DEVELOPMENT OF A METHODOLOGY FOR THE PERFORMANCE IMPROVEMENT OF NIGERIAN OFFICE BUILDINGS CONSIDERING BIOCLIMATIC DESIGN PERSPECTIVES

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This thesis is submitted in partial fulfilment for the degree of Doctor of Philosophy

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Dedication

This work is dedicated to Almighty God, the loving memory of Prof. Samson I Omofonmwan and to Mr Godwin O Omoragbon and the family.

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Declaration

To the best of my knowledge, I declare that the intellectual content and materials used in this thesis from other sources have been properly acknowledged. The results and conclusions of this work are the original contribution of the named candidate based on the University of Salford rules and regulations for the award of Doctor of Philosophy by research.

This thesis or a portion therein has not been previously submitted as part of the requirements for an award of degree, diploma, or other purposes at any higher educational institution under my name or another individual.

Dissemination

Omoragbon, O. M., Al-Maiyah, S., & Coates, P. (2023). A survey of environmental performance enhancement strategies and building data capturing techniques in the Nigerian context. *Buildings*, *13*(2), 452. (Appendix 6)

ABSTRACT

There is a need to improve the environmental performance of Nigeria's office buildings due to new expectations, and the current challenges including energy shortage, increasing population, changing user needs, and climate change. While several Nigerian cities have been expanding, existing buildings constitute a significant portion of the building stock. Improving the performance of existing buildings using a well-known, tested and relatively straightforward approach of modelling and simulation is more cost-effective than new construction. In Nigeria, the appropriate building information to facilitate this type of evaluation is difficult to come by because many building records are often not updated, are obsolete, deteriorated or buildings are not constructed to their original specifications. Previous studies that aimed at enhancing a building's performance in Nigeria hardly stated the acquisition of the required building data. This study developed a methodology for building performance improvement of existing buildings following the bioclimatic design initiatives recommended by Nigeria's Federal Ministry of Power, Works and Housing for new buildings.

In addition to the significant increase in commercial activities requiring more office buildings in Benin City, the study region, there is also a dearth of studies on building or energy performance improvement. Five objectives were set out, which helped to direct the research while adopting the mixed method research approach and a case study research strategy. In the initial phase, a combination of web-based and hard-copy questionnaires were completed by 133 building design professionals in Benin City followed by a complementary semi-structured interview of 15 building professionals to investigate the current built environment practices in the study region. This phase also helped in identifying the appropriate bioclimatic design characteristics of the buildings necessary for performance improvement and the as-built data capture of existing buildings in Nigeria. On-site surveys of the bioclimatic design features of three office buildings, selected to reflect the common office typology in the study region followed, utilising diverse surveying means. The data collected at this stage of the fieldwork were initially used to create digital models while findings from the analysis of all data collection methods employed in this study helped to inform and develop a suitable methodology for building performance improvement of existing buildings considering bioclimatic design perspectives. Operative temperature and solar gains for indoor thermal comfort were used during evaluation and the developed methodology was trialled using a prototype model created from the use of a smartphone which showed slight variations in measurements but no significant impact on thermal comfort. The developed methodology has great potential for building simulation and evaluation of the thermal performance of existing buildings to encourage environmental building performance in a developing world.

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CHAPTER 1

INTRODUCTION AND BACKGROUND OF STUDY

1.1. Introduction

This chapter expounds on some contemporary issues to establish the context for the research and to point out the particular problems addressed by the study. This chapter presented the background of the study, and the statement of the problem while stating the identified aims and objectives. It also clarified the scope of the research, described the outline of the research methodology and highlighted the significance of study. The thesis structure is presented and thereafter the chapter summary.

1.2. Background of study

Nigeria is by far the most populated African country with deep-seated and multifaceted socioeconomic challenges. The country's challenges are further exacerbated by population growth, excessive reliance on small businesses and the lack of public services. This rapid population growth (fastest growing among the world's 10 most populated countries) is projected by the United Nations to rise from the present estimated population of 200 million to about 400 million in 2050. Consequently, Nigeria's ability to meet the needs of the increasing population is undermined by the inadequate basic infrastructure and services especially electrical power as Nigeria only generates electricity for as much as about a quarter of its population (Campbell and Page, 2018).

According to the World Bank Group (WBG, 2022), Nigeria, the largest economy in Africa with a nominal Gross Domestic Product (GDP) of around 430 billion in US dollars in 2021, is projected to experience a yearly economic growth in GDP. The Nigeria Development Update (WBG, 2022) revised the growth estimate of Nigeria's GDP by 3.4% in 2022 and 3.2% in 2023 from a previous November 2021 forecast of 2.8%. The revisions are based on two factors including the better-than-expected performance of the services and agricultural sectors and higher oil prices as a result of the conflict in Ukraine. Notably, the resultant effect of this economic growth trend and the increasing population has put pressure on existing facilities leading to the demand for infrastructural development and buildings in Nigeria through a series of strategic national plans (PwC report, 2016). Energy is a key requirement for building and operating infrastructure, the current energy demands in Nigeria are mainly met in the form of electricity. Despite the availability of natural energy sources, more than 80% of the business sector comprising mainly small and medium-scale enterprises (Scott et al. 2014) is dependent on fuel-powered generators to get electricity. In recognition of these challenges, some of the recent strategies and national plans set up to strengthen infrastructure and employment including *Vision 20:2020* and the *Transformation Agenda* have focused on strengthening infrastructure and economic development.

The over 40% drop in revenue from exporting oil and gas in 2015 which provides funding for critical public programmes and facilities in Nigeria led to a dip in government finance and a significant growth in unemployment. An alternative non-oil economy, including services, has shown great prospects been the highest contributor to the Nigerian GDP in the first quarter of 2016 (Figure 1.2A). And since 2015, Services continued to contribute the most to growth even with high oil prices but declining oil output due to the "business-as-usual" policy stance by the Nigerian government that limits economic growth and job creation (Figure 1.2B).

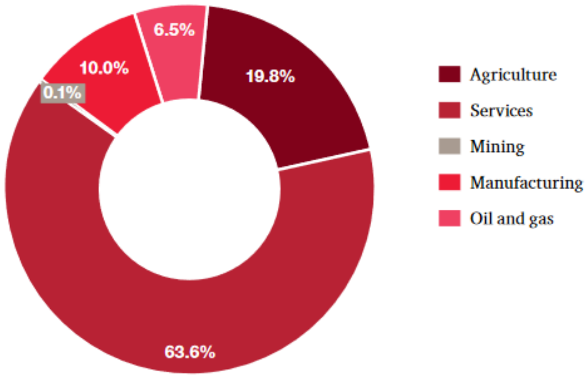


Figure 1.2A. Nominal GDP split, Q1 2016. (Source: PwC report, 2016)

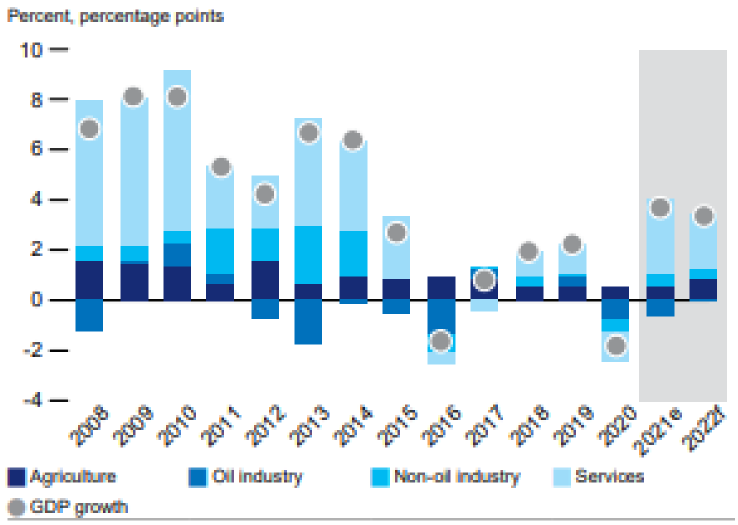


Figure 1.2B Services continued to contribute the most growth in 2021 (Source: WBG, 2022)

Strengthening and improving the services sector further requires appropriate facilities and infrastructure to boost productivity, businesses and in turn the economy, especially in the wake of the pandemic-related adjustments. Businesses are left with a more expensive alternative of using oil-fired backup generators due to power deficiency in Nigeria (IEA 2019), significantly contributing to the poverty level and poor economy. With the increased population and the level of poverty in the country, it has become necessary that the services sector, the most contributor to Nigeria's GDP and economic growth adopt ways to thrive with inadequate power.

1.2.1. The State of Energy Shortage and Electricity in Nigeria.

Nigeria is the largest producer of oil and gas in Africa and the fifth-largest oil exporter of liquefied natural gas in 2018 but has in recent years experienced sporadic supply disruptions affecting production and unplanned outages (IEA, 2021, 2022). As the country's main source of foreign exchange, oil and natural gas are the most exploited energy resource but are adversely affected by factors including poor production, theft, and conflicts. Other abundant energy resources including hydropower, coal, and several potentials for renewables like wind, biomass and solar are available in the country (CBN 2012). Figure 1.3 shows that in 2011, biomass and waste, oil, and natural gas dominated the energy supply by 82.2%, 10.6% and 6.8% respectively. Hydropower accounted for 0.4% of the total 118,325 Kilotonne of oil equivalent (electricity trade in 2011 excluded). It shows that Nigeria relies largely on biomass and waste for domestic purposes (heating and cooking) while there is minimal progress in the provision of non-solid energy sources especially electricity generated through natural gas, oil, and hydropower (IEA, 2014). The reliance on natural gas for electricity generation is reinforced by the "Decade of gas initiative" launched by the Nigerian presidency in 2021 (IEA, 2022). The use of nuclear, wind and solar energy sources are insignificant.

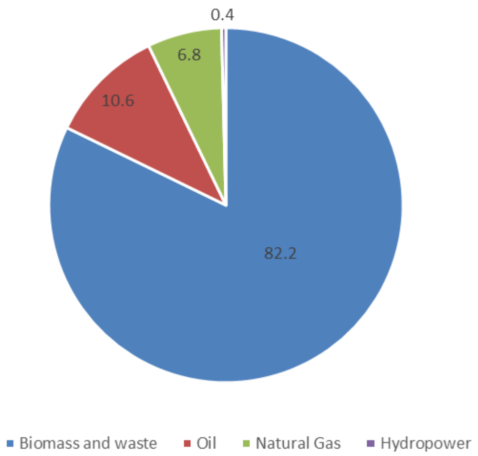


Figure 1.3. Energy supply by source in 2011 (Source: IEA, 2014)

Electricity, a secondary energy source is vital in meeting human needs and enhancing the standard of living and socio-economic growth of any nation but remains a marginal source of energy in Nigeria (Etukudor et al. 2015). It is concerning that in a highly populated Nigeria in the tropics with vast natural resources available for electricity generation, there is an inadequate electricity supply. Several attempts to improve the energy situation in the country include regulating the monopoly of the National Electric Power Authority (NEPA) system handling operation (power generation, transmission, and distribution) in 2005, restructuring to form the Power Holding Company of Nigeria in 2007 and privatising the electricity services in

2013. The federal government of Nigeria still retains the transmission grid (Emodi, 2016) and plans to invest in it to increase the electricity capacity to 25GW by 2025 through investment and new gas-fired and renewable generation, a Presidential Power Initiative (IEA, 2022). Today, the generation companies are called GENCOs, the distribution, DISCOs, and the Federal Government of Nigeria controlled transmission TCN.

Between 1980-2009 the total electricity generation ranged from 783.9MW to 4076.2 MW with an installed capacity ranging from 2507MW to 8702.25 MW, indicating a huge margin between generation capacity and installed capacity (Oyedepo, 2014). The difference in capacity utilization contributes to low energy consumption in Nigeria at 137kWh per head in 2007 one of the lowest in the world.

The issues of poor energy availability and distribution in Nigeria have been well documented (Oyedepo, 2012; Arup and Genre 2016; Ochedi and Taki, 2016; Adewale et al. 2018; Olatunji et al. 2018). Despite the shortcomings and less than 1% electricity sector contribution to the economy, resulting in the poor state of the Nigerian economy, there is a significant rise in electricity utilization and consumption as Fig 1.4. shows (Emodi and Boo, 2015). The rise in demand coupled with the unreliable nature of electricity has left industries, households, and commercial services that have not relocated to more business-friendly countries to rely on their own generating sets at an added production and service cost (Olatunji et al. 2018; Oyedepo 2013).

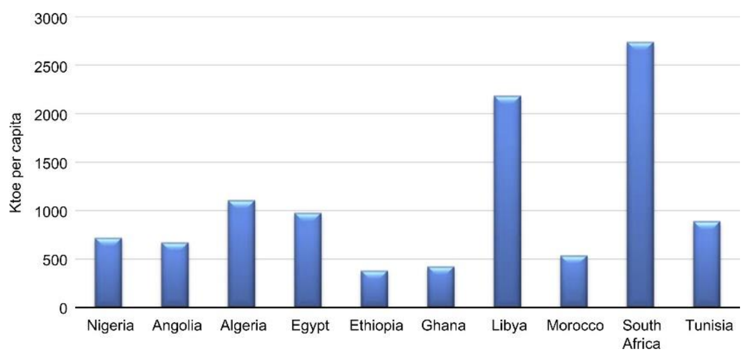


Figure 1.4. Energy consumption per capita in African countries (Source: Emodi and Boo, 2015)

The increased demand for energy due to rapid development and population growth is estimated that by 2030, the industrial sector will have the highest energy demand as shown in Figure 1.5. The services and commercial sector projects are the second highest while the household is expected to have the least energy demand. All at a 10 per cent GDP growth rate analysed by the Energy Commission of Nigeria.

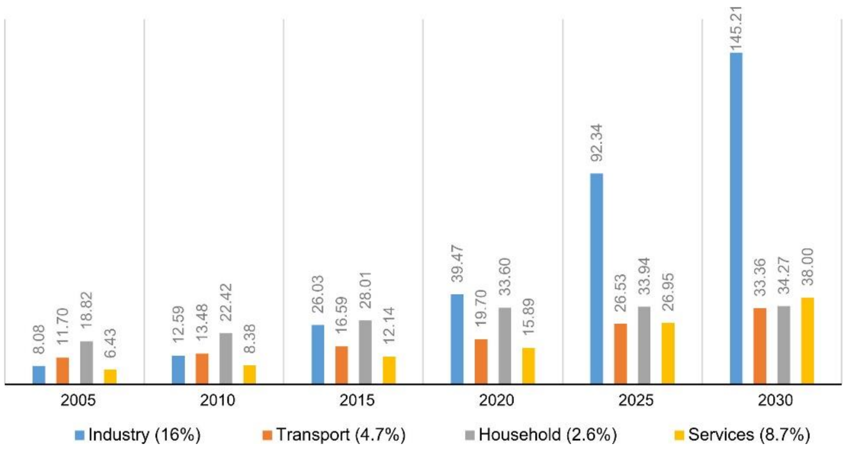


Figure 1.5 Total energy demand based on a 10% GDP growth rate (Source: Emodi and Boo, 2015)

What it implies is that

- There is an increase in energy consumption in the built environment even with minimal supply.
- It presents the exploration of energy savings in the residential and commercial sectors.
- It portrays that the consumption of energy is in line with that of other parts of the world where buildings consume an enormous amount of energy.

In addition to the above-mentioned, improving the environmental performance of commercial buildings, the economic powerhouse of Nigeria that contributes significantly to the national economic income is a major approach to enhancing energy efficiency and reducing cost (Olayinka and Andrew, 2018). In recognition of the need for energy efficiency in Nigeria, efforts have been made by the Federal Government through publications such as the Arup and Genre (2016)'s Building Energy Efficiency Guidelines (BEEG) and the FMPWH (2017)'s Building Energy Efficiency Code (BEEC). Both documents recommend the adoption of bioclimatic design initiatives (detailed in Chapter 2) for office buildings due to their significant benefits on energy efficiency, enhanced comfort, and economic strength.

1.3. Statement of Problem.

Several factors including population growth, urbanisation, unemployment, and poor energy situation in Nigeria require that commercial buildings especially offices, comprising small and medium-scale enterprises run at a reduced cost. It is necessary to understand the role of office buildings in reducing costs and promoting energy efficiency.

1.3.1. Energy and the built environment.

Office buildings consume a significant amount of energy for occupants' needs and satisfaction in several parts of the world including China, the United States of America, and the United Kingdom (Mu'azu and Gyoh, 2013; Ma et al. 2015). The high energy consumption of buildings contributes to the several uses of energy and environmental performance compliance frameworks in developed climes (Mu'azu and Gyoh 2013). These measures, including the

Leadership in Energy and Environmental Design (LEED) rating system, and Energy Performance Certificates (EPC) facilitate low energy consumption, environmentally responsive design, and energy efficiency. These compliance frameworks also impact how buildings are designed, built, and used now and in the future. However, in Nigeria and other sub-Saharan African countries, western methods of buildings and materials have been majorly adopted compared to the previous traditional building methods and materials originally constructed to respond to local environmental challenges (Geissler et al. 2018). As a result, Nigerian commercial buildings have not properly considered climatic adaptations and environmental enhancement strategies in its tropical climate which is further exacerbated by the concurrent impact of climate change (Panel, 2015). Mechanical means of cooling buildings to keep occupants comfortable and productive is due to a compromise in their environmental performance (including service, function, health, and comfort). The demand for such energy for mechanical cooling puts further strain on the energy sector, especially as the rate of building increase in Nigeria supersedes that of energy provision further emphasizing the need for bioclimatic design initiatives (Arup and Genre, 2016; FMPWH, 2017).

Previous studies have also pointed out that in the developed nations of the world, there are attempts, policies and mechanisms geared towards improving the performance of buildings but in developing countries including Nigeria, there is a shortage of evidence for this feat (Mu'azu and Gyoh 2013; Amasuomo et al. 2017). Geissler et al. (2018), argued that there are available series of foreign, modern, well-tested, and advanced strategies (including active thermal mass and use of phase change materials), however, there are no local examples available to establish their suitability to the Nigerian climate.

The National Building Code (NBC, 2006) is the main document used in Nigeria for all building works including specification, design, alteration, and use. However, the document does not include detailed energy efficiency requirements nor address achieving the building's environmental performance which has led to criticisms and calls for a review of the code (Ogunsote, 2011; Ayansian, 2013; Abdulkareem, 2016; Atanda and Olukoya, 2019). The revision of the NBC would include aspects of energy efficiency that are easy to implement, cost-effective and in turn energy savings (Arup and Genre, 2016). Despite the efforts by the Nigerian Energy Support Programme and the Federal Ministry of Power Works and Housing (Housing) targeting the use of the published BEEG and BEEC to help manage the energy inefficiency in the Nigerian building sector, (Discussed in Chapter 2), there is no detailed framework for designing energy-efficient buildings. Whereas, the increasing population, economic and urban growth has not limited the increasing rate of building development despite the absence of an institutional framework for energy-conscious and high-performance buildings (especially offices) in Nigeria. It is essential to take measures to meet occupants' needs and reduce energy use by improving the environmental performance of buildings.

1.3.2. Improving Building Environmental Performance.

The function of a building is to provide the occupants with a safe, conducive, comfortable, healthy, and secure indoor environment to carry out all necessary activities (Ibem et al. 2013; Amasuomo et al. 2016; Chidi et al. 2017; Gopikrishnan and Topkar, 2017; Ijaola et al. 2018). Historic and economic factors require a significant number of existing buildings to be upgraded instead of demolition or reconstructed if they are to be in continuous use (Cao et al. 2022). Also, the relationship between the building's role in performing its function and the changing need of the user is sacrosanct to the need for improving the environmental performance of buildings. Once a building starts to deteriorate or compromise in meeting its aim, actions to restore the building's function become imperative (Eghenure et al. 2012; Opara et al. 2019).

While the thermal requirement of building occupants may change with time, recently, the quality of the thermal environment of buildings is affected by climate change and extreme weather events (Ibem et al. 2013). Due to factors such as environmental agents, and users' activities in buildings (Eghenure et al. 2012), there is a need to improve building performance, especially in Nigeria where the practice of improving the environmental performance of buildings has received less attention (Opara et al, 2019). Population growth and urbanisation require new building development. Nevertheless, a significant proportion of the existing buildings are still in use, whereas, evaluating and improving the existing buildings are more economical than reconstruction (Adeyemi et al. 2017; Cao et al. 2022). Post-occupancy evaluation is one of the existing methods of assessing a building from environmental compliance to energy performance with benefits including continued development of design and construction criteria, energy use reduction and enhanced comfort for the occupants (Tookaloo and Smith, 2015). Traditionally, the performance evaluation of buildings was informal, and the lessons learned are applied in subsequent building types (Ilesanmi, 2010). However, the subjective differences between occupants can lead to unexpected outcomes necessitating the need to limit, control and account for the variables for post-occupancy evaluation (Tookaloo and Smith, 2015). According to the RIBA's pathway to Post occupancy evaluation report (Behar et al, 2017), the three integral reviews of post-occupancy evaluation (POE) include the effectiveness of the procurement process, the performance of the built fabric and construction details and the operational effectiveness of the building in terms of the users need. While the report advised that POE research should be repeated throughout the life cycle of a building to get the most out of it, given the range of approaches to carry out POE, the relevance of a technique depends on predefined deliverables. The outcomes which set the expectation for the users have a significant impact on their satisfaction while the approach is dependent on the available resources in terms of expertise, finance, and time. Some of the approaches that have been previously used to test a range of architectural and operational aspects of the building are, building users survey, the use of monitoring equipment including data loggers, building walkthrough and energy audit. Thus, the approach for this study focuses on energy-efficient means, using bioclimatic design initiatives as encouraged by the BEEC and the BEEG for the use of building simulation.

There is a preference including, by the Housing Sector of Nigeria's Federal Ministry of Power, Works, and Housing (Ilesanmi, 2010; Tookaloo and Smith, 2015; FMPWH 2017) for a systematic approach such that building information is used to compare and validate (evaluate) the performance of the building with set-out performance criteria (Olanipekun et al. 2017; Geissler et al. 2018;). For office buildings and all other building types, specifically, the BEEC (FMPWH, 2017 p18) although designed mainly for new buildings insist, in its performance route to compliance (3.2.1 and 3.3.2 respectively) that;

"*In the performance route, buildings shall have an overall energy performance determined by a competent person using an approved energy simulation program, less than or equal to that of a reference building designed in accordance with the prescriptive requirements for building elements and services defined in the BEEC.*

Therefore, for this compliance method, the building energy simulation should be performed twice: once for a building as it has been designed (referred to as the design building), and the second simulation for the reference building. The reference building shall meet all the minimum prescriptive requirements specified in the BEEC."

The prescriptive requirements described in the BEEC for the three subcategories (window-to-wall ratio and shading, lighting, and air-conditioning) requires that building evaluation are carried out utilising architectural and fenestration designs through modelling and simulation with the as-built documents prepared by the registered architect, registered engineers, and registered surveyors for performance simulation. Building simulation (explained in Chapter 4) analyses and evaluates a building by testing the different spaces and building elements under real-life scenarios (Henson and Lamberts, 2012).

Consequently, the evaluation of the thermal and environmental performance of office buildings requires the use of their technical characteristics including layout plans and architectural drawings (Ilesanmi, 2010; Amans et al. 2013). Previous studies (Abdulkareem, 2016; Arup and Genre, 2016; Ochedi and Taki, 2016) have demonstrated how the building's spatial information is used to evaluate and improve its performance through modelling and simulation. Whereas, in Nigeria, it is often challenging to get the functional details of existing buildings (Dalibi et al. 2017; Geissler et al. 2018) for various reasons. Firstly, most buildings were not built to the original specifications shown in the drawings as contractors or sometimes, architects tend to make modifications during the construction stages (Ibem et al. 2013). Most often, in Nigeria, even though building projects are designed by architects, to cut costs, building professionals are not contacted during the construction phase of the project. Previous studies indicated the loss of records due to degradation and poor storage. Amans et al. (2013) for instance, stated that, recently, many of the building details have been greatly compromised due to storage inadequacy, uncontrolled development, and neglect, among others whereas, documentation forms the basis for any modelling and simulation work. Together these factors and the necessity for improving the environmental performance of buildings as measures to address the issue of energy highlight the need for building data capture to facilitate the development of a reliable methodology for more cost-effective data capturing, modelling analysis and evaluation techniques. The methodology will help to harness various benefits of improving existing buildings including environmental friendliness, reduced maintenance cost, cheaper cost compared to reconstruction and as an exemplary model for others (Adeyemi et al. 2017).

Whereas a considerable number of studies have emphasized the need for environmental building performance improvement to achieve energy efficiency, such studies are still in their infancy stage in Nigeria (Efeoma 2017). A summary of these studies is given in chapter two, Table 2.11. Also, the limited studies in the study region demonstrate the use of building details for simulation and modelling but have neither specified how it was sourced nor stated the limitation of getting the as-built details. While only a few studies considered office buildings with a different aim (as illustrated in Chapter 2, sections 2.9 and 2.10), no study has been carried out on environmental enhancement strategies in Benin City, the South-South Geopolitical Zone of Nigeria whose climate varies from other parts of the country.

1.4. Research Questions.

This study presents two research questions which were derived from the research problem. The first question was developed from the problem statement captured in sections 1.2.1 and 1.3.1. The second research question was developed from section 1.3.2.

1. The state of energy provision in Nigeria is unsatisfactory coupled with the increasing population, increasing energy demand, and increasing need for buildings. There is also a strong nexus between energy and the economy of the nation such that It is well documented that office buildings in Nigeria are not climate responsive and as such performs badly thereby consuming a lot of energy in the form of electricity to complement their thermal performance, Hence,

   "What are the current practice conditions addressing energy-related challenges in Nigerian office buildings in critical comparison with key aspects of bioclimatic design initiatives?"

2. To appropriately enhance the environmental performance of existing buildings adopting bioclimatic design initiatives, an evaluation potentially through simulation is required (as stated in the BEEC) to evaluate alternatives, which can only be done utilising available building information. In the absence of such building records, and considering the level of poverty in the country,

   "How can Nigerian office buildings be retrofitted with bioclimatic design initiatives to help reduce their reliance on energy, translating to a reduced cost?"

1.5. Research Aim.

This research aims to provide a reliable and cost-effective methodology for the capture of as-built information for building simulation with an emphasis on bioclimatic design features to improve the environmental performance of office buildings.

1.6. Research Objectives.

A. To critically explore relevant bioclimatic design characteristics and their impact on building performance in order to explain retrofit scenarios for building performance improvement.

B. To review relevant literature to Identify, assess and compare the different available data-capturing techniques with key aspects of bioclimatic design conditions.

C. To specify the most suitable technology for as-built data capture needed for simulation considering bioclimatic design perspectives.

D. To critically analyse current practice conditions addressing energy-related challenges of office buildings in Nigeria.

E. To validate the proposed holistic methodology for as-built data capture and simulation

1.7. Scope of Research.

To limit constraints inherent in any research piece such as time, finance, and resources and to ensure that the research outcomes meet the aim, and objectives and answer the research questions, this study focuses on existing office buildings as part of services and commercial buildings. Its limitation to office buildings is due to their significant energy consumption and contribution to the economy. Also, for the growing need and refurbishment proposals for office buildings in the study region, Benin City (Explained in Chapter 2). The study is limited to environmentally friendly (Bioclimatic design) initiatives that address mainly indoor thermal comfort towards achieving energy efficiency.

Office buildings that are solely dependent on air-conditioning have not been considered in this study because part of the research aim is to reduce reliance on mechanical means of cooling and ventilation and its associated cost. Thus, this study focuses on the indoor thermal environmental condition as this is the highest energy consumer in buildings. Figure 1.7 shows the scope of the research of this study.

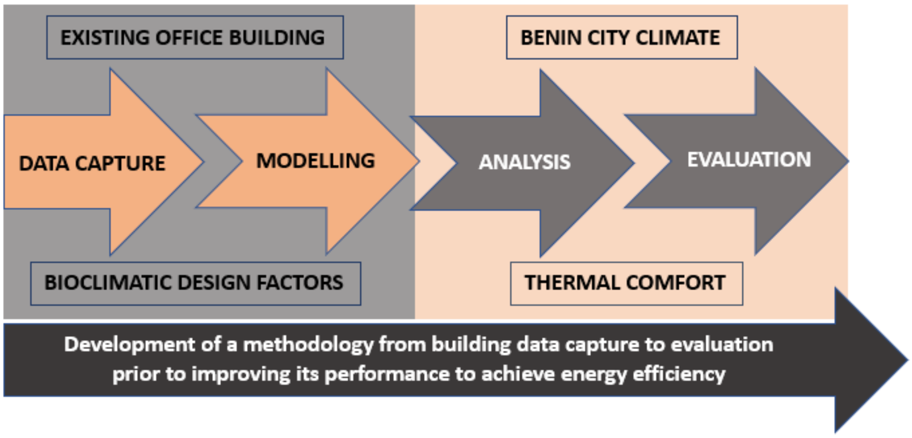


Figure 1.7. Scope of research framework

1.8. Research Methodology.

To satisfactorily answer the research questions and achieve the aim and set out objectives of this research, the research onion model consisting of six layers was adopted as a guide throughout the methodology of this study. Multiple methods of data collection were applied under which a mixed method research approach using both qualitative and quantitative concepts aided the realization of the research goals.

Due to the fact-finding nature of this study, a review of literature was followed by a case study approach (detailed in Chapter 4) to aid the exploratory elements. A combination of physical hard copy and electronic questionnaires was used to gauge building professionals' knowledge and practice on issues of building data capturing and energy-efficient building designs. Complementary semi-structured interviews were also conducted to understand the process of building information capture and retrofitting. Field studies utilising both measurement and observational surveys (including geometric and thermal) and photographic capturing of the case study building's physical components were undertaken. This led to a quantitative approach using computer-based simulation to analyse and evaluate the indoor thermal performance needed before the exploration of design impacts, indoor thermal condition improvements and energy-saving potentials in the building within a virtual environment. Real-life scenarios deduced from abstract models (simulation) are effective and less time-demanding compared to an actual model construction for evaluation. Table 1.7 summarises the research methodology following each research objective.

Table 1.8 Outline of the research methodology.

	Objectives	Method	Justification
A.	To critically explore relevant bioclimatic design characteristics and their impact on building performance in order to explain retrofit scenarios for building performance improvement.	Review of relevant literature	Literature review to understand the relationship between building characteristics and their impact on building performance. To identify the required parameters for data capture
B.	To review relevant literature to Identify, assess and compare the different available data-capturing techniques with key aspects of bioclimatic design conditions.	Review of relevant literature,	To gain insights into various data-capturing technology around the world and assess their suitability in achieving the pre-defined research aim.
C.	To specify the most suitable technology for as-built data capture needed for simulation considering bioclimatic design perspectives.	Case study, use of questionnaire, use of interviews	Use of on-site measurement (geometric, thermal, and photographic) by the researcher to collect as-built information and the relevant environmental data that affects the performance of the case study building. Subjective thermal information of occupants of case study buildings.
D.	To critically analyse current practice conditions addressing energy-related challenges of office buildings in Nigeria.	Analysis of collected data	Analysis of questionnaires and interviews to understand the factors and practice of geometric data capture and retrofits in the study area
E.	To validate the proposed holistic methodology for as-built data capture to simulation	Evaluative computer-based simulation	To ascertain the performance of case study building and to ascertain that the developed methodology is in line with the research focus.

1.9. Significance of study and contribution to knowledge.

The significance of this study is the creation of a reliable and cost-effective methodology for as built (emphasizing bioclimatic design features) data capture and modelling of existing buildings used for simulating their thermal performance before attempting improvement strategies. In Nigeria, some studies (Mu'azu 2015; Abdulkareem, 2016; Arup and Genre 2016; Abdulkareem et al. 2017; Amasuomo et al. 2017; Ochedi and Taki, 2019) have demonstrated the importance of using modelling and simulation utilising detailed building information to improve building performance. While many of the studies did not state their source of building information, Mu'azu (2015) indicated using as-built building information and also carried out measured drawings on instances of unavailable data. Abdulkareem, (2016) highlighted some limitations to getting the relevant technical data for evaluation including the use of tracing paper for storage in the past which has become obsolete and deteriorated, losing much of the required details. Additionally, the trend of not constructing buildings to original specifications in Nigeria due to alterations made by contractors or architects during construction has made it difficult to get the as-built representation of buildings (Ibem et al., 2013).

Another significance of this work is to help encourage performance improvement of buildings. The few numbers of studies carried out in this regard show that assessing building performance is not a priority even with the state of poor energy provision in the country. As there are no studies done on performance improvement of office buildings and data capture in the study region, study outputs can be used to support efforts aimed at energy-conscious and thermally conducive environmental design and policies.

In the same vein, the study provides a method aligned to existing knowledge of potential actions and value propositions and vantage for further research on other means of data capturing and simulation of bioclimatic as-built information for energy-efficient or building performance improvement in buildings.

1.10. Thesis structure

The thesis structure is shown in Figure 1.10, the thesis comprises eight chapters and is arranged in chronological order and the contents of each of the chapters are briefly summarised below.

1 Chapter 1: Introduction
This chapter explains the background of the study and introduces the research problem. It states the research aim and objectives, defines the scope and research methodology and highlighted the significance of the study and contribution to knowledge. This chapter clarifies the overall path of the thesis and the context.

2 Chapter 2: A literature review on building performance-related characteristics
The issue of building performance of existing office buildings and its relationship to energy efficiency in the study context are discussed in this chapter. The role of building regulations and necessary institutions in improving the thermal performance of buildings leading to the proposal for bioclimatic design initiatives are highlighted. The necessary building design characteristics required for building performance improvements are also identified in this chapter.

3 Chapter 3: Data capturing technologies.
A review of relevant studies on data-capturing techniques and methods used in other parts of the world are identified and summarised, leading to their critical evaluation in line with achieving the research focus are presented in this chapter.

4 Chapter 4: Research Methodology
In this chapter, the philosophies underpinning the adopted methods, approaches and paradigms are presented. Using the research onion, justifications on the methodological choice, research strategy, time horizon, data collection and analysis are discussed. They are abduction, mixed multi-method, case study and the use of survey questionnaires and interviews.

5 Chapter 5:
The results of the survey questionnaires completed by the built environment professionals are presented in this chapter. It discusses the survey process and the different sections of the data collection tool. The deductions and conclusions are also presented.

6 Chapter 6:

The Complementary interviews conducted as part of the data collection method of this study are presented in this chapter. It explains the interview process, the objectives, the analysis, the emerging themes, and the conclusion.

7 Chapter 7:

This chapter presents information about the case study buildings and the activities carried out on-site. It further applied the information and deductions from the other data collection methods adopted for use in this study to develop a reliable methodology for data capture, modelling, and evaluation before building performance improvement strategies.

8 Chapter 8:

This chapter concludes the research by summarising the findings about how the objectives of the study are met. The recommendations for future research work are also highlighted.

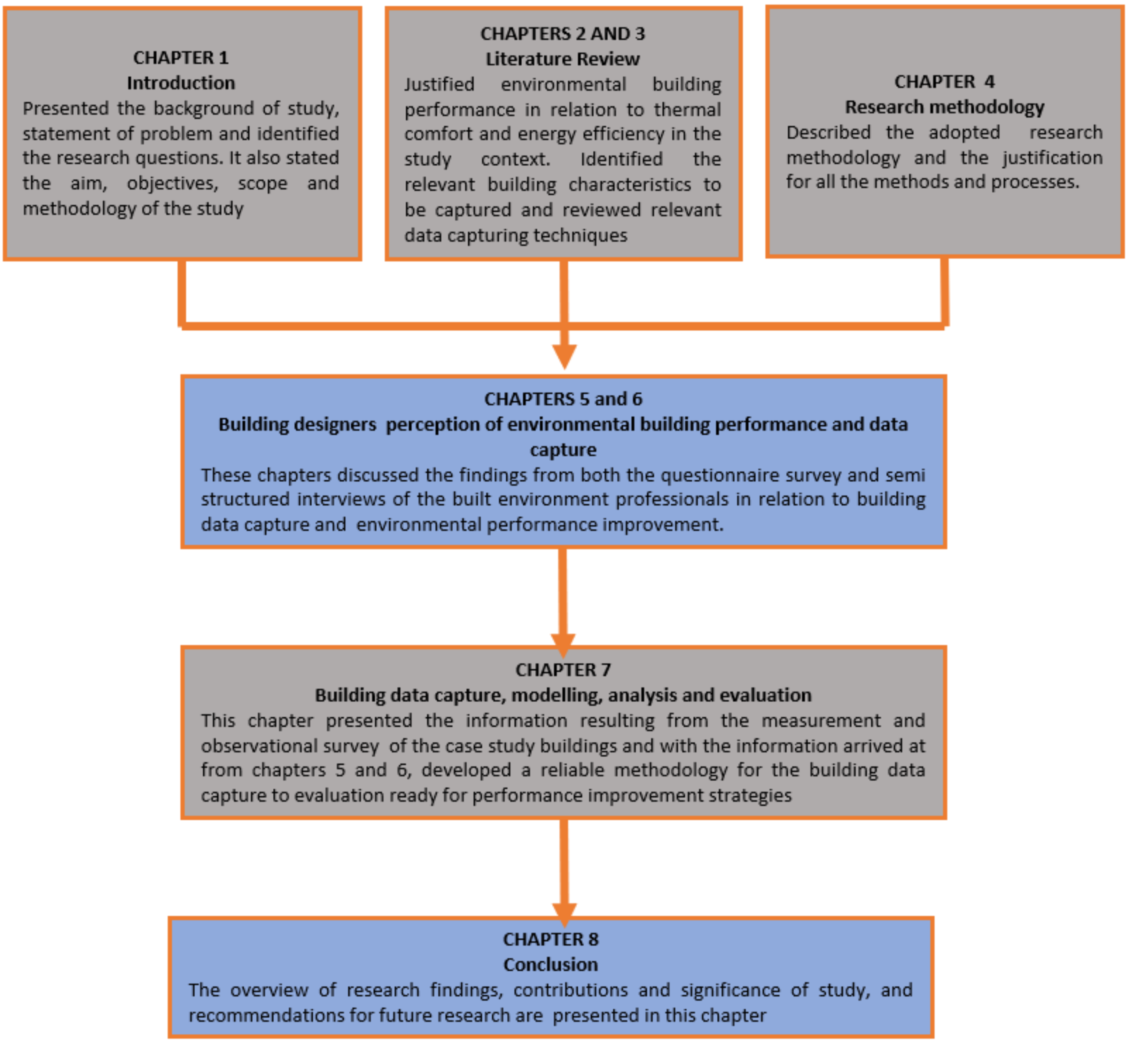


Figure 1.10. Research Structure

1.11. Summary

This chapter introduced the background of the study. It describes the statement of the problem, the research questions, the research aim, the objectives, and the significance of the study. The scope and limitations and the research methodology are explained followed by an analysis of the structure of the thesis. It is pertinent that an extensive review of literature is carried out on any research to ensure a thorough understanding of the research area. The next chapter discusses the context for building performance improvement and the building characteristics needed to enhance the indoor thermal environment towards energy efficiency.

CHAPTER 2

BUILDING PERFORMANCE-RELATED CHARACTERISTICS IN THE STUDY CONTEXT

2.1. Introduction

This chapter focuses on the environmental building performance-related characteristics for data capture in existing buildings. It starts by presenting relevant information about Nigeria and Benin City, the capital of Edo state and the research context concerning its climate, geography, people, status, and the prospective future of city development. It also expounds on the energy and building performance challenges in relation to population growth and rural-urban migration, the national building code, and the architecture of Benin City. It explains the concept of building performance and evaluation and identifies the occupant's comfort requirements in Nigeria's office buildings. Meeting occupants' thermal comfort requirement is the main energy consumer in office buildings leading to high energy demand amidst the energy poverty ravaging the country. In acknowledgement of the aforementioned issues in Nigeria, various documents including the Building Energy Efficiency Guideline (BEEC) published in 2017 and the Building Energy Efficiency Guideline (BEEG) published in 2016 have advised the adoption of bioclimatic design initiatives. A few of the vital aims of the recommendation are to help reduce the demand for energy from the national grid and meet occupants' comfort needs while contributing less harm to the carbon footprint. Concurrently various standards and guidelines are in place for several countries that buildings adhere to, but there is no evidence of such in sub-Saharan Africa, including Nigeria. Thus, it could be argued that in the absence of well-developed national regulations, the bioclimatic design guidelines developed by Arup and Genre (2016) could offer an alternative, especially in this era of climate change and changing building users' requirements. As discussed in Chapter 1 existing commercial (office) buildings, are among the highest energy-consuming buildings yet studies that aim at enhancing their performance have received less attention. Whereas actions aimed at enhancing the environmental performance of existing office buildings offer significant benefits compared to new construction. Thus, Identifying the existing buildings' components and characteristics where the maximum impact on environmental performance improvement strategies through bioclimatic design initiatives can be applied is important. In addition to identifying the building performance-related characteristics of existing buildings, the appropriate data-capturing techniques are also necessary for achieving the required performance improvement. The identified building characteristics also form the premise for the data-capturing techniques discussed in the next chapter.

2.2. Building Performance

Authors have made several attempts to define building performance. Ibem et al. (2013) and Gopikrishnan and Topkar (2017) state that a building's primary purpose is to provide the occupants with the needed conducive, safe, comfortable, healthy, and secure indoor environment to carry out various activities such as work, study, leisure, and family life to social interactions. Therefore, to meet this purpose, buildings are designed, planned, managed, and constructed under governments, professionals, and experts' established standards and specifications borne out of adequate knowledge of users' needs and requirements. De Wilde, (2018) summarising from three viewpoints (engineering, process, and aesthetics) described building performance as a building meeting users' requirement. In support, Hensen and Lamberts (2019) emphasised that in addition to protecting building users from undesirable outdoor environmental conditions, office buildings should provide a healthy, comfortable, and productive indoor environment. Thus, an office environment should provide the necessary user comfort that promotes well-being, health, and productivity as reiterated by De Wilde (2019) stating that building performance currently associates itself with issues including indoor environmental quality, energy efficiency, building fabric, occupant comfort and satisfaction.

Adeyemi et al. (2017) state that 87% of existing buildings (including offices) will be standing by the year 2050 and many of the buildings for the next century already exist. In addition to historic and economic factors, new expectations, and current challenges (discussed in Chapter 1) require the need to improve the environmental performance of existing office buildings (Cao et al. 2022). Regular performance evaluation gives an insight into the percentage of effectiveness and efficiency of a building in meeting users' needs and expectations (Ibem et al. 2013; Gopikrishnan and Topkar, 2017). It details occupants' feelings and provides the necessary information about the buildings on user's needs, requirements, preferences, and satisfaction to aid in improved design, quality, construction, and management of buildings (Gopikrishnan and Topkar, 2017).

It is well documented that buildings (mostly commercial) in Nigeria have poor performance but not much attention has been given to the practice of evaluation and improvement while the past two decades have mainly focused on constructing new buildings (Abigo et al. 2012; Adeyemi et al. 2017; Olayinka and Andrew, 2018). Attempts to improve the environmental performance of existing buildings commence by evaluating their current state. Building performance evaluation (BPE) is a systematic and rigorous approach that covers several activities such as research, measurement, comparison, evaluation, and feedback that takes place throughout the building lifecycle (Mallory-Hill et al, 2012). BPE focuses on the relationship between building designs and their technical performance concerning human needs so that lessons learned from evaluations can be used to inform future practices (enhancement). However, a major criticism of the built industry professionals is that they do less to access user satisfaction post-building occupancy unlike practitioners in other fields of human endeavour who commit resources to examine that the original function and user satisfaction meet with their everyday products and tasks while making the necessary adjustment (Meirs et al. 2009; Ibem et al. 2013).

Diverse methods are used to evaluate the performance of existing buildings including Post occupancy evaluation (POE), and the evaluation of the energy performance of buildings (EPB). The emphasis on human need or satisfaction is critical because user need determines the type and nature of any building and so are specific functions expected from certain building types. In recent times, how well the building is performing is evaluated through physical observation and measurement, building performance simulation, expert judgement, and stakeholder surveys (De Wilde, 2019). The aim of building performance evaluation is to help in creating a practical framework to measure a building's environmental performance and the construction process has generally proved to be successful (Amasuomo et al. 2016). However, the assessment of the performance of a building is highly contextual that is, climatic variations, local materials, and occupancy patterns across different countries ensure that a valid assessment criterion applies to different localities (Ijaola et al. 2018; De Wilde, 2019). Thus, the performance of a building will significantly differ in a hot climate from in a cold environment and the desired satisfaction, comfort and safety are at risk if the building fails to perform as required. In line with the study's focus on assessing building characteristics for environmental performance enhancements, it is imperative to shed some light on the building user needs which are contextual, starting with a general background of the study region, its geography and climate.

2.3. General Background of Nigeria.

Nigeria is a country located West of Africa and lies between latitudes 4° and 14°N and 3° and 15°E (see Figure 2.3A) with a varied climate (Central Intelligence Agency [CIA], 2022). Nigeria is made up of six geo-political zones which are the South-West, South-South, South-East, North-West, North-East, and North Central as shown in Figure 2.3B (brown arrow indicating the position of the State). Nigeria is subdivided into 36 states and the Federal Capital Territory (Figure 2.3B).

Figure 2. 3A. Geographical location of Nigeria on the map of Africa (Source: https://www.pinterest.com/pin/gpiafricanigeriamap--640918590690453431/ accessed 15/08/2022)

Figure 2.3B. Map of Nigeria showing its geopolitical zones (Source: http://aboutnigerians.com accessed 15/08/2022).

Nigeria's tropical climate consists of two main seasons: the rainy season (April to October) and the dry season (November to March). The dry season is characterised by its low temperature and a dry cool air (Harmattan), dusty and hazy atmosphere brought in from the northeast wind from the Sahara. In the southeast, it is wet and hot, and dry in the southwest. The north and west are savanna climates marked wet and dry (Heider, 2019). The rainy days decrease from south (3000mm) to north (500mm) annually. Temperature and humidity are relatively constant all year in the south while it varies in the north. Mean maximum temperatures are higher in the north (above 38°C) and reasonably steady on the coast (32°C - 33°C).

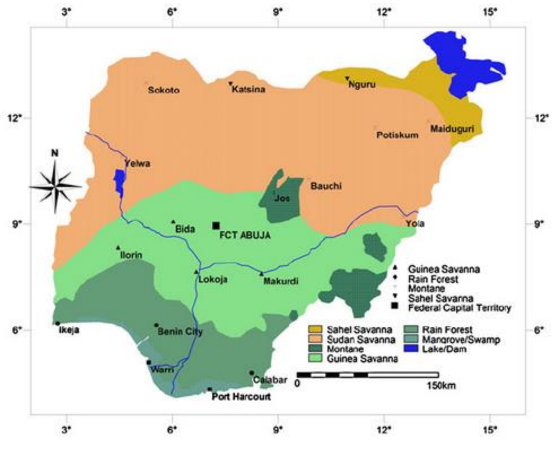


Figure 2.3C. Climate map of Nigeria (Source: Eludoyin and Adelekan 2013)

According to Barau (2010), the critical element of climate that affects buildings in Nigeria are rainfall and temperature resulting in overheating and flooding from uncertain patterns of rainfall.

2.4. General Background of Benin City.

Benin City, the focus of the study and the capital of Edo state is in the south-south geopolitical zone of Nigeria and lies within Latitude 6°06' and 6°30'N, and Longitude 5°30' and 5°45E, West and East boundaries, respectively (Balogun and Orimoogunje, 2015). Its origin dates back to when it was the seat of the king of the ancient Benin Kingdom in the 12th century, the seat of the Portuguese Foreign Mission, the centre of international commerce and now the capital of Edo state (Odjugo et al. 2015). Furthermore, Benin city metropolis cuts across four local government areas which are Oredo, Egor, Ovia North-East and Ikpoba-Okha local governments shown in Figure 2.4a. Furthermore, the city has remained a commercial hub linking the other parts of the country.

Benin City falls within the equatorial rainforest zone accompanied by heavy rainfall (Ezemonye and Emeribe, 2014). The two main seasons are the rainy season spanning from March to October; and the short dry season which spans from November to February (Balogun & Orimoogunje, 2015). Rainfall in Benin is usually continued for about 10-12 days with an average rainfall of 2000-2500mm and a mean monthly temperature of 28°C (Ezemonye and Emeribe 2014). The substantial amount of rainfall results from evapotranspiration amounting to high heat. The relative humidity is 80% and 70% in the wet season and dry season respectively (Cirella et al. 2019). The average daily solar radiation that is received on the horizontal surface of Benin city is 17.4MJ/m – 12.50MJ/m between November to August and the total global is 187.74MJ/m with August being the lowest due to the highest amount of rainfall in the city during that period (Njoku et al. 2018). Furthermore, the more significant variation of solar radiation that occurs in December and January could be a result of the harmattan dust from the Sahara Desert (See Figure 4.2b). The months of November and April marking the end and beginning of the rainy season are the steadiest months (Njoku et al., 2018). According to Weather Spark (2019), the length of sunshine hours in Benin City is roughly 12hrs, and the hourly average wind speed is more than 4.0 miles.

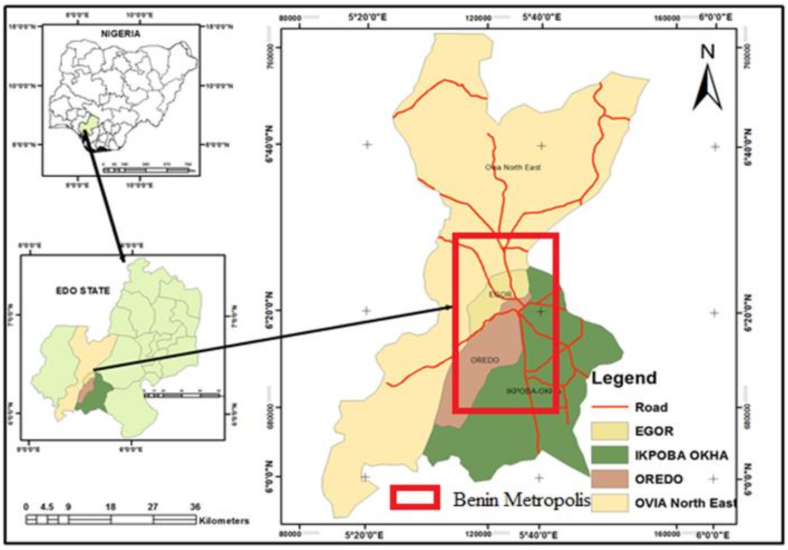


Figure 2.4a. Map of Edo state showing Benin City (Source: Odjugo et al., 2015)

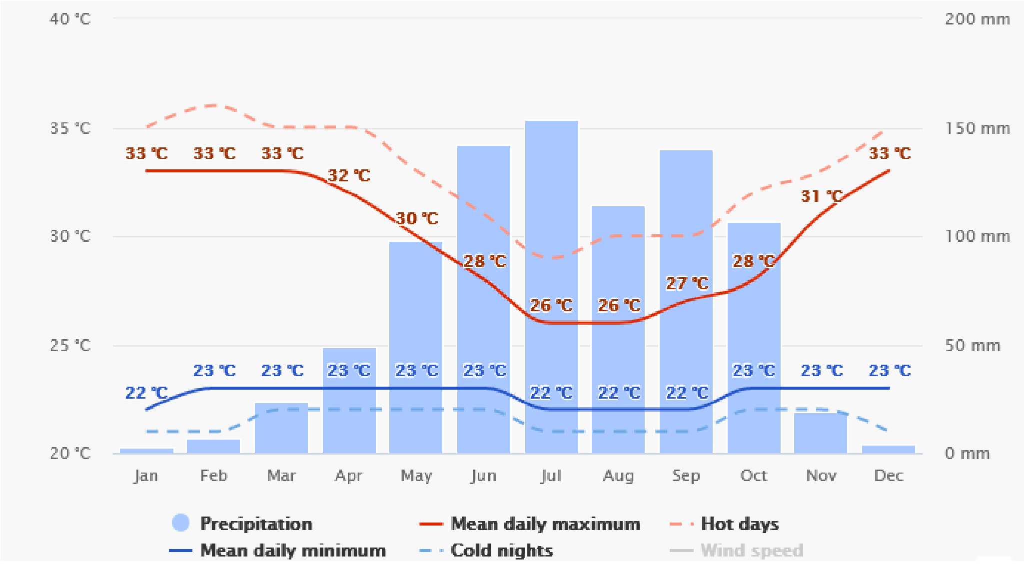


Figure 2.4b. Chart showing Benin City's average temperature and precipitation (Source: Meteoblue.com)

Other than climate that affects the design and functioning of a building, the socio-economic and socio-cultural characteristics of the inhabitants of a place significantly affect its settlement and architecture. Benin City, from the early days of the Mid-Western state, Bendel state and now Edo state has always been a state capital, thus, accommodating all state and federal ministries and institutions (Ekhaese and Adeboye, 2014). Furthermore, the city also benefits from road transporters because of its position serving as a central point that connects to the north, east-west and south of Nigeria. Benin City has and is also experiencing rural-urban migration resulting in a territorial expansion in addition to the rapidly increasing population experienced in the whole of the country. According to the World Population Review (2020), the city is attributed to be an urban settlement with a high population index of about 1,727,169 people (6th in Nigeria) with an estimated annual rise of 2.93%. Therefore, as suggested by Floyd et al. (2016), an imminent increase in the need for social infrastructures, the numerous small-scale establishments and commerce already going on in what Ekhaese and Adeboye, (2014) referred to as a civil service City including office buildings. Several socio-economic activities carried out in the city in the formal sector are by the government and are dominated by primary, secondary, and tertiary activities, and trading in the informal sector (Ezemonye and Emeribe, 2014). The impact of the status and prospective future of Benin City development regarding the need for commercial buildings are discussed next.

2.5. Status of Benin City Development.

Benin City grew into an urban centre and metropolis from a previous cluster of thirty-one villages and an informal settlement after undergoing a period of urban transformation (Ozo, 2009; Ekhaise et al. 2015). Koutonin (2016) in a Guardian newspaper stated that in precolonial times, city planning followed a fractal design process (careful planning of symmetry, proportionality, and repetition) with houses built alongside streets. See Figure 2.5.

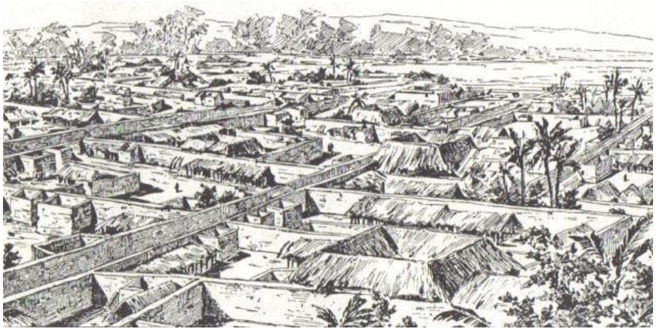


Figure 2.5A. A drawing of Benin City made by a British officer in 1897 (Source: Koutonin; 2016)

Pre-colonial cultural and architectural foundations of Benin City were influenced by the Western architectural style following the colonial period by the British leading to a more contemporary architectural phase post-colonial period (Ekhaise et al. 2015). Although there has been some form of resilience to the cultural significance and old architecture in certain forms, many of these are no longer controlled by religious or cultural ideologies. For example, Figure 2.5A of the precolonial era shows a semblance to post-colonial Figure 2.5B. in terms of spatial planning. However, contemporary issues of class, durability and aesthetics concerning building designs, materials and structure are now noticeable.

Figure 2.5B. Benin City in 2005 (Source: Liberal Dictionary 2018)

According to Ozo (2009), rapid modernization and urban development started when Benin City remained the headquarters of Edo State and after establishing the first university in the city in the early 1970s. The considerable growth rate in administrative functions and the development of administrative machinery in line with the growth in retail and education was then followed. This status of the administrative boom was said to have led to a significant increase in commerce, whose activities are now concentrated around the city centre symbolic of the city's historical and cultural representation. The high demand for spaces for these activities has led to the destruction and conversion of many historical buildings as well as the construction of new structures to meet up with the business-use demand. This period, from the early 1970s, marks the development of offices. It has been reinforced in the last decade by the rise in commercial land use activities and the influx of many civil servants, this is evidenced in the redevelopment of the inner ring road and dualizing of major converging roads to cater for the resultant surge in vehicular movements and other infrastructure. See Figures 2.5C and 2.5D

Figure 2.5C. Benin City in 2005 (Source: Liberal Dictionary)

Figure 2.5D. A picture of Benin City Centre (Source: Ikengawo 2013)

While there is a dearth of information on the economic sectors in Benin City (IRB, 2020), Osamwonyi and Tafamel (2010) alluded that Small and Medium Scale Enterprises (SMEs) provide a larger percentage of employment and income in Nigeria (including Benin City). The lack of infrastructural development including the lack of electricity has resulted in businesses providing expensive parallel infrastructure coupled with exorbitant rents charged by landlords thereby pushing businesses out of desirable locations (city centre) and influencing urban expansion. To curb rapid urbanisation and environmental degradation for the next 30 years, the executive Governor of Edo state ordered the Ministry of Physical Planning and Urban Development; Environment and Sustainability and the Edo Geographic Information System to develop a master plan for the city (Oni-Jimoh et al. 2018). Emphasizing the need for effective planning of development as well as provision of essential infrastructural facilities including constant electricity as one of the critical ways to solve the problem of urbanisation which results in poor health due to environmental degradation. While awaiting the master plan for Benin City, there have been several completed projects including the KADA cinema, renovated projects including the Secretariat office building as well as a host of other ongoing works including the Nigerian Petroleum Development Company office. The next sections provide a summary of the state of energy infrastructure in Benin City.

2.6. Energy Infrastructure, Energy Consumption and Office Buildings in Benin City.

Quality of life, economic growth and national development are impeded by the absence of electricity (Odior et al. 2010; Akhator et al, 2019). Benin City, like other parts of Nigeria, suffer from some form of the world's worst electricity deprivation where 45 per cent of the total population have access to grid electricity which is 60 per cent of the time epileptic and insufficient in supply (Uhunmwagho and Kenneth, 2013; Geissler et al. 2018; Olatunji et al. 2018; Akhator et al. 2019). While energy is the mainstay of Nigeria's economic growth (Oyedepo, 2012; Olatunji et al 2018), practices and products that minimise the need for energy (electricity) to light or cool are required given the current insufficient state of energy in the country (Geissler et al. 2018; GIZ 2015).

The annual energy consumed by office buildings varies between 100 and 1000 kWh per square metre depending on factors including geographical location; type of office equipment and its use; type of building envelope; type of lighting; kind of HVAC system and its application as well as the mode of operation (Santamouris and Dascalaki, 2002). With the dearth of electricity consumption by building type in Benin City, Lu and Lai (2020) state that commercial buildings (office buildings in particular) are major energy consumers citing Hong Kong's and Singapore's annual energy use intensity by commercial buildings doubles that used by residential buildings. Urbanisation and economic growth are factors in Benin City's increasing energy demand for commercial buildings but are faced with poor energy infrastructure.

Commercial and public services comprise public and private offices and also some business premises accommodate government offices and agencies. While office buildings have no internationally recognised classification standard, several organisations and studies have adopted certain criteria to classify office buildings (Efeoma and Uduku, 2016). Regardless of classification, it is clear however that office building consumes a significant amount of energy in the form of electricity mainly for cooling and lighting. Numerous office buildings in Benin City as well as other parts of Nigeria are reliant on generators (Uyigue et al. 2009; Oyedepo, 2012; Adewale et al. 2018;). It can be argued that offices consume a large amount of energy for productivity, however, it is well-documented that there are three main classes of energy consumption in office buildings as shown in Figure 2.6A. Arup and Genre (2016) reported that in Nigeria, with a tropical climate, office buildings consume energy in the form of electricity for ventilation and air conditioning, lighting, and office appliances. The study referred to a survey on energy consumption in seven Nigerian office buildings where fairly, a typical office building in the country shows the use of about 12-25 % for office equipment, 13-37% for lighting, and a massive 40-68% for VAC.

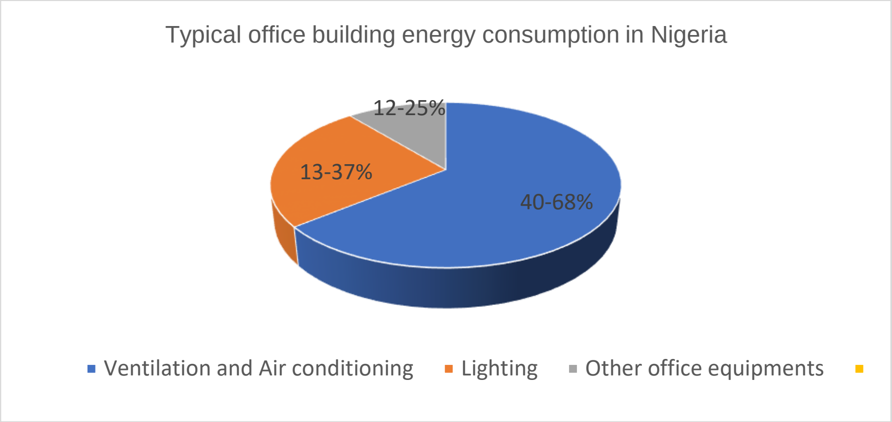


Figure 2.6A. A typical office building energy consumption in Nigeria (Adopted from Arup and Genre, 2016)

Figure 2.6A shows the energy consumption of office buildings in the operational phase, and it can be seen that the highest percentage is attributed to ventilation and air conditioning (HVAC) systems as can be seen in Figure 2.6B, followed by lighting and office appliances respectively. Thus, providing a more comfortable thermal environment through climate-responsive building design strategies and approaches could potentially diminish energy demand by the HVAC system for an office building contributing to more optimum performance. It supports GIZ (2015)'s position that the building sector can substantially reduce energy demands if cooling needs are decreased using energy-saving techniques including climate-responsive design while arguing that electricity generation from generators is impractical and not carbon and financially efficient.

Significant consumption of Nigerian office buildings is critical to why at least 10% of the facilities are referred to as Maximum Demand (MD) customers placed on dedicated transformers (Adewale et al. 2018). The power inefficiency further promotes adopting energy-saving conscious building design approaches (Geissler et al. 2018). The regulatory framework has yielded fruitful results in developed climes by helping to minimise energy needs and mitigate climate change, but not in Africa where their building regulations lack fuel efficiency and carbon reduction capacity (Mafimisebi et al. 2018). GIZ (2015) states that designing energy-efficient buildings is beyond the architect's role and expertise. Whereas, retrofitting existing buildings for appropriate lighting, better ventilation and air conditioning are viable targets with high potential for contributing to several social, economic, and environmental benefits including energy efficiency and low carbon emission. In addition to reducing energy demand enhancing comfort is vital because the poor performance of office buildings on the occupants has a negative health impact and lower productivity rate.

Optimum comfort in office buildings has a positive health impact and productivity rate facilitating the desired economic growth and development especially as the use of electricity from generators negatively impacts businesses and productivity costs (GIZ, 2015; Oyedepo, 2012; Efeoma and Uduku, 2016). Planning for generators is becoming a fast-growing part of the architecture within the built environment (GIZ, 2015). For instance, on July 4th, in the Nation Newspaper of 2019, the governor of Edo state disclosed his intention to transform the civil service in the state by rebuilding the entire civil service visited the secretariat complex where Blocks C and D have been renovated. The governor after mentioning some of the administration's efforts to make civil servants take pride in where they work by creating a conducive environment stated that there will be provision for an embedded generator plant to provide 5MW electricity to the complex. Thus, unless the energy supply meets demand, it is almost an impossible task to meet the comfort required for productivity in office buildings. Also, the argument that office buildings in Nigeria, are constructed with little or no climatic adaptations makes them rely more on energy for comfort and in turn productivity. Comfort can be achieved by alternative non-mechanical means due to the nexus between building design and technology (Mu'azu and Gyoh, 2013; Onochie et al, 2015; Geissler et al. 2018; Olatunji et al. 2018).

Figure 2.6B Typical office building with 21 air conditioning units on one facade (captured by the researcher)

In Benin City, there is a shortage of studies relating to the position of office buildings, but the work by Duru and Shimanwua (2017) on the work environment of the office of the Edo City Transport Service presents a synopsis of office buildings. The study advised that the management of the company should endeavour to provide an environment that is conducive, comfortable, and pleasant to enhance employees' job satisfaction and job motivation. This is similar to the Edo state Government's commitment to redefine the workplace and make it more conducive for workers. Also, other government's efforts to revamp institutions including renovating the Ethiope Publishing House located at the heart of the City to create a conducive pensioners office as disclosed in Vanguard newspaper by Adekunle (2018).

Due to the aforementioned, this research, therefore, considers environmental and energy-efficient building design methods that will mount less pressure on the epileptic energy grid of Benin City. Achieving this aim is to seek an alternative (climatic responsive) way of enhancing office buildings primarily due to their high energy consumption while addressing the comfort of building occupants. The climate-responsive means of achieving comfort in office buildings will follow the "Building Energy Efficiency Guideline (BEEG)" report published by the Federal Ministry of Works and Housing (Housing), Arup and Genre (2016).

To apply the recommendations stated in the BEEG publication, a brief overview of an office building user's comfort requirements is necessary.

2.7. Comfort in Office Buildings

Without a formal international classification for office buildings (Building Owners and Managers Association, [BOMA], 2014), several writers have adopted different criteria for their classification mainly based on cost and aesthetics. Classifying office building spaces can be a difficult task based on the requirement of the workplace in respect of the activity carried out (Bieleford, 2018). The Oxford Learners Dictionary (2021) defines an office as a room or set of rooms or buildings where people work usually sitting at desks. They are mainly for administrative and clerical purposes usually with the computer or other technical devices, processing information. Since office workers spend a significant amount of their day in the workspace, the working environment should offer the needed comfort for the several phases of the job routine which in turn promotes workers' health and productivity. Thus, a comfortable indoor environment is the main building user requirement for office buildings needed for increased productivity. Whereas the provision of adequate comfort in office spaces are issues bordered on lighting, thermal comfort (heating/cooling and ventilation) and personal factors such as age, gender and health as shown in Figure 2.7A (Bieleford, 2018).

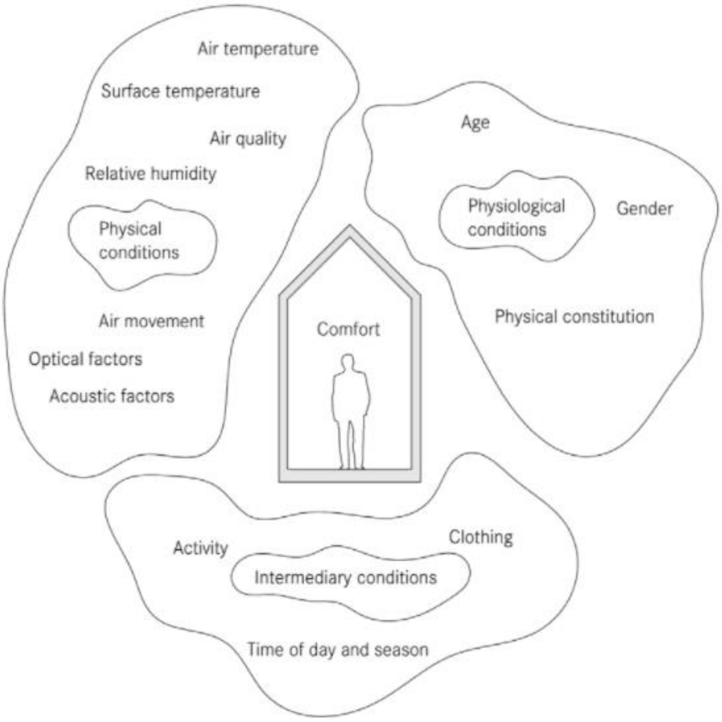


Figure 2.7A: Comfort in office space (Source: Bieleford, 2018).

What Figure 2.7A means is that while there is the possibility of a uniformly optimised indoor climatic condition, different employees can also feel a sense of discomfort due to health, clothing, activity or technical devices. Thereby emphasizing the need for workers to be able to regulate their comfort level.

In this regard and taking the local context and the climate of Benin City into consideration, the office workplace typologies used in this study are the most common in the city as well as their mode of ventilation. The features are described below.

- Enclosed or Single room office spaces: These are enclosed private workspaces that are usually arranged along a central corridor with varying sizes depending on the status and intention of the occupants. (Neufart and Neufart, 2019). This type of office space typology is also called the cellular office with a preferred option of individually controlled window ventilation, where noise or noxious substance is on the low (Bieleford, 2018).
- Open Plan Offices: These are workspaces with several workstations as dividers, most times in the form of desks. They usually do not have full dividing, partitioning or screen walls (Neufart and Neufart, 2019). It is usually more difficult to control open-plan offices because of the various users, as well as more cooling, is required due to the heat expelled by various devices (Bieleford, 2018).
- Ventilation which is the exchange of air helps in controlling the indoor climate and comfort in buildings (Mora and Bean, 2018) was observed by the researcher. The

observation and casual interview of some staff revealed that workers' status and budget are key determinants of the ventilation system in their offices such that the higher the status or budget of any staff, the more enhanced the ventilation system. The common ventilation systems in the study context are

Natural ventilation: Office spaces that rely strictly on passive measures such as the use of windows for the exchange of air and achieving comfort and those that make use of mechanical means.

Mixed mode ventilation: A workplace that considers the use of both natural ventilation and some form of mechanical ventilation control systems. For example, utilising both opening of windows (natural ventilation) and the use of air conditioners (mechanical ventilation) so that the occupants can have total control of their operation (switching it off and on).

Figure 2.7B Typical example of office arrangement in the study context.

Figure 2.7B shows a typical example of how offices are designed in the study region. They can be either open or enclosed and in various sizes,

Figure 2.7C Common ventilation system found in the study region.

Figure 2.7C shows the two methods common in the study region. The use of wall-mounted air conditioners and openable windows.

As the focus of this study is on identifying the building characteristics needed to improve for a thermally conducive indoor condition of the office for the occupants, the mechanical ventilation system, though not common in the study context was overlooked because it is energy-demanding which is beyond the study aim.

From Figure 2.7A and Section 2.7. it can be observed that the critical elements of achieving a generally comfortable indoor environment in the workplace also have a high impact on energy demand. For example,

- Although some office appliances may produce heat which can affect comfort, especially in hot climates, they are necessary for carrying out the various administrative tasks in the workplace. Oyedepo (2012) suggested that improved management, better technology, and responsible behaviour of the occupants can go a long way in achieving energy conservation and energy efficiency including through the required conducive indoor environment.
- Lighting and its effect on occupants, the main consideration for visual comfort in buildings can be harnessed naturally through architectural design strategies (International Energy Agency [IEA], 2010). Proper daylighting can provide energy savings and comfort for humans, in the tropics, the use of sunlight has not been maximised because of the accompanying solar radiation which can also be advantageous to reduce the energy consumption chiefly occupied mostly during the day as in the case of office buildings (Lim and Ahmed, 2010). That means that the need for utilizing energy through artificial lighting may be less as offices operate during the day when there is the availability of sunlight.
- Ventilation and air conditioning (VAC) are concepts of comfort used in most buildings to achieve thermal comfort. Thermal comfort is difficult to define within the built environment due to differences in the preferences and conditions of different people. Mora and Bean (2018) describe thermal comfort as "that condition of the mind that expresses satisfaction with the environment expressed by subjective evaluation". The state or condition of the mind could be determined by influences from physical, environmental, and work-related factors affecting a person's feelings and the interplay between these factors (Neto et al. 2016). Human thermal comfort has its link with the need to maintain a nearly constant internal temperature regardless of the quantity of heat produced in the human body or the environment. For proper health and well-being, this stable core body temperature of about 37°C is essential (Nicol et al., 2012). As several factors determine human thermal comfort (Figure 2.7A), the variation in one

of the factors may result in an uncomfortable condition necessitating the need for adaptive measures. Thus, adaptive thermal comfort adapts to a broader range of thermal conditions than assumed or targeted threshold through a more flexible approach and human connection with the outdoors and control over the immediate environment (Nicol et al. 2012). It is so because indoor comfort is influenced by outdoor climate due to humans, naturally adapting to various temperatures at different times of the year (Arup and Genre 2016).

Nigeria is one of the countries with high global demand for air-conditioning multiplying yearly among middle-income and low-income countries with warm climates and vulnerable to climate change, carbon emissions and environmental damage (Rodriguez and Alessandro, 2019). What it implies is that with an increasing population, building standards and specifications will not meet the users changing needs and expectations, thereby making the performance of the building unsatisfactory to its users. The compromise of the building's performance causes sick building syndrome and building-related illness and consequently the need for enhancement (Ibem et al. 2013; Gopikrishnan and Topkar, 2017).

Despite the shortage of information and knowledge on thermal comfort in the tropics, the lack of connection between building design and construction characteristics with thermal assessment procedures has been well noted. Thus, thermal comfort improvement strategies documented in many building types (including residential, hospitals and historic) suggest climate-responsive, vernacular, or low-energy design solutions (without the use of air conditioning). To effectively do this, there is the need to review building regulations in Benin City, the study region and efforts geared toward building performance and energy efficiency in Nigeria giving the following considerations.

- Considering that achieving thermal comfort is the highest energy demand in the office building, it also significantly impacts comfort and productivity rate.
- Considering the unsatisfactory state of energy in the form of electricity that could complement the compromise of a building's function. (A change from consumer to prosumer).

"Building performance for this study is the act or process of reducing energy demand in office buildings by creating a thermally comfortable indoor environmental condition "

2.8. Building Regulations in Benin City

To manage the rate of urban growth and development in Benin City, the Edo state government has mandated the relevant ministries to produce a master plan. However, in the spate of developments, two documents are used to control building activities. The National Building Code and the Edo State Urban and Physical Planning Regulations 2014

2.8.1. Edo State Urban and Physical Planning Regulations 2014

After Nigeria attained independence in 1960, development control before the independent era continued to be in use. In 1978, to solve the problem of land available for public use and where individual ownership of land mainly in southern Nigeria was rampant, the military government promulgated a Land Use Decree (Kio-Lawson et al, 2016). The decree granted permission to all states to own and administer all but Federal land within their territory to the benefit of all Nigerians so that a right of occupancy can be granted to citizens. The shortfalls of the 1946 Town and Country Planning Ordinance gave way to the 1992 Urban and Regional Planning Law which was divided into six parts including development control; renewal, rehabilitation and upgrading; and plan preparation and administration. The document was however updated by the Edo State Government to "Edo State Urban and Physical Planning Regulations 2014".

The document specified the minimum requirements for building setbacks on all sides of a building which depend on the density of the area and landmarks and the minimum built-up area for every building category. Thus, the document was partial to control, including where and what is to be built without consideration to the performance of what is built concerning commercial building.

2.8.2. National Building Code (NBC)

The national building code (NBC) came into law in 2006 after its evolvement was directed by the Defunct National Council of Works and Housing in 1987. The need arose due to six stated reasons including the incessant collapse of buildings, fire and other abuse and disasters of the built environment. Others include the dearth of referenced design and standards for professionals, quackery, lack of maintenance culture, untested products and material use and the absence of City and town planning. The NBC, a very detailed national document complements other local regulations including that it is referenced several times by the Edo State Urban and Physical Planning Regulations 2014. Despite the details contained in the document, there was not much conscious effort to address the performance and energy efficiency of buildings given the poor state of electricity in Nigeria. Also, specifications that pertain to design were not tightly addressed. For example, ventilation for office buildings in the document stated that there should be provision for natural and or mechanical ventilation and lighting. Where natural light shall be based on 2691 lux of illumination adequate to provide an average illumination of 64.58 lux at a height 75cm above floor level while artificial lighting shall be capable of providing the same illumination as natural lighting. It also stated that natural ventilation through openings should have a minimum openable area to the outdoors and it shall be 4% of floor area being ventilated as well as mechanical ventilation conforming to that stipulated for natural ventilation. Studies including that of Ogunsote (2011), and Atanda and Olukoya, (2019) have noted the shortcomings of the NBC suggesting that a review should be carried out and include building energy efficiency and performance thresholds. The NBC is said to be under revision (FMPWH, 2017)

2.8.3. Other Efforts at Achieving Energy Efficiency in the Nigeria Building Sector

Other than the two aforementioned building regulations, there have been efforts by the Federal Government of Nigeria to encourage renewable energy and energy efficiency. One of them is the National Renewable Energy and Energy Efficiency Policy (NREEEP) approved in 2015 by the Federal Executive Council. The policy proposed energy-saving measures by developing an energy-efficiency building code that encourages bioclimatic design initiatives. Ayangeaor (2022) in a review of the NREEEP stated that the policy does not articulate policy measures that would drive its development in Nigeria and recommend legislation that would establish the methodology for the formulation, review, and implementation. The National Energy Efficiency Plan (NEEAP) was approved in 2016 by the National Council on Power (NACOP) and it sets out the implementation strategy for the (NREEEP, 2015) to promote energy efficiency in Nigeria.

One of the policies and tools on energy efficiency in buildings by the NEEAP is the development of Building Energy Efficiency Guidelines (BEEG). The BEEG, approved in 2016 energy efficiency strategy steps are to minimize energy demand through climate adaptive designs, increase the efficiency of mechanical systems, appliances and lighting and use renewable energy for the remaining energy demand. A NEEAP implementation status is the development of Nigeria's first national "Building Energy Efficiency Code" (BEEC). The BEEC is published by the Federal Ministry of Power, Works, and Housing (Housing Sector) in August 2017. The BEEC is an extended development of the BEEG with the aim of "setting minimum requirements on building energy efficiency and to provide proper implementation, control and enforcement" (FMPWH, 2017 P.5).

The aforementioned regulations and efforts geared towards achieving energy efficiency in buildings do not give building designers the detailed framework for an energy-efficient building design for the different climatic conditions in Nigeria. Therefore, the onus falls on the designer to design in favour of building performance and energy efficiency or not, due to the imprecise nature of the building regulation. The focus of this study is on the first among the three strategies of achieving energy efficiency in buildings proposed by the BEEG which is the adoption of climate-responsive design initiatives. Identifying the characteristics and features in existing buildings is very critical to initiating measures or retrofitting for energy improvement as is their evaluation. To do this let us consider the previous studies done on building performance and energy efficiency in the study area.

