
**Benefits of BIM-driven 3D Building Printing Technology
adoption in the Nigerian Construction Industry**

Master Thesis

International Master of Science in Construction and
Real Estate Management (ConREM)

Faculty 2

from

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Date:

Berlin, 05.07.2022

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ACKNOWLEDGEMENT

Firstly, my deepest appreciation goes to God, the Father of wisdom and strength, for helping me through to achieve and complete this thesis report.

I am grateful to my supervisors: Prof Markus Kramer and Zsuzsa Bensenyoi for their acceptance to guide me through this research work. Every consultation put me to more work and helped me made progress at the end.

I appreciate the efforts of Prof. Nicole Riedeger in helping me to secure my first supervisor when it seemed impossible. Thanks to Mr Chikaeze Ugwu and Francois Perrot, 14Trees Managing Directorfor their efforts and support too.

To my wife, thanks for your encougaement and for believing in me.

Thanks to my parents for their prayers and encouragements. To my colleagues; Valentine, Ope, Tobi and Daniel, thank you all for your efforts.

COPY OF CONCEPTUAL FORMULATION



**International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin**

date 15.05.2021

Conceptual Formulation

Master Thesis for: Mobolaji Ajiboro

Student Number: 576642

Topic: Benefits of BIM Driven-3D Building Printing Technology Adoption in Nigerian Construction Industry

Introduction

Housing is recognized world-wide as one of the basic necessities of life and a prerequisite to the survival of man (Osabor, 2016) and demand continue to rise for the global construction industry to develop materials and methods that are more sustainable and still fulfil criteria such as affordability, safety and durability, eco-friendliness among others. Agbola and Odunola (2007) noted that housing problem is a global phenomenon confronting developing and developed, rich and poor nations and Nigeria is no exception. The global construction industry has also been noted to be responsible for generating millions of tonnes of waste annually, significant amount of global carbon emission footprint, emission of greenhouse gases, and high power consumption among other worrisome record. In response to these, industry players are considering alternative construction methods and materials.

Science and technology has been a major driving force in creating change in the 21st century and even more as the world gradually transcend into the fifth industrial revolution. Scientists and engineers are continually enthraling humanity on a daily basis with revolutionary technologies turning what was recently considered as science fiction or inconceivable futuristic into reality; thus, making lives much easier and stimulating (Raji, 2017). In Nigeria, all previous study (Osabor, 2016; Ocholi et. al, 2015; Aminu and Ruhizal, 2013; Ademiluyi & Raji, 2008) share thesame opinion of consistent failure and inefficeincy with all the previous government formulated housing policies in meeting the growing housing needs of Nigerians. However, with the understanding that every branch of human lives has been greatly influenced by modern innovation through the emergence of new products and processes, the global Construction industry isn't left out of this industrial transformation. New methods also include accelerated building construction via the use of modular construction, precast construction, BIM integrated processes and 3D printing construction.

According to Hossain (2020), 3D printing construction is an automated process that produces complex shape geometries from a 3D model (computer-aided design (CAD) model) on a layer-by-

layer basis, through a series of cross-sectional slices. Also known as Additive Manufacturing, 3D printing has been in practise for decades especially in the manufacturing industry. While research is still widely ongoing, there have been certain successes that further substantiate the practicality of the technology in solving various challenges. For example, while many still do not trust the system yet, 3D printing has been used to construct an estate of housing units for low income earner and displaced individuals at New Mexico and Malawi. Oluwole (2017) believes the technology is expected to keep growing, which makes it an important innovation to be tapped into by developing countries like Nigeria.

In Nigeria, the construction industry is continuously growing, particularly through real estate development. Ogunleye (2019) noted that the production of housing in Nigeria is primarily a function of the private market in recent times. These urban development comes at the costs earlier mentioned (pollution, carbon emission, waste, energy. However, in the process of producing more houses to meet demand, new challenges of unaffordability, construction delay, decentralized documentation, loss of details and inconsistent quality are created and persists. According to <https://www.centerforis.com>, it is however observed that houses built by Federal Housing Authority (FHA) are beyond the reach of the average worker. Available prices of FHA houses obtained from their portal indicate that 2 Bedroom flat can go for as much as N9.0m to N23.0m. The prices are beyond the reach of the average low/medium income earners. 3D printing is however developed to be economically viable, reduce construction time, labour and ensure resources efficiency (Venkatesh, 2016).

Reasearch Background

While it is true that BIM and 3D printing technology are increasingly gaining attention and breaking into new market, a highly populated country like Nigeria with alarming number of unsheltered and dispalced individuals stand to enjoy all the benefits attributed to it. However, the current socio-economic situation in Nigeria and most part of the Sub sahara region may pose some challenge to this. While other part of the world such as Europe and South America are setting up policies and achieving trememndious results in response to global concerns such as the social developmental goals using technology as a major tool, African countries such as Nigeria is yet to harness the benefits of these technologies at scale as viable tools applicable to solve her housing challenge. Achieving thesame or better results as currently seen in some countries such Germany and America within the Construction industry, require a honest assessment of the current technological outlook in Nigeria in order to the success rate of the implementation of growing innivation such as 3D construction method.

Focus of Research and Research Questions.

There are major and important factors that drives and determine the development, implementation and results of any technological innovation and product within a civil society. Energy, finance,

education and research, intellectual and natural resources, policies and existing technology are some among many. However, while the topic of this research work focuses on the benefits of implementation of 3D printing method within the Architectural, Engineering and Construction sector, the pivotal question I want to address are;

- (i) How can the Nigerian construction industry harness the benefits of BIM and 3D printing practices to revolutionize its building construction industry?
- (ii) What are the impediments to the technological growth of this practice within the country's construction industry?

There has not been enough research into this area as much as its operability within the Nigeria society is concerned, hence leaving above questions unanswered. The outcome of this research will help to improve the operability of 3D Construction technology in Nigeria construction sector.

Methodology for Research Proposal

(i) Literature review of existing study: Over 40 journals and online sources have been gathered for extensive study on BIM and 3D printing technology, their adoption and benefits. This include materials of BIM practice in Nigeria Construction industry.

(ii) Case Study: As 3D printing technology is yet to be practiced in Nigeria, a 3D printed building in Germany will be referenced for study. Information will be gathered from the construction team and studied closely. This will form contents for my Chapter 3 and 4 (research methodology and results and discussion). In Chapter 4, the details obtained will be compared with a typical case in Nigeria.

(iii) Interview and Data Collection: I have met with and conducted an interview with a 3D printing Engineer in order to obtain first-hand information on 3D printing. This will be incorporated into my chapter 3 and 4. Also, a questionnaire has been prepared and tailored to collect information from certain professionals within the AEC sector in Nigeria. The data will be collected and analysed in Chapter 4.

Expected Research Outcome

At the end of my research work, I hope to establish the following;

- (i) Benefits the Nigerian construction industry could derive from the adoption of BIM at scale and 3D printing construction.
- (ii) What are the technology-related challenges to the effective implementation of these methods?
- (iii) Recommendation for the use of the technologies by the different stakeholders

Estimated Duration

The estimated duration to complete this research thesis is about 6 months.

Possible Challenges

Delayed or no responses from individuals reached for information

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A handwritten signature in blue ink, consisting of stylized, cursive letters.

Signature of the Supervisor

A handwritten signature in blue ink, appearing to read 'Zusammenfassung'.

Signature of the Supervisor

30.06.2012

ABSTRACT

This study was undertaken to explore the potentials of new technologies leading digitalized construction globally. More particularly, this research aim to examine and highlight the benefits of implementing the combination of the BIM process and 3D concrete printing technology in overcoming the challenges of the building construction sector (housing deficit) in Nigeria. Nigeria, a country of over 200 million people grapples with serious housing deficits despite numerous efforts by the governments since her independence. While the country is not in isolation to this problem, other nations around the world have started to leverage on modern technologies to solve this challenge.

To achieve this, existing materials and reports on this topic were extensively studied. This helped to provide a robust and deeper insight into the topic and enable the possibility of achieving alignments first between various researches and secondly with this research. This was covered in the second chapter. Chapter three explains the methodologies adopted for this research. Qualitative approach of a case study and questionnaire survey were used to collect data which are interpreted descriptively in chapter four.

At the end of this research, results data obtained shows that a BIM driven 3D concrete printing technology can help deliver mass housing projects faster and better, BIM usage within construction industry professionals is still at infancy stage compared to how it's been used to its full capabilities in developed countries and lack of technological inclusion in projects is never considered as a contributory factor to earlier failed housing policies in Nigeria.

Keywords: BIM, 3D concrete printing, digitalization, implementation, deficit

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INTRODUCTION TO CHAPTER ONE

This is the beginning of the research report and it introduces readers to the structure of the report. Here, the research question upon which this research is based is revealed and briefly discussed. This chapter also highlights briefly the structure of the subsequent chapters. In this chapter, you will understand;

- introduction to the research work
- what is the research question
- what necessitated this question and the research
- what this research aims to achieve at the end
- the scope of research
- highlight of the research approach employed

INTRODUCTION

One of the first industries that humanity created is construction, which has shaped and is continuing to shape our way of life in various ways. Construction influences our way of life significantly and virtually all other enterprises depend on it to provide and maintain their facilities, plants, and infrastructure. (World Economic Forum, 2016). Today, the construction sector contributes roughly 6% of global GDP, with yearly revenues of close to \$10.01 trillion. More specifically, in industrialized nations, it makes up roughly 5% of overall GDP, whereas, in underdeveloped countries, it typically makes up more than 8% of GDP. In the upcoming years, the business is predicted to expand significantly, with projected revenues of \$15 trillion by 2025 (Md. Aslam, Altnay, Suvash & Jong, 2020). The global construction industry currently employs over 100 million people. (World Economic Forum, 2016). In the European Union (EU), by providing about 18 million employments and contributing to nearly 9% of the bloc's GDP, the construction industry is a key supporter of the EU economy. (European Construction Sector Observatory, 2021).

Despite this, the global construction industry is still lacking in many areas. Productivity is low, and there is an unevenly growing housing deficit. No country in the world is left out; it is more critical in certain countries or regions than the others. Although there is a question of affordability, another is availability. This study tilts towards availability more than affordability. Housing is a basic human need and it is defined by the World Health Organization as a "residential environment that includes all necessary services, facilities, equipment and devices needed or desired for the physical and mental health and social well-being of the family, in addition to the physical structure that man uses for shelter" (Habitat for Humanity, 2022). In developing countries alone, the number of people living in slums is now projected to be approximately 881 million, up from 689 in 1990. 59% of the urban population in Sub-Saharan Africa resides in slums (Habitat for Humanity, 2022).

Nigeria's housing deficit has steadily increased, from 7.0 million in 1991 to 14 million in 2010. According to a World Bank research from 2018, Nigeria needs to build 700,000 housing units yearly over 20 years to handle its growing population. With the present indices and Nigeria's housing sector's slow growth, this is utterly

unachievable (Epko, 2019). With over 200 million residents and a strong demand for housing units, Nigeria needs to take the housing shortage issue seriously in terms of quantity and quality. To tackle this challenge, the Nigerian government has developed and implemented different strategies such as low-cost housing schemes and public housing programs. The goal of the housing program is to increase the quantity and calibre of homes in a given area. Collaborating with local authorities to support them in achieving the housing aspirations for their areas generates opportunities for individuals to live in cheap houses of high quality and in sustainable locations. (Akinluyi & Adeleye, 2013).

