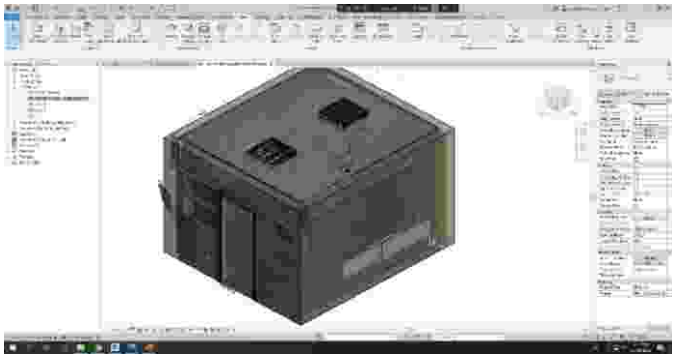
As Built Drawing of an Office

PIX 1: Normal Photo of the Office

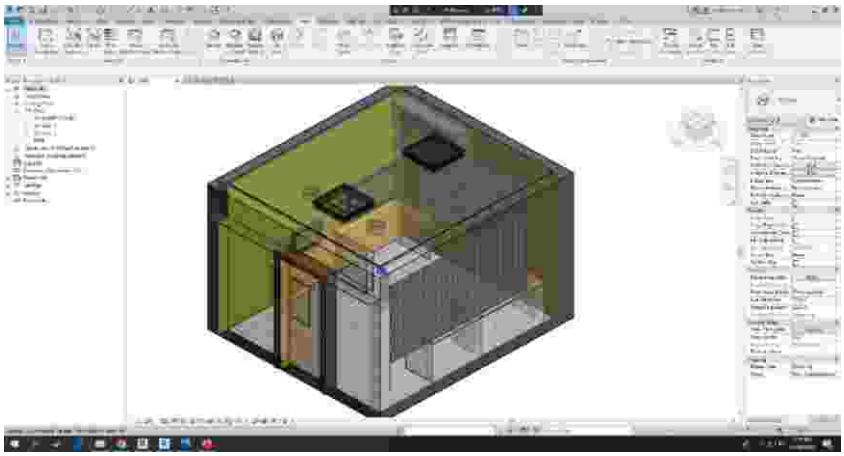
PIX 2: Processed Image from Reality Capture



PIX 3: Point Cloud Only



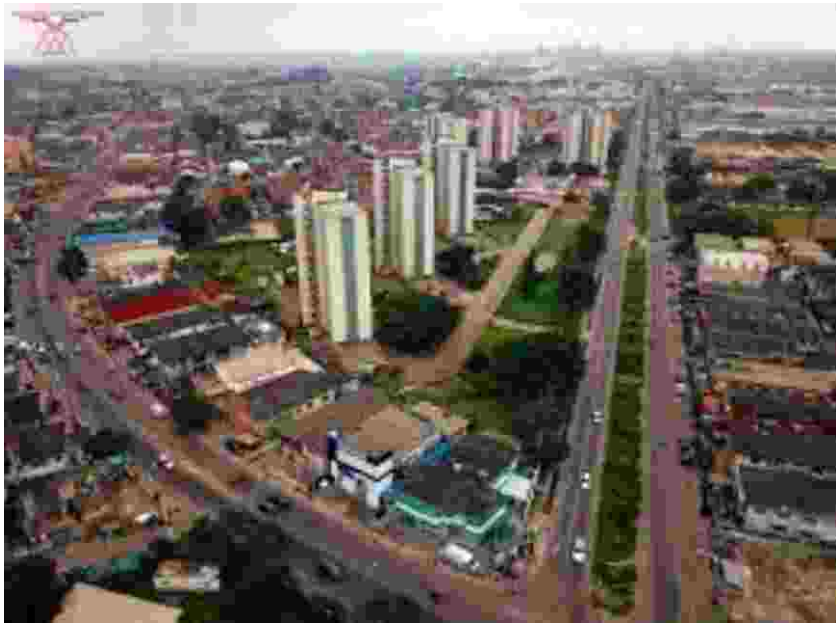
PIX 4: Point Cloud + New Model



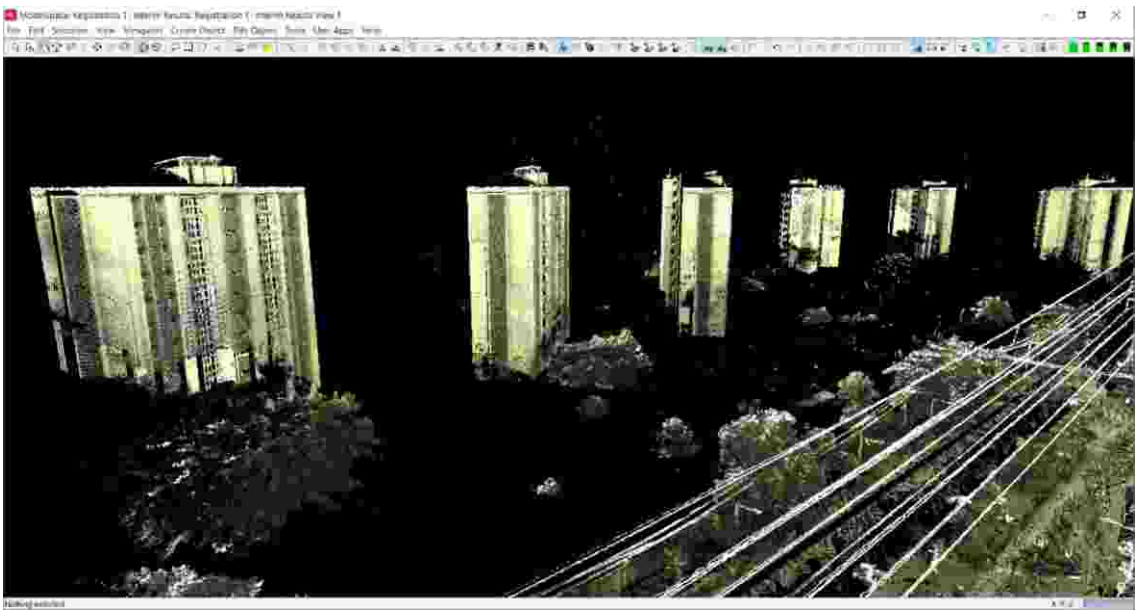
PIX 5: Model Only

Alignment Investigation on Eric Moore Towers, Lagos

Eric Moore Towers are six identical 14 storey building located off Eric Moore Road, Surulere, Lagos. For this paper, we selected them as open source data to demonstrate what reality capture can do. Our objective was to ascertain if the buildings are vertically aligned relative to one another.



PIX 6: Eric Moore Towers from Google Map



PIX 7: Eric Moore Towers from Laser Scan

PIX 8: Alignment Verification

PIX 9: Alignment Verification