2.9. Previous Work Done on Building Performance in the Study Region.

Some relevant studies on building performance and energy efficiency carried out in Nigeria are presented in Table 2.9.

Table 2.9 Some relevant studies on building performance and energy efficiency in Nigeria.

No	Author	Year	Title	Data Capturing Technology	Methodology	Type of Building	Region	Conclusions
1	Amasuomo et al	2017	Development of a building performance assessment and design tool for residential buildings in Nigeria	Not stated how the design was derived. However, the study mentioned the use of ArchiCAD, and the model was transferred to Google sketch-up for a year-long simulation using EnergyPlus.	Review existing building rating systems such as LEED and BREEAM to arrive at a system deemed fit for the Nigerian context.	Residential building.	Applicable anywhere in Nigeria	• Building challenges are not pre-defined and need to be explored in context as an iterative process. • Need to initiate controlled building measures to tackle the rapid degradation of the environment and reliance on unsustainable energy in Nigeria.
2	Ijaola et al.	2018	Building Energy Performance Evaluation for an Office complex in Nigeria.	Architectural design variables, identified from design guidance for low-energy buildings and design recommendations for tropical climates.	Energy-audit end-use analysis from fieldwork and using the SAVISCAD computer simulation software	Office Building	Akure, Nigeria	• Blockwork material with a concrete slab as the roof is not cost-efficient. Thus, it is unsuitable for office designs in tropical regions like Nigeria because of its too-high cooling capacity of 1.61TR compared to other materials to achieve human comfort in an office building. • Also, as building envelope and materials are crucial to occupants' comfort in the building, designers should consider the nature of materials for roofing offices. Besides, there need to be standard dimensions and shading materials for windows to curb excessive heat generation.

3	Ibem et al.	2012	Performance evaluation of residential buildings in public housing estates in Ogun State, Nigeria: Users' satisfaction perspective	Questionnaire and observation schedule	A cross-sectional survey of 452 household heads in nine public housing estates (2003-2009) was subjected to descriptive statistics and factor analysis.	Residential buildings in a public housing estate	Ogun state, Southwest Nigeria.	• Architects must engage in relevant design practices that encourage alternative energy sources. • The planning of residential buildings should reflect the way of life and security of users. • Mass-constructed residential buildings should consider type, location, size of primary activity space illumination, and thermal and visual comfort of occupants during planning design and construction.
4	Adeyemi et al.	2017	Facilities improvement for the sustainability of Existing Public Office Buildings in Nigeria.	Post-occupancy evaluation survey of end users' requirements and direct observation	A quantitative survey of 339 questionnaires analysed with SPSS v22 and MS Excel 2013	Office building.	Abuja, Nigeria	• Design variables of facilities require utmost consideration from end-users' perspectives that can only be defined by the end-users alone
5	Abdusalam et al.	2015	Energy efficiency in Nigerian buildings: Prospects and issues	A description of other studies.	Review of studies	Various building types.	Applicable anywhere in Nigeria	• The sustainable energy system is reliable, cost-efficient, and environmentally friendly. • The energy-efficient building promotes economic development. • Energy efficiency minimises the building of power stations and environmental conservation.
6	Mu'azu	2015	Sustainable design strategy: Assessment of the impact of Design	Empirical data from building plans, as-built drawings where available, measured,	Building inventory surveys and walkthrough energy audits of a	Office buildings	Abuja Nigeria	• There is a need to reduce energy consumption due to associated environmental impacts.

			variables on energy consumption of office buildings in Abuja, Nigeria	and estimated sketch plans, photos, walkthrough audit, and inventory of energy end-use appliances.	case study 2-D drawings and computer-based simulation			• Specification of the external building fabric is vital in energy-conscious building design in Nigeria.
7	Arup and Genre	2016	Building Energy Efficiency Guideline for Nigeria.	A typical Business as usual (BAU) building layout provided by the Federal Ministry of Power Works and Housing	Case study and simulation	Residential and Office Buildings.	Northern and southern Nigeria climates.	• Basic design measures, including bioclimatic design and best practices, allowed significant energy savings by reducing energy consumption by a minimum of 40% and further reduced to 75% with improved envelope and efficient systems added.
8	Oyedepo	2012	Efficient energy utilisation as a tool for sustainable development in Nigeria	National energy outlook of Nigeria, walkthrough and	Review of practices	Major economic sectors (industry, transportation, office and residential buildings)	Applicable in the whole of Nigeria.	• Energy efficiency should be seen as a quick and cheaper source of new energy supply. • Energy can be conserved through several measures including lighting, cooling and appliances.
9	AbdulKareem et al.	2018	Remodelling façade design for improving daylighting and the thermal environment in Abuja's low-income housing	Although not categorically stated. Building forms and information on building materials were also collected during fieldwork for modelling. purposes	Case study and on-site monitoring	Residential buildings	Abuja Nigeria.	• The frequency of thermal discomfort was reduced by 4-6% and visual discomfort by 4-29% from adjustments to the façade orientation. • Both thermal and visual discomfort was reduced by 4% and 29% respectively through external shading components.
10	Abdulkareem, M	2016	Investigation of daylighting and the thermal environment of Nigeria's low-	Architectural drawings and associated materials	Case study and on-site monitoring	Residential buildings	Abuja Nigeria.	• Shading elements are to be directed towards the shading of the façade and opening based on climate and orientation.

			income housing: The case of Abuja					• Although orientation has more impact on thermal and visual performance, other factors should not be left unconsidered. • Users may need behavioural adjustments to seasonal weather changes. • The National building code needs to be re-considered for different subregions of Nigeria in the area of window area to total floor area.
11	Isa et al	2016	Deployment of smart Technologies for Improving Energy Efficiency in office buildings In Nigeria	Not stated.	Review of smart technologies and energy strategies for improving energy efficiency.	Office buildings.	Applicable anywhere in Nigeria.	• Reducing energy consumption, Renewable energy technologies and Monitoring future GHG emissions are the three approaches that can mitigate GHG emissions and energy efficiency. • Policy enactment and energy advocacy will help get a clean and sustainable future for mankind and its future generations.
12	Ochedi and Taki	2019	Energy Efficient Design in Nigeria: An Assessment of the Effect of the Sun on Energy Consumption in Residential Buildings	Not stated.	Case study.	Residential buildings.	Lokoja, Kogi state, Nigeria.	• Building performance, as well as energy efficiency in Buildings, can be achieved by testing multiple design options rather than concentrating on one or two building elements. • Modelling can be used by designers to take advantage of the environment and test several design options

13	Okolie K C.	2011	Performance Evaluation of Buildings in Educational Institutions: A Case of Universities in South-East Nigeria	Questionnaire surveys, walkthroughs, or observations in the form of measurements.	Review of literature and case study.	Educational Buildings	South-East Nigeria	• The effectiveness of buildings is not maximised in terms of occupancy costs but in addition to user satisfaction. • The level of awareness of building performance is low and building performance appears unpredictable in terms of quality standards and user expectations. • Lack of interest in building performance and standard of approaches to building performance evaluation and practices are below performance criteria and best practice level.
14	Akande et al.	2015	Sustainable Approach to Developing Energy-Efficient Buildings for Resilient Future of the Built Environment in Nigeria	Fieldwork using a questionnaire survey and local health workers.	Non-experimental descriptive research	Residential buildings	Bauchi, Nigeria.	• A sustainable approach can lead to improved architectural design. • Retrofitting of existing buildings can improve indoor conditions, and reduce energy consumption and long-term running costs of the building. • Achieving energy-efficient buildings would require adapting to the changing energy-constrained world, appropriate planning and design for energy-efficient buildings and retrofits to existing buildings for an expensive or absence of energy future.

15	Geissler et al.	2018	Transition towards energy efficiency: Developing the Nigerian Building Energy Efficiency Code.	Fieldwork using case studies and practical testing of known strategies through stakeholder involvement.	Review of previous works and stakeholder discussions	Residential as a case study but applicable to all buildings	Abuja, Nigeria but applicable all over Nigeria.	• Developers play key roles in increasing widespread acceptance of energy efficiency measures and thus should be trained in that regard along with planners and engineers. • Materials and equipment providers should know and deliver key product-related data needed for energy-efficient buildings as well as implement testing procedures in line with new requirements. • Construction companies should limit employing unskilled workers as a recognition that energy efficient code is an advanced construction standard.
16	Musa and Abdullahi	2018	Optimising Energy efficiency of office buildings in the Tropical composite climatic belt of Abuja, Nigeria	Physical observation including measurements	Case study	Office buildings.	Abuja, Nigeria.	• The enhanced passive control strategy showed a significant reduction in cooling energy demand. • Also, the passive system increased the annual indoor comfort temperature duration.
17	Efeoma and Uduku,	2014	Assessing thermal comfort and energy efficiency in tropical African offices using the adaptive approach.	Survey and observation.	Mixed method approach, combining quantitative and qualitative data.	Office buildings.	Enugu, Eastern Nigeria.	• The adaptive approach to thermal comfort is more suitable for occupant-controlled natural ventilation. • The adaptive thermal comfort model helps to reduce energy consumption in buildings and thus improves energy efficiency.

18	Mafimisebi I. B.	2017	A model for reducing energy consumption in existing office buildings; A case of Nigeria and the United Kingdom building owners and facilities managers	Post-occupancy evaluation using three questionnaire surveys.	Mixed methods, multiple-case study approach.	Office buildings.	Nigeria and the United Kingdom.	• Suggested institutionalised regulatory framework for Nigeria and sub-Saharan Africa as a control measure. • Building energy performance and model and its operational sustainability tool can be used for benchmarking and assessment of energy. • The performance of Nigerian buildings was largely dependent on the context of their operation other than the weather.
19	Abdulhamid Y	2019	An assessment of energy performance index of the Nigerian Universities Senate Building	Not stated.	Case study approach	Office buildings	North-East region	• Designers need to be more proactive in energy efficiency strategies and incorporate them in office buildings
20	Odunfa et al	2018	Building Energy Efficiency in Nigeria's Major Climatic Zones	Not stated	Case study	Lecture theatre	Ibadan (South-West), Jos, (middle belt), Maiduguri (North-East)	• North/South longitudinal placement of buildings is best recommended • Cooling load is dependent on the location • Building material composition,

In Table 2.9 are some relevant studies in Nigeria that touched on building or energy performance evaluation and improvement. Amasuomo et al. (2017) concluded that building challenges are not pre-defined but require contextual exploration in an iterative process. Also stressed is the need to initiate controlled building measures to tackle the rapid degradation of the environment and reliance on unsustainable energy in Nigeria. The technology used to capture technical data or design was not stated nor how the design was derived. However, the study mentioned the use of ArchiCAD and the transfer of the model to Google SketchUp for a year-long simulation using EnergyPlus. Ijaola et al. (2018) used architectural design variables identified from design guidance for low-energy buildings and design recommendations for tropical climate and energy audit end-use analysis gotten from fieldwork to simulate office buildings. The study carried out in Ondo state, South-west Nigeria identified the importance of building envelope to achieving occupants' comfort in a building and emphasised the need for standard dimensions and shading materials that will limit the generation of excessive heat. Abdusalam et al. (2015) from a review of previous studies, highlighted the advantages of energy efficiency in various building types in Nigeria, Adeyemi et al. (2017) and Ibem et al. (2012) after carrying out a post-occupancy evaluation and survey emphasised that design variables from end-users perspective should have utmost priority. These studies mainly gave a generic advantage of energy efficiency in buildings but rarely on how to achieve it. Other studies went further to highlight ways to take such advantages. For example, Arup and Genre (2016) described that design measures, including bioclimatic design and best practices, ensured significant energy saving by reducing energy consumption by a minimum of 40% and further by 75% by improving the building envelope and adding efficient systems. Abdulkareem (2016, 2018) stated that shading elements could be utilised towards shading façades and openings based on climate and orientation adding that although orientation has more impact on thermal and visual performance, other factors should not be left unconsidered. It also advises that users may need behavioural adjustments to seasonal weather changes and that the National Building Code need to be re-considered for different subregions of Nigeria in the area of window area to total floor area.

History has shown that the performance of buildings was informally evaluated through technical inspections, walkthroughs and informal complaints while applying the lessons learnt in subsequent structures. However, in recent times, the evaluation requires a systematic assessment that needs a clear and detailed performance criterion that could allow performance measures to be compared (Ilesanmi, 2010; FMPWH, 2017)—thereby seeking expert attention (Geissler et al. 2018). The building performance standards, therefore, set out the principles and factors of consideration in a building. For example, the International Organisation for Standardization as a federation of national standard bodies ISO 6241 constitutes an ISO technical committee that develops international standards for the members. It involves work standards at all levels, from fundamental to specific and is approved for up to 25 countries. ISO 1183 specifies how to define functional performance requirements for building and related facilities and their capability to meet identified needs. Also, green building rating schemes including the Leadership in Energy and Environmental Design (LEED), United States Green Building Council (USGBC) and Building Research Establishment Environmental Assessment Method (BREEAM) are efforts put in place to ensure buildings meet up with specific criteria. Notwithstanding, existing buildings require evaluation to ascertain if they measure up to the set targets, especially with the changing climate and changing users' requirements.

2.10. The Need for Building Performance Simulation

Further to the recommendation of the BEEG and especially the BEEC in its performance route to compliance, most studies in Table 2.9 have also demonstrated the use of simulation to improve building performance in one way or the other. Meanwhile, building performance simulation has become an essential part of the entire building process from conception to operation to achieve the desired quality (Hensen and Lamberts, 2011; Chang et al. 2020; Casini 2022). Some sort of simulation carried out by most authors in Table 2.9 commenced by creating a three-dimensional (3D) virtual representation (modelling) of the building for visualisation. From deduction, the main stages proceeding building performance simulation, are data capturing, modelling, analysis, and evaluation. Chang et al, (2020) used different terminologies to describe the process as represented by Figure 2.10. The stages are described below.

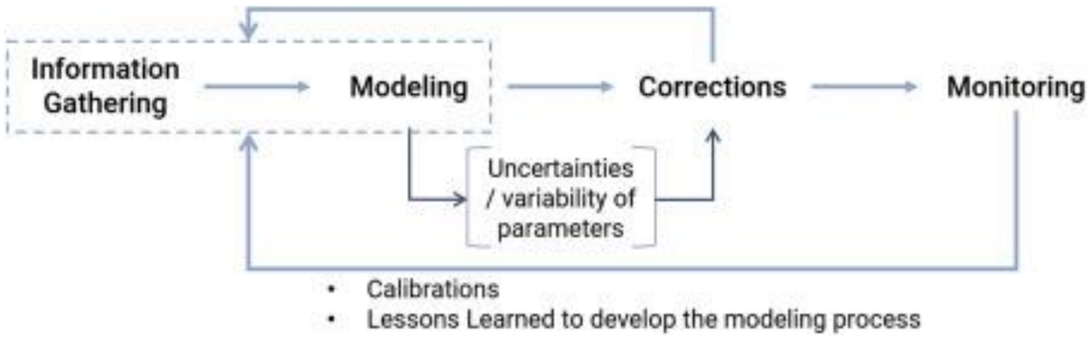


Figure 2.10 The common stages proceeding building performance simulation (Source: Chang et al, 2020)

- Modelling-- Information about a building is used to generate the virtual model using interoperable software in a computer environment to help identify and resolve design and construction issues like in a real word context (Kubba 2017; Casini 2022). Modelling building information data in a digital environment has gained widespread popularity, forming a reliable basis for building analysis and decisions from conception to demolition. The continuous advancements in the act of building information modelling now referred to as the BIM process presents numerous advantages. Other than visualization and interoperability, some of the several benefits of BIM include lower cost and risks compared to the actual structure, more accurate analysis and evaluation of the proposed scheme, improved quality, project performance, productivity, and coordination of construction (Kubba, 2017; Di Biccari et al, 2022).

- Analysis—the process of analysis and evaluation are carried out almost simultaneously. While modelling can be done for the sole purpose of visualisation using building modelling tools or plugins for 3D CAD, analysis goes further to simulate the building physics. The analysis stage, referred to as "corrections" by Chang et al (2020) entails applying all the original features including weather and energy data sets (where available) to the model using suitable building performance software before evaluation. These details are difficult to be specified during the modelling stage and depending on the level of information available and the nature of building performance software used, they include the selection of building type, materials, and systems (Chang et al 2019; 2020),
- Evaluation—The process of evaluation (referred to as "monitoring" by Chang et al 2020) is required to ascertain the assumed status of the building when in use. This stage helps to measure predicted performance with predefined standards while adjusting the necessary building parameters to achieve the required results. The BEEC requires that the evaluation of the "*designed building*" should be in accordance with the "*reference building*" which must comply with prescriptive requirements for building elements and services using an approved simulation program, by a competent person as stated in section 3.3.2, referenced in section 1.3.2 of this study. While adjusting the parameters of the designed building to meet actual performance is carried out by the experts heuristically with many unknown parameters (depending on the simulation program), each of the stages must be constantly reviewed (Chang et al 2019).

In Table 2.11 for instance, the studies that gave quantitative values of their solutions to enhance building performance used case studies to show and prove the percentage effectiveness of the strategies tried, through simulation. A supporting note to the idea that modelling, and simulation can be used by designers to take advantage of the environment by testing several design options for building performance or energy efficiency improvement with the climatic region of the building (Loonen et al. 2017; Ochedi and Taki 2019). However, for efficient simulation, essential requirements for datasets including building location, geometry, household composition, construction materials, weather and simulation parameter datasets are required. This dataset constitutes a piece of detailed or complete building information for building performance evaluation. The first step proceeding building performance evaluation is to get the technical characteristics of the building, including layout plans and architectural drawings (Ilesanmi, 2010).

2.11. The Need for Building Data Capture

Some of the authors in Table 2.19, including Ochedi and Taki (2019), Amasuomo et al. (2017), Arup and Genre (2016), Mu'azu (2015), Abdulkareem, (2016), Abdulkareem et al. (2018) all carried out building performance simulations using detailed building information. Although some of the studies did not state the sources of building information, Mu'azu (2015) admitted the use of as-built building information while also carrying out measured drawings on instances of unavailable data. Abdulkareem, (2016) also highlighted that the limitation of getting the relevant technical data for evaluation is traceable to the use of tracing paper for storage in the past, which is now obsolete and deteriorated, losing much of the required details. It is, therefore, challenging to get the relevant technical characteristics of many existing buildings (Dalibi et al. 2017; Geissler et al. 2018). Additionally, most buildings, especially in Nigeria, are not built to the original specifications in the drawings as contractors, or sometimes architects tend to make modifications during the construction stages (Ibem et al. 2013). The difficulty in getting the required technical details of existing buildings does not negate the fact that the benefits of evaluating and improving the current building stock are enormous. It is also a more economical alternative to assess, evaluate, and enhance old buildings compared to the cost of demolishing and reconstructing new ones. To cut costs, several building projects designed by architects have been, constructed by non-professionals. Such practices, in conjunction with the absence of standard guidelines to assess the technical know-how of building contractors, have led to the loss or misinterpretation of the design details. Thus, impeding the intended performance of the building projects (Ibem et al. 2013; Ogunde et al. 2018).

Therefore, to carry out efficient building performance simulation, and evaluate and test strategies for building performance enhancement, it is necessary to capture the required technical characteristics that will benefit from simulation testing. In the BEEC (FMPWH, 2017 P. 18), the "compliance method 2 – performance route to compliance" indicates that building modelling and simulation should be used to determine the building's overall building energy performance. This study focuses on identifying the relevant building characteristics that are to be captured and used for building performance enhancement through modelling and simulation to achieve energy efficiency. More emphasis is placed on the indoor thermal condition of office buildings due to its significant impact on energy consumption for cooling in the Nigerian climate.

Following the recommendation by the BEEG, climate-responsive (bioclimatic design) strategies in response to achieving thermal comfort and in turn energy efficiency are explored next. Exploring the bioclimatic design initiatives would help to identify the relevant building features and characteristics required for capturing and use for performance modelling and simulation.

2.12. Bioclimatic Design

As previously discussed, (section 2.9), several factors affect the environmental indoor condition and energy demand in buildings; they include climate, building envelope, building materials, character and behaviour of building occupants, ventilation systems, building design and appliances. Although these factors determine the thermal performance and energy consumption of buildings, energy-efficient, and bioclimatic design measures applied to the building through the external envelopes and its components can be advantageous. It is especially useful in Nigeria with energy poverty where less than half of the population can access electricity. Previous studies have shown a 40% to 60% decrease in energy consumption (Ochedi and Taki, 2019) through bioclimatic design strategies. Several studies have been carried out around the globe to develop creative solutions to enhance building performance, especially in this era of climate change. A considerable amount of success has been achieved that has turned into policies, standards, assessments, and regulations to force a re-evaluation of potential adverse effects of buildings on occupants and the environment. All of the frameworks have, however, been designed and useful for different localities, climatic conditions, availability of materials, cultural adaptation, land, population growth, public awareness, and legal support. Conversely, there is limited evidence of similar initiatives available in sub-Saharan Africa. Thus, in the absence of that, proactive measures such as bioclimatic design initiatives are encouraged (Muazu 2015; Amasuomo et al. 2017; Ochedi and Taki 2019). The concepts are discussed next.

2.12.1. Concepts of Bioclimatic Design

The concepts of bioclimatic design started in 1963 with architect Victor Olygay's book publication "Design with Climate: Bioclimatic Approach to Architectural Regionalism". Four stages describe the design. It states that the essence of a bioclimatic design is to create a favourable microclimate within and outside of the building through the application of architectural design principles (Bondars, 2013). The study outlines rich theoretical eco-friendly design information and method for various climatic regions, used a bioclimatic chart and determines comfort zone. Furthermore, the work highlighted that bioclimatic design processes consist of four successive linear stages, and they range from consideration for climate, evaluation of biological needs depending on the level of occupant's comfort, technological practices, and their application in architecture. In the same line of thought, Arup and Genre, (2016) also asserted that bioclimatic design base its approach on special considerations to climatic conditions and attempts to achieve physical comfort for occupants using fewer resources, while simultaneously accounting for the behavioural and emotional conditions. Furthermore, the bioclimatic design (designs tending to a comfortable indoor environment without extraordinary cooling) approach is fundamental and is the first step to achieving energy efficiency in a building.

There are several ways of achieving bioclimatic designs and there is hardly any specific route that a designer must follow to accomplish this feat, hence, the availability of several well-documented strategies (Ourghi et al. 2007; Arup and Genre, 2016; Ochedi and Taki, 2019, Jegede and Taki, 2021). Always, buildings are in constant interaction with their environment, function, and occupants so, it is almost impossible to relate to the physicality of any building without affecting other facets associated with it. In the same vein, the features, characteristics and relationship between the structure, environment and occupants through passive design measures have ensured a positive and significant effect on the building's energy consumption (Mu'azu, 2015). Zr and Mochtar (2013) further described the strategies involved in implementing the relationship between these phases so that achieving maximum occupants comfort does not contradict minimum energy consumption as shown in Figure 2.12.1

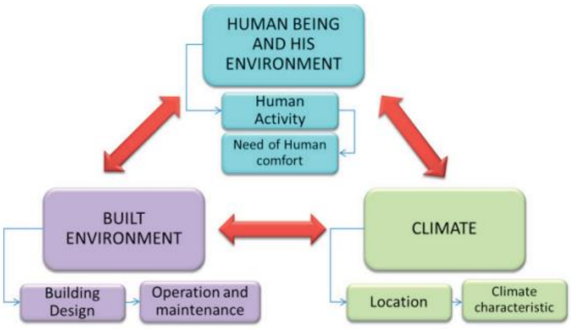


Figure 2.12.1. Relationship in bioclimatic design perspective (Source: Zr and Mochtar, 2013).

Studies, including Jegede and Taki (2021); Odunfa et al (2018); Adetooto et al (2020) and Ochedi and Taki, (2019) noted that while some factors rely on the climate, other factors depend on the construction materials, the construction technology, and the use of space within the building. For instance, a study by Oral et al. (2004), used the optimal performance of a building envelope design to ensure thermal comfort, visual comfort, acoustic comfort, and energy conservation in a building sample. Another study by Ourghi (2007), focused on the significance of optimising building shape, glazing type and glazing area to minimise energy use in buildings. Jegede and Taki (2021) applied indigenous materials to the building envelope to enhance comfort thus, reducing the high operative temperature by 8% and a significant reduction in CO_2 emissions and construction costs by 32.31%, 35.78%, and 41.81% respectively. The effects of the strategies employed by the aforementioned studies to improve performance and reduce energy use in the sample buildings are directly linked to the specific climates where the studies were carried out. Thus, in Nigeria with a tropical climate, the Federal Ministry of Power Works and Housing, (Housing) in a Building Energy Efficiency Guideline (BEEG) computed by Arup and Genre (2016), described a sequence of bioclimatic design strategies. Applying bioclimatic design strategies is one of the three pathways to achieving energy efficiency in Nigeria in acknowledgement of the problematic energy situation in the country. It is also one of the prescriptive routes proposed by the BEEC and it enhances the indoor environmental performance required for building users in the climatic region while also reducing carbon footprint. It helps to minimize the use of resources and improves human health and well-being (by eliminating noise and air pollution) that alternative sources of power, pose. An analytical discussion of bioclimatic design strategies forms the underlying framework for assessing the relevant characteristics required for enhancing the environmental performance of buildings by paying particular attention to indoor thermal comfort conditions.

2.12.2. Bioclimatic Design Strategies Applicable in Nigeria

The importance of bioclimatic design is to maintain a comfortable indoor temperature which can be achieved by the control of heat gains in the building or the regulation of heat loss from the building. Climate is a distinctive characteristic of a building site that should receive significant attention in the building design process. As it differs across places, so will building strategies responsive to the climate vary from one place to another (Zr and Mochtar, 2013). The climate particular to this research was earlier discussed (Section 2.3). Necessary parameters that ensure successful implementation of the bioclimatic design processes will be expatiated upon. The climatic difference that results in the regional differences in architecture is to be identified to ease the design process and for a proper understanding and implementation of the component involved in the design principle. For example, see Figure 2.12.2

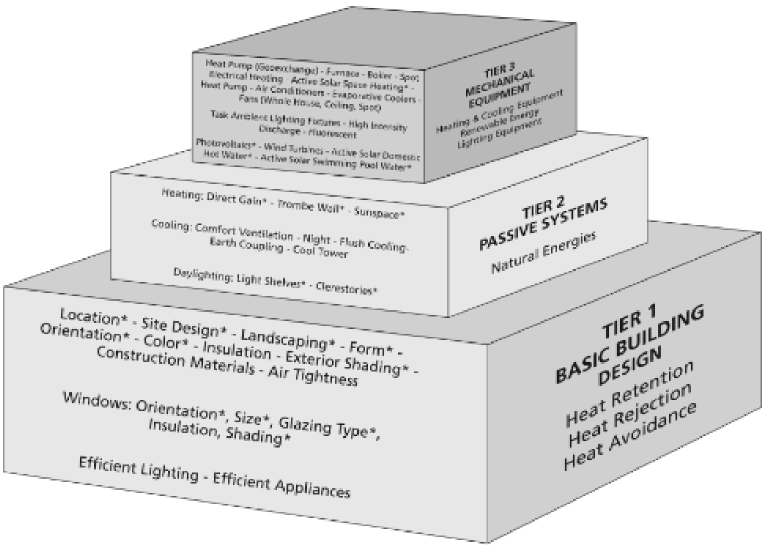


Figure 2.12.2. A three-tier approach to the design of heating, cooling, and lighting (Source: Lechner, 2014)

In Figure 2.12.2 Lechner (2014) set out a three-tier approach to design for heating, cooling, and lighting. Tiers one and two are purely architectural responses. Tier one can minimise up to sixty per cent, tier two by twenty per cent and a combination of both for eighty per cent. Note that all marked with an asterisk are solar-responsive (climatic) designs. Similarly, these bioclimatic design factors were considered in the BEEG with special consideration for the tropical Nigeria climate in other to minimise heat gains and promote heat loss. They are:

- Site selection and orientation.

- Building form.
- Envelope design.
- Passive cooling.

2.12.3. Site Selection and Orientation:

The orientation of the building towards the sun and the wind should be carefully considered to maximise solar potential and cooling breezes in the building through the building envelope (McGee, 2013; Guedes, 2013; Ochedi and Taki, 2016; Odunfa et al, 2018). The sun path: the apparent seasonal and hourly changes of the sun and daylight duration due to the rotation of the earth around the sun's axis and together with solar radiation intensity in diverse places must be well understood (Ochedi and Taki, 2019). Otherwise designing an energy-efficient building becomes problematic. Due to Nigeria being close to the equator, the variation in the sun's path across the year is minimal in favour of the best use of orientation and shading (Arup and Genre, 2016). Thus, site selection and orientation are the main factors to be considered in the design of heating or cooling to reduce energy consumption. For example, Figure 2.12.3 shows that positioning the longest façade of the building to face north/south will ensure the gain of indirect sunlight thereby reducing glare and solar heat gain from the north and south. And, by controlling direct solar gain from the east/west side of the building through minimal glazing and or shading (Mirrahimi et al. 2016; Odunfa et al. 2018).

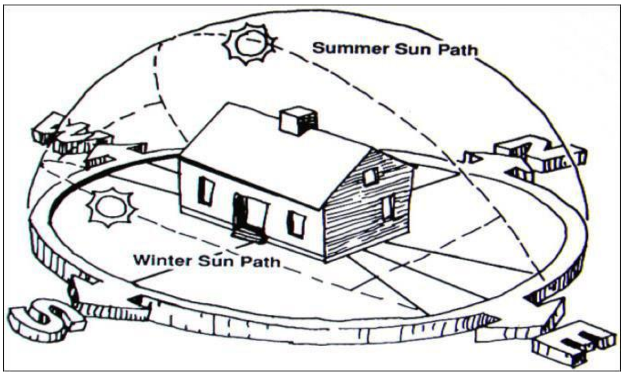


Figure 2.12.3. Solar path for winter and summer (Source: Greentechconstruction.com)

2.12.4. Building form and geometry:

Building form and geometry is maximising the potential of the building volume, geometry or shape, openings, and indoor and outdoor spatial configuration to curtail unwanted heat gains and encourage heat loss. Mu'azu (2015) stated that the building form enables the disposition of any material attachment thereby affecting wind, solar radiation, and heat exchange and thus, affecting the eventual energy consumption. For example, a study by St. Clair and Hyde (2009) shows that floor plan dimensions that exceed fifteen metres reduce the efficiency of natural ventilation, thereby impeding thermal comfort. Also, a large building's outer surface area will receive higher heat gains compared to a lower building's outer skin (see Figure 2.12.4A). The commonly used indicator for the building form is given by surface area to volume ratio (S/V)

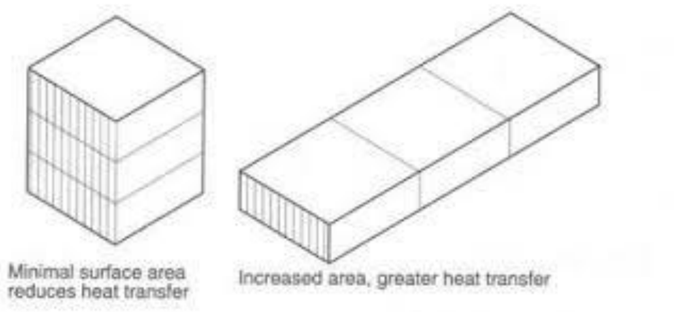


Figure 2.12.4A Surface area to volume ratio (Source: https://www.new-learn.info/packages/clear/thermal/buildings/configuration/surcafeareato_vol_ratio.html)

Ochedi and Taki (2019) state that in instances where best orientation cannot be maximised due to problems of land allocation, functional spaces must then be placed according to the pre-determined sun path also referred to as zoning. The use of buffer zones as a condition to shield the indoor environment from unfavourable weather conditions through the use of balconies (Figure 2.12.4B and C) or by placing activity spaces requiring more lighting closer to windows. Courtyards can be used to provide lighting, especially in places with high solar altitudes (Mirrahimi et al. 2016). See Figure 2.12.4D.

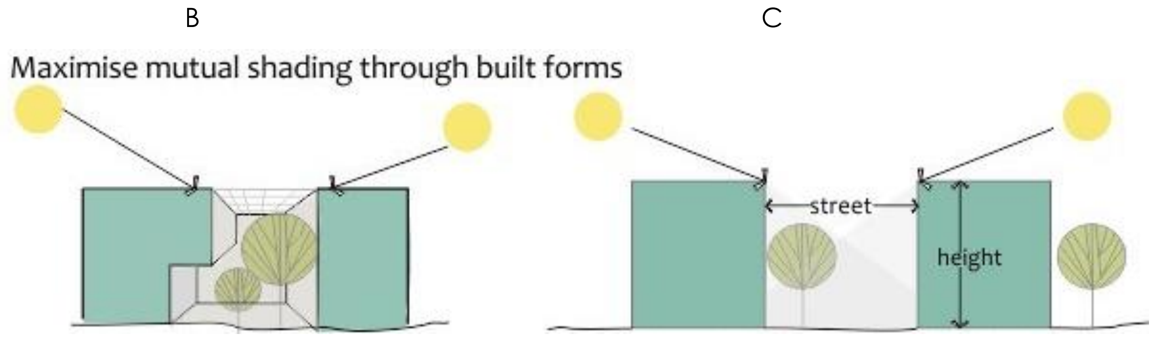


Figure 2.12.4B and Figure 2.12.4C. Shading through buffer zones (Source: http://fairconditioning.org/)

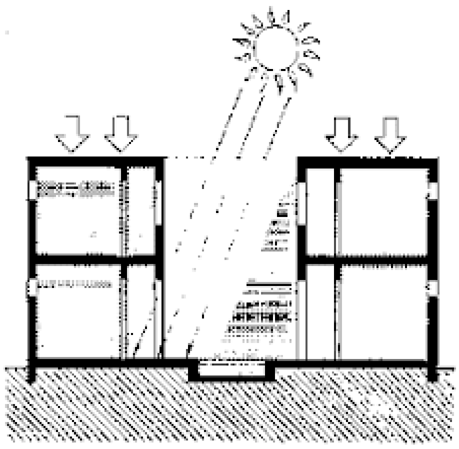


Figure 2.12.4D. Use of courtyard for lighting (Source: http://www.nzdl.org/)

The courtyard form has been described to offer greater flexibility and opportunity for bioclimatic designs, especially for natural ventilation and passive climate control.

Building form and geometry have a significant impact on the consumption of energy due to the ratio of a building's exposed surface area to effect radiation balance and the exchange of heat and wind in the building scale. Meanwhile, at the urban scale, building form and geometry in its complexity allow trapped heat from solar radiation resulting from heightened buildings in the urban fabric, thereby significantly affecting thermal comfort and lighting Mu'azu (2015). Thus, the height-to-width factor is significant. See Figure 2.12.4C.

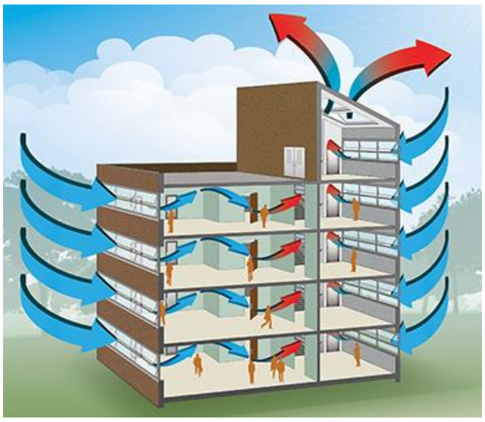


Figure 2.12.4E Natural Ventilation Strategies (Source: https://www.constructionspecifier.com)

Also, consider natural ventilation; the movement of air between the exterior and interior part of a building acts on both pressure differences driven by wind – "wind-driven ventilation" and temperature difference called "stack effect" ventilation (Guedes 2013). For effective natural ventilation, it is essential for an understanding of wind conditions including speed and ventilation informs the distribution of size, direction, and shape of openings, through the design of doors, windows, and vents. See Figure 2.12.4E There are several rules of thumb for natural ventilation necessary for better indoor air quality and an overall better indoor environment.

2.12.5. Envelope Design

The building envelope is the totality of elements made up of components separating the indoor environment of a building from its outdoor and it is a significant determinant of the indoor atmospheric quality (Oral et al. 2004; Sadineni et al. 2011). It controls the indoor conditions regardless of the extremity of the outdoor conditions while also facilitating climate control (Mirrahimi et al. 2016). It consists of various components including walls, roofs foundation, insulation, shading devices, and thermal mass which comprising of opaque and transparent elements (Sadineni et al. 2011; Mirrahimi et al. 2016). Environmental control installations should be severely considered in response to the outdoor environments due to their exposure, varied temperature, humidity, solar radiation, precipitation, and air movement.

To ensure the anticipated reduction in a building's energy consumption and the desired optimal comfort in the building, the building envelope should undergo a series of climatic thermal designs. These are the design for:

- **Shading:**

  Shading is a strategy that helps to reduce the effect and penetration of solar radiation into the building so that transparent or glazed areas and likewise the opaque envelope of the building are protected (Guedes, 2013; Kamal, 2012). Glazing can permit a significant heat gain to the building because it has minimal resistance to radiant heat transfer. Thus, because shading devices allow daylight into a building space yet reduce the direct penetration of the sun, they are designed to; counter overheating, minimise cooling load, and improve the natural visual quality of a building's interior by controlling; colour, glare, light and even enhance internal thermal conditions (Kamal, 2012; Mirrahimi et al. 2016). With the high solar altitude in Nigeria, overhangs and horizontal shading is advised for the north and south-facing façades of the building while a mix of horizontal and vertical shading is necessary for the more complicated east and west-facing surfaces of the building. Figure 2.12.5A shows different types of shading techniques. The fact that shading works with a proper understanding of the sun angle's impact on the building location cannot be overemphasised. The sun angle's impact is required to calculate building overhangs and shading. The example shown in Figure 2.13.5B shows a typical example of a calculation or rule of thumb used to effect shading by an understanding of the sun angles. It shows that the eave or overhang width should be forty-five per cent of the height of the windowsill (McGee, 2013).

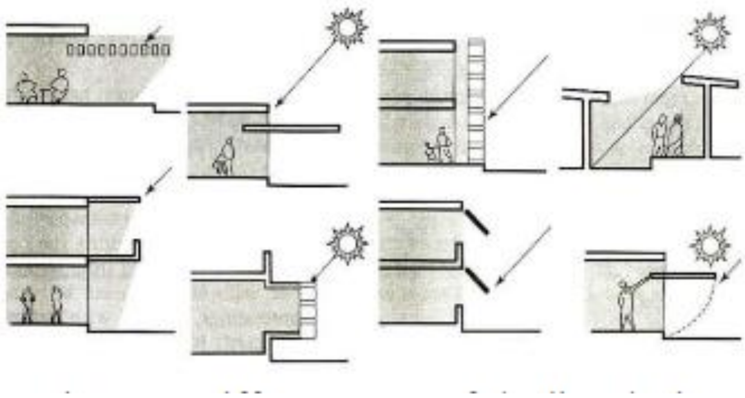


Figure 2.12.5A Different types of shading devices and techniques (Source: Kamal 2012)

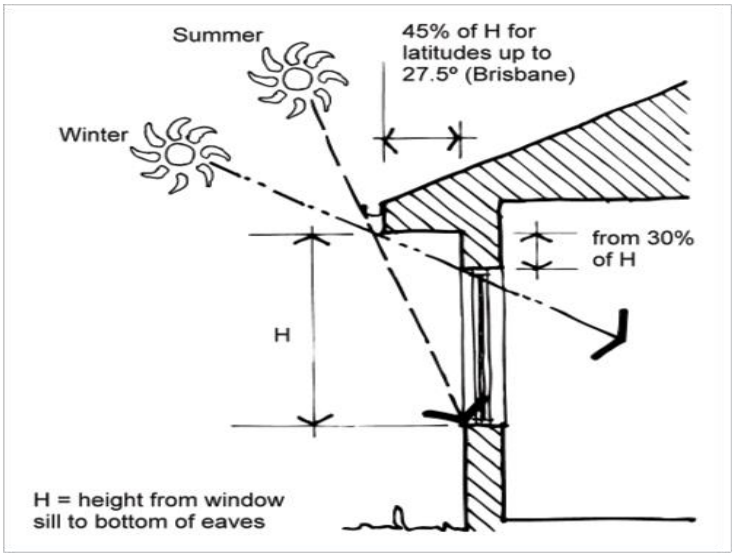


Figure 2.12.5B. Typical Shading calculation (Source: McGee, 2013)

- **Window design**

Daylighting is imperative and effectively exploiting the advantages of natural light, allows a flexible approach to designing the building façade with a great potential for more energy efficiency and reduced energy demand, and consumption in commercial buildings (Saridar, 2004). Windows are less resistant to radiant heat transfer, as such, the glazed area or façade accounts for much of the heat gains into the building and as such, the sizing and orientation of the windows is a significant determinant of penetration of solar radiation (Guedes, 2013). Thus, in addition to aesthetics, windows play a vital role in the thermal comfort and visual illumination levels in a building demanding the need for proper thought-through methods of window design and technology. Examples of these considerations in recent times are in the form of low emissivity coatings, solar control glasses and various cavity fills together with frame enhancement (Sadineni et al. 2011). In addition to the assertion by Guedes (2013) that it is a herculean task designing for windows which has been made easier in recent times by various simulation software, Oral et al. (2004) alluded that the complexity is dependent on parameters like region, latitude, function, and occupation time. Against this backdrop, it is advised that for tropical climates, glazing in the north and south façades should not exceed forty per cent with less than twenty per cent on the east façade and if possible, avoided towards the west (Guedes 2013; Lechner, 2014). However, a case-by-case basis should be strictly adhered to. This is because the transmission of solar heat gain is also dependent on the window coating, hence some coatings minimise heat gains but permit maximum daylight. Thus, visual transmittance (VT), solar factor (g value) and thermal conductivity performance are key to window selection (Oral et al. 2004; Sadineni et al. 2011; Guedes, 2013; Arup and Genre, 2016).

- **Building envelope surface properties.**

  The build-up of heat can be lowered using light colours on the exterior surfaces of the building envelope as a considerable amount of solar radiation is reflected by the light colours of fabric coatings (Guedes, 2013). By this, the indoor temperature is reduced and in turn, results in the enhancement of thermal comfort (Latha et al. 2015). Therefore, secondary light sources (light reflection coefficients of surrounding surfaces) and their associated colours are of great significance in the design process (Oral et al., 2004). Arup and Genre (2016) reported that the solar reflectance index (a material's capacity to emit heat and reflect solar radiation) for a black surface is about zero compared to about 100 for a white surface. Also stating, most green building certification schemes including LEED recommend a solar reflectance index value higher than seventy-eight for roof surfaces to lessen heat gains as well as diminish contribution to the effect of urban heat island. Latha et al (2015) added that cool roofs with high emittance and solar reflectance index are suitable options for hot climates so that the roof is heated up to forty-three to forty-six degrees Celsius.

- **Insulation**

  Insulation properly used, places the building at an advantage in warmer seasons against heat gains thereby improving thermal comfort all year round (Guedes, 2013). As insulation helps to reduce heat gain and heat loss, it, therefore, controls the interior's mean radiant temperature by separating the interior from external conditions as well as limiting draught created by the difference in temperature between air and walls (Kamal, 2012). The potential heat transfer of materials (U-value) defines the insulating effect of the material. For example, the lower the U-value, the greater the insulation provided by the material and, a material's large thermal resistance (R) indicates it is a good insulator. Good placement and optimum thickness of insulation are essential in reducing the need for space conditioning because thick insulation material reduces internal space (Mirrahimi et al., 2016). Placing insulation on the exterior facing surface of the building envelope (wall or roof) is advised in a hot climate.

- **Airtightness**

  Many buildings have gaps in their building envelope that allow the leakage of air through them thus making air conditioning ineffective (Kodama 1998; Sadineni et al., 2011). It can be cracks around fenestrations or at the juncture where the roof meets the wall. It can be acceptable in a naturally ventilated building; however, occupant comfort could be improved as well as the energy consumption used by space conditioning if sealing is improved. Condensation on the wall surface result in biological contamination thereby negatively affecting the indoor air quality (Camara et al., 2017). The airtightness test is done by measuring the pressure difference between the building envelope over a range of applied pressures of about 10 Pa increase and the corresponding air flow rate (Delmotte, 2013). For offices and some other commercial buildings, lobbied entrance helps to minimise the quantity of air flowing into the building. (Arup and Genre 2016).

2.12.6. Passive Cooling

Passive cooling concepts go beyond preventing thermal gains in the building (through orientation, form and geometry and envelope design) to promoting heat loss from it with the advantage of creating a better and more comfortable indoor condition (Kamal, 2012).

- **Thermal mass**

  Thermal mass is a medium for storing heat, storing cold and for temperature regulations and smoothing temperature fluctuations. It can dissipate the heat stored during the day for ventilation at night. It requires a large surface area. Thermal mass is effective in tropical climates.

- **Evaporative cooling**

  Evaporative cooling is achieved by reducing the sensible air temperature and compensating for latent heat gains by use of specific techniques including vegetation, fountains and pouring water on the floor. This is done during hot and dry weather. Evaporative cooling can also be done by mechanical aid (Indirect evaporative cooling) where the air is cooled without the water vapour content increasing.

2.13. Bioclimatic Design Performance Indicators Specific to the study context

Table 2.13 Bioclimatic Design requirements specific to the study context

Bioclimatic Design factor	Design variable	Data needed to capture	Unit	Notes
Site selection and orientation	Sun path	The direction of the sun to a building (Building coordinates).	North, East, West, South	The seasonal and hourly changes of the sun and daylight direction due to the earth's rotation around the sun's axis together with solar radiation is critical to designing for heating by controlling solar heat gain. The latitude of Benin City lies within Latitude 6°06' and 6°30'N, and Longitude 5°30' and 5°45E, West and East boundaries, in addition to using the appropriate weather data for Benin City, the building coordinates are critical to maximizing the effect of solar radiation on the building to effect heat gain or heat loss.
Building form and geometry	Building volume, shape, openings, and outdoor spatial configurations.	Total surface area, indoor volume, building area and perimeter, area of openings	Distances in metres (height, length, and width)	The building form is necessary as it permits all other material attachment, thereby affecting wind, solar radiation, and heat exchange. The size and shape of openings also direct the flow of air travel. While buildings differ in volume, shape, area and building type/use, knowing these parameters is important in effective bioclimatic use of building form and geometry to achieve bioclimatic design initiatives. Office buildings in Benin City are the target of this study.
Envelope Design	Shading, window design, envelope surface properties, insulation	The total area of the window and that of the wall, length of shading device, U-value of glazing	Dimensions in metres (height to width), name and property of the material.	As the building envelope separates the internal from the external, it is necessary to capture the characteristics as these help in the analysis and evaluation during performance simulation. The use of insulation is rare in the study area, sandcrete blocks are

			popularly used for wall construction, concrete floors are usually plastered or tiled, common ceiling types are polyvinyl chloride (PVC) and asbestos. different kinds of finishing including tiles and carpets are not unpopular. These materials, sizes and thickness have an impact on the emissivity, reflectance and general u-value and R-value of the envelope design. The envelope design properties are key semantic information required for achieving bioclimatic design initiatives in the study area.

Table 2.13 gives a summary of the bioclimatic design measures while extracting the design variables and building characteristics that demand attention that could be captured and required for modelling. The model is required for simulation and to test design strategies that can help to achieve or improve the required indoor thermal environment and in turn, energy efficiency.

2.14. Conclusion

This chapter presents necessary information about the research context and the justification for the study. It identified the need for building performance enhancement (which must be encouraged) due to building users' needs. It happens that the highest user needs in a building, especially for office buildings is to achieve a conducive indoor thermal environment and this happens to be the highest energy consumer in the workplace. Thermal comfort is climate-related and necessary to increase the productivity of the office workplace and reduce operating costs.

It is well documented that office buildings in Nigeria are not climate responsive and as such performs badly thereby consuming a lot of energy in the form of electricity to complement their thermal performance. However, the energy situation in the country is inefficient because its supply is epileptic, unsatisfactory, and unreliable, in turn resulting in an additional cost to use alternatives (mainly generators) for office productivity.

Although the increasing population and urban growth require more commercial buildings due to their economic benefit to the country, the focus on new buildings is high even though the advantages from the evaluation and improvement of existing building stocks are enormous. This has necessitated the course of this study, to evaluate the building performance to optimise energy-saving potentials, it is necessary to understand the characteristics of the buildings that can help to promote the necessary adjustments. Evaluating and improving existing buildings including testing different design strategies must be done in such a manner that is adaptive enough by the building users to achieve a conducive indoor thermal condition because several factors determine thermal comfort. Testing these strategies requires modelling and simulation, which can only be done with the availability of the relevant building characteristics. Unfortunately, as the practice of performance improvement is still in its infancy in the study region, the building technical characteristics including architectural drawings are hardly available for several reasons thereby requiring the need for building data capture. The technical building information required to improve the thermal environmental condition of the workplace follows a previously studied and tested framework of bioclimatic design principles recommended in the BEEG and the BEEC. This has helped to identify the design variables needed to define the choice and capacity of building data-capturing technology in the next chapter. This chapter also identified some useful design considerations that are needed to gauge the built environment professionals on building performance improvement to inform future practices.

CHAPTER 3

DATA CAPTURING TECHNOLOGIES

3.1. Introduction

This chapter focuses on capturing the as-built representation of existing buildings in line with the study's aim of creating a reliable and cost-effective methodology for the capture of as-built building information for simulation with emphasis on bioclimatic design features to improve the environmental performance of buildings. The basis of the as-built information capture is concerned with those relevant to the building characteristics identified in the previous chapter to extract information, significant to modelling that could be used for improving the indoor environmental condition of office buildings in Nigeria.

After an overview of the need for as-built data capture necessary for building performance simulation, some commonly identified data capturing technologies are listed followed by a detailed description of their features, mode of data capture, advantages, limitations, and method of processing together with other useful information. Afterwards, a summary of the identified data-capturing techniques helped to critically evaluate the technologies to ascertain those suitable for achieving set objectives. This chapter also points to the need for a survey where the practice and knowledge of the built environment professionals in the study context are necessary to effectively define what technique or combination is suitable and achievable to meet study goals.

3.2. Overview of the Need for as-built data capture

According to Volk et al. (2014), there are only a very few constructed facilities today that can boast of properly documented as-built information due to the predominance of incomplete, obsolete, or fragmented information about the building. In recent times, the acquisition of as-built three-dimensional (3D) data, also known as "as-built data" on a civil infrastructure has become more efficient due to advancements in on-site spatial data capturing or surveying technologies (Brilakis et al. 2010). Advanced technologies for capturing and documenting the actual state of a building post-construction have eased and ensured that 3D as-built data from buildings had to define geometric properties and components of structures (Son et al. 2015).

Documentation of a building's spatial information not only forms an accurate record of the structure, but also adequately supports data for maintenance, deconstruction processes, and conservation through identification, interpretation, and protection (Volk et al. 2014; Lekan et al. 2018). It provides a comprehensive base dataset that the building professionals can assess and perform necessary improvement works where possible to ensure the physical integrity of deteriorating buildings (Amans et al. 2013). The dearth of as-built documentation of existing buildings due to omitted updating, limitations to the potential benefits of the as-built data (including retrofit planning, heritage documentation, management, service information and others) in existing buildings and research challenges are imminent (Volk et al. 2014). Okpalanozie and Adetunji (2021) emphasized that the use of information technology has led to enhanced data capture, data display, data management, data analysis and data presentation for decision-making, guidance facility management, recovery, and other forms of support. They further stated that despite the success rate of the implementation of innovative techniques in building conservation and documentation in Europe, traditional methods are continually applied in Nigeria leading to ineffective and poorly managed conservation of buildings. While it can be inferred from literature that most of the various techniques available meet certain requirements in the construction industry, The yardstick to assess and ascertain that the selected data-capturing technique is fit for the given purpose must be pre-defined. The data-capturing techniques and technologies described next are those identified that can help to capture the bioclimatic design characteristics of existing buildings deduced from the previous chapter (2.13).

3.3. Traditional and Manual Site Survey Method

Traditional surveying techniques have been used extensively in preparing and producing documentation in the form of maps, building plans, elevations, sections, and several other geometric characteristics. These techniques are either land/site surveying or aerial surveying (Bayyati, 2017).

The manual site survey method is a predominant and traditional mode of building measurement that uses conventional measuring techniques to produce an analogue form of plans, elevations and sections using ordinary surveying equipment (Petzold et al. 2004). The conventional approach captures mostly spatial and other component-related information (Volk et al. 2014) which forms part of the bioclimatic design requirements mentioned in the previous chapter. The tools required for carrying out this traditional measuring technique are measuring tape, digital camera, laser distance meters as well as large-scale area plans for documenting. These manually record the overall dimensions of different building components, including doors, windows, walls, and facades (Jung et al. 2014) including the capture of photographs for future reference with the aid of the digital camera. The process entails holding the measuring devices in direct contact with the building while taking distances between two points visible from each other at an instance (Petzold et al. 2004) and every room of interest is measured separately. Basic dimensions: length, breadth, and height of the space, components and inventory of the permanent furniture and equipment are also taken (Klein et al. 2012). The manual technique is usually time-consuming, labour intensive and error-prone (Jung et al. 2014) with an as-built documentation accuracy threshold of 2% or 10cm for the exterior (Klein et al. 2012). Thomson and Boehm (2015) state that automated modelling is desirable to minimise time and cost, which presents a medium for a series of tasks to be done in the building's lifecycle. The digital models, useful for building simulation or representation differ from that in the case of existing buildings as the main aim of the model is to create a real as-built model. Therefore, the operator, after deriving the required immense knowledge from the time-consuming, subjective, and tedious process of creating 2D CAD from a point cloud, utilises the knowledge input as a guide to efficiently trace around the geometry in a BIM tool, interpret the scene and add the rich semantic information that makes the modelling process valuable. Most of the BIM design tool minimises the modelling that can do without an enormous operator input which is not necessary to have tight tolerance depending on the anticipated use of the model.

Model accuracy can be achieved through geometric abstractions, helping to save cost and time with reduced geometric precision. Both the abstraction and measurements from any surveying technique can be combined with the aid of a computational adjustment model applied by the field of geodetics to enhance the model's accuracy (Donath and Thurow, 2007) as shown by the example in Figure 3.3. It is usually helpful depending on the standard for modelling required, defined by the use, or aim of the proposed model.

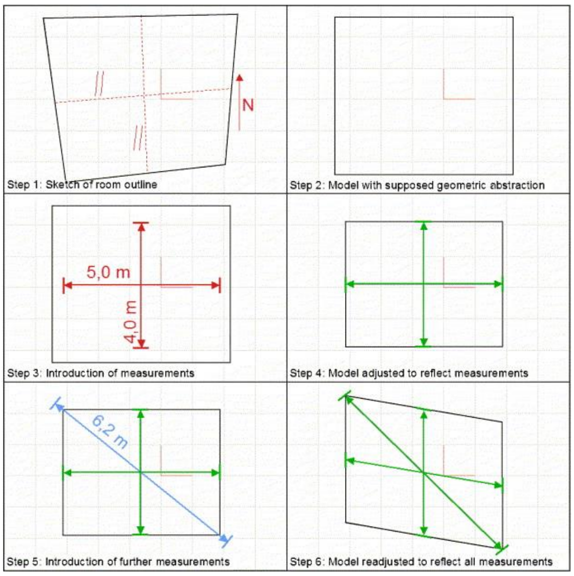


Figure 3.3. An application of geometric abstraction is shown by the step-by-step surveying and model representation of a room in a plan (Source: Donath and Thurow, 2007).

Step 1 shows the room in sketch form, according to the pre-determined criteria by the user, on applying the measurements, the system (geodetic computational adjustment) supposed the sides of the room are parallel and perpendicular to the cross walls with the parallel orientation to the co-ordinate axis as in step 2. In step 3, the measurements and deviation are represented in colour, while phase 4 shows the system adapting to the actual size. A further value of the diagonal measurement is added in step 5, contradicting the geometric abstraction assumed by the model, the model adjusts to it in step 6.

3.4. Total Station

The total station is an electronic/optical surveying instrument that consists of a theodolite integrated with an electronic distance meter (EDM). The theodolite is capable of measuring angles with the aid of the electronic distance meter (distancer) to get the horizontal and vertical angles and slope distance between specific points (Chekole, 2014; ME et al. 2019). Chekole, (2014) states that, with an established direct line of sight between two points, total stations can determine either the position of points or the locations and height of points by using the co-ordinate of a known point to ascertain the relative of the unknown one. Furthermore, computing with trigonometry and triangulation from the position of the total station, coordinates (X, Y, Z) of surveyed points are determined.

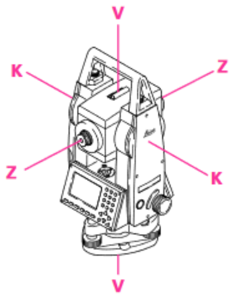


Figure 3.4. An example of a total station with points to consider for setting (Zeiske 2000).

As shown in Figure 3.4, The line-of-sight ZZ must be perpendicular to the tilting axis; the tilting axis KK also must be perpendicular to the vertical axis VV. And the vertical circle at the peak should read zero (0) otherwise there will be errors.

Chekole (2014), noted three critical points to getting precision and accuracy during measurements while using the total station daily and they are,

a. To regularly check and adjust the instrument.
b. To capture high-precision measurements while on the checks and adjust procedures.
c. To eliminate errors by measuring targets in two faces and using the average of the angles from both fronts.

Notably, objects passing between the target and the EDM influence the result of the measurement made. However, modern electronic total stations have an optoelectronic distance meter as well as an electronic angle scanning such that the coded scales of both the horizontal and the vertical circles can be scanned electronically. In contrast, the angles and distances appear digitally. Thereby helping to prevent errors from passing objects between the EDM and its target as the information (measurements and distances) can be recorded quicker and with better precision.

Studies by ME et al. (2019) and Julian et al. (2012) decline the need for an assistant operator as a remote positioning unit found in the more recent total stations making it easier for an operator to control the device from an observed point. Measurements from the device affected by temperature changes, pressure and relative humidity are corrected for atmospheric effects by imputing the differences recorded in temperature, pressure, and relative humidity (Zeiske, 2000; Beshr et al. 2011).

Mill et al. (2013) stated that with the help of either a downloaded internal or an external microprocessor, digital data could transform to the remote x, y, and z co-ordinates where it electronically encodes angles of 1 arc-second down to 0.5 arc-second accuracies and 0.5mm distance accuracy. The advanced total station referred to as the robotic total station if integrated with the global positioning system can derive global coordinates from the local one. It can also be used as an image-assisted total station by fixing a digital camera to a reflectorless measuring total station (Mill et al. 2013; Lachat et al. 2017). This method is also slow and cumbersome for recreating existing conditions and 3D objects in a meaningful way (Lemmens, 2016).

3.5. Photogrammetry

Arago, a geodesist with the French Academy of Science, first made photogrammetric use of photography in topographic surveying using photographic plates. Recognised as the "Father of photogrammetry", Colonel Aime Laussedat's work presented in 1859 was a result of the earliest experimental work that took place in 1849 (Clarke, 1991). Coined in 1855 by Kersten, many of the initial uses of photogrammetry were for taking survey data, initiated by military interest. Therefore, "*photography is the art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena*". An architect named Albert Meydenbauer introduced the term photogrammetry after his first photographic survey in 1867. Historically, the use of a photographic image was attributed to photogrammetry. In recent times, the use of solid-state cameras allows the analysis of data after collection to eliminate the post-processing event.

Bayyati (2017) described photogrammetry as "the science of precise measurements from photography". Depending on the need, capturing the photographs may involve the use of specialised aircraft and cameras (aerial) or terrestrial capture on the ground surface. The author further states that the principle of photogrammetric measurements centres on reconstructing the captured three-dimensional image which can be achieved by a snapshot of successive overlapping photographs.

According to Rocha et al. (2020), the technique of photogrammetry involves the extraction and reconstruction of 3D objects from at least two-dimensional photo images, the product of a point cloud file. To correctly perform a photogrammetric survey, it is necessary to ensure that pictures with enough information overlap capture geometries and avoid large jumps between photos. It is also essential to have proper weather conditions and homogeneous lighting. It is of great importance to take further notes and measurements on-site to correctly size and orient the model. Photogrammetry allows the construction of bioclimatic design requirements such as position, orientation, shape, and size of objects from images that are either digital or conventional. It provides a cheaper alternative to capturing inaccessible and complex areas due to its fast data acquisition pace with an effective offline measuring ability (Chapman, 2004). Photogrammetry, especially using the more recent digital camera is a reliable and more efficient technology to create an as-built BIM from the capture of the as-built condition of a building (Jung et al. 2014). It involves measuring objects from images without any contact with the object to be measured, thereby reducing some repetitive steps of most conventional surveying processes (Kraus, 2011; Aydin, 2014).

A combination of photographic and mathematical techniques to extract the building's geometry for bioclimatic design are fed into the information systems for processing (Mantzouratos et al. 2004; Kraus, 2011). Photogrammetry measures the position, size and shape of an object captured at a close range of not more than 100 metres in width, positioning the camera approximately to it (Aydin, 2014). Images from capturing all around the building as desired are used with the help of a modern computer-aided photogrammetric tool to produce highly accurate CAD drawings (Mantzouratos et al. 2004). 3D models are made by orienting the photographs, referencing points in more than one oriented image and by use of mathematical intersection, to reconstruct the 3D model (Aydin, 2014). With the advent of higher quality and lesser price cameras with software applications, photogrammetry can be used by non-specialised users (Ordonez et al. 2010). However, this system needs a calibration system that defines the parameters of the camera. A commonly used calibration system is the photomodeler (Guaneri et al. 2006; Aydin, 2014) and it also establishes the eccentricity of the distance meter (An element used in conjunction with the digital camera (Ordonez et al. 2010). The use of specialised cameras makes the photogrammetric process relatively easy (Kraus, 2011). However, there is now a shift from photogrammetric software to cloud computing resources. Cloud computing now used on an external server has made even camera-enabled mobile devices capable of performing photogrammetric processing. An example of such processing uses applications such as SCANN3D and TRNIO (Pena-Villasenin et al. 2019). It is now possible to carry out photogrammetry surveying with a drone for the 3D modelling process of different building sites. This process requires less time on site (Mantzouratos et al. 2004). A scan to BIM methodology study carried out by Rocha et al. (2020) emphasised the need for taking vital measures on the point cloud including noise reduction, removal of inaccurate points and undesired objects on the scene to optimise the point cloud and reducing the file size for processing. This is because noises, occlusions, and moving objects limit the efficiency of the photogrammetric survey.

3.6. Videogrammetry

The development of high-resolution video sensors capable of capturing many million pixels in each frame has made photogrammetry based on video cameras, also known as "videogrammetry" gain significant interest in recent times (Brilakis et al. 2011). Videogrammetry has a basis for acquiring digital imagery where the processing of data or information is a naturally embedded feature of digital images with the advantage of an instantaneous and linked processing feature. A videogrammetric system, however, should have the capability for self-diagnosis or quality control, be reliable with high precision potential and be flexible with the task of a three-dimensional object reconstruction. Videogrammetry is known to be a reliable measuring technique with a high degree of maturity and extensive use for diverse applications including health, hydromechanics, biomechanics and in architecture for monument preservation.

According to Brilakis et al. (2011), videogrammetry consists of four basic steps in its processing. They are.

- *Video camera calibration.*
- *Video sequences acquisition.*
- *Measurement of the two-dimensional location of a pre-existing target point or tracking the new target point of a two-dimensional location.*
- *Reconstructing the target point in three-dimensional space.*

This standard measurement technique can achieve a sub-pixel accuracy of a well-defined target of about 1/25 of a pixel. Enhancement to this method is through additional geometrical constraints or a piece of precious knowledge on object shapes such as resemblance. A similar process used in photogrammetry, using the orientation and the calibration of the cameras allows for the computation of the three-dimensional coordinates of the target point by a forward ray intersection on establishing the equivalent two-dimensional locations.

Gruen (1977), describes some of the advantages of videogrammetry. They include its use in, non-contact and three-dimensional measurements, a large number of targets, and objects in motion, requirements for precise and reliable results, good temporal resolution requirements, instantaneous processing, and rapid recording. It also helps to generate long-term or permanently stored images to be accessed for remeasurement, or verification at any time. Torresani and Remondino (2019) also point out that the components of the videogrammetric hardware are generally cheap as they are usually off the shelf. The main limitation of the structure from motion (videogrammetric principle) is to derive the three-dimensional point starting from image matching utilising triangulation. Ganci and Handley (1988) also state that there is a high relative level of technical know-how to complete the measurement. However, the advent of smartphones can now significantly reduce the amount of skill required to process images technically and manually as well as for three-dimensional construction purposes for automated processing (Ganci and Handley, 1988; Torresani and Remondino, 2019).

3.7. Photo Modelling or Image Modelling

According to Gore et al. (2011), the advent of the digital camera for creating 3D as-built models is a transition from the age-long photogrammetry whose fundamental principle is triangulation. Hadidi et al. (2015) described the digital photo as one of the most useable sources of field data because, without an additional cost or time incurred on construction projects, the capture of data is possible. The writer further states that photographs are among the progress report documents regularly required of a contractor to send to the owner as stipulated in the Conditions of Contract for Construction by the International Federation of Consulting Engineers. Other than for progress documents, the photographs showing as-built scenes have more applications, including image-based modelling. Image-based or photo modelling helps to derive three-dimensional models from two-dimensional images.

Tenerelli et al. (2013), state that photographs from digital cameras provide general information for image interpretation and risk assessment as collecting the location of an image aids its integration with other space-referenced data. Geo-tagging (attaching location to pictures) is a GPS receiver feature of some digital cameras that helps to generate geo-tagged digital photos. The photos, once taken with the GPS coordinates are saved with the image's exchangeable image file format and other information that can later be accessed using image processing tools.

Hadidi et al. (2015) study focused on data capturing approach for improving the quality of image-based three-dimensional reconstruction models. The study hypothesised that the method for image capture in construction sites does not result in three-dimensional point cloud models for as-built data visualisation, especially where there are several buildings and work areas.

A study by Gore et al. (2011) states that human intervention for the automation of reality capturing and modelling has been limited by recent advancements in digital photography and three-dimensional modelling techniques. Four steps to the approach for space planning identified in the study are site photo acquisition: point cloud generation, automatic surfacing and space modelling as shown in Figure 3.7.

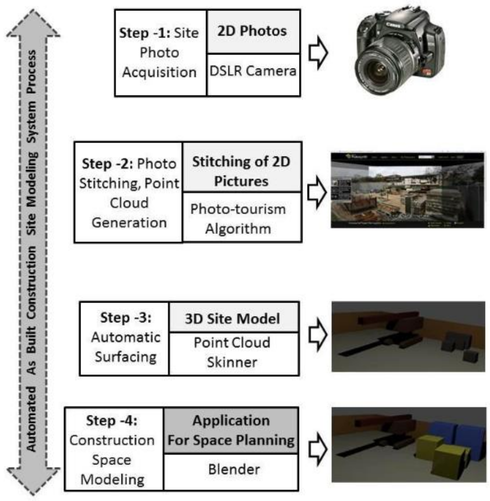


Figure 3.7. An overall framework for automatic as-built system process (Source: Gore et al. 2011)

In the first step, digital cameras acquire the photographs which are stitched together and used to derive the three-dimensional point cloud model in step two. Step three involves the development of a three-dimensional surface model from the three-dimensional point cloud model before using the three-dimensional surface model for the desired purpose. The study recommendation for picture acquisition is in line with that of Hadidi et al. (2015). It is also recommended that photos should be captured at every 25°, and a panoramic view of the object should be obtained by shooting at a wide angle. Scenes with lots of details and textures should be captured for effective image matching and point extraction and some photos showing object details and spatial relationships to other parts of the site.

Image matching and point cloud generation generate a three-dimensional representation of the target scene through an optimisation process stitching together large photo collections with matching overlapping features. The image matching and point cloud generation are done through a computer vision algorithm with examples including Photo-tourism and Autodesk Photofly. Points that represent geographical data need to be linked to represent objects as point cloud data shows discreet points in a three-dimensional point coordinate that only carries little information that can be used for space planning and modelling. Manually linking these points can be time-consuming, thus, an automated alternative that requires less computational time and the entire process is given. The last phase now has the 3D surfaced model, the conditions of the site, measurements including volume can be carried out and for other purposes including retrofitting proposal.

It has the limitation of object occlusion, moving objects, workers, equipment, and other noises.

3.8. Light Amplification by Stimulated Emission of Radiation (LASER)

Light amplification by stimulated emission of radiation usually referred to as Laser scanning can be described as a unique form of reflectorless tacheometry where a building or part of it is scanned in detail producing a high-resolution 'cloud' of points (Petzold et al. 2004). Like photogrammetry, laser scanning is a survey technique, suitable for capturing information on highly complex objects of different scales, also known as the mass data collection technique (Rocha et al. 2020). According to Bayyati (2017), laser scanning uses a "laser scanner", a range of instruments that work on distinct principles in different environments and even different levels of accuracy. Bayyati further described a laser scanner as "*a device capable of collecting 3D coordinates of a given region of an object's surface automatically and in a systematic pattern at hundreds or thousands of points per second achieving the three-dimensional coordinates in near time.*" Laser scanners measure the distance from their sensor to the nearby target surface with high accuracy (millimetre to centimetre) at speeds of up to hundreds of thousands of point measurements in a second. See Figure 3.8 (Tang et al. 2010).

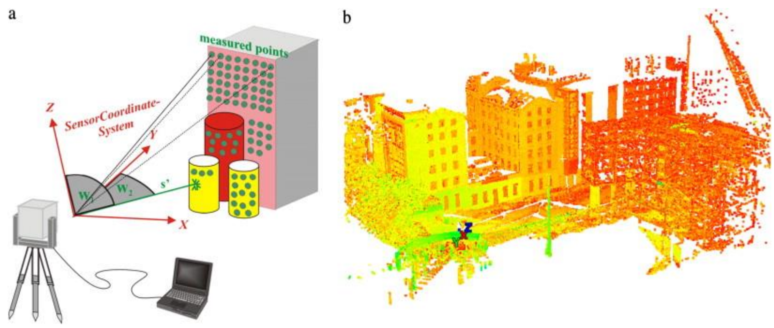


Figure 3.8. (a) The process of using laser scanning to measure 3D points and (b) an example of a building under construction scanned with a laser scanner (Tang et al. 2010)

Laser scanners are used more as a surveying instrument for terrestrial applications and can work under different and real-world environmental conditions (Frohlich & Mettenleiter, 2004). It is an expensive instrument that can capture and record bioclimatic data (geometry and sometimes texture) in less survey time, with high accuracy, and the ability to obtain a very little detail of up to 0.6mm 3D precision from a ten metres range as well as capture complex shapes geometry (Sanhudo et al. 2020). Laser scanning technology involves the use of a laser scanner where a capture software filter, registers and then export or convert the point cloud data (Coates, 2018), a three-step process of data capture, processing, and modelling (Tang et al. 2010). Thus, it requires a high level of expertise in its operation and even a stationary field of view, demanding several stations points to avoid obstruction (Sanhudo et al. 2020).

The limitations of laser scanning are related to the required number of scanning points, continually changing site conditions that must be frequently captured, the high cost of equipment and the need for a high degree of expertise especially for processing the captured data. (Gore et al. 2011)

3.9. Global Positioning System (GPS)

Popularly referred to as a global positioning system (GPS), is short for the "Navigation Satellite Timing and Ranging Positioning System Global Positioning System or NAVSTAR GPS" (Lange and Gilbert, 1999). The GPS provides users with specific information which is three-dimensional (latitude, longitude, and elevation) location information, velocity, and timing. It comprises a constellation of 24 operational satellites, and the main point is that there are four satellites based on each of the six orbital planes. They orbit the Earth at around 20,200 kilometres twice daily, thereby, ensuring that worldwide coverage is always available. The US ground control stations determine the operation and position of GPS satellites (Bayyati, 2017). There are three main elements involved in the process, and they are, the space segment, the control segment, and the user segments (El-Rabbany, 2002). There has been a revolution in surveying and navigation since the early development and use of GPS. It is dependent on at least 24 satellites, a receiver (e.g., phone and computer) and ground stations (an algorithm to give a location velocity and time synchronisation for air, sea, and land) and works with almost all-weather conditions (Li et al. 2005). For surveying, GPS has been noted to be a cost-effective process with a minimum of fifty per cent cost reduction and the possibility of using a real-time kinematic GPS.

A study by Chen et al. (2012) states that The GPS utilises satellite positioning technology using receivers, to show locations on Earth. Geographical data acquisition by GPS in modern terms is to produce geometrical databases to store geometrical data and support analysis. The study explained that ground-based data acquisition methods measure the position of an object by direct observation with the surveying instrument placed within sight of the point to be measured. For measuring distance, the accuracy of GPS receivers ranges from sub-centimetre to over a hundred metres. It is fast and less labour intensive compared to high precision total stations with the added advantage of not needing inter-visibility between stations. At the expense of accuracy, air-based methods are devised to make it easier to perform position measurements. Direct observation is not used in this method, preferably, an image of the area upon which to base the measurements is produced.

According to O'Connor et al. (2019) and Chekole (2014), the GPS only accurately identify and map boundaries and land feature, even so, the GPS does not provide improved accuracy over other techniques, especially in instances with interference to the line of sight between receivers on the ground and satellites in the sky. Although not negatively affected by overhead obstructions, the GPS cannot measure points in the absence of a line-of-sight requirement. This implies that the signal is, weakened when it passes through solid objects such as buildings and also, it cannot pass through objects containing metals (Lange and Gilbert, 1999).

Figure 3.9. An example of a GPS receiver (Source: Chekole, 2014).

3.10. Geographic Information System (GIS)

The Geographic Information System (GIS) is a technology medium for managing site information, historical data, metric, and non-metric data including, plans, sections, maps, and photographs. It is an information technology system that permits the entrance, storage analysis, visualising, and interrogation of digital data. Thereby, metric, and non-metric data sets are stored and managed by the system in layers interlinked through the GIS database to a spatial geo-referenced location (Bayyati, 2017).

Tomlinson (2007) states that the term "GIS" is a horizontal technology. Because of its wide range of applications, it resists a common definition and therefore, a standard understanding is needed to describe it. A model, as shown in Figure 3.10, is a more flexible tool for elaborating GIS as a simple definition is insufficient.

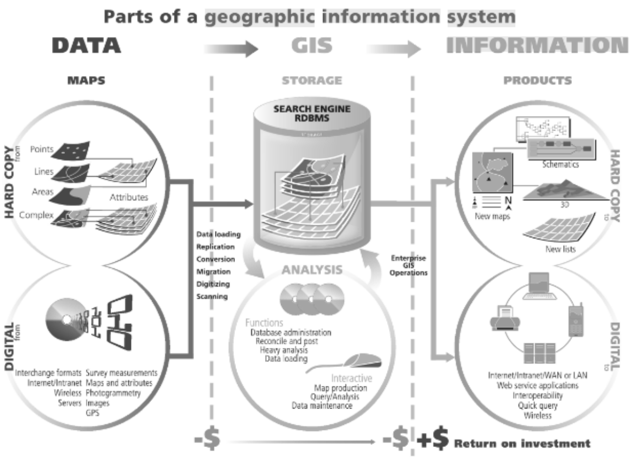


Figure 3.10 Parts of a Geographic Information System Source: (Tomlinson, 2007)

The model shown in Figure 3.10 is a functional, geographic information system that analyses data into useful information. In the middle, the model indicates that GIS accumulates spatial data well stocked from the left with its *logically linked attribute information* in a GIS database where the human operator interactively controls analytical functions to come up with the desired information products at the right. Note that the term spatial data is raw data characterised by a right geographical reference, represented by a combination of lines, points and polygons to show the features seen on a map including the common ones, buildings, roads, and lakes. Attributes are when applied to a place, non-spatial information linked to the geographical features of spatial data and often stored in the format of a table, they include building owner, seasonal temperature, and road names. These attributes are what make spatial data powerful in a changing, working GIS.

Tomlinson (2007) further states that much of the human and physical GIS data comes from maps and other documented hard-copy records as the standard mode of conveying geometrical information in history. This is processed, scanned, digitised, and logically linked with other digitised hard copy records converted to use for GIS. Other measuring and surveying devices, including GPS, and photogrammetry also generates data to use for GIS. They are now easily shared by advanced technologies through the internet and interchange formats. These logically linked data after a systematic integration, under the primary organising key of geographical location, are saved and managed as a single "database" entity where it avails itself and all its attributes and features for software functions (including analysis and mapmaking). The computer then uses its power to work with the software to do things that seem extraordinary and labour-intensive to perform tasks. For instance, compare, analyse, search, and measure specific data according to the desired purpose.

Bayyati (2017) states that it is a useful facility for various professionals including architects, engineers, conservationists and archaeologists as construction materials, structural conditions, historical importance, and others can be interrogated for specific information. And this information can be analysed and interpreted to make a necessary informed decision. Bayyati added that there are numerous GIS commercial desktop systems available on the market including ArcGIS, MapInfo, Smallworld and even the most useful and free online access including GRASS GIS, MapWindow GIS and Capware. This is especially advantageous since traditional GIS tools are not inexpensive, they are not very flexible for geo-visualisation, they have a steep learning curve and possess the difficulty of automatically and seamlessly integrating a high amount of data from other different sources (Luo et al., 2018).

3.11. Google Earth

A decadal review (from 2006 to 2016) carried out by Liang et al. (2018) on the applications and impacts of google earth stated that Google Earth was first released in June 2005 and came out a little later. By 2006, Google Earth has since generated a significant impact. For instance, by proving to be useful in applications like lake mapping, relief efforts, and making GIS available to non-GIS experts, so that by 2007, its mashup and its capacity to disseminate data made it be referred to as "the new era of geo-information". Liang et al. (2018) further state that from 2008, different from GIS conventional uses, the first four use cases of Google Earth included, visualisation, interoperability and mashups, modelling, and simulation as well as ease of use. It added that other subsequent reviews classified the applications of Google Earth to make up eight categories (data collection, data exploration, dissemination of research outcomes, data integration, validation, decision support, visualisation, modelling, and simulation).