An example of the National Housing Policy aimed to build around a million homes annually, offer mass housing to Nigerians regardless of their financial situation, and implement social housing policies to make money available to those working in the unofficial economy. However, the previous housing policy has faced criticism from experts for failing to address the financing of house creation and for remaining silent regarding the government's responsibility to support the National Housing Fund adequately. For instance, the Sheu Shagari Administration's Policy on Affordable Housing, launched in 1979, was one of the significant housing policy measures. Although admirable, the strategy failed to achieve the country's housing needs since it was built on the unviable premise that the government would provide housing. Although the exercising of the housing policy reforms in 2002 was a positive start, much work still needs to be done. (Akinluyi & Adeleye, 2013). Various researchers have understudied the reasons for this problem, and they always share similar discoveries; the rising cost of construction, political instability, mismanagement of funds, inter-ethnic crisis leading to displacement, rising migration to urban centres, delay in project delivery leading to abandonment among others.

However, integrating digital technologies into the construction industry is frequently seen as a crucial component that can assist address some of the aforementioned challenges. (ECSO, 2021). By utilizing new technology, materials, and techniques, enormous opportunities are open to us. For instance, new digital technologies will not only increase productivity and cut down on project delays, but they can also improve building quality, safety, working conditions, and environmental compatibility

(World Economic Forum, 2016). Modern technology is the major tool that has transformed our world into what it is today, introducing knowledge beyond physical possibilities to abstract realities. The advent of Artificial intelligence, Virtual reality and machine learning is continually applied to expand the human-machine symbiotic world. Building Information Modeling (BIM) and 3D Printing are two of the latest breakthroughs of modern technologies that enjoy so much attention and growing application in our world today. From the research office to the work field, efforts continue to grow in understanding the dynamics and opportunities inherent in their application.

Building information modelling (BIM) is a digital asset operations and construction approach. It combines technology, process enhancements, and digital information to enhance client and project outcomes and asset operations significantly. Throughout the entire lifecycle of both buildings and public infrastructure assets, BIM is a strategic facilitator for better decision making. (ECSO, 2021). According to (World Economic Forum, 2016), BIM, the primary enabler and facilitator for many other technologies, is important in this context. For instance, the combination of robotics and 3D printing with a specially built 3D model can substantially speed up family-sized housing units' construction. Large businesses are mostly in charge of implementing BIM, with SMEs adopting it somewhat (ECSO, 2021; Ibidem). Another technological advancement that has an impact on the building sector is 3D concrete printing. A 3D printer uses a Computer-Aided Design (CAD) or BIM file to direct the nozzle as it solidifies a material (such as plastic, metal, wood, or concrete) to create an object. This technique is known as additive manufacturing or 3D printing. Building components or entire structures can be printed using 3D printing in the construction industry. Buildings, bridges, printed moulds, and architectural models have all made use of it. (ECSO, 2021). One Chinese company has already taken advantage of the chance by "printing out" building components using a mixture of rapid-hardening cement, industrial waste, rubble, and glass according to the specifications of a 3D construction design. For a three-story building, the printing process takes two days, reducing construction time by up to 70%, manual labour by up to 80%, and material consumption by up to 60%. (ECSO, 2021).

1.1 Research Background

In Nigeria, there is yet a limited number of completed research and available materials on the latest technology within the Construction Industry, particularly on the topic of BIM and 3D concrete printing technology. Additionally, a global survey was undertaken by reputable organizations that often exclude Nigeria and Africa in their report. The deficient application of BIM and other cutting-edge technology in the Nigerian Construction industry is one of the primary reasons for this. Currently, BIM is only used up to level 2, and the only application of 3D printing in Nigeria is within the manufacturing sector only. This poor attitude towards the latest technologies further makes it less possible for the Nigerian construction industry to harness their potentials to solve prevalent issues. This shortcoming is shared by all stakeholders involved- government, companies, professionals and private clients. Therefore, this situation provides the basis for this study to examine the potential of these technologies in leading a disruptive and sustainable transformation within the construction industry, in which solutions are technologically based and driven.

1.2 Problem Statement

Submissions from various literature reveal that the governments' multiple efforts, through various housing programs and policies, failed to meet targeted goals. Private companies continually face various factors that impede their productivity and profitability. The urgent need to make at least 700,000 adequate and affordable housing available annually to meet the current demand now stares the building construction industry in the eye. The questions that necessitate this research are;

- i. Is the Nigerian construction industry improving in the application of modern technologies at all?
- ii. Can the adoption of digitalization and new technologies such as BIM-driven 3D concrete printing help Nigeria solve her housing deficit challenge better?

1.3 Aim

This research aim to examine and highlight the potential benefits of implementing the combination of the BIM process and 3D concrete printing technology in overcoming the challenges of the building construction sector (housing deficit) in Nigeria. This research aim to accomplish this by:

- (i) assessing the current technological situation of the Nigerian construction industry
- (ii) identifying the relationship in the usage of BIM and 3D concrete printing
- (iii) establishing how the adoption of these technologies will influence the Nigerian construction industry.

1.4 Scope of Research

By the classification of Barbosa et al., (2017), construction is divided into Building, Civil, Industrial and Specialty Construction. Therefore, the scope of this research considers only the Building construction sector. Secondly, out of the various factors contributing to the challenge of housing deficit, this research focuses only on the solutions and benefits provisional in adopting the latest technologies to tackle the problem. Lastly, of the various technologies disrupting and driving a digitalized construction industry in the world today, this research focuses only on BIM and 3D Concrete Printing.

1.5 Research Approach

This research is carried out using a qualitative approach. Interview, via a customized questionnaire, formed the medium through which professional perspectives were collated and observed. Relevant details were also extracted from journals and research reports related to this topic, which all form the primary source of information.

INTRODUCTION TO CHAPTER TWO

In this chapter, you will learn and understand the relevance of this research topic through the lens of relevant existing researches and academic materials. Many authors and researchers before now had worked somewhat similar topic, enabling this research work to have a robust foundation for a scholarly discussion on this topic. This chapter begins by introducing readers to a brief description of the components of the building industry, a brief history on the transformation of the Nigerian building industry, housing policies that have shaped the industry and its numerous challenges. Midway into this chapter, you will be introduced to the emerging technologies changing the construction industry globally. The later part then focus on the two technologies that this research considers for discussion. At the end of this chapter, readers will understand;

- the opinions of earlier researchers and how they align with this research work
- the challenges within the Nigerian construction industry which validates the importance of this research work
- what informed the choice of the research scope
- the extent of application of technologies in construction industry
- and so on

LITERATURE REVIEW

2.1 Definition of the Building Industry

Akinluyi & Adeleye (2013) described the building industry as a group of qualified experts (such as architects, engineers, builders, surveyors, etc.) who collaborate on construction sites to create desired buildings. To develop a building, specialists such as architects, builders, surveyors, etc. must simply interact. Any country's economy revolves around the building industry, which generates major revenue and a sizable amount of employment. In the absence of infrastructure and civil engineering projects, it can alternatively be described as the area of the economy in charge of building design, construction, alteration, repair, maintenance, refurbishing, and demolition. In other words, the creation and upkeep of buildings is its primary preoccupation, as suggested by the name. The building industry, therefore, refers to a primary facilitator and significant index of the socioeconomic development of any nation (Akingbongbe, 2002; Windapo, 2006). According to estimates, it is the second-largest industry in the world (Towry-Coker, 2006). Buildings, the industry's main products, are the results of significant financial investment and provide value to the environment, making them deserving of being presented as legacy for future generations. (Akingbohunge, 2002; Dada, 2006; Towry-Coker, 2006).

2.2 Development of the Building Construction Industry in Nigeria

Old buildings in Nigeria were originally made out of earthen materials such as clay and rocks. Other materials like bamboo, wood, and fronds were also used (Fig 1a). As a country with heterogeneous societies, there were visible variations in the architecture and style of construction of houses moving across different cultures and tribes from the east to west; from the north to south. Rikko & Gwatau (2011) put this in perfect perspective by stating that the various traditional dwelling types found in the various regions of Nigeria are the end results of man's search for a reasonable place to live as impacted by culture, religion, climate, urbanization, and most recently professionalism. Over time, the arrival of the British would later become the earliest exposure of Nigerian people and local communities to new construction style. The

emergences of multi-floor structures, most of which have become historical edifices today, are now the relics of western architecture that formed the origin of modern Nigerian architecture. Examples of such buildings are the Badagry Storey Building in Lagos and the Residence at Cross River State, both in Southern Nigeria (Fig 1b).



Fig. 1 An example of old mud house in Nigeria¹



Fig. 2 The Badagry Storey Building (First Storey building in Nigeria)²

¹ www.flickr.com/photos/iita-media-library/4745485291

² Source: www.vanguardngr.com/2018/01/nigerias-first-storey-building-records-9009-visitors-2017

With a few foreign enterprises, organized construction in Nigeria started in the early 1940s. The country at that time opened up to global and domestic investments, and there was an evident need for infrastructure to support economic growth. This led to an increase in construction and demand for construction services during the "oil boom" that followed roughly 10 years after Independence (Nigeria Bureau of Statistics, 2015). After Independence in 1960, the construction industry was catalysed by the oil boom in the 1970s, which improved construction activities and lasted until 1983 (Olanrewaju 2012). Consequently, the Construction industry grew to become a key sector in driving urban development and improved wellbeing. Some of the earliest changes affected building materials, methods and architecture.

The need for homes and real estate, the need for infrastructure to sustain a growing population, and the desire to open up communities to promote interstate and interregional trade and movement have all contributed to the growth of the construction sector over time (NBS, 2015). Today, the industry has grown even though its size of the Nigerian construction industry is relatively small compared to other sectors of the economy. In 2008, constituted only 0.2% of the value of the global construction industry, which was estimated at \$3.15bn (Olarenwaju, 2012). Real growth in the construction industry was 4.83 percent (year over year) in the first quarter of 2022, up 3.41 percent points from the rate seen in the year prior. There was a 1.38 percent point rise compared to the previous quarter. Real growth for the sector was 3.31 percent quarter over quarter. In the first quarter of 2022, it contributed 4.18 percent to the total real GDP, which was greater than the 3.46 percent it contributed the previous quarter and the 4.12 percent it contributed in the same quarter the year before (Nigeria Bureau of Statistics, 2022). The GDP contribution of the real estate industry is anticipated to rise, barring any unfavorable unexpected events. Between 2022 and 2025, the construction market in Nigeria is anticipated to grow by 3.2% yearly. Through all of these, the Nigerian construction industry remained technologically backward and deficient. Low demand and lack of policy for technological inclusion are some of the reasons responsible for this. Previous housing policies were designed to tackle the challenge of housing deficit with little or no focus on technology based solutions.

2.3 The Nigeria Housing Policy and its Challenges

An increase in the demand for building infrastructure by both the public sector and private clients from the mid to late 20th century (the 1940s-1980s) resulted in over stress of the few foreign companies and contractors serving the Nigerian construction industry. However, an unprecedented level of degradation of standards in the project delivery process was noticed and recorded during this period. Projects were poorly conceptualized, carelessly planned and improperly executed. This resulted in unreasonably high time and cost overruns, low quality and widespread abandonment (Mbamali & Okotie, 2012).

According to Mbamali & Okotie (2012), the recurrent event of a continuous collapse of buildings, fire infernos and other disasters necessitated the government, through the National Council on Housing and Urban Development to generate a National Building Code. The code provided the minimum standards for all the stages of building construction (from pre-design to post-construction) to ensure quality, safety and proficiency in the building industry. Noting that the housing industry can be a stimulus to the national economy (Onibokun, 1983), the national housing policy also had to be introduced to make development evenly inclusive to a great extent. Waziri & Roosli (2013) defined policy as a declaration of intent, typically made by the government, on a topic like health, energy, education, housing, or population, which is intended to direct the subject's activities by outlining its goals, objectives, and strategies for achieving the goals/objectives, as well as the institutional framework and the necessary funds, human resources, and material resources. The document serves as the foundation for governmental action as well as the benchmark for program performance assessment. (Sanusi, 1997). According to Ibimilua & Ibitoye (2015), housing policies are derived from laws, regulations and administrative practices that can aid the production and delivery of housing. The housing policy became the playbook of detailed instructions, plans and strategy the Nigerian government developed to create and provides affordable housing for the growing population through various schemes and programs. Ibimilua & Ibitoye (2015) contend that Nigeria's housing policy predates the nation's history. They roughly divided its historical development into the following five major timelines:

- (i) the colonial period (before 1960),
- (ii) the post-independence period (1960-1979),
- (iii) the second civilian administration (1979-1983),
- (iv) the military era (1984-1999), and
- (v) the democratic era (1999 to date).

Waziri & Roosli (2013) further stressed that the core goal of housing policy is to ensure that every citizen of a country is adequately housing located in a decent house and suitable environment at an affordable cost. Housing policies and housing programs work together to reach a housing goal that can be accomplished through housing programs. According to Nigeria's National Housing Policy (NHP), housing is defined as providing a proper place to live in a neighborhood that is supported by sustainable building maintenance enabling people to go about their daily lives and engage in community activities.. According to the World Health Organisation (1961), a good house is described and characterized to have:

- (i) a sturdy roof to prevent rain
- (ii) Good walls and doors keep out animals and shield against poor weather.
- (iii) In hot weather, sunshades surround the home to shield it from direct sunshine..
- (iv) windows and doors with wire netting to keep out mosquitoes and house flies

While all these consist of the basic necessity of safety, a good house in today's world should encompass more sustainability-centred proponents such as lesser carbon footprint, durability and affordability. These are ingrained in meeting the targets of sustainable development goals. Even though section 16 (1)(d) of the 1999 Nigerian constitution stipulates that the government shall provide adequate housing for all citizens, the reality within the Nigerian society and building industry today is a far cry from all these. Despite the efforts of successive governments and administrations to provide adequate housing for the Nigerian citizens, the challenges of homelessness and inadequate standard of living continued to soar, mainly affecting the low-income earners. Ademiluyi (2010) argues that a number of inherited housing issues are to blame for the housing programs' inability to deliver affordable homes to low-income populations as planned. Ocholi, Manase, Lowe & Sommerville, (2015) and Osubor (2016) listed some of the issues as long-term neglect, an underdeveloped housing

finance system, a lack of long-term funding, low household income levels, high unemployment, high inflation, high mortgage interest rates, a high cost of land and building materials, poor planning and implementation, the existence of administrative bottlenecks, an unstable economy, and bureaucracies. Umoh (2012) observed that the involvement of the public sector in providing housing infrastructure for the Nigerian populace has been limited to policy formulation rather than housing delivery. Osubor (2016) also supported this, noting that all promises end at the policy level. Studies undertaken by earlier researchers like Aminu and Ruhizal (2013) and Ocholi et al. (2016) detailed the history and impact of Nigerian housing policies from the pre-independence period till recent times.

In 1928, the Lagos Executive Development Board oversaw the introduction of the first intervention that can be considered a housing strategy (LEDB). The guidelines' main objective was to solve the housing issue on a national level. Following a review by the colonial government, the Nigerian Building Society was founded to enable housing opportunities in both the public and private sectors. This copy of what is available under the British system, where mortgage banks are referred to as building societies (Waziri & Roosli, 2013). A decree in 1973 was promulgated to establish the Federal Housing Authority, which started full operation in 1976. Making recommendations to the federal government on housing and auxiliary infrastructural services and carrying out those that are approved by the government are among its duties. (Waziri & Roosli, 2013), acting as a client-representative of the government for public projects handled by contractors and monitoring the allocation of budgeted housing infrastructures across the Nigerian states at the time. Some of the housing schemes achieved within this period (1975- 1980) include the FESTAC town housing building project to host the first all African Festivals of Arts and Culture (FESTAC), Ipaja Town, the Amuwo Odofin Phase 1 Estate; all in Lagos and the first ever low cost housing estates in the eleven state capitals (Ocholi et al., 2013). Despite all, there still was a tangible housing shortage across the country as the proposed target was never achieved.

In 1991, the military government in power reviewed the existing housing policy and developed a more relevant, effective and robust plan. Waziri & Roosli (2013) termed

it ambitious due to the slogan adopted “Housing for All by the Year 2000A.D” and the target was for every Nigerian to have access to safe, affordable and decent housing by the year 2000. Apart from the earlier objectives, the 1992 policy considered the need to comply with and integrate the enabling objective of the United Nations Commission on Human Settlements (Ocholi et al., 2013). To achieve this feat, some of the strategies employed include:

- (i) data estimation for allocation by capturing the housing gap in both urban and rural areas
- (ii) the creation of the National Housing Fund Scheme to raise loanable funds from employees. These funds would then be distributed via the newly established Primary Mortgage Institutions (PMIs), with the Federal Mortgage Bank of Nigeria serving as the scheme's governing body. (Ibem, 2011a).
- (iii) adequate participation of the private sector in providing infrastructural amenities (Waziri & Roosli, 2013).

At this time, a simple family house of two or three bedrooms (depending on the size of the family) was the most common design adopted for construction as most of those in need of these houses are low to medium income earners. Makinde (2013) however, stated that despite the fact that some federal government organizations are used to produce houses in large quantities and housing schemes, building the required quota to meet the ever growing demand of the citizens remained unachieved and inadequate in quantity and quality as well as costly. The deficits recorded in each administration and policy era have continually been passed on. Sources from the extensive study and observations undertaken by earlier researchers highlighted the factors responsible for these failures to include:

- (i) implementing a single house design throughout the board (irrespective of the differences in culture and climate), and poor allocation based on political interest rather than societal interest (Onyike, 2012)
- (ii) Inconsistency in approach and strategy, delay in building plans approvals, poor implementation of policy, non-availability of mortgages, and mismanagement of funds (Ocholi et al.,2013)

(iii) change in leadership and lack of continuity structure

Policy era	Estimated Houses	Constructed Houses	% Achieved	% Deficit
1962-1968	24,000	500	2%	98%
1970-1972	54,000	0	0%	100%
1975-1980	200,000	28,500	14.25%	85.75%
1981-1985	200,000	47,500	23.75%	76.25%
1990-1999	121,000	1,104	0.91%	99.09%

Tab. 1 Data of the previous era by Federal Government 1962 to 1995³

As shown in the table above, the performance of previous housing policies based on projected data against actual data corroborates with earlier researchers such as Mtafu et al., 2011; Aribigbola, 2006, who suggested housing problems cannot be eradicated. Consequently, the belief of Ibimilua and Ibitoye (2015) that housing policy is a tool for solving housing problems and also for achieving sustainable housing has not been well proven as sufficiently effective over the years as the challenges keep outgrowing the promises of the policies.

Following decades of growing housing deficit, the Nigerian government, in the early 2000s, came up with new housing reforms that placed private investors as crucial players in growth and development within the building construction industry. Aminu and Ruhizal, 2013 noted that between the years 2000-2004, the policy focus was on the private sector to come into the scene and act as a catalyst for housing delivery in Nigeria, while the government concentrated on the construction of basic infrastructures (such as land, roads) on the new housing development. This

³ Source: <https://nairametrics.com/2021/11/23/a-housing-policy-for-nigeria/>

approach enables private individuals and investors to operate the housing industry concurrently with the government, closing the wide gap of housing deficiency, especially in the urban centres where demand is higher. In addition, the current new housing policy has eliminated some bottlenecks that enable private developers to scale up their participation. Some of the changes introduced include:

- (i) the prior policy's 25-year amortization period was extended to 30 years.
- (ii) interest on National Housing Fund (NHF) loans to PMIs (Primary Mortgage Institutions) got reduced to 4% from 5%
- (iii) rate of lending to investors and developers is reduced from 9% to 6%

2.4 Current Housing Realities in Nigeria

Iroegbu (2015) pointed out that previous housing units, using the Lateef Jakande housing unit scheme in Lagos as a case study, suffered from a lack of maintenance. Osubor (2016) also stated that the poor supervision and construction quality of these large scale projects was another peculiar problem attached to the schemes. To a great extent, these reasons account for why many of the housing units constructed under the implementation of previous policies across the various states have fallen into dilapidated conditions today. For example, the housing estate built at FESTAC area of Lagos in preparation for the Festival of Culture and Art in 1977, and the low-cost mass housing units built particularly in state capitals during the Shehu Shagari regime(1979-1983) (popularly known as Shagari village). In order to save the buildings from total ruins, a move was taken to sell out the units to the occupants and interested buyers or investors. This was also confirmed by Osubor (2016), who explained that all of the homes that had previously been built for government employees were sold to members as owner occupiers, and the housing allowance program was monetized to provide housing subsidies to employees while still collecting 2.5 percent of their monthly salaries as repayment. In a recent publication by Vanguard newspaper, the following were observed in some of such sites in Kaduna, Ondo and Lagos State:

State	Details
Kaduna	<ul style="list-style-type: none"> (i) many of the one-bedroom and three-bedroom houses built have been sold out. (ii) while some owners renovated them, others demolished them and rebuilt new ones. As a result, only a few of the original houses are still standing. (iii) a single unit of a two-bedroom apartment that once sold for N6,000 later sold for over N10 million in 2020.
Ondo	<ul style="list-style-type: none"> (i) one bedroom and two-bedroom apartments no longer have the aura of an estate that it was originally conceived to be.
Lagos	<ul style="list-style-type: none"> (i) only a few old buildings were still standing as new houses had replaced the old ones with entirely new occupants, landlords and tenants. (ii) A two-bed room flat costs as much as N32m in the estate now as against N6,000 to N10,000 when the Federal Government sold the flats to beneficiaries in 1982.

Tab. 2 Current situation of Housing built under previous housing scheme⁴

Moore (2019) mentioned in a recent research of the Nigerian housing situation, which put the current housing stock at 23 per 1000 people. The country's present housing shortage as of December 2018 is put at a staggering 20 million units: increasing by 15.0% from the data recorded in January 2019. Nigeria had a housing shortage of 7 million homes in 1991, 12 million in 2007, 14 million in 2010, and 20 million today. The deficit must be serviced with at least N21 trillion. By the market and economic conditions of today, more than this will be required to meet the same need.

⁴ Source: Daily Trust

Year	Housing Deficit	Population	Cause
1991-1993	4 – 7 million	104 million	Mortgage inefficiency
2007	8 – 10 million	145 million	Slum demolition and Urban Migration
2013-2015	16 – 17 million	178 million	Over population urban expansion and increased poverty
2017-2019	18 – 22 million	184 million	Increased poverty, overpopulation and urban migration

Tab. 3 Housing Deficit Statistics in Nigeria from 1991-2019⁵

Although in recent times, specifically from 2004 to date, there have been a handful of government and foreign-aid funded low-cost building projects completed across Nigeria (Fig. 3). Also, few public housing projects, while still under construction, have been abandoned or temporarily suspended due to administrative fallouts, harsh economic situations, lesser priority for FHP implementation, lack of political will, corruption, the rising cost of construction and lack of technological integration in building construction phases.