Luo et al. (2018) described Google Earth formerly named EarthViewer 3D, a geographical information application, as the most popular and influential virtual globe program (A 3D planet representation software that can change viewing angle and position and can move freely in the virtual environment). Thus, a virtual globe can explore a virtual environment, add, and share users' data with others, represent natural and artificial features on the Earth, provide the ease to access image and terrain data and make annotation abilities user-friendly. The study explained that Google Earth's imagery, displayed on a digital globe, is generally captured by satellite or airborne sensors. The imagery shows the planet's surface using only a composited primary colour (Red, Green Blue) from a considerable distance. The image transits to various pictures with the same area but with finer details on zooming far enough as the spatial resolution of the imagery is between 15m to 15cm. Google Earth uses digital elevation model data collected by the National Aeronautics and Space Administration's SRTM (Shuttle Radar Topography Mission) for large parts of the Earth. They, therefore, create the impression of a three-dimensional terrain though images are two-dimensional. Very high-resolution images with a spatial resolution of less than five metres of the Earth's surface are displayed by Google Earth so that, users can see regions that are intersecting and targets at oblique angles. This is among the advantages of Google Earth's popularity including the acquired images on several dates for any specific location.

In simple terms, Isikdag and Zlatanova (2010) described Google Earth as one of the most known Geospatial Browsers with the capability to retrieve geospatial data over the web and visualise it over a virtual globe representing them in the form of raster or rector forms. And the base layer of the virtual globe has its data formed by satellite images with distinct resolution that changes depending on the user's interaction with the browser. Geospatial information including address and a coordinate pair can be derived from the browser as well as other information by navigating (by panning, zooming, rotating) using a simple mouse or appropriate toolbar. The data resource is from the user input as well as several layers of maps so that users can generate the desired points of interest, define geometries and some other information about the point and areas of interest. Building models (Boundary Representation) visualised in Google Earth are often created using modelling software and imported as KML/KMZ formats. Figure 3.10 shows the visualisation of two 3D building models on Google Earth.

The main limitations of Google Earth mentioned by Yu and Gong (2012) are 1. Consistent analysis tends to be difficult because of an inconsistent remotely sensed image in Google Earth caused by varying coverage for high-resolution imagery across different parts of the world. 2.

Quantitative measurements and analysis are not precise in Google Earth because its images are for visualisation purposes only, quantitative values of certain topographic parameters can only be done with additional software or data sets. It supports a minute fraction of a full GIS application and is inadequate for analysis utilities; therefore, it needs integration with analytical tools to ensure spatial analysis. 3. Earth's surface representation and tessellation in Google Earth contains operations that are not adequate.

Figure 3.11. shows the visualisation of two 3D building models in Google Earth (Source: Isikdag and Zlatanova, 2010).

3.12. Scanned Two-Dimensional Architectural Drawings

Two-dimensional (2D) floor plans are the fundamental standards used by architects and in the broader field of architecture to express design and generate three-dimensional (3D) models. 3D models are intuitive and find applications in numerous areas such as virtual realities and various types of simulations, so an accurate, reliable, efficient, fast, and automated creation process is vital to its creation (Zhu et al. 2013; Pandey and Sharma 2016).

A study by Pandey and Sharma (2016) states that 2D architectural plans contain all information about a building's architectural design and geometry and are usually in two formats. The two formats are vector and scanned copies of hand-drawn floor prints (raster). Most often, the vector form of the floor plans is used for 3D computer-assisted models while the raster is first converted into vector format through image processing algorithms to obtain architectural information.

According to Yin et al. (2009), floor plans come with various detailing levels and even the most widely available set of floor plans does not have detailed construction data. They, however, manage to cover the complete layout of the building, which is enough to create models for most applications. Even though some of the floor plans, either hand-drawn or computer-drawn, carry fewer details, it is still accepted as legitimate input data by many systems. Still, they usually have a graphic symbol which is a major challenge. Thus, due to the drawback of analysing and interpreting an image floor plan, human intervention becomes necessary.

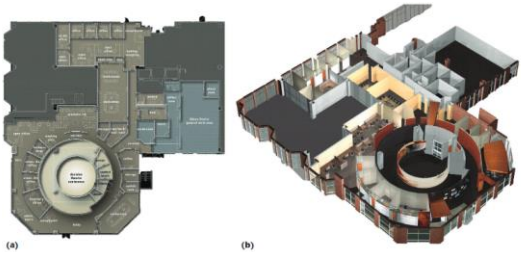


Figure 3.12A. (a) input and (b) output of a system that converts 2D architectural floor plans to 3D computer models (Source: Yin et al., 2009).

The examples shown in Figure 3.12A are (a) Input and (b) Required output from an automated 3D building model system.

A study by Gimenez et al. (2015) gave a brief description of both the vector and the raster floor plans. The study states that scanned 2D drawings (raster format) are gotten from paper and then scanned by an optical image scanner to transform them into digital images. Depending on the scanner quality and system of digitisation, further processing may be required. Also, these plans are elaborate and contain a significant amount of information leading to a considerable amount of noise in the image afterwards, so it is crucial to clean the images to eliminate the useless information in the first instance of processing. The goal is to derive meaningful and structural information (including texts and geometric primitives like lines and polylines); however, a general setback to this is errors and inaccuracies in drawings. The drawing deficiency can, therefore, cause significant inconsistencies which can make recognition and reconstruction tasks difficult. The vector format, mainly CAD plan is made up of geometric primitives instead of just pixels, and they are organised in layouts so that each arrangement is related to certain types of drawing elements. The designer's requirements and constraints might cause layout configuration to vary. According to Lewis and Sequin (1998), more than just geometrical information is desired in a building model, the concept of rooms and other spaces with a record of their identity is required to support verification of the original building program. Zhu et al. (2013) state that to get the semantic and topological information of spaces and to create 3D models from analysis of 2D architectural drawings, the links between different spaces and architectural components are useful and are embedded modelling software (an example is REVIT). They are component symbol recognition, loop search to get space information and 3D extrusion. Several studies (including Zhu et al., 2013; Lewis and Sequin 1998; Santos et al. 2011) gave a detailed explanation of these steps, but they require some manual work. The limitation of the vector method is that in some instances and for old buildings, the architectural plans are hardly available. The general and various stages involved in converting a 2D architectural plan to 3D models are similar in process. Compare Figure 3.12B and Figure 3.12C

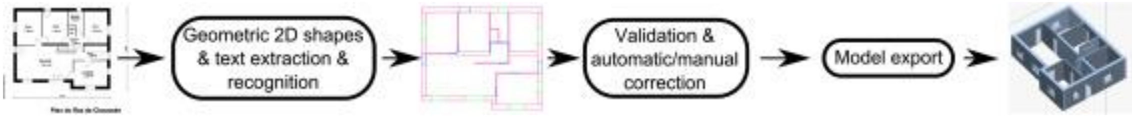


Figure 3.12B The general process of conversion of a 2D plan to a 3D building model (Source: Gimenez et al., 2014)

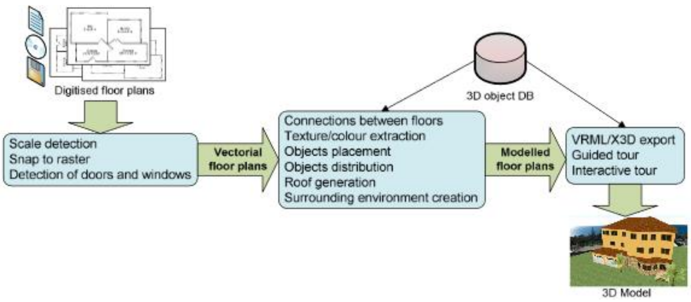


Figure 3.12C. Method of creating 3D building models from 2D architectural drawings (Source: Santos et al. 2011).

3.13. Walkthrough and Occupant Surveys

According to Preiser et al. (2017), walkthrough is a data acquisition technique used in buildings that involves site visits, so that team members carry out an individual survey with one-on-one interviews focused on their team members' discipline. The two categories of data usually generated fall under the hard metrics (measures systems and infrastructure performance) and the soft metrics (how well facilities meet their purpose). These two classes of data are necessary to inform the decision-making process for building performance modification or enhancement of existing buildings. A series of post-occupancy reviews of buildings and their engineering (Probe) studies is an example of the walkthrough and occupant survey that captures both hard and soft metrics data. The first (Probe 1), second (Probe 2) and third (Probe 3) series mainly dealt with the hard metrics, and the fourth (Probe 4) and fifth (Probe 5) series were more about the soft metrics.

Cohen et al. (2001) in Probe 1 investigated eight buildings (four commercial and four institutional) using two established tools; *the occupant survey method and the energy survey Method*. A detailed pre-visit questionnaire helped in collecting vital information including services, occupancy, use and management to make the first visit more effective. The occupant survey method derived from the building use studies in the 1980s ensured that Probe carefully designed a self-completion questionnaire. It collected information from staff on 49 variables in twelve groups, including building overall as "*in buildings, physical design issues and management are inextricably linked*". Figure 3.13 shows the key stages of the survey.

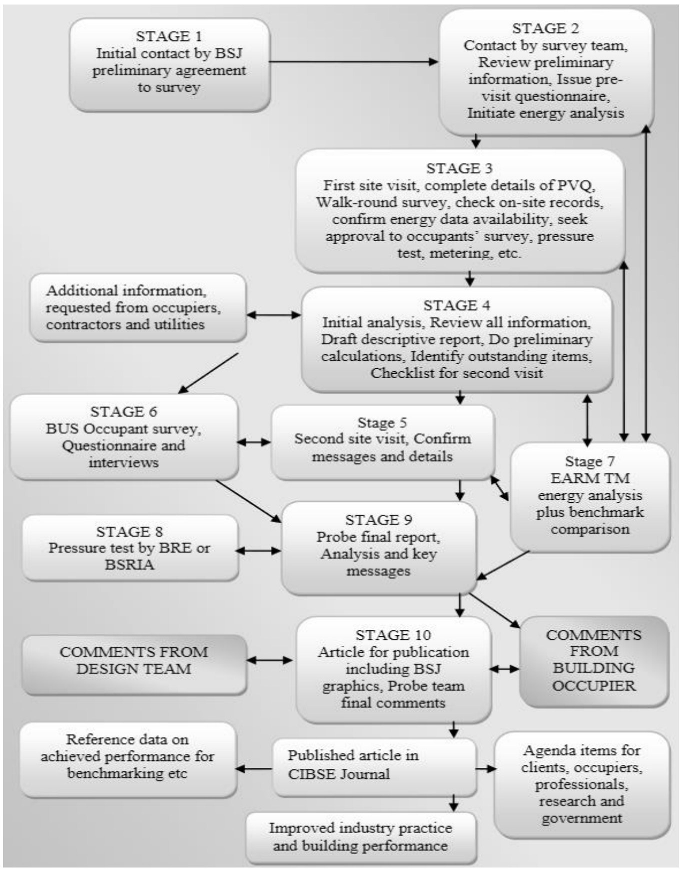


Figure 3.13**.** Flowchart of the Probe survey and the reporting process (Source: Cohen et al., 2001).

As shown in Figure 3.13., Probe carefully prepared to collect the required information on two site technical visits carried out by two experienced assessors who know the proper direction, the right questions to ask and the right priorities to set. The principal technical assessor who was present on the first visit carried out the second visit accompanied by a quality assessor who was absent from the first visit for quality control. Stage 1 involved initial contact with the occupiers of the building as the designers are not allowed to accompany the investigators. In stage 2, good advance information is needed by the assessor to make efficient use of the first site visit. Such information about the project includes plans of the building, its operation and use of the building, its level of energy consumption and certain design information that may require a preliminary site visit or contact with the designer if unavailable. Stage 3 is the first site visit and the beginning of earnest work. Vital information about the building is obtained from an initial interview with the host using the pre-visit questionnaire, a walk around of the building, informal discussion with management, and staff, a review of specifications drawing and other records. With the use of basic equipment, including meters, temperature indicators and cameras, spot measurements were taken. Initial analysis was carried out in step 4, all the notes and other materials were analysed, and this stage helps to identify the gaps that were not covered on the first visit and to generate a checklist ticked on the second visit. The checklist gives the survey team a different view of the building so that in stage 5, help from contractors and others is required to clear all uncertainties and inconsistencies. In Stage 6 involving the building use occupant survey, approved questionnaires (by relevant managers) are distributed to specialist groups. Energy analysis is done in stage 7, a pressure test in step 8, the final report in phase 9 and an article is produced following the final report in stage 10.

Probe 1 by Cohen et al. (2001) detailed the process, and Bordass et al. (2001) explained the technical and energy performance of the process in Probe 2 and 3, respectively. The occupant survey by Leamen and Bordass (2001) is in Probe 4, and Bordass et al. (2001) documented the conclusions and implications in Probe 5. Blyth et al. (2006) mentioned that the walkthrough and occupant survey data capturing technology is best to validate inaccurate or outdated existing drawings as well as to complement other data capturing techniques to provide useful information quickly and even for the basis of a more in-depth study. Thus, the implication is that the walkthrough occupant survey data-capturing technique is vital but cannot be a stand-alone process in creating a 3D as-built model.

3.14. Remote Sensing

Campell and Wynne (2011) after reviewing a series of the definition of remote sensing by various authors define it thus.

"*Remote sensing is the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth's surface.*"

An "SYNER-G Report 3" by Tenerelli et al. (2013), defines remote sensing as a primary means of acquiring spatial data (from a distance or without getting in direct contact with the object to be measured) as it measures electromagnetic radiation interacting with the atmosphere and objects. Campell and Wynne (2011) further state that remote sensing is a cost-effective method of extracting spatial information (height, building footprint and shape) of the built environment with the aid of certain instruments such as optical satellites, laser scanners, radar and cameras otherwise known as sensor data. Sensor data formed by a record of emitted or reflected electromagnetic radiation from the landscape appears abstract and foreign due to unfamiliar overhead perspective, unusual resolutions, and using spectral regions that is not within the visible spectrum. Thus, for sensor data to have practical use in addressing problems, analysis, and interpretation to convert the data to information are required, and these interpretations produce extracted information consisting of sensor data transformation designed to give certain kinds of information. See Figure 3.14A.

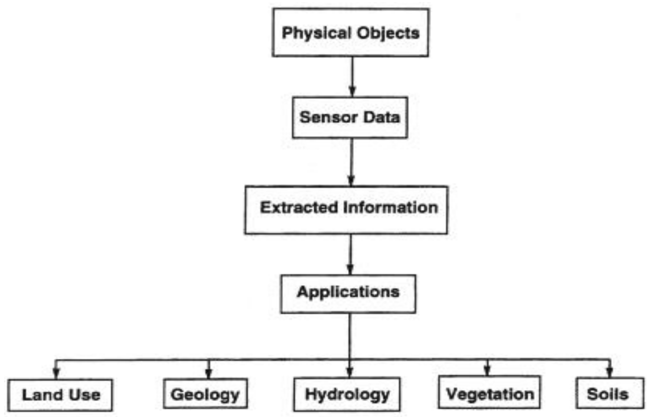


Figure 3.14A. Overview of the remote sensing process. (Source: Campell and Wynne, 2011)

Tenerelli et al. (2013) point out that the sensitivity of the different types of remote sensing systems to specific wavelengths of the electromagnetic spectrum also has distinct merits and demerits for certain applications. For instance, optical sensors have a sensitivity to visible and infrared wavelengths, information in huge spectral bands is specifically collected by hyperspectral sensors, and information in the Optical and Radar part of the electromagnetic radiation spectrum is typically captured by satellite and airborne remote sensing. Stereo models for processing 3D surfaces can be produced by optical and radar data. Spatial resolution is, therefore, vital to map-out buildings and civil engineering works. For instance, a ten metres square building requires not more than 5mx5m. Data of minimal resolution of 1mx1m is termed very high resolution, between 1mx1m and 10mx10m as high resolution, and between 10mx10m and 100mx100m as medium resolution. Accessibility of high and very high-resolution data from remote sensing depends on the funding as the higher spatial resolution is more expensive. The cheaper satellite imagery covers a broader area with almost global coverage from various data providers while also allowing for data sets and spatial resolutions compared to that of the more expensive aerial photography. As only above-ground physical infrastructure such as buildings can be observed by remote sensing and with the rapid increase in satellite data applications buildings, Table 3.14. shows the data types and the physical parameter used to gather information on the European buildings at risk.

Table 3.14. Remote sensing data types and detectable physical parameters for a typical European building at risk

Typical European elements at risk	Visible from remote sensing	Automatic and semi-automatic detection	Physical parameter that can be identified	Suggested data types
BUILDINGS	Yes	Possible	Building location, planar view, built-up density, roof type, building age, geometrical parameters (shape, perimeter, size height, volume)	Optical VHR/ HR/MR; Stereo VHR/HR; Hyper-spectral HR; Oblique Aerial; LIDAR*; SAR VHR/HR

The various suggested data types are detailed by Tenerelli et al. (2013) in the SYNER-G Report 3 and they include optical very high resolution, aerial, or satellite stereo high and very high resolution, hyperspectral among others. A study by Sarabandi & Kiremidjian (2008) also gave a comprehensive geometric information extraction from satellite images, according to Figure 3.14B (a and b). shows that sensors' elevation and azimuth angles describe approximate image acquisition geometry and satellite orientation.

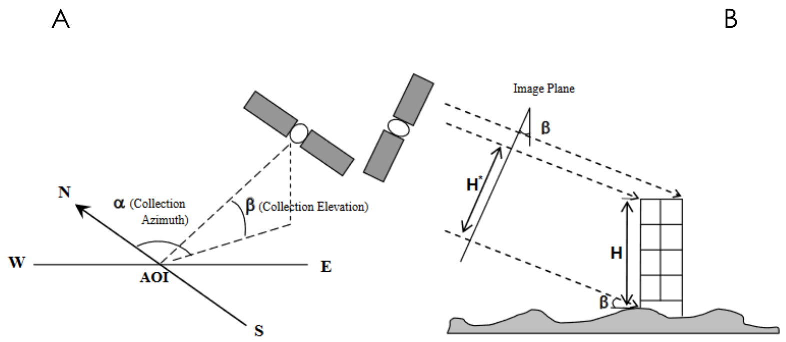


Figure 3.14B. (A) Image Acquisition geometry and (B), the relationship between the real height of a building and measured height on the image plane. (Source: Tenerelli et al., 2013).

Errors and the amount that can be introduced by an operator when selecting ground points, and rooftop points affect how accurate differential height estimation is and thus the total accuracy in getting the 3D dimensions.

3.15. Light Detection and Ranging (LIDAR)

Light Detection and Ranging (Lidar), is a laser imaging technology used to capture scenes with millimetre-to-centimetre accuracy. It produces accurate, fast, comprehensive 3D data of captured scenes per second at a rate of hundreds of thousands of point measurements (Sepasgozar et al. 2014). Lidar uses a high-technology sensor to ensure a more top form of automation and accuracy of the data collection process in real-time so that it can scan certain surfaces in detail. Lidar sensors can increasingly produce complete data of visible surfaces with features that the average human eye or a digital camera cannot capture. It is the highest quality of 3D data capture as well as the most expensive alternative requiring high technical expertise and software and a relatively high-end workstation (Wheeler, 2017). Melin et al. (2017) who described Lidar as a remote sensing method that measures distances with the aid of a laser also state that pulses of light reflected from a laser scanner hit a target. A portion of its photons is reflected on the scanner. Due to the reason that the scanner location, pulse directionality and time between pulse locations are known, the 3D coordinates (XYZ) are calculated from where the pulse is reflected. Lidar data are versatile and highly complementary in that they can be used with satellite or aerial imagery to capture data that just one technology cannot capture. However, its limitations are that the datasets are only available to a minute world fraction and limited to data captured at a single point in time. It is complex to process and interpret with a high cost of collection and it cannot penetrate thick layers.

3.16. Summary Table of Data Capturing Technology

Table 3.16 Summary of data capturing technology.

No	Techniques	Equipment involved	Nature of Bioclimatic Data Captured	Ability	Cost efficiency
1	Manual site Survey.	Measuring tape, digital camera, laser distance meters and large-scale area plans for documentation.	Basic dimensions; length, breadth, and height of the space.	Used to produce 2D documentation of geometric characteristics of buildings	Cost efficient
2	Total Station	Theodolite integrated with an electronic distance meter (EDM)	Position of points or the locations and height of points.	For recreating existing conditions and 3D objects, and location data	They are non-Inexpensive
3	Photogrammetry	Camera	Building geometry	Uses Photographic images to capture inaccessible and complex, building data at a high acquisition pace, effective offline measuring ability, and less repetitive steps. Photogrammetry is a reliable and more efficient technology to create an as-built BIM.	Cheaper alternative to videogrammetry and laser scanning
4	Videogrammetry	Video cameras	Location and building geometry	It uses video frames to capture and reconstruct 3D data	It Is more expensive compared to photogrammetry
5	Photo modelling and image modelling	Camera or 2D photos	Three-dimensional point cloud	Use of photographs for image/photo-based modelling helping to create 3D models from 2D photos.	Cost efficient
6	Laser Scanning	Laser scanner	Three-dimensional co-ordinates	Uses a sensor coordinates system (radiation) to capture a very little detail of up to 0.6mm 3D precision from a ten metre range as well as capture complex shapes geometry	Laser scanners are not in-expemsive.
7	GPS	GPS receiver	Location information	GPS receiver processes GPS microwave radio signal transmitted by GPS satellite using its built-in software to provide location information.	GPS is cost-effective
8	GIS	Geographic information system	Maps and other geographically referenced documented records	Software and hardware are integrated to capture, manage analyse and process site information, historical data, metrics, and non-metric data	GIS tools are not inexpensive
9	Google Earth	Geographic information application	3D planet representation (Imagery) and location information	The imagery displayed on a digital globe is captured by satellite or airborne sensors.	Google Earth is cost-effective
10	Scanned 2D floor plans	2D drawings	Texts and geometric primitives like lines and polylines.	Vector and raster.	Scanned 2D drawings are relatively less expensive.

11	Walkthrough and surveys	Site visits and surveys (including the use of cameras, questionnaires, and others)	Hard and soft metrics data	Walkthroughs and surveys are used to validate inaccurate or outdated existing drawings and to complement other data-capturing technologies to provide useful information quickly and even for the basis of a more in-depth study	
12	Remote Sensing	Sensor data (such as optical satellites, laser scanners, radar, and cameras)	Spatial information (height, building footprint and shape	Images from electromagnetic radiation	It is cost-effective, with a wide coverage area and expensive for small areas
13	Lidar	Laser	3D data of captured scenes	Lidar uses high-technology sensors to scan and produce high-quality 3D data of scenes	Lidar is very expensive

3.17. Critical Evaluation of Identified Data Capturing Technologies.

Table 3.16 contains the commonly available data-capturing technologies in use for existing buildings; they all have certain and different features, characteristics, abilities, advantages, and limitations from one another. The aim of this chapter is partly in response to the outcome of the previous chapter. As identified in chapter two, the major need for building performance improvement that has the most significant impact on the energy consumption of Nigeria's commercial buildings is for cooling purposes. Data capturing technologies that help to create an efficient, cost-effective three-dimensional model needed for evaluation and analysis before proposal formulation or simulation are important. It is the most advanced way of testing, analysing, and replicating different strategies and scenarios and is also recommended by the Nigerian building energy efficiency code. In this regard, the role, limitations and benefits of each or a combination of the data-capturing technology will determine their suitability for adoption in line with the study goal. As-built modelling can be actualised through the data capturing of the present building information and condition, and data modelling (Pătrăucean et al. 2015) which are critical factors to consider in the selection.

As gathered from the description of data capturing methods, the manual site survey and total station can be used to capture the 2D input data set from an existing building, to create a 3D model that can be used for simulation provided contact is possible. This must be fed into any of the 3D creation software available with plugins or simulation applications for processing. For example, Ali and Mohammed (2015) described in detail using a Nikon Nivo-5C total station using AutoCAD software to represent a 3D building of the Civil Engineering Department at Baghdad University Campus. The steps involved in the process are

- Recording survey station.
- Setting up survey.
- Measuring building height.
- Using AutoCAD to present the 3D model.

The study showed that it is possible to create a 3D model with data captured from the total station; however, it is very time-consuming and requires a lot of human intervention, this is also confirmed in a study by Stančić et al. (2014). In the study, a St. Nicholas church on the island of Hvar was surveyed and represented in 3D using both laser scanning and a reflectorless total station. In the case of this study, MicroStation, a computer-aided design software, was used for 3D modelling. It reported that points imported into the software from Microsoft Excel computational part of the total station acquired data and complemented it with data gathered using a measuring tape to create a wireframe and a rendered 3D model as shown in Figures 3.17A(a and b) respectively.

a b

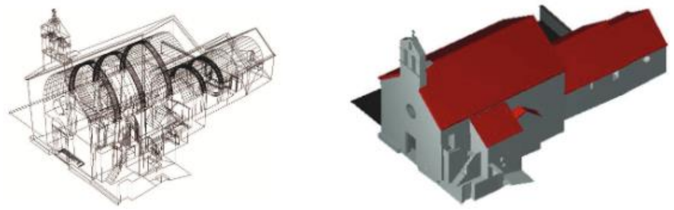


Figure 3.17A (a) Wireframe 3D model and (b) Rendered 3D model (Source: Stančić et al. 2014).

Lack of hardware resources and time resulted in Laser scanning being used to collect data that were partly processed and used, and overlap of survey results made, the result showed no discrepancies between the two surveys.

Photogrammetric, videogrammetric and photo modelling are non-contact, fast and cheap data-capturing technologies that capture and process images to create a 3D model. Although photogrammetric measurements are less accurate than field measurements, it, however, has the advantage of a lesser personnel and time requirement. A comprehensive and step-by-step process of the photogrammetric process carried out at the Indian Institute of Technology, the Institute of Engineers building, Roorke campus area is detailed in a study by Shashi and Jain (2007). The study used a Kodak CX7300 camera and a photomodeler 5, a photogrammetric software package. The stages involved are.

- Acquisition of photos.
- Processing of acquired photos.
- Generation of the 3D model.
- Texturing and visualisation.

The result of the process (less than 1.5) conforms with the specification for accuracy given by photomodeler 5 of less than 3. Therefore, making it a good advantage over CAD-based techniques. Photogrammetry usually required a special camera and equipment that needed to be processed manually in the past until the advent of digital cameras that can produce photos to create a 3D point cloud (image modelling). Videogrammetry requires high expertise and will not be considered for this study because of the advantage of similar technologies such as image modelling over it.

Laser scanning has seen extensive applications in capturing as-built data from buildings; however, due to its high cost, lack of portability and high expertise, it will not be considered for use in this research.

The GPS, GIS and Google Earth are geographical data acquisition systems. Lange and Gilbert (1999) however mentioned that the GPS is not suitable for specific applications because its signal (from satellite) is weakened by obstructions such as buildings, roofs and others as is the case in this study. The GIS according to Luo et al. (2018) is not very flexible for geo-visualisation, this is in addition to it having a steep learning curve and the difficulty of automatically and seamlessly integrating a high amount of data from other different sources. This implies its unsuitability for this study. Google Earth was used as a visual representation by Isikdag and Zlatanova (2010) as shown (Figure 3.17B). The steps involved are detailed in the study; it also made clear that this is only possible for visualisation of geospatial environment purposes; thus, space analysis is not possible with google earth. It can be used for building modelling, however, there may be difficulty in using google earth solely for testing strategies through simulation. In the case of this research and to enhance the environmental performance of buildings, measures must take account of spatial analysis so that the indoor thermal environmental condition needs can be addressed in other to achieve the study aim.

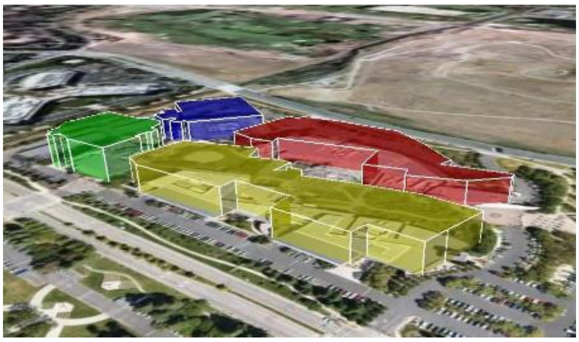


Figure 3.17B. Visual representation of four buildings (Source: Isikdag and Zlatanova, 2010)

Scanned 2D drawings have been used in various studies referenced in section 3.12 (including Lewis and Sequin 1998; Santos et al. 2011; Zhu et al. 2013) and it has proven to be effective and cheap. However, the unavailability of drawings from some existing buildings as well as some drawings not updated poses a problem. In the case of the availability of drawings, it needs to be complemented with the walkthrough and survey method of data capture as this method of capturing data helps to confirm and validate the inaccuracies of existing or outdated existing drawings. The Probe process referenced in section 3.13 details the processes involved in the walkthrough and survey; this is especially useful in the process of retrofitting, as technical and design deficiencies are easily recognised to inform decision-making.

Lidar is a fast, accurate and highly automated data-capturing technology that is not affected by day and night-time light variation. However, its suitability for use in this research is questionable. It has a high cost of data collection, and it is complex to process and interpret coupled with the fact that its datasets are only available to a smaller world fraction while its data capture is by a single point in time. The use of ultrasonic testing, although instantaneous and accurate, can only test for diagnosis or testing for defects in building materials. Thus, it cannot be used to create a model but can be used to support other data capture technologies. For example, a detailed workflow and results of an ultrasonic 3D investigation and 3D survey application were presented in a study by Di Pietra et al. (2017). The work assessed the internal integrity of ancient sculpture, also showing the ability of methods devoted to acquiring 3D geometric data of small objects. In addition to several difficulties the authors described, including laborious manual processing requiring high expertise, it is beyond the scope of this study.

Thermal imaging uses a specialised type of camera to produce images of thermal information. The information cannot be used for a 3D model that can suit testing retrofit strategies. However, in some studies, it has been used to complement other data-capturing technologies like laser scanning and photogrammetry to produce a model specific to improving energy performance in a building. For instance, Borrmann et al. (2013), in a study, used a 3D laser scanner, a thermal imaging camera and a photo camera to present a multi-modal 3D mapping of building facades.

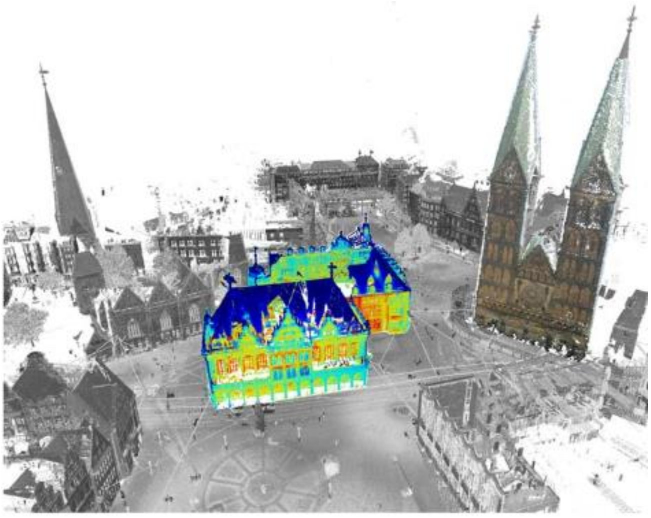


Figure 3.17C. Laser scan with reflections, colour, and thermal information (Source: Borrmann et al., 2013)

The study aimed to devise a technology capable of capturing a precise 3D representation of buildings while providing thermal information at the same time. The process is detailed in the study, and it concluded that reliable temperature measurements are impossible during the day because of sunlight while collecting photo camera information at night was not feasible. So that at different times, data collected were reconstructed with a Bundler (Patch-based Multi-view Stereo Software in this case). The bundler does not preserve the scale of the environment. Thus, the model was semi-automatically scaled to a point cloud by the laser scanner, and the result is shown in Figure 3.17C.

Similarly, a study by Alba et al. (2011) gave a detailed procedure for texturing thermal images on a model. Although the main work was done with a laser scanner, the study stated that existing CAD drawings and photogrammetry could be used. The work reported that integrating laser scanning, photogrammetry and thermal imaging boosts the possibility of discovering thermal anomalies, and locations, and enhancing the geometric resolution of the resulting 3D model. This process is still relatively not inexpensive, time-consuming, labour-intensive, and requires a high degree of expertise.

While a critical evaluation of the data capturing techniques identified and summarised in Table 3.17 indicates that photogrammetry is more suitable for achieving the study aim, there is a need to understand if and how others can be utilised either solely or jointly in the study context. Therefore, the role of understanding the practice of building data capturing in the study context cannot be overemphasized if research goals must be efficiently achieved.

3.22. Summary

This chapter presented an overview of the need for building data capture as well as information on the common data-capturing technologies identified and used for existing buildings around the globe. It describes their identified features, tools or components, benefits, processes and the limitations of their technologies and techniques. In line with the study's aim, to efficiently answer the research questions, there was a critical evaluation of the various data capturing tools and techniques identified where some of the technologies appeared not to produce the best result to achieve the set research objectives. Some of the capturing methods appeared to be suitable for certain phases of the study, partially helping to fulfil study aims, it was identified that most often, a combination of different tools and techniques has achieved optimum results. Therefore, to suit the study contest and to ensure that other identified limitations are avoided, there is a need to survey the built environment professionals in the study region, who are conversant with such practices. Their knowledge and experience in practice will be deduced from the survey. The output of the survey will serve as a guide to future practice on what is suitable and achievable for creating an efficient and cost-effective methodology for data capturing, modelling, evaluation, and analysis, before a possible proposal formulation that is required for improving the indoor thermal environment of existing buildings in Nigeria.

The next chapter expounds on the methodology used in carrying out the research objectives including conducting the surveys, exploring the data capture techniques and the analysis process.

CHAPTER 4

RESEARCH METHODOLOGY

4.1. Introduction

This chapter provides insight into the methodology applied in this research to answer the research questions and to fulfil target objectives. It does so by using the research onion, one of the widely used methodological models by Saunders et al. (2016) in line with the theoretical framework adopted from studies in chapter two, chapter three and the study's aim and objectives. It reviews general research approaches, research philosophies, research choices, research strategies, data collection and analysis. The chapter goes further to consider ethical issues, justifications and limitations of the methods adopted to provide a full description of the scope and research methods.

As discussed in Chapter 1, this study aims to develop a reliable and cost-effective methodology for the capture of as-built bioclimatic design information of office buildings, for the simulation before improving their environmental performance. The methodology is to aid the reduction of energy demand and its associated cost in buildings while creating less financial burden on either the clients or the built environment professionals through the set-out objectives.

4.2. The Research Methodological Model

The research methodology is the scientific way of solving research problems, and it involves a study of the various paths that leads a researcher to solve research problems while stating the rationale behind such an approach (Ayodele, 2017). Research methodology takes a step further from research methods to justify the logic behind the path followed or the adoption of a chosen technique. Whereas how data is collected, the ways by which information is analysed as well as the means of validation of research results are explained as part of the research methods (Al-Awad, 2015). Thus, research methodology is broader in scope than research methods

The common platform that researchers can relate to at any given time and place as part of any research effort is the methodology. Therefore, concerning the methodology, as part of a research effort for this work, it is vital to explore the philosophical review of the research layers of knowledge relating to the research. It is incredibly beneficial that the study is managed, following a step-by-step approach or guidelines to ensure that the investigation is carried out as intended and achieves the desired results. The advantages of these different stages involved in conducting the research were outlined by Saunders et al. (2009). Thus, adapting an established research model following the systematic exploration of a research philosophy becomes essential. The research onion model (Figure 4.2) has six layers that systematically take care of the research methodology and is one of the methodological research models widely used in research, an improvement of the widely used Nested model (with three layers) by Kagioglou et al (2000).

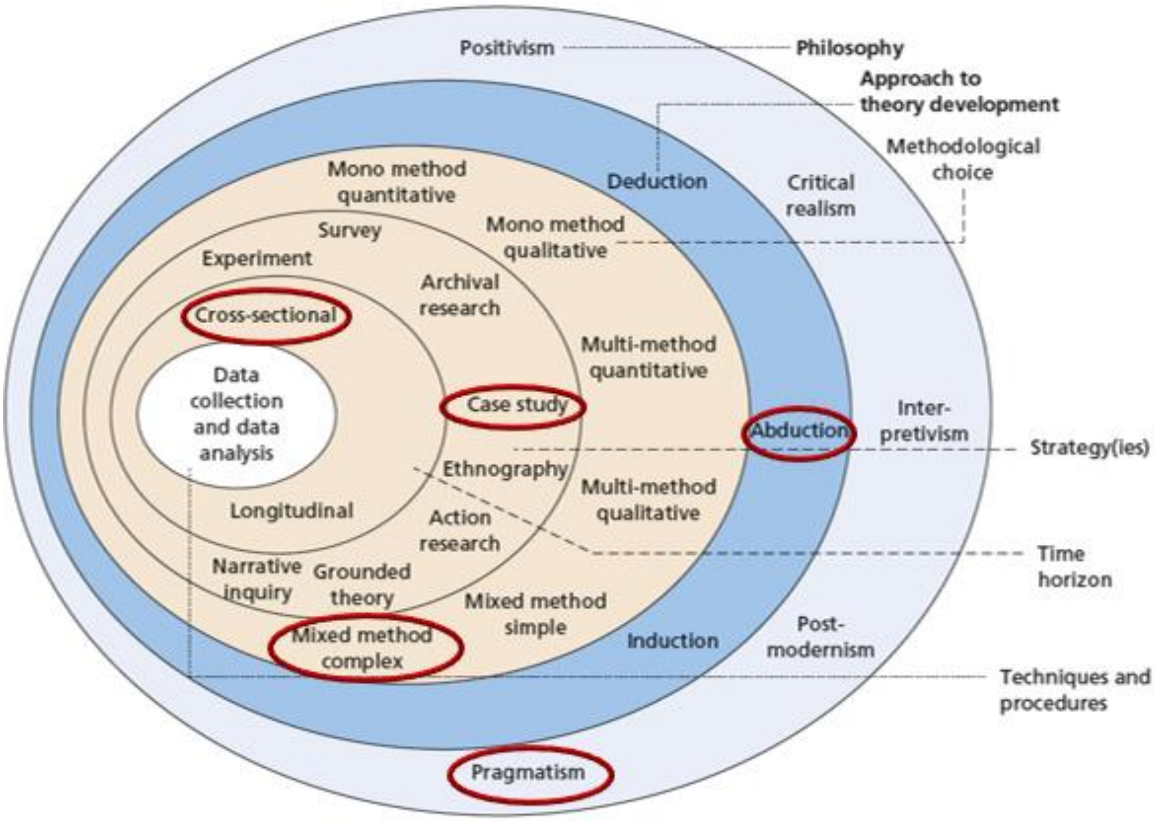


Figure 4.2. The research 'onion' Model (Source: Saunders et al., 2016)

According to Saunders et al. (2009), the research onion methodological model is a unit and simple framework used in a research process. It is comprehensive enough to allow researchers to systematically review each layer and ascertain issues and reasons surrounding the choice of a research method. As shown in Figure 4.2. the model has six layers and are, philosophies, approach to theory development, methodological choice, strategies, time horizon, techniques, and procedures.

The design of the research onion model is done in such a way that to get to the core (data collection and data analysis techniques), a step-by-step method of peeling the initial layers of the model must be followed. Starting with the outermost (philosophy) layer whose decision directly affects the conclusion of the preceding layer (approach) and so on.

4.3. Research Philosophies

According to Saunders et al. (2009), research philosophy is the development of knowledge and the nature or character of the developed knowledge. A system of assumptions and thinking about knowledge development (Saunders et al., 2016). Simply, it depends on a researcher's thoughts and assumptions about the progress of knowledge which then directs how the research is carried out. It is the researchers' views and opinions and the manner, in understanding the world. To differentiate or analyse individual research philosophies, there is a need to understand the assumptions made in research as this helps to distinguish the philosophies. They are Ontology, Epistemology and Axiology.

4.3.1. Ontological Philosophy

The ontological philosophical assumption appears abstract yet tends to shape the manner a research object is seen and studied as this assumption is about the nature of reality and the way the world works (obligation to a particular perception) as stated by Saunders et al. (2016). It has two characteristics; they are objectivism and subjectivism (May 2011). Objectivism is a state of being objective, it bases its tradition outside of the mind or social actors (including interpretations and perception) whereas subjectivism has the view that social phenomena emanate from the impressions, interpretations, and actions of the social actors. Naturally, it is a norm that reality is subjective or based on an observer's mindset, feelings, intuition, and perspective rather than observing the physical environment. It could also be said that the subjectivism ontological position is nominalism, and the objectivism ontological position is realism (Saunders et al. 2016).

Justification for the ontological position of this study.

Ontologically, by the nature of this study, it is neither solely objectivist nor subjectivist rather, it is a combination of both objective and subjective views because social phenomenon from social actors (interpretations and perceptions) as well as a practical observation of the physical environment is necessary.

The ontological position for this study is based on the nature of the reality of the study in answering the research questions. The reality of this study involves recruiting professionals in the built environment to complete questionnaires and answer interview questions based on their knowledge, experiences, and professional practices. The responses to the semi-structured interviews and questionnaires are justifiable as a result of their feelings, mindset, and perspective. Particular to this research is to gauge the role of building designers towards achieving energy efficiency through the process of retrofitting or redesigning, surveying, and performance enhancement. Design considerations about building envelope configuration, end users and compliance issues and as-built data capturing experiences are all based on the professional's (social actors) knowledge and practices that come from their brain as their opinions and mindset. Similarly, the building surveyors' responses to semi-structured interviews to inform their considerations and decisions on geometric data capture as well as the trend in Benin City, the study region is based on their instincts and interpretation. Therefore, the respondents' opinions and mindsets are valued by this research, in this case, falls under subjective ontology,

Whereas this study also considers objectivism because as-is building representation capture of existing office buildings using tape and photographs are phenomena that happen outside the mind but the reality on the ground. To determine the office space temperature using a measuring device (such as the data logger) is also independent of the mind. Data observed and captured on-site falls under objective ontology. Therefore, this research seats between subjective and objective ontology.

Ontology is one of the subsets of research philosophy, therefore having explained and justified this study's ontological position, the next subset of the research philosophy philosophical position (epistemology) is discussed as a variant of this subsection.

4.3.2. Epistemological Philosophy

Epistemological philosophical assumption explores what constitutes acceptable knowledge in a particular study, and it is an assumption that guides how the world is perceived and deals with the theory of the study of knowledge (Saunders et al. 2009). The philosophical bases for epistemology are positivism, postmodernism, pragmatism, realism and interpretivism.

According to Creswell, (2009), positivism sees reality from only observable phenomena (real objects), it posits that the only authentic knowledge is if it results in laws or lawlike generalisation derived from the physical and natural sciences (Knowledge from theories through scientific methods). Facts from practical, experiments and reality in place of impressions are associated with positivism.

Interpretivism demonstrates an understanding of the dissimilarities existing between people and social actors, and it implies that the subject matter of the natural sciences differs from that of the social sciences (Saunders et al. 2016). The tradition of interpretivism is that knowledge is not determined by convention, facts, or data but instead by what is obtainable from practitioners' practices and experiences.

Realism differs from positivism with the assumption that objects are not dependent on our knowledge of their existence. Its two factions according to Saunders et al. (2009) are direct realism (accuracy of the world is defined by experiences from our senses) and critical realism (actual reality may not be seen owing to a possible deception of our senses).

Pragmatism is directed by and focuses on the research problem and question while solving the problem. Knowledgeable future practical solutions become the outcome and it is carried out through action research, mixed and multiple methods (Saunders et al. 2016). Furthermore, pragmatist research is initiated by a problem to provide practical solutions that inform future practice; thus, concepts can only be appropriate if it supports actions. Therefore, research questions borne out of the researcher's doubt or sense of something wrong is attempted based on the researchers' values and drive for enquiry by which there may be a possibility to employ different methods and type of knowledge.

Postmodernism deals with knowledge as the dominant ideology, and it is mainly qualitative involving thorough investigations of the dormant and anomalies.

Justification for the epistemological position of this study.

The epistemological stance for this study is pragmatism because the aim of this study is to encourage the enhancement of office buildings' performance through the development of a cost-effective and efficient process of data capture, modelling, analysis, and evaluation. The premise of the research question is borne out of the researchers' interest in capturing the necessary building information that will aid in reducing the energy demand of office buildings and their associated costs through modelling and simulation. It is also to make it effective enough without additional cost to the client or built environment professional. The goal of developing such methodology (practical effect of ideas and knowledge) is to enable future practice, not in an abstract form but as an instrument of thought and action and that is the position of pragmatists. It is the practice of putting ideas, theories and research findings that have been done about the performance of buildings as well as the capture of relevant building performance data from other places that will ensure its success in Nigeria.

Following an explanation and justification of the epistemological position for this study, the next philosophical assumption is discussed next.

4.3.3. Axiological Philosophy

According to Saunders et al. (2016), axiological philosophy deals with the judgement about values. It weighs how much our values play a role in our opinion, and research topic and impact how to go about the research (methodology). Two axiological positions exist, and they are value-laden (biased) and non-value-laden (unbiased). Value is the quality of an object (for example questionnaires) that satisfies the desire of the respondents (subjects), In a nutshell, the actual value is that which is attested to by the respondents (subject) otherwise the value remains with the object (dormant).

Justification for the axiological position of this study

As established in Chapter 1, hence this study is borne out of the need in developing a methodology beginning from building data capture to the analysis of bioclimatic design initiatives. As an important step to aid in reducing energy demand in office buildings by improving the indoor thermal condition, questionnaires and semi-structured interviews were distributed to the relevant built environment professionals. The responses to both the interviews and questionnaires by the built professionals indicate for instance their level of satisfaction with the objects. In this case, the subjects are the respondents, and the objects are the questions that they are responding to. Such an axiological position is value-laden (biased) as the subject responses reflect the degree of satisfaction with the object qualities (where value is concentrated). Consider some ratings in the questionnaires for instance, where 1 means least significant and 5 means most significant. The rating options from least (1) to most significant (5) are the values the professionals will choose from which they think is most appropriate. Also, as the research is inspired by the researcher's doubts and beliefs, the researcher's values have a long way in directing the path of this study.

This section described and justified the philosophical position of this study. The next layer of the research onion methodological model is the research approach which is discussed in the next section.

4.4. Research Approach

The research approach is the concept of developing new knowledge or the process of enhancing the understanding of a subject. The approaches include.

The Inductive approach involves data collection with no prior developed theory; hence the theory is generated from the analysis of data, and according to Saunders et al. 2009), it is moving from the specific instances to the generic.

The deductive approach allows the development of theory and/or hypothesis deduced from generic principles, while the hypothesis is tested by a designed research strategy. That is to say, it is moving from the generic to specific instances.

Abduction allows data to be used to explore a phenomenon, explain patterns, or identify themes to produce or modify an existing and previously tested theory. This moves back and forth

Justification for this study's research approach

The research approach for this research is abduction as it combines both inductive and deductive approaches. Abduction allows the researcher to make knowledgeable decisions on what, the nature of the evidence gathered and how it is interpreted to answer the research questions. The argument for choosing abduction for this study is that to develop a methodology for data capture, modelling, analysis and evaluation needed to improve the thermal environmental performance of office buildings is that data are used to explore a phenomenon to aid in modifications to achieve research aim. It initially identified generic (bioclimatic design initiatives) and deduced the specific building characteristics required for data capture needed to improve the thermal performance of office buildings. Afterwards, the help of responses (generic) from the built environment professionals generated through the semi-structured interviews and questionnaires informed the decision of choice (specific) of building data-capturing technology. The specific instances, the data captured from case study buildings, helped to develop a virtual model of the case study buildings used for analysis and evaluation through the Design Builder simulation package to produce a methodology that can be generally adopted when improving for thermal performance of buildings which is generic (Inductive). Thus, abduction in this regard helps to explore and explain the process of developing a methodology for building data capture through modelling, analysis and to evaluation adopting previously tested theory, but modified to suit the study context and validated through the analysis and evaluation using a simulation tool as summarised by Figure 4.4

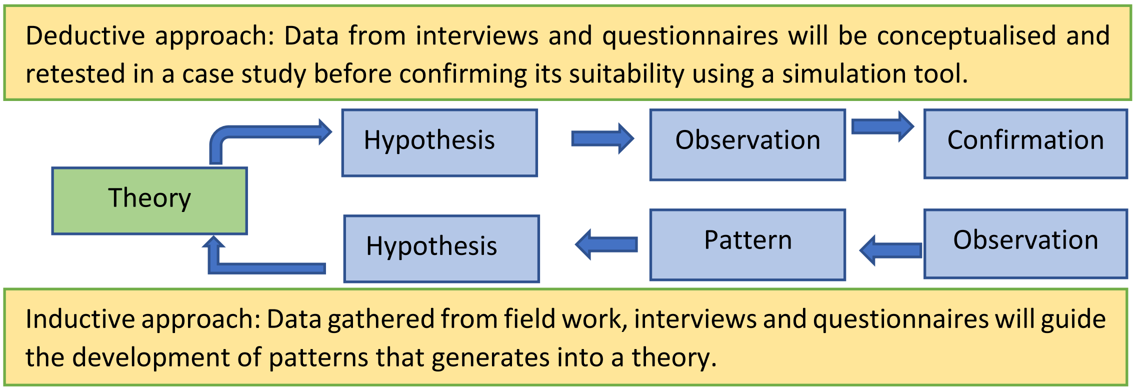


Figure 4.4 Research approach for the study.

This section discussed and justified the choice of research approach used in this study. From the research onion model, following the research approach is the methodological choice. It is important to note at this point that the first two layers (research philosophy and approach to theory development) earlier discussed significantly influence the way to answer the research questions. The research philosophy and approach to theory development in the same manner influence the choice selection for the next three layers of the research onion model and can also be referred to as the research design (Saunders et al. 2016). The research design is how the research questions are turned into a research project to achieve coherence throughout the research design.

4.5. Research Design

As Figure 4.2 shows, two layers, the research philosophies, and the approach to theory development, the first two layers have been carefully considered and peeled away from the model. The research design (methodological choice, time horizon, research strategies) is the general outlook of how to answer research questions and show thoroughly thought-through elements of the research to achieve coherence. The third layer and methodological choice of the research onion model depend on the research questions and informs whether to follow a quantitative, qualitative, or mixed-method research design. The path adopted to attempt the research question/s and the objectives will further dictate the nature of the study. The nature or purpose of the study may be exploratory, descriptive, explanatory, evaluative or a combination of more than one. Firstly, let us consider the methodological choice.

4.5.1. Methodological Choice

The research methodological choice (See Figure 4.5.1A) to be followed can be grouped into two methods (mono and multiple methods). The mono-method requires using a single data collection technique as well as the corresponding data analysis procedure. The multiple methods are the adoption of more than one way of data collection and when more than one (either qualitative or quantitative) method is used and the corresponding data analysis, it is referred to as multi-method. On the other hand, when a researcher adopts more than one method in a research design but in a combination of qualitative and quantitative techniques of data collection and analysis, it is termed a mixed method.

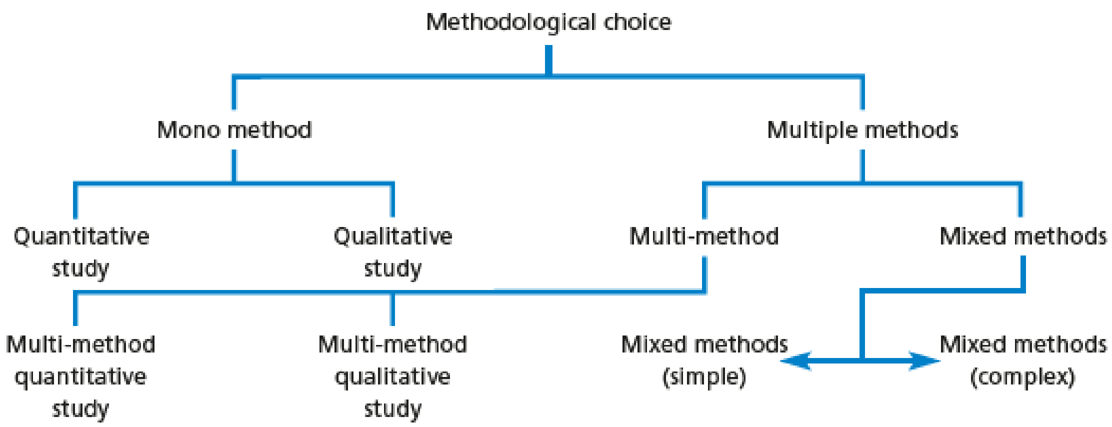


Figure 4.5.1A. Methodological choice (Source: Saunders et.al., 2016)

According to Creswell & Creswell (2018), the simple mixed method could be explanatory sequential, convergent, and exploratory sequential mixed methods. While convergent collects and merges quantitative and qualitative data to analyse a research problem, explanatory builds on the result of previously analysed quantitative data, using more detailed qualitative means. Exploratory is the direct opposite of explanatory which involves moving from the qualitative to the quantitative. See Figure 4.5.1B. The complex mixed methods are either;

- Intersecting a mixed method within qualitative or quantitative research or
- Intersecting a mixed method within another methodology or
- Intersecting a mixed method within a theoretical framework.

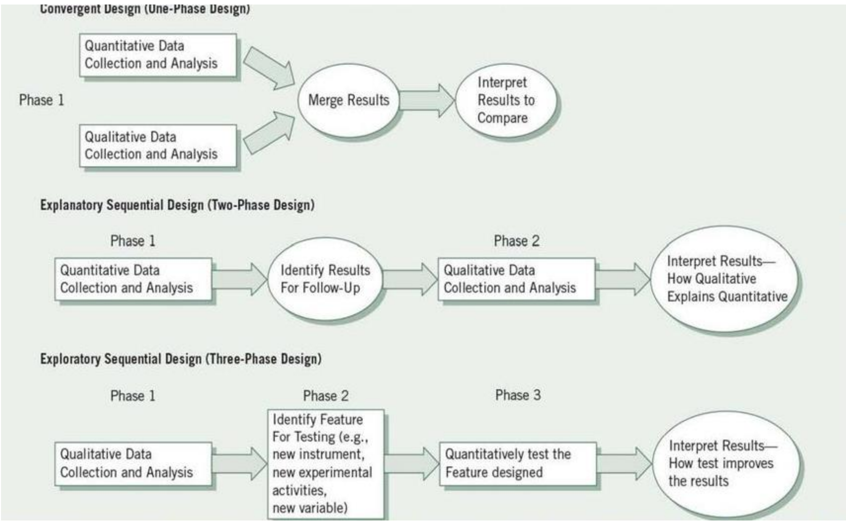


Figure 4.5.1B. The three core (simple) mixed-method design (Source: Creswell & Creswell, 2018)

To better understand methodological choice and to make an informed decision, it is mandatory to understand the finer details of data collection and data analysis research methods earlier mentioned. They are qualitative and quantitative research methods and are discussed in the next paragraph.

Qualitative research methods are dependent on text and data images and require different data analysis steps using various design options. They were developed in the social sciences to study social and cultural phenomena by researchers. It helps researchers to understand the underlying factor for specific attributes by a study of the subjects in their natural form, and their techniques include observation, interviews, opinions, and documents. Analysis of data is descriptive.

Quantitative research analyses its data statistically (numbers) while surveys and experiments are used to collect the data by measuring variables and expressing the relationship between variables in forms including numbers, percentages and means. It usually requires a hypothesis before the study and was developed in the natural sciences for the study of natural phenomena.

Saunders et al. (2016) also suggested a dynamic approach to the research process using double or multiple phases for research design as one phase informs the next phase of the research. Stating further that where a mix of quantitative and qualitative methods are used in every stage of a study, it is described as a fully integrated mixed methods research design, unlike the partially integrated mixed method that uses the same mix of methods at one stage of research.

Recall that the purpose of the study is a key driver of the research design, and this purpose is what the research tends to fulfil through the set-out objectives. To suitably justify the methodological choice, there is a need to understand what the nature of research entails. They are discussed next.

Nature of research

The purpose of a research design is what the research is meant to fulfil. It can be exploratory descriptive, explanatory, and evaluative. The following are brief descriptions adopted from Saunders et al. (2016).

- An exploratory study is about discovering and getting adequate information about a research question or topic of interest. It is essential when issues of clarification or sorting and understanding the precise nature of a phenomenon, problem, or topic. It includes the use of mainly interviewing experts, focus groups and a review of the literature. Adapting this type of research provides the advantage of flexibility such that it might begin with a broad premise and become more focused as the study progresses.
- Descriptive studies could be an extension of an exploratory study or a forerunner of an explanatory study to gain a clear picture of a phenomenon or an event and is mainly a means to an end instead of itself an end. Questions asked in a descriptive study during data collection are targeted at obtaining a description of events, situations, and phenomena. It is mandatory to have a foreknowledge of a phenomenon that you wish to collect data about before the actual data collection.
- Explanatory studies tend to create and explain the relationship between variables. Questions such as why and how are common in order to obtain explanatory responses during data collection.
- Evaluative studies seek to know how well something works and could include comparisons between phenomena with an end product of producing a theory as a contribution with emphasis on how effective and why a phenomenon is in comparison to previous studies.

However, studies can also combine more than one of the fore-listed purposes in their design as "combined studies" especially when using a mixed-methods in the research design. Conversely, the use of a single method can be used so that it leads to more than one purpose. Particular to this study is Table 4.5.1 which outlines the objectives and the justification for the nature of research.

Table 4.5.1. Nature of research

	Objectives	Nature of the research project	Justification
A.	To critically explore relevant bioclimatic design characteristics and their impact on building performance in order to explain retrofit scenarios for building performance improvement.	Exploratory	In Chapter 2, the relevant building characteristics, and their impacts on the performance of buildings (exploratory) were done. These bioclimatic responses of the relevant building characteristics identified are necessary for identifying the required parameters for building data capture and simulation.
B.	To review relevant literature to Identify, assess and compare the different available data-capturing techniques with key aspects of bioclimatic design conditions.	Exploratory and explanatory	Various environmental building performance data-capturing techniques are identified in previous literature (exploratory). The relationship between the bioclimatic design features and the suitability of capturing techniques was carried out in Chapter 3. This objective, therefore, combines an exploratory and explanatory purpose.
C.	To specify the most suitable technology for as-built data capture needed for simulation considering bioclimatic design perspectives.	Exploratory.	To answer objective C, an interview, and questionnaire survey of built environment professionals in the study region are necessary to understand the practice of data capture and building performance enhancement considering bioclimatic design initiatives. Case studies were also adopted to explore the previously identified data-capturing technique,
D.	To critically analyse current practice conditions addressing energy-related challenges of office buildings in Nigeria.	Descriptive and explanatory	To answer objective D, the practice conditions of data capture and building performance improvement as gathered from the multiple sources of data are compared and analysed in a descriptive and explanatory manner considering bioclimatic design initiatives to achieve study goals.
E.	To validate the proposed holistic methodology for as-built data capture to simulation	Evaluative computer-based simulation	Ascertaining the holistic methodology for as-built data capture, modelling analysis, and evaluation using case study buildings and a computer-based simulation program helped to achieve objective E.

From a review of the literature, objective A is fulfilled in chapter 2 while objective B is fulfilled in chapter 3. Objective A is both exploratory; Objective B is exploratory, and explanatory as stated in Table 4.5.1. Objective C is exploratory. Objective D follows a descriptive and explanatory format analysing every process and stage involved in the adoption of a suitable data-capturing technique by the building design professionals in the study area. Ascertaining the suitability of the data capturing, and modelling method developed are evaluated in objective E through simulation and also to validate the capture technology with the created model which is evaluative. Thus, this study combines the exploratory, descriptive, explanatory, and evaluative nature of research in a single study. The nature of research also directs the methodological choice adopted to answer any research question. The justification for this research's methodological choice is discussed next.

Justification for the methodological choice of this study

The set-out objectives and the nature of this study justifies the use of mixed methods. Mixed methods (discussed in section 4.11) involve the use of both qualitative and quantitative methods of data collection and analysis as informed by context, purpose, and nature of research. Objectives A and B for instance review relevant literature to identify and assess different available data-capturing techniques and also examine and identify building characteristics and their impact on building performance to be used in the study context. Objective C goes a step further to explore the building designers' practice towards energy efficiency and data capture using questionnaires. Objective C due to the exploratory and explanatory nature of the research explored the opinions of the built environment professionals deduced from the questionnaire and semi-structured interviews to understand their role in data capturing and retrofitting to be carried out on the field. Field studies involving data capturing by use of photographs, and other forms of physical measurement were also adopted. Thus, the use of more than one method of collecting data makes it a multiple-methods methodological choice as shown in Figure 4.5.1. The use of questionnaires, interviews and physical measurement employs both quantitative and qualitative means, it is referred to as a mixed method approach. The mixed method approach used is also suggested when more than one nature of the study (exploratory, descriptive, explanatory, and evaluative) is used to fulfil the research goal. In addition to the use of a mixed method approach for data collection, the analysis of data is neither solely qualitative nor quantitative as with the simple mixed method. Therefore, as the complex mixed method is adopted for this study, let's define the mixed method as a branch of multiple methods as well as its pros and cons.

4.5.1.1. Mixed Methods

According to Cresswell and Clark (2017), the mixed method involves a combination of at least a qualitative and a quantitative component in a piece of study. This is similar to an earlier definition of mixed method research by Johnson and Onwuegbuzie (2004) as a type of research that mixes both quantitative and qualitative research techniques, approaches, methods, and concepts into a single study. It, therefore, implies that complementary strengths of both quantitative and qualitative research methods can be harnessed depending on the nature of the research. The goal of employing a mixed method is not to replace any of the qualitative or quantitative methods but to reduce the weakness inherent in either of the approaches and to expand the researcher's understanding (Johnson and Onwuegbuzie, 2004). What it means to expand the researcher's understanding is to present the pros and cons of its usage. For instance, if after using a mixed method approach and there are conflicting findings the researcher can make the necessary modifications to the conclusions and interpretation; on the other hand, there is greater confidence in its use compared to the mono-method if the findings present themselves to corroborate both qualitative and quantitative approaches.

Having known about the mixed method, and the methodological choice, it is imperative to also understand the research strategy as this study uses both qualitative and quantitative methods and approaches to achieve the study aim.

4.5.2. Research Strategy

Research strategy, as part of the research design, serves as a roadmap or helps the researcher to plan for achieving results from the research aim (Saunders et al. 2009; Yin, 2009). The two research strategies according to Bryman and Bell (2015) are quantitative and qualitative and the approach to be followed by a researcher depends on the type and purpose of the study and the relevant information available as well as the data analysis. The seven strategies for research are highlighted below:

- Experiment- This is common in laboratory-based research manipulating certain variables (independent variable) while keeping other variables constant (dependent). The dependent is thus used as a control while recordings are taken from comparisons to assess the role of the variable or independent (Saunders et al, 2016; Kothari, 2009).
- Survey- This involves statistical sampling from relevant respondents to answer questions on, what, where, and how much. It describes, records, analyses, and interprets existing conditions to standard ones. The two main types are descriptive and analytical. The questionnaire, interview, literature, measurements, and observations are some of the techniques used in survey research (Yin 2009; Saunders et al. 2016).
- Action research- This requires the active involvement of the researcher throughout the process of the study so as to highlight problems that are of genuine concern to them thereby influencing the manner of the research activity to provide potential answers (Levin, 2003). In this study, the researcher is independent of the study and is not a respondent by participating in giving data (Blichfeldt and Andersen, 2006)
- Ethnography- This involves the researcher observing the behaviour of the participants as they interact with their social world or to capture social reality. It is qualitative (observation) as it aims to understand the reason someone decides in certain circumstances (Ayodele, 2017).
- Grounded theory- This tries to have a grasp of the tradition of an issue and interprets it in a manner so that the need for an experiment is unnecessary. It is initiated with the collection of data mainly through observation and developing a theory from the data to generate predictions requiring testing for its validity (Saunders et al, 2016).
- Archival- This involves data collection from records (some examples include artefacts, maps, and pictures), using objective tools (Yin, 2009; Ayodele, 2017)

- Case study- This is qualitatively analysing a phenomenon through a careful and complete observation which aids in achieving the development of theory and contribution to knowledge. This method requires an in-depth approach fashioned to solve the issues related to how and why (Blichfeldt and Andersen, 2006; Yin 2009).
  Narrative Inquiry- This technique is qualitative; it studies the lives of individuals and derives stories from such individual/s and it is often retold by the researcher.

Justification for the research strategy of this study

The research strategy, as part of the research design, applied for this research, is the case study. A case study is a thorough enquiry into a case subject within its real-life setting (Saunders et al. 2016). Yin (2009, p18; 2017) defines a case study as an "*empirical enquiry that investigates a contemporary phenomenon in depth and within its real-life context; especially when the boundaries between phenomenon and context are not evident*" and secondly as "*an enquiry that copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result; relies on multiple sources of evidence with data needing to converge in a triangulation fashion and as another result; benefits from the prior development of theoretical prepositions to guide data collection and analysis*". An implication that case study is an all-encompassing method that involves "*logic of design, data collection techniques and specific approaches to data analysis.*"

Thus, sourcing information for this research is critical and is crucial to adopting a case study research design for this study. The case study can utilise quantitative or qualitative research and the mixed methods for enquiry, data collection and all research facets not covered by other approaches to get a full understanding of the case (Saunders et al., 2016). Multiple case studies will be used in this study to check if findings can be replicated among cases with the advantage of results comparison over a single case study method.

4.5.2.1. Case study

Further to the justification and definition of the case study strategy in section 4.5.2, which shows that quantitative and qualitative data can be incorporated into a case study method, the researcher does not influence the participant's behaviour. This is necessary in a case study approach because it involves a deep enquiry into a subject that may involve variables of interest. For this study, the thermal condition of office buildings and the factors that influence their performance bother on contemporary issues, not influenced by the researcher and the research questions as a basis for the study's informed decision (Yin, 2009). Consider *Yin* (2009, p18; 2014)'s description of a case study as

"*An all-encompassing method involving logic of design, data collection techniques, and specific approaches to data analysis based on two-fold technical definition*".

The two technical definitions are

- *"A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context; especially when the boundary between the phenomenon and the context are not clearly defined"; and*
- *"A case study involves a unique technical circumstance in which there exist more variables of interest than data points, thus researcher depend on multiple sources of evidence, and benefit from the prior development of theoretical propositions to guide data collection and analysis".*

These are the basis on which this study's research method is hinged. The aim is to answer the research question and to help develop a methodology for building data capture, modelling analysis and evaluation required to improve the environmental and thermal performance of existing office buildings with less energy cost. This is viewed as a holistic case because the thermal performance of the building is considered from impacting factors and contextual variables (holistic perspective) within a system in a real-world setting. Holistic because the thermal environmental condition is a phenomenon that ensures that independent variables were considered with other contextual factors. What this means is that what affects the thermal condition supersedes just internal factors but also contemporary external factors (Thomas, 2016).

Therefore, to achieve the study aim and objectives, the building characteristics required for capturing to aid in improving the quality of the building's thermal environment cannot be separated from the various contextual factors including location and operations. Several contexts inherent in the investigation into the case buildings are beyond the researcher's control unlike in a laboratory with controlled variables (Yin, 2009; Yin 2014). The case study is deemed appropriate based on its combined nature of study including exploratory and evaluative.

The methods used to collect data for the case study method are field studies, review of documents and archives, direct participant observations, and exploration of artefacts and interviews (Yin, 2009; Yin 2014). The case study method has been used in similar studies including that done by Thomson (2016) in a PhD work titled "From Point cloud to Building Information Model: Capturing and processing survey data towards automation for high-quality 3D models to aid a BIM process". Muazu (2015), also used a case study approach to assess the impact of design variables on the consumption of energy in office buildings which is similar to the adopted framework for this study. The framework ensures site selection followed by the selection of particular cases. This approach is also similar to a study carried out by Mafimisebi (2017) titled" A model for reducing energy consumption in existing office buildings".

The case study approach presents the opportunity of exploring the study area in a way that has received less attention. Also, the creation of a case study can demonstrate the workflow from the capture of building data to evaluation before improvement and is seen as viable, cost-effective, timely and with less human input (Bryman and Bell (2015). This study uses a multiple case study method, and the next sub-section is a brief insight into what it entails.

4.5.2.2. Multiple Case Study Methods

To fully appreciate the use of multiple case studies, it is important to define what a case is. According to Bryman and Bell, (2015), most often, the term case study is associated with a geographical location, but it is different from other research designs because it focuses on a bounded system. The emphasis is on the in-depth investigation of a setting, an assertion that, in a case study, the case is the object of particular interest that the researcher aims to investigate.

In place of this research that involves comparative studies both in exploring different as-built data capture technology and evaluating the various building characteristics for the improvement of thermal environmental conditions of office buildings; Thomas (2016) and Yin (2014) have shown that multiple case-study approaches are more effective. Multiple case study approaches using three office buildings are used to examine different as-built data capture technology to develop a methodology suitable in the study context to encourage the improvement of their thermal environmental conditions. According to Yin (2014), the appropriateness of using multiple case-study methods is the advantage of replicating logic through findings conducted in more than one study, hence multiple sources of repeated evidence. Also, it helps to compare and contrast the findings derived from each particular case, pointing to the uniqueness and commonness across cases to enable theoretical reflections of findings. (Bryman and Bell, 2015; Yin, 2014, Thomas, 2016). However, inherent in a multiple case study is the criticism that it is time and resource-consuming, thus the need to scope the study or bound the case. Bryman and Bell (2015) state that the suitability of a case is dependent on how well a researcher deems it fit for purpose to use in the case study design and these are a result of its reliability, replicability, and validity. Similarly, Yin, (2014) states that the theory developments or previous literature can be a guide in defining the case boundary. Herein, this study hinges on the proposition of Yin (2014) and Bryman and Bell (2015) to define the case boundary or case study building selection criteria in line with the research question based on the study literature in the next section.

4.5.2.3. Case selection

The choice of buildings selected to achieve study aims, and objectives and answer the research questions are for precise reasons. The reasons that qualified the buildings are based on building type or usage, location, the HVAC system in place regarding energy consumption and user profile. Other critical factors including time and access were considered. The justifications, some deduced from the literature cited in Chapter 2 (Section 2.9) of this study for the case selection include.

- Access to data could deter any case study research or alter the research questions (Saunders et al. 2016) Thus, only buildings that access were permitted.
- Location is a key determinant of the environmental or thermal condition of any space. The cases selected are from previously determined climatic locations for this study.
- Building type or usage goes a long way in determining the thermal environment of any space. Office buildings are known to consume a significant amount of energy to meet up with a conducive thermal environment.
- The type of heating and ventilation system used is also critical to the choice of the cases. The presence and use of several mechanical means of cooling signify a compromise in the original thermal condition of case buildings.
- The user profile talks much about occupancy, energy usage and even its thermal environment. For good comparison. The user profile for this study was commercial office use only with a specific occupancy time frame. This also ensures that replicability can be achieved because it represents the widely available office typology in the study region.

Benin City, the capital of Edo state, was selected due to reasons already mentioned in chapter one including the fast-paced growth of commercial activities and the rural-urban migration as well as its position as the capital of Edo state. There have been commitments by the state government to redefine the workplace with evidence of current renovations, and proposals for reconstruction including an invitation to tender for existing office buildings in the state. Thus, presenting an opportunity to evaluate the existing building stock. Providing guidelines through successfully simulated exemplars of the improved thermal environmental performance of buildings that promote energy efficiency can only be possible with the capture, modelling, analysis and evaluation of the existing buildings, a void this study aims to fill. Multiple case study helps for comparison, which must be controlled in vital aspects; otherwise, it becomes misleading (Yin, 2009).

4.5.3. Research Time Horizon

The two types of research time horizons are cross-sectional requiring a short time often restrained by time and finance while longitudinal requires a larger time to study to enable the researcher to gain control or have a record of change of the occurrences over time (Saunders et al. 2016).

Justification for the time horizon of this study

This research adopts the cross-sectional time horizon as it does not allow for data to be collected for a longer period say over three years to compare results as in the case of the longitudinal time horizon. As the second year of a PhD is for the collection of data and preparation for the interim evaluation report, therefore the time frame allotted to this can only permit the cross-sectional time horizon.

4.6. Data Collection

The research problem and background determine what method is most suitable for data collection and various methods can be used either individually or together with other(s). This study uses more than one method of data collection as earlier justified in section 4.5.1 thereby employing multiple methods. While using the multiple methods, allows for the use of a mixed method (methodological choice), within a multiple case study strategy in the research. The strategy of inquiry is discussed next.

4.6.1. Strategy of Inquiry

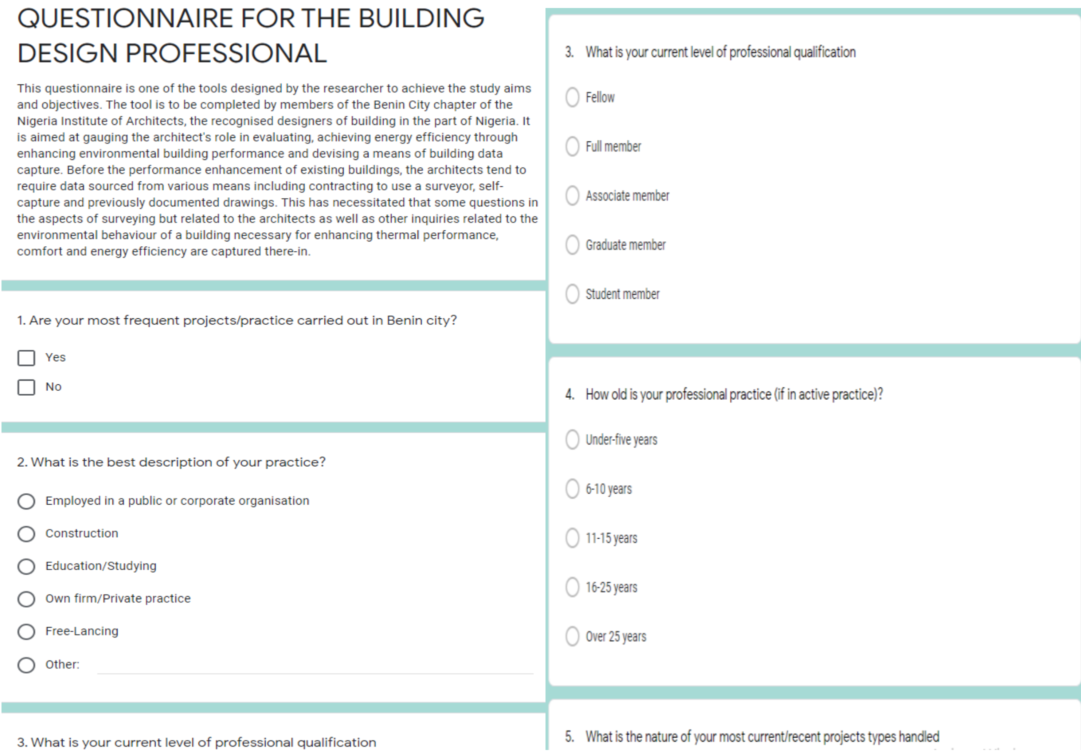
In line with meeting research objectives and with the justified choices made so far following the research methodological model, attempting to answer the research question requires that a specific direction is followed. The strategy of enquiry directs the procedure in research and contributes to its approach (Creswell and Clark, 2018).

The current study adopts a mixed methods strategy within multiple case-study approaches by intercepting mixed methods within a case study. The use of quantitative and qualitative methods is also recognised by Yin (2014).

To answer the research questions, this stage of the enquiry was followed by the development of the questionnaire, semi-structured interview questions and on-site measurements.

- **Questionnaire Survey:** The questionnaire for this study was derived from the literature in Chapters 2 and 3. And questionnaires from other studies were also reviewed to guide the development. To manage time and cost, this study used a questionnaire survey both in hard copy (See Appendix 2) and online copy and distributed them to the members of the Nigeria Institute of Architects. The online questionnaire was sent in the form of a link (https://forms.gle/dqHU38xGPeWFEMUg7) to the official WhatsApp group of the membership body. The questions are designed such that it requires ticking from the provided options with the alternative to add options when and if required (Figure 4.6.5). Hard copies were also presented in person and with the help of a colleague to some accessible professionals. The questionnaire survey was designed in two parts and four sections. The first part of the questionnaire comprises one section and is related to general information questions about the respondent and the practice similar to that used in a previous study by Ayodele (2017). Part two of the questionnaire is made up of three sections on energy efficiency, building design considerations and as-built data capturing technology respectively. Overall, the second part of the questionnaire comprises questions similar to that of Reinhart and Fitz (2006) created by the researcher and targeted towards achieving the aims and objectives of this study. It includes questions on how to capture building data for existing buildings, and methods and tools used in processing captured building data. It also considers post-occupancy evaluation, design features and the primary retrofitting needs that are most important to clients, building types that mainly benefit from retrofitting and improvement, and who are their main clients. It is necessary, to gauge the architect's professional body (main recognised building designers in Nigeria) to understand how they respond to retrofitting jobs, as well as the most considered building design feature that impacts their design.

The design of the questionnaire was done in several stages, ranging from drafting the questions deduced from findings in literature until the final stage. It was repeatedly reviewed and refined by supervisors to ensure its suitability. It was tested and trialled by the researcher and colleagues before putting it to use.



QUESTIONNAIRE FOR THE BUILDING DESIGN PROFESSIONAL

This questionnaire is one of the tools designed by the researcher to achieve the study aims and objectives. The tool is to be completed by members of the Benin City chapter of the Nigeria Institute of Architects, the recognised designers of building in the part of Nigeria. It is aimed at gauging the architect's role in evaluating, achieving energy efficiency through enhancing environmental building performance and devising a means of building data capture. Before the performance enhancement of existing buildings, the architects tend to require data sourced from various means including contracting to use a surveyor, self-capture and previously documented drawings. This has necessitated that some questions in the aspects of surveying but related to the architects as well as other inquiries related to the environmental behaviour of a building necessary for enhancing thermal performance, comfort and energy efficiency are captured there-in.