Fig. 3 A site of low cost housing scheme in Abuja, Nigeria⁶

⁵ Source: Moore (2019)

These apply to both federal and state government funded projects. On the other hand, the Nigerian building construction industry has seen an upsurge in the number of private investors within the sector in the last three decades. The retinue of real estate and property development companies continues to widen due to a new policy which provides enabling business environment and conditions for non-governmental individuals to fund building projects and hence provide more houses for the growing rental demands, especially in the urban areas. The opportunity created by the housing deficit is expressed in a World Bank report, which stated that the Nigerian population of over 180 million would require additional 720,000 houses annually in order to keep up with the UN SDG target for 2030.

Unlike the style of mass housing construction adopted by the governments, real estate development companies and investors design and build different kinds of the market –tailored houses that satisfy modern requirements. Through various means such as rent by contract, rent-to-own, and outright purchase, the masses are able to access different option of houses that suits their need and status financially and socio-economically.

2.5 Qualitative and Quantitative Challenges of Housing Production

Akinluyi and Adeleye (2013) noted that the inadequacies within the Nigerian housing market situation can be described to be qualitative and quantitative in nature. To further break down the shortage of housing in Nigeria, Ibimilua & Ibitoye (2015) explained that the nature of the challenges differs in both urban and rural areas. According to World Bank data, in 2020, about 52% (representing 106,107,007 million people) of the entire population living in the major cities (shown in Fig. 4 below), pressure continues to mount on the already scarce housing available in the market. While the qualitative deficiencies are vast and complex, the quantitative housing problem might be resolved by expanding the quantity of current stocks. (Akinluyi and Adeleye, 2013). Hence, the housing problem

⁶ Source: <https://viewpointhousingnews.com/2021/04/26/why-mass-housing-remains-elusive-by-experts/>

in urban areas is more about quality than quantity, whereas, in the rural areas, it is the reverse – quantity over quality. Oladapo (2006) also indentified the qualitative problem as the predominant issue of urban housing in Nigeria. The physical appearance of the buildings, the amenities offered, the quality of the walls used in the construction of the building, the excellence of the roofing materials, the condition of other structural components of the house, and the environmental condition of the house are all considered when determining the quality of housing. (Ibimilua & Ibitoye, 2015). In the search for access to opportunities and better livelihood, there has been a growing case of intra-boundary relocation of people from rural areas to urban areas, both within a state and between states. Growing insecurity has also been responsible for the relocation of many people moving into the bigger cities in recent times. All of these contributed to creating more opportunities for private housing developers to grow their businesses. Ogunleye (2019) noted that the private market plays a major role in Nigeria's housing production. He added that 85% of the increase in urban population may be attributed to rural-to-urban migration, which creates a housing demand that accounts for about 90% of the housing built by private developers in cities. Consequently, there is no record of implementation of modern technologies and techniques in the construction of these houses.

This situation has therefore led to the strong reason for the neglect suffered by rural dwellers across the country as almost all stakeholders focus more on the urban centres (Ibimilua, Adewale, & Ibitoye, 2015). While there is no exact figure to capture how many of the urban buildings are actually adequate and not, it has been discovered that there quite a good number of houses in urban areas lack at least one or more basic amenities. According to Ibimilua & Ibitoye (2015), numerous homes in urban core areas are characterized by poor ventilation, a lack of built-in bathrooms and kitchens, subpar waste disposal systems, and insufficient infrastructure. Other issues with urban housing include poor design, the growth of shanty settlements, and the availability of deteriorated homes. While urban areas experience rapid infrastructural development such as highway construction, hospitals and electrification projects, rural and remote areas experience a low growth, housing production inclusive.

This imbalance in developmental coverage has led to inadequate monitoring of building activities in rural areas as the majority of dwellers are only able to afford what is within their financial capacity, with less preference for modern building practices, methods and materials. This has contributed to the continuous substandard or inadequate standard of living mostly noticed in every rural area, both in developed and developing countries. Houses in rural locations are said to have quality issues that are characterized by shortcomings in the house's location, degree of goodness, and value. (Ibimilua, Adewale, & Ibitoye, 2015; Ibimilua & Ibitoye, 2015).

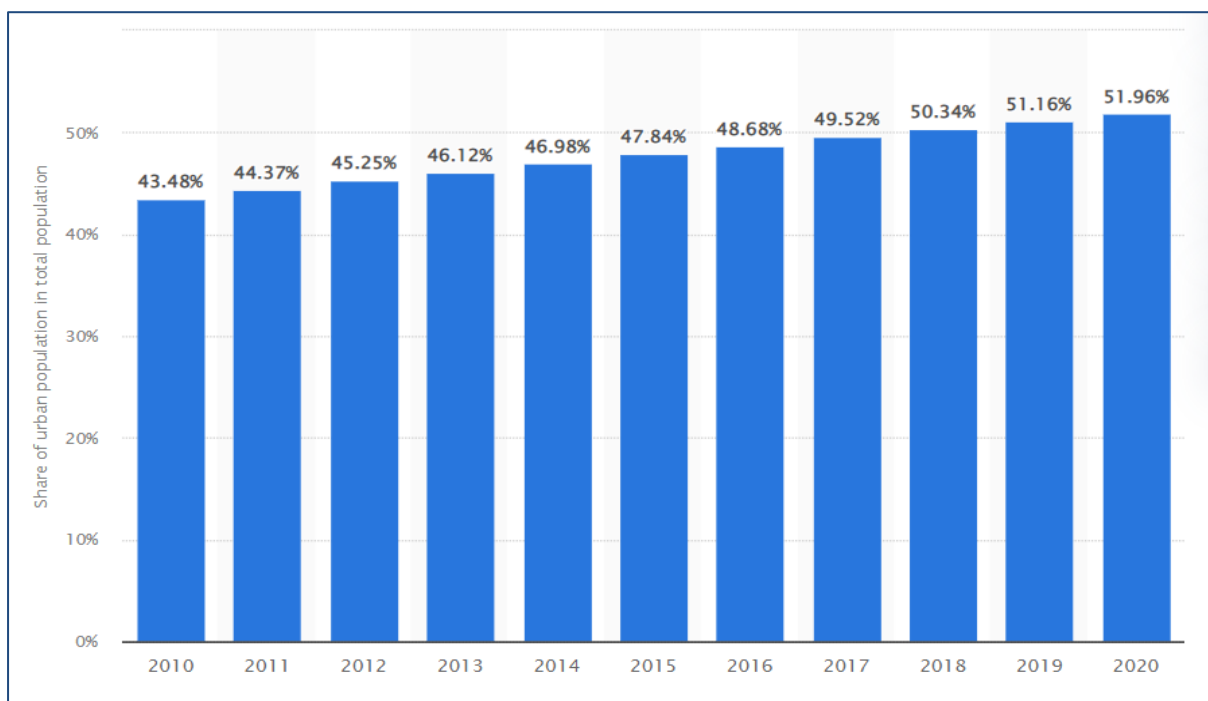


Fig. 4 Rise in Urban Population in Nigeria between 2010 and 2020⁷

2.6 The Nigerian Building Industry Stakeholders

Like every other country, there are public and private bodies that oversee the operations, control and monitoring, development, and regulation of the Nigerian Building Industry. The major players in the Nigerian housing industry sector are the private and public subsectors (Sgrenci, 2021). What can be regarded as the building industry is practically built around these interdependent entities. Ultimately, the

⁷ Source: <https://www.statista.com/statistics/455904/urbanization-in-nigeria/>.

government sits at the top of the operations and activities of all sectors of the economy in Nigeria, owning exclusive responsibilities such as policy formulation and reformation, implementation and standardization of operations. All these responsibilities and others are discharged through public institutions and units, which are first empowered with an extent of authority and secondly, have all responsibilities decentralized, well detailed and designated within teams and departments.

2.6.1 Public Sector: Government

The Nigerian government is sub-divided into three tiers: federal, state and local governments. The Federal government displays the highest form of authority and influence on the Construction industry. The Federal government has the widest coverage on project delivery and infrastructural development as it considers all the thirty-six states within the country in its yearly plans. Annually, the Federal government always come up with housing provision plans which will be distributed across the country's thirty-six states in order to increase the available stock and thereby lessen the existing housing deficit. State governments also do develop and execute state-funded housing projects. However, most of the funding for these projects is derived from allocations given by the federal governments. For wider monitoring and control of the construction industry, the Federal government created various institutions (ministries and departments) to provide direct and indirect specific services and duties across the supply chain of the building industry.

The Federal Ministry of Works and Housing (FMWH), as the name suggests, is that governmental institution established to handle everything concerning the provision of infrastructures throughout the country and for the citizens. Between 2015 and 2019, the current administration merged the ministry with the Ministry of Power. Aside construction of new roads and housing, the ministry through one of its agencies, is also in charge of rehabilitating federal roadways. According to the information available on the ministry's official website, her goal is to improve Nigerian roads to the point that they are true national economic assets and instruments for societal integration, rapid economic growth, and national development (Works), as well as to

give the Nigerian people access to house ownership and rental programs (Housing). By ensuring that all Nigerians have access to safe, livable, and quality housing in both urban and rural regions, the mission also aims to assist the supply of Nigerian roads that are always in good working order. The agencies under the ministry are detailed in Tab. 4 below. For this study, the two agencies of most concern are the Federal Housing Authority and the Federal Mortgage Bank of Nigeria due to their direct and specific involvement in the provision of housing.

Decree 40 of 1973, also known as Act CAP F-14 Laws of the Federation of Nigeria 2004, established the Federal Housing Authority (FHA), a fully owned body of the Federal Government of Nigeria (www.fha.gov.ng). The Federal Ministry of Works and Housing is in charge of overseeing the Authority. In line with Decree No. 25 of 1988, the Authority, which was partially commercialized, was given the following powers:

- (i) acquire, hold, and manage real estate, including mobile and immovable.
- (ii) acquire, construct and maintain dwelling houses, schools, communal and commercial buildings and other structures
- (iii) sign agreements for the building, upkeep, management, or repair of any property.
- (iv) buy or otherwise acquire any assets, businesses, or other property where doing so is required for the proper discharge of its functions under this act.
- (v) dispose of any property owned by the Authority by selling, renting, leasing, or another means.

FMWH Agencies	Year of Establishment	Core Mandate/Responsible
Council of Regulation of Engineering in Nigeria (COREN)	1970	To enforce and regulate the practice of Engineering in Nigeria
Federal Housing Authority (FHA)	1973	To execute housing programmes in Nigeria
Federal Mortgage Bank of Nigeria	1956	Formerly known as Nigerian Building Society (NBS), FMB is to operate a viable secondary mortgage market in Nigeria
Federal Road Maintenance Agency (FERMA)	2002	To fix federal roads across the country. To ensure that federal roads are in good condition.
Surveyors Council of Nigeria (SURCON)	December 14, 1989	To set the standard for persons who want to become a registered survey in Nigeria
Office of the Surveyor-General of the Federation		

Tab. 4 The different agencies under FMWH⁸

As indicated on (www.fha.gov.ng), the functions undertaken by the agency have been further expanded. The Authority has also been further empowered under the 2012 National Housing Policy to:

- (i) develop and oversee commercial real estate projects in all of the Federation's states and the Federal Capital Territory (FCT);

⁸ Source: <https://infomediang.com/agencies-federal-ministry-of-works-housing-nigeria-mandates/>

- (ii) offer websites and services to people of all income levels, with a focus on the low- and no-income groups. The federal government and other sources shall provide the funding necessary to support these two groups.;
- (iii) provide rural, cooperative, rented, and low-income housing in all of the Federation's states and the Federal Capital Territory utilizing funding from the government and other sources.;
- (iv) execute housing programs in the public interest that the federal government has approved.;
- (v) obtain offshore funds for house construction

According to the information available on her official website (www.fmbn.gov.ng, 2022), the Federal Mortgage Bank of Nigeria (FMBN), established in 1956 and formerly known as the Nigerian Building Society (NBS), is a joint venture of the Commonwealth Development Corporation and the Federal and Eastern Governments of Nigeria. The agency's vision is to advance the delivery of accessible and affordable homeownership by offering sustainable liquidity, cutting-edge goods and services, and top-notch customer service. The agency's vision is to become the preferred mortgage institution providing reliable and affordable access to homeownership for Nigerians. The Federal Government possessed the NBS with the implementation of the Indigenization Policy and renamed it the Federal Mortgage Bank of Nigeria as a result (FMBN). The FMBN Act 82 [1993] and the Mortgage Institutions Act 53 [1989] were both promulgated in 1994, giving FMBN the status of an apex mortgage institution in Nigeria. Additionally, it started the administration and management of the National Housing Fund (NHF), a contributing savings program created by Act 3 of [1992]. The National Housing Fund (NHF) is a public savings program created to raise long-term capital from Nigerian employees, banks, insurance providers, and the federal government to provide donors with low-interest loans.