1. Are your most frequent projects/practice carried out in Benin city?

- Yes
- No

2. What is the best description of your practice?

- Employed in a public or corporate organisation
- Construction
- Education/Studying
- Own firm/Private practice
- Free-Lancing
- Other:

3. What is your current level of professional qualification

3. What is your current level of professional qualification

- Fellow
- Full member
- Associate member
- Graduate member
- Student member

4. How old is your professional practice (if in active practice)?

- Under-five years
- 6-10 years
- 11-15 years
- 16-25 years
- Over 25 years

5. What is the nature of your most current/recent projects types handled

Figure 4.6.1A. Excerpt from the online survey questionnaire form

- **Semi-Structured Interview**: Another strategy of inquiry, the semi-structured interview is deemed appropriate for use in this research to get details and explore the context of building data capture and processing from the members of the Nigeria Institute of Building. A semi-structured interview allows respondents to express the topic in their own opinion which will further enrich the researcher. It ensures that fundamental questions are open-ended; there is no uniform behaviour for every interview; the relationship between the participant and the researcher is also not strictly scripted (Yin, 2011). The semi-structured interview is beneficial to guide the respondent's focus as implied by Saunders et al. (2016), especially since building surveying is an area of fast technological advancement. A lot of computer-based tool and simulation has also helped to make producing captured data appear easier dependent on need. Therefore, the questions of the interview are those deduced from the literature and significant to achieving the study's aims and objectives. Some relevant questions used in the study by Reinhart and Fitz (2006) were extremely useful in shaping some of the interview questions.

- **On-Site Measurement**: Fieldwork and in-situ measurements and capture of building data, including characteristics and specifications, are also needed and form part of the strategy of inquiry for this study. Objective capture of building characteristics to get the as-is building information that can be used for modelling for further improvements where necessary. Due to the need to create more economic and efficient data-capturing techniques, a mobile phone (Figure 4.6.1D) as a photographic device was used to capture the as-it-is representation that would be used to generate models through the captured images. The use of a measuring tape (Figure 4.6.1C) to take the necessary dimensions as well as the use of temperature and relative humidity data logger (Figure 4.6.1B) for objective thermal measurement.

Figure 4.6.1B. Temperature and humidity data logger

Figure 4.6.1C. Measuring Tape (Source: Flipkart.com). Figure 4.6.1D Mobile Phone (Source: Primerunner.com)

As part of the fieldwork and to complement the objective thermal measurement, a few data inventory forms that record the building characteristics previously identified in the study (chapter 2), as well as the building's energy consumption data, were filled by the researcher in conjunction with the occupants of the case study buildings. A similar building inventory form has been used in previous PhDs by Muazu (2015) and Saridar (2004) but designed to meet the aim and objectives of their studies. However, the building inventory form for this study is tailored towards occupant behaviour and thermal condition, an aspect critical to the focus of this research. The form is designed to collect the building design variables for bioclimatic building responses identified in Section 2.8. that are needed to create options for improvement in designing and planning a thermally conducive workplace. Multiple sources of evidence are more compelling and robust (Yin, 2014). An accompanying questionnaire section of the form is shared in two parts -- part one is to obtain the general information of the occupants; part two involves the subjective perception of the occupants towards their thermal comfort. These questions have been found relevant for determining occupants' thermal comfort in several studies (such as Nicol et al. 2012) and thermal comfort surveys including those in the studies by Nasrollahi (2007) and Efoema (2016), that assisted in the design of that adopted for this research. It is useful when considered during the building evaluation stage. The strategy of inquiry is summarised in Figure 4.6.1E

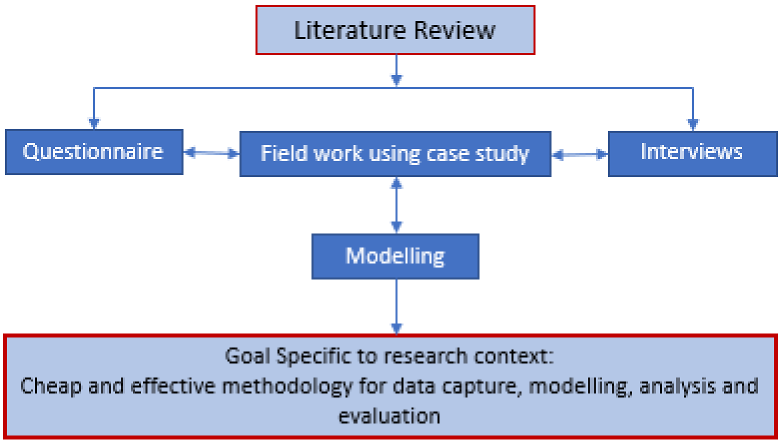


Figure 4.6.1E. Strategy of Inquiry.

The next section discusses briefly on sampling, that is how participants (both buildings and respondents) were recruited.

4.6.2. Sampling

Saunders et al (2016) state that two types of sampling techniques are available, and they are probability or representative sampling and non-probability sampling. In probability sampling, the tendency of cases being selected from a target population and usually equal for all cases is familiar. Non-probability sampling does not allow the tendency of case selection from a known target population and thus, even if generalisations can be made from non-probability sampling about the target population, this will be without defined statistical evidence. As this research aims to develop a methodology for data capture, modelling analysis and evaluation to encourage the improvement of the thermal environmental performance of existing office buildings employing bioclimatic means, the study and target population are known. (Probability or representative sampling). Note also that the target population to source information from and to apply the methodology for data capture and modelling to encourage the improvement of existing office buildings and data capture are identified and they are among the built environment professionals concerned with building designs and surveying. Three buildings dependent on accessibility and time were considered from Benin City, the study region. This strategy serves as the samples' benchmark from the population as the existing office building stock makes up the study population (Bryman and Bell, 2016).

The sample frame in the case of probability sampling as with this research piece is a list from the identified population where the sample is to be selected. The sample frame in this study includes the users of the case study buildings and the professional body of the built environment professionals concerned with designing, surveying, and retrofitting buildings as participants from the population that could be accessed. This will curb unit non-response error owing to web surveys and difficulty in getting potential respondents among other limitations. Thus, probability sampling using random sampling techniques as well as purposive and snowballing as non-probability sampling is used to collect data.

Purposive sampling and snowball sampling ensure that interviewees are registered with the professional body, highly placed in an organisation or practice and with over five years of experience. Snowballing was useful as every interviewee recommended the next suitable participant to be interviewed. The sample size for this study is dependent on time, cost, and size for both the interviews and in-situ surveys.

4.6.3. Sample size

The sample size for the selection of case buildings is dependent on time, cost, absolute size, and type of analysis. Although the sampling is based on the case study selection procedure, the issue of absolute sampling within case buildings reflected over 80% of samples within the sample size (Bryman and Bell, 2016).

The questionnaire survey was hinged on the size of the target population which are the non-student and affiliate building design professionals registered with the Nigerian Institute of Architects contained in their official WhatsApp group. A higher response rate was needed to ensure that the response is representative to guide against error. The higher the response rate, the lower the margin of error (Saunders et al. 2016).

The sample size of the interviews factored in the confidence the data tends to give and the type of analysis. The interview in this study supports the questionnaire survey. Also, the response from the interviews conducted appeared to be replicating itself, nearing saturation as representative of the sample size (Saunders et al. 2016). While case-study buildings constitute representative samples of the common office typology in the study area where findings on energy consumption and analysis are similar to others for generalisation purposes.

English was used throughout both the interviews and in the questionnaire design as it was the major means of communication. However, the local language in the study area was used informally to introduce the research during participant recruitment, this was advantageous to achieving a higher response rate and getting access to case buildings.

4.6.4. Reliability and validity.

This study utilised a combination of the respective traditional quality measure of results for each of the methods (qualitative and quantitative) to assess the quality of inferences drawn for the adopted mixed methods (Clark and Vicki, 2016). Validity according to Clark and Vicki, (2016, p166) is "*the degree to which inferences can be accurately made based on a test score or other measures; and reliability is the accuracy of a measurement procedure to produce the same score*". To avoid misrepresentation and errors, this study considered these quality measures.

The use of questionnaires administered to the building design professionals ensured the neutrality and reliability of the quantitative data collected. The respondents had the freedom to answer the questions in the questionnaire without undue influence while the answers provided to the questions followed a similar and consistent pattern, a principle referred to as the half-split by Denscombe, 2014). For qualitative data involving the use of semi-structured interviews where data were audio recorded and transcribed, the validity and reliability were ensured through previously established criteria. During the conduct of the semi-structured interview follow-up questions, examples and the use of local dialects helped to avoid ambiguity while audio recordings were listened to repeatedly, taking account of the tone and body language to give a comprehensive transcript. It helped to avoid the possibility of false reporting, while the conclusions drawn from the transcribed data were reviewed by academics (supervisors), enhancing accuracy, internal validity and attaching credibility to the study (Yin, 2009).

A detailed description of the processes from the data collection to the conclusions was made for replication, enquiries and referencing to enhance the quality and reliability (Clark and Vicki, 2016). Information about case studies can help to inform readers on how it applies given other circumstances while findings from varying findings were explained rather than neglected to exonerate the researcher from bias (Denscombe, 2014). Also, the research questions and hypothesis were used to validate the appropriateness of the study datasets to meet research objectives as a form of content validity (Denscombe, 2014).

4.7. Data Analysis

Data analysis is conducting a logical or statistical analysis in a systematic process to explain, present, describe and evaluate information. It is used to either generalise or distinguish findings (Saini, 2020). The two methods of analysing data are quantitative and qualitative, each with unique properties in the search for knowledge. They are discussed next.

4.7.1. Qualitative Data Analysis

Qualitative data are more complex than quantitative data because of their characteristics richness and fullness due to their tendency to explore a subject in a manner as real as possible. It is a method that is widely used for the search for knowledge, distinct with an enquiry into the quality of data rather than quantity (Saini, 2020). Images and words, the most common forms of qualitative data are expressions, non-standardised and conceptualised require great care to explore, analyse and transform so as to address research objectives. Therefore, analysing qualitative data will involve condensing, coding, and categorising according to themes that will serve as a link that creates a structure in response to the research question (Saunders et al. 2016). The qualitative data used in this research is the semi-structured interview of the building professionals involved in building surveying and this is to source the knowledge on the processes and methods used to get existing building information.

4.7.1.1. Semi-structured Interview

Due to the nature of the enquiry, semi-structured interviews of the built environment professionals in this study generates audio-recorded qualitative data which must be transcribed or produced as it is, in a word-processed format considering the manner the interviewee said it and body language as well (Bryman and Bell, 2016). Every response from persons interviewed is saved separately on a word-processed file. This research adopts the thematic analysis to analyse the responses. Thematic analysis is a generic approach to analysing quantitative data as it searches for themes that are consistent within a data set, and responses from the series of interviews as is in the case of this study (Saunders et al, 2016). It, therefore, leads to the premise for a theoretical understanding of data to make theoretical contributions to the study. (Bryman and Bell, 2016). Coding of the responses is done manually because the number of interviews is not much, hence the interview was designed to support or complement the questionnaire survey. It is necessary to thematically code the responses so that the relevant information that supports this study's research questions is categorised under separate themes to help find connections between content and emerging themes for informed decision-making (Saini, 2020).

4.7.2. Quantitative Data Analysis

Quantitative data conveys little meaning until they are processed or analysed to turn them into useful information which can be done by qualitative analysis techniques such as tables, graphs and statistics (Bryman and Bell, 2016). Qualitative analysis techniques therefore within the data explore, present, describe and examine its trends and relationships. The quantitative data to be used in this study involves a collation, coding and computing of data collected from onsite measurements including thermal comfort measurements and questionnaires. The questionnaire gauging the architects' response to achieving a better quality of the thermal environment towards energy efficiency and retrofitting is compiled and coded into different Excel spreadsheets and then converted into Statistical Package for the Social Sciences (SPSS) file after eliminating data errors. The final information is analysed using descriptive statistical analysis. SPSS is a set of software programs widely used for statistical analysis of data and even complex data manipulation with minimum possibility of errors occurring while also presenting findings in various forms including charts and descriptive formats.

4.7.2.1. Descriptive Statistical Analysis

Descriptive statistical analysis is used to collect, analyse, describe, and summarise a set of known variables. This research applied the data collected from questionnaires and thermal measurements and applied the results as a threshold for the exploration of building data capture to encourage building design improvements using computer-based building performance simulation.

4.7.2.2. Modelling

To fulfil objective C, the use of a modelling package to recreate the digital representation of data captured on-site through tape measure and photographs is necessary. To fulfil the study, the aim of providing a cost-effective model, Revit was adopted, Meshroom was initially trialled to model the case study buildings given its advantages while Autodesk ReCap Pro and PolyCam presented to be more viable at the latter.

- Revit is an Autodesk building information modelling software package that unifies all architecture, engineering, and construction into a single modelling environment to drive efficiency and accuracy from the conception stages of design, visualization and analysis (Autodesk, 2021). Revit is increasingly used in the study region for modelling.
- Meshroom for photogrammetry is a free open-source three-dimensional (3D) reconstruction software based on AliceVision Framework. The AliceVision photogrammetric framework provides 3D reconstruction and camera algorithms and comes up with a strong software basis that can be tested, analysed, and reused (Meshroom Manual, 2021). Figure 4.7.2.2 shows what the meshroom workflow looks like.

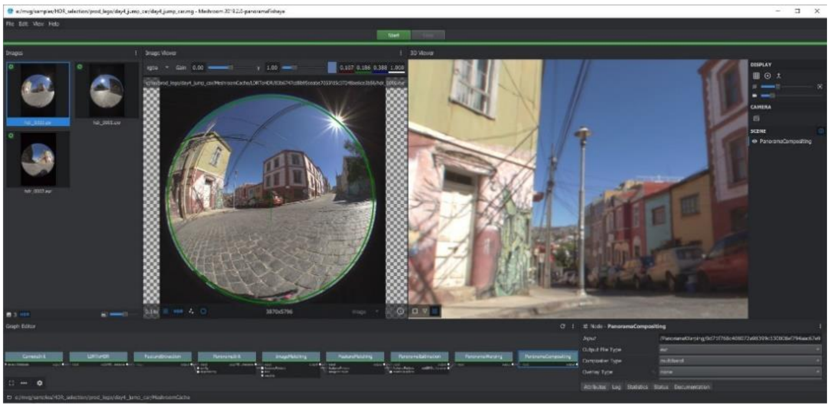


Figure 4.7.2.2 The Meshroom Workflow (Source Alicevision.org)

- Autodesk ReCap Pro, according to the Autodesk website (2022) is used by building designers and engineers to capture real-world scenes in high quality to understand and verify the conditions of the existing or as-built building. It is suitable for the survey, planning, construction, and renovation of buildings with the advantage of delivering a point cloud mesh for BIM purposes.
- PolyCam is extensively discussed in Chapter 7 and it is a 3D scanning app for mobile devices including IOS, web and Android (Polycam, 2022)

4.7.2.3. Computer-Based Simulation

To fulfil objective E, computer-based simulation as a predictive strategy is necessary to enable replication and validation of case study typology and evaluate and analyse the performance of fieldwork data through building modelling and simulation. Whereas the growing complexity in the built environment and the increasing concern for building performance have broadened the traditional architectural modelling pattern (Yezioro et al. 2008). Building modelling consists of the traditional model and other aspects including energy consumption, thermal, lighting, and environmental performance. Lamberts and Henson (2012) described this as computational modelling (representing a real system at a designated conceptual level of generalization by a computer-based generation) and simulation (making or putting a model into the practice of predicting future actions or exhibiting future characteristics of a real system). Thus, simulation is important in comparing the energy implications of various building design variables as a step towards improving energy.

Simulation involves generating data that could also be used to predict or suggest replications of a real-world context that contains dynamic interactions that result from manipulated factors (Loonen et al. 2019; Abdulkareem, 2016). Although some level of expertise is required throughout the simulation process, it remains inexpensive and the most advanced way of testing, monitoring, and evaluating the results of different retrofit interventions.

4.7.2.4. Building Performance Simulation Tool

Building performance simulation tool is important in predicting and analysing the energy savings or enhancing the environmental performance of buildings by testing different retrofit or architectural design solutions (Lamberts and Henson, 2012; Daly et al, 2018; Yezioro et al., 2008; Hien et al, 2000). The use of inaccurate simulation assumption is critical to the well-documented actual and predicted performance gap, due to limited access to detailed data on building construction and operation characteristics available to the users of the building performance simulation tools (Daly et al, 2018). This has resulted in practitioners relying on what they deemed best fit or assumptions or default values relating to the occupant's behaviour and hard-to-measure characteristics of the building that are needed inputs to the building performance simulation programs (Daly et al, 2018; Cuerda et al. 2020).

According to Yezioro et al. (2008), the simulation tool's accuracy, reliability, and available building information (input data) determine what type is suitable for a given project, especially with the variety of simulation tools available in recent times. Also, the confidence of users of the simulation tool depends on the understanding of the tool, its merits, and demerits even as a considerable amount of time is consumed before arriving at reliable results. Lamberts and Henson (2012) state that answers are not automatically generated from building performance simulation as its essence is to enhance understanding rather. Several theories from various disciplines (including environmental, material, computational, and human behavioural sciences) determine its complexity and potentiality. The idea of the rapidly maturing and evolving simulation can be described by a system of interactions between occupants, equipment (including actuators and sensors), the outdoor environment, the HVAC system and the building as shown in Figure 4.7.2.4.

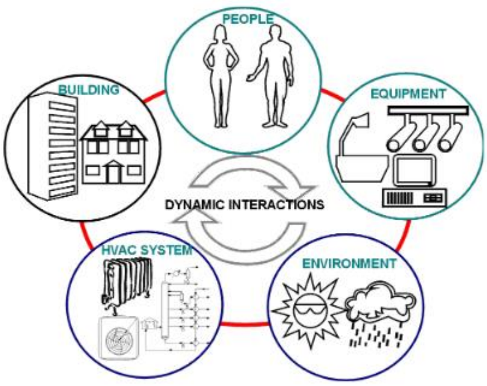


Figure 4.7.2.4. The changing interacting subsystems in buildings (Source: Henson 2004)

According to Attia (2010), the plethora of choices of building performance simulation tools has created the challenge of selecting appropriate tools in the building design as such tools now available in the United States Department of Energy (DOE) Building Energy Software Tools Directory (BESTD) website have risen significantly. Attia (2010)'s study is a result of the lack of independent evaluation and classification of the use and function of the tools, identifying five criteria for tool selection. See Figure 4.7.2.5,

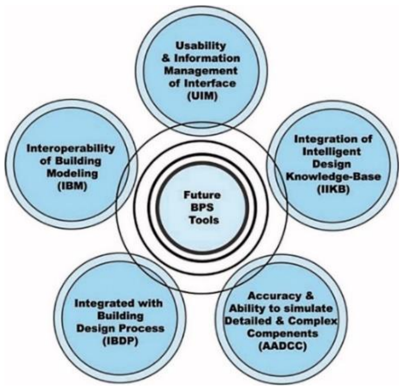


Figure 4.7.2.5. The five simulation tool selection criteria (Attia, 2010),

From Figure 4.7.2.5, Maile et al. (2007) state that the user interface is very critical to input generation and output analysis yet, such an interface does not make simulation possible for everyone. Thus, emphasizing the need for prior knowledge of the use of the program and the subject matter for the development of the tool (CIBSE, 2015). Also, depending on the need, users (mostly architects) consider certain aspects of the criteria as more or less important. However, the goal of using the simulation tool is to idealise reality with a model, although the models will not perform in the same way as the actual building, it is however the most advanced way available for use within an acceptable range of uncertainty. This buttresses the idea of quality assurance that ensures that work undertaken is of high standards by addressing clients' needs and accurate models (CIBSE, 2015).

With the various simulation tools available this research will use the DesignBuilder due to its easy-to-use graphical user interface, its low expertise requirement, and Hand-drawn geometric and extensive template data. Data can also be imported from 3D BIM & 2D floor plans. DesignBuilder is an EnergyPlus simulation engine that runs simulations of models using real hourly weather data, models lighting control systems, gives an extensive range of comfort output including the adaptive comfort metrics, calculate for heat transmission through the building envelope, can be used to model for natural ventilation, can be used to test daylighting, glazing and shading systems (Design Builder 2019).

4.8. Ethical Consideration

This study sought ethical approval from the University of Salford through an online application with guidance and approval from the supervisory team. In line with the university's ethical policy, the participant's well-being was considered and also it ensured the parties are protected from harm and risks. The research started by formally issuing participants with information relating to the purpose of the project, choice of voluntary participation, study procedure, use of collected data, confidentiality and anonymity and consent form.

Information given by participants was treated confidentially and without compromise with the option for them to opt out. The study data collection tool was designed to not reveal or collect the details of participants. The information gathered from the participants will be stored for the study duration and will only be used for no other purpose other than the PhD study and other academic publications.

4.9. Summary

This chapter on research methodology adopted the research onion methodological model. It justified the use of the research methodological model and progressed to discuss and justify its position on the different layers of the model. This chapter discussed the research philosophies, approaches, strategies, methodological choice, time horizons and data and analysis techniques. It further described the strategy of enquiry and sampling. Thus, employing the mixed methods research, the researchers conducted a review of literature, semi-structured interview, and questionnaire survey of practices of environmental performance by the built environment professionals of the study region to support the first and second objectives of identifying and accessing different suitable environmental data capturing techniques. The third objective is achieved by exploring different data capturing techniques on multiple case study office buildings selected based on access, type of building and HVAC. Achieving the fourth objective is through the analysis and evaluation of the result of the previous objectives. The holistic research process workflow is shown in Figure 4.9 and further discussed in Chapter 7 while issues of ethical consideration were also discussed. The next chapters provide information on findings from the different strategies of enquiry adopted by this research to achieve the research aim.

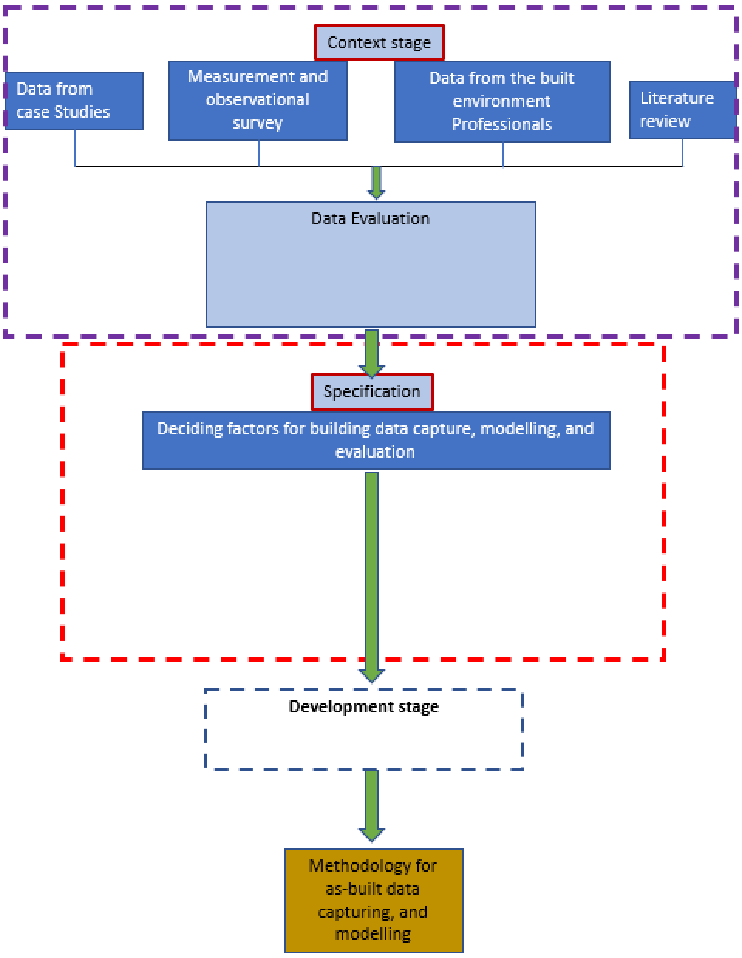


Figure 4.8. Chart showing the research process leading to the development of the methodology from as-built data capture to evaluation.

CHAPTER 5

QUESTIONNAIRE DATA REVIEW AND ANALYSIS

5.1. Introduction

This chapter presents the findings of a questionnaire survey done as part of this study and can also be referred to as "A survey of building designers' perception of environmental building performance and building data capture". It begins by presenting an overview of the questionnaire as one of this study's data collection tools, how they were conducted and briefly describes the processing and analysis of the questionnaire data before presenting findings from the responses. The findings from the survey are analysed according to the four sections of the questionnaire design followed by the conclusion.

5.2. Overview of the Questionnaire

As stated in Chapter 4, the questionnaire is one of this study's data collection tools. The questions contained in the questionnaire are those relevant to achieving study aims deduced from the literature in Chapters 2 and 3 of this research piece. The questions were developed and guided by a review of questionnaires from other relevant studies, criticised, reviewed and refined by supervisors and trialled among colleagues to ensure their appropriateness and suitability to achieve the research aim and objectives before their use.

The questionnaire (Appendix 2) consists of two parts and four sections. The first part contains section one which is the demographics of the building design professionals and has questions from with questions numbered 1-6. The demographics attempt to understand if most of their projects are carried out in Benin City and the study region, the best description of their practice, their level of professional qualification, their years of practice, the nature of their most recent projects and the contract type frequently undertaken.

Part two consists of three sections (7-20) concerned with energy efficiency, building design considerations and as-built data-capturing technology. Section two comprises questions 7-9 which are questions created by the researcher targeted towards gauging the architect's understanding and level of significance of issues of energy efficiency when considered in their project and how they are addressed. It asks questions on how the building design professionals describe energy efficiency in their project, how energy efficiency is addressed and the level of significance of how the environmental behaviour and design of buildings impact energy efficiency. Section 3 numbered 10-15 design considerations that relate to the environmental behaviour of buildings including the design conception and post-occupancy evaluation. Questions that inform the building design professional's decision-making including building envelope configuration, end-user-related considerations and compliance considerations during building design and their significance on environmental behaviour and occupant's thermal comfort as it relates to energy efficiency are contained in this section. Questions on how often and how the professionals regularly get feedback on a completed project to understand the design's environmental behaviour and occupant's thermal comfort about the building's energy efficiency are also contained in section 3. The reasons stated by the clients for retrofitting, where and how the building-related data are derived as well as the order of importance and factors considered before engaging a building surveyor are the final questions of section 3.

Section 4 ranges from numbers 16-20 of the questionnaire focusing on factors of as-built data capturing and processing technology. Questions asked in section 4 are to help to identify the data-capturing technique that the professionals are familiar with, the measure of the significance of the factors influencing the adoption of the chosen techniques and the factors that would make them consider other capturing techniques. The significance of the factors impacting data processing during the data capturing process, the manner of processing and validation of as-built data and the computer software used to process the captured building information both for modelling and for simulation are also contained therein.

5.3. The survey processes.

Ethical approval was granted on the 11th of November 2020 from the University of Salford to ensure the security and well-being of participants as well as protection from any form of risks or harm. Due to the impact of Covid-19 leading to travel restrictions, and to further manage time and cost, the questionnaires were made into hard copies and in a digital link format for online transmission. Other documents presented with the questionnaires are the participant information sheet and the consent letter detailing the responsibilities of the participants, their contribution, how the information they provide is used and contacts in case of any query. Recruiting the participants was initially done with the help of third parties and in the form of a link sent to the official WhatsApp group of the Edo State Chapter of the Nigeria Institute of Architects (NIA) by first providing them with the participant information sheet and the consent letter before providing the questionnaires. While the hard copies were often immediately attended to when handed to participants with the help of a third party, weekly reminders were sent by the researcher to the official WhatsApp group of the NIA. Further hard copies were also directly presented to members of the NIA by the researcher when travel restrictions eased. Sending reminders continued both in person and on the WhatsApp group until the responses to the questionnaires closed on the 7th of May 2021 ready for analysis.

5.4. Analysis of the questionnaire data.

After closing the questionnaire survey, the responses were received both in hard copies and in the online format as Comma Separated Values (.csv) files as plain text easy to import into a spreadsheet. The responses in the CSV format were converted into a Microsoft Excel spreadsheet and collated together with responses from the hard copies. The total responses were entered into a single Excel spreadsheet. The data was prepared, coded, and cleaned (eliminating data errors) for further exploration and descriptive analysis using the Statistical Package for the Social Sciences (SPSS).

The survey and the analyses were based on the building designers' perception of the environmental building performance and building data capture of existing buildings starting with the demographics. To satisfactorily meet the study's aim and objectives, descriptive statistics of simple frequency distribution, percentages, charts, mean value scores and significant level analysis were employed. Frequency and percentages are used to analyse the demographics and a few other questions. Some other questions designed in the form of a Likert scale to help quantify the subjective thoughts of the survey respondents are analysed with the significant level analysis. The Likert scale used options such as "very significant/very often" to "least significant/never" such that the options were allotted a score from 5 (very significant) to 1(least significant). The value of a mean greater than or equal to 3 (≥3) indicated that the respondents' perception of the variable is significant, while those less than 3(<3) suggest that the perception is less significant (Adeyemi et al. 2017, Adetooto et al. 2020) The mean was used to determine the levels of variation in the professionals' perception of building performance improvement and reasons for the selection of certain data capturing technologies to be buttressed by a complementing interview of the professionals involved in building surveying.

5.5. Demographics

The first 6 questions of the questionnaire are the demographics. A total number of 133 respondents (n=133) participated in the study and they have all either carried out or are actively undertaking the practice of building design or construction in Benin City. Although they have all undertaken or are carrying out projects in the city, some do most of their projects outside the city. Table 5.5.1 presents the participants' information on the frequency of jobs carried out in the study region.

Table 5.5.1. Where respondents' projects are mostly carried out.

Respondents practice within Benin City	Frequency	Percentage (%)
Most of the jobs carried out within Benin City	125	94.0
Most of the jobs carried out outside Benin City	8	6.0
Total	**133**	**100.0**

Of the 133 survey respondents, 125(94%) of them carry out most of their jobs in Benin City while the other 8 (6%) persons carry out most of their projects outside the city. All the respondents, although many do practice in more than one form, expressed what they do most as the best description of their practices which is shown in Table 5.5.2.

Table 5.5.2. The best description of the respondent's practice

Nature and best description of Practice	Frequency	Percentage (%)
Employed in a public or corporate organisation	19	14.3
Construction	38	28.6
Own firm/Private practice	47	35.3
Free-Lancing	29	21.8
Total	**133**	**100.0**

Table 5.5.2 shows that of the total number of respondents, 19(14.2%) persons are employed in a public or corporate organisation, 38(28%) people are more into construction, 47(35.3%) respondents own a private practice or firm while the remaining 29(21.8%) of the building designer professionals are involved in freelancing. Meanwhile from the total, the highest representative number of the building designers are associate members with about 58(43.6%) persons followed by full members with a representative 39(29.3%) people. The numbers of fellow are 4(3.0%) while the numbers of graduate member are 32(24.1%) as shown in Table 5.5.3.

Table 5.5.3. Respondents' professional qualification

Professional qualification	Frequency	Percentage (%)
Fellow	4	3.0
Full Member	39	29.3
Associate Member	58	43.6
Graduate Member	32	24.1
Total	**133**	**100.0**

The requirements for professional qualification of the building designers presented in Table 5.5.3 are stated in the NIA portal (https://www.nia.ng/membership-requirement/), and the official website of the Architects Registration Council of Nigeria (ARCON) (https://arconigeria.org.ng/old/registration-requirements). The requirements to qualify as a graduate member of the institution are that the candidate must have a degree or diploma awarded after a minimum of 5 years of full-time study from any Nigeria University or Polytechnic approved by the council; any Commonwealth of Architects recognised schools and any foreign schools which have produced accepted Nigerian architects or other qualifications that may be approved from time to time by the council. Associate members, full members and fellows are those with higher professional qualifications than the graduate members after securing a master's degree or its equivalent, having the desired number of years of active practice and contribution to architectural practices respectively. student members were not considered in this study because they are still in the process of gaining the required training involved in the design and construction of buildings as contained in the National Building Code (2006).

As presented in Table 5.5.4, a significant number of the survey respondents have more than 5 years of experience. Of all the 133 building design professionals, a total number of 22(16.5%) respondents have been practising for less than 5 years while 61(45.9%) of the building designers have over 5 years of practising experience but not more than 10 years. 32(24.1%) of the professionals have been practising between 11-15 years and 12(9.0%) of the respondents have been practising between 16-25 years with the remaining 6(4.5%) of the professionals having over 25 years of practising experience.

Table 5.5.4. Years of Professional Practice.

Years of practice	**Frequency**	**Percentage (%)**
Under-five years	22	16.5
6-10 years	61	45.9
11-15 years	32	24.1
16-25 years	12	9.0
Over 25 years	6	4.5
Total	**133**	**100.0**

As shown in Table 5.5.5, of the total 133 survey participants, 3(2.3%) of the respondents did not indicate what their most frequently handled projects are whereas, a total of 65(48.9%) persons are mostly involved in carrying out new construction works while 54(40.6%) of the respondents are mainly involved in carrying out both new construction and retrofits. The other 11(8.3%) design professionals have most of their projects as renovation works.

Table 5.5.5. Most frequent project type handled by respondents.

Most project types handled	**Frequency**	**Percentage (%)**
New Construction	65	48.9
Renovation/Refurbishment/Retrofit	11	8.3
Both A and B	54	40.6
Unspecified	3	2.3
Total	**133**	**100**

Of the total 133 survey respondents (See Table 5.5.6), a total of 101(75.9%) of them are frequently involved in the design and build contract, 11(8.3%) people are mostly involved in conventional contracts, 15(11.3%) mostly carry out construction management contracts only while turnkey contracts are frequently carried out by 6(4.5%) people of the total numbers.

Table 5.5.6. Most frequent contract type handled by respondents.

Contract type	Frequency	Percentage (%)
Design only	0	0.0
Design and build	101	75.9
Traditional/conventional	11	8.3
Construction management only	15	11.3
Turnkey	6	4.5
Total	**133**	**100**

5.5.1. Deductions from the Demographics

Part 1 and section 1 of the survey questionnaire comprise questions relating to the demographics of the respondents, the information on the demographics of the survey respondents is needed to,

- Determine if the participants are the representative targets needed for the survey.
- Understand the reasons for their choices and decisions as well as identify the patterns or trends from the information gathered.
- Ascertain if a conclusion can be generalised or grouped into categories from the information gathered.

From the information gathered through this study's questionnaire survey, it can be concluded that.

- A significant 94% of the building design professionals frequently carry out their practice in the study region. This implies that the information gathered presents the true nature and practice of the design and construction of buildings in Benin City.
- All 133 survey respondents are in one way, or another involved in the design and construction of buildings either in the form of private practice, construction, freelancing or employed in an organisation.
- The conduct of the survey was guided to ensure that only those with adequate knowledge of the practice of design and construction who have a minimum of a B.Sc. in architecture or its equivalent ARCON requirement participated. Over 75% of the respondents have at least a master's or ARCON requirement. From the information, and with the level of education of most of the respondents, one can conclude that there is a proper knowledge of architectural practices by the survey respondents in Benin City.
- A great number (83.5%) of the survey respondents have over 5 years of experience in the practice of building design and construction in Benin City. it means that the information gathered can be assumed to be a representative picture of what is obtainable in practice in the study region.

- Only 11(8.3%) of the survey respondents are frequently involved in retrofitting or refurbishment practices. The greatest number 65(48.9%) of respondents are involved in new construction while 54(40.6%) participants agreed to frequently carry out both new construction and renovation works. 3 people did not specify their nature of frequent jobs. The information shows that there is a lesser concentration of retrofitting jobs by the respondents. Several reasons including less availability of retrofitting projects may have led to it. However, that less frequent retrofitting is carried out by the survey respondents does not mean such jobs are not carried out because a significant (54%) of the professionals agreed to frequently carry out both renovation and new construction work. The role of project types frequently handled by the survey respondents helps to throw more light on the project types handled (See Figure 5.5.1).
- According to the contract type regularly handled by the survey respondents, Design and build are the greatest with 101(75.9%) persons while traditional and turnkey are 11(8.3%) and 6(4.5%) people respectively. It implies that all are involved in design except for those involved in construction management with only 15(11.3%) persons.

From the last two deductions stated above, it can be adjudged to align with the assertion by previous studies (Bloch et al, 2015; Onyebueke, et al. 2020) that increasing demand for housing and ongoing urban expansion is associated with new construction projects. While fewer (n=11, 8.3%) numbers of people are mostly involved in renovation works, the significant number of people that agreed to carry out both new construction and retrofitting shows that there are somewhat number of people experienced in the act or retrofits as represented in Figure 5.5.1.

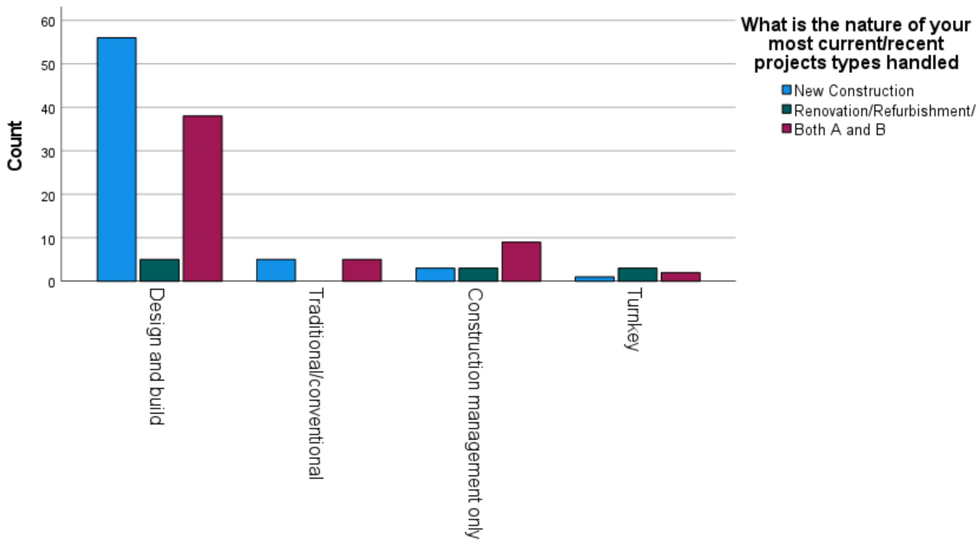


Figure 5.5.1. Nature of most recent job types based on contract procurement.

Figure 5.5.1 compares the nature of projects frequently handled by building designers in Benin City with the nature of contract types frequently handled. All the contract types represented tend to have members who are experienced in carrying out renovation works. It, therefore, implies that although refurbishment is not the major practice of building designers, the most contract type regularly handled by the survey respondents (design and build with over 75%) signifies a high level of knowledge in the general practice of design and renovation by the participants. A brief description of the different contract types is contained in the next chapter in section 6.1.1. Figure 5.5.1 also points to the practice of renovation and refurbishment with the inclusion of those involved in the combination of new construction and renovation (Both A and B) in all the different contract roles carried out by the professionals.

The information on the demographics in addition to giving credence to the participants being in the right position to provide the necessary information needed to achieve study goals helps to understand the reasons for their decision as well as to identify trends and patterns. Whether the decisions can be generalised or categorised depends on the nature of the responses provided. In line with the study aim, the perception of the building design professionals on the consideration for energy efficiency during project execution is presented next.

5.6. Building designers' perception of energy efficiency considered in their projects

Questions 7 to 9 of the questionnaire survey are aimed at gauging the building designers' understanding of energy efficiency in a building. Their understanding of energy efficiency will further inform how and if they address energy issues in their projects.

Question 7 asks the professionals how they best describe energy efficiency if considered in their project. The response to the question (Figure 5.6A) shows that 132 of the 133 survey respondents gave their opinions on the description of energy efficiency considered in their projects (n = Valid =132). Some of the respondents (n=24;18.0%) described energy efficiency in their projects as the use of renewable. 30(22.6%) persons opined that less use of electricity from the national grid is the best way to consider energy efficiency. The majority of the respondents (n=68; 51.1%) described energy efficiency in their project as less use of both the main source of power (electricity from the national grid) and the alternative sources including generators and inverters. Only 10(7.5%) respondents consider less use of alternative power sources for energy efficiency in their projects.

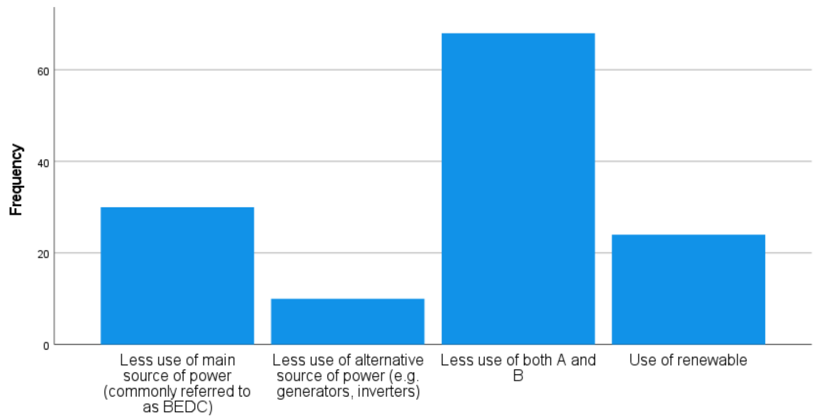


Figure 5.6A. The best description of energy efficiency considered in a project

Figure 5.6A goes further to show that somehow the survey respondents tend to describe energy efficiency in one way or the other in their projects with the highest proportion being to use less of the alternative source of power or from the national grid. How they go about achieving this feat constitutes some of the questions in the latter parts of the questionnaire survey and is discussed in the latter part. In line with the study aim and as discussed in this study literature, among the several advantages of addressing energy efficiency in buildings include providing the required human comfort and reducing costs for the occupants (Amasuomo et al., 2016; Ijaola et al., 2018). How the building designers achieve this feat given the earlier discussed energy problems in Nigeria and the increasing energy demand for use in buildings is asked in question 8 of the questionnaire. The option with the highest number of respondents (n=75; 56.4%) from the question indicates that energy efficiency is achieved by building professionals through efficient building designs. Respondents that never paid much attention to energy efficiency in projects (n=20; 15.0%) are slightly followed by those who leave it to the end users to implement and those who use renewable energy sources both (n=19; 14.3%) respectively See figure 5.6B).

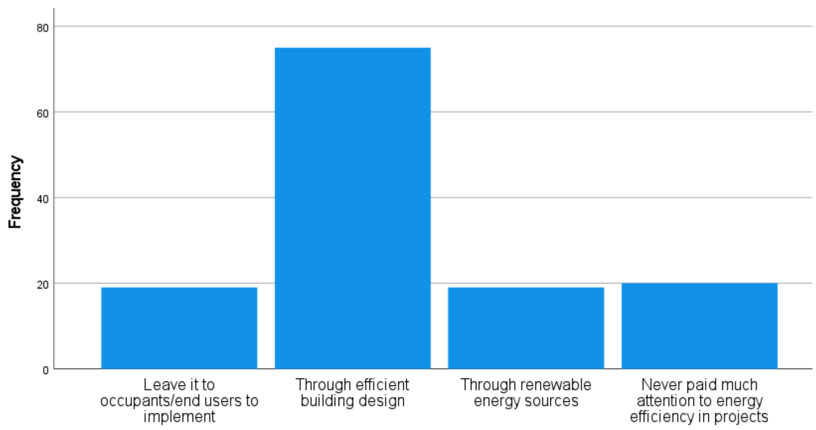


Figure 5.6B. How energy efficiency is addressed in a project

Figure 5.6B shows that over half of the survey respondents achieve energy efficiency in their projects through efficient building design. Previous studies (Ochedi and Taki, 2016; Geissler et al. 2018; Olayinka and Andrew, 2018) have not only depicted the relationship between energy efficiency and the environmental behaviour of a building but further stated that improving the buildings' environmental performance is a major approach to enhancing energy efficiency and reducing cost. Question 9 of the questionnaire survey tends to gauge the perception of the building design professionals on their understanding of the impact of the environmental behaviour of the building and its design on energy efficiency. It uses a scale of least significance (1) to most significance (5). As previously established in section 5.4, the data presents a mean of 3.93 showing that many (n=127; 95.5%) building design professionals such that those on moderately significant (3 on the scale of 1-5) are grouped to be significant and perceive a higher level of significance of how energy efficiency is impacted by the environmental condition and design of a building project (See Figure 5.6C).

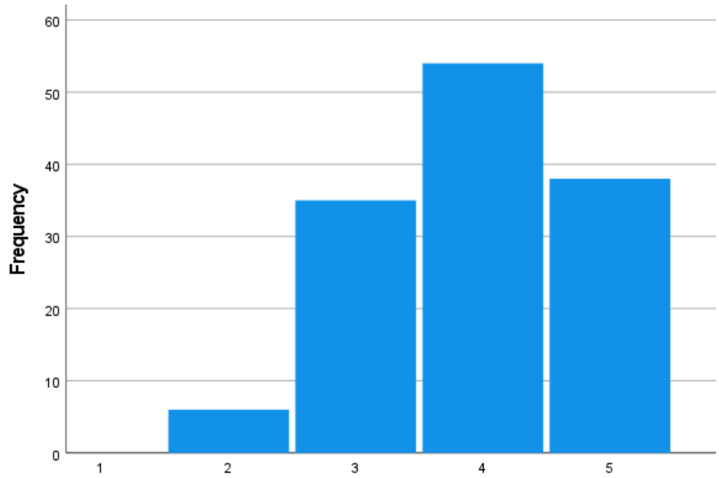


Figure 5.6C. Impact of building design on energy efficiency

Figure 5.6C shows that the survey respondents' perception of the impact of design and the environmental condition of a building is significant with many of the respondents considering using efficient building design to achieve energy efficiency. The next section discusses building design-related information starting with the evaluation of a series of factors categorised under design considerations, end-user-related considerations, and statutory compliance considerations to gauge the survey respondent's perception of how significant each of the factors is.

5.7. Evaluation of building and design-related information by building design professionals.

This section comprises questions from 10-15 of the survey questionnaires. It starts by rating the respondents' agreed level of significance of several factors considered during the design or renovation of a project.

5.7.1. Factors influencing design decision making by professionals

Several decision-making factors have been identified and tested by some studies (Arup and Genre, 2016; Ochedi and Taki, 2019; Amasuomo et al. 2017; Geissler et al. 2018; Mu'azu and Gyoh, 2012, Jegede and Taki, 2021) that can influence the building design professional's decision towards energy efficiency and indoor comfort. Some of the environmentally friendly building design decision-making factors considered in this study are deduced from the study literature and shown in Figures 5.7.1A, 5.7.1B and 5.7.1C respectively. The factors are grouped under three categories, they are envelope design configurations, end-users-related considerations and compliance considerations. As earlier stated, bioclimatic design initiatives place no particular style on the building designers (Arup and Genre, 2016; Jegede and Taki 2021) and thus, the factors in each of the categories are presented in no defined order but to rate the respondents perceived level of significance for each factor and to understand what extent each factor influences design decision.

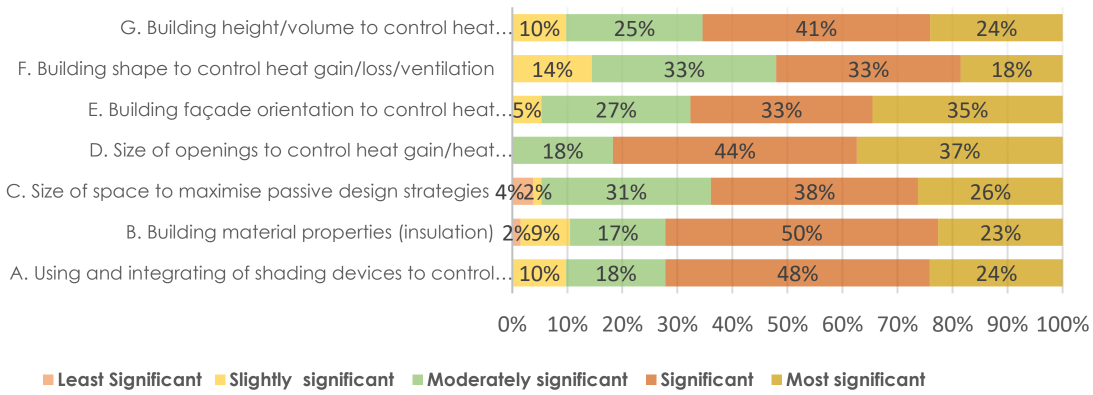


Figure 5.7.1A. Significance rating of factors of building envelope configuration

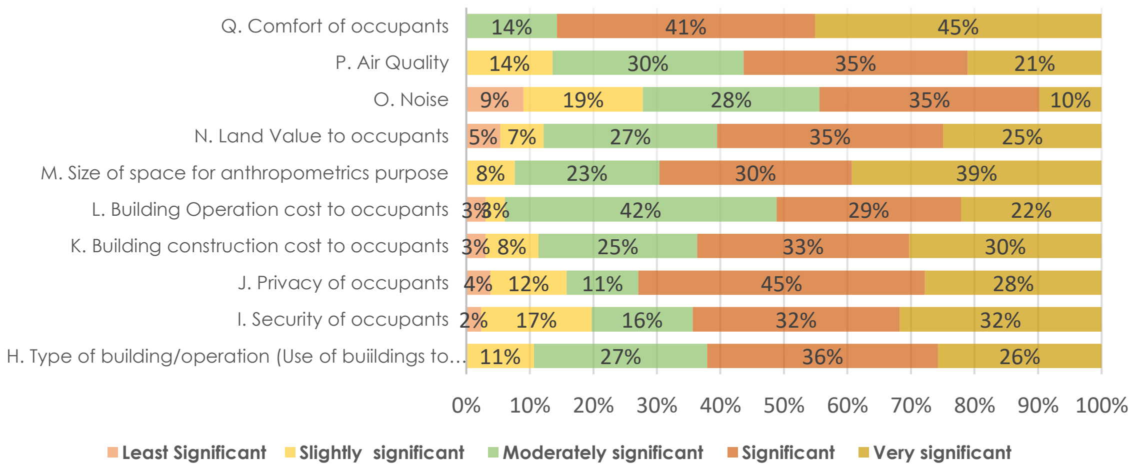


Figure 5.7.1B. Significance rating of end-user design considerations

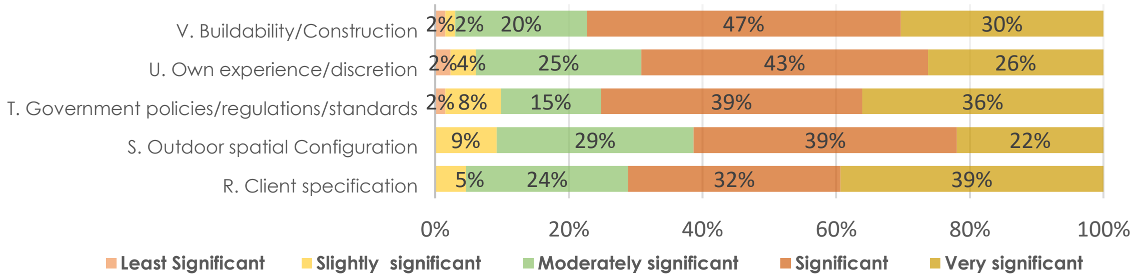


Figure 5.7.1C. Significance rating of compliance configuration

Figures 5.7.1A, 5.7.1B and 5.7.1C show various previously identified bioclimatic factors that influence the building design practitioners' choice of design on building energy efficiency, and environmentally conducive indoor conditions to enhance occupants' comfort and productivity. For clarity, the percentages of each of the factors shown in the figures are rounded up to the nearest whole numbers while the means and the actual percentage (to one decimal place) are discussed in the next subsections.

5.7.1.1. Envelope design configurations:

Figure 5.7.1A shows that the building design professionals consider all the listed building envelope configurations of great significance during their projects given that their mean values are greater than 3 (>3). as shown in Table 5.71.1. Following the alphabetical order, (that is starting from the bottom of Figure 5.7.1A) The first factor of building envelope consideration is the use and integration of shading devices to control heat gain or loss. A mean of 3.86 implies that 120 (90.2%) of the total number (133) respondents control heat gain and heat loss through the use of shading devices. Studies (Guedes, 2013; Kamal, 2012) indicate that shading works with a proper understanding of the sun angle to reduce the effect and penetration of solar radiation into buildings.

Table 5.7.1.1 Mean and actual percentage values of building envelope configurations

Building envelope configuration	Mean	Percentage (%)
Building height/volume to control heat gain/loss/ventilation	3.80	88.8
Building shape to control heat gain/loss/ventilation	3.56	84.2
Building façade orientation to control heat gain/loss/ventilation	3.97	94.8
Size of openings to control heat gain/heat loss/ventilation	4.19	98.4
Size of space to maximise passive design strategies	3.81	94.7
Building material properties (insulation)	3.83	89.5
Using and integrating shading devices to control heat gain/loss	3.86	90.2

Other envelope design configurations are, building materials properties (n=119; 89.5%), size of space to maximise passive design strategies (n=126; 94.7%) size of openings to control heat gain heat loss and ventilation (n=131; 98.4), building façade orientation to ventilate, control heat gain or loss (n=126; 94.8%) applying building shape to ventilate, control heat gain and heat loss (n=112; 84.2%) as well as utilizing building height to ventilate the building and control heat gain and heat loss (n=100; 88.8%) have a high significance rating mean value of 3.83, 3.81, 4.19, 3.97, 3.56 and 3.80 respectively. It implies that the survey respondents consider all the factors of building envelope configuration highly significant in their design and construction projects. All the listed factors of building envelope configuration as previously identified in previous studies (Arup, 2016, Ochedi and Taki, 2019, Mirrahimi et al., 2016; Abdusalam et al., 2015; Geissler et al, 2018; Musa and Abdullahi, 2018) are environmentally friendly initiatives that impact the indoor condition of a building and in turn energy efficiency.

The respondents' rating of the level of significance of the factors of building envelope design configuration buttresses their previous responses (Figure 5.6C) that environmental design and behaviour of buildings impact energy efficiency. It also validates the professional's stance that they attempt to address energy efficiency through energy-efficient building design (Figure 5.6B). Factors such as the building occupancy profiles and internal heat gains from the use of technologies (including computers) also lead to heat gain or loss in the building.

5.7.1.2. End-Users design consideration:

There are factors also considered by the building designers in their projects. They include physical factors, sociocultural factors, economic factors, and financial factors (Akanni et al., 2015), These factors when considered in any building project tend to look at the variables with the potential of influencing the end users or building occupiers. In this study, such identified factors are grouped as end-users-related considerations with the building design professionals' responses to the presented in Figure 5.7.1B.

Different end-user design considerations identified from the literature were listed and rated by the survey respondents based on their perceived level of significance when considered in their projects. They include variables such as building type or use to occupants, security to the users, the privacy of occupants, building's construction cost, building's operation cost, size of space for anthropometric purposes, land value to occupants, noise, air quality and comfort of occupants. The mean value of each of the variables is shown in Table 5.7.1.2.

Table 5.7.1.2 Mean and actual percentage values of end user-related considerations

End user-related consideration	Mean	Percentage (%)
Comfort of occupants	4.31	99.2
Air Quality	3.64	86.5
Noise	3.17	72.2
Land Value to occupants	3.68	87.2
Size of space for the anthropometrics purpose	4.02	91.8
Building operation cost to occupants	3.64	92.5
Building construction cost to occupants	3.80	88.0

Privacy of occupants	3.81	84.2
Security of occupants	3.74	79.7
Type of building/operation (Use of building to occupants)	3.77	89.0

According to the data shown in Table 5.7.1.2, listing all the identified factors rated by the survey respondents, there is a high rating (>3) of the significance level of all the factors when considered in their projects. Following the alphabetical order (Figure 5.7.1B), the perception of significance of each of the factors are building use to the occupants (n=119; 89.0%), security of occupants (n=106; 79.7%), privacy of occupants (n=112; 84.2%), Building construction cost to occupants (n=117; 88.0%), building operation costs to occupants (n=123; 92.5%), size of space for anthropometrics purpose (n=122; 91.8%), land value to occupants (n=116; 87.2%), consideration for noise (n=96; 72.2%) while air quality (n=115; 86.5%) and the comfort of occupants (n=132; 99.2%). While noise is the least significant consideration among the end-user-related variables ranked by the respondents, its significance is still highly considered (>3). The data indicates the high degree of significance placed on end-users by the survey respondents during their design. It support's the opinion of Adeyemi et al (2017) with the opinion that successful improvement of existing office buildings should give more attention to end-user needs. The aforementioned factors are directly linked to the clients/end-users to understand how they influence respondents' design decisions. Its necessity is borne out of the enormous opportunity for end-users, like design professionals to reduce building energy demand in an energy-poor country, reduce reliance on mechanical energy sources and enhance comfort (Ochedi and Taki 2019).

5.7.1.3. Compliance consideration:

Other notable factors influence the decision of the built environment professionals other than the end-user-related considerations and the building envelope configuration. They have a significant impact on developments and are most often the first set of variables that all other factors hinge on during the execution of projects. They are described as institutional factors by Oladapo and Olotuah, (2007) and Akanni et al. (2015) because they are either recognised by the government or are constituted institutions established by an Act or a Decree such as the NIA. Also, the NBC, (2007) is the national document detailing several guides that building design professionals must adhere to amidst other local regulations. For this study, these factors are referred to as compliance considerations and the survey respondent's responses are represented earlier in Figure 5.7.1C.

It could be seen from Figure 5.7.1C that the rating of the factors that make up compliance consideration as perceived by the survey respondents in their projects are high (>3) given the mean values as shown in Table 5.7.1.3.

Table 5.7.1.3 Mean and actual percentage values of compliance consideration

Compliance considerations	Mean	Percentage (%)
Buildability/Construction	4.03	88.8
Own experience/discretion	3.87	84.2
Government policies/regulations/standards	4.00	94.8
Outdoor spatial Configuration	3.74	98.4
Client specification	4.06	94.7

From the mean values of the variables of compliance consideration shown in Table 5.7.1.3, following the alphabetical order (Figure 5.7.1C) client's specification has a mean value of 4.06 and it implies that 126(94.8%) of the professionals give a rating of high significance to client's requirement. Other considerations are for the outdoor spatial configuration with a mean value of 3.74 implying 130(90.2%) of the respondents, government policies with a mean of 4.00 indicating 120(90.2%) professionals, the experience of the professionals with a mean of 3.87 signifying 125(94.0%) respondents and buildability having a mean value of 4.03, indicating that 128(96.2%) of the respondents rate the respective compliance factors significant.

The data shows that compliance consideration is greatly considered by the architects during their project execution due to the high rating (>3) of the level of significance of each of the factors. Although not all compliance considerations are directly linked to environmental performance or energy efficiency of buildings, there are the advantages of using policies and institutional stances to further encourage the adoption of environmentally friendly initiatives to create a conducive indoor environment towards comfort. In other words, compliance considerations set the precedent that guides and informs design decision-making by professionals. Its high significance rating in this survey means that the listed factors, whether government policies, personal conviction, or natural and physical phenomenon (including outdoor configuration and construction) have no negative impact on achieving energy or environmental performance to the respondents. Overall, It shows and reinforces the respondents' awareness of the impact of design on building performance.

With the professional's significant knowledge of the impact of the environmental behaviour and design of buildings and in turn energy efficiency. There is the need to ascertain the performance level of existing buildings by evaluation of completed projects in comparison to the positive attitude of the building designers towards achieving environmentally conscious designs. The next subsection expounds more on how feedback is derived from a building post-construction and occupancy.

5.7.2. How survey respondents get feedback from a building post-occupancy

Previous data indicate that building design professionals are aware of the impact of their design on human comfort, whether they put the factors into practice or not can only be adjudged from evaluating the performance of the building post-occupancy. Question 11 of the questionnaire tends to gauge how often the survey respondents get feedback from buildings after occupancy while question 12 attempts to understand how the professionals go about getting feedback to understand the performance of the project.

The data in Figure 5.7.2A are the responses to question 11 of the questionnaires showing that some respondents (n=4; 3.0%) did not give their responses to the question. The analysis of the responses to the question is also on a 5 significant level scale similar to that used in the previous subsection but with different options also rated from 1-5(never, rarely, sometimes, often, very often). While some 4(3.0%) respondents very often obtain feedback from their projects post occupancy, another 16(12.0%) respondents often get feedback. 51(38.3%) building design professionals sometimes get feedback while the other 38(28.6%) and 20(15.0%) respondents respectively, rarely, and never get feedback on post-occupancy to understand the building's environmental performance and occupants' thermal comfort about energy efficiency.

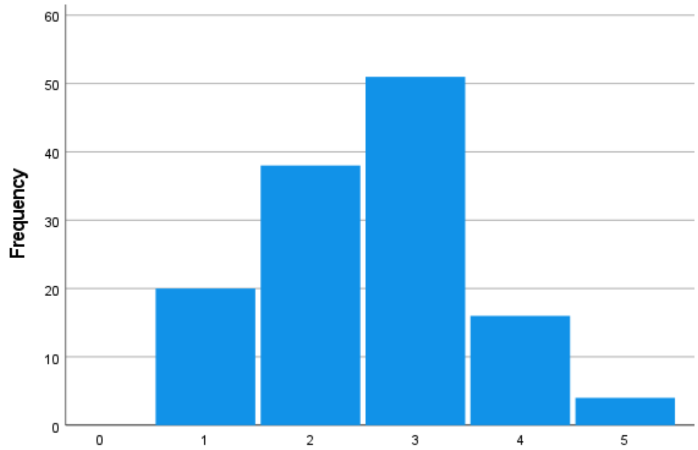


Figure 5.7.2A. How often respondents get feedback from a building post-occupancy.

The indication of Figure 5.7.2A is that it is an uncommon practice in the study region to obtain feedback on a project after completion and occupancy to understand if the building is meeting the occupant's needs as intended. The highest number of people (n=51; 38.8%) tend to sometimes get feedback from their projects post-occupancy and has a mean of 2.58 (<3). The next question (12) in the questionnaire is about the ways respondents usually derive feedback from their projects post-construction and occupancy haven known from Figure 5.7.2A that the practice of obtaining feedback is not common. Figure 5.7.2B help to give clarity on the percentage of respondents as well as how they go about getting the needed feedback.

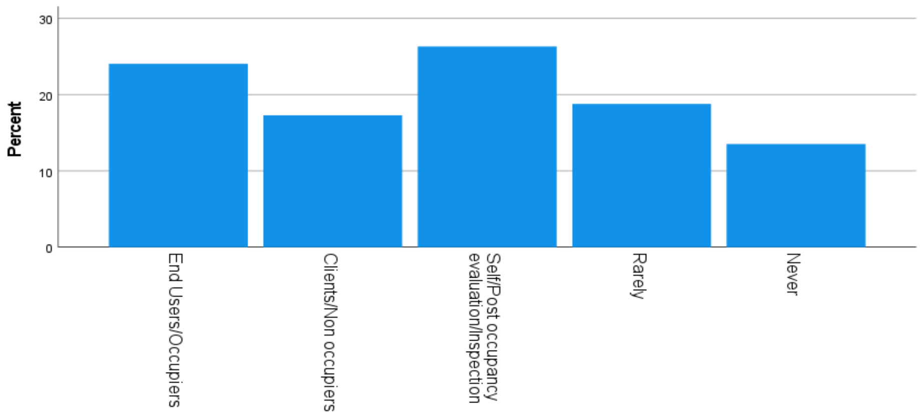


Figure 5.7.2B. How respondents get feedback from a building post-occupancy

Figure 5.7.2B helps in clarifying the built environment professionals' position in terms of percentages on what ways are used to derive the necessary feedback. The options to the questions are never, rarely, self-evaluation, non-occupying clients, and occupiers or end-users. It can be deduced from the data that for those who get post-occupancy feedback from a project, self-evaluation (n=35; 26.3%) is the most frequently used method followed by sourcing feedback from end-users or occupiers (n=32; 24.1%). Feedback from non-occupiers or clients (n=23; 17.3%) follows afterwards. While it can be argued that non-occupying clients are not in the best position to give feedback on the impact of the building in terms of its design's environmental effect or indoor condition because they don't have first-hand experience, 25(18.8%) and 18(13.5%) of the respondents rarely and never bother with feedback to understand the internal condition of the building. The data imply that despite the awareness of issues of environmental concerns, energy, and comfort and how it is impacted by building designs the attitude of the design professionals to understand their designs and how they are performing is not encouraging. The practice is consistent with previous studies (including Ijaola et al. 2018) indicating that building professionals hardly obtain feedback post-building occupancy to understand how their design decisions meet user needs. It, therefore, impedes the opportunities to improve on existing building stock in the study region, especially with the concurrent changing building user's needs and building deterioration over time.

To understand if the building professionals use their design to promote a conducive indoor environment and in turn energy efficiency, let's consider the reasons for redesigning or retrofitting stated by building owners. Given that end-user considerations highly impact the professional's decision-making to understand the role of the clients towards ensuring a conducive indoor environment, Figure 5.7.2C presents the information from the survey respondents on reasons for redesigning or retrofitting stated by clients.

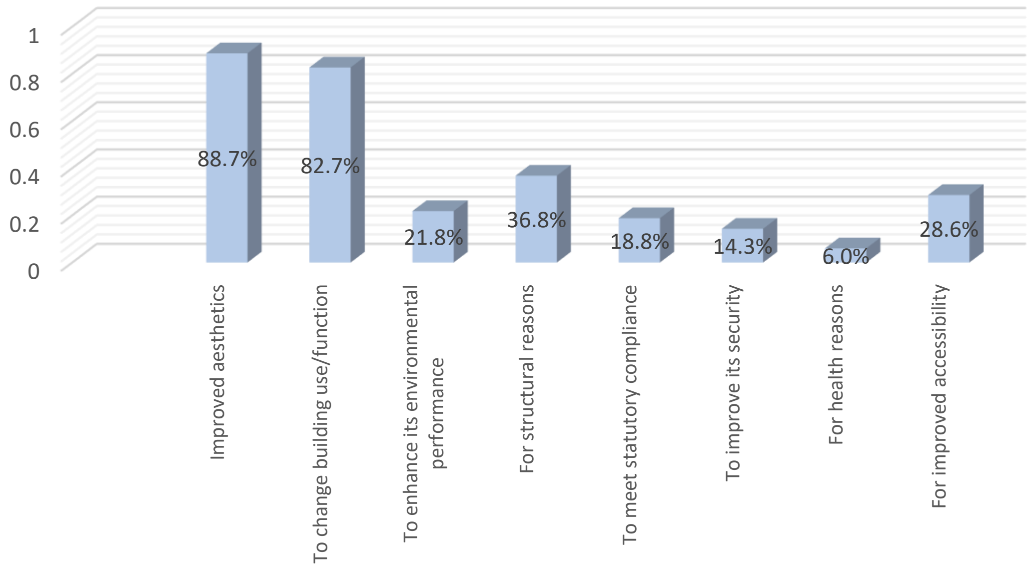


Figure 5.7.2C. Reasons stated by clients for redesigning and retrofitting.

Figure 5.7.2C are the reasons given to survey respondents by clients on why they redesign or renovate their buildings. The four highest occurring frequencies from the options are for improved aesthetics (n=118; 88.7%), to change building use (n=110; 82.7%), structural reasons (n=49, 36.8%), and to improve accessibility (n=38, 28.6%) respectively and are the major reasons given by clients in justification for renovating or redesigning. The other reasons stated by respondents on why they are contracted by clients to refurbish, or redesign buildings are to enhance the environmental performance (n=29, 21.8%) of their buildings, to meet statutory compliance (n=25, 18.8%), to improve the security of the building (n=19, 14.3%) and for health reasons (n=8, 6.0%) respectively. The data shows that clients' need for renovation or redesigning is seldom linked to having an improved indoor environment or reducing the energy consumption of the buildings. One can conclude from the data (Figure 5.7.2C) that the client's needs for renovation or redesigning are mainly for reasons other than to provide a conducive indoor environment that promotes energy efficiency health and comfort.

Also, it is arguable that clients are less attuned to enhancing a conducive indoor environment in their building because they already have the required comfort, considering the survey respondent's knowledge of the relationship between the environment, design, and a conducive indoor environment. Even though there is a poor attitude on the side of the professionals in getting feedback on buildings post-completion and post-occupancy to understand how well the building is performing, it has been said that Nigerian buildings are performing poorly (Geissler et al. 2018). The Africa Progress, Panel (2015) attributed the poor performance and the rate of building increase to the extensive use of mechanical cooling to keep occupants comfortable and productive. Additionally, the changes in building occupants' requirements with time and other environmental agents require the need for regular building evaluation and performance enhancement. Improving existing buildings are more cost-effective compared to constructing new ones (Adeyemi et al., 2017). The recent and increasingly used method of building evaluation and testing of design strategies recommended by the BEEC and BEEG requires the use of detailed technical building details. Question 14 of the questionnaire asked respondents how they get the building-related details which are the requirements for building evaluation and improvement. Table 5.7.2.1 presents the responses from the survey respondents.

Table 5.7.2.1. How building-related information is captured before redesigning.

Source of building information before redesigning	Frequency	Percentage (%)
Existing as-is drawings/design	43	32.3
Engage a building surveyor to capture the as-is building details	25	11.3
Personally conduct surveys	67	50.4
Nil response	8	6.0
Total	133	100.0

The data presented in Table 5.7.2 on how building-related data including characteristics (including design and specifications) shows that the information is accessed by the building design professionals. According to the data presented, as-is building details are mostly collected through surveys personally conducted by the practitioners (n=67, 50.4%) followed by the use of existing building designs (n=43, 32.3%). While there were nil responses from 8(6.0%0 engaging another professional to capture the required building information, ideally, a building surveyor (n=15, 11.3%) is the least among the three options. Considering the two higher percentages of the survey response to question 14 (personal surveying at 50.4% and the use of existing as-is building information at 32.3%) indicate that the building design professionals either work on their own, are properly skilled with data capture on as-is representation or work in exclusion of the professional responsible for surveying buildings. However, according to the data emerging from the complementary semi-structured interviews carried out as part of the data collection methods for this research, there is no independent practice of the building surveyor profession in Nigeria. Further information is discussed in the next chapter (analysis of the semi-structured interview). Meanwhile, other than the absence of a specialist professional known as a building surveyor in Nigeria, several reasons could be responsible for the low percentage (11.3%) for contracting someone trained in the act of building surveying by the survey respondents. Some of the reasons are listed in question 15 of the questionnaire. The level of significance of each of the factors is rated by the survey respondents on whether or not there is the need to engage a professional saddled with the responsibility of building surveying to capture the necessary building information needed for building evaluation and testing of improvement strategies. In addition to ascertaining the suitability of data capturing techniques used by the design professionals, the information is also necessary to gauge their knowledge of the importance of accessing and processing the building data towards improving building performance and enhancing indoor comfort. The survey respondents' responses to question 15 of the questionnaires are represented in Figure 5.7.2D

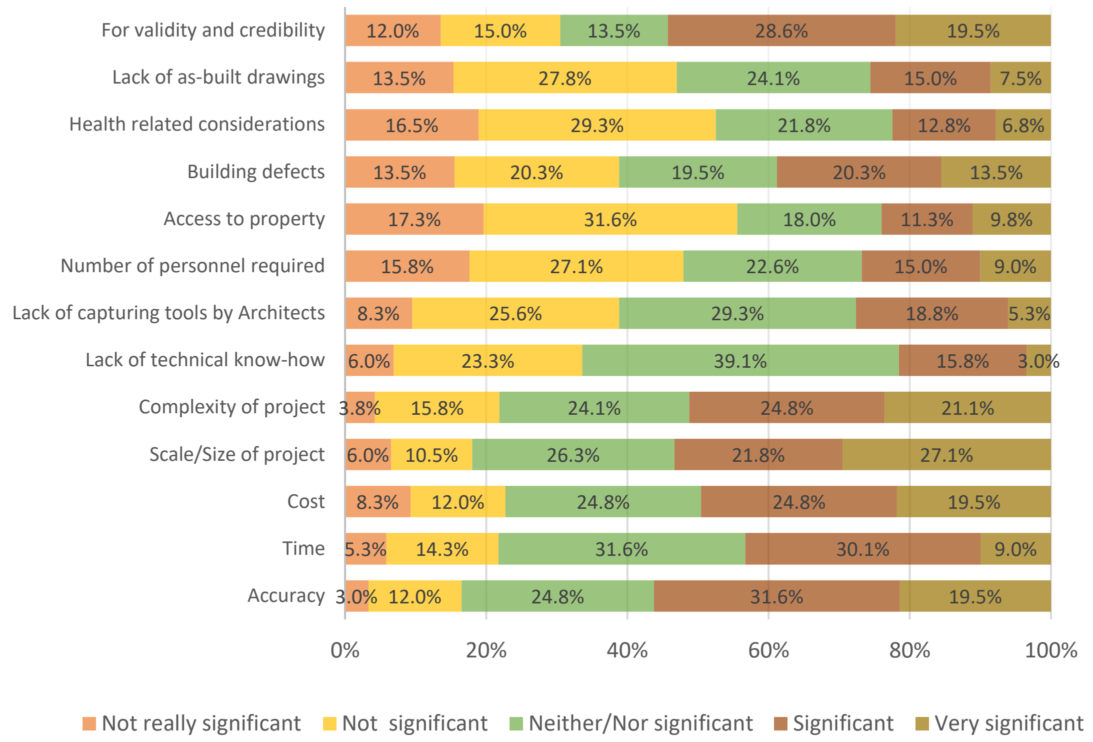


Figure 5.7.2D. Consideration factors for engaging a building surveying professional.

From the data presented in Figure 5.7.2D, according to their perception of significance level, the survey respondents initially rated each variable considering whether or not to engage a professional trained in the act of building surveying. The mean and percentage values of the variables are also shown in Table 5.7.2.2.

Table 5.7.2.2 Mean and significance percentage values of factors considered for engaging a survey professional.

Factors considered for engaging a surveying professional	Mean	Percentage (%)
Accuracy	3.58	75.9
Time	3.26	70.7
Cost	3.39	69.1
Scale/Size of project	3.58	75.2
Complexity of Project	3.49	70.0
Lack of technical Know-how	2.84	57.9
Lack of capturing tools/instruments by architects	2.85	53.4
Number of personnel required	2.71	46.6

Access to property	2.60	39.1
Building defects	3.00	53.3
Health-related consideration	2.59	41.4
Lack of as-built drawings	2.72	46.6
Validity and credibility	3.32	61.6

The mean value presented in Table 5.7.2.2 indicates that there is more significance on certain factors than others when considering engaging a professional trained to offer the services of building surveying. The factors considered more significant (>3) are accuracy (mean=3.58), time (mean=3.26), cost (mean=3.39), scale or size of project (mean=3.58), complexity of project (mean=3.49), building defects (mean=3.00) and for validity and credibility (mean=3.32). The other factors considered with less significance (<3) rating by the building design professionals to engaging a surveying professional are due to lack of technical know-how (mean=2.84), lack of capturing tools by the architect (mean=2.85), number of personnel (mean=2.71), access to the property (mean=2.60), health-related considerations (mean=2.59) and lack of as-built drawings (mean=2.72).

The data imply that while for instance, factors such as accuracy (75.9%) and time (70.7%) are positives to engaging a building surveying professional, the cost (69.1%) of engaging one is rated as a significant factor to be considered. The lack of technical know-how (57.9%) and lack of capturing tools (53.4%) also appear to be less significant because it has a mean of less than 3, meaning that the tools are either easily available or that the survey professionals are grounded with the necessary knowledge of the capturing tools available. The number of personnel (46.6%) that appears to be a less significant consideration could mean that it is easier to get the required personnel, or the process of capturing building data requires less personnel, or it is automated due to a <3 mean value. Access to the property (39.1%) rated of low significance may mean that access is always available to the required building or there is the absence of barriers that makes data capturing difficult. Health-related considerations (41.4%) less considered also imply that there are either no health-related reasons for data capture or that they hardly affect the capture of as-built information. The scale of the project (75.2%) and complexity of the project (70%) considered significant (>3) to engage a building surveying professional could be due to ease of accessing the as-built information, improved data capturing technology accuracy or due to time constraints during project execution. More of the reasons are explored in the analysis of the interview chapter (chapter 6). The information from the available data (including the rating of the significance of the variables) so far points to the fact that building design professionals seldom engage the building surveying professionals or that they carry out less data-capturing work. Haven known this it is, therefore, useful to consider the data capturing and processing technology used by the survey respondents and the accompanying processes involved.

5.8. As-built data capturing and processing technology.

In this section are questions 16 to 20 of the survey questionnaire are questions relating to the capturing and processing of as-built data. It starts by enquiring about what data capturing techniques and technology are familiar (used or known) to the building design professionals. It then proceeds to seek an understanding of the factors leading to their choices of adopting such a technique. How processing of the captured data impacts the capturing process and how they are captured and processed with the corresponding computer applications where necessary are also part of this section.

5.8.1. As-built data capturing technique.

Question 16 of the questionnaire lists some building data capturing techniques identified in chapter 3 of this study and attempts to know which ones the survey respondents have used or are aware of. Figure 12 shows the comparison between the various data-capturing techniques known and used by the survey respondents.

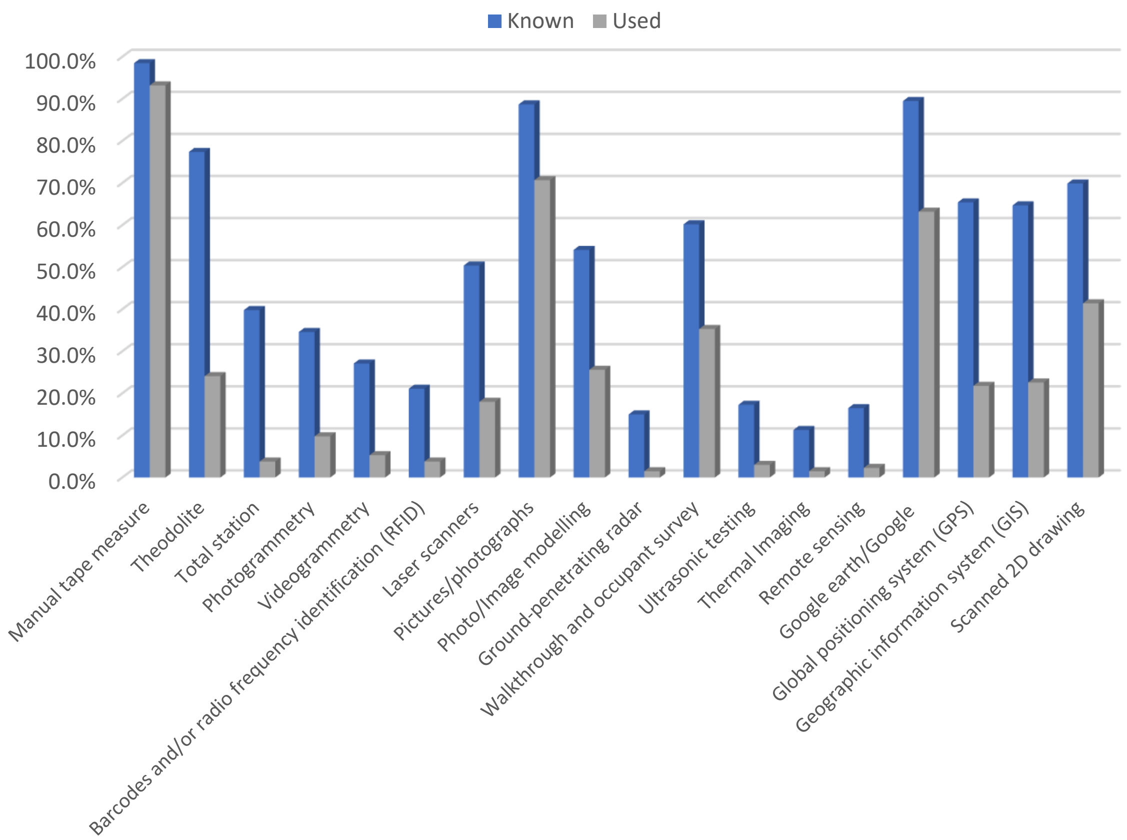


Figure 5.8.1A. Data capturing techniques known and used by respondents.

The data represented in Figure 5.8.1A shows that the use of a manual tape measure is the most frequently known (n=131, 98.5%) and frequently used (n=124, 93.2%) data capturing technique. Two others mostly known technique that follows after the tape measure are the use of google earth or google maps (n= 119, 89.5%) and the use of photographs (n=118, 88.7%). Meanwhile, Google Earth is less used (n=84, 63.2%) compared to photographs (n=94, 70.7%) which is not as known. The least known among the data capturing techniques are thermal imaging (n=15, 11.3%), ground penetrating radar (n=20, 15.0%), remote sensing (n=22, 16.5%) and ultrasonic testing (n=23, 17.3%). It is not surprising that they are also the least used. As deduced from the survey data, the frequencies of their corresponding use are given by; thermal imaging (n=2, 1.5%), ground penetrating radar (n=2, 1.5%), remote sensing (n=3, 2.3%) and ultrasonic testing (n=4, 3.0%). The data shows a gap of about 50% (upper bound and the lower bound) between the capturing tools known and their corresponding use except for the manual tape measure, use of photos, and Google Earth. With the wide gap between many data-capturing techniques that are known but not used, therefore, It signifies that other factors contribute to the choice of techniques adopted by the professionals. Question 17, of the questionnaire survey, tends to understand the rationale behind such choices, and also to ascertain if there are significant reasons for the possibility of adopting other data-capturing techniques by the survey respondents. Figure 5.8.1B presents the responses from the survey.

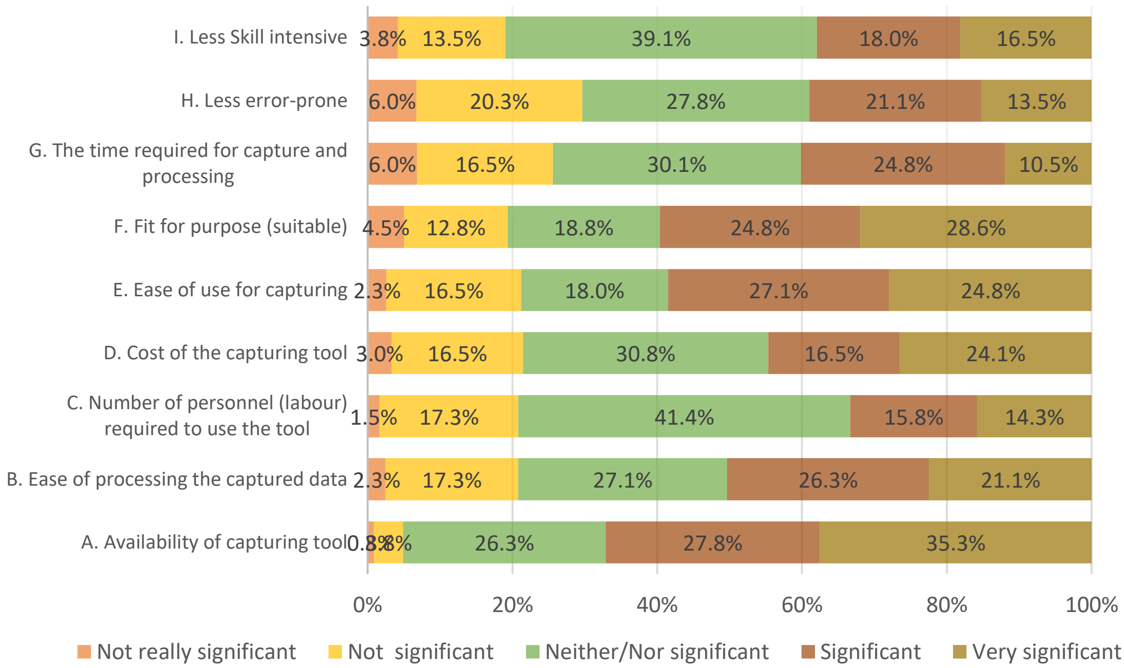


Figure 5.8.1B. Reasons for adopting the preferred data capturing techniques.

The information presented in Figure 5.8.1B are some of the reasons identified in the literature that could influence the adoption of any data-capturing technique. The survey respondents rated each of the factors according to their perception of the significance level and their mean values are used to determine the significance of each factor. The mean and percentage values are shown in Table 5.8.1.

Table 5.8.1 Mean and significance percentage values of factors considered for adopting a data-capturing technique.

Factors considered for adopting a data-capturing technology	Mean	Percentage (%)
Availability of capturing tool	3.99	89.4
Ease of processing the captured data	3.50	74.5
Number of personnel (labour required) to use the tool	3.27	66.1
Cost of the capturing tool	3.46	68.4
Ease of use for capturing	3.63	69.9
Fit for purpose (suitable)	3.67	72.2
The time required for capture and processing	3.20	62.5
Less error-prone	3.18	62.4
Less skill intensive	3.33	73.6

The mean and percentages values of the factors considered for adopting a data capturing technique are shown in Figure 5.8.1B and Table 5.8.1 are availability of capturing tool (mean= 3.99; 89.4%), the ease of processing the captured data (mean=3.50; 74.5%), number of personnel needed to use a capturing tool (mean=3.27; 66.1%), cost of capturing tool (mean=3.46; 68.4%), ease of use of capturing tool (mean=3.46; 69.9%), suitability (mean=3.67; 72.2%) time (mean=3.20; 62.5%) required for capturing and processing, less error-prone (mean=3.18; 62.4%) and less skill-intensive (mean=3.33; 73.6%). Given that the mean values for all the factors rated according to the significance level of perception by the respondents are >3, it, therefore, indicates that all the factors were considered highly significant to their adoption of data-capturing techniques. Figure 5.8.1C shows the significance rating of each of the aforementioned factors of consideration in comparison with the individual data-capturing techniques.

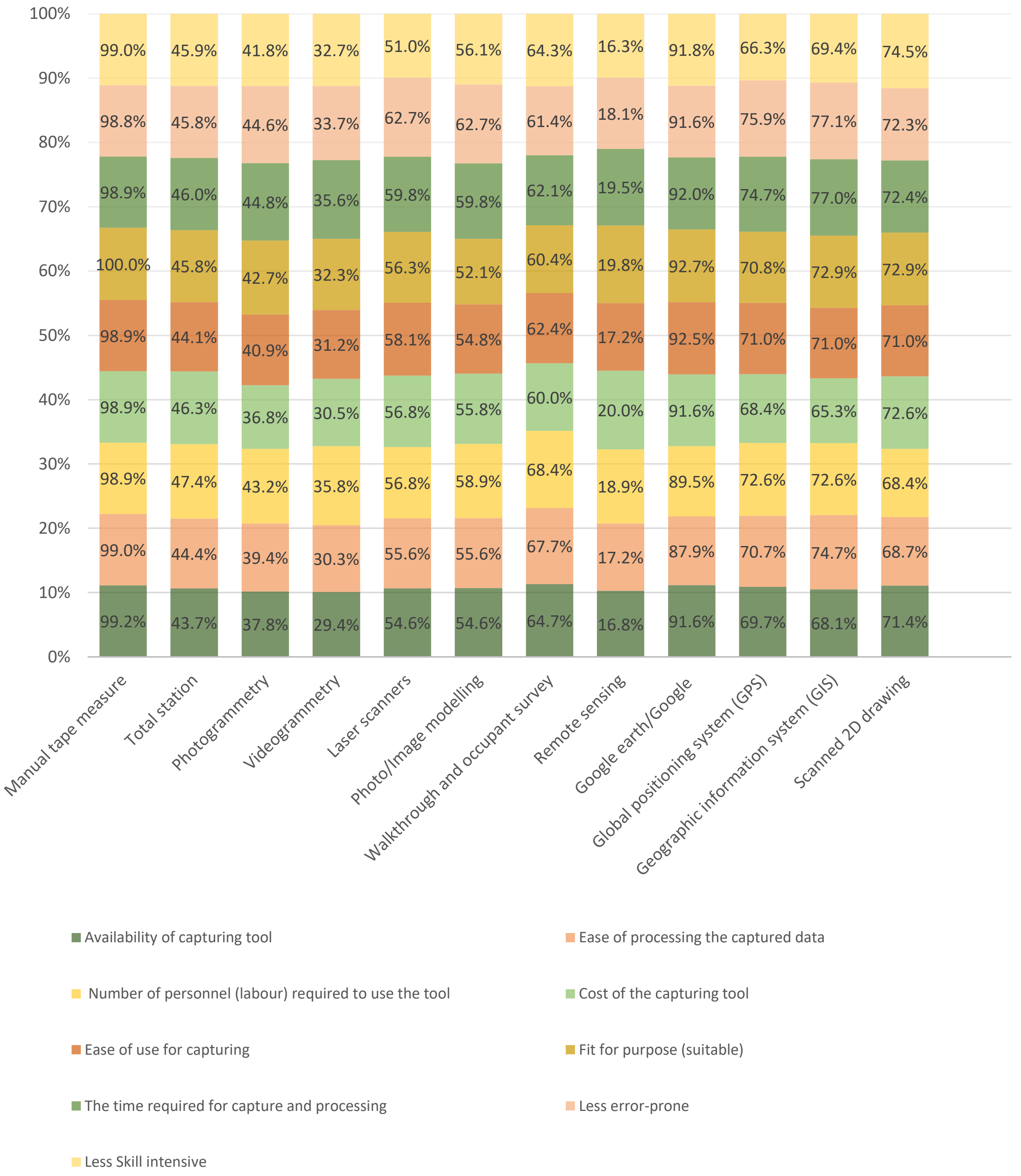


Figure 5.8.1C. Significance rating of the individual data capturing techniques in comparison with factors considered for their adoption.

It can be deduced from Figure 5.8.1C that the highest reason stated by all the survey respondents on any capturing technique is that the tape measuring tool is fit for purpose (100%). Similarly, all other reasons rated in order of significance by the professionals for their choice of data capturing point to the use of the manual tape measuring tool such that all the factors are of the highest significance when it comes to the use of the tape measure. The mean values help to indicate the factor that is most significant to adopting one or more from the list of all the identified data capturing techniques and overall, availability of the capturing tool (mean=3.99; 89.4%) has the most significant influence on the choice of data capturing tool chosen by the survey respondents. Following closely are fit for purpose (mean=3.67; 72.2%), ease of using the data capturing technique (mean=3.63; 69.9%) and ease of processing (mean=3.50; 74.5%) the captured data. The others in the order of significance are the cost of the capturing tool (mean=3.46; 68.4%), less skill intensive (mean=3.33; 73.6%), number of personnel (labour) required to use the tool (mean=3.27; 66.1%), the time required for capture and processing (mean=3,20; 62.5%) and less error-prone (mean=3.18; 62.4%) all influenced the survey respondents decision to adopt their choice of the data capturing techniques.

Considering the level of significance rating (>3) of the aforementioned factors and with the numerous data capturing techniques available in recent times, the professional's concentration and frequent use of a few data capturing techniques identified in Figure 5.8.1A is surprising. With the emergence of new technologies and data-capturing techniques, there are certain features attributable to certain techniques making them either advantageous or a limitation depending on the context and need for it. As previously identified in Chapter 3 some of those factors are rated by the survey respondents according to their perception of significance level for consideration in adopting other data-capturing technologies. The responses to such reasons to be considered by the professionals in adopting other data capturing techniques given the wide margin between the data capturing techniques known compared to those used are shown in figure 5.8.1D. Their level of significance is rated by the survey respondents and the means and percentage values are presented in Table 5.8.2.

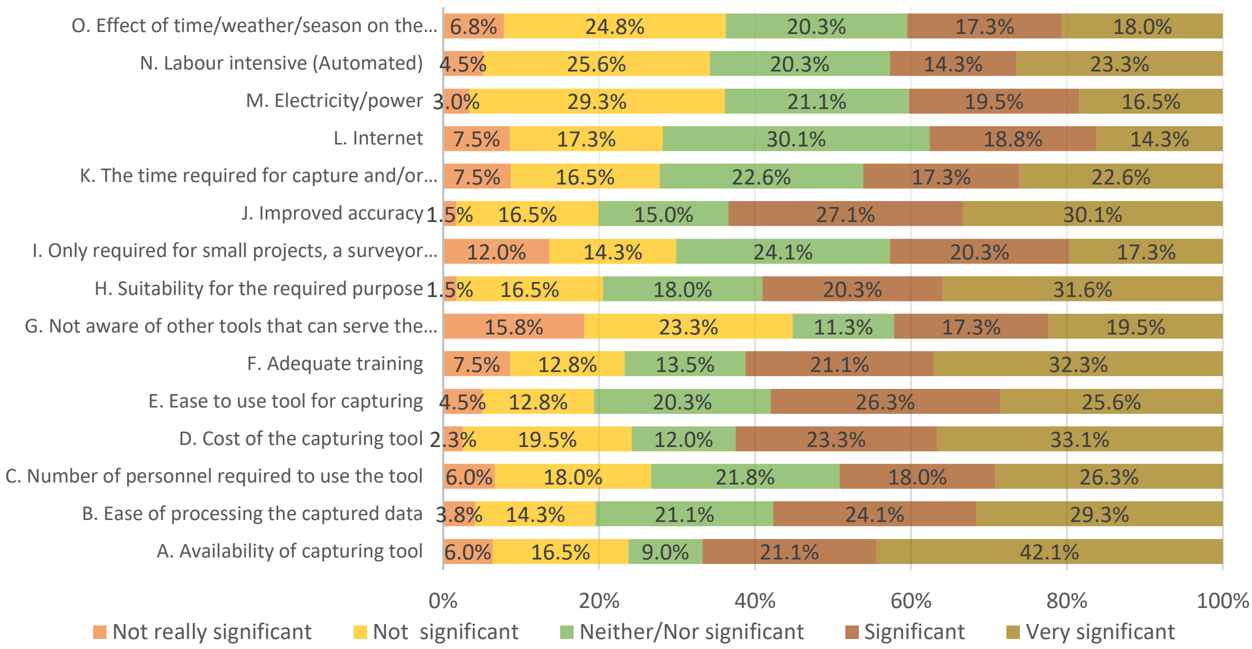


Figure 5.8.1D. Reasons to consider other data capturing techniques.

Table 5.8.2 Mean and significance percentage values of factors considered for adopting other data capturing technique.

Factors considered for adopting other data-capturing technology	Mean	Percentage (%)
Availability of capturing tool	3.81	71.2
Ease of processing the captured data	3.66	74.5
Number of personnel (labour required) to use the tool	3.45	66.1
Cost of the capturing tool	3.73	68.4
Ease to use tool for capturing	3.62	72.2
Adequate training	3.66	66.9
Not aware of other capturing tools that can serve the same purpose	3.02	48.1
Suitability for the required purpose	3.73	69.9
Only required for small projects, a surveyor must be engaged for complex needs	3.19	61.7
Improved accuracy	3.75	72.2
The time required for capture and /or processing (instantaneous)	3.36	62.5
Internet	3.17	63.3
Electricity/Power	3.19	57.1
Labour-intensive (Automated)	3.30	57.9
Effect of time/weather/season on the capture process	3.17	55.6

Table 5.8.2 presents the mean value significance level of the factors considered by the survey respondents for adopting other data-capturing techniques. Similar to the reasons stated for their choice of data capture, the availability of the data capturing tool (mean=3.81; 71.2) has the highest significance rating. The other factors stated according to their level of significance

are improved accuracy (mean=3.75; 72.2%), cost of the capturing tool (mean=3.73; 68.4%), suitability for the required purpose (3.73; 69.9%), ease of processing the captured data (mean=3.66; 74.5%), adequate training (mean=3.66; 66.9%), ease to use tool for capturing (mean=3.62; 72.2%), number of personnel required to use the tool (mean=3.45; 66.1%), the time required for capture and/or processing (mean=3.36; 62.5%), labour intensive (mean=3.30; 57.9%), electricity/power (mean=3.19; 57.1%), only required for small projects a surveyor must be engaged for complex needs (mean=3.19; 61.7%),), internet (mean=3.17; 63.3%), effect of time/weather/season on the capture process (mean=3.17; 55.6%) and not aware of other tools that can serve the same purpose (mean=3.02; 48.1%). According to the responses, with the professionals' positive (>3) rating level of significance in variables that could make them consider other data capturing techniques and considering the several available data capturing techniques, more information can be deduced from analysis of the interview data to understand why only a few ones are adopted.

To properly fulfil the aim and objectives of this study, there is the need to understand how as-is captured data is processed to aid in building performance improvements. How processing of the captured as-is building data impacts its processing can also be a key consideration when selecting a data-capturing technique. Figure 5.8.1E presents the data on the responses by the building design professionals asked in question 18 of the questionnaire. It rates the level of significance given by survey respondents of how processing as-built data impacts the capturing process while table 5.8.3 shows the corresponding mean values.

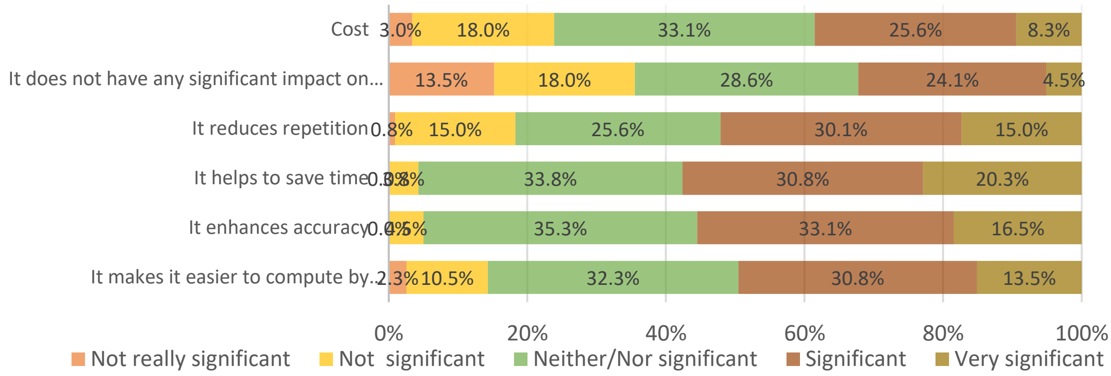


Figure 5.8.1E. How processing as-built data impacts the capture process.

Table 5.8.3 Mean and significance percentage values for how processing as-built data impacts the capture process.

How processing impacts capturing of as-built data	Mean	Percentage (%)
It makes it easier to compute by abstraction, approximation etc.	3.48	76.6
It enhances accuracy	3.69	84.9
It helps to save time	3.76	84.9

It reduces repetition	3.50	70.7
It does not have any significant impact on the capturing process	2.86	57.2
Cost	3.21	67.0

From the data shown in Figure 5.8.1E and Table 5.8.2, the building designer's perception rating the significance level of how processing captured building data impacts the capturing process, five of the variables were rated highly significant (>3). The variables according to the respondents' rating of their significance levels are, it makes it easier to compute by abstraction (mean=3.48; n=102; 76.6%), it enhances accuracy (mean=3.69; n=133; 84.9%), it helps to save time (mean=3.76; n=113; 84.9%), it reduces repetition (mean=3.50; n=94; 70.7%), it does not have any significant impact on the capturing process (mean=2.86; n=38; 57.2%) and cost (mean=3.21; n=89; 67.0%). The data indicate that all the listed factors are rated significant except for the variable that, it does not have a significant impact on the capturing process having a mean of 2.86 (<3). Given that the processing of captured data has a significant impact on the capturing method (more to be covered in the interview analysis session), it is necessary to understand how the captured as-is data is processed. Question 19 attempts to understand how the captured building information are processed and the way they are validated. The values of the survey responses are presented in tables 5.8.4 and 5.8.5 and pictorially shown by figures 5.8.1F and 5.8.1G.

Table 5.8.4 Mean and significance percentage values for how processing as-built data impacts the capture process.

Captured as-is/as-built data processing	**Frequency**	**Percentage (%)**
Manual hand design	3	2.3
Computer-aided	49	36.8
Both A and B	73	54.9
Unanswered	8	6.0
Total	133	100

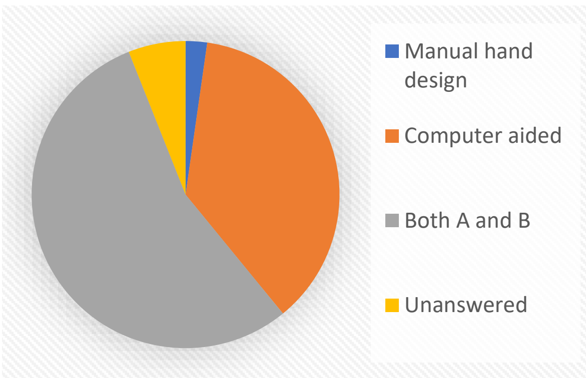


Figure 5.8.1F. How captured as-is data is processed.

Table 5.8.4 and Figure 5.8.1F, present the data on survey respondents' ways of processing and validating captured data. Knowing that there are several reasons for data capture of existing buildings, the processing and validation are important to achieving the most accurate representation of existing buildings. Table 5.8.2 shows that few (n=3, 2.3%) process their captured building information through only the manual hand design probably using basic manual drawing techniques and equipment (including the use of a drawing board and pens). A total of 49(36.8%) persons agreed to only use computers and their applications to process captured building information. While 8(6.0%) persons did not respond to the question, 73(54.9%) persons declared using both manual and computer packages. This information indicates that there is a significant use of computer applications and packages combined with hand design. The ways the building design professionals validate the captured data are contained in table 5.8.4 and it shows that a few (n=3, 2.3%), validate the results of their data capture through manual methods while computer-aided validation is carried out by 49 (36.8%) persons. The need to validate the processed information is written off by 6(4.5%) persons as they assume the processing of the data is correct. Applying both manual and computer applications to validate processed data is the highest (n=65, 48.9%) while 10(7.5%) persons did not give their responses to the question. The data points to an encouraging practice of validating and processing building data, suggesting the need for accurate results from captured building information needed for redesigning or retrofitting purposes.

Table 5.8.5 Mean and significance percentage values for how processing as-built data impacts the capture process.

Captured as-is/as-built data validation	Frequency	Percentage (%)
Manual hand design	3	2.3
Computer-aided	49	36.8
Both A and B	65	48.9
Usually, don't (assume it is correct)	6	4.5
Unanswered	10	7.5
Total	133	100

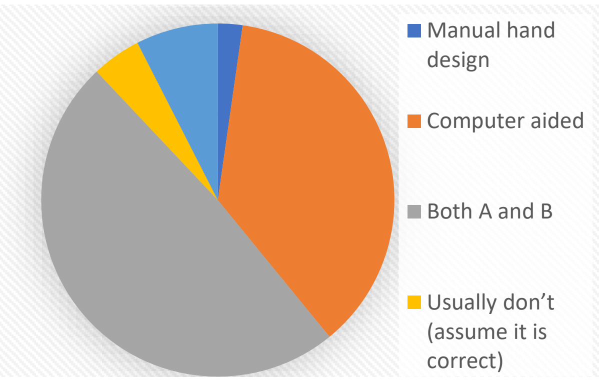


Figure 5.8.1G. How captured as-is data is validated.

In recent times, computer software applications have been embraced in the field of building design to create the three-dimensional (3-D) representation of the built form. The advent of several modelling packages has increased competition among software manufacturers, therefore, posing the opportunity to create unique features for individual software to suit certain design and modelling needs. The survey respondents were asked in question 20 of the design questionnaire what computer design and modelling application they are familiar with, their responses are shown in Figure 5.8.1H.

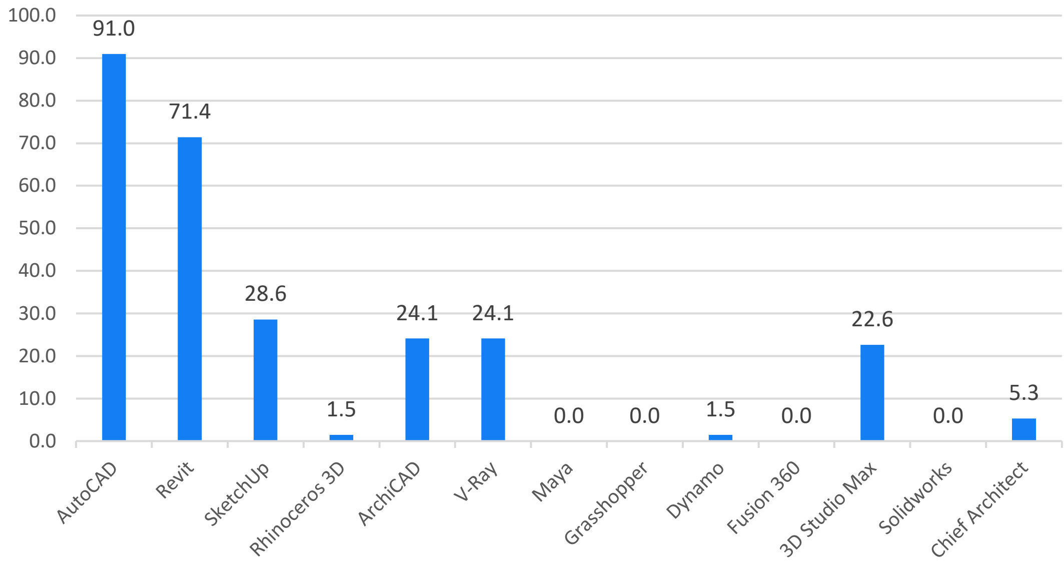


Figure 5.8.1H. Computer software used by design professionals to process building information.

Figure 5.8.1H presents the common computer-enabled design and modelling software identified by the researcher (with an option to add more by the survey respondents). The building designers specified those that they are familiar with. The most frequently used computer package is AutoCAD (n=121, 91%), followed by Revit (n=95, 71.4%) and then google SketchUp (n=38,28.6%). ArchiCAD and V-Ray were both 24.1% (n=32) while at least 2 people each (1.5%) agreed to the use of Rhinoceros and Dynamo followed by Chief Architect at 5.3% (n=7). The data indicates that there is a high use of computer software and encouraging use of 3D modelling packages, agreeing with Figure 5.8.1G. However, there is less emphasis on the performance of the buildings as represented in Figure 5.8.1I

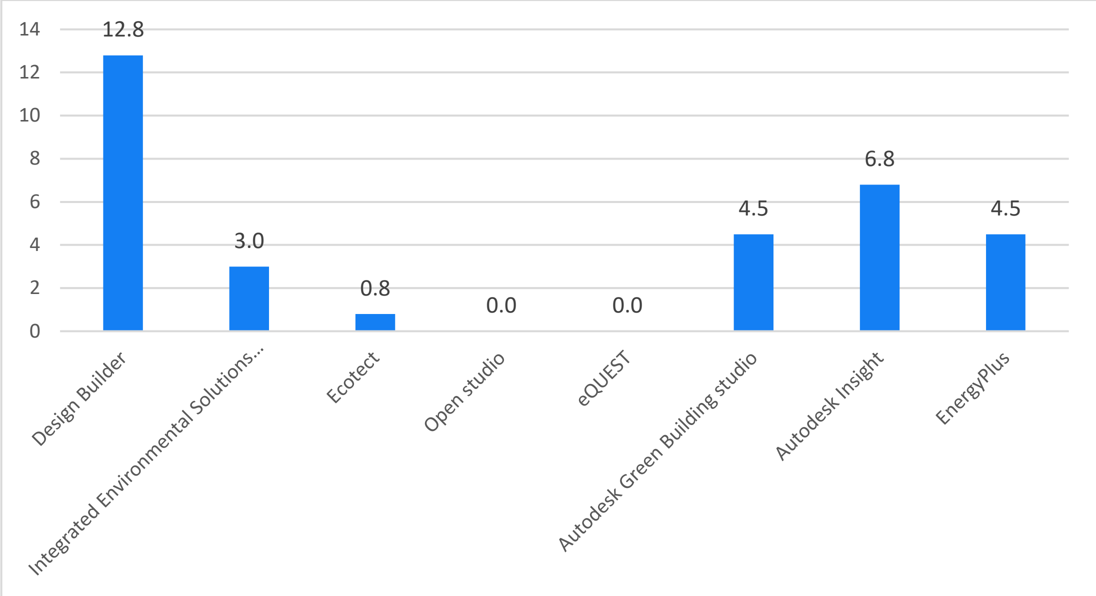


Figure 5.8.1l. Simulation software used by design professionals to process building information.

Figure 5.8.1l shows the common building performance simulation software identified by the researcher while also allowing the respondents to mention others not contained in the list. The survey respondents identified those they are familiar with, and DesignBuilder appeared to be the most used at 12.8% (n=17) followed by Autodesk Insight and EnergyPlus and Autodesk Green Building Studio each having a tie of 4.5% (n=6). Integrated Environmental Solutions Virtual Environment at 3% (n=4) and Ecotect the least use at 0.8% (n=1). While it appears that only a few of the performance software are recognised and used by the building design professionals, some of the survey respondents agreed to the use of more than one of the packages, thereby reducing the percentage of users in the actual sense. The data indicates that building performance evaluation and enhancement has received less attention in the study area, a field that should be properly harnessed and encouraged to create a conducive indoor environment, enhance comfort, increase productivity, improve health, reduce reliance on energy or mechanical devices producing Co_2 and in turn reduce cost.

5.9. Conclusion.

This chapter presented the analysis of the questionnaire survey involving local building design professionals in the study area as one of the methods of data collection adopted in this study. The survey of environmental performance enhancement strategies and building data techniques carried out in Benin City shows the building design professionals' awareness of the relationship between building design, energy efficiency and the environment. The data further suggests that such awareness is not fully utilised by the survey respondents as there is hardly any evidence to support it and because they hardly go back to understand if their designs are performing to expectations. It would have been immensely beneficial considering the power inefficiencies in Nigeria, to enhance comfort and boost productivity in office buildings and in turn reduce operational costs. The advantages provided by the design professionals' awareness of the relationship between building design, energy, and the environment, present the opportunities and potential for meaningful retrofits and to mitigate energy shortage and its cost implication. However, data indicates that while retrofitting and redesigning buildings is not yet a significant activity in the study area, there is a high prospect for retrofitting and redesigning while the few clients who currently do are more attuned to enhancing aesthetics rather than improving comfort and the performance of their buildings, Thus, creating more strain on the unsatisfactory energy situation in the country and an increased reliance on alternative means including the use of air conditioners and generators to achieve the desired comfort.

It is also clear from the data that current practice between the building design professionals and the professionals specialised in the role of building surveying is fragmented in addition to the indication that redesigning and retrofitting jobs are uncommon in the study region. Data also shows that the most frequently known data-capturing techniques by the survey respondents are the manual tape measure (98.5%), Google Earth (89.5%) and photographs (88.7%). Their corresponding uses are tape measure (93.2%), Google Earth (63.2%) and photograph (70.7%) Overall, the three most significant reasons among several others rated for the choice of data capturing tools by the design professionals are the availability of capturing tools (mean=3.99), fit for purpose (mean=3.67) and ease of using the data capturing technique (mean=3.63). While data also indicates that with the numerous data capturing techniques available in recent times, building design professionals are willing to adopt other capturing techniques depending on availability (mean=3.81), improved accuracy (mean=3.75), and a tie of suitability for purpose and cost of the capturing tool (mean=3.73) among other factors. This presents the opportunity to introduce data-capturing techniques that can be used to effect building performance improvement from capturing modelling, analysis and evaluation through a more recent and advanced BIM form compared to the frequently utilised traditional techniques.

In addition to recognising and attesting to the knowledge and use of bioclimatic design initiatives although not fully utilised, findings also show that there are not many evaluations and improvements of buildings. However, the knowledge of the relationship between the environment, comfort and building design by the professionals can be harnessed and utilised through building performance and simulation software to test various retrofit options, thereby encouraging a redesign, and retrofitting of existing buildings that boasts of several advantages compared to reconstruction.

CHAPTER 6

SEMI STRUCTURED INTERVIEW DATA REVIEW AND ANALYSIS

6.1. Introduction

This chapter presents and analyses data relating to interviews with local practitioners conducted as part of this study's data collection. It begins by summarising the planning and contents of the semi-structured interviews, discusses the conduct of the interview, and briefly describes the analyses of the interview data followed by a presentation of the data and findings gathered from the exercise. The summary of the findings birthed the emerging themes discussed and considered for application in the next chapter.

6.2. Summary of the semi-structured Interview.

As stated in Chapter 4, semi-structured interviews are part of the data collection tools used in this study to meet the research aim and objectives. The data collected from the interview helped to explore the context of building information capture and processing from the professional tasked with the responsibility of building surveying in Benin City. The views of the professionals actively involved in the industry are believed to be helpful as they have the characteristics relevant to answering the research questions (Morse, 2016; Yang et al, 2021). Their responses helped in identifying and evaluating the feasibility of various bioclimatic data-capturing techniques needed for improving the environmental performance of existing buildings through simulation.

Regardless of any scope and topic, the semi-structured interviews are mainly designed and conducted such that fundamental questions are open-ended with no particular or uniform behaviour expected for every interview. This also gives leverage to the respondents to express the topic in their opinion and to further inform the researcher (Yin, 2011). The nature of the semi-structured interview is such that the relationship between the interviewer and the interviewee(s) is not strictly scripted rather, it helps to guide respondents toward the focus of the topic (Saunders et al. 2016). As the area of building information and data capturing is currently faced with fast technological advancement that needs to be explored in the study region, the questions contained in the interview were those deduced from the literature and are relevant to achieving the study goals.

As a basis for exploring the subject area, 16 questions are contained in the interviews, starting by asking the respondents to give brief information about the general process of building surveying and/or building data capturing methods. In addition to deductions from the literature necessary to meet the study aim, relevant questions used by Reinhart and Fitz's (2006) study, "*findings from a survey on the current use of daylight simulations in building design*" as well as scrutiny by supervisors helped in shaping the interview questions. See Appendix 3 for the final draft of the interview questions guide.

As listed in the interview guide, the first three questions focused on the general practice of building data capture (surveying) in Nigeria and Benin City, during the Covid-19 pandemic and also considered the future. Questions 4 to 6 are targeted to understand both the view of society and the perception of fellow built environment professionals on the practice of as-built data capture. The questions also explored whether there are any standards or criteria set out by the government or necessary institutions to guide the process of building surveying. Questions 7 to 14 are more topic-specific, focusing on current building information and data capturing methods used, the type of clients, data resolution and the basic levels of details required, variations to data captured and collaboration between the surveyor of a building and the designer for retrofitting purposes. Question 15 inquired some clarification to understand which is more critical between data capturing and data processing, to achieving a more appropriate as-is representation required during renovation or retrofitting projects. Question 16 inquired about information on the availability of mandatory building data-capturing techniques for use by the government or professional body.

6.3. The Interview Process.

Having sought ethical approval (Appendix 1) on the 11th of November 2020 from the University of Salford to secure the well-being of all participants and to ensure that the parties are protected from harm and risks, the preparation for the interviews started. The first phase of the process was to invite the prospective interviewees by telephone and through a third party to take part in the study and to inform them of the research topic, their role, and the value of their contribution to the study. This early stage of the process was useful as it gave the interviewees a clue to the focus of the topic while also giving them ample time to decide on their participation and to agree on a suitable date and time for a formal interview after deciding to take part. The early stage also assisted in recruiting other suitable candidates to participate in the study through a snowballing process. As participation is voluntary, after an informal discussion, six of the prospective interviewees did not respond anymore and after a series of unsuccessful follow-up contacts, they were not interviewed.

The interviews were carried out to complement other data collection methods (the questionnaire and the in-situ site surveying) from the 12th of January 2021 until the 6th of May 2021. As most of the participants were briefed before the formal interviews, the sessions lasted between 40 to 70 minutes. Due to early travel restrictions as a result of rising cases of COVID-19 in the UK in December 2020, the first sets of five interviews were conducted through a telephone call, recorded with a laptop voice recorder, and saved in a password-secured iCloud account with the consent of the participants. All other interviews were conducted face to face in Benin City and recorded through a mobile phone voice recorder with the interviewee's consent and also saved in a password-secured iCloud account. Participants chose their preferred venues and time. Of all the face-to-face meetings three were held in neutral locations including a building site, and a business venue. and the others in their office buildings.

The interview was facilitated using the draft of the questions with follow-up questions to help direct the interviewees to the focus of the research topic. The interviews were conducted in English language, the formal means of education and communication language although the Benin local dialect was sometimes used informally and to help describe certain events and places. Due to time constraints and travel restrictions at the time of the fieldwork, a total of 15 interviews were conducted and transcribed. The interviews are a complimentary data collection tool designed to assist in achieving the research aim of developing a reliable and more cost-effective data capturing, modelling, analysis, and evaluation methodology required for building performance improvement. The numbers are believed to be sufficient to shed enough light to complement the results of the survey questionnaire on the building surveying practice in the region.

6.4. The Interview Analysis.

After the successful conduct of the interviews, they were recorded and saved for further analysis. The semi-structured interviews were designed by the researcher to explore the knowledge and experience of how data from existing buildings are captured to fulfil the research goals. As an exploratory means to an end, the inductive approach of analysing qualitative data ensures that data is collected and explored to identify the emerging themes or issues to follow or concentrate on (Saunders et al. 2016). Furthermore, the inductive approach begins with a clear research purpose (through a clearly defined research question and objectives) and preparation before data collection and analysis so that there is the development of a competent level of knowledge about a research topic.

The analysis of the data started immediately after conducting the first interview and subsequently other interviews. Taking notes and listening to the audio recordings of earlier interviews to note themes, patterns and relationships as an interactive process helped to reorganise, ask, and explain certain questions to subsequent interviewees.

6.4.1. Transcribing the interview data

The audio recordings of the interviews were transcribed, which is produced "as said" in a word-processed format while putting into consideration the tone, manner and other non-verbal or contextual information. The recordings were listened to repeatedly while producing word-processed information by the researcher which lasted over 2 weeks (30th June to 13th July 2020), coded, and saved securely. Transcribing the recordings by the researcher, although cheaper than paying a touch typist or a transcription machine, ensured familiarity with the data and that only sections relevant to the research focus are included to achieve accuracy (Saunders et al, 2016).

6.4.2. Thematic Analysis

Thematic analysis is a generic approach used to analyse qualitative data. As a foundational method of analysis, it is also found in other approaches used in analysing qualitative data. Peculiar to thematic analysis is to search for themes or patterns that occur across a set of interview data in a logical and orderly manner for further analysis in line with the study's research questions (Saunders et al. 2016). Thematic analysis method can be used to analyse both large and smaller qualitative data sets to produce rich descriptions, explanations, and theories. It is a fairly straightforward approach due to its flexibility compared to other approaches that may expend more time ensuring a more particularised approach to data analysis following stringent rules. Due to the few numbers of interview data to be analysed and the exploratory nature of the interview, thematic analysis is adopted for use in this study. It is believed to present a better analysis option because the process of identification of categories and themes is more data-driven and research-focused (Bryman, 2016). Relevant information supporting the research questions was identified from the word-processed transcripts and marked out with a pencil and further grouped into themes.

6.5. Data Presentation

This section presents the analysis of interview data relating to the study. It starts with the general information on respondents and then proceeds to present and analyse the interview data to achieve the research objectives.

In line with the aim of this study which is to provide a methodology to encourage an improved performance of office buildings through reliable and more cost-effective data capturing, modelling, analysis and evaluation techniques, semi-structured interviews were conducted by the researcher along with supporting data from using a questionnaire survey. A sample of fifteen semi-structured interviews focusing on the general practice of data capturing and processing in the study region was successfully conducted due to factors such as time, the confidence the data tends to give, and the type of analysis. All participants interviewed have over 10 years of experience and are registered with the Nigeria Institute of Building (NIOB), the professional body of the building profession in Nigeria. The interviews were conducted upon agreement by the participants who also helped in suggesting the next suitable interviewee in a snowballing process.

As thematic analysis helps to search for emerging themes and codes, presenting general information about the interviewees is also thought useful in generating and defining certain trends. Due to ethical concerns of anonymity and confidentiality, the interviewees are classified as participants, abbreviated as P and represented in Table 6.5

Table 6.5 General information on respondents

SN	Interviewee number	Years of experience	Main sector	Establishment
1	Participant 5	40+	Public	Employed in a government institution and private practice
2	Participant 7	38+	Private	Own firm/Private practice only
3	Participant 1	29+	Public	Academics and private practice
4	Participant 4	21+	Public	Academics and private practice
5	Participant 6	20+	Public	Academics and private practice
6	Participant 3	18+	Public	Academics and private practice
7	Participant 14	18+	Private	Own firm/Private practice only
8	Participant 11	16+	Private	Own firm/Private practice only
9	Participant 2	15+	Public	Academics and private practice
10	Participant 9	14+	Public	Employed in a government institution and private practice
11	Participant 8	13+	Private	Own firm/Private practice only
12	Participant 13	12+	Public	Employed in a government institution and private practice
13	Participant 15	12+	Private	Own firm/Private practice only
14	Participant 10	11+	Public	Employed in a government institution and private practice
15	Participant 12	10+	Public	Employed in a government institution and private practice

Table 6.5 presents the general information about the interviewees. Participant number is assigned according to the conduct of the interviews while the serial numbers (SN) are graded based on the number of years of experience starting with the highest.

It can be deduced from the data as shown in Table 6.5 that the years of experience of the interviewees are between over 10 years and under 41 years. All respondents carry out private practice either by owning a firm or by working in a corporate or government establishment in the capacity of a builder under certain departments including as a building and maintenance officer. The number of years of experience is crucial because it helps to reflect on the actual nature of practice and transition over the years.

Anyanwu (2013), states that the role of some of the professionals in the management of construction projects in Nigeria is confused and misinterpreted such that qualified and appropriate professionals are often not engaged in the design and execution process of building projects. In 2006, the building regulations and laws to regulate the various stages of design and construction came into law in the form of the National Building Code (Section 2.10.2). Section 13.12.2 and 13.12.4 of the NBC state that "*all building works shall be generally supervised by a registered architect and engineer in line with their input*" and "*the management and the execution of the building works including the supervision of the artisans and tradesmen shall be carried out by a registered builder*". (2006, Pg 441). The same applies to the repair, maintenance, or alteration of any existing structure where the building condition report shall be carried out by the professionals involved in design and construction.

Olatunji et al. (2014) describe an 'Architect' as a professional that plan, design, and oversee a building construction project and a builder as the professional responsible for the building production management, construction, and maintenance of buildings. As stated by NBC (2006), both are responsible for carrying out the redesign and retrofit of existing buildings for performance improvement. As highlighted in Chapter 2 of this study, one of the increasingly used methods of building performance improvement is through building modelling and simulation for the analysis and evaluation of various retrofit scenarios. The process requires the use of an as-built representation of the existing structure to achieve desirable results. The need for as-built representation has made building surveying mandatory. The process of building surveying (also captured in the questionnaire survey), is the first question in the interview. Section 6.6 summarises the participants' description of building surveying and the results leading to the themes discussed thereafter.

6.6. Summary results

Table 6.6 below is a summary of the data collected on the description of building surveying in Nigeria through the interviews of 15 building professionals. The participants are all registered with the Nigerian Institute of Building (NIOB) regulated by the Council of Registered Builders of Nigeria (CORBON) beginning with the most experienced participant (P5).

Abbreviations
BS- Building Surveying
NIOB- Nigeria Institute of Building
CORBON- Council of registered builders of Nigeria

Table 6.6. Descriptions of Building Surveying in Nigeria from the Semi-structured Interview.

S/N	Interviewee	Description
1	Participant 5	*There is no building surveying program in Nigeria, most of the BS works are handled by architects, builders, and a few quantity surveyors, mostly rehabilitation of old buildings. Most buildings are not so old, and most people do not bother to renovate the few old ones because of the material (mud). Surveying is not prominent in Nigeria as a whole, most times even when they do, they totally change the architecture, demolish, and rebuild. BS in Nigeria is approached as a new building*
2	Participant 7	*BS is basically to go out there to inspect and investigate a building structure that is earmarked for either renovation, maintenance, or reconstruction.*
3	Participant 1	*BS is not a stand-alone profession in Nigeria, it is embedded in the practice of building technology. It is an area of specialisation and a core aspect of the curriculum of building technology. Therefore, as a registered professional builder, you are well trained, equipped, and qualified to function in all the specialities of the profession including building surveying, statutorily regulated by the NIOB and CORBON*
4	Participant 4	*BS is the analysis and comprehensive assessment of a building from one point to the other, if need be, for renovation, remodelling and other purposes.*

5	Participant 6	*BS is embedded into building technology. BS is done to check the buildability, serviceability, and integrity. BS are construction exercises carried out on a building that requires maintenance commencing from the area where the building is defective including loading, decays, dead load and to look at the compositions and environmental conditions of the building.*
6	Participant 3	*Looking at BS profession in Nigeria, the key professional saddled with the responsibility is called a builder, someone that has passed through the four walls of the higher institution and is statutory registered with the NIOB and CORBON. they carry out work on-site in terms of structure where there is maybe a dilapidated building.*
7	Participant 14	*BS is an aspect of the builder's work by training to ensure that buildings carry out the required performance or function. It is a kind of diagnosis for buildings. BS is accessing the quality of buildings by examining the conditions of the buildings and advice on ways to improve them.*
8	Participant 11	*The BS work in Nigeria is an attachment under the building production practice in Nigeria. A builder undertakes BS works. As a result, BS is not fully practised separately in Nigeria except in rear cases of industrial or government buildings requiring renovation or restructuring.*
9	Participant 2	*BS is a subset of maintenance activities of buildings in Nigeria, it is an option in the building profession. BS are done for maintenance purpose or sales of building and that is the way it has been treated in Nigeria. Generally, in Nigeria, a lot of builders are not specialised with the exception of a few.*
10	Participant 9	*BS has to do with carrying out a physical inspection of a bldg. especially an existing building to be able to see the defects in the building.*
11	Participant 8	*BS is to take statistics of types of buildings, usage of buildings, where such buildings are needed and purposes which such buildings should serve. It also entails building information capture including geometry, volume, and statistics of the population to use a facility.*
12	Participant 13	*BS entails the detailing of an existing structure. BS in construction is not only pertaining to builders though they are the sole professionals, depending on the nature of tasks that needs to be done.*
13	Participant 15	*BS is taking cognisance of every aspect of the building and how those aspect functions, their usefulness as pertaining to their functionality and how you can obtain knowledge of every part of the building. As per maintenance, you must know every part of the building and how they function. But for now, the builder does the role of the BS.*
14	Participant 10	*BS is an act of inspecting an existing building to tell its condition, maybe for a dilapidated structure or an abandoned one, BS will tell you about the condition on what to do so that it can be used.*
15	Participant 12	*BS is to carry out findings about a building for certain aims (valuation or sales, dilapidation, maintenance). Builders are the focal point in carrying out any BS*

Overall, it can be gathered from all 15 participants that:

- In Nigeria, there is no official recognition of the building surveying profession. However, most of the participants (P5, P1, P6, P3, P14, P11, P2,) agrred that it is embedded under the curriculum of the building profession.
- Building surveying is to source information about existing buildings for several reasons including continued construction, maintenance, sales, planning, remodelling, and retrofitting (P5, P7, P1, P4, P6, P14, P2, P9, P8, P13, P15, P10, P12).

The above deductions are in line with the recommendation of the NBC (2006) that the building professionals (builders) are saddled with the responsibility of building production including renovation or retrofitting. They have also described what building surveying (data capture) entails which implies that the participants are the representative targets and generalisations can be inferred from the information they provide to achieve the study goal.

To achieve the study's aim of creating a methodology that is reliable and more cost-effective data capturing, modelling, analysis, and evaluation techniques for improving the performance of office buildings in Benin City, it is vital to focus on the practice of building surveying in the region. Hence, building surveying is sacrosanct in generating vital bioclimatic information about existing buildings before any future work.

6.6.1. Building surveying practice in Benin City

As can be deduced from Table 6.6, the practice of building surveying is not a profession on its own like in some other countries such as the United Kingdom. Thus, it was uneasy for the participants to single out the practice of building surveying from their other activities as building professionals. Although there are indications that the practice of building surveying or building data capture is not yet prominent in Benin City and Nigeria at large, there is optimism for an increased need for as-built information capture in the future. For example,

P5 states that "*Most infrastructures are not so old, most buildings are not more than 30 years in Abuja for example, but few in Benin and Lagos and most people do not bother to renovate them, because of the materials (mud). Surveying is not prominent in Nigeria as a whole, most times even when they do, they totally change the architecture unlike in the UK where the architecture of old buildings of the 1800s are maintained, but over here they demolish and rebuild, and most times it is remodelling, and it does not require surveying. Thus, the building surveying approach in Nigeria is approached as a new building*".

Similarly, in Benin City, P1 states that "*Most buildings we have are private residential buildings, the only area where building surveying is practised is with respect to institutional and corporate buildings which are very few when compared to the number of private residential buildings. Most private housing owners do not bother to carry out formal building surveying, they renovate their buildings bringing a renovator to the site to carry out what they intend to do".*

Notwithstanding, the prospects for more building data capture is increasing. Consider the following statements.

P1 further states that "*Presently, the prospect of building surveying in Nigeria is bright because the Nigeria Institute of Building is mounting mobilization and carrying out publicity on the need for building surveying to be conducted as buildings are constructed and after they are constructed so that we have data for further use for post-delivery maintenance, so far, the NIOB is doing that and in major cities with public and corporate buildings are buying into the need to carry out bldg. surveying from time to time".*

P4 states that "*Building practice in the city is tremendously changing the face of the city as more innovation like frame structures and Industrialized Building System have taken over from the traditional procurement that are still common in other parts of the country".*

P6 states that "*The future of building surveying is high in the country because of the intention of the government to make the buildings abandoned over the years habitable for use".*

The above three statements are similar and agree with the position of most of the interviewees that there are great prospects of building surveying in the study region where the capture of bioclimatic design features in the building could help to model and simulate for building performance improvement. Thus, all participants agreed that the act of building surveying (including the capture of bioclimatic design features) as it stands in the study region requires a site visit either once or more to get the required details depending on the scope of work required. Thus, as the interview was conducted during the COVID-19 pandemic, all participants revealed that it significantly impacted most activities involved with all stages of building development. For several months, there were no physical site visits and when site visits occurred, COVID guidelines were strictly adhered to. None of the participants attested to doing a virtual building data capture opposing the consensus among participants that acquiring building information requires the physical presence of a professional on the building site. One would have considered it helpful to use certain building information capture technology including desktop surveys instead (Sanhudo, 2018). COVID-19 guidelines such as physical distance, use of facemasks and regular washing of hands only allow for building data capture on certain or limited instances while impinging on the operational efficiency of workers on site. For example, according to P12

"Covid generally affected construction including survey, numbers were reduced at the detriment of time and cost due to the covid guidelines including from getting the mobile tape. In BS, you still need to ask a lot of questions and the absence of personnel or risk of the personnel on the ground makes it difficult".

P13 also added that,

"*When covid started, to follow covid guidelines, time and cost were the major impacts of BS by using of more expensive walking tape or laser tape".*

Thus, major setbacks identified by the participants during COVID-19 resulted in "*attendant project time and cost overruns, while disputes among the contractual parties were the order of the day*" according to P4.

Although the practice of building surveying or building information capture is still in its infancy in Nigeria, the process of building information capture in Benin City compared to other parts of Nigeria is on average with few states including Lagos, Abuja, and Port Harcourt at the forefront. While technological advancement in terms of building surveying is slow in the study region compared to developed climes, the participants foresee great prospects due to several factors including improvement in project handling, increased awareness of the need for building surveying, the government's effort to reuse abandoned buildings, increasing building development that would require future retrofits and increased collaboration between building professionals (P4, P1, P2, P8). New and more automated technologies such as laser scanners for data capture are known by some professionals but are not inexpensive to acquire especially when compared to the fewer jobs they would serve. All the participants considered new technologies as a positive step even though it is assumed that it might lead to job shortage, it was argued that such tools can only be maximised in the hands of those with proper knowledge, understanding, and training in the act of building surveying compared to one with just expertise of using a new tool or technology. See some notable statements by the participants below.

P1 "*Technology is helping the profession in the sense that what could not be accessed accurately in the past can be accessed accurately now and the time for delivery of the report by the building surveyor has been enhanced, thus newer technology/software has positively impacted the building surveying process and not negatively because they can only be operated by those who understand the input"*

P3 "*New technologies have positively affected the work. The professionals will not have a good run because of their pay, that is what tends to be quackery, because even if newer technologies and applications are used by others to get the survey done, as you have not been certified to practice that profession. That is another aspect of the profession but once the necessary legislation is put in place, then those things will be checked. Of course, If anybody does that, in terms of using the newer application for BS they will need to contact the right professional to certify and attest to that what he has done is on the right path".*

P8 "*Most of what we have here both in our school is the conventional way of producing building apart from theodolite to give levelling and reading, and AutoCAD. The biggest developer is government, and they are public buildings where we see some innovations that the contractor on site brings in and it is positively affected in terms of time and others. Although it also comes with a negative effect, the positive outweighs the negative because for example, if the person is not an expert in the profession, many may not be able to use the new technologies".*

P10 *"A professional is a professional, and the use of newer technologies is on the positive side to the building surveyors because the result differs or is not as effective from that of those not professionals. It has given speed and ease."*

P11 "*New technologies in every work of life have both positive and negative impacts. In BS, new technologies bring in easy data collection and at the same time render some human operatives redundant".*

P15 "*Yes, technology has been positive to BS, it makes the work easier to the BS, a quark in the field and someone with the knowledge there is a big difference. If you don't have the knowledge of all the technologies, you can't effectively put the technology into use. So, with the knowledge add the technology to it, you get the best".*

Arguably, other professionals in the built environment who know about building data capture could maximise the use of newer technologies as Anyanwu (2013) states that the conflicting roles played between the professionals are notable in construction management projects. This situation is further exacerbated by the absence of a defined role of building surveying as a stand-alone profession in the country even though it is obvious in the NBC that the act of building data capture (building surveying) is the responsibility of the building profession.

Respondents were therefore asked to comment on their perceived understanding of building surveying by the society and by the built environment professionals.

6.6.2. Society and building professionals' understanding of building surveying.

To properly understand whether the process of building information capture is understood in society and by the built environment professionals, one of the questions asked in the draft semi-interview questions is given below with the accompanying responses from the participants shown in table 6.6.2

Question 4: Do you believe that the role of the building surveyor is properly understood among building professionals or society?

Table 6.6.2 Society and building professionals' understanding of building surveying.

S/N	Interviewee	Building professionals	Society
1	Participant 5	*The professionals don't appreciate it, especially the professionals that are selfish.*	*It is not properly understood in society.*
2	Participant 7	*The building professionals are well-informed as well as other built professionals understand the role of the BS.*	*In Abuja and Lagos, it is well understood, unlike in Benin where many clients do not understand the need to contact the appropriate professionals.*
3	Participant 1	*The role of the building surveyor to capture building information is understood by other professionals but not totally embraced.*	*Building owners do not understand the need for building surveying, they would spend the money and time towards retrofitting.*
4	Participant 4	*In Nigeria, the building profession is not properly understood. The National Building Code which defines the roles and set boundaries for various professionals in the building Industry has not been adhered to.*	*It is not properly understood by society.*

5	Participant 6	*Professionals are aware of the role of BS.*	*Clients are aware of the role of BS.*
6	Participant 3	*The role of BS is not properly understood because a lot of people dabble into what they are not trained for, even among builders because there are areas of specialisation within the profession.*	*The role of BS is not also understood by society.*
7	Participant 14	*The building professionals understand the role of the building surveyor and complement each other.*	*Society is where the challenge is, but we are moving forward.*
8	Participant 11	*BS is not pronounced except by professionals in the public sector who knows for instance that they have to do a dilapidated schedule of a building.*	*The private sector or society only consults someone about a perceived defect in a building.*
9	Participant 2	*The unhealthy rivalry between the professions in the built environment in Nigeria makes BS easily argued by other professionals that it is their profession even though it is supposed to be the core responsibility of the registered builder. Professionals know the role but still, get involved in one way or the other even if they are not trained in it.*	*The society does not know about the different building professionals.*
10	Participant 9	*The role is understood by professionals.*	*The role is understood by society.*
11	Participant 8	*Among other building professionals, the builder or BS role has suffered the most in terms of encroachment by other professionals in the built environment, the awareness is growing to see that there is a need for collaboration between the built professionals because the built environment is large enough to accommodate all the professions.*	*Presently, the consciousness is growing through the NIOB that there is a profession of such nature.*
12	Participant 13	*For the professionals, the awareness is still low although some may be practising it knowingly or unknowingly, it is not yet established.*	*No to the society.*
13	Participant 15	*Yes, as per professionals.*	*The society is not that informed about the built environment professionals.*
14	Participant 10	*BS is not practised as it ought to be, the turn-up is low the awareness of BS in Nigeria is low by professionals, many carry out an enquiry about a building but don't know it is BS and don't do it to standard.*	*The awareness of BS in Nigeria in the society coupled with economic reasons that sees that people hardly consult professionals but artisans.*
15	Participant 12	*Professional-wise, we are not there yet.*	*I don't think there is a good orientation concerning BS in society.*

From the above-stated responses, all participants but Participant 6 agreed that the society does not understand building information capture or building surveying as a distinct role of the built environment professional. As NBC outlines the responsibilities of the different built environment professionals. surprisingly, nine (9) of the participants believe that for certain reasons, the professionals do not practice the roles as stipulated. It, therefore, implies the presence of challenges in capturing bioclimatic as-built data if both the society (clients) and professionals are not clear on the role of the building surveyor.

Meanwhile, capturing building information as part of the building profession has also been done in collaboration with other professionals in the Nigerian built environment with the interdisciplinary transfer of data between them on certain occasions or as required. Some of the terms used by the participants to describe the occasions of collaboration include, “in an ideal situation”, “when the need arises”, “in an organised or formal setting”, “based on bill of quantities”, “only when there is no choice” and “dictated by the scope of work” indicating that the collaboration between the professionals is conditional. The nature of the client which most often determines the contract procurement system is significant among the conditions that promote collaboration between professionals or influence how job roles are carried out (Figure 6.6.2).

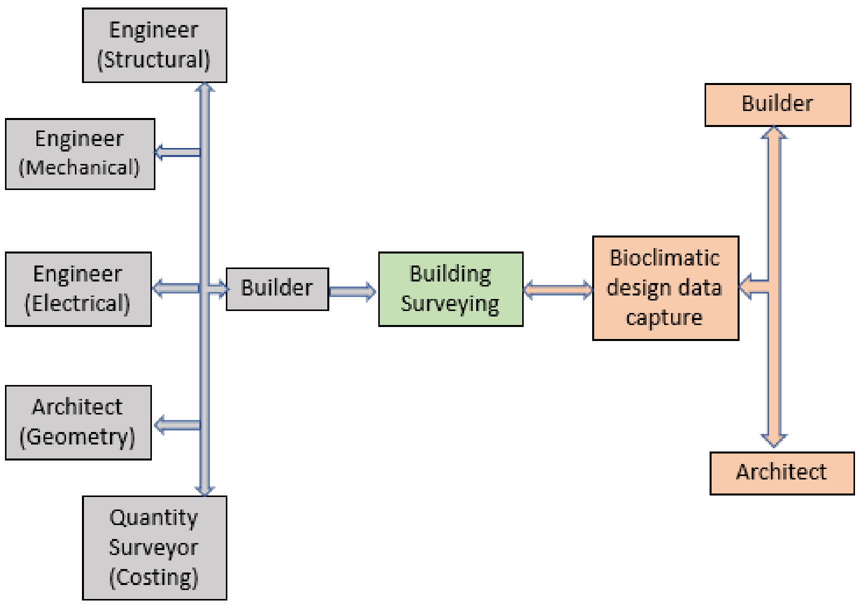


Figure 6.6.2. The “ideal” flow of building information-capture by the various built environment professional

It is contained in the NBC that each professional carries out delegated roles according to their speciality so that there is collaboration within a single project for optimum output as presented in Figure 6.6.2. It therefore implies that the as-built data capture of bioclimatic design characteristics is the role of the builder and the architect given that they are mostly geometric and environmental data as Figure 6.6.2 shows. In addition to adding credibility to responses from the interviewees, it can be deduced from the survey that, its effectiveness in Nigeria is largely dependent on the client. The presence of more multinationals, government and corporate enterprises that may require a proper standard of work ethics, speed, and accuracy has put some states ahead of others during project delivery including building information capture.

6.6.3. Major clients for as-built data capture

To further understand the practice of as-built data capture of bioclimatic design characteristics regarding compliance with professional standards or client requirements, interviewees were asked to share their thoughts on the following with the corresponding responses given in Table 6.6.3.

Question 8: Is there a standard set aside by the government or the surveying institution on a particular standard of work, or is it according to the client's requirement?

Table 6.6.3. Major clients for as-built data capture

S/N	Interviewee	Major clients of as-built data capture
1	Participant 5	*Government and corporate organisations, private is minimal. Many are through procurement*
2	Participant 7	*The private people are more of the clients since government jobs are mainly through influence to win the contract*
3	Participant 1	*BS is most often formally carried out by the government and corporate organisations. These are the regular clients who can afford to pay and recognise the need, and importance of BS documents. With rare cases from fellow professionals.*
4	Participant 4	*Governments, corporate bodies, private and public collaborative projects promoters.*
5	Participant 6	*Private individuals and corporate organisations. But more of private because many buildings are owned by private individuals. Job scouting from the public sector is mainly done by influence and is political in most cases.*
6	Participant 3	*Most of the jobs are from individuals because it takes a lot of lobbying to get institution or government projects.*
7	Participant 14	*Private corporate organisations*
8	Participant 11	*It is mainly corporate organisations. Even when you get from the private sector, they only just require a little information about a defect and not a proper BS because the awareness is not fully there.*
9	Participant 2	*They are government jobs because that is the level where there is awareness. Building surveyors' clients are based or dependent on the procurement system*
10	Participant 9	*For me, I work with the government and that is where I get most of the Jobs.*
11	Participant 8	*Private individuals most times based on level of friendship and previous work done.*

12	Participant 13	*The government sectors and a few corporate institutions*
13	Participant 15	*Private individuals*
14	Participant 10	*Private/Corporate institutions like churches because many of them will go through approval scrutiny with the government due to capacity and use that will require the need for such documents.*
15	Participant 12	*Public sector because the awareness is not really there in the private sector. Followed by corporate institutions*

The above responses imply that depending on the participant's sector and connection, government institutions, corporate or private organisations including schools and churches are the major clients requesting building surveying. Some participants (P1, P2, P11) revealed that the government understand the building contract procurement system and they can fund such projects many of which are public buildings, thereby setting the precedent for the devolved professionals in compliance with the NBC (2006). Some corporate organisations such as churches also follow the appropriate procurement methods of carrying out different job roles and engaging the appropriate professionals due to the process of high scrutiny experienced during approval being that they are public buildings (P10). Private residential buildings are usually the least clients when it comes to contacting the right professionals for carrying out a building survey (P5). Therefore, the size and the nature of work would greatly determine the tools and techniques used in the building data capture before maintenance or retrofitting of existing buildings. The responses from the interviews regarding the data-capturing methods are summarised in section 6.6.4.

6.6.4. Data capturing technique.

The data capturing tools and techniques frequently used in Benin City among the available methods and the reason for adopting them according to the participant's knowledge are given below.

Question 7: I understand that there are several data capture technology used in different parts of the world, what are the ones frequently used in this City and why?

Table 6.6.4. Data capturing technique.

S/N	Interviewee	Data capturing techniques
1	Participant 5	*Tape measure, total station, theodolite, photographs, electronic tape measure, pictures GPS. They appear to be more accurate*
2	Participant 7	*Use of camera to take pictures in and out, use of tape to do physical measurement because it is what is available for use*

3	Participant 1	*Most often, it's a combination of manual (using linear tape and sometimes laser tape) and basic surveying instruments (total station).*
4	Participant 4	*End-Use Data such as bills.*
5	Participant 6	*Different builders with different ideologies adapt different tools available to them*
6	Participant 3	*Theodolite and other traditional methods are used because they are cheaper or because of the cost*
7	Participant 14	*Tape and laser tape measure due to familiarity and expertise.*
8	Participant 11	*Tape and photographs*
9	Participant 2	*Traditional methods are used for physical measurements using tape and rarely the use of laser tape measure. There are laser scanners used all over the world that can be hired but it is very costly and also there are not really many retrofitting works and building surveying work going on in the city*
10	Participant 9	*The measuring tape is mainly used. We can't say it is the most accurate because now some tapes have different calligraphy from each other rather because it is easily available and accessible*
11	Participant 8	*Theodolite, total station, tape and levelling instruments due to availability especially as surveying and geoinformatics have been in place, the instruments are already available.*
12	Participant 13	*Laser tape and walking tape.*
13	Participant 15	*Generally, people use tape due to familiarity and ease of use.*
14	Participant 10	*Basically, it is tape and laser tape, eye gauge. It is less encouragement from both private and government parastatals who do not place much value on it. As professionals also in business, the cost of getting this equipment does not match the pay except government provides for their staff*
15	Participant 12	*Theodolite, total stations, laser tape and walking tape.*

The responses from Section 6.6.4, question 7 reveals that the basic surveying instrument (total station and theodolite) and tape measure are frequently used in Benin city due to availability and cost while the laser tape measure (digital tape) is rarely used in some of the bigger projects. Although all of the respondents agreed that there are no endorsed data capturing techniques for building data capture, there appears to be a consensus that capturing the as-is representation of a structure is a more important process and is critical to achieving a better representation. Against the backdrop that technological advancements using modelling packages can produce a good representation of data with a low level of detail. The participant's views on whether there are standards set aside to achieve the desired output are presented in Section 6.6.5

6.6.5. Building surveying standards

Question: Is there a standard set aside by the government or the surveying institution on a particular standard of work, or is it according to the client's requirement?

Table 6.6.5. Standards of building surveying

S/N	Interviewee	Data capturing techniques
1	Participant 5	*There are minimum standards in place.*
2	Participant 7	*The standard of work applies alongside the training of the profession on how to carry out inspection, investigation and to document.*
3	Participant 1	*The client's requirement is what drives it. The NIOB has a made pronouncement on the need to carry out a condition survey and they have a template for doing such and they derive their power from the NBC. The NBC is a national document, and it is not adopted in most of the states, and it is only in the states where it is adopted that clients are constrained to secure the service of the builder to prepare a BS document but in other states where such law has not been promulgated, or adopted, people, go about doing what they are doing.*
4	Participant 4	*Yes. There are various standards established by relevant regulatory bodies to guide the professionals operating within the system. Most often in Nigeria, the clients influence the operators with their personal requirements.*
5	Participant 6	*Every regulatory body is regulated by the law. There is a standard set aside by the NIOB. However, the wrong professionals dabble into other roles and cannot be held accountable if the role is not done in line with their professional practice. For example, you can only persecute an Architect with the ARCON code of conduct whereas the document does not empower them to build.*
6	Participant 3	*There is no standard but client's requirements, some can be based on the traditional method, some can be based on procurement, and some can be based on a project management approach, there is no standard on how deep on the professionals, as the job comes you just go about it. But generally, the government has their standard set aside which depends, from institution to institution.*
7	Participant 14	*There are standards and not what the client requires.*
8	Participant 11	*Often to the client's requirement.*
9	Participant 2	*Depending on the scope of work, there are particular standards for example procurement acts, following laid down rules in contract awards, and even in contract execution, you follow laid down codes, in the construction process.*
10	Participant 9	*We have a standard and a building code that all builders usually work along with, we don't work according to the client's directive rather you are a professional in it and are in the position to advise the client on what ought to be in line with the building code.*
11	Participant 8	*There is a building code that has not been domesticated in Benin City compared to some other parts of the country. Before the building code, there was nothing on ground. BS is a profession of its own under Building as a course, the building code did not envisage the*

		future, it was done like it was still in the past, BS is supposed to be such that throughout the entire building cycle to know what works and what does not, but of the old way of producing a building such that architects for architectural drawings, electrical for electrical drawings, structural for structural drawings, a builder who is a production manager on site etc, and going by that, the same mistake we are avoiding is what we are making, The truth is there are no much of people in the building/BS profession and many people who have no business with buildings are involved with buildings. Because with a lot of people in the profession, for example, lately, estate managers/valuers requested lawyers not to do building agreements or manage properties anymore because they are becoming much, with the innovation and specialist courses in the building industry today, there may be adherence standards. In a nutshell, the standard set aside is not followed accurately so he who pays the piper dictates the tunes. (Following client's requirement)
12	Participant 13	*We have a standard when it comes to building construction methodology, we follow the British standard, but we also have our professional body which regulates every professional. The client who is not a professional might give their brief; it is the responsibility of a professional to balance.*
13	Participant 15	*There are standards, the CORBON that the Builder works with.*
14	Participant 10	*I try to defend my profession rather than please the client and in doing that the client may not have his view in full even though I try to work with what he wants, but also consider my profession which is my standard*
15	Participant 12	*A profession is something you hold with high esteem and there are bodies whose regulations guide the profession. We have CORBON and NIOB*

Except for Participant 11, the responses given in Table 6.6.5 indicates that there are minimum standards given by the NIOB, CORBON and the NBC (2006) that must be adhered to for every building surveying job. However, many of the respondents (P1, P4, P6, P3, P8) did not forget to mention that although there are standards set aside by the regulating body of the profession, the client's requirement is the driving force to what is obtainable especially due to factors including lack of enforcement of the standards by the government. While it is understandable that the responses were more focused on the general practice of building rather than on building surveying in particular due to its absence as a profession on its own, Participants 3 and 2 reiterated that the nature of the contract including the scope and procurement system significantly informs how any construction job is conducted. Note that Procurement is the organisational structure or process undertaken by clients (the most important stakeholder when considering project performance) to bring about the construction or refurbishment of construction projects (Muhammad et al. 2015; Bello, 2018). The procurement method reflects certain considerations of which time, cost and quality are given priority considerations, which are the key performance indicators and the emerging themes driven by the professional's experience in practice.

6.7. Emerging Themes

The emerging themes are those deduced from the respondents' answers to the questions asked during the interview. The questions are critical to achieving the research aim and revolve around factors leading to the general practice of an as-built survey of bioclimatic design features in the study region, which involve understanding and collaboration by built environment professionals, as-built data capturing techniques and reasons for their adoption and available compliance or regulations. While the general practice is dependent on the perception of society and the professionals, the three subcategories are factors that bother on the project procurement or contract methods as represented in Figure 6.7.

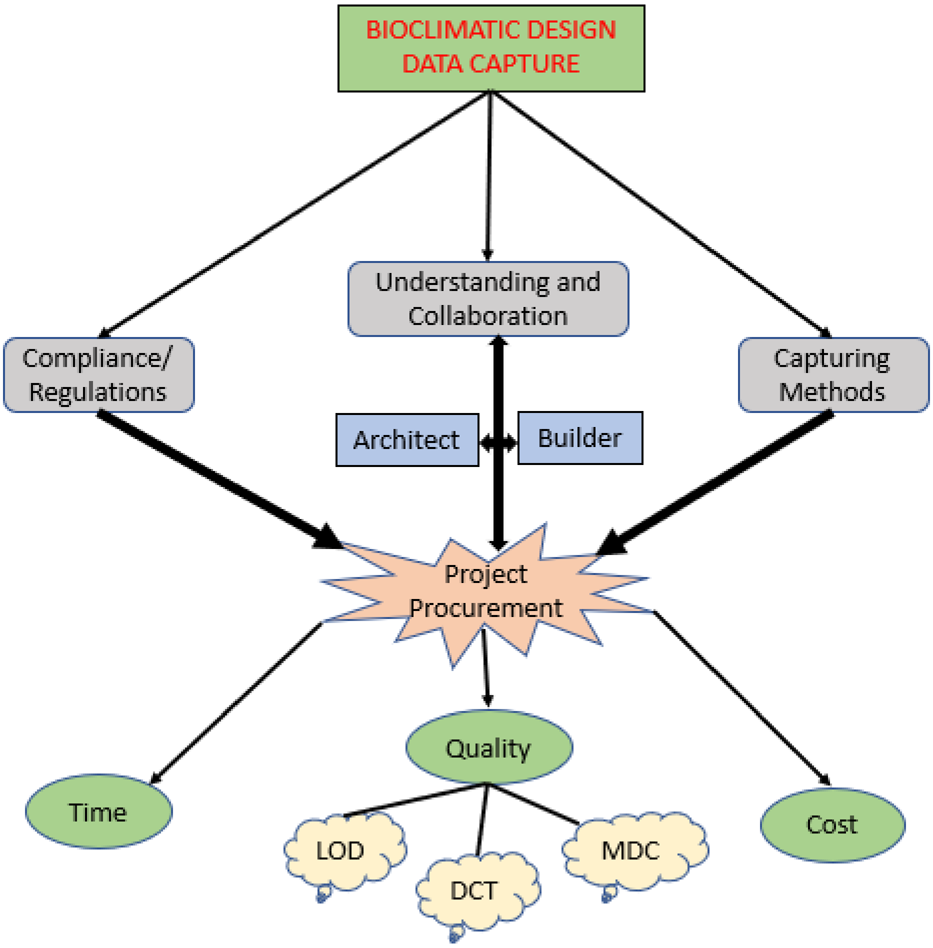


Figure 6.7. The conceptual flow of the interview results leading to the emerging themes.

The results of the interviews are very much in line with Akanni et al. (2015)'s view stating that *"Nigeria's construction industry is a wide range of loosely integrated organizations that* *collectively construct, alter, and repair a broad range of different buildings*" Pg 91. When carrying out any project, factors such as time, cost, and standard of quality are key performance criteria depending on the appropriateness of the chosen contract procurement system, for achieving project goals and meeting client requirements (Ayodele, 2017; Akanni et al. 2015; Bello, 2018). Similarly, the study aims to develop a methodology that would help to encourage the improvement of the performance of office buildings that also hinge on such factors through reliable and more cost-effective data capturing, modelling, analysis, and evaluation techniques. To start with, the results of the interviews indicate, as opposed to what is expected in the NBC (2006) that the fragmentation and other irregularities experienced in the Nigerian construction industry are due to the project procurement system. Studies (Dissanayaka and Kumaraswamy, 1998; Bello, 2018; Akanni et al. 2015) show that the inappropriateness of the procurement system is one of the main reasons leading to project inefficiency and engagement of the appropriate professional. While there are three main project procurement types, the success of any project is evaluated in terms of time, quality and cost. Figure 6.7 further expatiates on quality being accuracy based on the level of details, accuracy based on the data capture technology, and accuracy based on the mode of data capture. The subcategories are briefly discussed next.

6.7.1. Project procurement system in Nigeria

The public sector is the major client of the Nigerian construction industry where traditionally, building design and construction are handled in separate phases by separate teams (design and construction teams). Procurement is the organisational structure or process undertaken by clients (the most important stakeholder when considering project performance) to bring about the construction or refurbishment of building projects (Muhammad et al. 2015; Bello, 2018). The procurement method reflects certain considerations of which time, cost and quality are given priority consideration.

- The design team consist of consultants such as architects or engineers while;
- The construction team consists mainly of contractors and subcontractors.

In the case of as-built data capture of bioclimatic design features of a building assuming a correct scenario, the architect remains the designer and the builder, the contractor or subcontractor. Given that every construction or retrofitting project has its unique peculiarities, any successful project performance is a product of good contract procurement measured in relation to critical success factors of time, cost and quality (Muhammad et al. 2015; Bello, 2018; Ayodele, 2017) and they are discussed next.

6.7.2. Quality

Quality is a member of the three significant performance indicators for construction projects usually known as the iron 'triangle', the others being time and cost. Due to the subjective nature of quality, it varies from client to client such that several project characteristics including project type, size, availability of materials, innovation and client characteristics are also variables that help the client to choose an appropriate procurement method (Ogunsanmi, 2013). Quality is dependent on the availability and effectiveness of project participants and project management factors and is achieved when it conforms to the specification of the project (Bello, 2018; Omoniri and Lawal, 2014). Quality cannot be justified for this study by merely developing reliable and more cost-effective data capturing, modelling, analysis, and evaluation techniques necessary for building performance improvement. To achieve quality, there must be standards and specifications set aside that must be met. In most cases, these are dictated in the contract document but must conform to the client and regulatory authorities (Ayodele, 2017; Omoniri and Lawal, 2014). According to the result from the interviews, although there is no separate body for building surveying, there is a standard of work spelt out by the NIOB and the NBC (2006) concerning building condition surveys. Several limitations to the adoption of the NBC invariably impact the quality of work. Whereas reliable or accurate data recorded from appropriate surveying practices could facilitate and contribute to more informed and contextualised environmentally friendly retrofitting solutions. Thus, quality in terms of building surveying is the degree of accuracy of data captured. Given that all participants consider the capture of as-built information as a key consideration to achieving accuracy because the more reliable the building information captured, the more definite its modelling, analysis and evaluation would appear. Meanwhile, as deduced in chapter three, the accuracy of any captured building information is affected by the technology or technique used for the data capture, the minimum level of details it can capture and the mode of capture or environmental factors.