In order to carry out its mandate, the Bank must also list capital market instruments like mortgage-backed securities and bonds for sale to institutional investors like pension funds, insurance companies, securities firms, and banks in order to raise long-term funds for its secondary mortgage lending activities. This

is done to guarantee a steady flow of funds to finance the origination of first mortgage loans. After the housing industry in Nigeria underwent reform, FMBN was reorganized as a Federal Government-Sponsored Enterprise (FGSE) with a stronger emphasis on its capital market and secondary mortgage operations. FMBN is changing its operational focus to broaden its functions from just providing social housing on-lending under the NHF to other business areas, such as commercial housing on-lending, refinancing commercial mortgages made by mortgage loan originators, buying and warehousing mortgages, and mortgage-backed securitization. The Bank's current business strategy focuses on forming partnerships with domestic and foreign businesses that have the financial and technical resources necessary to build inexpensive mass housing for the low-income end of the market. FMBN capabilities include to;

- (i) Provide long-term credit facilities to mortgage institutions in Nigeria
- (ii) Encourage the establishment and growth of viable primary and secondary mortgage institutions to meet the demand for housing delivery in all of Nigeria
- (iii) Mobilize both domestic and foreign funds into the housing sector
- (iv) Connect the capital market with the housing industry
- (v) Establish and run a viable secondary mortgage market
- (vi) Collect and manage the National Housing Fund (NHF)
- (vi) Take any action or engage in any transaction that the Board deems appropriate to ensure the proper discharge of its obligations under the FMBN Act.

Regarding housing delivery, the minister stated that the Federal Mortgage Bank of Nigeria (FMBN) and the Federal Housing Authority have added 16,447 housing units to the national stock since 2011 (Sgrenci, 2021)

2.6.2 Private Subsector

Having just recently admitted that it cannot provide houses for its population, the Federal government sought more cooperation and participation from the private players in housing provision (Sgrenci, 2021). It is important to recognize the role private developers play in providing housing in urban areas. In Nigeria, the private market has mostly served the purpose of producing housing, accounting for around

90% of urban (Ogunleye, 2019). Furthermore, Sgrenci (2021) stated that the private housing subsector had produced more than 85% of the total housing stock in the country. As contained in the National Housing Policy (2004), (Ogunleye, 2019) listed the role and contribution of the private sector in housing provision as follows:

- (i) Participate completely in the delivery of housing, especially in terms of adhering to the requirements of the Employees Housing Scheme (Special Provisions) Act (Cap 107).
- (ii) Create key lending institutions, such as building societies, thrift and credit organizations, etc.
- (iii) Participate in the creation of estates, rental or for-sale homes, or estates with joint ownership.
- (iv) Work with any government agency or the federal, state, local, or local governments to provide housing and promote economic growth..

The recognition of the government of the increasing difficulty to solely surmount the challenge of insufficient housing for the citizens has availed the private sector the opportunity to expand and grow into well structured organizations. The establishment of the Real Estate Developers Association of Nigeria (REDAN) and Building Material Producers Association of Nigeria (BUMPAN) is an example of one of the offshoot of the Private sub-sector establishments.

2.6.3 Building Construction Companies

Foreign firms have dominated the scene since since the Nigerian construction industry's organized sector was established in the early 20th century. However, quite a few domestic businesses that have grown over the years and are also fiercely competitive in the nation. In order to increase their competitiveness, several of these domestic businesses frequently collaborate with overseas businesses (Dantata, 2008). In the case of building construction, today, there is a plethora of construction companies that usually act as and termed as Contractors, operating across the country. Their services have been engaged in the production of various sizes of building projects ranging from private residential family house to large estates of

blocks of buildings and high rises. Also, the list of clients these companies served includes:

- (i) Private individuals
- (ii) Governments
- (iii) Corporate institutions
- (iv) International organizations

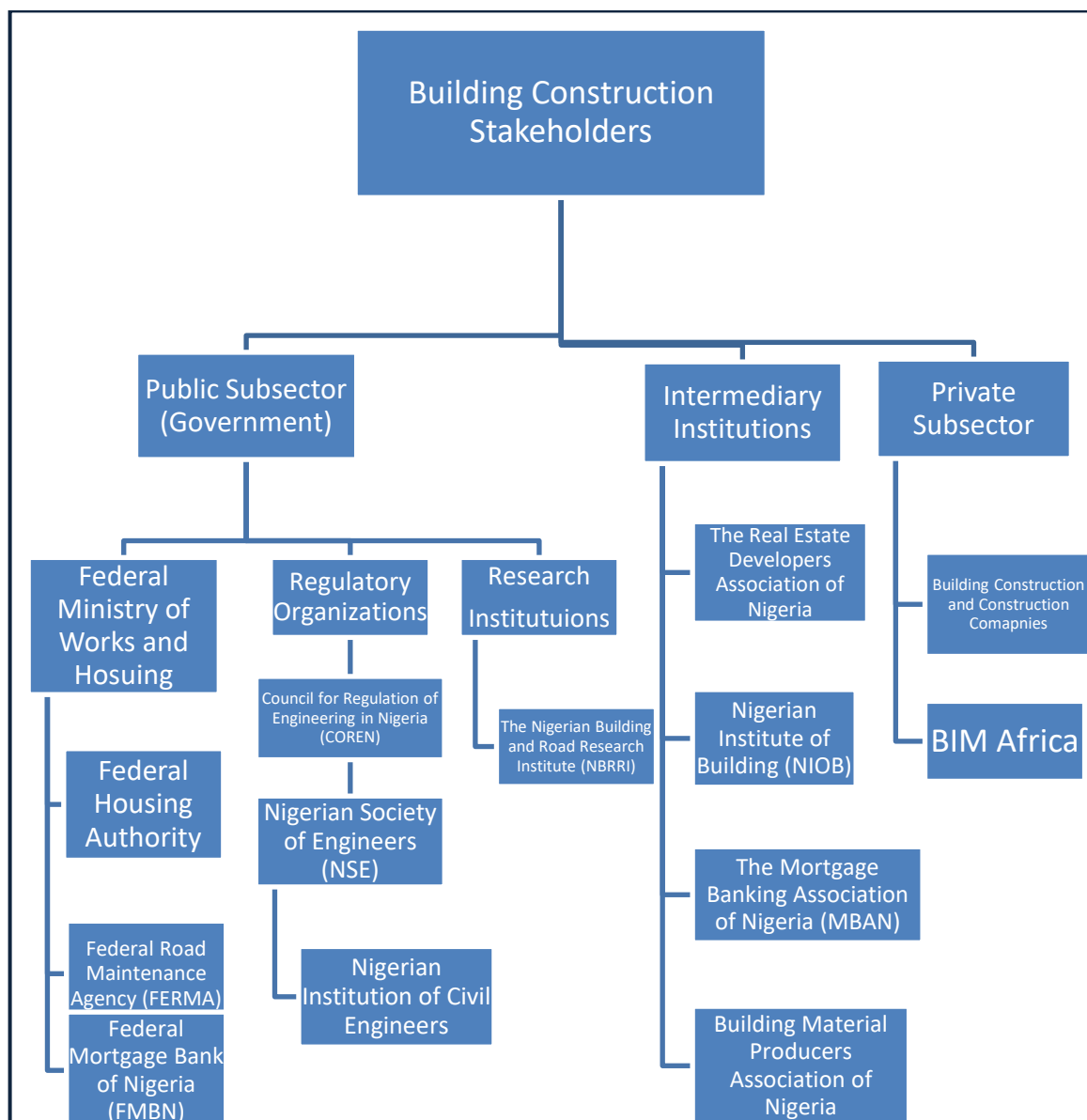


Fig. 5 Chart of various Key players within the Nigerian Building Construction Industry⁹

⁹ Source: Own figure

2.7 Global Construction Industry and its Innovative Gap

The worldwide construction industry currently accounts for around 13% of global GDP, with that figure expected to rise to 15% by 2020. Despite this, the building industry has not fully adopted technology until lately. It has traditionally been one of the least digitized industries globally (Martec, 2022). The digital revolution over the past fifty years has significantly decreased the size of the world by creating new markets, introducing new goods and products, and facilitating communication. Emerging economies are rapidly industrializing. With the current rate of innovation, it's been amazing to see how much better communication and productivity have improved. Many industries, including as health sciences, education, and consumer goods, are affected. For instance, in the automotive industry, robotics, computerized design, and a slew of other technical and work-process innovations have helped to create a global industry that is currently more productive and cost-effective, and is becoming more and more important sustainable and environmentally friendly. Engineering and construction (E&C) lags behind other global sectors to absorb and adapt to new technologies. While enterprise or company-level innovation has occurred to some extent, overall performance in the sector has remained essentially unchanged in the last 50 years or more. Historically, E&C has taken a conservative approach to product design and delivery as an industry focused on competitive procurement procedures, resulting in project management silos and a relatively fragmented industry (World Economic Forum, 2016). Owing to the magnitude and scale of E&C industry, the slow rate of innovation is significant. The industry contributes roughly 6% of global GDP and is expanding. It can account for more than 8% of GDP in some developing countries, such as India. E&C utilizes the greatest resources, using more than 3 billion tonnes of raw materials and more than half of the world's steel production. Any increase in productivity as well as the successful implementation of current innovative processes will have a significant influence. 1% increase in global productivity, for example, might save \$100 billion each year (World Economic Forum, 2016).

Digitalization is the most adopted term used in connection with the most recent advancement in Construction practices and within the industry at large. Digitalization

means converting analogue information to digital, thereby bringing together new technology, new capabilities, and shifting consumer behaviour (Ernest & Young (EY), 2015). Additionally, according to Sategna (2019), digitalization can also be defined as analysing information to acquire insights and harnessing the "potentials of information" that comes from data gathering, examining, and management to deliver innovative solutions with increased benefits. Project and Field Management software are among the most widely used technologies among construction professionals. Other technologies that will be more extensively implemented in 2020 include: Drones, Virtual Reality, 360 Video, Prefabrication, Wearable Devices, 3-D Printing (Martec, 2022). Technological digitalization is already used in a variety of industries (as highlighted in Figure 11) and promotes high productivity. Given these advantages of digitization, there is a lot of potential in implementing it in the engineering and construction industry (Viktor, 2021).