6.7.2.1. Accuracy based on data capturing technology:

Hence the traditional method using the measuring tape is the main data capture technology used in the city, as earlier described in Chapter 3, the process is time-consuming and error-prone. Sometimes there are slight variations in the calibration of different measuring tapes. The use of a more enhanced laser tape measuring tool appears more advantageous in this regard because it is more precise. With the variation and error margin presented by the manual tape measuring tool, it did not prevent its preference as the choice of data capturing technique stated by the interviewees to be accurate.

6.7.2.2. Accuracy based on the minimum level of details:

The consensus by all 15 interviewees is that a millimetre is the minimum level of detail usually used both in design, construction and for as-built information capture of buildings in Benin City and Nigeria at large. The manual tape measure, as the most frequently used data capturing tool however can capture this minimum level of details needed for representing as-built information, modelling, analysis, and evaluation.

6.7.2.3. Accuracy based on the mode of data capture

The use of tape measure requires visible and direct contact with all surfaces that requires capturing and could lead to more variations in the information captured if there is no clear line between the two points of capture or if there is a break between the two points. Also, most tapes have limited length.

Knowing the aforementioned factors about the manual tape measure, it is still recommended by most of the professionals (P1, P2, P5, P7, P8, P9, P15) but with a combination of other techniques such as photos and GPS provided the job is done. While a few participants (P2, P9) advised that larger projects should make use of the laser tape measuring tool, some others (P1, P3, P14) advised the adoption of the project management approach. The approach involves contracting a firm with several professionals within its organizational structure to carry out a project. All these are suggested by the participants to reduce the cost to them and the clients likewise.

6.7.3. Cost

In conjunction with quality and time, the cost is one of the three factors used to measure a project's success, based on the degree of achievement of project objectives (Omoniri and Lawal, 2014). Cost performance is a measure of the degree to which general conditions aid project fulfilment given an estimated budget (Bello, 2018). As this study focuses on providing a methodology for building data capture, modelling, evaluation, and analysis to encourage the improvement of office building performance, cost-effectiveness is as critical as developing a reliable methodology, hence a key focus of the interview. Several data capturing techniques have been identified in chapter 3 of this study which may be fit for purpose but cost and availability of the data capturing techniques are critical factors considered by the interviewees for adopting the manual tape measuring technique. The two major cost-related considerations deduced are.

- The tape as a manual data-capturing technique is cheap and efficient for smaller projects. Even for large and medium projects the interviewees at the expense of time still consider it preferable or either the more expensive laser tape or walking tape, because it is relatively cheaper compared to other data-capturing technologies like laser scanners.
- There are not many buildings surveying jobs, thus, it is unprofitable to hugely invest in data-capturing technologies that are only used occasionally thereby giving rise to less return on investment.

Participant 2 stated explicitly that "*Traditional methods are used for physical measurements using tape and rarely the use of laser tape measure and taking photographs of key areas. There are laser scanners used all over the world now in Nigeria that can be hired but it is very costly and also there are not many retrofitting works* *and building surveying work going on in the city."* It, therefore, implies that cost-effectiveness is achieved at the expense of time.

6.7.4. Time

For every building project, time is of great importance and the third member of the iron triangle that determines the success of the project. In terms of building data capture, the focus of this study and in line with the purpose of the interview, time remains a key consideration in the responses given by the interviewees. The consensus by the interviewees for the adoption of the manual tape measure, especially when used in large and medium-scale projects does not mean that it is fast. In fact, using the manual tape measure for as-built information capture is a time-consuming process as earlier stated in Chapter 3 of this study. What can be deduced from the responses is that the time is compensated for with cost and vice versa. Participant 1 made it clear by stating that "*Manual in itself is not good enough in terms of time but the time you will use to input the data may be more but the processing, the time gained in the manual will be lost in the computation. The manual may be less costly but disadvantaged by time."*. Similarly, Participant 5 stated that "*Every project is relative to time whether small medium or large-scale jobs. Clients try to avoid cost and thus cost is a driving factor and is now dependent on the professional however many professionals also try to cut corners".*

Although there is general agreement about it being at the discretion of the building professionals on how to go about their job depending on the project scale, if not but to cut cost, the interviewees are well aware that the manual method is time-consuming and welcome newer or more enhanced techniques with training where possible. In the same view, engaging a firm with different professionals in the organizational structure will also be adjudged by the three factors of time, cost, and quality (accuracy of data captured to create the as-is representation) of project delivery.

6.8. Conclusion

This chapter presented and analysed data from semi-structured interviews carried out as one of the data collection tools used in achieving the aim and objectives of this study. It commenced by explaining the structure of the interview, how it was conducted and analysed the results before discussing the emerging themes from the analysis.

The data shows that all the interviewees practice building information capture whether or not they are employed in an organisation. The data shows that the practices of proper building surveying are almost non-existent in Nigeria, nor is there a recognised building surveying profession compared to the developed climes. Compared to other parts of Nigeria, Benin City is on average in terms of building project delivery. Despite technological advancements with several new data capturing techniques, the use of manual tape measure appears to be the most adopted for use giving rise to the three emerging themes of project success delivery of time, quality, and cost.

The method of project procurement which is most often decided by the client greatly directs the practice of building surveying on a project and invariably determines the quality, time, and cost of the project. Quality in this study is a product of accuracy and significantly affects the building surveying process and technique.

In line with findings from the questionnaire survey, the traditional tape measure which is not the most accurate is the preferred and frequently adopted technique used in data capturing of as-built representation owing to cost. The cost-benefit of adopting the tape measure is either due to it being a cheaper data-capturing tool or due to fewer data capturing (building surveying) jobs for retrofits, thereby impinging other more efficient but more expensive tools for data capture. Time as the third emerging theme is a factor considered but given less attention when adopting the time-consuming manual tape measure as a preferred choice of data-capturing technique. The professionals have to look for ways around it either at the expense of cost or by combining it with other data-capturing techniques. Having known the aforementioned, the outcome of the interviews suggests however that the interviewees are willing to embrace new techniques if provided with the necessary training.

With the findings of this interview in conjunction with findings from the analysis of the questionnaire survey of the building design professionals, there is a need for developing a reliable methodology for data capturing. Considering the fragmented nature of the built environment professionals in Nigeria, especially in this era of BIM, and the absence of an independent profession of building surveying, a methodology suitable for carrying out building survey modelling, analysis and evaluation is necessary to encourage performance improvement. Given the economic stance of the study region, such a methodology must be reliable, time-efficient, and cost-effective as compared to the current adopted techniques. It would further encourage building performance improvement and the reuse of old buildings in the fast-paced developing City and changing climate. In response, the next chapter carries out in-situ measurement and considers resolutions of both the interviews and the analysis of the questionnaire to adopt, compare and develop a suitable methodology from data capturing to evaluation required for building performance improvement.

CHAPTER 7

BUILDING DATA CAPTURE, MODELLING, ANALYSIS, AND EVALUATION

7.1. Introduction

This chapter describes the stages involved in achieving the research aim of providing a reliable methodology to capture, model, analyse and evaluate building information before possible use for performance improvement and testing of strategies. It achieves that by evaluating current practices derived from analysis of interviews and questionnaire surveys carried out in the study region to create a cost-effective and reliable methodology for data capture, modelling, analysis, and evaluation using the DesignBuilder simulation tool. It initially used the current techniques in the study region to capture as-is data of three case study office buildings to evaluate the process and to create a model to understand their thermal performance before using a different case study to develop an alternative.

This chapter starts by describing the case study buildings, and their data-capturing process including measurement and observational survey, photogrammetry, modelling, and the analysis of their thermal performance in terms of solar gains and operative temperature. The major research findings in addition to forming the basis for achieving the research aim, buttress, direct and inform the course of action leading to the development of a methodology for as-built data capture, modelling, analysis, and evaluation of buildings with bioclimatic design perspectives. The methodology was also trialled in a photogrammetric process using the smartphone to create a prototype model and compare it to a model created from measurements using the manual tape measuring tool. The suitability of exploring the developed methodology with a smartphone in a photogrammetric process is in relation to several contextual factors including quality, cost, time, availability, and lesser number of personnel. The model created with the aid of the developed methodology helped to utilise the DesignBuilder graphical user interface that uses the EnergyPlus simulation engine to analyse, evaluate, and validate the as-built representation, a process critical to testing strategies for environmental performance enhancement about thermal comfort. The validation of the developed methodology from both models confirms that the slight variation between the measured dimensions and those derived from the photogrammetric has a negligible impact on thermal comfort and is thus reliable.

7.2. Case study buildings

Due to the cross-sectional time horizon of this study, three case study buildings were assessed as part of the data collection in the study region. The buildings are named building A, B and C for easy reference and anonymity and they are described in the next subsections.

7.2.1. Case study building A

Building A is one of the three case buildings assessed for this study. The building has three floors and each of the floors is occupied by the Local, State, and Federal Governments respectively. Access to the whole building was not possible but for three office spaces on the second floor. The building is said to have recently undergone refurbishment and has been occupied since December 2020. The building is located around the centre of the study region and although the building has recently been renovated, benefits from several air-conditioning units for cooling that requires an enormous amount of energy to run and at a significant cost. There was also no access to the original footprint of the building. Excerpts of the building are shown in Figure 7.2.1

Figure 7.2.1. Case study building A

7.2.2. Case study building B

Building B is a Local Government Secretariat building, consisting of office spaces spread across a single story. It is located in one of the Local Government Areas that make up Benin City and has extensive use of air conditioners. Access was also restricted to three office spaces as occupants of some of the offices were absent at the time of the visit. The building was last constructed or renovated in the year 2000. Access to the original drawings of the building was not possible. Figure 7.2.2 shows the exterior part of the building where access was granted.

Figure 7.2.2. Case study building B

7.2.3. Case study building C

Building C is a privately owned building that is spread across three floors. The ground floor is a shop and is surrounded by similar buildings and buildings made of mud reflecting the evolvement of commerce nearer the core of the city as stated in Chapter 2. It is located on one of the adjourning roads to the centre of Benin City. The other two floors are office buildings however, access was only granted to one wing of the first floor comprising four office spaces and a reception area. There was no information on when the building was constructed or last renovated nor was the original building documentation accessed. The exterior of the building showing some surrounding buildings is shown in Figure 7.2.3.

Figure 7.2.3. Case study building C

7.3. Capture Technology of Bioclimatic Design Features

As stated in Chapter 3 of this study, there are various techniques used by built environment professionals to capture building information in different parts of the world. However, each capturing tool has its peculiarities that depend on the required accuracy and need for data. As the aim of data capture in this study is geared towards the bioclimatic design characteristics of existing buildings, the design variables identified in Chapter 2 including building geometry, sun path and envelope design were captured. Predominantly used in the study region for geometric data capture is the tape measuring tool, which manually records the dimensions of different building components, including doors, windows, walls, facades, and other spatial features (Jung et al. 2014). It is used by holding the measuring device in direct contact from one point of the building while manually taking the measurement to another visible point of interest and at an instance. The orientation was captured using the compass application on the iPhone and in addition, remotely comparing the results to those derived from google earth while the building envelope properties were noted and captured in photos. Although other capturing techniques could be effective and viable for use as alternatives or to complement the capturing tool used in the study region if trialled, the need for data capture is vital to its adoption. In line with achieving the study aim of capturing, modelling, analysing, and evaluating building information required for improving the performance of office buildings, this study focuses mainly on the data capture of interior spaces which is critical to achieving indoor thermal comfort and reducing energy demand in buildings. Thus, acquiring and reconstructing the indoor built environment is a critical aspect of this study, especially with the unavailability of original blueprints of case study buildings. Compared to acquiring the exterior of buildings, the interior is more challenging due to several factors including the problem of visibility arising from interconnected rooms/spaces and poor texture walls (Pintore et al, 2014). While there are 3D (laser scanning and image-based) approaches, they tend to require high expertise and specialised devices (cameras/scanners and computers) that are often not inexpensive nor require computer experts (Sankar and Seitz, 2012; Pintore et al, 2020). Semi-automatic methods that simplify the capturing process tends to be faster and more cost-effective while there has been a growing interest in automatic 3D reconstruction and modelling of indoor spaces (Jung et al. 2014; Pintore et al, 2014;2020). Thus, the economic situation of Nigeria necessitates that the means of building data capture, modelling and analysis for its environmental performance improvement requires a cost-effective approach. Of the several building data-capturing techniques identified in Chapter 3, the frequently adopted technique is the manual tape measuring tool. Its cost-effectiveness has been earlier identified as an important factor for its adoption from the analysis of other data collection methods (survey questionnaires and interviews) used to help achieve this study's aim and objectives. Therefore, putting the economic situation of Nigeria into perspective requires that adopting an alternative data capturing, modelling analysis and evaluation methodology must be cost-effective and require less time, unlike the manual tape measuring tool. Evaluating the performance of the building is a critical step before testing or proposing improvement strategies as is the case of this study. While photogrammetry initially appeared more appropriate to adopt for use in the study area, an initial method of measurement and observational survey were carried out on case study office buildings A, B and C, modelled, analysed, and evaluated to ascertain the current buildings' performance.

7.3.1. Measurement and Observational Survey

In the first instance, the three case study buildings were measured using both the 100m manual hand-held measuring tape, and the digital tape measuring tool (an in-phone application) while being supported by taking several photos. The manual tape measure which is predominantly used in the study region was used to take measurements (length and breadth) of two points, visible from each other and with the help of extra personnel. An in-phone application, "measure", on an iPhone was used as a form of digital tape measure to take measurements of points that were not easily accessible including floor-to-ceiling height of interior spaces. Free-hand sketches of the building and target spaces aided in recording the dimensions on paper while several photographs showing all the interior parts and some useful parts of the building's exterior were captured which helped to piece them together. The captured data were quickly put together using Revit and the floor plans are shown in figures 7.3.1A, 7.3.1B, and 7.3.1C.

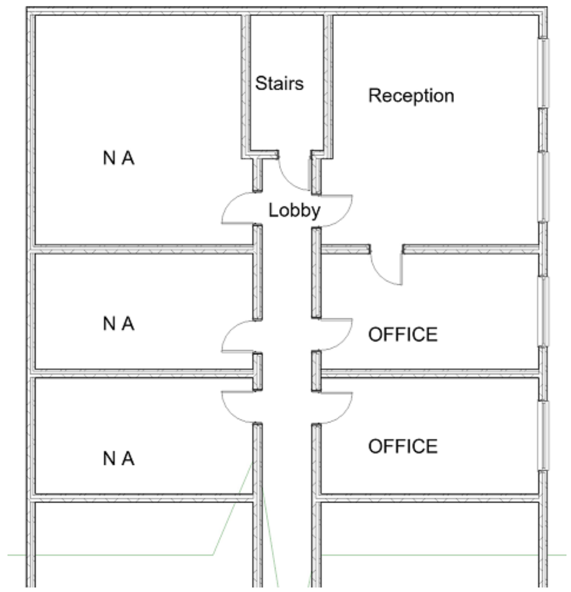


Figure 7.3.1A. Plan of case study building A.

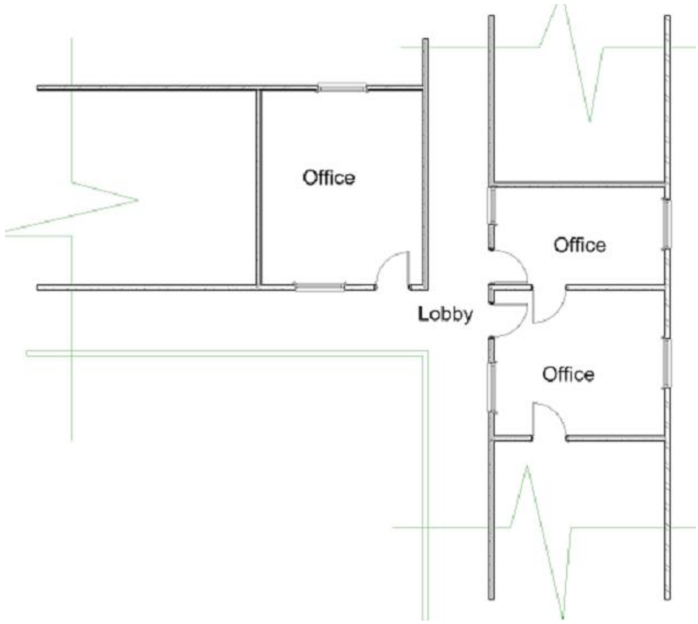


Figure 7.3.1B. Plan of case study building B.

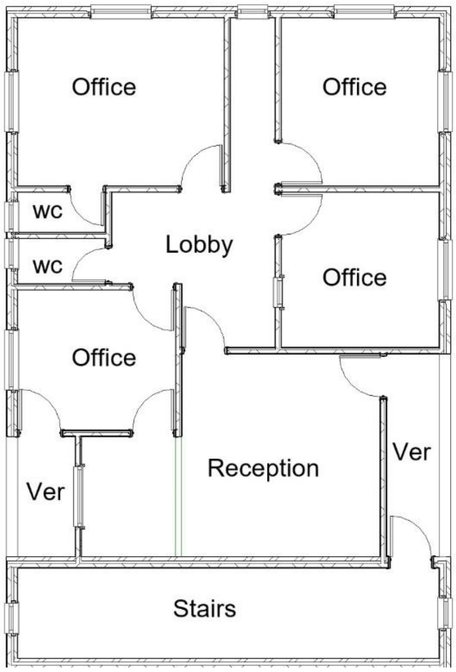


Figure 7.3.1C. Plan of case study building C.

Figures 7.3.1A, 7.3.1B and 7.3.1C are the floor plans assembled from data captured from the case study buildings through the earlier described measurement and observational survey. The aforementioned figures are for visualization before modelling for energy assessment, analysis, and evaluation ready for testing of retrofit alternatives. They can also be imported into energy modelling and simulation applications to make the process of model creation easier and faster. All necessary details of building C were captured in about 30 minutes, and about 15 minutes to measure each of the accessible office spaces in both buildings A and B.

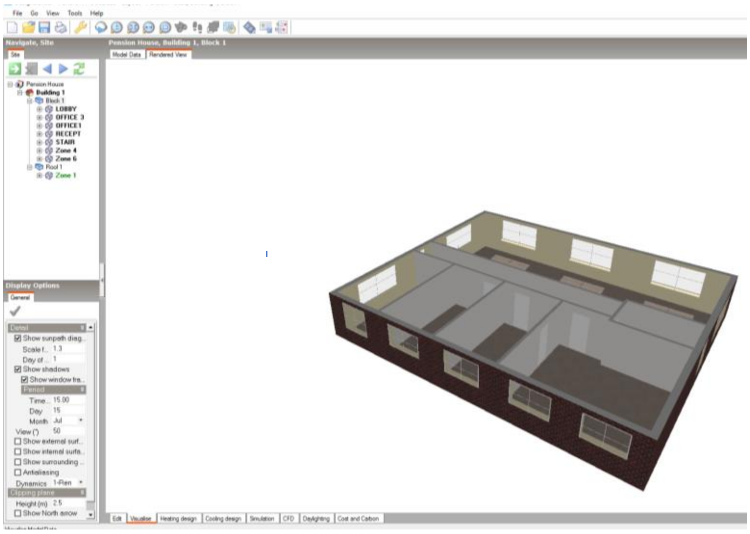
7.3.2. Photogrammetric Survey

After the measurement and observational survey, there was also an attempt to adopt the photogrammetric surveying method due to its ability to make measurements from photographs. Photogrammetry, as described in Chapter 3 tends to meet the study aim of a reliable and cost-effective approach to capturing as-built data needed for modelling towards performance improvement because it involves reconstructing 3D objects from 2D photos while it is processed with photogrammetric software (Rocha et al. 2020). Instead of using specialist and even costly cameras that may require some degree of expertise for their calibration, iPhone cameras were trialled for this study's photogrammetric process. Two iPhone models (7 Plus and X) were used to take photographs of the interior spaces following the photogrammetric principles of overlapping images (Rocha et al. 2020; Bayyati, 2017). It took about 15 minutes to take photos of the five office spaces in building C and about 5 minutes each for buildings A and building B respectively. Attempts to create a 3D reconstruction from the captured images with Meshroom and ReCap Pro proved difficult. Meshroom for photogrammetry is a free open-source three-dimensional (3D) reconstruction software based on AliceVision Framework. The AliceVision photogrammetric framework provides 3D reconstruction and camera algorithms and comes up with a strong software basis that can be tested, analysed, and reused (Meshroom Manual, 2021). According to the Autodesk website (2022), ReCap Pro is an Autodesk software used by designers and engineers to capture high-quality, detailed real-world assets to understand and evaluate the conditions of existing buildings and deliver a point cloud mesh to aid BIM processing. It comes with a subscription but is free to students and educators. Although it is difficult to ascertain the inability for the 3D reconstruction of the photos captured in a photogrammetry process trialled, there are implications that it could be based on the absence of the non-inexpensive alternatives of either specialist cameras to capture the photos or cloud and GPU (Graphics Processing Unit) accelerated computation or both (Pintore et al. 2020). An earlier study (Pintore et al. 2014) also highlighted some of the difficulties in reconstructing internal environments including visibility and texture-poor walls that complicate image-based processing that are not features of outdoor reconstruction. Recently, 3D-model reconstruction of the indoor environment from acquired data (images or 3D point clouds) using smartphones is thriving due to complementing scientific, technological and market trends in computer graphics coupled with its widespread availability (Pintore et al. 2020). They further reiterated that the rapid increase in high-fidelity visual and 3Dsensors on smartphones or their associated applications has made options for large data processing requiring expensive cloud and GPU-assisted computation cost-effective and a novel means of visual exploration.

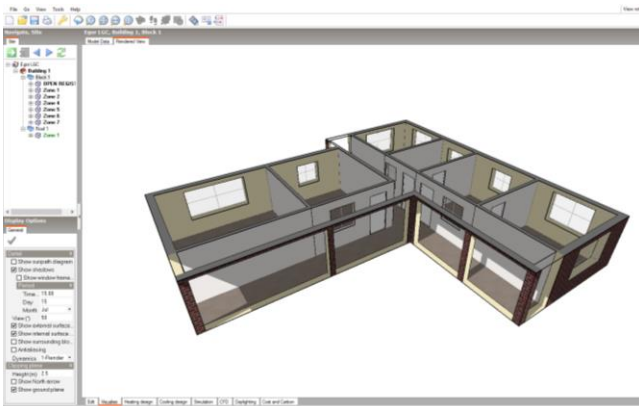
In an attempt to create an alternative to the measurement and observational survey method with the extensive use of the tape measuring tool coupled with the challenging model creation from photos requiring onerous modelling stages, a more recent version of the iPhone was also trialled. It was adopted after the period of data collection in the study region and the workflow of the as-built data capture and modelling of the indoor environment of buildings is demonstrated with a different building but in a process that is applicable anywhere, including the study region. Its use is in line with the study's aim as it shows the various stages involved in creating a cost-effective and reliable methodology for data capturing and modelling existing buildings for building performance improvement through simulation for testing retrofit options. The methodology is described in the later part of this chapter, after the three-dimensional (3D) modelling of captured data discussed next.

7.4. Three-Dimensional (3D) Modelling

Geomatics as the science that deals with the collection, analysis and interpretation of earth's surface data seek to model entities as they exist in reality thus digital modelling helps to provide a representation or simulation of the non-existing entity in reality (Thomson, 2016). Creating 3D models manually requires high knowledge input and rich semantic information to enable the operator to effectively produce the required geometry and in a valuable process for documentation and interpretation (Tang et al. 2010). Such semantic information including materials and paints are hardly noticeable when tracing from point clouds as with 2D CAD plans similar to Figures 7.3.1A, 7.3.1B and 7.3.1C. For valuable interpretation, analysis and testing of strategies, As earlier justified in Chapter 4, DesignBuilder was adopted in this study. It provides advanced tools to model and quantify building performance in an easy-to-use graphical user interface with EnergyPlus as the simulation engine. According to the DesignBuilder website (2022), it can generate a wide range of outputs to help compare design alternatives, optimise buildings at any design stage, model complex buildings, import existing CAD design, generate impressive rendered images, and simplify EnergyPlus thermal simulation. It was used to model the accessible floors with particular emphasis on the captured office spaces of the three case-study buildings A, B and C as shown in Figures 7.4.1A, 7.4.1B, 7.4.1C.



Figures 7.4.1A Model showing the interior of the case study building A.



Figures 7.4.1B Model showing the interior of the case study building B.

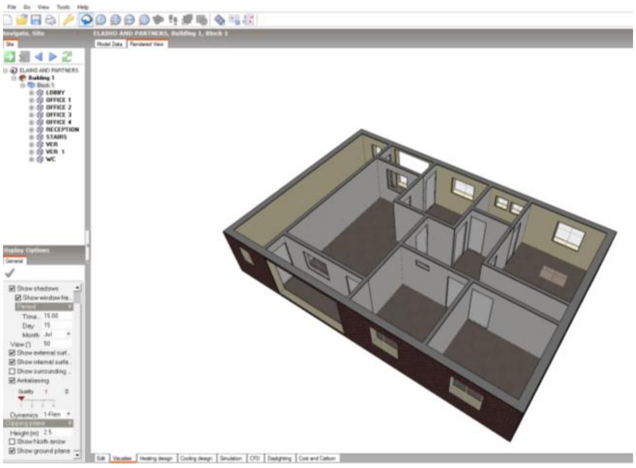


Figure 7.4.1C Model showing the interior of the case study building C.

The models shown by Figures 7.4.1A, 7.4.1B and 7.4.1C were created from previously produced 2D CAD drawings (Figures 7.3.1A, 7.3.1B Figure 7.3.1C) exported in a DXF (Drawing Interchange Format) file compatible and imported to DesignBuilder. The imported DXF files were used separately to create the geometric models with parametric data. While the geometric model can be used to visualise the true representation of the captured case study buildings, semantic information such as the building materials are vital in determining the performance of the building during simulation (Xue et al. 2021; Thomson, 2016). To support this, a guide was created to document the information while questions in the form of a questionnaire (See Appendix 4) were also distributed to occupants of the offices to understand how they feel inside the building. The information is applied together with the semantics information to simulate the model for the purpose of analysis and evaluation.

7.5. Building Performance Simulation of case study buildings

As previously established, accessing the energy performance of buildings including those adopted for this study requires the use of simulation software as one of the most recommended and effective tools for analysis available. To do this requires that the semantics data (building materials and properties) are incorporated into the built digital model, to reflect the real-life scenarios involving the dynamic interactions of buildings with changing sub-systems (Hansen and Lamberts, 2012). Building performance simulation helps to analyse measures of improving energy efficiency and their complex interactions, especially by enhancing thermal comfort (Toledo et al. 2016). The building performance modelling using the DesignBuilder's graphical user interface (GUI), adopted in this study uses EnergyPlus, a dynamic simulation engine as a computational technique to assess a building's energy and environmental performance. The EnergyPlus is a United States Department of Energy's (DOE) whole simulation program that models a building's consumption of heating, cooling, ventilation, lighting and plug and process load (DOE, 2022). In addition to newly developed capabilities, EnergyPlus combines the best features and capabilities of BLAST and DOE-2, providing a more accurate prediction of space temperature, occupant comfort and system (Ochedi, 2018).

Also, as earlier stated (chapter 2), the role of weather in designing energy-efficient buildings cannot be overemphasized as the simulation outputs depend largely on the weather data to determine its reliability which varies from place to place (Ijaola et al. 2018; Wilde, 2019). The DesignBuilder, adopted for the modelling and simulation of existing case study buildings, despite having a database of hourly weather data for several locations of the world have no weather data of any Nigerian location at the time of the study. Hence, the need to reliably source the weather data for Benin City, the study location. The Benin City weather file used in the study was sourced from Meteonorm, one of the private sources that supply appropriate weather data for building simulation. Getting weather data from Meteonorm can be through its software containing either single datasets or the world and is a combination of both climate and weather generators. Uploading the weather file for simulation using EnergyPlus in DesignBuilder requires it to be in an .epw format (DesignBuilder, 2022). The overview of the weather data in pdf format is attached under Appendix 5 of this study. The guide provided on the DesignBuilder website for adding new hourly weather data was used to load the weather file provided by Meteonorm. Other vital information including those derived from measurements and observational surveys such as building elements are highlighted as part of the description of the individual case study buildings.

7.6. Case study building A

As stated in section 7.2.1, access was limited to three office spaces on the second floor of the building with an orientation of 68°E. As shown in Figure 7.2.1, two of the office spaces are occupied by single individuals while the third and largest is classed as the reception, occupied by two individuals with a sitting arrangement to accommodate guests when necessary. Both the internal and external walls of the building were finished with sand-cement plastering with the external wall painted in grey and a lighter shade of grey emulsion paint for the internal. The windows are single glazed fitted with aluminium casement swinging outwards as well as an aluminium framed sliding mesh and an aluminium burglary proof. The function of the sliding mesh is to help prevent insects mainly mosquitoes from entering the building while the burglary proof is mainly to enhance the security of the building by preventing thieves and burglars from breaking in. The ceiling is flat and finished with a 6oomm-by-6oomm panel of suspended PVC ceiling throughout. The ceiling-to-floor height is 2750mm. The whole floor surface was covered with the off-white square-shaped ceramic tile panel of 450mm by 450mm.

7.6.1. As-Built modelling requirement

The specifications applied to the modelling and simulation of case study building A are those contained in the component library of the DesignBuilder application so that some of the specifications were either adopted or modified to reflect the appearance of the case building.

They are represented in Tables 7.6.1A, 7.6.1B and 7.6.1C respectively.

Table 7.6.1A Floor specification for the case study building A.

Floor specification	
Floor Material	Reinforced concrete slab
Floor Thickness	125mm
Floor Finishing	Ceramic glazed tiles
U-Value	2.828 W/m^2K
R-Value	0.354 m^2K/W

Table 7.6.1B Wall specification for the case study building A.

Wall specification	
Wall Material	Hollow lightweight concrete block
Wall Thickness	225mm
Wall Finishing	Cement sand plaster, 25mm thick on both sides
U-Value	1.938 W/m^2K
R-Value	0.516 m^2K/W

Table 7.6.1C Roof specification for the case study building A.

Roof specification	
Roof Material	Lightweight aluminium pitch roof
U-Value	3.773 W/m^2K
R-Value	0.265 m^2K/W

As shown by Figure 7.3.1A, case study A was modelled using the specifications observed during its survey. The accessed office spaces were located on the second floor of the building as shown in Figure 7.6.1. The floor adopted from the DesignBuilder template suites that, mainly used in the study area, usually of a 125mm thick reinforced concrete slab and finished with ceramic glazed tiles with a total U-value of 2.828 W/m^2K, R-value of 0.354 m^2K/W as shown in table 7.6.1A.

The template used for the walls consists of a 225mm thick hollow lightweight concrete/sandcrete block and was uninsulated and finished with 25mm cement-sand plaster on both sides. The thickness of the wall was assessed from the window and door opening and has a total U-value of 1.938 W/m^2K and an R-value of 0.516 m^2K/W as shown in table 7.6.1B.

The roof template used for modelling is a pitch roof made of lightweight aluminium and polyvinylchloride (PVC) ceiling giving a total U-value of 3.773 W/m^{2}K and an R-Value of 0.265 m^{2}K/W.

The doors were made of hardwood and thus the modelling was done using a solid hardwood door template as observed during the measurement and observational survey. It is a single layer with a U-Value of 2.557 W/m^{2}K and an R-Value of 0.391 m^{2}K/W. A single, clear glazing of 6mm was selected from the component library template and it has a total solar transmission of 0.819 and a U-Value of 5.778 W/m^{2}K

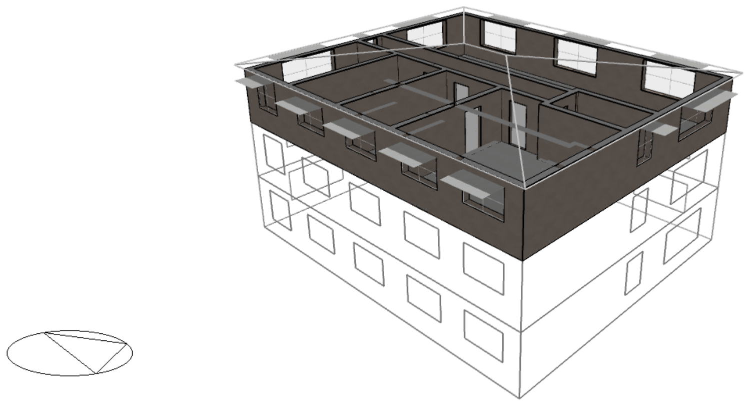
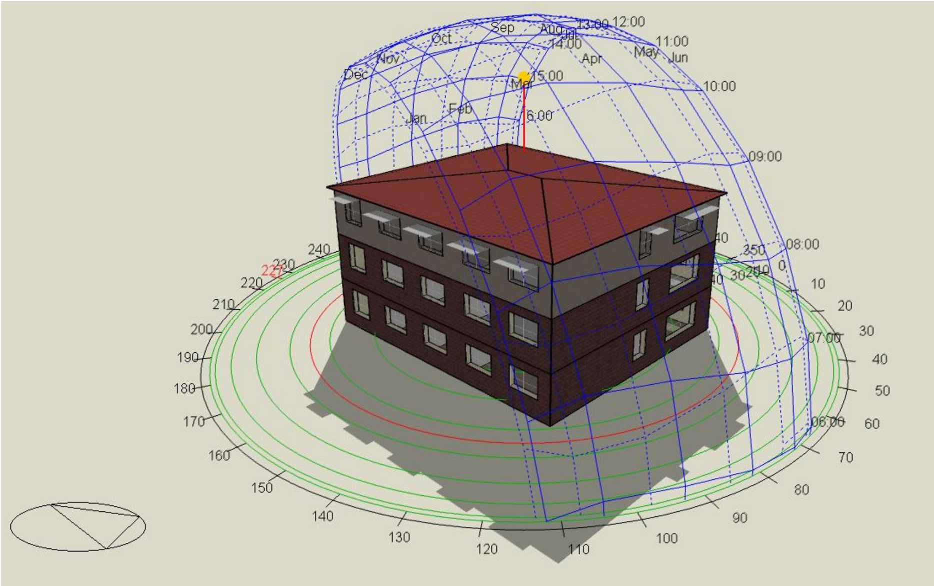


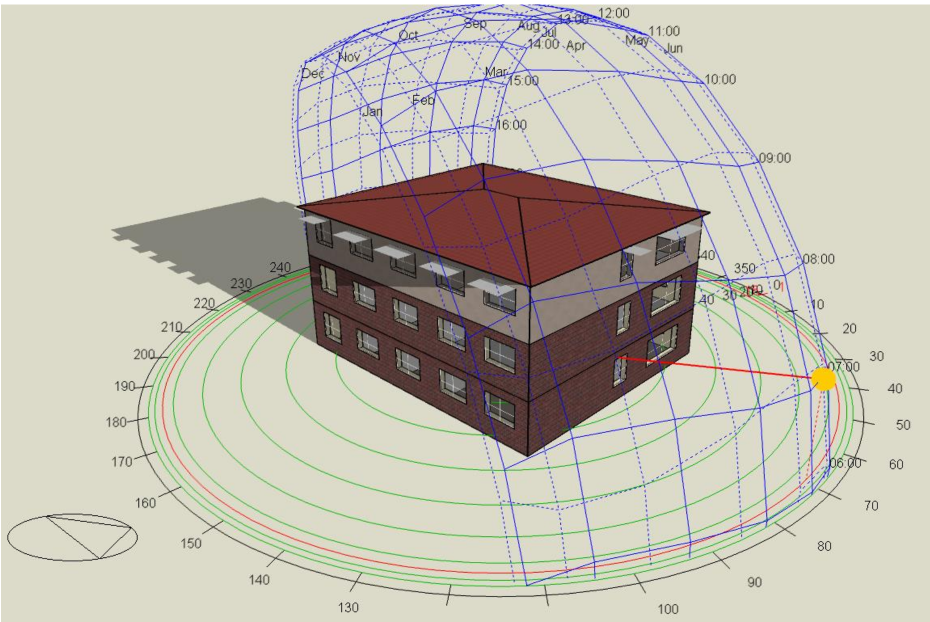
Figure 7.6.1 Model showing the floor containing the three office spaces accessed.

7.6.2. Sun path and daylighting analysis

As previously illustrated in Chapter 2 of this study, buildings are in constant interaction with the environment including features such as sun and wind. The sun path diagram feature in the DesignBuilder application helps to inform the users and to visualise the position of the sun in relation to the building throughout the year. Its interactive nature is such that the view of the sun in the building at different times of the day can be assessed, thereby giving designers an except on solar positions needed for design options including for design of shading systems. Figures 7.6.2A and 7.6.2B show the direction of the sun on the case study building A at 15:00 and 07:00 on July 15th respectively. The provision of appropriate design solutions can be guided by the visual information provided by the sun path diagram showing the impact of the sun on buildings.

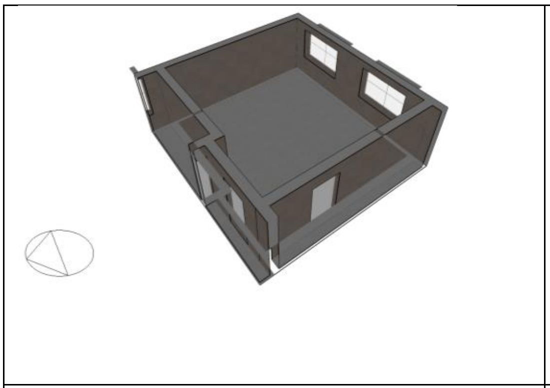


Figures 7.6.2A Sun path of the case study building A on 15th July at 3 pm.

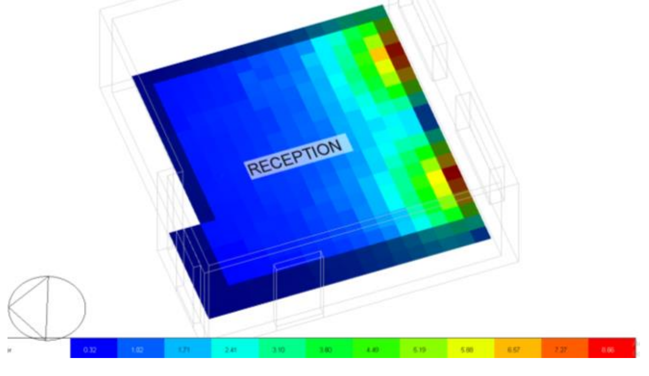


Figures 7.6.2B Sun path of the case study building A on 15th July at 07 am

Achieving energy efficiency in buildings through active or passive design means has been strongly linked to the impact of the sun either through direct or diffused light as well as through solar radiation. Maximising solar potentials in buildings through daylighting is very critical to the sizing of heating and cooling loads (Pejic et al. 2014; Ochedi and Taki, 2019; Jegede and Taki 2021). Thus, the design of daylighting in buildings works hand in hand with the design for cooling and heating in the form of solar gain. For example, consider the impact of daylighting in the three accessible office spaces shown in Figures 7.6.2C, 7.6.2D and 7.6.2E respectively.

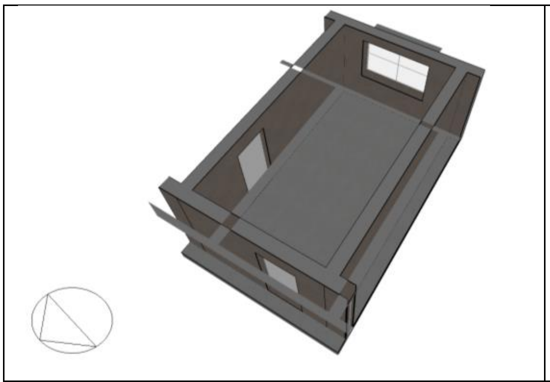


a. Sun path diagram at 0300pm on July 15

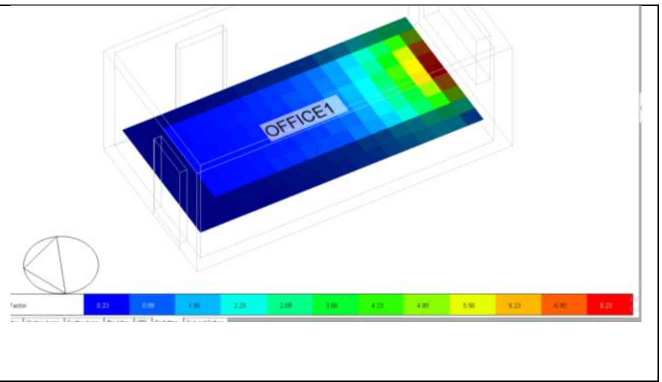


b. Daylight and Illuminance Map

Figure 7.6.2C Sun path diagram(A) and Daylight and illuminance map(B) of the reception.

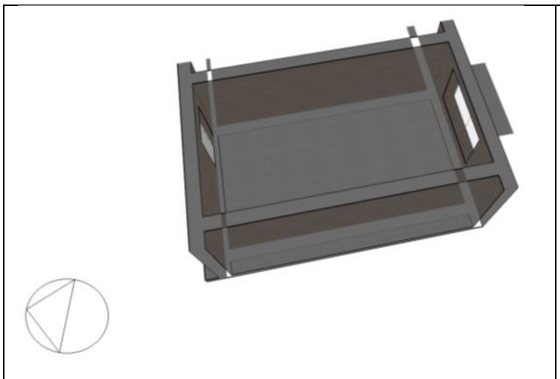


a. Sun path diagram at 0300pm on July 15

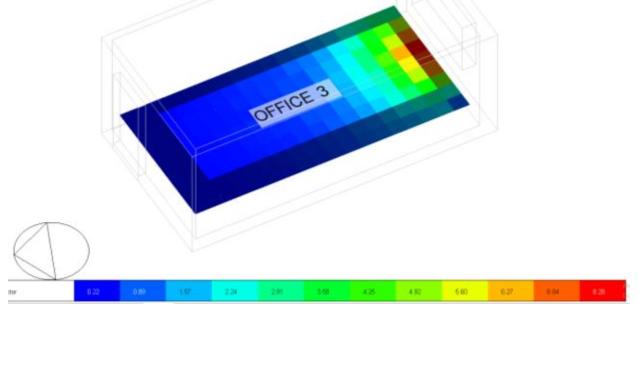


b. Daylight and Illuminance Map

Figure 7.6.2D Sun path diagram(A) and Daylight and illuminance map(B) of Office 1



a. Sun path diagram at 0300pm on July 15



b. Daylight and Illuminance Map

Figure 7.6.2E Sun path diagram(A) and Daylight and illuminance map(B) of Office 3.

The daylighting analysis shown by figures 7.6.2C, 7.6.2D and 7.6.2E of the case study building A are summarised below.

Reception Area

Floor area (M^2) = 31.9

Minimum daylight factor (%) = 0.34

Uniformity ratio (Min/Avg) = 0.21

Average Daylight factor (%) = 1.6

Area Adequately lit(m^2) = 0.0

Bream health and wellbeing status =Fail

Office 1

Floor area (M^2) = 16.5

Min DF (%) = 0.25

Uniformity ratio (Min/Avg) = 0.18

Average Daylight factor (%) = 1.4

Area Adequately lit(m^2) = 0.0

Bream health and wellbeing status =Fail

Office 3

Floor area (M^2) = 16.6

Min DF%= 0.23

Uniformity ratio (Min/Avg) = 0.16

Average Daylight factor (%) = 1.4

Area Adequately lit(m^2) = 0.0

Bream health and wellbeing status = Fail

All three accessed office spaces, office 1, office 2 (reception) and office 3 did not achieve the BREEAM Health and Wellbeing Credit HEA01. The benchmark requires that 80% of the area is adequately lit, a uniformity ratio greater (>) or =0.3, Min daylight factor=0.8. Several factors including window size, window-to-wall ratio, size of the room, and window position in relation to the sun paths and openings could have led to inadequate daylighting but its implication points to the need for a complimentary artificial source of lighting which would in turn add to the energy load of the building translating to cost.

One significant observation during the survey of the office spaces was that the office desks and other key office arrangements were positioned closer to the window, the source of lighting. There are no mandatory national energy efficient building guidelines for designers on achieving thermal comfort of buildings in Nigeria (Abdulkareem et al. 2018), It is unclear if the design was intentional to avoid excessive solar heat gains in the office spaces especially as the building was recently refurbished before its occupation in December 2020. The thermal comfort requirements used to define the accessed office spaces are based on the ASHRAE standard 55-2010 adaptive model for thermal comfort in naturally ventilated buildings discussed next.

7.6.3 Thermal performance of accessed office spaces

Solar gains and operative temperatures are used to check for the performance of the accessed spaces. Only the performances of the individual spaces accessed are discussed. The annual operative temperature and solar gains of the three offices are presented in Table 7.6.3. The annual operative temperature is the average operative temperature for 12 months.

Table 7.6.3. Annual operative temperature and solar gains of office spaces in case study A

Office space	Annual operative temperature (°C)	Annual solar gains (KWh)
Office 1	28.63	722.09
Reception	29.09	1440.57
Office 3	28.88	716.64

The simulation results of the office spaces shown in Table 7.6.3 were carried out assuming a standard general office and using natural ventilation, without cooling or heating. The performance of each of the spaces varied both in terms of the operative temperature and solar gains which is not surprising due to their differences in the number of windows, their positioning, and sizes. Figure 7.6.3.A. shows the simulation results for one of the office spaces, the reception room.

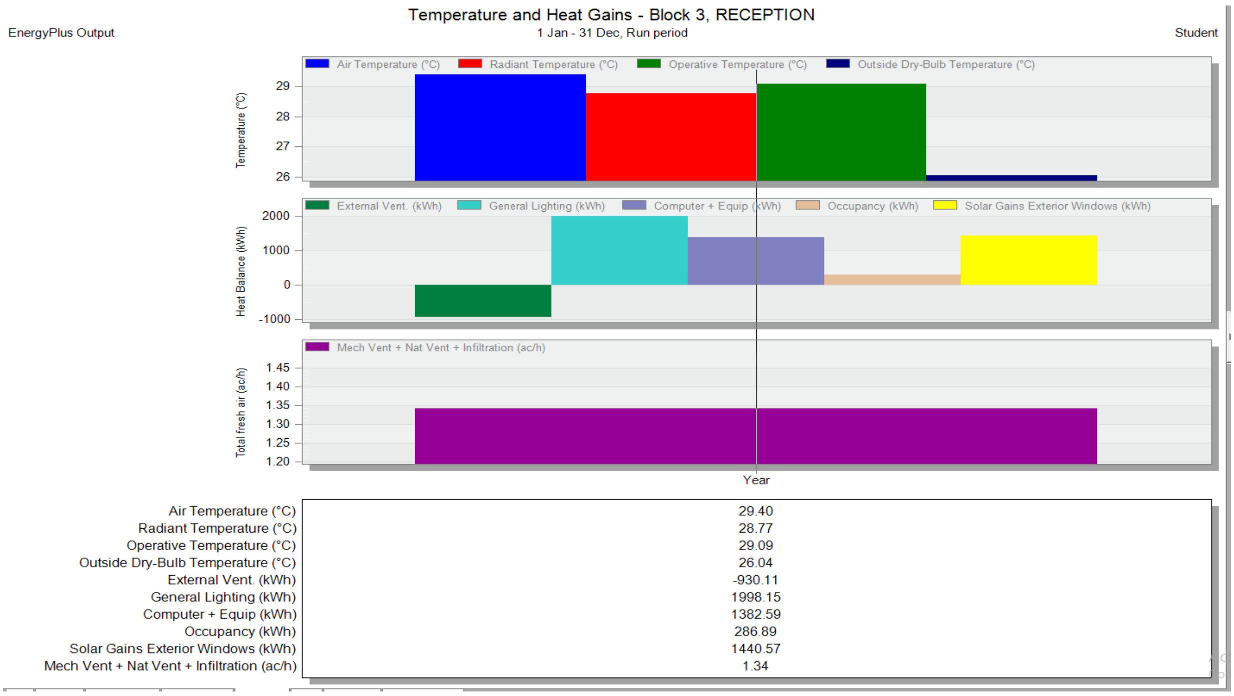


Figure 7.6.3A Annual simulation results for the reception, case study A

The monthly performance in terms of operative temperature and solar gains of the assessed office spaces of case study A are shown in Figures 7.6.3B, 7.6.3C and 7.6.3D with the trend showing values similar to those captured during the site visit.

In Office 1, between January to December, the lowest operative temperature recorded was in August at 26.94°C and the highest was in December at 29.98°C. While four of the months (June, July, August, and September) fall between the average ASHRAE standard 55 considerable thermal comfort zone of between 25°C and 28°C, for the larger part of the year, the office feels uncomfortable. This pattern replicates itself among the three office spaces with the reception experiencing the highest temperature of 30.38°C in December as well as the most uncomfortable temperature range compared to the other spaces. The highest monthly solar gains across the three office spaces occurred in December at 174.87KWh for the reception and the lowest solar gains were recorded in July at 44.6KWh. This goes further to signify that there is a strong correlation between solar radiation and thermal comfort. However, the relationship does not imply that a higher solar gain must lead to a higher operative temperature. Consider for instance, across the three office spaces, there are higher solar gains in August, whereas August has the lowest operative temperature.

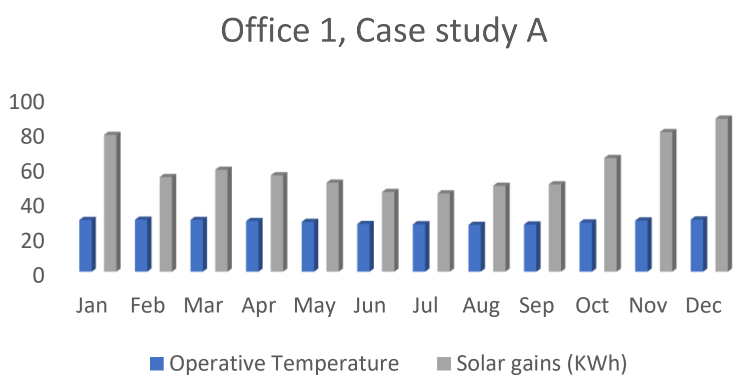


Figure 7.6.3B Monthly operative temperature and solar gains for Office 1, Case study A

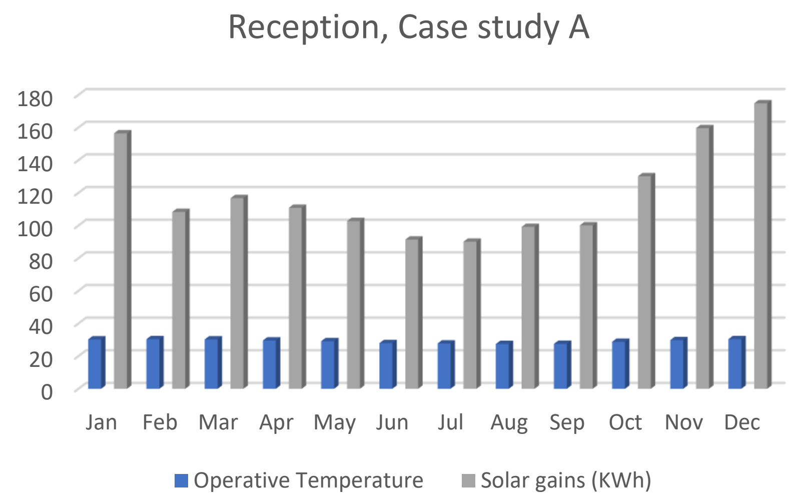


Figure 7.6.3C Monthly operative temperature and solar gains for the reception, Case study A

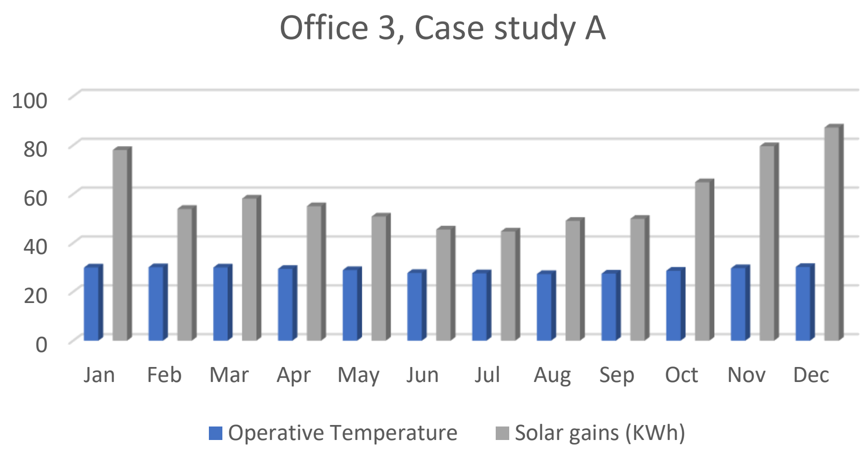
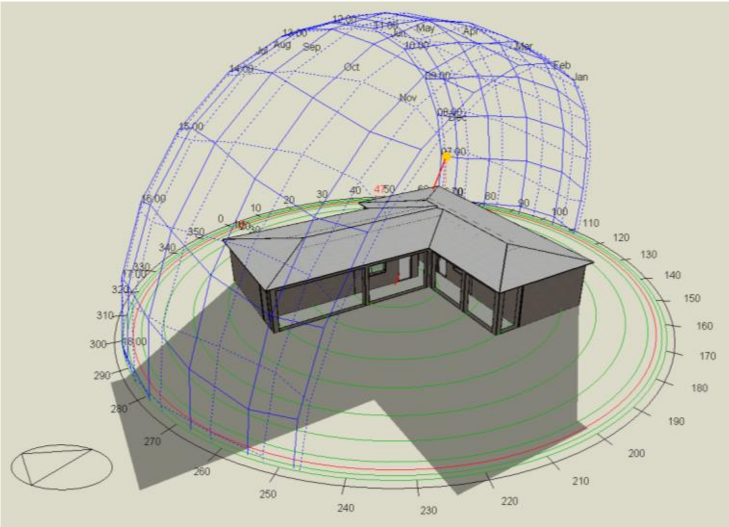


Figure 7.6.3D Monthly operative temperature and solar gains for Office 3, Case study A

Comparing the three office spaces, office 1 appears to perform best in terms of annual average operative temperature. It has the lowest annual operative temperature of 28.63°C while the performance of the reception is worse with an annual average operative temperature of 29.09°C. The three offices, between June and September, are within the ASHRAE 55 average thermal comfort threshold (25°C -28°C). In terms of solar gains, the reception has the highest annual solar gain of 1440.57KWh compared to the others. The monthly solar gains across the three spaces also point to the fact that higher solar gains do not mean higher operative temperature. Other factors such as area, orientation, height, and shading could influence the effect of solar gains on the operative temperature.

7.7. Case study building B

The case study building B is a single floor building with an orientation of 22°NE as shown by the sun path diagram captured on the 15th of July at 07 am in Figure 7.7. Access was granted to three office spaces as earlier indicated in Figure 7.2.2, so, the model was therefore created to show the accessed spaces instead of the whole building. One of the offices has a single occupancy with an attached office (a reception room) leading to it. The third office space is occupied by more than three staff. The building wall is made of 225mm thick hollow sandcrete block with sand-cement plastering and painted with yellow and off-white emulsion paint on the exterior and the interior respectively.



Figures 7.7. Sun path diagram of case study building B on 15th July at 07 am

All windows are sliding and single-glazed with aluminium frames. There are also burglary proofs made of aluminium on all the windows. The floor-to-ceiling height is 2750mm. The ceiling is flat and made up of asbestos ceiling boards boarded using battens and finished with white emulsion paint. The floor is composed of ceramic tiles of off-white-coloured square-shaped 450mm by 450mm ceramic tiles.

7.7.1 As-Built modelling requirement

Most of the building specifications applied for modelling and simulation are those recorded from the pre-installed component library in DesignBuilder and they are represented by tables 7.7.1A, 7.7.1B and 7.7.1C.

Table 7.7.1A Floor specification for case study building B.

Floor specification	
Floor Material	Cast concrete slab
Floor Thickness	150mm
Floor Finishing	Ceramic glazed tiles
U-Value	2.593W/m^{2}K
R-Value	0.386 m^{2}K/W

Table 7.7.1B Wall specification for case study building B.

Wall specification	
Wall Material	Hollow lightweight concrete block
Wall Thickness	225mm
Wall Finishing	Cement sand plaster, 25mm thick on both sides
U-Value	1.938 W/m^2K
R-Value	0.516 W/m^2K

Table 7.7.1C Roof specification for case study building B.

Roof specification	
Roof Material	Lightweight aluminium pitch roof
U-Value	3.658 W/m^2K
R-Value	0.273 W/m^2K

The building was modelled by creating a template from a pre-existing template in DesignBuilder and then modified based on the key features observed from case study B. A 150mm concrete slab was adopted for modelling as it is the most used floor construction type in the study area. The floor finishing recorded and applied to the model was ceramic glazed tiles having a combined U-value of 2.593W/m^2K and an R-value of 0.386 m^2K/W as shown in Table 7.7.1A.

As was also recorded in the building, the modelling of the external wall and internal partition are of the same material of hollow lightweight concrete/sandcrete block with a sand-cement plaster of 25mm thick on both sides and without insulation. The overall U-Value of all layers of the wall composition is 1.938W/m2K and the R-Value is 0.516 m2K/W as shown in Table 7.7.1B.

Aluminium pitched roof as observed from the case study building was used for the modelling. It has a U-value of 3.658W/m^2K with an R-value of 0.273m^2K/W as shown in Table 7.7.1C.

All door models used are edited from the solid hardwood door template in DesignBuilder to reflect the key observation from the existing buildings. It has a single layer and a U-Value of 2.557W/m^2K and an R-Value of 0.391m^2K/W. The windows comprise clear single glazing of 6mm adapted for use from the DesignBuilder template with a total solar transmission of 0.819 with a U-Value of 5.778 W/m^2K.

7.7.2. Sun path and daylighting analysis

The implication of the sun path overlay on case study building B has a significant impact on its daylighting, solar gains, and comfort. The results for the three spaces where access was granted are shown in figures 7.7.2A, 7.7.2B and 7.7.2C.

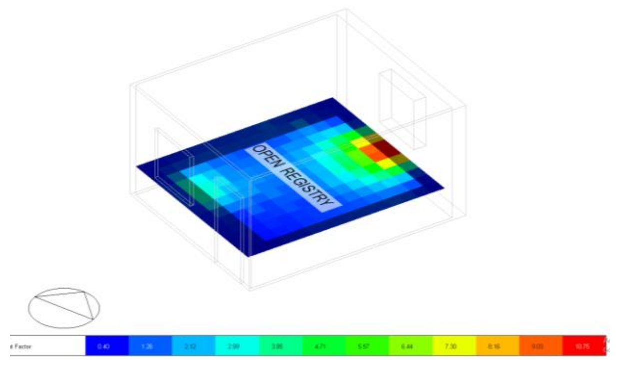
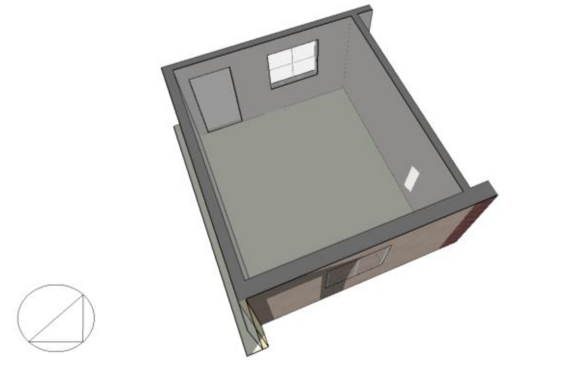
	
Daylight and Illuminance Map	Sun path diagram at 0700am on August 15

Figure 7.7.2A Daylight and illuminance map(a), Sun path diagram(b) of the open registry

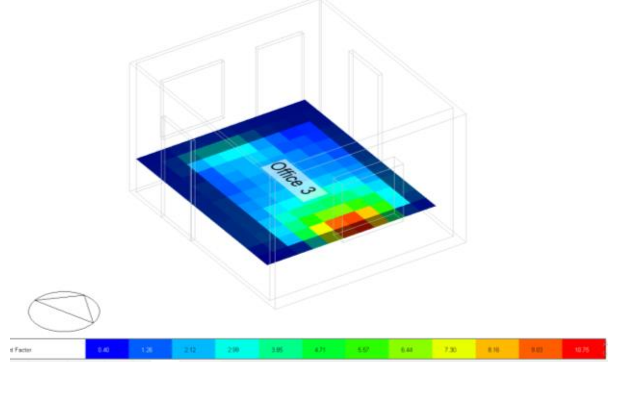
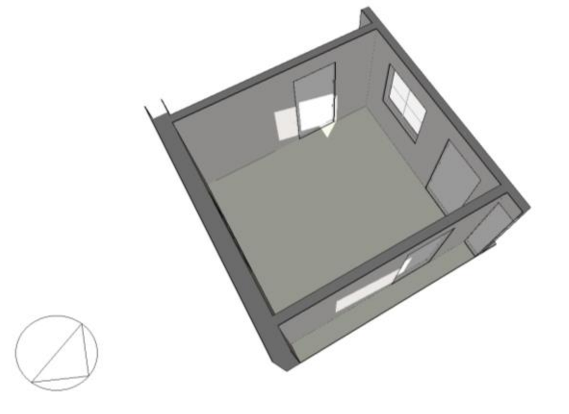
	
Daylight and Illuminance Map	Sun path diagram at 0700am on August 15

Figure 7.7.2B Daylight and illuminance map(a)and sun path diagram(b) of Office 3

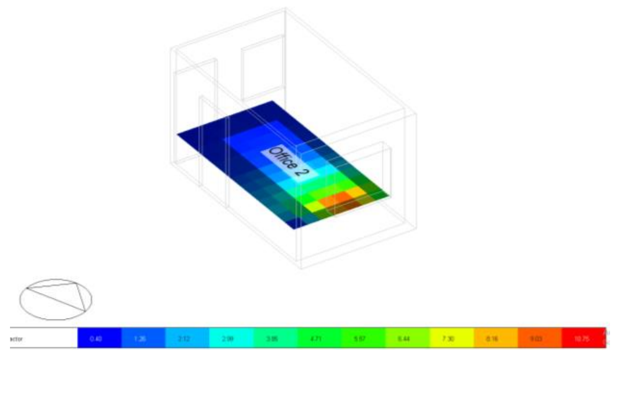
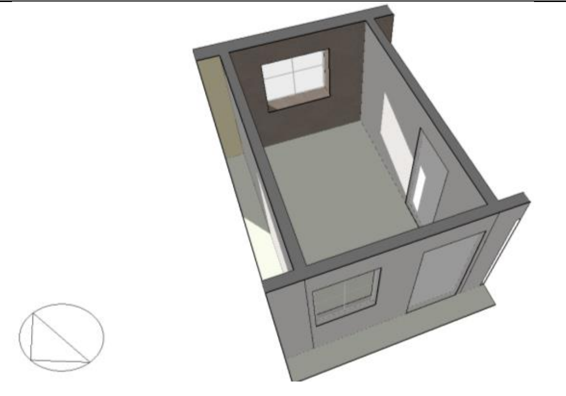
	
Daylight and Illuminance Map	Sun path diagram at 0700am on August 15

Figure 7.7.2C Daylight and illuminance map (a) and sun path diagram(b) of Office 2

The open registry passed for daylighting in terms of the BREEAM Health and Wellbeing Credit HEA 01 status requiring that 80% of any zone can achieve an average daylight illuminance of 300 lux for 2000 hours per year (an average daylight factor of 2.0%). Considering a total floor area of 18.4m^2, minimum daylight factor = 0.54%, uniformity ratio (Min/Avg) = 0.27, average daylight factor =2.0%, the overall BREEAM Health and Wellbeing Credit HEA 01 status= fail. In the same manner, using the same credit the simulation result for office 2 is adequately daylit but with an overall failure status because it did not meet other criteria. Office 3 however passed in terms of average daylighting which must be at least 2.0, a uniformity ratio which must be at least 0.3 or a minimum point daylighting of 0.8, thus having a Pass in the overall BREEAM Health and Wellbeing Credit HEA 01 status. The results suppose that Office 3, in terms of daylighting and illuminance performs better than the reception area and office 2 of case study building B.

7.7.3. Thermal performance of accessed office spaces.

The thermal assessments of the accessed office spaces of case study B are in terms of operative temperature and solar gains. The simulation results of each of the spaces showing the annual operative temperature and solar gains are shown in Table 7.7.3.

Table 7.7.3 Annual operative temperature and solar gains of accessed office spaces in Case study B

Office space	Annual operative temperature (°C)	Annual solar gains (KWh)
Office 2	30.13	766.58
Open registry	29.94	515.68
Office 3	29.71	768.00

The simulation results presented in Table 7.7.3 show the annual operative temperature and solar gains when performed without any form of heating or cooling but naturally ventilated and without any artificial source of lighting. The results identified the differences in individual performances when compared. Figure 7.7.3A shows the simulation results of the open registry.

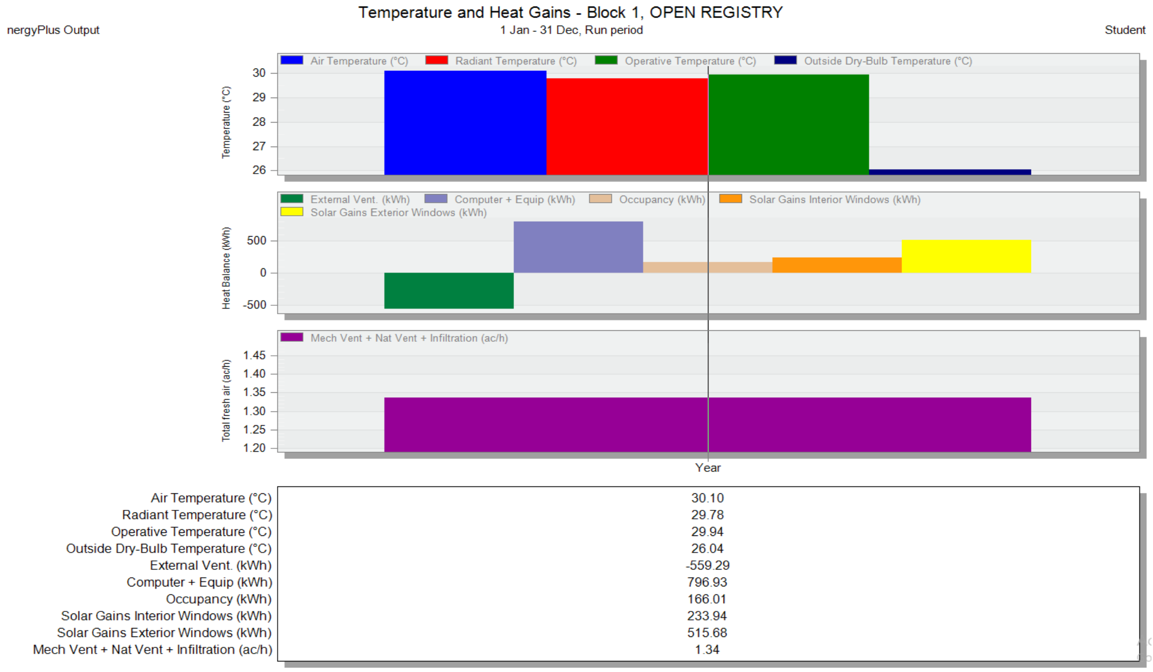


Figure 7.7.3A Annual simulation results for the open registry, case study B

The monthly simulation results showing the operative temperature and the solar gains of the three office spaces in case study building B are presented in Figures 7.7.3B, 7.7.3C and 7.7.3D. For office 2, the lowest operative temperature was in August at 28.48°C and the highest operative temperature was in December at 31.59°C. The lowest solar gain to office 2 occurred in February by 65.59KWh and the highest solar gain in November with 96.41KWh. Similarly, the same condition occurred in office 3. The lowest operative temperature and solar gains recorded were 28.03°C, 66.32KWh and the highest at 31.26°C, 97.45KWh in the same months in office 2. The open registry, whose position is perpendicular to offices 2 and 3 had a different experience in terms of solar gain as the highest solar gain of 79.24KWh occurred in May and the lowest occurred in February at 50.14KWh with the highest and lowest operative temperatures of 31.30°C and 28.39°C in December and August respectively. The results indicate the need for mechanical means of cooling throughout the year unless for August in office three. Mechanical means of cooling require energy and at an added cost.

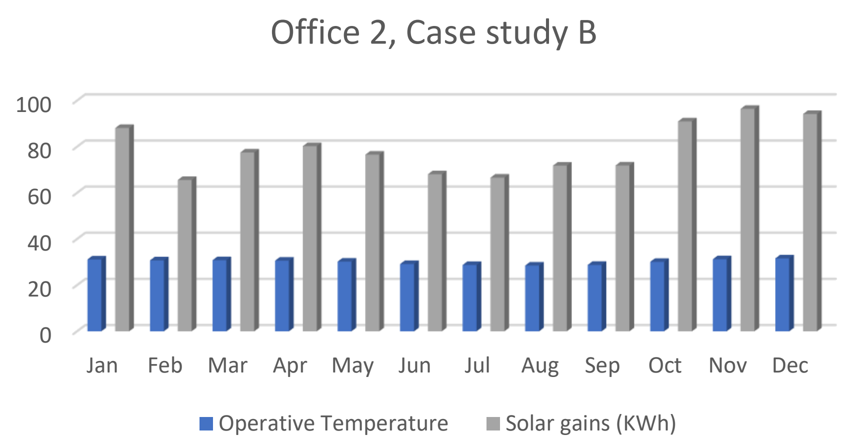


Figure 7.7.3B Monthly operative temperature and solar gains for Office 2, Case study B

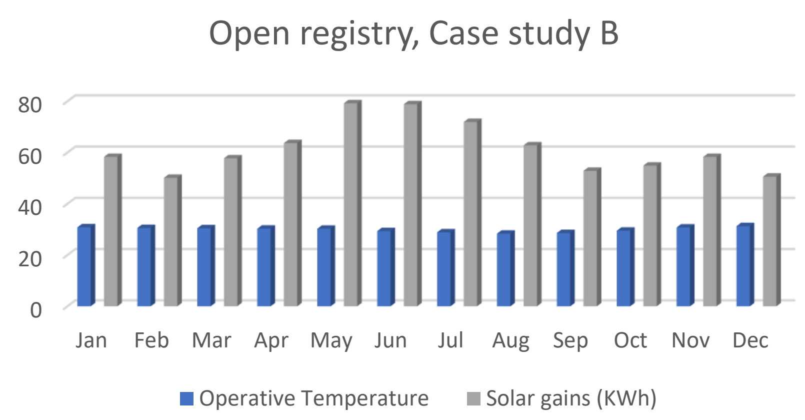


Figure 7.7.3C Monthly operative temperature and solar gains for open registry, Case study B

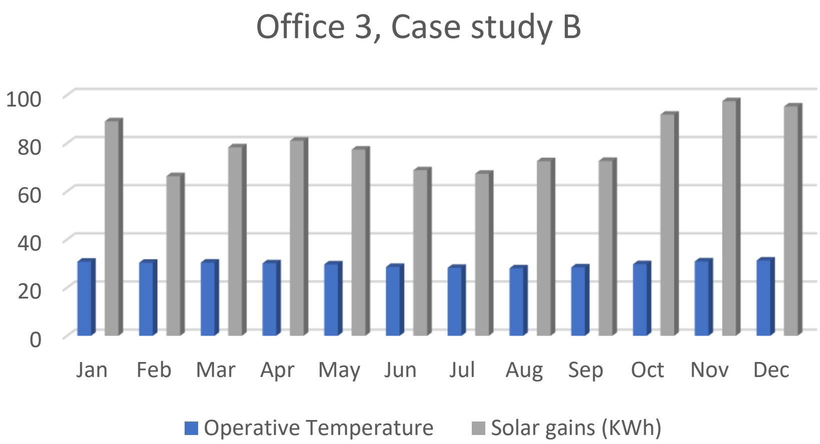


Figure 7.7.3D Monthly operative temperature and solar gains for Office 3, Case study B

The figures show that in terms of operative temperatures, office 3 with an annual operative temperature of 29.71°C performs better than the others and against the backdrop that it has the corresponding highest solar gains of 768.00KWh compared to others. It further reinforces that lower operative temperature does not automatically lead to lower operative temperature due to other factors.

7.8. Case study building C.

Case study building C has an orientation of 313°NW as shown by the sun path diagram in Figure 7.8A and consists of three floors. Access was only granted to the first floor of the building (Figure 7.8B). There are four separate office spaces and a large reception room. Two of the offices are occupied by two individuals each, the other two office spaces are each occupied by a single individual. Sandcrete blocks were used for the wall construction and plastered with sand-cement plaster and finished with grey emulsion paint on the exterior and yellow on the interior. All the windows are single-glazed with aluminium sliding frames and an aluminium burglary-proof. The floor-to-ceiling height is 2600mm. The ceiling comprises a flat sand-cement-plastered reinforced concrete slab painted with white emulsion paint while the floor is finished with square-shaped ceramic tiles.

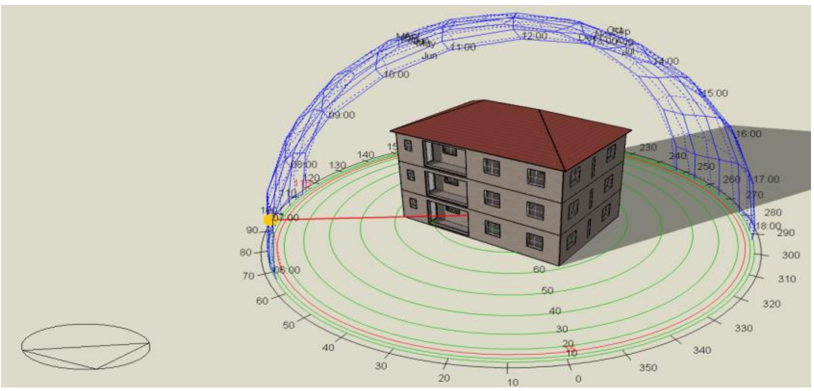


Figure 7.8A Sun path diagram of case building C on 15th July at 0700am

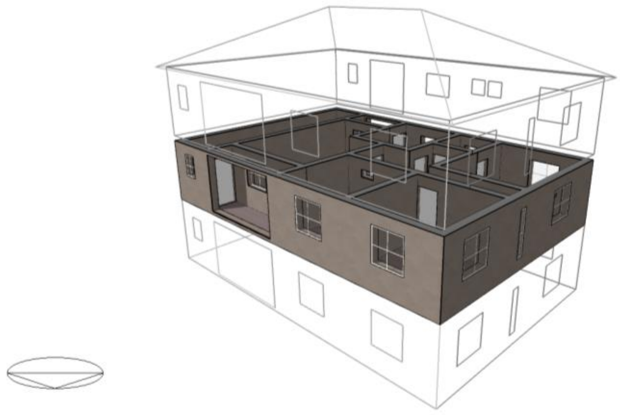


Figure 7.8B Model showing the floor containing the accessed office spaces of Case study C.

7.8.1 As-Built modelling requirement

Similar to other case study buildings, the specifications used for modelling on DesignBuilder are gotten from the pre-installed template and modified to represent the recorded observation from the case study building C. The specifications adopted are shown in Tables 7.8.1A, 7.8.1B and 7.8.1C respectively.

Table 7.8.1A Floor specification for case study building C.

Floor specification	
Floor Material	Reinforced concrete slab
Floor Thickness	125mm
Floor Finishing	Floor/roof screed
U-Value	2.600 W/m^{2}K
R-Value	0.385 W/m^{2}K

Table 7.8.1B Wall specification for case study building C.

Wall specification	
Wall Material	Hollow lightweight concrete block
Wall Thickness	225mm
Wall Finishing	Cement sand plaster, 25mm thick on both sides
U-Value	1.938 W/m^{2}K
R-Value	0.516 W/m^{2}K

Table 7.8.1C Roof specification for case study building C.

Roof specification	
Roof Material	Reinforced concrete slab
U-Value	2.600 W/m^{2}K
R-Value	0.385 W/m^{2}K

Like the other case study buildings, the specifications for modelling and simulation of case study building C are presented. As the accessible office spaces are located in the middle of a three-story building as Figure 7.8B shows, the floor and roof tend to have the same material composition of a reinforced concrete slab finished with a screed on both sides. Both the external wall and internal partition are made of hollow lightweight concrete slab with a sand-cement plaster of 25mm thick on both sides and without insulation. The solid hardwood template was adopted for the door as well as a clear single-glazing template for the windows, to reflect the reality of the case building.

7.8.2 Sun path and daylighting analysis

Although access was granted to the full office building block of case study C, the emphasis will be more on the office spaces. The daylight and illuminance simulation from the sun path overlay on the building is shown in Figure 7.8.2.

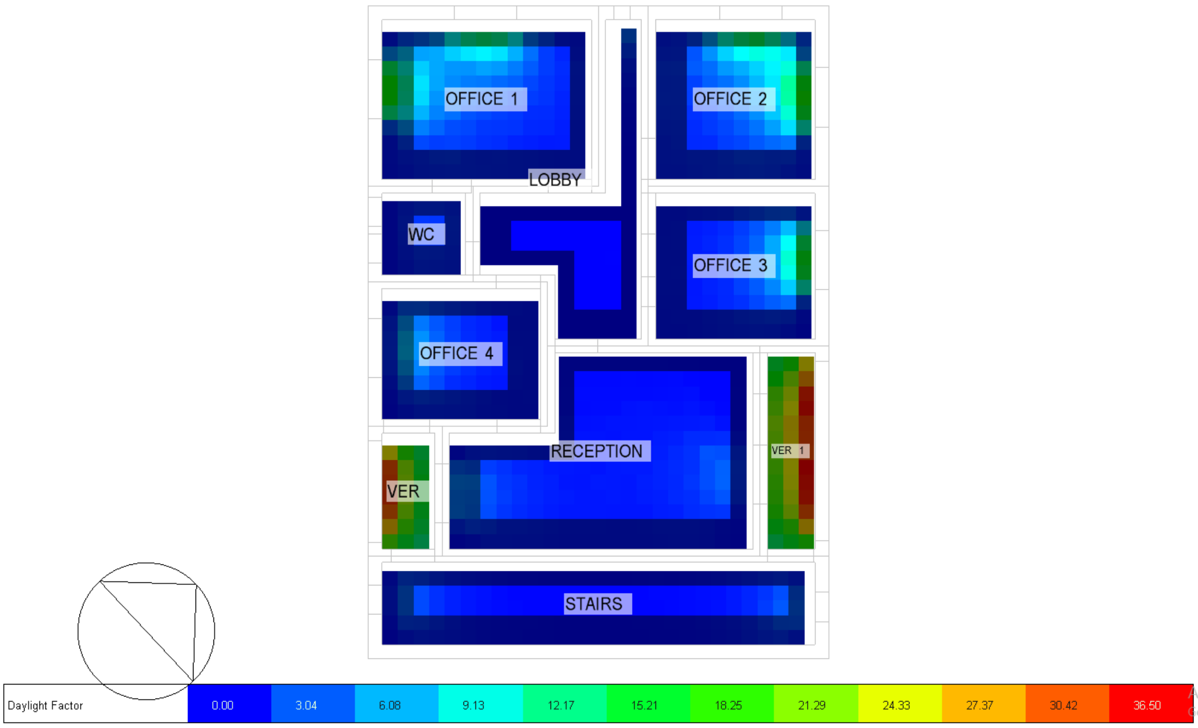


Figure 7.8.2. Daylight and illuminance Map of case study building C.

For the individual office spaces shown in Figure 7.8.2, office 1, office 2 and office 3 all have a pass status, meeting the requirement of BREEAM Health and Wellbeing Credit HEA 01 status. The status requires that at least 80% of the net lettable floor area is adequately daylit by having an average daylight factor of 2.0%, a uniformity ratio of 0.3 or a minimum point daylight factor of 0.8%. Office 4 and the reception failed to meet the BREEAM Health and Wellbeing Credit HEA 01 status.

7.8.3. Thermal performance of accessed office spaces.

Table 7.8.3 shows the annual operative temperature and solar gains for each of the offices accessed as part of case study C while figures 7.8.3A, 7.8.3B, 7.8.3C, 7.8.3D, and 7.8.3E show the corresponding monthly operative temperature and solar gains.

Table 7.8.3 Annual operative temperature and solar gains of case study C

Office space	Annual operative temperature (°C)	Annual solar gains (KWh)
Office 1	28.39	1401.09
Office 2	28.51	1335.10
Office 3	28.72	662.95
Office 4	28.95	534.86
Reception	29.72	40.27

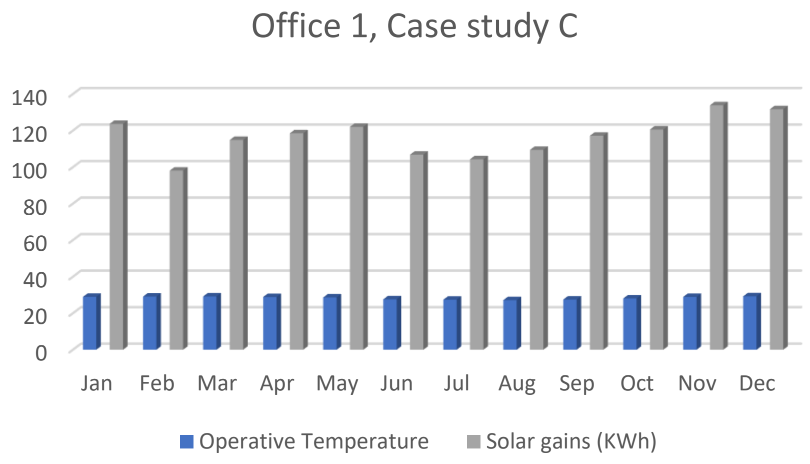


Figure 7.8.3A Monthly operative temperature and solar gains for Office 1, Case study C

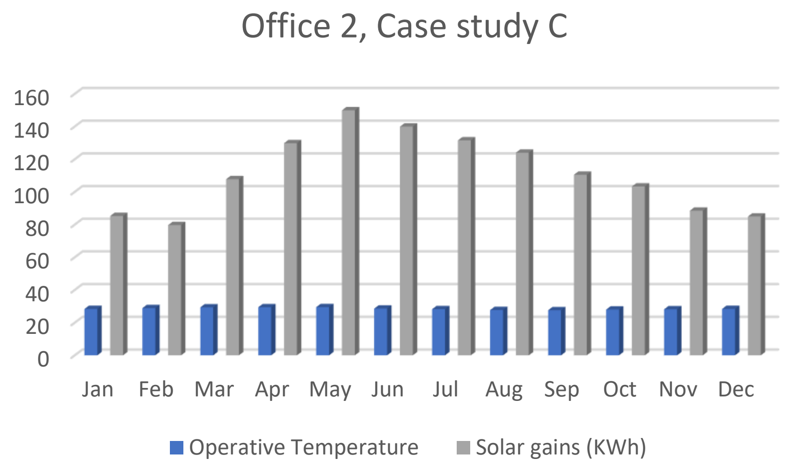


Figure 7.8.3B Monthly operative temperature and solar gains for Office 2, Case study C

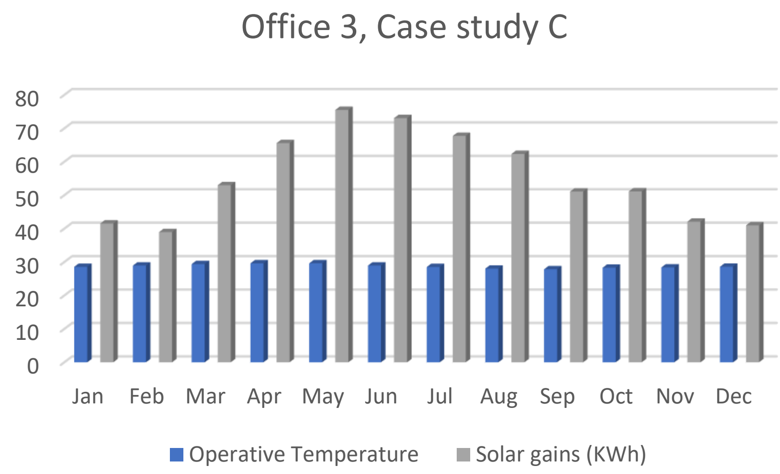


Figure 7.8.3C Monthly operative temperature and solar gains for Office 3, Case study C

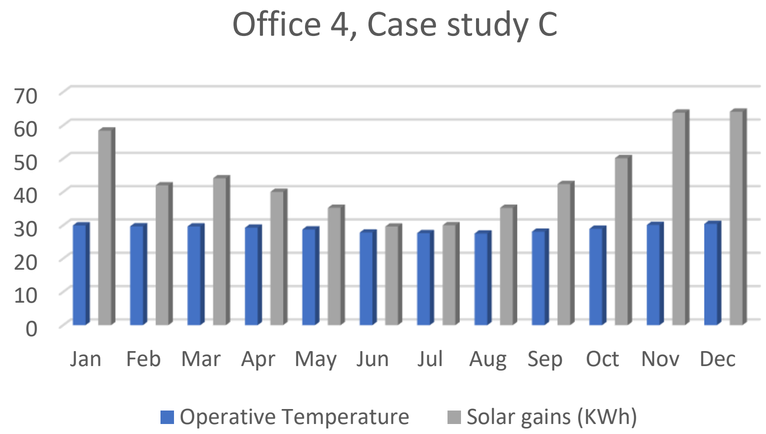


Figure 7.8.3D Monthly operative temperature and solar gains for Office 4, Case study C

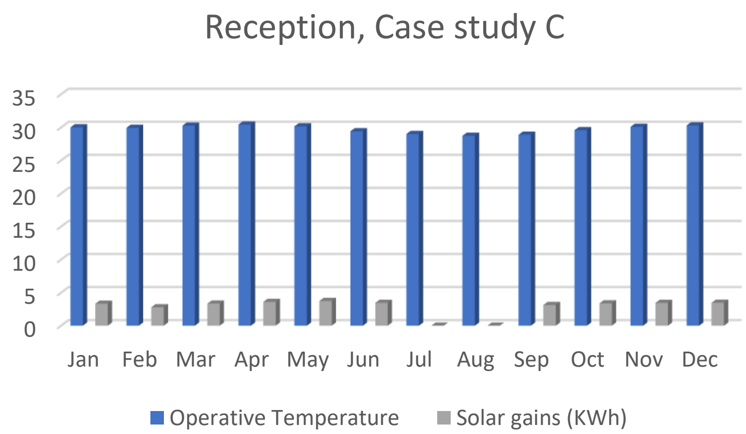


Figure 7.8.3E Monthly operative temperature and solar gains for the Reception, Case study C

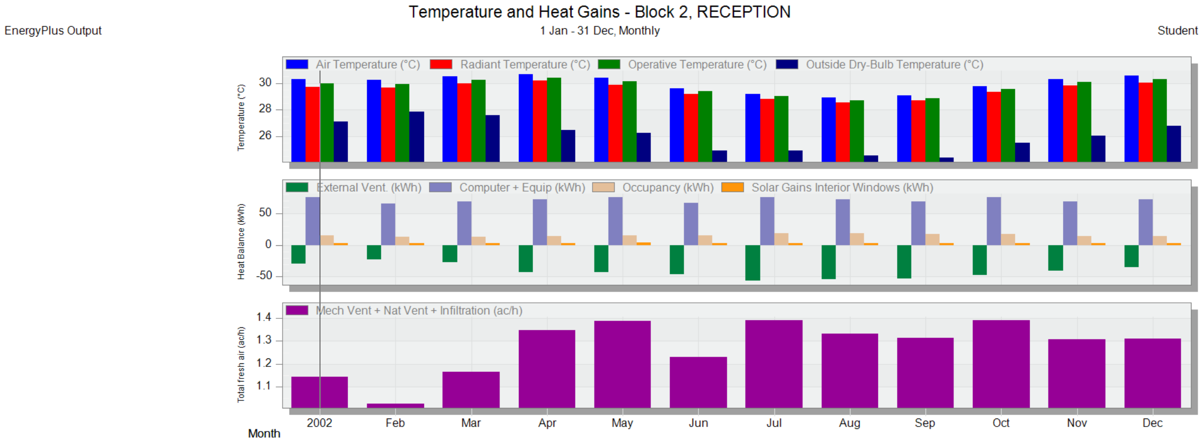
For 12 months, office 1, shown in Figure 7.8.3A has an average operative temperature of 28.39°C, its lowest and highest monthly operative temperatures are 27.14°C and 29.24°C in

August and December respectively. According to the ASHRAE 55 average thermal comfort range of between 25°C and 28°C, and the months between June to September fall within the average comfort range. A complementary source of cooling is required for other months. The month of February experienced the lowest solar gains at 98.1Kwh in office 1 and the highest in November at 133.84Kwh.

Office 2 (Figure 7.8.3B) has an average annual operative temperature of 28.51°C. The 3 months between August and September fall between the ASHRAE 55 average thermal comfort range. The highest operative temperature (29.48°C) occurred in May and the lowest (27.60°C) in September. The results imply that alternative sources of cooling are required for a larger part of the year. Solar gains to office 2 were highest in June at 149.90Kwh and lowest at 79.69Kwh in February.

Figure 7.8.3C indicates that office 3 has an annual operative temperature of 28.72°C with only the month of September falling within the average thermal comfort range and the highest operative temperature of 29.62°C in May. The highest solar gains to office 3 occurred in May at 75.50Kwh and the lowest at 38.96Kwh in February. The annual operative temperature of office 4, shown in figure 7.8.3D is 28.95°C with June, July and August attaining the average thermal comfort threshold while experiencing the highest monthly operative temperature in December at 30.39°C. Solar gains to office 4 were highest in December at 64.08Kwh and lowest in June at 29.59Kwh.

As Figure 7.8.3E shows, the reception room has an annual operative temperature of 29.72°C with its lowest monthly operative temperature of 28.72°C occurring in August and the highest in April at 30.42°C. Of all office spaces, the reception received the least solar gain with a minimum of 2.78KWh in February and a maximum of 3.74KWh in May. The reason could be because of the presence of a veranda of at least 1200mm depth, casting a shade on the two reception windows. The monthly simulation output of the reception room is shown in Figure 7.8.3F



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	30.29	30.23	30.52	30.66	30.40	29.62	29.20	28.91	29.06	29.80	30.30	30.54
Radiant Temperature (°C)	29.72	29.65	29.99	30.19	29.89	29.20	28.80	28.53	28.70	29.35	29.84	30.03
Operative Temperature (°C)	30.01	29.94	30.26	30.42	30.15	29.41	29.00	28.72	28.88	29.57	30.07	30.29
Outside Dry-Bulb Temperature (°C)	27.12	27.87	27.59	26.50	26.29	24.95	24.94	24.57	24.42	25.50	26.06	26.81
External Vent. (kWh)	-29.73	-22.10	-27.59	-42.81	-42.81	-46.07	-55.80	-54.39	-52.44	-47.27	-40.50	-34.46
Computer + Equip (kWh)	75.58	66.04	69.82	72.40	75.58	66.64	75.58	72.70	69.52	75.58	69.52	72.70
Occupancy (kWh)	15.93	13.39	13.63	14.57	15.56	15.96	19.00	19.13	17.72	17.82	14.35	14.51
Solar Gains Interior Windows (kWh)	3.32	2.78	3.34	3.60	3.74	3.45	3.30	3.32	3.13	3.38	3.45	3.46
Mech Vent + Nat Vent + Infiltration (ac/h)	1.14	1.03	1.16	1.35	1.39	1.23	1.39	1.33	1.31	1.39	1.31	1.31

Figure 7.8.3F Monthly simulation results for the reception, case study C

Comparing all the offices in case study building C, office 1, despite having the highest annual solar gain of 1401.09Kwh performs better than others especially between June and September in terms of operative temperature with an annual average of 28.39°C.

The use of more than one case study building was to understand the similarities and dissimilarities if any, among the most popular office building types found in the study region in terms of thermal comfort leading to significant energy demand and its associated cost. While each of the case study buildings helped to give clarity on the performance and comfort level of the buildings that were demonstrated, the results are in line with the comments received from the occupants of the office users. Additionally, each of the buildings and the accessed offices established the room with greater discomfort and at what time of the year further points to where there will be a benefit for remedial work. The outcome of the assessment of the office spaces in all the case study buildings reveals that thermal discomfort is experienced for the most part (at least 8 months) of the year if not throughout the year in office buildings. There are no significant differences in the building types comparing the annual operative temperature of the case study buildings located at three different floor heights. The results of the simulation, having suggested thermal discomfort in office buildings have a trend showing similar values to those captured on-site and further point to the need to improve the environmental performance of office buildings to rely on less energy needed for mechanical cooling and its cost implication.

7.9. Reflection on the Case Study Buildings.

The above three case study buildings were captured using the most frequently adopted as-built data-capturing technology in Benin City. As earlier established, the focus of the as-built data capture and simulation necessary for performance improvement of the buildings are with consideration for bioclimatic design initiatives. And the bioclimatic design variables arrived at in Chapter 2 of this study were needed for the data capture, followed by the holistic building performance simulation (modelling, analysis, and evaluation). The bioclimatic design factors and their design variables are briefly discussed below.

7.9.1. Site selection and Orientation

The orientation of buildings remains a significant factor in harnessing the benefits of solar gains to the building. As such, appropriate weather of Benin City was purchased from Meteonorm and building coordinates of the case study building were taken also taken.

7.9.2. Building Form and Geometry

The building form and geometry of the case study buildings were measured using a measuring tape and an in-phone application called "Measure" to capture the spaces that were not easily accessible such as ceiling height. The building form and geometry are used in the form of size, shape and area to control the effect of wind and solar radiation in the building. The building form and geometry were captured with the help of extra personnel and recorded on a piece of paper for further processing.

7.9.3. Envelope Design

The building envelope separates the internal from the external environment and can be utilised to control the harsh effect of the exterior to achieve a conducive indoor. The building envelope mainly wall, roof, floor and openings come in the form of material composition, size, thickness and design. Thus, the building envelope properties of the three case study buildings were identified and taken note of. Different properties have different emissivity and reflectance resulting in their U-value and R-value of the building envelope. Shading devices and methods that were applicable were also identified and recorded.

Other semantic information including building envelope colours, operation schedule and occupancy were recorded and applied where necessary during the building simulation and analysis and for further evaluation.

Although improving the environmental performance of existing office buildings is beyond the scope of this study for several reasons including accessibility and undefined level of disruption, its importance cannot be overemphasised. However, as carried out with the three case study buildings, a crucial stage in enhancing the environmental performance of existing buildings requires an evaluation of the initial performance of the buildings (especially in terms of thermal comfort) before proposing enhancement strategies. Also demonstrated using the three case study buildings is one of the advanced and increasingly adopted ways of carrying out such type of in-depth evaluation in recent times utilising modelling and simulation requiring detailed building information. Thus, due to several factors limiting the availability of as-built details of the buildings, the capture of such building information for the purpose of modelling and simulation for evaluation and analysis before performance improvement is the aim of this study. Achieving the study aim requires a proposal for an effective methodology for the data capture, modelling, evaluation, and analysis of existing buildings in the study area by reflecting on the findings (employing bioclimatic design initiatives) already carried out as part of this study.

As earlier stated, before the analysis and evaluation of the as-built case study buildings through simulation, it is imperative that a workflow, in line with the study aim of generating a reliable and cost-effective data capturing and modelling methodology suitable for the study region, is described following the discussion of the earlier research findings.

7.9. Discussion on major research findings.

To achieve the aim of this study through the set-out objectives, there is the need to consider the findings already gathered from all data sources to inform a proper understanding and development of the required proposal suitable for the study region. The key findings identified right from the literature review (chapter 2) to the evaluation and analysis of the case study buildings are further stated to serve as a reminder.

- The problem of energy shortage in Nigeria amidst increasing demand for energy due to factors including increasing population improved living standards and rapid development.
- The poor economy of the nation where cost savings are vital for increased productivity and economic growth.
- High demand for energy required for achieving occupant comfort through mechanical means in commercial buildings.
- The highest demand for energy in the tropical climate where the study is carried out is for cooling due to the poor environmental response of the building to the climate. It further buttresses the need for improving the performance of buildings to respond to environmental challenges.
- The absence of conscious effort at achieving energy efficiency in existing buildings by the current building regulations in Nigeria which therefore encourage building performance improvement through bioclimatic design initiatives.
- Enhancing the performance of existing buildings compared to new construction has several advantages. However, to do so requires an evaluation of the existing condition of the as-built considering bioclimatic design initiatives.
- Determining the performance of existing buildings before attempting enhancement strategies requires as-built documentation for modelling and simulation, the increasingly used method for accessing the performance of buildings in recent times.

- The dearth of as-built details (due to factors such as degradation and poor storage) is needed for determining the initial condition of existing buildings using modelling and simulation.

The above key points lead to and reinforce the need for devising a means for capturing and modelling as-built information and technical characteristics necessary for building performance evaluation using building modelling and simulation discussed next.

7.9.1. The need for a methodology for building data capture, modelling, and simulation.

Environmental building performance improvement of existing buildings towards achieving energy efficiency is not a common practice in Nigeria, as such, the presence of limited studies. While the BEEC and BEEG have encouraged the adoption of bioclimatic design features for building constructions to curb energy inefficiencies, there is no evidence of studies enhancing the environmental performance of office buildings in Benin City, the study region. The limited studies carried out in other parts of the country to enhance energy performance indicated the use of building performance simulation and modelling to achieve such an aim but did not specify the sources of building information they used. Getting the required building information for existing buildings are usually challenging due to several factors including that, buildings are not built to original specification as those shown in the original design as well as post-design modifications carried out during construction, neglect, uncontrolled development, compromise arising from degradation, inadequate, and poor storage of as-built records are also critical factors that make the required technical details of the as-built documentation difficult. It, therefore, necessitates the development of a methodology for building data (bioclimatic design data in the case of this study) capture. There exist several building data-capturing tools and techniques available that are used in several parts of the globe with some previously identified in chapter 3. The different characteristics of the capturing techniques have some pros and cons due to factors such as need, speed, weather, availability, affordability, time, and quality of the captured as-built information. The need to adopt a methodology for the capture of bioclimatic design building information for environmental performance improvement through modelling and simulation should therefore consider these factors to propose for its effectiveness. Both questionnaire surveys and interviews were carried out in the study region to understand current building practices and to seek the opinions of the built environment professionals concerning a building's energy efficiency, environmental performance improvement, bioclimatic strategies, data capturing, modelling, and simulation. The outcome of the survey forms this study's focus on achieving a reliable methodology for building data capture, modelling, analysis, and evaluation of existing buildings in preparation for performance improvement.

7.9.2. Methodology for building data capture, modelling, analysis, and evaluation

The decision to develop the methodology for building data capture, modelling, analysis, and evaluation of existing buildings was borne out of the knowledge gap realised from the built environment professionals' practice deduced from the various data collection methods employed in this study regarding environmental building performance improvement and data capture. The literature review has been properly documented in chapters 2 and 3 of this study. To design the methodology, relevant requirements about the study context needed to be explored such that the opinions of architects and builders, the built environment professionals mainly saddled with the responsibility of building design and construction in the study region were sought through the use of questionnaires and interviews respectively. The survey of the architects provided information on the current building practices, especially concerning retrofitting for energy efficiency and environmental building performance improvement, post-construction evaluation, data capturing and modelling. The interviews of the builders helped to explore the context of building information capture and processing in the study area, highlighting the need and challenges of data capturing for building performance enhancement to achieve energy efficiency. Findings from the measurement and observational survey of the case study helped in the trial of building performance evaluation from the as-built data capture, modelling, and analysis of the bioclimatic design feature of the case study buildings. It helped to provide information on the state of existing office buildings and to inform the decision-making factors towards the development of a methodology from building capture to evaluation, ready for testing of improvement strategies. Figure 4.8 in Chapter 4 is an excerpt of the chart, improved in Figure 7.9.2 showing the research process leading to the evolvement of the developed methodology hereby discussed.

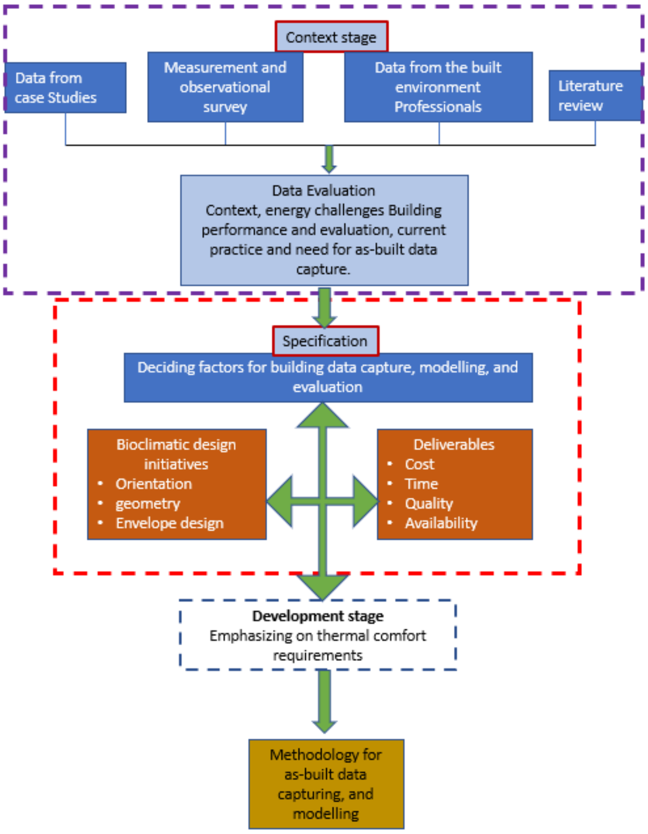


Figure 7.9.2. Improved chart showing the research process leading to the development of the methodology from as-built data capture to evaluation.

7.9.2.1. Context stage

The context stage is the basis wherein all decisions about the entire methodology, ranging from the as-built data capture to the evaluation of the existing building hinge. The stage is divided into four sections, and it helped to identify relevant data to portray that the study intervention complies with the research aim and is useful for the study area. The four components are grouped according to information sources from case studies, literature reviews, measurement and observational surveys, interviews, and questionnaire surveys from the built environment professionals.

As earlier discussed in Chapter 4, the case study method was used in this study in other to investigate a contemporary phenomenon within its real-life context and also to gather multiple sources of evidence for comparison. Multiple case studies of the most common existing office building types in the study region were conducted to ascertain their performance in terms of thermal comfort leading to energy consumption. This was necessary as there is a dearth of documented evidence of office building performance in Benin City, the study location. Thus, the evaluation of the selected case study buildings reinforces the need for evaluating the conditions of the existing buildings before testing environmental performance enhancement strategies.

Another important information source is the measurement and observational survey. It was needed to capture the relevant bioclimatic design variables needed for modelling and simulation in terms of thermal comfort. It captured information relevant to adopting the bioclimatic design requirements including orientation, window sizes, volume, area, and materials to validate the existing climate with building information and in terms of comfort and its resultant effect.

Information sourced from the built environment professionals, including questionnaire surveys of building designers and interviews conducted with the building professionals both in the Edo state chapters of Nigeria are crucial aspects of the context stage. The data collected in these categories are presented in chapters 5 and 6 and are critical to identifying the challenges of current practices faced by the professional ranging from the data capture to evaluation of existing buildings' information for environmental performance improvement. they also help to point to the future regarding the need for building development and as-built information capture, modelling, analysis, and evaluation.

The first stage of information sourcing for this study and like in every other study is the review of existing literature. It helps to identify the knowledge gap, especially what has been done in the study area, what needs to be done and practices from other regions that could be adapted or modified to achieve the study goals.

The information arrived at from the four groups of the context stage is then evaluated based on certain factors that were discovered from the context stage to inform the development of a suitable methodology needed from the phase of as-built data capture to the evaluation of existing buildings, before testing of building performance improvement strategies. The crucial aspect of this stage is that there is the difficulty of developing a methodology from data capture to the evaluation of buildings without understanding the context, the current practices in the region and the current performance of the building in terms of thermal comfort leading to energy consumption.

7.9.2.2. Specification stage.

The specification stage for as-built data capture and modelling is a result of the evaluation of the data analysed from the components of the context stage. It identified the relevant factors that will guide the development of the proposed methodology for as-built data capture, modelling, analysis, and evaluation in preparation for testing strategies for building performance modification. It is required to determine the fundamental criteria and the effectiveness of the methodology for delivering the requirement for thermal comfort enhancement for existing office buildings in the study area. It is informed by the factors highlighted in the context stage and further broken down into two categories which are the bioclimatic design initiatives and deliverables.

Bioclimatic design initiatives as discussed in Chapter 2 are recommended by the Nigerian government and published in the building energy efficiency guide (BEEG) as well as the building energy efficiency code (BEEC). The BEEC, although designed for new building constructions, in its performance route to compliance method requires the use of an energy simulation program. Energy simulation is the recent and most increasingly used program for analysing and evaluating building performance which requires a detailed input dataset for the building. Adopting bioclimatic design initiatives requires that bioclimatic data-set are modelled, simulated, and tested for and this forms the basis for capturing bioclimatic design requirements including building form and geometry, orientation, envelope design and its properties.

The deliverables arrived are mainly those captured from the built environment professionals' perception of the issues of building performance improvement and data capture of existing buildings in the study region. Both the interviews and the questionnaire indicate that the practice of environmental building performance improvement in Benin City as well as in Nigeria as a whole is uncommon whereas, several factors including population growth and recent harsh weather events point to the need to encourage it. In doing so, certain deliverables have been identified by the built environment professionals including availability and cost. An evaluation of these factors leads to the development of a methodology suitable ranging from as-built data capture to evaluation that is effective for the study context.

7.9.2.3. Development stage

Evaluating the performance of an existing building through modelling and simulation is a crucial step in the testing of improvement strategies. The absence of as-built building information on existing buildings coupled with the recent trajectory of BIM adoption necessitates the need for developing a process that can capture the as-built representation needed for building performance improvement. There are several reasons for improving the performance of buildings which is also reflective of the survey and interview results of the built environment professionals in Edo state. This study however focuses on building performance improvement with a special emphasis on thermal comfort, the highest means of energy demand in office buildings to achieve the desired comfort and reduce cost.

The development stage should critically evaluate the outcome of the context stage and the specification stage to develop a methodology that is appropriate and effective for as-built data capture, modelling, analysis, and evaluation before the thermal comfort improvement of buildings. The capture of as-built information in this instance refers to those that can be used to effect bioclimatic design initiatives while keeping in mind that deliverables like cost and availability considering the economy of the study region must be met.

7.10. Methodology for as-built data capture and modelling, analysis, and evaluation

Developing a methodology from as-built data capture to the evaluation of bioclimatic design initiatives for this study is initiated from a careful consideration of the inherent factors identified during the specification stage. It identified the specific details to be captured and the deliverables based on findings from the literature review and the other research methods adopted for this study.

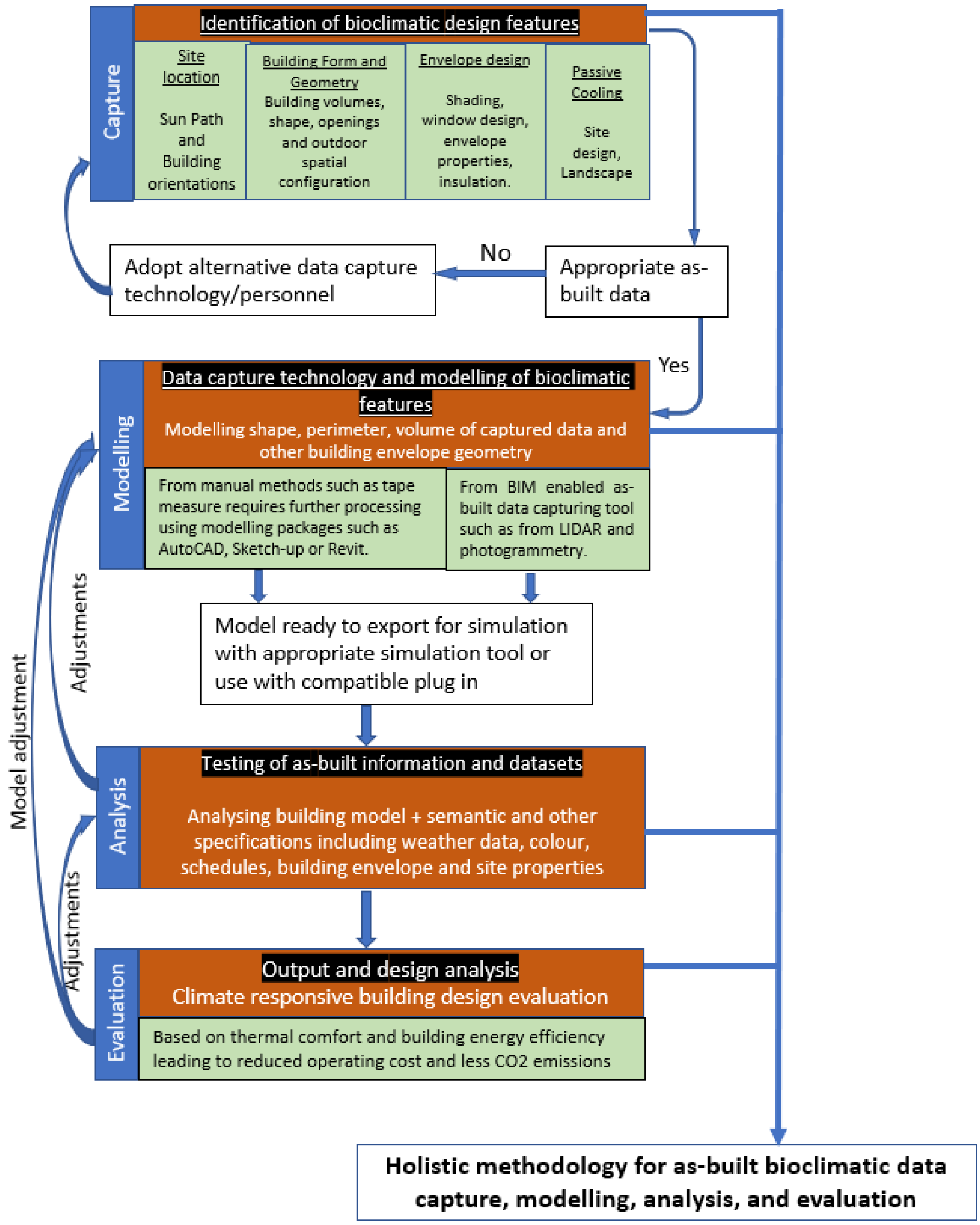


Figure 7.10. Methodology for as-built bioclimatic data capture, modelling, analysis, and evaluation

The methodology follows the four stages of data capture, modelling, analysis, and evaluation as shown in Figure 7.10 and described as follows.

- Capturing: The bioclimatic design features of existing buildings such as site location in relation to the sun, building form, building envelope design and properties necessary for building performance improvement are first identified. This is useful in choosing the appropriate data capturing technology, and depending on several factors such as accessibility to building, cost, time, and availability of data capturing tool. The appropriateness of the tool will produce the necessary as-built data required for modelling and if inappropriate, the need to device other capturing technology or personnel that is capable. Although bioclimatic design initiatives impose no particular style on any designer, examples of features that can be used to effect bioclimatic design initiatives include orientation, size of openings to control ventilation, heat gain and heat loss, size of space to maximise passive design strategies, and building shape to control heat gain or loss or ventilation as previously discussed in Chapter 5 While the bioclimatic design features captured for the case study buildings are contained in sections 7.6, 7.7 and 7.8.
- Modelling: Captured as-built bioclimatic data are assembled in a virtual environment using the appropriate modelling tool to portray the actual representation of the real-life building. Ensuring the shape, perimeter, area, volume, thickness, shading and other geometric features help to produce the geometric representativeness of the building. Depending on the method and tool of as-built data capture and modelling, the model is ready to use for simulation (assuming the use of a BIM-enabled capturing tool) or further processing if the manual method such as the tape measure of as-built data capture is used. The model can then be used for simulation with the help of compatible plug-ins or exported into an appropriate simulation tool. BIM-enabled tools include photogrammetry, videogrammetry and laser scanning. Modelling of the case buildings was done on Revit because the manual methods were employed for as-built data acquisition before simulation.
- Analysis: The geometric model most often is for visual purposes and thus it is necessary after adding the required semantic information to virtually analyse or calculate how the building will function during its use. They include applying the representative specifications of the building envelope properties and shading, applying the actual weather data of the region, and occupancy schedules while making necessary adjustments to the model where necessary. Depending on the type of evaluation required and the choice of simulation tool adopted, some assumptions are required to make the model ready for evaluation.
- Evaluation: After utilising the appropriate simulation tool and adding the necessary semantic information, calculations based on climate-responsive designs can be extracted from the virtual model to portray several forms, depending on the need. Such calculations can be in terms of thermal comfort, daylighting, CO_2, energy

efficiency and cost. Depending on the simulation tool, some aspects of the model or semantic information are tweaked to reflect reality or a proposal (in the case of improvement). The evaluation carried out on the three case study buildings is on thermal comfort towards energy efficiency.

While the aforementioned methodology explains all the stages involved, technological advancements have made it possible for two or more stages to be done simultaneously, especially with the advantage of cost, time, and quality. For instance, one of the most available and increasingly used devices during formal and informal site visits that have also been used to complement the whole building design and construction processes is the smartphone. Its application is described in the next section it follows the aforementioned methodology to capture the bioclimatic design requirements (as built) of interior spaces and compare it with that captured using the tape measuring tool to achieve a less expensive holistic methodology, putting the Nigerian economy into perspective to encourage building performance improvement.

7.10.1 As-Built data capturing and modelling of Indoor environment with smartphones.

The advantages presented by the widespread availability and portability of smartphones in recent times cannot be overemphasized. The use of smartphones in buildings is fast evolving with technological advancements including in computer graphics, high-fidelity visual and 3Dsensors for laser scanning and image capture capabilities (Pintore et al 2020). This study adopts and expounds on the ability and use of the iPhone 12 pro max to capture and model the interior environment of a building for evaluation before building performance enhancement. The iPhone 12 pro max has a pro 12MP camera system (Ultra-Wide, Wide, and Telephoto camera), shift optical image stabilization sensor, LIDAR scanner sensor, and built-in GPS. To harness the advantages of the inherent features of the iPhone 12 pro max for 3D capture of building interiors, Polycam, a 3D capture application for iPhone and iPad was installed. Polycam can create 3D models from photos with any compatible iPhone or iPad and rapidly generate scans of spaces with the help of its LIDAR sensor, editing the 3D captures directly on the device before exporting in over 12 file formats. It has the advantage of both LIDAR which is fast and Photo Mode with great detail and precision even as it can also take measurements and generate blueprints. The workflow showing the stages from the as-built data capture to model creation is described as follows.

A. As-built data capture: The Polycam application can capture data both in the form of a Lidar scanner and in photo mode. The photo mode can be done either automatically or manually. To automatically capture the building interior in the photo mode, the phone is positioned facing a point of interest while it automatically captures many photos while walking through the capture area, up to 250 images at once that are relevant to creating a mesh. It has the advantage of directing the user to slow down or move closer. The manual method allows the user to be in control of the process and to tap the capture button each time the camera focuses on the object of interest and so on. Once this is done, it is processed in the phone to create a 3D mesh as shown in figures 7.10.1B to 7.10.1G. This stage of the work can be done with the free version of the application, and it has a tool within it that can be used to measure from one point to the other to get the dimensions. This is a fairly straightforward process of taking measurements of a captured building off-site but on the screen. A paid version will also help to bring out the dimensions of the internal footprint. As shown in Figure 7.10.1I

B. Save for export: Once the 3D mesh is created, with a paid version, it can be saved in many formats compatible with other CAD and modelling applications to be exported. The formats are thus shown in Figure 7.10.1H below. For example, it can be exported and saved in a high point density cloud format as DXF or other formats. Revit was adopted for use in this study, whereas it only accepts rcp. and rcs. file formats. So, the point cloud was saved in a PTS format which is compatible with Autodesk Recap Pro to help convert it into an rcp, file for export to Revit.

C. Import and detail extraction: After saving in a compatible file format, depending on the modelling application it is imported and cleaned up and then the 3D of the building is available for use depending on the need. For this study,

The example (building D) used in this study to capture the interior space of a building using Polycam shows the workflow from building geometry acquisition to the reconstruction of models for the indoor environment. The captured data is saved by the application on the phone and the file is exported first to ReCap in a PTS file for conversion to rcp format to Revit in a manner explained in A, B and C above and illustrated graphically by Figure 7.10.1A.

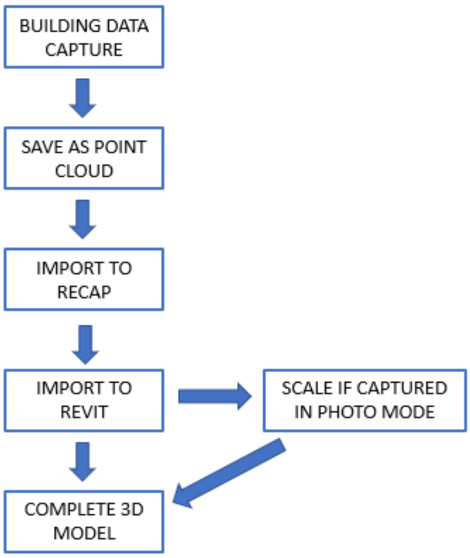


Figure 7.10.1A. Workflow showing building data capture to modelling from an iPhone using Polycam to Revit.

Figures 7.10.1B to 7.10.1G are some screenshots of the 3D model created with polycam on the iPhone 12 pro max. The model was saved and exported as a point cloud into Revit with the help of the paid version.

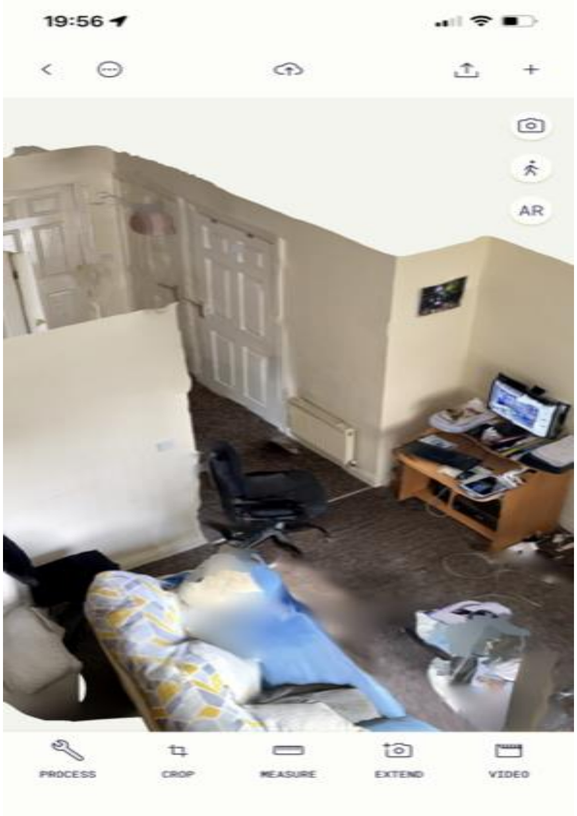


Figure 7.10.1B. 3D model screenshot

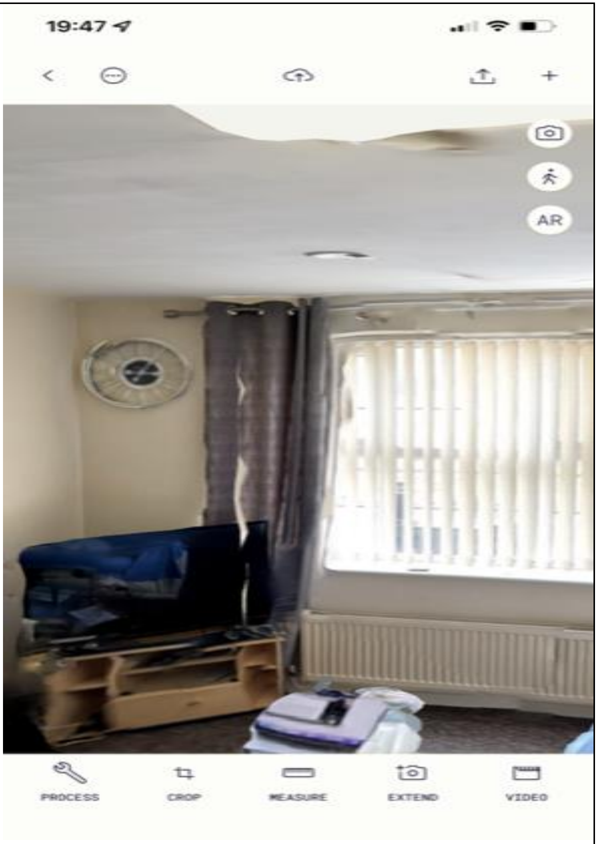


Figure 7.10.1C. 3D model screenshot

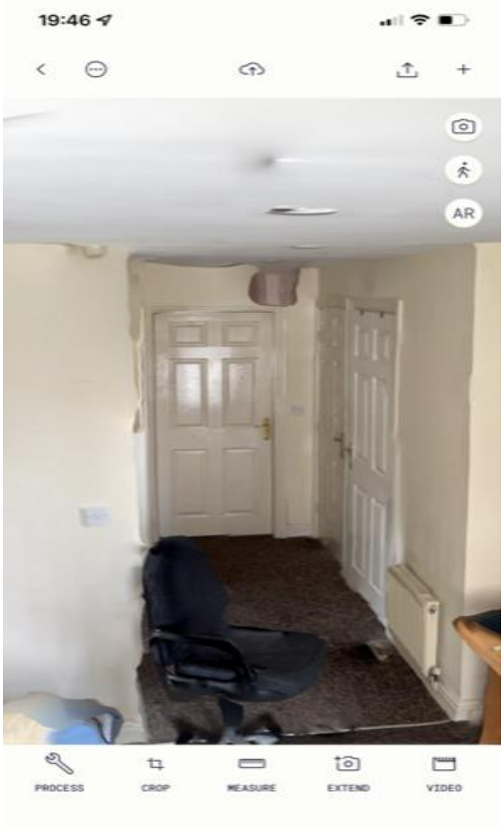


Figure 7.10.1D 3D model screenshot

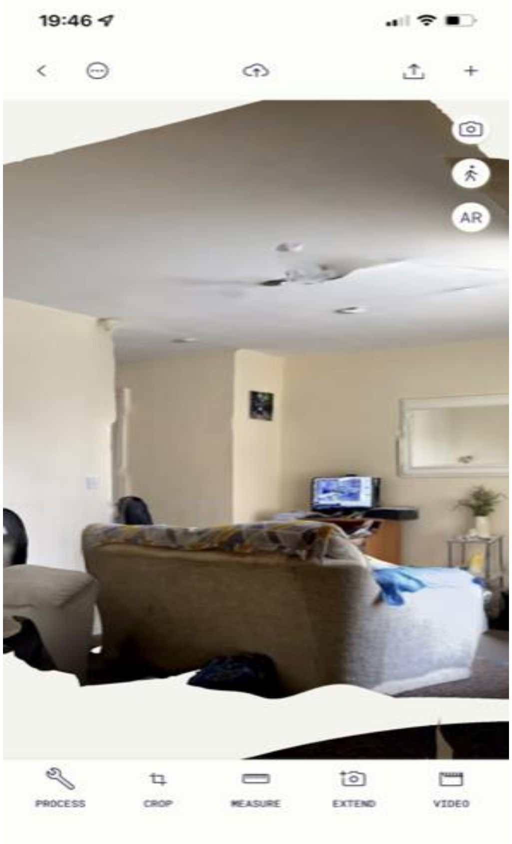


Figure 7.10.1E 3D model screenshot

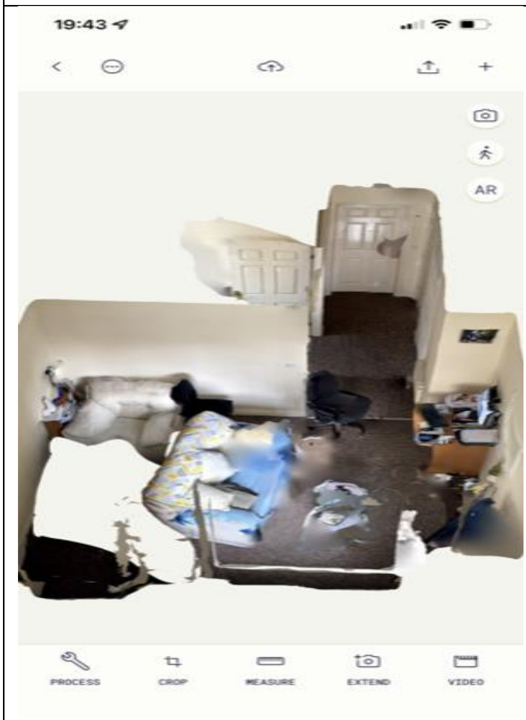


Figure 7.10.1F 3D model screenshot

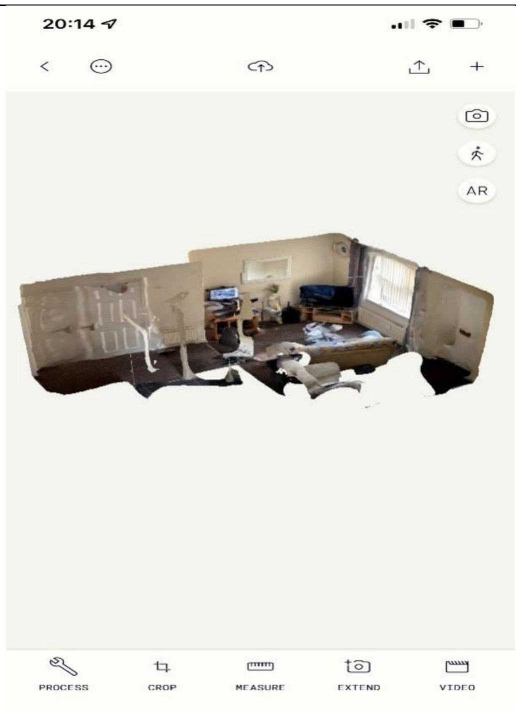


Figure 7.10.1G 3D model screenshot

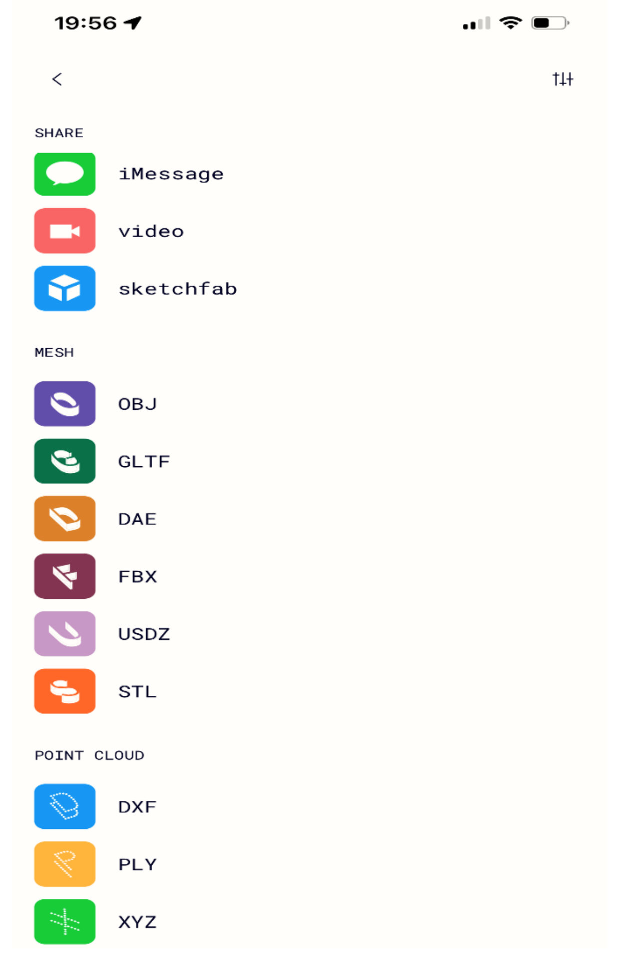


Figure 7.10.1H Export compatible formats

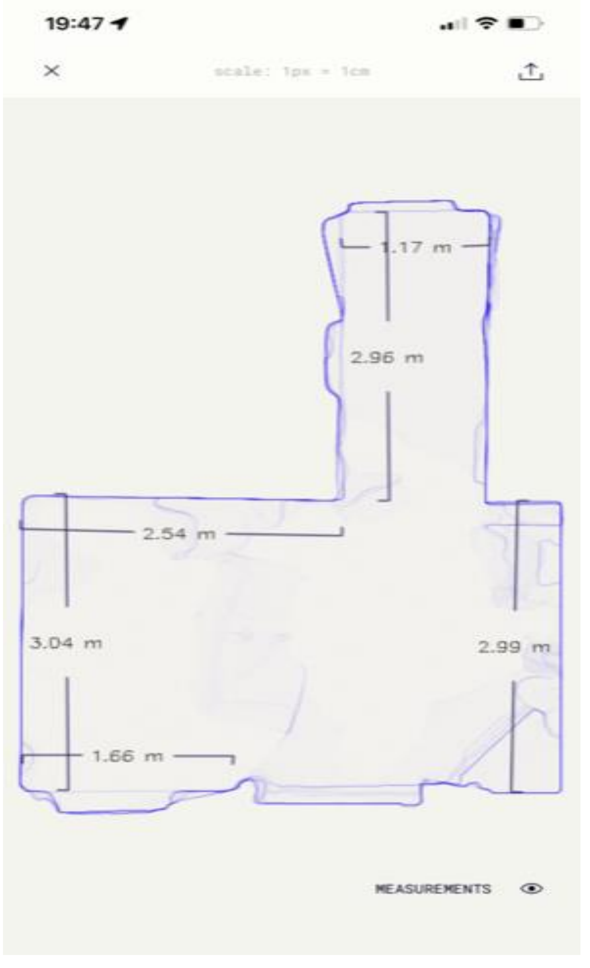


Figure 7.10.1I Generated floor dimensions

As seen from the bottom of the initial six screenshots, the third button can take measurements of points from the model even on the free version. Measurements can also be derived from the generated floor plan as Figure 7.10.1I shows. The dimensions are ready for use or the for the model to be cleaned up if needed. Although dimensions can also be derived from the point cloud in ReCap (see Figure 7.10.1J), Revit is more fluid and has several features. Importing to Revit on the laser scanning mode means that the model is already to scale unlike when imported from the photo mode, it then requires that it is scaled. Scaling can be achieved with the help of a reference measured during the capturing stage and then scaled by dividing the desired (measured reference) by a multiple of the actual measurement and current scale factor on Revit.

In addition to geometry acquisition from the app as shown in Figure 7.10.1I or from ReCap (Figure 7.10.1J), after importing to Revit and scaling, if necessary, dimensions can be extracted from the model either in the form of a plan or section as shown in figure 7.10.1Ka. Figure 7.10.1Kb shows the plan view 3D model in a raw form that could be cleaned, and the footprint used for model creation on Revit which is beyond the scope of this study. Creating a model in design builder from scratch or by using an imported 2D point cloud appears to be less problematic compared to importing a 3D model, due to modifications and misrepresentations that would be noticed from the different software.

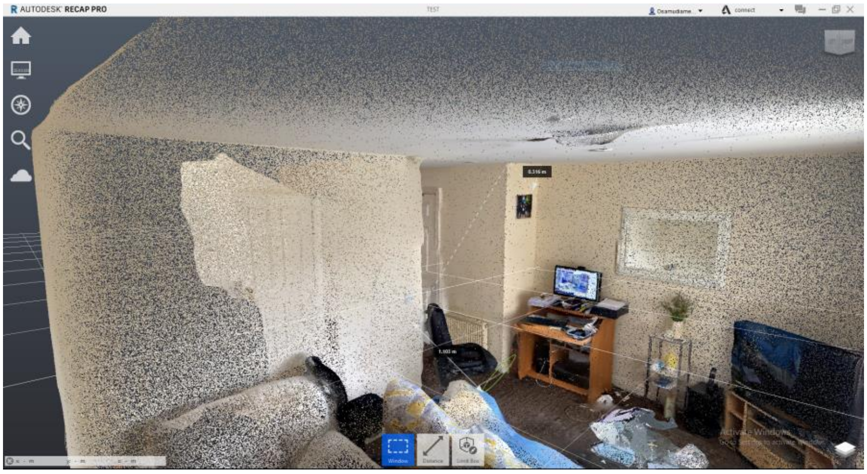


Figure 7.10.1J Point cloud model (Recap) ready for dimension extraction or export.

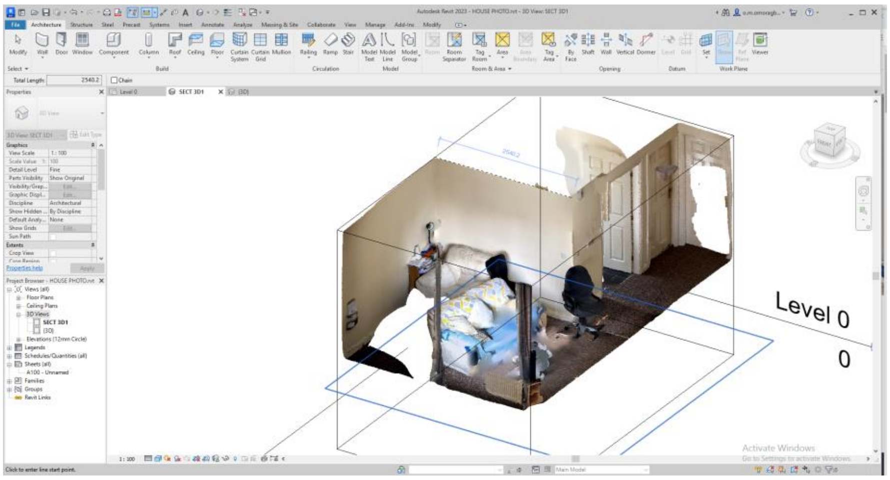


Figure 7.10.1Ka 3D model (Revit) section of a building to aid the extraction of measurements.

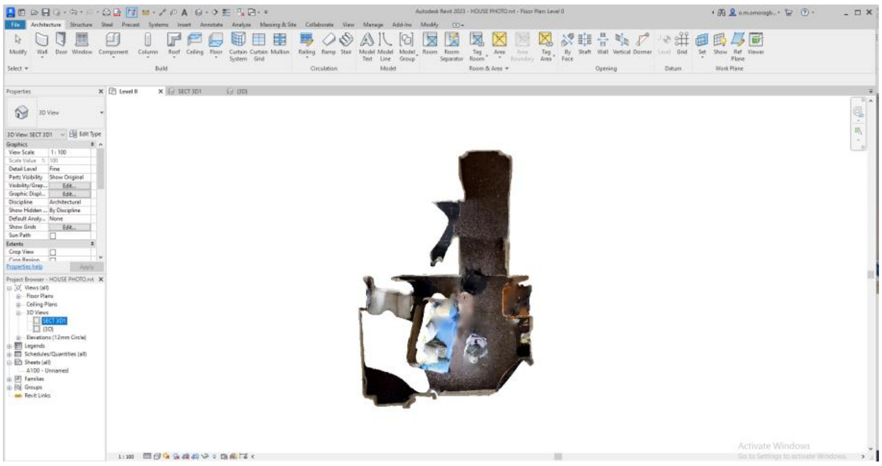


Figure 7.10.1Kb. Raw 3D model (Revit) plan ready for dimension extraction for modelling.

It is also obvious from the created 3D model that the presence of clutters is inevitable as seen in Figure 7.10.1Kb, this then requires it to be cleaned as there may be some variations in the dimensions. To enable comparison of the measurements derived from the model, the model was measured using the measuring tape and the values are recorded and compared to those from the model as shown in Table 7,10.1L.

To extract the perimeter dimensions from the model on Revit, Dimensions were taken at a plane above the ground floor as a way to eliminate the clutters. Alternatively, the clutters could be catered for by using the detail line tool to carefully trace the model boundaries. The dimension tool on Revit was used to take the spot dimensions as can be seen in Figure 7.10.1L. Depending on the required detail, this process can be applied to any part of the model sections, elevations, and floor plans by picking the clearest view or representative of the as-built model or checking for discrepancies. A plane was created above the ground level of the model to help with more precise dimensions and geometry acquisition and was annotated for easy comparison.

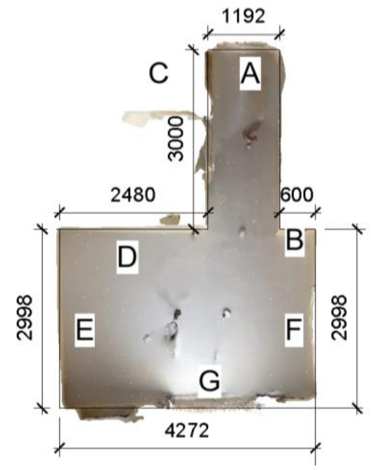


Figure 7.10.1L. Model measurement extracted from Revit.

Table 7,10.1. Annotated model dimensions extracted from Revit.

Model annotation	Extracted dimension(mm)	Measured dimension(mm)
A	1192	1200
B	600	600
C	3000	3000
D	2480	2475
E	2998	3000
F	2998	3000
G	4272	4275

Table 7.10.1 shows that while some of the dimensions from the actual measurement tallied with the dimensions extracted from the models, some showed a disparity of less than 10mm. The results imply a high accuracy tolerance between the measured and the extracted measurements even though it could be argued that fittings and other construction features could account for the slight variations. Both models were then tested to also see the variations in thermal performance by subjecting both to the same conditions, including natural ventilation only and without an artificial source of lighting. The results as can be shown in figures 7.10.1M to 7.10.1P show that the slight variations observed in both the measured and the extracted dimensions of building D produced no noticeable effect on their thermal gains or operative temperatures.

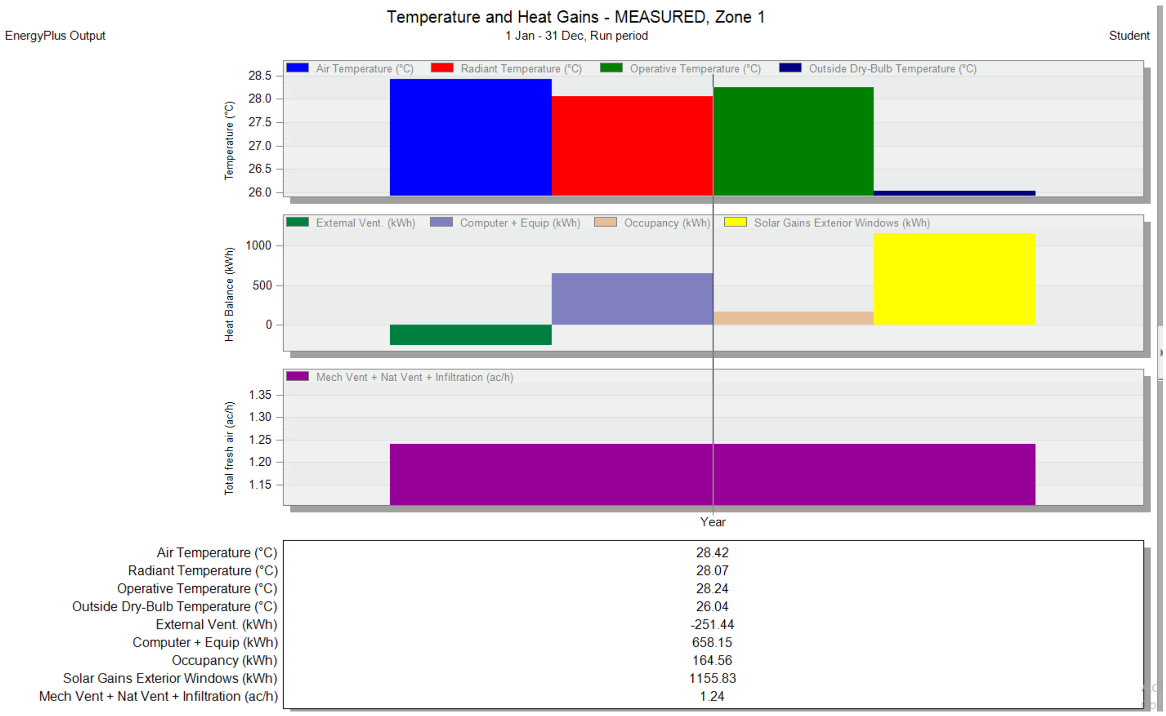
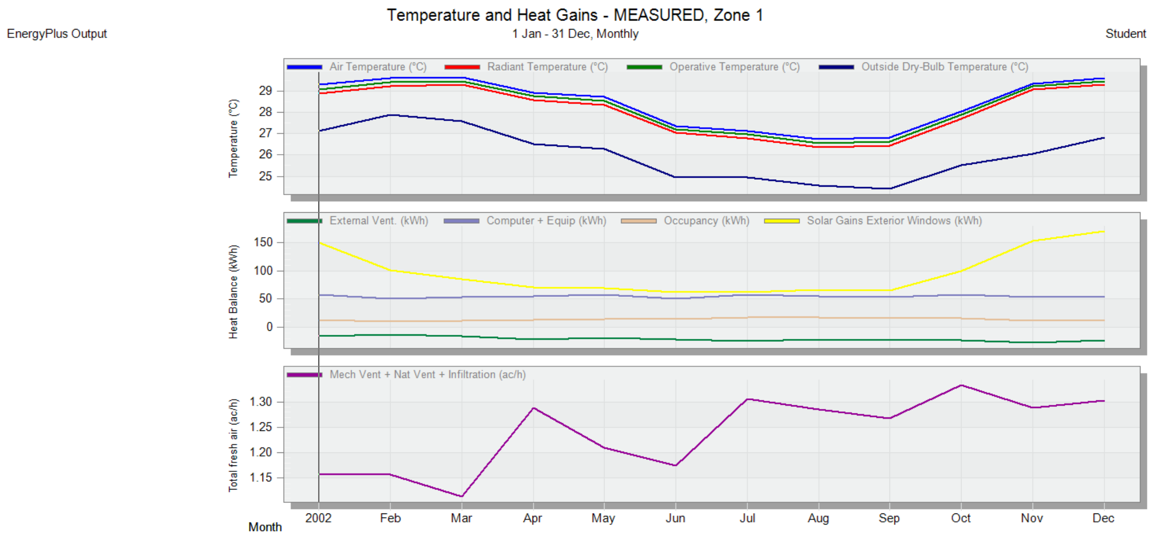
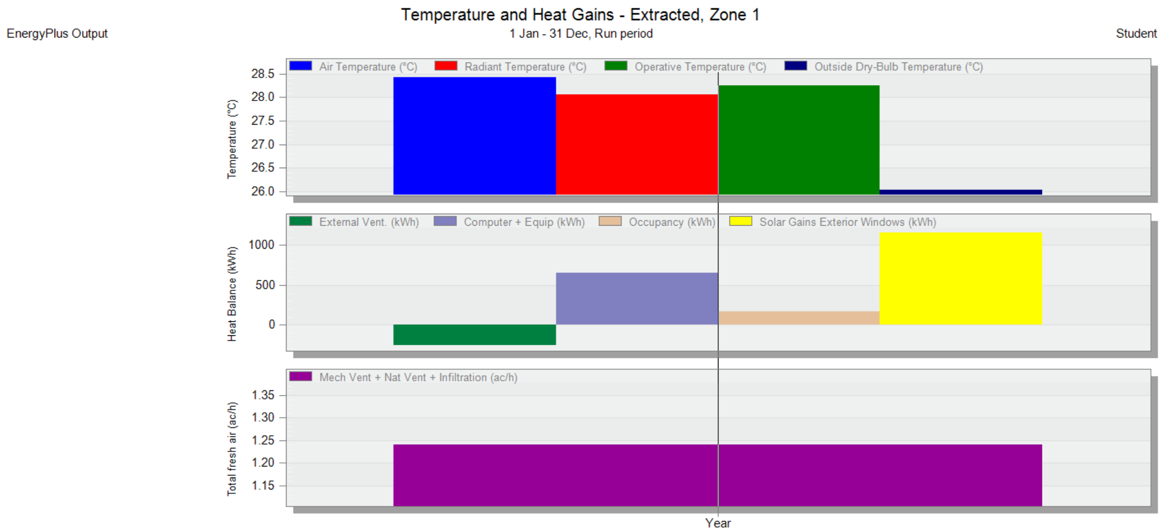


Figure 7.10.1M Annual simulation results using the measured dimension of building D.



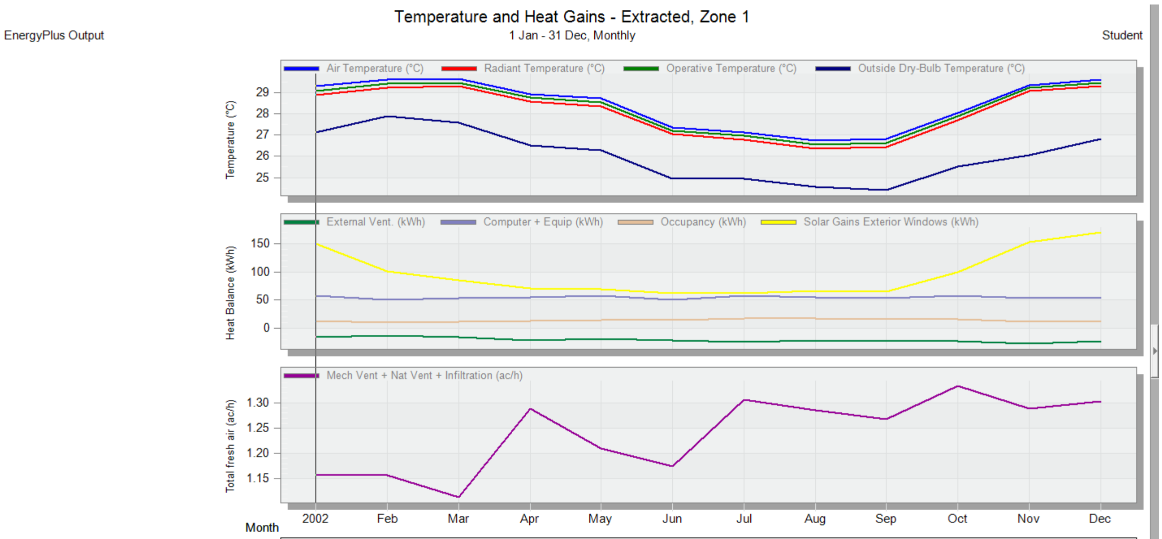
Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	29.28	29.60	29.62	28.91	28.70	27.35	27.13	26.73	26.79	28.05	29.34	29.60
Radiant Temperature (°C)	28.86	29.21	29.28	28.58	28.33	27.03	26.76	26.35	26.43	27.69	29.07	29.28
Operative Temperature (°C)	29.07	29.41	29.45	28.75	28.51	27.19	26.95	26.54	26.61	27.87	29.20	29.44
Outside Dry-Bulb Temperature (°C)	27.12	27.87	27.59	26.50	26.29	24.95	24.94	24.57	24.42	25.50	26.06	26.81
External Vent. (kWh)	-16.09	-13.25	-15.83	-21.41	-19.64	-21.68	-24.53	-22.15	-22.77	-23.43	-27.20	-23.46
Computer + Equip (kWh)	57.73	50.44	53.33	55.30	57.73	50.90	57.73	55.53	53.10	57.73	53.10	55.53
Occupancy (kWh)	13.01	10.54	11.24	12.87	13.96	14.11	17.12	17.34	15.98	15.42	11.46	11.50
Solar Gains Exterior Windows (kWh)	150.99	100.73	85.89	70.65	68.90	62.18	61.43	66.18	64.96	100.28	153.54	170.09
Mech Vent + Nat Vent + Infiltration (ac/h)	1.16	1.16	1.11	1.29	1.21	1.17	1.31	1.29	1.27	1.33	1.29	1.30

Figure 7.10.1N Monthly simulation results using the measured dimension of building D.



	Year
Air Temperature (°C)	28.42
Radiant Temperature (°C)	28.07
Operative Temperature (°C)	28.24
Outside Dry-Bulb Temperature (°C)	26.04
External Vent. (kWh)	-251.44
Computer + Equip (kWh)	658.15
Occupancy (kWh)	164.56
Solar Gains Exterior Windows (kWh)	1155.83
Mech Vent + Nat Vent + Infiltration (ac/h)	1.24

Figure 7.10.1O Annual simulation results using the measured dimension of building D.



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	29.28	29.60	29.62	28.91	28.70	27.35	27.13	26.73	26.79	28.05	29.34	29.60
Radiant Temperature (°C)	28.86	29.21	29.28	28.58	28.33	27.03	26.76	26.35	26.43	27.69	29.07	29.28
Operative Temperature (°C)	29.07	29.41	29.45	28.75	28.51	27.19	26.95	26.54	26.61	27.87	29.20	29.44
Outside Dry-Bulb Temperature (°C)	27.12	27.87	27.59	26.50	26.29	24.95	24.94	24.57	24.42	25.50	26.06	26.81
External Vent. (kWh)	-16.09	-13.25	-15.83	-21.41	-19.64	-21.68	-24.53	-22.15	-22.77	-23.43	-27.20	-23.46
Computer + Equip (kWh)	57.73	50.44	53.33	55.30	57.73	50.90	57.73	55.53	53.10	57.73	53.10	55.53
Occupancy (kWh)	13.01	10.54	11.24	12.87	13.96	14.11	17.12	17.34	15.98	15.42	11.46	11.50
Solar Gains Exterior Windows (kWh)	150.99	100.73	85.89	70.65	68.90	62.18	61.43	66.18	64.96	100.28	153.54	170.09
Mech Vent + Nat Vent + Infiltration (ac/h)	1.16	1.16	1.11	1.29	1.21	1.17	1.31	1.29	1.27	1.33	1.29	1.30

Figure 7.10.1P Monthly simulation results using the extracted dimension of building D.

The photogrammetric methodology for as-built data capture and modelling of indoor environment using smartphones is illustrated using the example of building D. Although building D is not one of the case study buildings A, B and C, the illustration of the methodology can be applied to any type of building. It emphasized the various steps and stages from the data capture to the modelling. Its suitability or applicability in the study region is dependent on a lot of factors previously identified by the built environment professionals and they are discussed in the next session.

7.11. Assessment of the methodology for as-built data capture and modelling of indoor environment using smartphones.

There are several methods available for use in various parts of the globe for as-built data capture modelling and evaluation of buildings. However, they all have unique capabilities and features that make each tool unique in comparison. Particular to this study is concerned with the process of as-built data capture to modelling of interior spaces needed for improving the environmental performance of existing buildings with an emphasis on thermal comfort.

To start with, the practice of environmental building performance improvement is only growing in the study region, considering its advantages over reconstruction, there is a need to motivate it. To encourage it would mean that its practice should be met with minimal difficulty. For instance, photogrammetric capturing and modelling using smartphones will be easier and cheaper for the building designer to adopt in the study region, especially in the absence of a stand-alone building surveying profession. The themes that emerged from both the interviews of the registered builders also happen to be the three factors rated of high significance by the building design professionals on the need for engaging a building surveyor in Benin City and even Nigeria. The major factors identified by the built environment professionals deduced from the analysis of data where the use of smartphones could be effective compared to traditional data capture and processing are described in the subsequent sub-sections.

7.11.1. Cost.

Cost is one of the key factors used to measure the success of any project. Cost can be incurred in different forms including for the purchase of equipment and even extra personnel. The commonness of smartphones in addition to technological advances used as described in section 7.10 reduces the need for extra personnel and its associated cost. This is in comparison with a manual tape measuring tool for data capture. One of the reasons given by the interviewee as highlighted in Chapter 6 is that fewer retrofitting and building surveying jobs are being carried out in the study area and it is unprofitable to invest hugely in data-capturing technologies that are occasionally used.

Another cost-effective strategy of using smartphones is that compared to other photogrammetric processes even using packages such as Meshroom and ReCap requires specialist computers or photos from specialised cameras, which are not inexpensive, the use of Polycam is relatively cheaper as it does most of the computation that would have required more enhanced compute compatible computers such as those with certain types of graphics card and eliminates the need for special cameras. The photo mode is available on all iPhones made after 2015 and the LiDAR (video mode) is available on iPhones 12 pro and after, while the application is free to use or with unlimited export on a subscription of $399.99 or $7.99 as at the subscription time for this study compared to other photogrammetry apps that charge to scan and export.

7.11.2. Time.

In terms of time, the proposed methodology takes less time to capture especially in terms of accessibility. Assuming an accessible space, using a building D above for the illustration, the time taken to capture using a smartphone is 3 times less than that used to measure the same space with a possibility of when larger areas are to be captured. The interviews and the questionnaire survey of the built environment professionals indicate that time has always been the alternative to compensate for a reduced cost. The use of a smartphone as described in the above methodology will help to eliminate the time-related difficulties in personnel, equipment, technique, and computation.

Another dimension of time savings is that compared to some other photogrammetry packages where you need to upload the photos to the computer for computation, the computation using Polycam is not more than 250 secs. It, therefore, eliminates the need and time for a second site visit and the cumbersome workflow.

7.11.3. Quality

The built environment professionals agreed that different work requires different capturing techniques to achieve the desired goal. It also implies that each work would require different details to be captured to achieve the set-out goals whose quality is related to the accuracy of performing the needed task. The minimum level of detail used in the study area is millimetres (mm). The methodology proposed using smartphones can also capture mm. However, the accuracy shown is about ±10mm in dimensions. This is in line with the study by Luetzenburg et al (2021) stating that length has an accuracy of ±1cm for the iPhone LiDAR sensors. The methodology illustrated in section 7.10 on building D using a smartphone implied that the impact on the variations in the dimensions is negligible and has no effect on solar gains and operative temperature. The implication of this is that as-built data capturing and modelling for environmental performance improvements can be effectively carried out using smartphones in the manner earlier described. Quality is also enhanced while following the instructions in the application.

Other benefits that the methodology for as-built data capture and modelling of indoor environments using smartphone proffers are integrated data processing, accessibility, usability, and it requires less personnel.

Given the above factors, the methodology described in section 7.10 is a suitable and reliable methodology for the capture of building information that can be easily edited, and processed, and the model created is exported into compatible design software including Auto Cad and Revit. Revit was used in this study and according to the analysis of the questionnaire survey, Revit is the most adopted building design software used by building design professionals after AutoCAD with more BIM-enabled features. This can then be either exported to a simulation tool for analysis and evaluation before testing retrofit strategies for building performance improvement or the dimensions are extracted to create the required model in the simulation tool as adopted in this study. Exporting a model is usually very cumbersome because the material and component libraries differ and are not aligned from one package to another which could significantly impact the results of the simulation results during analysis.

7.12. Conclusion

This chapter presents a methodology for as-built data capture, modelling, analysis, and evaluation of indoor spaces useful for testing strategies for performance improvement of office buildings suitable in Benin City, the study region. It discusses the overview of three case study office buildings and thereafter the process of as-built data capture of bioclimatic design features through measurement and observational survey and the unsuccessful attempt of the ordinary photogrammetry survey. The observational survey was carried out with the assistance of extra personnel using the manual tape measuring tool, a digital phone in-app measurement tool and several captured photographs of all accessed interior office spaces of the building. The spaces accessed as part of the case study buildings were on the ground floor (building B), first floor (building C) and second floor (Building A). It further explained the modelling, analysis, and evaluation of the case study buildings concerning thermal comfort. The analysis helped to show the room with greater discomfort and the parts that would benefit more from remedial work. It expounded on the need to improve the overall indoor thermal condition of office buildings, an area where there is a dearth of studies to show that office buildings in the study area are thermally uncomfortable. Mechanical means have compensated for the poor thermal performance of such buildings resulting in energy expenditure and its associated cost, especially with the poor economic situation of the country, energy shortage and changing climate.