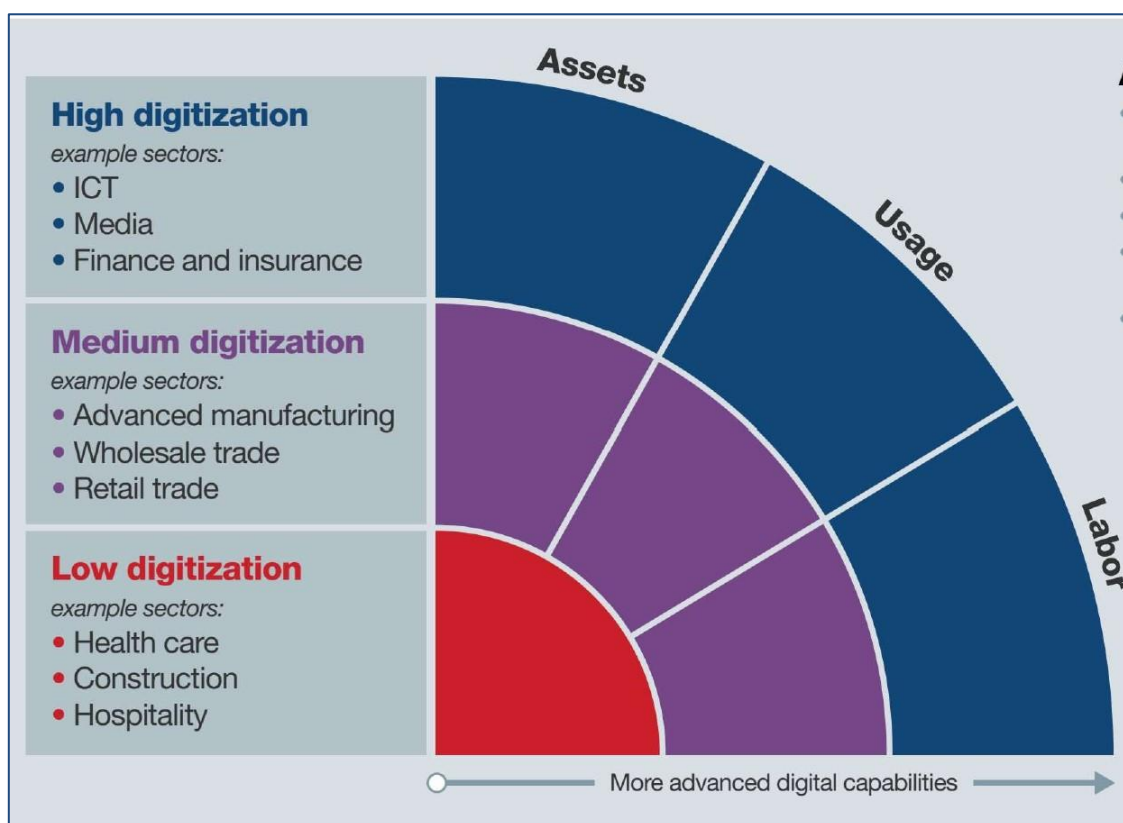


Fig. 6 Global application of digitization by business sector¹⁰

¹⁰ Source: McKinsey Global Institute industry digitization index; 2015

According to some estimates, robotics will make up 30% of the working population in 50 years. The impact of this new technology on construction is mostly unknown. It is however known that construction has traditionally trailed other businesses in this regard. This is despite indications suggesting the use of these new technologies might result in productivity increases of 30 to 40%. Some of the more imminent technologies on the horizon that promise to transform the construction industry include new smart, super-strong, and sustainable materials, new energy technologies, GPS, BIM, virtual and augmented reality, robotics, 3D printing, wireless, ultra-mobile, wearable computers, and new touchscreen APPs (Construction Digital Magazine, 2020). Figure 8 further strengthens the widespread belief that there is indeed a relatively low application of digitization and innovative technology within the Construction industry, leading to the wide technological gap experienced within the sector. In the construction industry, by embracing disruptive technologies and techniques that can result in new processes, business models, materials, and solutions, digitalization can create enormous opportunities for the whole value chain. To summarize, digital technologies can aid the construction industry in addressing a number of concerns, including labor shortages, productivity, waste and greenhouse gas emissions, as well as health and social issues (ECOSO, 2021).

Although generally low, considering the level of adoption and integration of digitization and innovative technology within the construction industry across different parts of the world, one would notice a vivid disparity that is caused by a combination of reasons or factors. Barbosa et al. (2017) also stressed that the global construction industry's productivity is not uniform and that there are significant regional differences as well as significant variations within the industry. The construction industry is made up of big-scale players working on large-scale projects like rehabilitating single-family homes and civil and industrial work, as well as vast numbers of businesses working on smaller projects like subcontracting mechanical, electrical, and plumbing work. The first group is often 20 to 40% more productive than the second. Developed countries such as United Kingdom, Germany, Singapore and United States lead developing nations in Africa – Nigeria for example, in the development, adoption and implementation of digitally-driven construction

industry. Awareness and advocacy for increased adoption of digitized construction practices, though slowly, continue to grow within the Nigerian construction industry. In an interview report extracted from This Day newspaper website, Ramzi (2018) urged for the digitization of Nigeria's construction industry, claiming that digital technology will help the industry thrive, reduce project delays, reduce the number of accidents, and ensure cost-effective building projects. Furthermore, digital technology adoption will open the path for the establishment of green and smart buildings, which will benefit the environment. A careful study of a 2017 McKinsey Global Institute report; reinventing construction, on the construction industry across geographies showed that the industry lags behind in productivity index, leading to enormous financial loss in global GDP annually (Filipe Barbosa et. al, 2017).

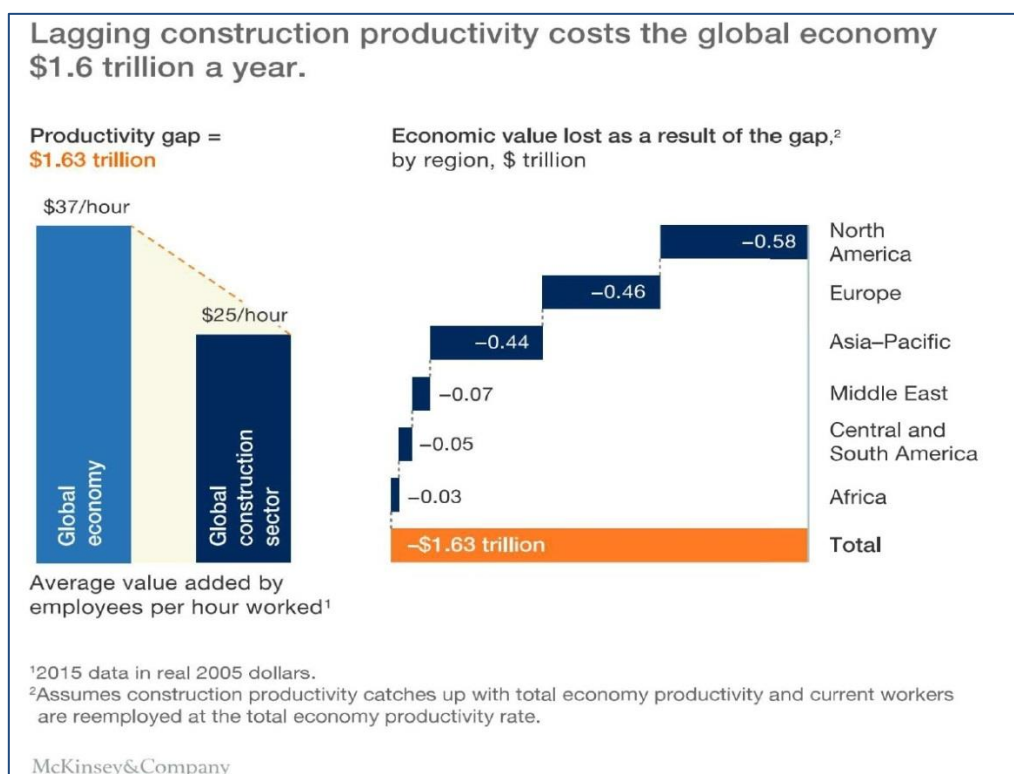


Fig. 7 Economic loss due to Productivity Gap within the Global Construction Sector¹¹

Evidently, when every key player along the value chain of the Construction industry harnesses the benefits of digitization and emerging disruptive innovations, the global

¹¹ Source: McKinsey Global Institute February 27, 2017 report

labor-productivity growth would improve and consequently close the existing economic losses. Building material manufacturers are increasingly focusing on digitizing production and distribution. Construction companies, on the other hand, are primarily focused on the digitization of planning, construction, and logistics (BIM and the related "building site 4.0"). Building material sellers, on the other hand, place a great emphasis on digital sales (online trading) as part of their logistical considerations (Roland Berger, 2016). The most heavily digital segments of the economy are media, professional services, and financial services, in addition to the ICT sector, which often sets the standard for the highest level of digitization on numerous measures.

The index also identifies areas where digital capabilities might be improved. Utilities, mining, and manufacturing, for example, are only beginning to digitize and connect their physical assets, and they might be at the vanguard of the next wave of digitalization. Digital use is growing in labour-intensive areas like retail and health care but a significant portion of their enormous workforces do not make heavy use of technology. Construction, leisure, and hospitality industries, which are both labour-intensive and localized, rank lower in utilization, particularly in the manner they conduct client interactions. If the long tail of smaller and less digitized enterprises begins to close the gap with leading corporations, lagging industries may experience catch-up growth (Manyika et al., 2015).

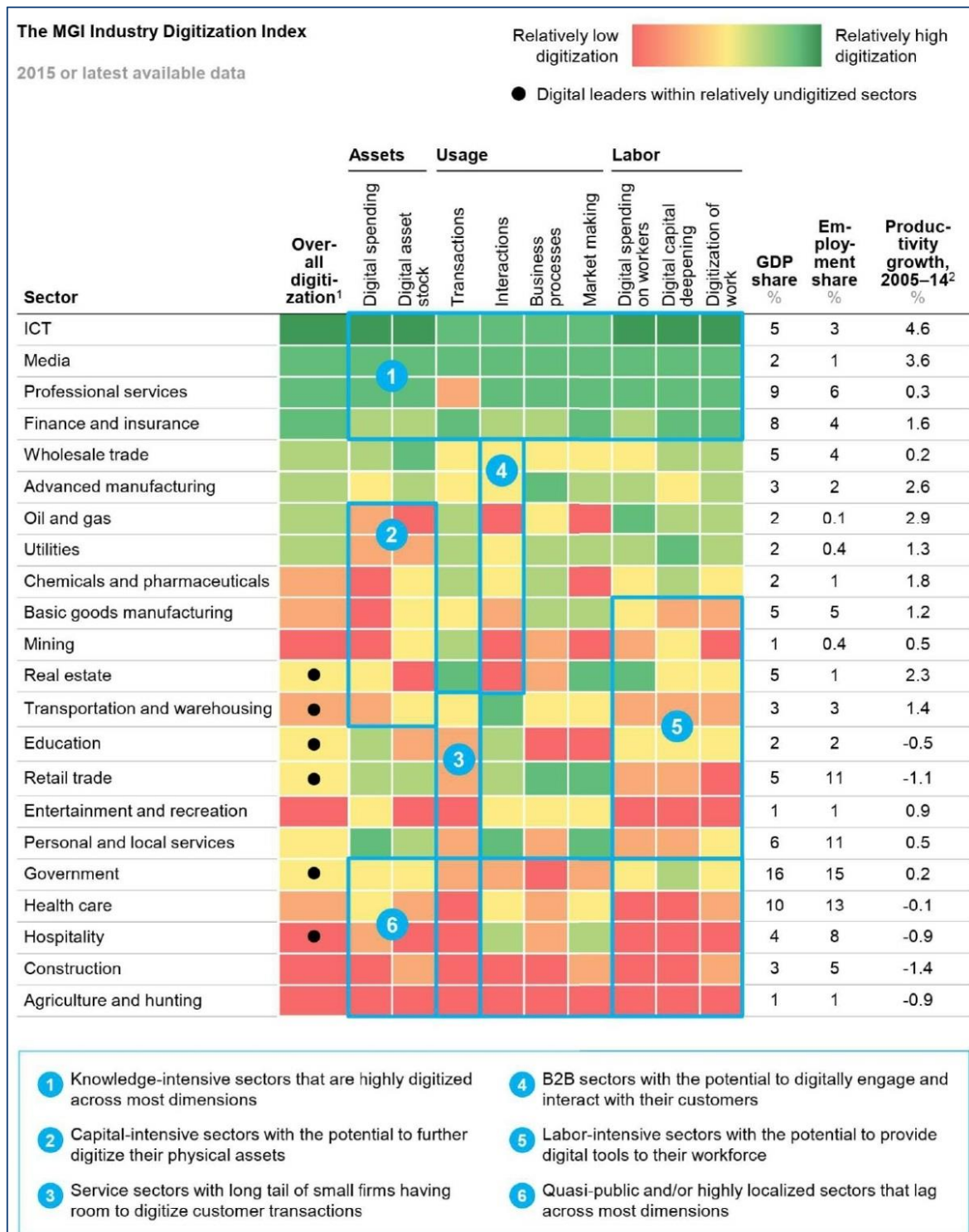


Fig. 8: Digitization index by Sectors¹²

¹² Source: McKinsey Global Institute industry digitization index; 2015

2.8 Recent Trend in Global Construction

The inclusion of latest and advanced technology in the processes and practices of other sector has proven to be of great advantaged with positive results of improved productivity, efficiency and sustainability. Today, tasks are achieved faster, easier, smarter, sustainably and also with lesser materials. The idea of digitization has been the most prolific concept with the most influence on all human endeavours. Manyika et al. (2015) noted in their report for Mckinsey & company that many industries are transforming as a result of digitization. Value chains are breaking down, new markets are developing, and profit margins are shifting. Building on the foundations of previous technology and the demand for improved processes, products and services, digitization has brought about a continuously widening disruption to the way we live and work. Consumer adoption and Industry processes has skyrocketed as a result of the Internet, mobile connection, social media, and smartphone apps (Manyika et al., 2015). According to MGI's digitization index, most of the construction industry has progressed only at a glacial rate, making it the least digitized sector in the world while other industries have revolutionized themselves and their productivity performance as seen in Figure 8 (Barbosa et. al, 2017). Finance, professional services, and retail were among the first to invest in information technology in the 1980s, and the trend has continued ever since. Other industries are still in the early stages of development (Manyika et. al, 2015).

To further boost productivity by over 50%, (Barbosa, et al., 2017) in their report suggested seven key areas to innovative firms and regions. They are;

- (i) regulation reformation
- (ii) reshape industry dynamics by remodelling contractual frameworks
- (iii) reimaging both design and engineering processes
- (iv) procurement and supply-chain management improvement
- (v) improving execution of work onsite
- (vi) integrating digital tools, new materials and advanced automation
- (vii) upskilling the workforce

Today, interest continues to grow towards connectivity, platforms, data, and software (Roland Berger GmbH, 2016). Project and Field Management software are among the most widely used technologies among construction professionals and these have formed a progressive trend driving change within the industry (Martec, 2022). Investment into research and development, capacity building and training, increasing awareness, development of technology based policies, government involvement, improved industry productivity based framework and so on are some of the underlying factors that have encouraged the growing demand for new products and in-place utilization framework observed, especially within developed countries. According to (Swan, 2022), some of the current trends transforming the construction are highlighted as follows;

- (i) Drones and virtual reality are among the cutting-edge technologies that are making work safer, faster, and more flexible.
- (ii) Internet of Things (IoT): Construction companies are now able to gather data on the job site that was previously difficult to get. For instance, tracking equipment, employees, and production amounts enables the smart contractor to more effectively manage resources and streamline workflows.
- (iii) Pre-fabricated systems and modular construction: More and more customers are accepting pre-fab products and realizing the advantages of consistent quality, increased energy efficiency, and reduced cost. Pre-fabricated systems and modular construction are also growing in popularity, saving enormous amounts of work and reducing expenses. According to the Modular Building Institute, modular construction will account for 5% of the market by 2020.
- (iv) Building information models (BIMs) that are fully connected are being more thoroughly integrated across all subcontractors, and the data quality is rising. What started as a 3D modelling system has evolved into a 10D modelling system that includes scheduling, cost, lifecycle management and lean construction. It is now possible to predict a project's success before the first shovel is placed on the ground.

Other trends in practice as identified by (Barbosa, et al., 2017) include;

- (v) Big data. Today's techniques and data has resulted in significant increases in the accuracy of cost and schedule estimations, as well as engineering productivity.

(vi) Predictive analytics and pattern recognition have permitted significantly more advanced construction project monitoring. One such is the network of sensors used to monitor the effects of digging operations for the Crossrail project in London.

(vii) Automation and robotics application in building construction continues to gain more attention as it they record significant success with the few projects already completed around the world, as they evolve through their current early development stage.

(viii) Apps that employ GPS or other navigation technology to locate products and materials are currently available. Radio Frequency Identification (RFID2) technology, in particular, provides up a plethora of opportunities. Electromagnetic fields can be used to identify products equipped with this technology. They can also be registered and scanned, making equipment rental easier and providing openness about the whereabouts of machinery and goods on the construction site. It is even conceivable to install RFID technology on newly laid concrete surfaces in order to examine them (Roland Berger, 2016).

(ix) One of the most critical jobs in every construction project is land surveying. In this context, 3D laser technology brings up new options. 3D lasers can swiftly locate water pipelines, sewers, phone lines, fiber optic cables, and power lines in addition to surveying the area. They collect all of this information and feed it into digital planning tools that the project manager may use right away (Roland Berger, 2016).

Furthermore, (Viktor, 2021) stressed the opinion of Gartner (the world's leading research and advisory company) that spots hyperautomation and democratization as two of the 10 major strategic technology trends that will drive disruption across various business sector. These trends are believed to facilitate the digital transformation within the construction industry. Democratization of technology refers to giving people easy access to technical or business competence without requiring considerable (and expensive) training. It is usually referred to as "citizen access," focuses on four key areas, including application development, data and analytics, design, and knowledge, and has led to the emergence of citizen data scientists, citizen programmers, and other professionals." Any person inside or outside the company, including customers, business partners, corporate executives, sales experts, assembly line workers, professional application developers, and IT

operations professionals, could be the focus of the democratization trend (Viktor, 2021) . As defined by Gartner, hyperautomation deals with the application of advanced technologies to increasingly automate processes. In simple term, it is the mixture of existing automation technologies to improve and expand natural human capabilities and work processes (Viktor, 2021). Construction 4.0 is another newly emerged megatrend toward digitization within the European E&C industry.

Unarguably, the construction industry must embrace innovative technology faster and better than it currently does in order to improve its productivity and profitability. Going forward, a (Roland Berger, 2016) report has identified and suggested four keys to unleash the potential of digitization in construction for a massive transformation as: digital data, digital access, automation and connectivity. The ECSO (2021) report extensively emphasized the necessity of the European Union (EU) to promote the adoption of digitization. It is well believed that digitalisation is both inevitable and pivotal for the competitiveness and sustainability of the European construction sector. The paper also highlighted the position of industry players in recognizing the crucial role of EU-level actions, emphasizing the necessity for three distinct types of intervention: legislation, public awareness campaigns, and financial support for construction enterprises.. Similar report of research undertaken by (James Manyika, 2015) for McKinsey Global Institute in the United States also decry the low and unequal adoption of digitization and the slow pace of digitization growth within the different sector of the economy. As a contributor to global economy, both the public and private stakeholders of developing economies like Nigeria and many other countries in Africa must also be at the forefront of leading a digital revolution across its various sectors.

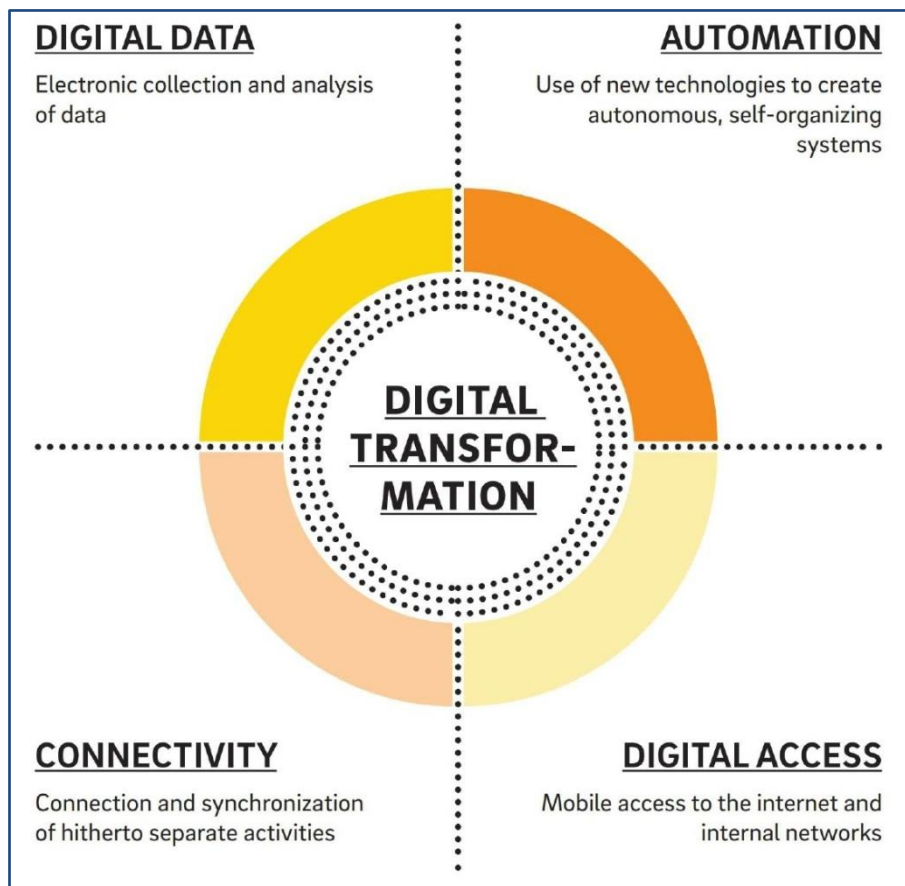


Fig. 8 The Four keys to Digital Transformation¹³

2.9 Construction Innovations and Technology

Digital advancement has altered whole industries over the last three to five decade, ushering in a new technology era dubbed as the Fourth Industrial Revolution. Companies' productivity and sustainability have improved as a result of innovation, as well as the skills and competencies required to succeed (Michael Buehler, 2018). Though late into modern technological disruption, the building and construction industry has finally begun to experience gradual transformation in so many ways. There is however an uneven distribution to the extent and level of technological adoption across various markets as well as different sectors within the same market (Barbosa F. et. al., 2017). For instance, (European Construction Sector Observatory,

¹³ Source: Roland Berger GmbH, 2016

2021) noted that there are significant differences in maturity and adoption amongst EU Member States, different technologies, and even different periods of the same construction project. However, it is clear that the adoption of digital technologies in the EU construction industry is progressing.. In the McKinsey Global Institute report compiled by Manyika et al. (2015), it is revealed that in the US economy, digital innovation, adoption, and usage are accelerating at breakneck speed. The most intelligent users have pulled far ahead of everyone else in the race to stay up with technology and create the most effective business uses for it as successive waves of invention broaden the notion of what is conceivable. In the case of African economies, the reality seems to be at the extreme end of the rule. Gadzala A. (2018) revealed that African economies currently suffer fewer entry points into global supply chains and hence make industrialization harder to achieve. This is largely because most African countries lack crucial technology and industrial skills, therefore they will not be able to exploit innovations like 3D printing and automation to compete worldwide in manufacturing in the near future. While there may be possibilities to leap forward to new technologies, acquiring the necessary worker know-how, infrastructure, and corporate skills will most likely be a long process.