This chapter discussed and reflected on the research findings which helped to inform the development of a suitable and reliable photogrammetric methodology for as-built data capture, modelling analysis and simulation that can be used in the study area. While putting the contest and all research findings together the developed methodology was practically tested with a prototype building D. The methodology applied had a slight variation in dimensions using the prototype model from the smartphone compared to as-built data capture using the tape measure, however, it presented a negligible impact on solar gains and operative temperature leading to thermal comfort. It also presented to have significant advantages in terms of time and cost. Thus, the developed methodology appears to show the significant impact required to encourage environmental building performance enhancement of existing office buildings in the study region where improving buildings is not a common practice despite the advantages, they have over new constructions.

CHAPTER 8
CONCLUSION

8.1. Introduction

This chapter reflects and presents an overview of discussions of the entire research work. It highlights the issues the study tried to address, discusses the findings from the review of literature, and comments on how the study's aims and objectives have been achieved. It further highlighted the contribution and significance of the research, the scope, and the opportunities for further research work.

8.2. Overview of research findings

This study has succeeded in developing a methodology for data capturing, modelling, analysis, and evaluation of existing buildings also trialled using a smartphone in a photogrammetric process to aid future decisions on environmental performance improvement in relation to thermal comfort. Measurement and observational surveys were carried out in accessible office spaces of three case study buildings typical to the office typology found in the study region using a measuring tape, digital tape (phone application), several photos of the interior spaces and with the help of extra personnel. The captured information was first produced in a BIM format using Autodesk Revit before extracting 2D the CAD format and exporting for 3D modelling in DesignBuilder which uses an EnergyPlus simulation engine to assess the performance of the buildings regarding thermal comfort. The results indicated that for most parts of the year, there is thermal discomfort in all of the case study buildings implying that there would be a benefit for remedial work. Also, attempts at creating 3D reconstruction from ordinary photos captured using mobile phones and saved and exported for use in a photogrammetric process using Meshroom proved futile which reinforced the need for devising other means for 3D modelling from building data capture. Whereas, compared to other data capturing techniques previously identified, photogrammetry appears more promising to achieving the study aim.

Mixed methods employing both qualitative and quantitative research techniques, methods and approaches in a single study helped to expand the researcher's understanding while employing the multiple case study method to help in comparing results. In addition to the review of literature, a questionnaire survey, complemented by semi-structured interviews of the built environment professionals as the strategy of inquiry helped to understand current practices that bother on factors including building data capture, energy efficiency, retrofitting and modelling in the study region. Afterwards, on-site measurement to capture the building information (including measurements, temperature, orientation and building materials) and a complementing questionnaire designed for the building occupants helped in ways including computer-based modelling and simulation to determine the current performance of the office spaces accessed.

This study, initially from a review of the literature identified the need to enhance the environmental performance of Nigerian office buildings due to new expectations and several challenges including energy shortage, increasing population, changing user needs, and climate change. While improving the performance of the existing building stocks comes with numerous advantages compared to new construction, evaluating the performance of existing buildings is critical. Bioclimatic design initiatives and the use of building performance simulation are recommended by the Nigerian Building Energy Efficiency Code (BEEC) for assessing the performance of buildings. Detailed as-built information is required to effectively determine and evaluate the building's performance which is hardly available in the study region due to several factors including deterioration poor storage and unchecked building development thus requiring the need to capture such necessary details for modelling and simulation The following are the key findings from the entire study.

- The increasing electricity demand borne out of rapid development and population growth such that the services and commercial sector, the highest contributor to the Nigerian GDP in 2016 is predicted to consume a significant amount of energy, second to the industrial sector by 2030 (Emodi and Boo, 2015) requiring the need to reduce the energy demand of office buildings, in turn improving socio-economic growth amidst the poor economy.
- There is certainty that the high energy expenditure by office buildings in the study region mainly for cooling is due to the poor environmental response of the building to the climate. This is because one of the main aims of a building is to provide its occupants with a safe, conducive, healthy, and secure indoor environment to carry out their necessary activities (Gopikrishnan and Topkar, 2019; Ijaola et al. 2018). The quality of the indoor thermal environment is climate-related and while the thermal requirement of building occupants could change with time, it is recently exacerbated by climate change and extreme weather events (Ibem et al. 2012).
- The practice of improving the environmental performance of buildings has not gained sufficient attention in Nigeria (Opara et al, 2019). In the developed climes, there have been efforts geared towards enhancing the environmental performance of buildings and reducing the consumption of energy by setting up measures and rating criteria such as LEED and EPC. These measures inform design decisions in such countries whereas, in Nigeria with a tropical climate where western methods of buildings and materials have been adopted as supposed to the previous traditional climate-responsive construction methods and materials (Geissler et al. 2018). As a result, buildings in Nigeria, including offices have not properly considered climatic adaptations thereby resulting in the occupant's use of mechanical means of cooling to aid the compromised environmental performance of the building.

- Achieving the required comfort in office buildings is vital to reducing energy demand in the building and its associated cost especially due to power shortages and inefficiencies that have resulted in the use of costlier alternatives mainly fuel-powered generators.
- Knowing that the highest use of energy in office buildings is for achieving comfort, most significantly, thermal comfort, it emphasises the need to adopt measures that help in achieving thermal comfort and energy efficiency. In Nigeria, unlike other developed countries, the concept of energy efficiency is in its infancy. Before 2016, when the first Building Energy Efficiency Guide (BEEG) was published accompanied by the Building Energy Efficiency Code (BEEC) in 2017, the National Building Code (NBC) came into law in 2006 and was the main document guiding building design and construction. Also, in 2014, the Edo State Urban and Physical Planning Regulations were adopted in Benin City, the study area. Both documents did not make any conscious effort to address energy efficiency in buildings which has also sparked criticisms. The BEEG, realising the need for an energy-conscious and thermally conducive indoor environment proposed the adoption of bioclimatic design initiatives as this imposes no direct path the building designer must follow in achieving the aim of reducing energy demand in buildings given the power shortages and cost of alternative power sources.
- Bioclimatic design initiatives use architectural design principles to create a conducive indoor climate to reduce the need for energy to compensate for the building's inability to provide the required comfort using fewer resources. Its approach of maximising the understanding of the constant interaction between climatic conditions and buildings to achieve occupant comfort has been well documented in achieving energy efficiency even as it does not impose any path on the designers (Ochedi and Taki, 2019). Its strategies include site orientation, building form, building envelope design and passive cooling.
- With population growth and urbanisation requiring new building development, understandably, both the BEEG and BEEC targeted the new building. Whereas a significant proportion of the building stock is still in use and requires performance improvement. For example, the office spaces in the three case study buildings indicate the need for performance improvement. The advantages presented by improving the existing building stock are enormous including that it is cheaper compared to new construction.
- The survey of the built environment professionals so far indicates that there is an understanding of the relationship between comfort and energy efficiency as well as between the building and the environment. The survey also indicates that the professionals apply bioclimatic design concepts but there is hardly any evidence of the effectiveness of their claims probably because, as gathered from the survey, the

building designers rarely go back to their projects after construction to understand how well it is performing.

- The need to carry out a performance evaluation remains a vital step before the environmental building performance improvement of the existing building stock. In recent times, there has been a preference for a systematic approach that requires that detailed building information be used to evaluate and validate the performance of the building (Geissler et al. 2018; Olanipekun et al. 2017). The BEEC also specify in its "compliance method 2" that as a building's performance route to compliance, the initial building design should be validated or compared to the reference building (modelled and simulated) to ensure it meets minimum prescriptive requirements.
- Building modelling and simulation, necessary for building performance evaluation, analysis, improvement, and testing of strategies require detailed building information and technical characteristics of the building.

Because of the above findings and that there exist several as-built data-capturing tools and techniques in different parts of the world, and considering the study context, this study's data capture focused on those for achieving thermal comfort through bioclimatic design initiatives. Five objectives were set out to fulfil the study aim and the discussions set forth next bear these objectives in mind.

8.2.1. Review of Objective One.

The first objective of this study was to critically explore relevant bioclimatic design characteristics and their impact on building performance to explore retrofit scenarios that can be used to improve building performance. Considering the study context and the literature review including those recommended by the Building Energy Efficiency Guide (BEEG). Bioclimatic design initiatives offer the best alternative to achieving comfort while using fewer resources with less demand for energy and its associated costs. Its approach of maximising an understanding of the constant interaction between climatic conditions and buildings to achieve occupant comfort has been well documented in achieving energy efficiency even as it does not impose any specific path on the designers (Ochedi and Taki, 2019). Its strategies, including site orientation, building form, building envelope design and passive cooling point to the relevant building characteristics and emphases on those features required for as-built data capture towards modelling and simulation for collecting and determining performance. Examples of these building characteristics concerning thermal comfort include the direction of the sun to the building, total surface area, indoor volume, building area and perimeter, area of openings, the total area of the window and that of the wall, length of shading device, and U-value of glazing.

8.2.2. Review of Objective Two

The second objective of the study was to review relevant literature to Identify assess and compare the different available data-capturing techniques with key aspects of bioclimatic design conditions. The several available data capturing techniques available in many parts of the world tend to have certain unique features thereby resulting in certain limitations as well as benefits and leading to their suitability depending on certain factors including region, requirement, availability, cost, and technical know-how. The identified data-capturing technologies were assessed based on the bioclimatic design characteristics that they can capture, which further helped in developing a questionnaire and interview survey to garner more information from the built environment professionals in the study region.

8.2.3. Review of Objective Three

Objective three was to specify the most suitable technology for as-built data capture needed for simulation (modelling, analysis, and evaluation) that can be used for building performance improvement considering bioclimatic design initiatives. An analysis of the context and practices of the building professionals in Benin City, Nigeria, the study region tends to agree that the use of photogrammetry is more beneficial to achieving the study goals. Photogrammetry requires the use of photogrammetric software and the use of photos. A smartphone (iPhone 12 pro max) was used to capture photos of an existing building, process them into a model, and export them for further analysis and evaluation.

8.2.4. Review of Objective Four

The fourth objective was to critically analyse current practice conditions addressing energy-related challenges of office buildings in Nigeria. The current practice of as-built data capture in the study region was assessed from the questionnaire and interview survey of the built environment professionals in the study region. It showed that the manual tape measure is the most adopted method used in the study area. However, this is due to certain factors including that it is cheap and available but to the detriment of time. It is not surprising since there are no significant retrofitting jobs carried out in the study region. The need to encourage the practice of improving the performance of buildings in line with the recommendation of the BEEC and BEEG is critical to adopting a methodology for bioclimatic as-built data capture, modelling, analysis, and evaluation

8.2.5. Review of Objective Five

The fifth objective was to validate the proposed holistic methodology for as-built data capture to simulation. The methodology capturing bioclimatic as-built details to aid building performance simulation was initially carried out considering solar gains and thermal performance. The results followed the same pattern as those captured on-site. The methodology was also trialled using smartphones in a photogrammetric capture and guided by that of the manual tape measuring tool as described in Chapter 7. There was a difference of ±10mm between the dimensions extracted from that modelled from the smartphone compared with the measurement using the measuring tape, which is the most adopted data-capturing tool in the study area. DesignBuilder, with an EnergyPlus simulation engine, was used to determine their performance and it was observed that there were no noticeable differences in both models in terms of thermal performance and solar gains thereby achieving the study aim.

8.3. Contributions and significance of the study

First, this study has identified that despite a vivid understanding of the relationship between the environmental performance of buildings and energy consumption concerning building user needs, building design professionals hardly get feedback to understand if and how the buildings are performing to their desired expectation after construction and occupancy. Secondly, this study has helped to show that despite the increasing need for comfort in office buildings amidst urbanisation, population and economic growth and changing user needs, the practice of building performance improvement is still in its infancy which must be encouraged given its numerous advantages. Thirdly, there is a dearth of studies to indicate that office buildings in the study region are thermally uncomfortable, this study has revealed that through the use of the DesignBuilder simulation tool. Fourthly, this study further emphasises the importance of modelling and simulation using detailed building information to assess, analyse and evaluate the performance of the building before testing strategies for improvement purposes. Ultimately, this study developed a methodology for building data capture and modelling needed for building analysis and evaluation of existing buildings needed for performance improvement purposes considering bioclimatic design initiatives. While, identifying the absence of the speciality of the building surveying profession in Nigeria the methodology involving data capture, modelling, analysis, and evaluation of the interior spaces of a building was trialled utilising a building prototype developed from the use of a smartphone and an appropriate simulation tool. The developed methodology with the absence of surveying professionals does not encourage quackery because to be successful in its application requires a good knowledge of building surveying and bioclimatic design initiatives which is mainly expected of the appropriate professionals.

Thus, this research after examining the current practice of building performance improvement and data capture technologies in Benin City, in response to the poor state of energy in Nigeria made some recommendations both for theory and practice (including for policy).

8.3.1. Recommendations of the study to practice

- Encourage that bioclimatic design initiatives as contained in the BEEC and BEEG are considered not only for new buildings but for existing buildings both in the design and construction phases to help improve energy efficiency in Nigeria's building sector.

- Encourage the use of building information modelling technology (software and tools) for the different phases involved in retrofitting and redesigning a project due to its numerous benefits including improved building performance.
- Advocate that the building design professionals carry out a regular evaluation of building projects post-construction and occupancy, to identify areas where improvements can be made.
- To encourage building performance improvement and energy efficiency, there is the need for policy changes including a review of the NBC as the document currently does not contain a detailed way of achieving energy efficiency.
- Mechanisms to enhance collaboration (specialist professionals contributing at an appropriate stage of a project) between the built environment professionals in executing project delivery should be made paramount to eliminate quackery or contradictions and its implications on building performance improvement.
- End-users and building owners should be made aware of the relationship between the environment, comfort, and energy as this will further influence their design and retrofit requirements.

8.3.2. Recommendations of the study to theory

- The energy efficiency attempts made by the Nigerian government through the BEEG and BEEC documents encourage the use of bioclimatic design initiatives however, it does not give a detailed framework to design professionals on how to implement it on existing buildings. This study has produced a systematic and contextual-based methodology from building data capture to evaluation for performance improvement and in turn, energy efficiency.
- There has been no research to show the performance of office buildings in Benin City. This study has used office buildings in the city as a case study to show their level of thermal discomfort which is a novel and a significant contribution to knowledge.
- This study in addition to developing a methodology for as-built data capture, modelling, analysis and evaluation of the effects of bioclimatic design initiatives in the building has also trialled the methodology using a prototype produced with the use of smartphone technology.
- There is flexibility in the developed methodology which implies that it can be applied to other existing building types as well as climatic conditions.
- This study will serve as a reference point in various forms including in the areas of methodology, policy-making and a guide for professionals when retrofitting existing buildings for the purpose of building performance and energy efficiency of buildings.

8.4. Limitation and scope

There is a paucity of publications on the environmental performance of buildings and energy efficiency as well as building data capturing in the study area to guide new research on the subject area. This served as a limitation on this study, however, the researcher was able to reflect and relate publications from other parts of the country and other parts of the world to achieve the study's aim. The focus of this study was on office buildings due to their significant energy consumption and contribution to the economy, therefore only building information about bioclimatic design initiatives were considered for as-built data capture. Access to case study buildings was also limited to some spaces, a more robust assessment of whole buildings would have provided more information on the overall thermal comfort condition of the office spaces. This limited the study to the indoor environmental quality of only the accessed parts of the buildings. As the buildings were existing and were occupied, the level of disruption is critical to the analysis arrived at. It is also important to mention that the efficiency of using the developed methodology is limited to the built environment professionals, especially during cleaning clutters and dimension extraction from a point cloud model.

8.5. Suggestions for future research

Future research efforts can go a step further from the analysis and evaluation of the as-built model to seek possible strategies for building performance enhancement of office buildings and other building types. Future research can also attempt to employ other strategies including the use of renewables to achieve thermal comfort and in turn energy efficiency of buildings. Also, there may be the need to explore options of using smartphones with other operating systems including Android phones as well as other formats of exporting as-built digital models from the mobile phones to the needed computer application for further processing.

8.6. Conclusion

This chapter summarised the key points of the research, presenting how the objectives were achieved. It highlighted the research contribution, and scope of the study and also provided some recommendations for future study.

Overall, it identified the research gap from existing literature and set out four objectives to achieve the research aim of developing a methodology required for building data capture, modelling analysis and evaluation of existing office buildings needed before building performance improvement. Mixed methods using case studies, interviews and survey questionnaires were employed to achieve research objectives and the findings were presented and discussed. The findings further helped to inform the development of a suitable methodology from as-built data capture and modelling to an evaluation of office buildings for thermal comfort leading to energy efficiency and in turn cost. The methodology could also be applied to other building types.

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APPENDIXES

Appendix 1: Ethical Approval

Appendix1

Ethics Application: Panel Decision

E

ethics

To Osamudiamen Omoragbon

11/12/2020

This message was sent with Low importance.

The Ethics Panel has reviewed your application: Improving environmental building performance for Nigerian office buildings using data capturing techniques.
Application ID: 1017

The decision is: Application Approved.

The Chair of the Panel made these comments:

I refer to the academic ethics policy of the University of Salford, clause 3.2.3:

The confidentiality of Information supplied by the participant, and participants' right to anonymity must be held in accordance with the Data Protection Act 2018 and the University Data Protection Policy and GDPR.

While it is mentioned in the consent form that data will be stored anonymously, it is important to refer to the specific policy of DPA and make all the parties aware of the context in which the research operates. with respect to data protection.

Please use the Ethics Application Tool to review your application.

Appendix 2: Questionnaire

Part 1 General Information on Respondent/Participant

1. Are your most frequent Practice carried out in Benin City? Please Tick			
Yes		No	

Please tick as appropriate for the remaining questions of Part 1

	1. What is the best description of your practice?
A.	Employed in a public or corporate organisation
B.	Construction
C.	Education/Studying
D.	Own firm/Private practice
E.	Free-Lancing
F.	Not in active practice/ others, please state
	2. What is your current level of professional qualification
A.	Fellow
B.	Full member
C.	Associate member
D.	Graduate member
E.	Student member
	3. How old is your professional practice (if in active practice)?
A.	Under-five years
B.	6-10 years
C.	11-15 years
D.	16-25 years
E.	Over 25 years
	4. What is the nature of your most current/recent projects types handled
A.	New Construction
B.	Renovation/Refurbishment/Retrofit
C.	Both A and B
D.	None
	5. What is the nature of the role/contract you regularly handle?
A.	Design only
B.	Design and build
C.	Traditional/conventional
D.	Construction management only
E.	Turnkey
F.	Others, specify

Part 2. This part comprises of questions created by the researcher and targeted towards gauging the architect's role towards the process of retrofitting/redesigning, surveying and performance enhancement.

6. In your opinion, how best can you describe energy efficiency if considered in your Project?	
A.	Less use of main source of power (commonly referred to as NEPA)
B.	Less use of alternative source of power (e.g. generators, inverters)
C.	Less use of both A and B
D.	Use of renewable
E.	When use of power generates more income/is justified
7. How do you in the field of architecture address energy efficiency in your Project?	
A.	Leave it to occupants/end users to implement
B.	Through efficient building design
C.	Through renewable energy sources
D.	Never paid much attention to energy efficiency in projects
E.	Others, specify

8. In your opinion, on a scale of (1) least significant to (5) most significant, to what extent does the environmental behaviour and design of buildings impact energy efficiency?	**1**	**2**	**3**	**4**	**5**

Question 10 are some common design considerations in the field of architecture that impacts decision making. Please assess the importance of each in your practice on a scale of (1) least significant to (5) most significant on environmental behaviour and occupants thermal comfort concerning the energy efficiency of buildings

9.	**Design Considerations**	**1**	**2**	**3**	**4**	**5**
Envelope Configurations						
A.	Using and integrating of shading devices to control heat gain/loss					
B.	Building material properties (insulation)					
C.	Size of space to maximise passive design strategies					
D.	Size of openings to control heat gain/heat loss/ventilation					
E.	Building façade orientation to control heat gain/loss/ventilation					
F.	Building shape to control heat gain/loss/ventilation					
G.	Building height/volume to control heat gain/loss/ventilation					
End user related considerations.		1	2	3	4	5
H.	Type of building /operation (Use of building to occupants)					

I.	Security of occupants					
J.	Privacy of occupants					
K.	Building construction cost to occupants					
L.	Building operation cost to occupants					
M.	Size of space for the anthropometrics purpose					
N.	Land Value to occupants					
O.	Noise					
P.	Air quality					
Q.	Comfort of occupants					
Compliance consideration		1	2	3	4	5
Q.	Client specification					
R.	Outdoor spatial configuration					
S.	Government policies/regulations/standards					
T.	Own experience/discretion					
U.	Buildability/Construction					
10. How often do you get feedback after the completion of a project to understand its environmental behaviour and occupants thermal comfort in relation to the building's energy efficiency. (5) is very often and (1) is never		1	2	3	4	5

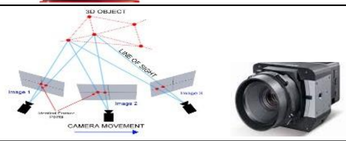
12. How do you regularly get feedback on a project after completion to understand the design's environmental behaviour and occupants thermal comfort in relation to the building's energy efficiency/use	
A.	End Users/Occupiers
B.	Clients/Non-occupiers
C.	Self/Post occupancy evaluation/Inspection
D.	Rarely
E.	Never
13. What are the main reasons stated by clients for redesigning/retrofitting/renovating buildings? Please tick all that applies	
A.	Improved aesthetics
B.	To change building use/function
C.	To enhance its environmental performance
D.	For structural reasons
E.	To meet statutory compliance
F.	To improve its security
G.	For health reasons
H.	For improved accessibility
H.	Others specify
14. How do you get building-related data/characteristics (Including design and specifications) before redesigning/retrofitting/renovation?	

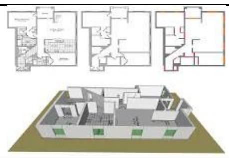
A.	Existing As-is drawings/design (Including from architects records, archival records, planning authorities collections, online, etc.) Please answer II
B.	Engage a building surveyor to capture the as-is building details
C.	Personally, conducting surveys
D.	Others Specify
E.	
	If you chose A above, where do you usually get existing as-is drawings/design?
A.	Architects record/Archives
B.	Planning authorities collection
C.	Online
D.	Others, please specify

15. In order of importance, what do you consider before engaging a building surveyor to capture as-is building characteristics; Using a scale of (1) least significant to (5) most significant						
	Consideration	**1**	**2**	**3**	**4**	**5**
A.	Accuracy					
B.	Time					
C.	Cost					
D.	Scale/Size of Project					
E.	Complexity of Project					
F.	Lack of technical Know-how					
G.	Lack of capturing tools/instruments by architects					
H.	Number of personnel required					
I.	Access to property					
j.	Building defects					
K.	Health-related consideration					
L.	Lack of as-built drawings					
M.	For validity and credibility					
N.	Others specify					

Please answer question 16 by ticking. Which of the following or a combination of building data (including building characteristics/drawings/design and specifications) capturing technology you are familiar with and the capturing technology frequently or previously used

16. As-is/As-built data capturing technology			**Known**	**Used**
On-site as-is/as-built data capture				
A.	Manual tape measure			

B	Theodolite			
C.	Total station			
D.	Photogrammetry			
E.	Videogrammetry			
F.	Barcodes and/or radio frequency identification (RFID)			
G.	Laser scanners			
H.	Pictures/photographs			
I.	Photo/image modelling			
J.	Ground-penetrating radar			
K.	Walkthrough and occupant survey			
L.	Ultrasonic testing			
M.	Thermal Imaging			
N.	Remote sensing			
Off site and desktop as-is/as-built data capture/survey				
O.	Google Earth/Google Maps			
P.	Global Positioning System (GPS)			

Q.	Geographic Information System (GIS)			
R	Scanned 2D drawing			

17. **In order of importance, what made you prefer the option/combination of options for use in Q16? would you consider others? Using a scale of (1) least significant to (5) most significant**

I.	Why use capturing tool/s selected in Q16 above	**1**	**2**	**3**	**4**	**5**
A.	Availability of capturing tool					
B.	Ease of processing the captured data					
C.	Number of personnel (labour) required to use the tool					
D.	Cost of the capturing tool					
E.	Ease of use for capturing					
F.	Fit for purpose (suitable)					
G.	The time required for capture and processing					
F.	Less error-prone					
G.	Less Skill intensive					
II.	What will make you consider other data-capturing methods	**1**	**2**	**3**	**4**	**5**
A.	Availability of capturing tool					
B.	Ease of processing the captured data					
C.	Number of personnel required to use the tool					
D.	Cost of the capturing tool					
E.	Ease to use tool for capturing					
F.	Adequate training					
G.	Not aware of other tools that can serve the same purpose					
H.	Suitability for the required purpose					
I.	Only required for small projects, a surveyor must be engaged for complex needs					
J.	Improved accuracy					
K.	The time required for capture and/or processing (Instantaneous)					
L.	Internet					
M.	Electricity/power					
N.	Labour-intensive (Automated)					
O.	Effect of time/weather/season on the capture process					

	18. How does processing building data impact the capture process? Using **a scale of (1) least significant to (5) most significant**	**1**	**2**	**3**	**4**	**5**
A.	It makes it easier to compute by abstraction, approximation etc.					
B.	It enhances accuracy					
C.	It helps to save time					
D.	It reduces repetition					
E.	It does not have any significant impact on the capturing process					
F.	Cost					

	19. How do you usually process or validate the captured as-is building information when redesigning?
i.	Captured as-is/as-built data processing
A.	Manual/Hand design
B.	Computer-aided
C.	Both A and B
D.	Usually, don't, (Assume it is correct)
E.	Others, specify
ii.	Captured as-is/as-built data validation
A.	Manual/Hand design
B.	Computer-aided
C.	Both A and B
D.	Usually don't, (Assume it is correct)
E.	Others, specify

	20. What tool or computer software do you normally use to process the captured as-is building information?
i.	Design/modelling package
A.	AutoCAD
B.	Revit
C.	SketchUp
D.	Rhinoceros 3D
E.	ArchiCAD
F.	V-Ray
G.	Maya
H.	Grasshopper
I.	Dynamo
J.	Fusion 360
K.	3D Studio Max
M.	Solidworks
N.	Chief Architect
O.	Others, Specify
ii.	Simulation Package (if applicable)

A.	Design Builder
B.	Integrated Environmental Solutions Virtual Environment (IES-VE)
C.	Ecotect
D.	Open studio
E.	eQUEST
F.	Autodesk Green Building studio
G.	Autodesk Insight
H.	EnergyPlus
I.	Others, Specify

Appendix 3: Guide for semi-structured Interview

Question 1: Tell me brief information about you as a surveyor and the surveying profession in general.

Question 2: How is surveying in recent times? What is the impact of new COVID-19 guidelines on the building surveying process? What is the profession's response?

Question 3: What is the future of building surveying in this city compared to other parts of Nigeria and the world at large? Do you feel new technologies have negatively impacted the surveying process in any way?

Question 4: Do you believe that the role of the building surveyor is properly understood among building professionals or society?

Question 5: Do you as a building surveyor work effectively together with architects and other professionals in Nigeria's built environment? Is there an interdisciplinary transfer of data or interaction among the professionals within a single project?

Question 6: Is there a standard set aside by the government or the surveying institution on a particular standard of work, or is it according to the client's requirement?

Question 7: I understand that there are several data capture technology used in different parts of the world, what are the ones frequently used in this city and why?

Question 8: Who would you consider to be your most clients in the capture of as-is building information?

Question 9: What are the basic levels of details required in any as-built survey needed for redesigning?

Question 10: Are there significant variations to the types of as-built data capture needed for a specific variety of jobs? For example, when renovating for aesthetical purposes or other performance (thermal, lighting, etc.) requirements.

Question 11: Do you believe there is a strong collaboration between the surveyors and the designers (architects) in carrying out retrofitting measures in?

Question 12: For the benefit of cost and time, what technique/combination do you feel is most appropriate for small, medium and large as-built data capture?

Question 13: In terms of accuracy, what as-built data capture technology would you recommend?

Question 14: Overall, will you or what will be your advice in terms of as-built data capture technology that can be used by designers for retrofitting purposes that will have a less financial impact on them or the clients?

Question 15: Technological advancements using modelling packages have made low level of detail to be useful. Do you agree that this gives a higher level of accuracy in capturing the as-is form of existing buildings? Simply put, in capturing the as-is representation of a structure, is it the capturing process or the processing of data captured that is the key consideration to achieve better representation?

Question 16: As noted by both the UK and the US governments that laser scanning is the method of choice for building geometry capture (Thomson 2016). Is there any similar endorsement agreed for use in Nigeria for a building's geometry capture?

Appendix 4: Building Inventory Survey

Building Information

Building Name		Floor	
Building Address		Room name/number	
Date of last renovation/construction			

Building Physical component

Building site and orientation

Building Orientation				Setback distances							
N	E	W	S	N	NE	E	SE	S	SW	W	NW

Building form and geometry

Shape	
Building Area	
Story height/Surface area	
Floor to ceiling height/Volume	
Spatial configuration	
Building form factor	
Compactness ratio	

Envelope Design

Name of wall material	
Glazing type	
U-Value of opaque material	
U-Value of Glazing	
Total area of windows	
Total area of wall	

Shading Type

Depth of shading				Shading orientation							
N	E	W	S	N	NE	E	SE	S	SW	W	NW

Building occupancy and energy management

Building Occupancy

Number of occupants	
Building operation hours	
Extended hours of operation	
Percentage of staff during extended hours	

Energy resources

Main source of Energy (Electricity)	
Average monthly energy consumption	
Annual energy consumption	
Daily average duration of main energy supply	
Alternative source of energy	
Capacity of alternative source of energy	
Fuel type	
Average use of alternative energy source	
Average monthly alternative energy consumption	

Building energy uses

Ventilation and air conditioning

Types of air conditioners	
Types of fans	
Total energy consumption (%)	

Lighting

Types of fittings	
lighting systems	
Total energy consumption (%)	

Office equipment

Equipment type	
Total energy consumption (%)	

Building services and others

Type of appliance/equipment	
Total energy consumption (%)	

Appendix 5: Benin City weather data

Benin City

Location name

6.339 Latitude [°N]

5.617 Longitude [°E]

V, 2

Altitude [m a.s.l.] Climate region

Standard
Radiation model

Standard
Temperature model

Perez
Tilt radiation model

Contemporary

Temperature period

Contemporary

Radiation period

Additional information

Uncertainty of yearly values: Gh = 4%, Bn = 8%, Ta = 0.8 °C

Trend of Gh / decade:
Variability of Gh / year: 5.0%

Radiation interpolation locations: Satellite data (Share of satellite data: 100%)

Temperature interpolation locations: Benin City (23 km), Lagos/Ikeja (254 km), Lagos/Ikeja (254 km), Cotonou (357 km), Ilorin (264 km), Tabligbo (455 km)

P90 and P10 of yearly Gh, referenced to average: 94.2%, 105.6%

Month	H_Gh	H_Bn	H_Dh	Lg	Ld	N	Ta	Td
	[kWh/m2]	[kWh/m2]	[kWh/m2]	[lux]	[lux]	[octas]	[°C]	[°C]
January	151	92	86	22269	15031	3	27.2	20.0
February	131	52	88	21537	16438	4	27.9	22.6
March	163	76	101	24369	17856	4	27.6	24.0
April	168	93	96	26153	18453	3	26.9	24.2
May	166	105	89	25032	16284	4	26.3	24.1
June	146	94	79	22773	14752	4	25.3	23.4
July	142	89	78	21474	13622	5	24.8	22.8
August	143	77	88	21617	15363	5	24.6	22.5
September	146	95	78	22783	14342	5	24.8	22.9
October	160	111	81	24258	14749	4	25.5	23.4

November	161	126	75	25085	14881	3	26.4	23.7
December	155	104	84	23120	15619	2	26.8	21.7
Year	1831	1115	1023	23372	15616	4	26.2	23.0

Month	**RH**	**p**	**DD**	**FF**
	[%]	[hPa]	[deg]	[m/s]
January	65	1004	232	1.6
February	73	1004	228	1.8
March	81	1004	225	2.0
April	85	1004	221	1.8
May	88	1004	218	1.5
June	89	1004	222	1.6
July	89	1004	233	1.9
August	88	1004	236	2.0
September	89	1004	232	1.6
October	88	1004	225	1.3
November	85	1004	225	1.3
December	74	1004	231	1.4
Year	83	1004	228	1.7

Gh: Irradiation of global radiation horizontal

Bn: Irradiation of beam

Dh: Irradiation of diffuse radiation horizontal

N: Cloud cover fraction

Lg: Global illuminance

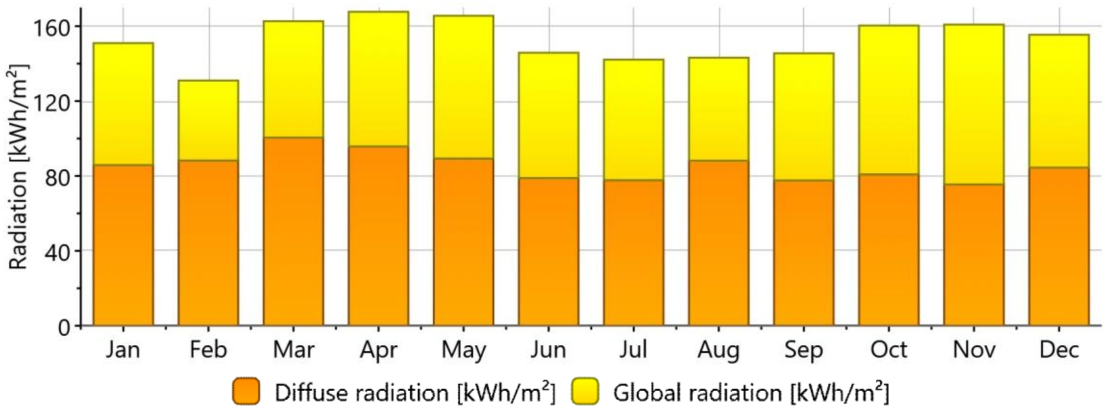
Ta: Air temperature

RH: Relative humidity

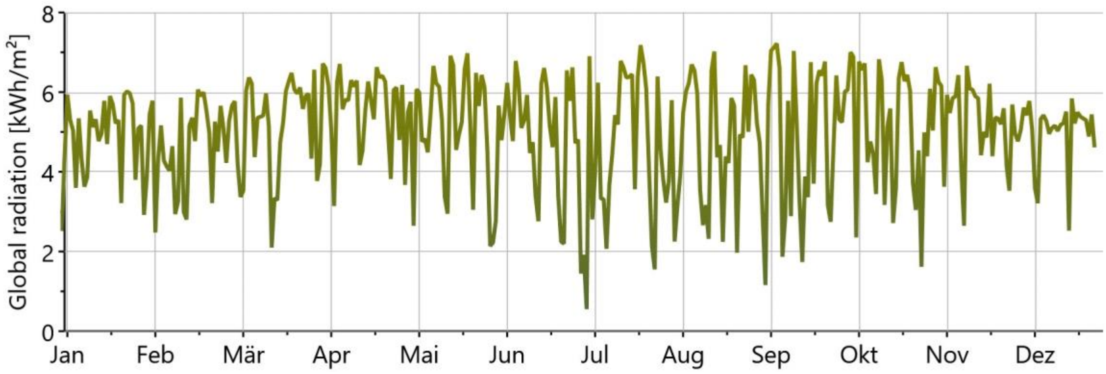
Td: Dewpoint temperature

DD: Wind direction
FF: Wind speed p:
Air pressure

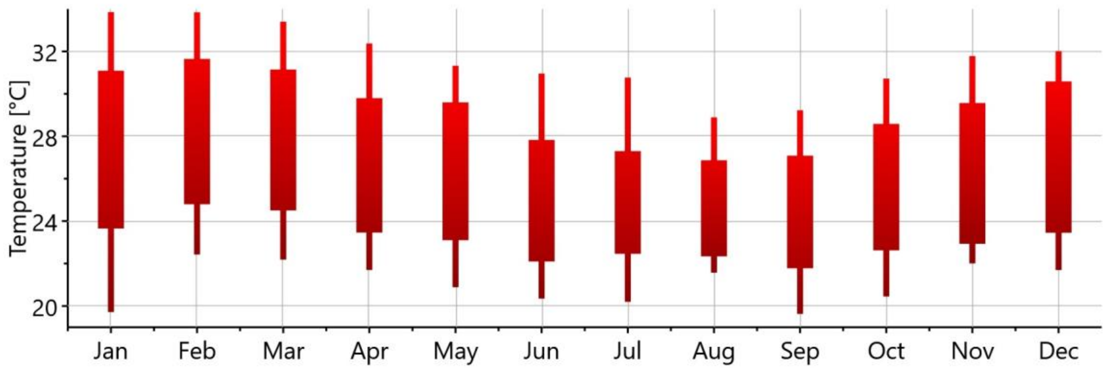
Monthly radiation



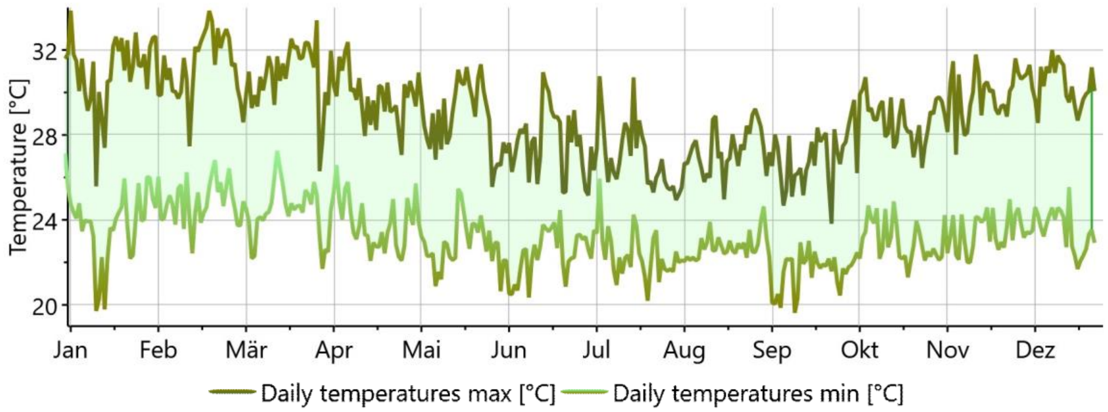
Daily global radiation



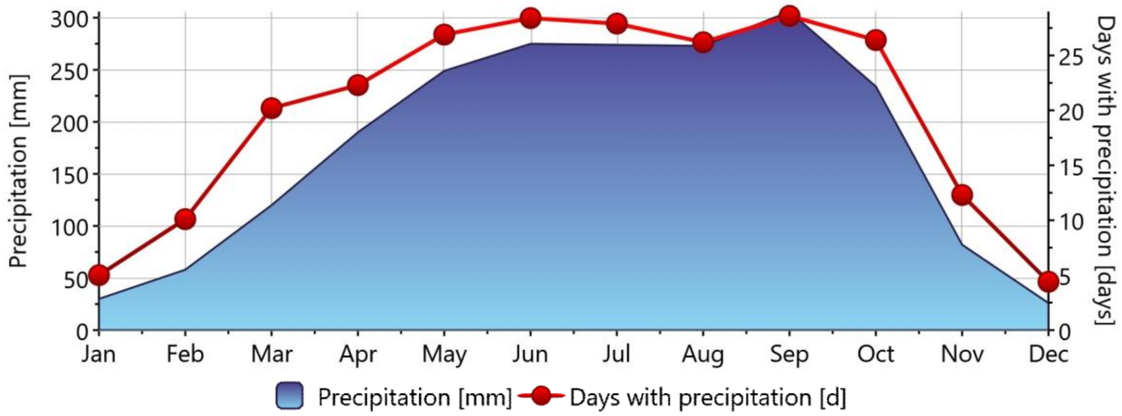
Monthly temperature

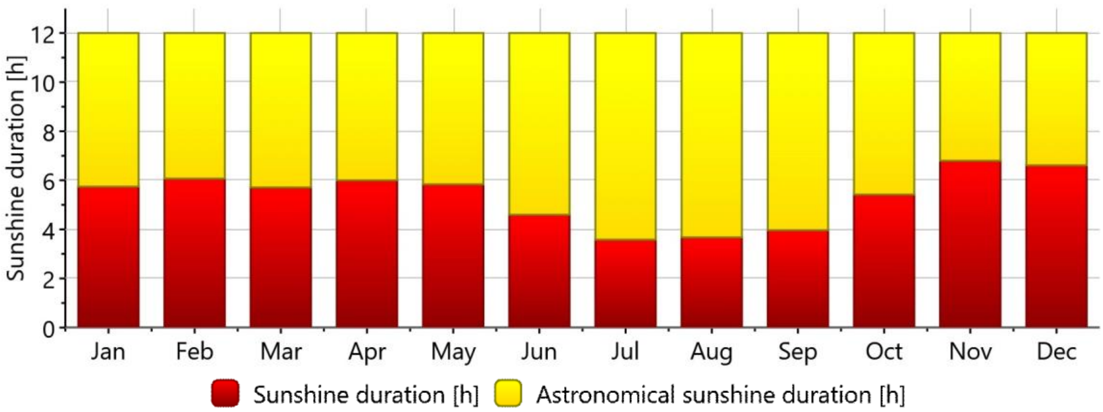


Daily temperature



Precipitation





Sunshine duration

Appendix 6: A Survey of Environmental Performance Enhancement Strategies and Building Data Capturing Techniques in the Nigerian Context

buildings

MDPI

Article

A Survey of Environmental Performance Enhancement Strategies and Building Data Capturing Techniques in the Nigerian Context

Osamudiamen Meek Omoragbon *, Sura Al-Maiyah and Paul Coates

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Abstract: The need to improve the performance of Nigeria's office buildings is due to, energy challenges, increasing population, changing user needs, and climate change. With the expansion of several Nigerian cities, existing buildings constitute a significant portion of the building stock, and improving their environmental performance could be more cost-effective than reconstruction. The use of simulation packages to assess alternative retrofitting enhancement scenarios is a straightforward approach. However, in Nigeria it is often challenging to get appropriate information to facilitate this type of evaluation; many buildings were not built to their original specifications, and when available, the records are often in a poor state due to deterioration. Studies that aimed at enhancing a building's performance hardly stated the acquisition of the required building information. This paper investigates current practices and future possibilities of improvement measures and data capturing of existing buildings using a questionnaire survey of 133 building professionals in Benin City. The inter-relationship between energy efficiency, the environment, and building design with a high potential for meaningful retrofit to mitigate energy inefficiencies is known but not fully utilized. The collected thought on current practices signifies the need for developing a more economical and reliable methodology for data capturing and evaluation.

Keywords: building performance improvement; data capturing techniques; energy efficiency; existing buildings; Nigeria

check for updates

Citation: Omoragbon, O.M.; Al-Maiyah, S.; Coates, P. A Survey of Environmental Performance Enhancement Strategies and Building Data Capturing Techniques in the Nigerian Context. *Buildings* **2023**, *13*, 452. https://doi.org/10.3390/buildings13020452

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1. Introduction

Nigeria is by far the most populated African country with multifaceted socioeconomic challenges exacerbated by population growth, excessive reliance on small businesses, and the lack of public services. Whereas the construction sector is of key importance to the development of the country with more than 80% of the business sector, comprising mainly small and medium-scale enterprises [1], depending on fuel-powered generators to get electricity. Inadequate electrical power is one of the factors undermining Nigeria's ability to meet the needs of the increasing population especially because the country only generates electricity for about a quarter of its population [2]. Strengthening the business sector requires appropriate facilities and infrastructure to boost productivity, businesses, and in turn the economy. However, businesses are left with a more expensive alternative of using oil-fired backup generators due to power inefficiency in Nigeria [3], significantly impacting the economy and poverty level.

Offices as part of commercial buildings consume a significant amount of energy for occupants' comfort needs and satisfaction translating to cost [4]. As Office workers spend a significant time of their day in the workspace, the working environment should offer the needed comfort to promote workers' health and productivity. Energy and environmental performance compliance frameworks in developed countries (e.g., the LEED rating system) facilitate environmentally responsive design solutions and energy efficiency [4,5]. These compliance frameworks also impact how buildings are designed, built, and used now and in the future. However, in Nigeria, there is widespread adoption of the western methods of buildings as compared to the previous traditional building methods that were originally constructed in response to the local climate [6]. The National Building Code [7], the main document used in Nigeria for all building works including specification, design, and alteration does not address achieving a building's environmental performance leading to criticisms and calls for a review [8,9]. In recognition of the need for buildings' energy efficiency in the country, efforts have been made by the Federal Government including through the Nigerian Energy Support Programme and the Federal Ministry of Power Works and Housing (Housing). Several documents including the Building Energy Efficiency Guidelines (BEEG) and the Building Energy Efficiency Code (BEEC) have been published as part of efforts geared to encourage energy efficiency and manage energy inefficiency in the Nigerian building sector. Despite these efforts, there is no detailed framework for designing energy-efficient buildings amidst the increasing population, urban growth, and increased rate of building development in Nigeria. As a result, the Nigerian building stock has not properly considered climatic adaptations and environmental enhancement strategies in their tropical climate, now exacerbated by the concurrent impact of climate change [10]. With the absence of such an institutional framework for energy-conscious buildings, it is essential to take measures to meet occupants' needs and reduce energy use.

Although population growth requires new building development, a significant proportion of the existing buildings remain in use [11]. Other than for historical reasons where a significant number of existing buildings cannot undergo demolition and reconstruction, improving the environmental performance of the existing building stock could be more cost-effective than reconstruction [11,12]. Traditionally, understanding the condition of buildings was conducted informally. Recently, there is a preference for a systematic approach to compare and validate how the building performs using set-out performance criteria [6,13]. The evaluation of the environmental and thermal performance of buildings requires the use of their technical and geometric characteristics which is also a requirement set aside in the BEEC [14]. In Nigeria, it is often challenging to get the functional details of existing buildings [6,15] for several reasons including insufficient or lack of 2D geometric documentation. Many buildings are not built to the original specifications shown in the drawings due to modifications by contractors or sometimes architects during construction [16]. Building projects designed by architects are often not constructed by the relevant building professionals in a bid to cut costs and therefore, they are not built as designed. The loss of building records due to degradation and poor storage has also led to a compromise in many building details coupled with storage inadequacy, whereas documentation forms the basis for modeling and simulation work [17]. Thus, carrying out efficient evaluation and testing of strategies for building performance enhancement necessitates the capture of the required technical characteristics that will benefit from simulation testing. The BEEC categorically states in its "compliance method 2—performance route to compliance" indicates that building modeling and simulation should be used to determine the building's overall building energy performance. While not much has been done on environmental building performance improvement in the study region, the limited studies carried out illustrate the use of building details for building performance enhancements through modeling and simulation but have either not specified how it was sourced or stated the limitations of getting as-built details. This study investigates current practices of building design professionals in Benin City to help identify the relevant building characteristics to be captured and used for building performance enhancement through modeling and simulation to achieve energy efficiency

2. Environmental Performance Enhancement Strategies

In addition to protecting building users from undesirable outdoor environmental conditions, office buildings should provide a healthy, comfortable, and productive indoor environment [18]. Studies by De Wilde [19] and De Wilde [20] also reiterate that an office environment should provide the necessary user comfort that promotes well-being, health, and productivity. New expectations and current challenges require the need to improve the environmental performance of existing office buildings given that around 87% of existing buildings will be standing by the year 2050 [11]. Thus, regular performance evaluation gives an insight into the percentage of effectiveness and efficiency of a building in meeting users' needs and expectations.

Evaluating the performance of existing buildings is crucial to improving their environmental performance. The built environment professionals have done less in committing resources to examine the original function and user satisfaction of buildings with everyday tasks while making the necessary adjustments [21,22]. Building performance evaluation (BPE) is a systematic and rigorous approach that covers several activities including exploration, comparison, and feedback that takes place throughout the building lifecycle [23]. It focuses on building designs and the technical performance of the buildings in response to human needs so that lessons learned can be used to inform future practices (enhancement). The Nigerian Federal Ministry of Power, Works, and Housing recognizes that energy and the performance of buildings are climate-related, and its Building Energy Efficiency Guideline (BEEG) publication [24] confirmed that the highest user requirements for building occupants are for cooling and lighting. It recommends environmentally friendly buildings through the consideration and integration of '*bioclimatic*' initiatives that could eliminate or reduce occupants' needs for cooling and lighting. Energy-efficient and bioclimatic design measures applied to the building through the external envelopes and its components can be advantageous, especially in Nigeria with energy poverty where less than half of the population can access electricity.

2.1. Bioclimatic Design

The Arup and Genre's [24] '*Building Energy Efficiency Guide*' (BEEG) defines bioclimatic design as a design that bases its considerations upon climatic conditions and attempts to achieve physical comfort for occupants using fewer resources, while also accounting for the behavioral and emotional conditions. The bioclimatic approach is fundamental to achieving energy efficiency in buildings achieved through architectural design principles and the control and regulation of heat gains and heat loss from the building [25]. The adoption of bioclimatic design strategies in previous studies has shown a significant success rate, for example, there was a 40% to 60% decrease in energy consumption when applied by Ochedi and Taki [26]. Another study in Nigeria [27] also applied a bioclimatic design approach by using indigenous materials on the building envelope to enhance comfort by reducing the high operative temperature by 8% and a significant reduction in CO_2 emissions and construction costs by 32.31%, 35.78%, and 41.81% respectively. The level of adoption of bioclimatic design considerations such as 'site selection and orientation, building form and geometry, envelope design, and use of passive cooling is assessed as part of the questionnaires used in this paper. While understanding the bioclimatic design variables is a vital step in evaluating and enhancing the performance of existing buildings, it helps to identify the necessary building data needed for capturing especially due to the difficulty in getting as-built information in the study area. The captured building information is a key requirement for the evaluation and testing of environmental performance enhancement strategies for existing buildings.

2.2. Data Capturing

While the adoption of bioclimatic design is recommended by both the BEEG and the BEEC. It is also stated in the BEEC [14] that a common method for exploring the effectiveness of building performance, its enhancements, and the integration of bioclimatic design initiatives is using digital building models and simulation. To do this, it is necessary to capture the required design variables (technical and geometrical characteristics) of the building. A range of data-capturing technologies with certain specifications, abilities, and limitations are currently in use for existing buildings to capture the data needed to create as-built replicated simulation models. In addition to the manual site surveying and traditional total station, there are more recent and modernized data-capturing techniques including Photogrammetry, Videogrammetry, Photo-Modelling, Image-Modelling, Laser scanning, GPS, Google Earth, Scanned 2D floor plans, Remote sensing, Barcode, Lidar, Ultrasonic Testing, and Thermal imaging. Given the various data capturing techniques available, this part informed the development of the questionnaire to understand the commonly used type of data capturing techniques in the study region.

3. Materials and Methods

The study relied on survey data carried out in Benin City, Edo State of Nigeria, where the prospective future of the city development and the State Government's commitment is to redefine the workplace and make it more conducive for workers. Benin City is regarded as a civil service city by Ekhaese and Adeboye [28] because of the several socio-economic activities carried out in the city. It also benefits from its position as the road transporter's central point that connects the north, east-west, and south of Nigeria while experiencing rural-urban migration and imminently increasing the need for social infrastructures, numerous small-scale establishments, and commerce already going on [29]. The data was gathered from the City's building design professionals whose main role is to oversee the design of buildings as stipulated in the NBC. Both hard-copy and digital-copy questionnaires were distributed, and responses were collected between 7 November 2020 and 11 May 2021. A total of 133 responses were collected and analyzed using based on the building designers' perception of the environmental building performance towards energy efficiency and building data capture of existing buildings. The survey used in this study is deduced from a questionnaire comprising four sections designed for a larger PhD study. Section 1 with questions numbered 1–6 is about the demographics of the building design professionals, and Section 2 (questions 7–9) gauges the architect's understanding of issues of energy efficiency. Section 3 comprising questions 10–15 relates to the environmental performance of buildings including design conception and post-occupancy evaluation. Section 4 (questions 16–20) focuses on factors of as-built data capturing and processing technology. After gaining the research's ethical approval, to manage time and cost alongside the travel restrictions caused by COVID-19 a combination of web-based and hard-copy questionnaires was used. Recruiting the participants was initially done with the help of third parties, in form of a link sent to the official WhatsApp group of the Edo State Chapter of the Nigeria Institute of Architects (NIA). Further hard copies were presented directly to members of the NIA when travel restrictions eased with weekly reminders both in-person and on the WhatsApp group.

Responses to the questionnaires were received both as hard copy documents and digital ones as Comma Separated Values (CSV) files as plain text easy to import into a spreadsheet. The CSV files were converted and collated together with responses from the hard copies into a Microsoft Excel spreadsheet for preparation, coding, and elimination of data errors for exploration using the Statistical Package for the Social Sciences (SPSS). Descriptive analysis using simple frequency distribution percentages, charts, mean value scores, and significant level analysis was utilized to satisfactorily meet the aim of the study.

4. Results

Tables 1–4 are some demographics of the survey carried out. A total number (n) of 133 questionnaires were completed by members of the Edo State Chapter of the Nigeria Institute of Architects, 125 (94%) of the participants carry out most of their projects in the city (Table 1). Table 2 shows that all survey respondents are involved in the design and construction of buildings either through private practice (n = 47; 35.3%), construction (n = 38; 28%), freelancing (n = 29; 21.8%) or employed in an organization (n = 19; 14.2%). All respondents have adequate knowledge of the practice of design and construction with a minimum of a BSc. degree in architecture or its ARCON (Architects Registration Council of Nigeria) equivalent. As shown in Table 3, a total of 58 (43.6%) associate members, 39 (29.3%) full members, 4 (3.0%) fellows, and 32 (24.1%) graduate members show that over 7% of the respondents have at least a master's degree or its ARCON requirement. A significant number (n = 111; 83.5%) of respondents have practiced building design and construction for over 5 years in Benin city. The years of professional practice (Table 4) are 22 (16.5%) less than 5 years, 61 (45.9%) between 6–10 years, 32 (24.1%) between 11–15 years, 12 (9.0%) between 16–25 years and 6 (4.5%) over 25 years. The participant's significant years of practice give credence to their suitability for providing relevant information to achieve study results.

Table 1. Where respondents' projects are mostly carried out.

Respondents Practice within Benin City	Frequency	Percentage (%)
Most of the jobs are carried out within Benin city	125	94.0
Most of the jobs are carried out outside Benin city	8	6.0
Total	**133**	**100.0**

Table 2. The best description of the respondent's practice.

Nature and Best Description of Practice	Frequency	Percentage (%)
Employed in a public or corporate organization	19	14.3
Construction	38	28.6
Own firm/Private practice	47	35.3
Free-Lancing	29	21.8
Total	**133**	**100.0**

Table 3. Respondents' professional qualifications.

Professional Qualification	Frequency	Percentage (%)
Fellow	4	3.0
Full Member	39	29.3
Associate Member	58	43.6
Graduate Member	32	24.1
Total	**133**	**100.0**

Table 4. Years of Professional Practice.

Years of Practice	Frequency	Percentage (%)
Under-five years	22	16.5
6–10 years	61	45.9
11–15 years	32	24.1
16–25 years	12	9.0
Over 25 years	6	4.5
Total	**133**	**100.0**

The demographic data were quantified and analyzed using descriptive statistics of simple frequency distribution. Quantifying the subjective thoughts of the survey respondents ensured that most questions after the demographics were based in the form of a Likert scale of "very significant/very often" to "least significant/never", with the options for evaluation allotted from a score of 5 (very significant) to 1 (least significant). Mean values greater than or equal to 3 ($\geq$3) indicated that the respondents' perception of the variable is significant, while those less than 3 (<3) suggest that the perception is less significant [11,30]. The mean was used to determine the levels of variation in the professionals' perception of building performance improvement and reasons for the selection of certain data-capturing technologies.

4.1. Perception of the Impact of Building Design on Energy Efficiency

The respondents' description or application of energy efficiency in their projects include the use of renewables (n = 24; 18.0%), less use of electricity from the national grid (n = 30; 22.6%), less use of both the main source of electricity from the national grid alternative sources including generators and inverters (n = 68; 51.1%) and less use of alternative power source (n = 10; 7.5%). Given the poor energy situation in Nigeria, the participants also indicate how issues of energy efficiency in buildings are addressed, mostly through efficient building designs (n = 75; 56.4%), While some respondents never paid much attention to energy efficiency (n = 20; 15.0%), an equal number of respondents (n = 19; 14.3%) each considered renewable energy sources or left it to the end-users to implement. As earlier stated, improving a building's environmental performance is critical to enhancing energy efficiency and reducing cost. Most respondents, who had stated that they address energy efficiency in buildings through efficient building designs are clear on the correlation between energy efficiency and the environmental performance of a building. On a 5-point scale, they rated the impact of building design on energy efficiency as significant (>3) with a mean m = 3.93 (see Figures 1–3).

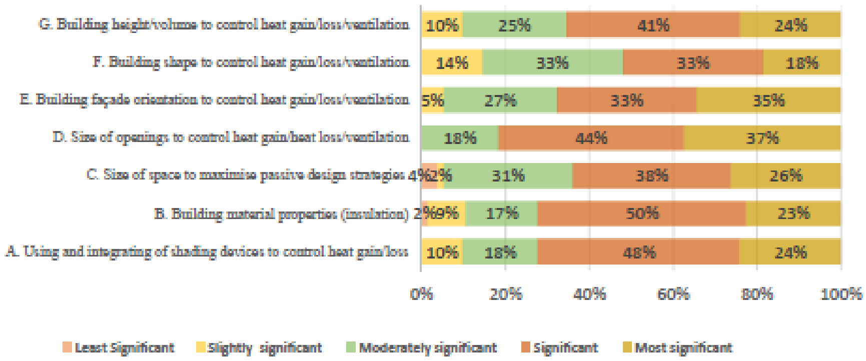

Figure 1. Significance rating of factors of building envelope configuration.

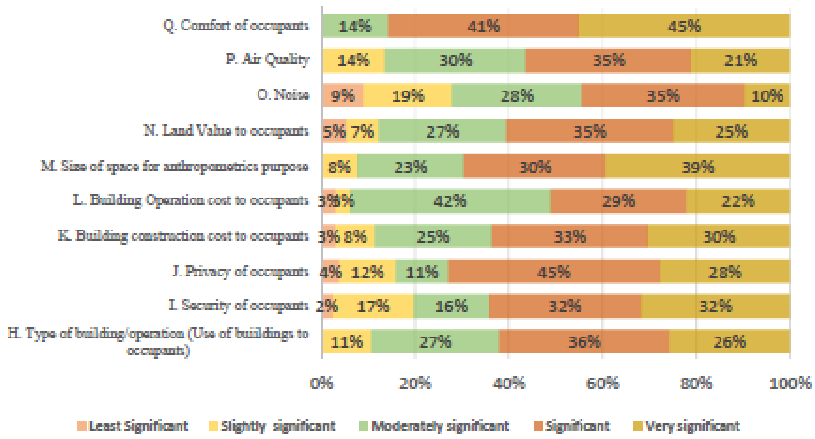

Figure 2. Significance rating for end-user-related considerations.

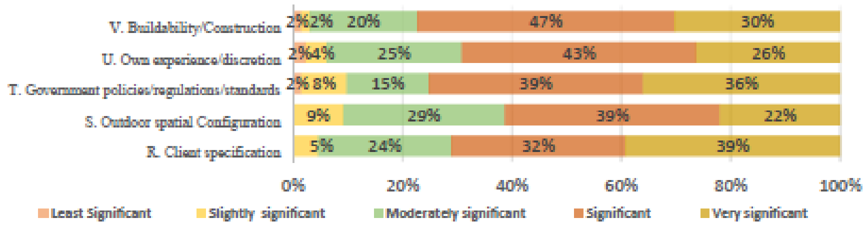

Figure 3. Significance rating for compliance considerations.

Figures 1–3 show various previously identified bioclimatic factors [5,6,24,26,31] influencing practitioners' choice of design on building energy efficiency, environmentally conducive indoor conditions, and enhancing comfort and productivity. The factors are categorized into three, according to how they are achieved. However, as the bioclimatic design approach imposes no particular style on building designers [24], the factors in each group are presented in no particular order of significance but to understand what extent each factor influences the professional's design decision.

4.1.1. Envelope Design Configurations

The respondents' perception of factors of 'Envelope design configurations' are rated as follows. Using and integrating shading devices to control heat gain or loss (n = 120, 90.2%, m = 3.86), building materials properties (n = 119, 89.5%; m = 3.83), and size of space to maximize passive design strategies (n = 126, 94.7%, m = 3.81). When used with a proper understanding of environmental factors such as the sun, and the wind, envelope design configurations are effective strategies to improve building performance [6,24,26]. Other ratings of Envelope design configuration' are, the size of openings (n = 131, 98.4%; m = 4.19) building façade orientation (n = 126, 94.8%, m = 3.97), building shape (n = 112, 84.2%; m = 3.56) and building height (n = 100, 88.8%, m = 3.80). From the collected mean values, all factors are rated to be significant (>3) and support the previous indication of the respondent's view that the environmental design and performance of buildings impact energy efficiency. Only bioclimatic approaches, maximizing the potential of the building envelope design in response to environmental factors are considered in this study. Other important factors such as building occupancy profiles and internal heat gains from technology usage that also impact the heat gain or heat loss from a building [26] are not considered.

4.1.2. End-User Related Considerations

The End-User related considerations are those needs that are of high significance to the users or owners about the satisfaction they intend to derive from the facility. Considerations of the end-users rated by the building design professionals are, building use (n = 119, 89.0%, m = 3.77), security (n = 106, 79.7%, m = 3.74), privacy (n = 112, 84.2%, m = 3.81), building construction (n = 117, 88.0%, m = 3.80) are >3 supporting the opinion that successful improvement of existing office buildings should give more attention to end-users needs [7]. Other 'user-related considerations' ranked by the professionals are, building operation costs (n = 123, 92.5%, m = 3.64), size of space for anthropometrics purposes (n = 122, 91.8%, m = 4.02), land value (n = 116, 87.2%, m = 3.68), noise (n = 96, 72.2%, m = 3.17), air quality (n = 115, 86.5%, m = 3.64), comfort (n = 132, 99.2%, m = 4.31) indicating that end-user considerations are highly significant to the building design professionals when designing and retrofitting. The aforementioned factors are directly linked to the clients/end-users to understand how they influence respondents' design decisions. Its necessity is borne out of the enormous opportunity for end-users, like design professionals to reduce building energy demand in an energy-poor country, reduce reliance on mechanical energy sources and enhance comfort [26].

4.1.3. Compliance Considerations

Also, factors of compliance including client's specification (n = 126, 94.8%, m = 4.06), outdoor spatial configuration (n = 130, 90.2%, m = 3.74), government policies (n = 120, 90.2%, m = 4.00), the experience of the professionals (n = 125, 94.0%, m = 3.87) and buildability (n = 128, 96.2%, m = 4.03) are significant (>3) considerations during building design. They can influence building performance and its improvement as they set precedents that guide the design professional during decision-making. Its significance reinforces the respondents' awareness of the impact of design on building performance and is consistent with previous studies e.g., [22] indicating that building professionals hardly obtain feedback post-building occupancy to understand how their design decisions meet user needs.

Given that 1 is never and 5 is very often, the respondents' rating, with a mean of 2.58 (<3) depicts the poor practice of obtaining feedback on a project after completion and occupancy to understand if the building is meeting the occupant's intended need. Thus, impeding opportunities to improve the existing building stock. Periodic feedback about a building's performance is vital for continuous and consistent improvement [11]. While the plan for generators is becoming a fast-growing part of the architecture within the built environment to meet the desired comfort and productivity in offices there is also the argument that offices are built with little or no climatic adaptation [6]. It, therefore, reinforces the need to achieve the required comfort through a more economical and non-mechanical means due to the established link between building design and technology by capturing the desired building information for performance evaluation and enhancements [5].

4.2. Data Capturing Techniques

Evaluating the performance of the existing building stock is important for assessing the effectiveness of integrating improvement measures. It is a vital step towards keeping occupants comfortable and productive in the study area as studies have indicated the poor performance of office buildings leading to the excessive use of energy mainly for cooling [10]. While evaluation and testing of improvement strategies require the use of the building's technical and geometric documentation, Figure 4 shows common data-capturing techniques known and adopted for use in Benin City. Using a simple frequency distribution, the manual tape measure is the most known (n = 131, 98.5%) and frequently used (n = 124, 93.2%) technique. Closely followed is Google Earth (n= 119, 89.5%), but used less (n = 84, 63.2%) compared to photographs (n = 94, 70.7%) which are not as known (n = 118, 88.7%). The least known and used among the data capturing techniques are the most advanced methods; thermal imaging (known n = 15, 11.3% and Used n = 2, 1.5%) ground penetrating radar (known n = 20, 15.0%, Used n = 2, 1.5%), remote sensing (known n = 22, 16.5% and used n = 3, 2.3%) and ultrasonic testing (known n = 23, 17.3% and Used n = 4, 3.0%). Other than for the manual tape measure, use of photographs, and Google Earth, the data indicate that there is a great gap of about 50% between the capturing techniques known and their corresponding use.

The contributing factors to the choices of the capturing techniques used are rated by the professionals as follows. Availability of capturing tool (m = 3.99, 89.4%), ease of processing the captured data (m = 3.50, 74.5%), number of personnel needed to use a capturing tool (m = 3.27, 66.1%), cost of capturing tool (m = 3.46, 68.4%), ease of use of capturing tool (m = 3.63, 72.2%), the time required for capturing and processing (m = 3.20, 62.5%), less error-prone (m = 3.18, 62.4%) and less skill-intensive (m = 3.33, 73.6%). The collected mean values of these factors are significant (>3) and currently only a few data-capturing techniques are in use. The respondents also gave their perceived rating of significance on factors that would make them consider other data-capturing techniques (See Figure 5).

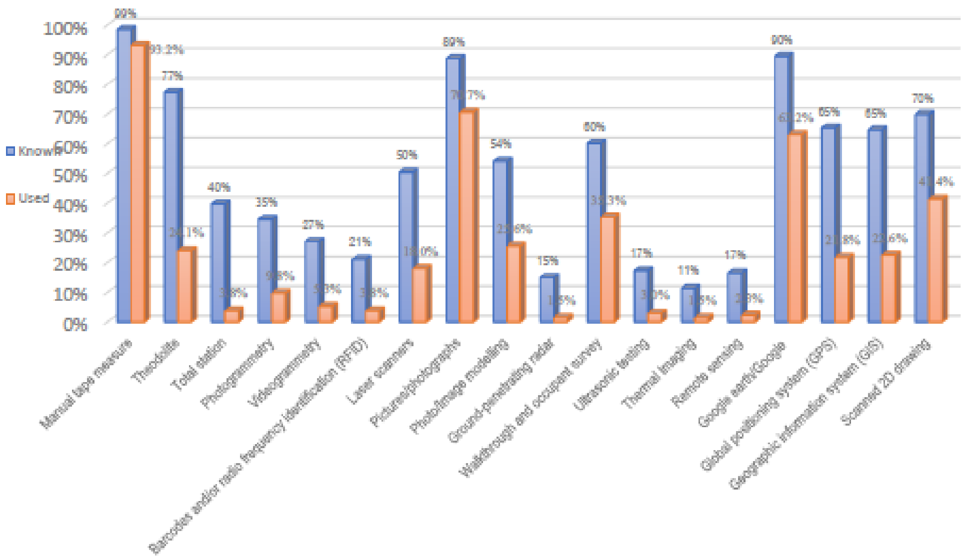

Figure 4. Known data capturing techniques used by building design professionals.

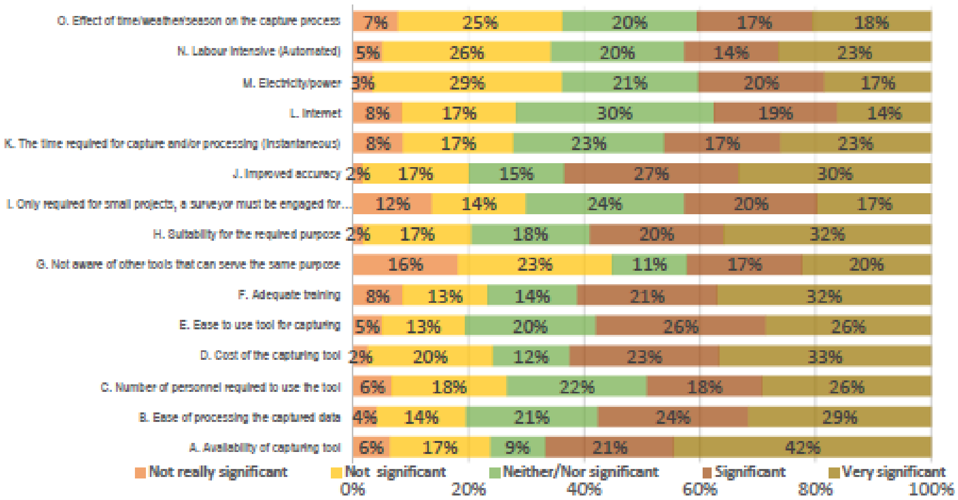

Figure 5. Reasons to consider other data capturing techniques.

From Figure 5, the availability of the data capturing tool (m = 3.81, 71.2%) has the highest significance rating, The other factors stated according to their perception of significance are improved accuracy (m = 3.75, 72.2%), cost of the capturing tool (m = 3.73; 68.4%), suitability for the required purpose (m = 3.73, 69.9%), ease of processing the captured data (m = 3.66, 66.9%), adequate training (m = 3.66, 66.9%), ease to use tool for capturing (m = 3.62, 72.2%), the number of personnel required to use the tool (m = 3.45; 66.1%), the time required for capture and/or processing (m = 3.36, 62.5%), labor intensive (m = 3.30, 57.9%), electricity/power (m = 3.19, 57.1%), only required for small projects a surveyor must be engaged for complex needs (m = 3.19, 61.7%), internet (m = 3.19, 63.3%), the effect of time/weather/season on the capture process (m = 3.17; 55.6%) and not aware of other tools that can serve the same purpose (m = 3.02, 48.1%). Assuming that only the five most significant factors are to be considered, the data indicate the professional's willingness to adopt other data capturing techniques by considering, the availability of the data capturing tool, improved accuracy, cost of the capturing tool, its suitability for the required purpose, ease of processing the captured data or adequate training.

Looking at the five most used data capturing techniques by the respondents, the manual tape captures a 2D input dataset, mostly spatial and other component-related information from an existing building provided contact is possible [32]. A Building Information Modelling (BIM) operator can utilize the knowledge input as a guide to efficiently trace around the derived 2D data in a BIM tool, interpret the scene and add the rich semantic information that makes the modeling process valuable [33]. This must be fed into any of the 3D creation software available with plugins or simulation applications for processing. Photographs usually complement other data-capturing techniques for future reference [34] including for progress reports, image interpretation, and risk assessment [35]. Applying certain guidelines, photographs can be captured and with the aid of special packages create 3D models in a Photo/image modeling process. Google Earth is a geographical data acquisition system used as a visual representation only possible for the visualization of geospatial environment purposes [36] thus, space analysis is not possible with Google Earth. It can be used for building modeling, however, there may be difficulty in using Google Earth solely for testing strategies through simulation on its own [37]. Scanned 2D drawings have proven to be effective and cheap in other geographical contexts [38]. The unavailability of drawings from some existing buildings as well as designs not updated post-construction pose a problem. Where drawings are available, they need to be complemented with the walkthrough and survey method of data capture as this method of capturing data helps to confirm and validate the inaccuracies or outdated existing drawings and is especially useful in the process of retrofitting, as technical and design deficiencies are easily recognized to inform decision making.

From the five most utilized data-capturing techniques by professionals, not much can be done to test retrofitting options for building performance improvements and mitigate energy inefficiencies without needing a corresponding modeling and simulation package. Figure 6 presents the common computer-enabled design and modeling software familiar to the survey respondents. The most used are AutoCAD (n = 121, 91%), Revit (n = 95, 71.4%), and Google SketchUp (n = 38, 28.6%). Both ArchiCAD and V-Ray follow (24.1%, n = 32) while at least 2 (1.5%) people each use Rhinoceros and Dynamo followed by Chief Architect (5.3%, n = 7). The data signifies the high use of computer software and encouraging use of 3D modeling packages for visualization purposes but with less emphasis on the performance of buildings. Figure 7 shows the commonly identified building performance simulation software that could assist designers to assess the effectiveness of energy-conscious and environmental performance initiatives. Design builder is the most used at 12.8% (n = 17) followed by Autodesk insight, EnergyPlus, and Autodesk Green building studio each at 4.5% (n = 6). Integrated Environmental Solutions Virtual Environment at 3% (n = 4) and Ecotect the least use at 0.8% (n = 1). The data indicate that building performance evaluation and enhancement have received less attention in the study area, a field that should be properly harnessed and encouraged to create a conducive indoor environment, enhance comfort, increase productivity, improve health, reduce reliance on energy or mechanical devices producing CO_2 and in turn reduce costs.

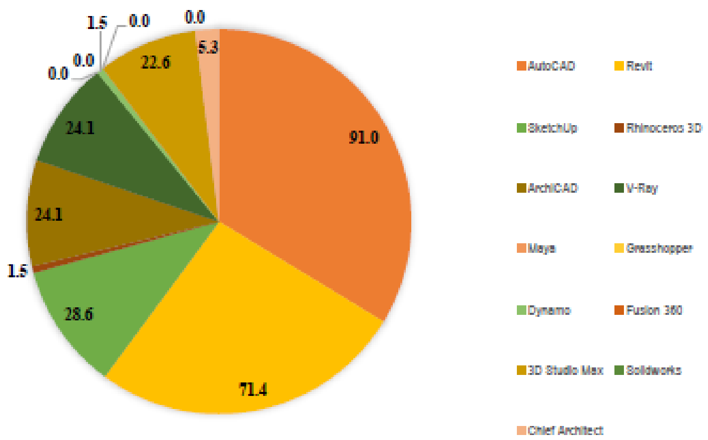

Figure 6. Computer software used by design professionals to process building information.

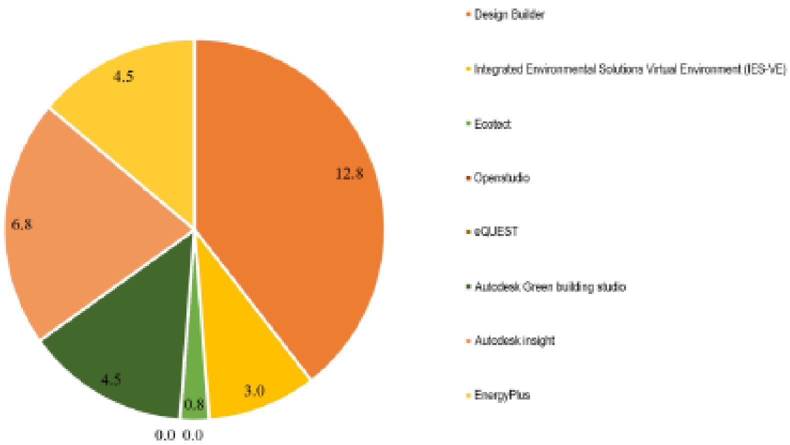

Figure 7. Simulation software used by design professionals to process building information.

5. Discussion

The survey of environmental performance enhancement strategies and building data capturing techniques in Benin City, Nigeria indicates the building design professionals' awareness of the relationship between building design, energy efficiency, and the environment. With power inefficiencies in Nigeria, to enhance comfort and boost productivity in office buildings resulting in reduced operational cost, indications suggest that such awareness is not fully utilized. While the need for retrofitting and redesigning existing buildings to meet the dynamic users' comfort needs in office buildings cannot be overemphasized [16,39], the result of the survey agrees with previous studies [21,22] indicating that the practice is uncommon as the building design professionals hardly get feedback on the performance of their projects post-occupancy. The vantage provided by the building design professional's awareness between building design, energy, and the environment, present the opportunities and potential for meaningful retrofit to mitigate earlier energy inefficiencies and their associated cost in office buildings. Current practices from this survey show that the most frequently known data capturing techniques used by the respondents are tape measure (98.5%), Google Earth (89.5%), and photographs (88.7%). Their corresponding uses are tape measure (93.2%), Google Earth (63.2%), and photographs (70.7%). Several factors are perceived to be significant both in the choice of the adopted data capturing techniques (availability of capturing tool, 89.4%; ease of processing the captured data, 74.5%; the number of personnel needed to use a capturing tool, 66.1%; cost of capturing tool, 68.4%) and for considering to use other data capturing techniques including due to availability of the data capturing tool (72.2%), improved accuracy (72.2%), cost of the capturing tool (68.4%) and suitability for the required purpose (69.9%). The survey results indicate the possibility of developing a suitable data-capturing technique that can carry out building performance enhancements as current practices of data capture is mainly used to model for visualization purposes mostly with AutoCAD (91%) and Revit (71.4%). Whereas testing retrofitting options for building environmental performance improvements and mitigating energy inefficiencies require corresponding modeling and certain simulation packages [19,20]. It, therefore, creates the vantage for developing a suitable and reliable methodology needed for building data capturing and evaluation towards performance improvement. The knowledge of the relationship between the environment, comfort, and building design by professionals can be harnessed and utilized through building performance and simulation software to test various retrofit options. It would be of great benefit in encouraging the evaluations and improvements of existing buildings as indicated by this study, subsequent studies as part of a larger PhD thesis tend to garner more information from the professionals saddled with building surveying in the study region. The information would be invaluable to developing a methodology for the data capture, modeling, analysis, and evaluation of existing office buildings before testing building performance enhancement (bioclimatic design) strategies.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because it is part of a yet-concluded PhD thesis.

Conflicts of Interest: The authors declare no conflict of interest.

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