According to Jones (2019), some of the technologies with the highest adoption rate within the Building and Construction industry are;

- (i) Building Information Modeling (BIM)
- (ii) Data analytics
- (iii) Project management and information systems
- (iv) Drones
- (v) Mobile platforms



Fig. 9 Modern Technologies in Building and Construction Industry¹⁴

Others, which are considered to fall within the lowest adopted range of technologies by companies, are; Cognitive machine learning, Robotics, Artificial intelligence, Machine engineering and design and 3D printing.

Across the different phases of construction, these new technologies find application for either a specific or multiple uses. Some find usage through more than two phases or through the entire construction phase from conception and design to operations, some are used only within a certain phase. The Fig. 10 below further how disruptive

¹⁴ Source: World Economic Forum, Boston Consulting Group

technologies are categorized by construction-phases based application.

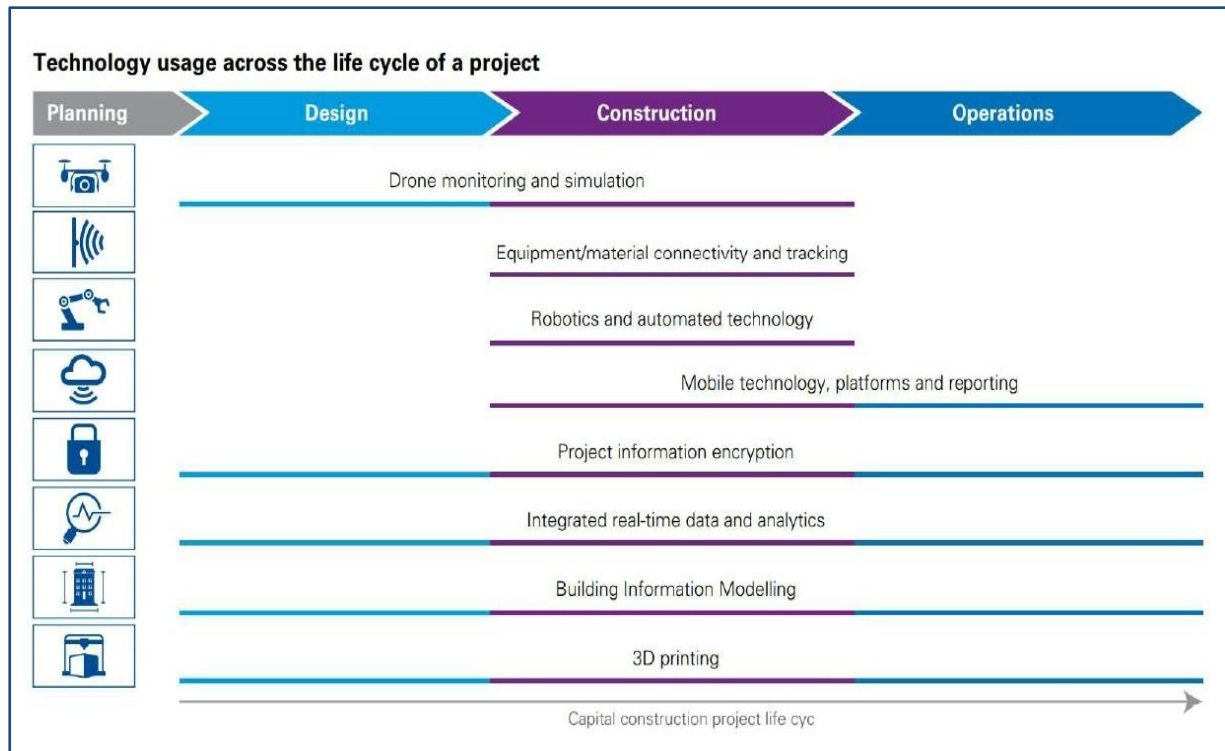


Fig. 10 Application of Technologies across the various phases of Construction¹⁵

The digital frontier is yet to be fully understood but it is brimming with great opportunities for productivity and creativity. Simultaneously, it increases competitive pressure and the risk of disruption for organizations without the greatest digital assets and capabilities (Manyika, 2015). Sategna L. G. et al , (2019) realized through majority of businesses that digital technologies have the potential to provide considerable benefits in a variety of construction-related jobs, as shown in appendix A. Interconnectivity between separate software and applications is another feature that enables the usability of these technologies less complex. The ECSO (2021) in its report categorizes robotics, drones, and sensors as three distinct technologies, despite the fact that drones can be fitted with a variety of sensors and robotic components. While being used in different contexts or at different stages of the same technology, 3D scanning, BIM, augmented reality, and digital twins are all intricately

¹⁵ Source: KPMG Global Construction Survey 2016

linked to one another (for example, augmented reality in the construction sector can be seen as a combination of BIM projects with visual sensors; a Digital Twin is a BIM project that is regularly updated using data from multiple sensors, scanners, and other sources).

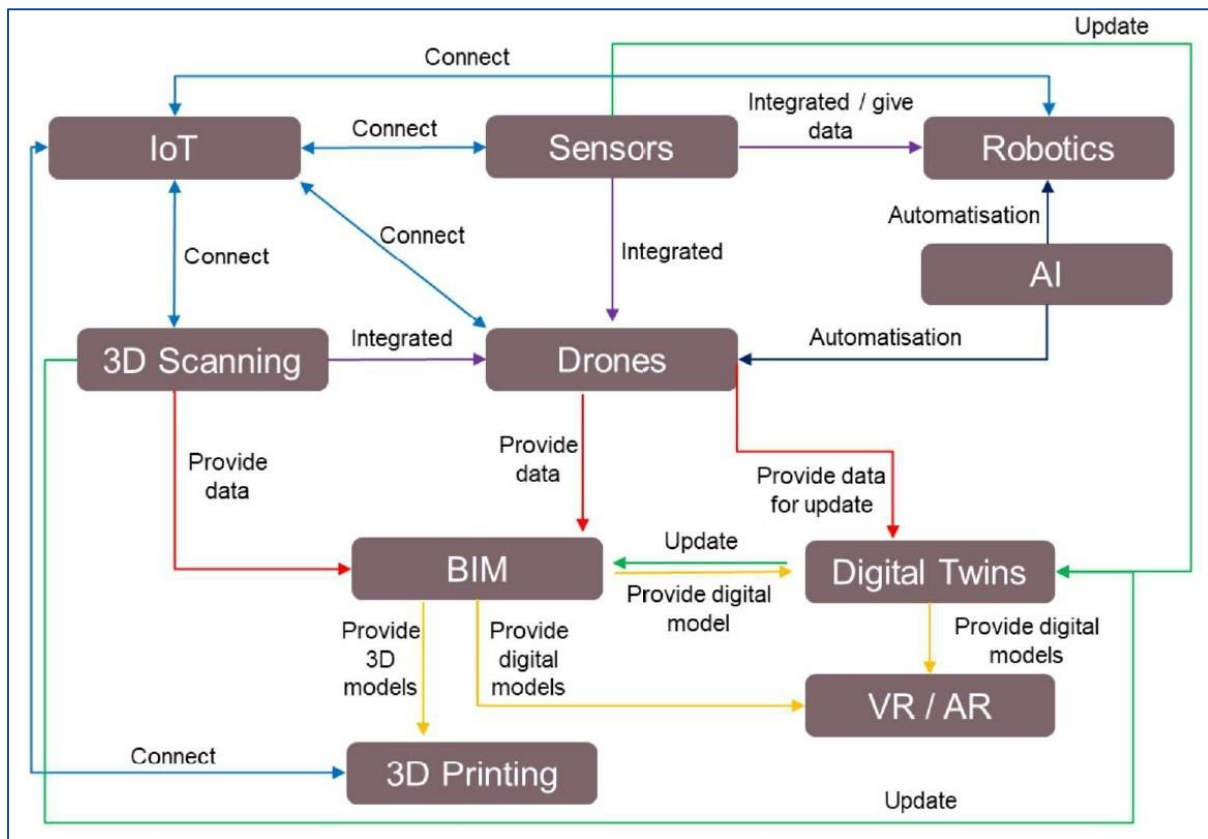


Fig. 11 Interactions among digital technologies in the construction sector¹⁶

According to European Construction Sector Observatory (2019), the different technologies, based on mode of operations and nature of end product, can be classified into three categories as follows;

- (i) Data acquisition – examples are Sensors, 3D Scanning, Point Cloud and IoT
- (ii) Automating processes – examples are Robotics and 3D printing
- (iii) Digital Information and analysis – examples include BIM, Virtual Reality and Digital Twin.

¹⁶ Source: European Construction Sector Observatory, 2019 page 20

2.9.1 Building Information Modeling

The notion of BIM has been around since the 1970s, but it wasn't until the early 2000s that it became a widely accepted word. Standards development and BIM acceptance have advanced at varying rates in different countries; standards produced in the United Kingdom from 2007 onwards formed the basis of worldwide standard ISO 19650, which was released in January 2019 (Al Hammoud, 2021). The term BIM does not have a singular generalised definition. Adewuyi and Umoren (2020) attributed the reason for this as the user's understanding and its application. Some definitions from earlier researchers on BIM are as follows;

- From the perspective of managing building design and project data in digital form throughout all phases of the lifespan, Penttilä (2006) defined BIM as a collection of interdependent policies, processes, and technology.
- Sacks, Kaner, Eastman, & Jeong, (2010) described BIM as a conceptual approach to building design and construction that includes computer-intelligent building information exchange between design, construction, and other disciplines as well as 3D parametric modeling of buildings for design and detailing.
- Adillah Ismail et al. (2019), BIM is an innovation that creates a technique to manage the design of construction projects and the data they contain as well as to digitally coordinate relationships between building components for construction activities.
- BIM (Building Information Modeling) is a digital copy or model to construction and asset management. In order to drastically improve client and project outcomes, as well as asset operations, it combines technology, process modifications, and digital data. (ECSO, 2019)
- BIM is a new platform for information technology in construction that is manifested in new tools (software) that provide new functionality by modeling design data and specifying a building or installation, allowing current processes, which are currently document-based, to be carried out in much more efficient (model-based) ways (BIMMDA).

Branthonne D. (2017) identified that building information modeling is fast becoming a key component of the construction industry's digital transition. Building Information Modeling (BIM) is a strategic enabler that improves decision-making for both buildings and public infrastructure assets over their entire lifecycle. Krämer, M. and Besenyői, Z.(2018) also mentioned that in the BIM usage, a digital model of the actual building is used throughout the entire building lifecycle, from planning to construction and building operation, in order to establish an optimized information exchange and collaboration between all stakeholders and disciplines in the building industry, as illustrated in the figure 12 below.

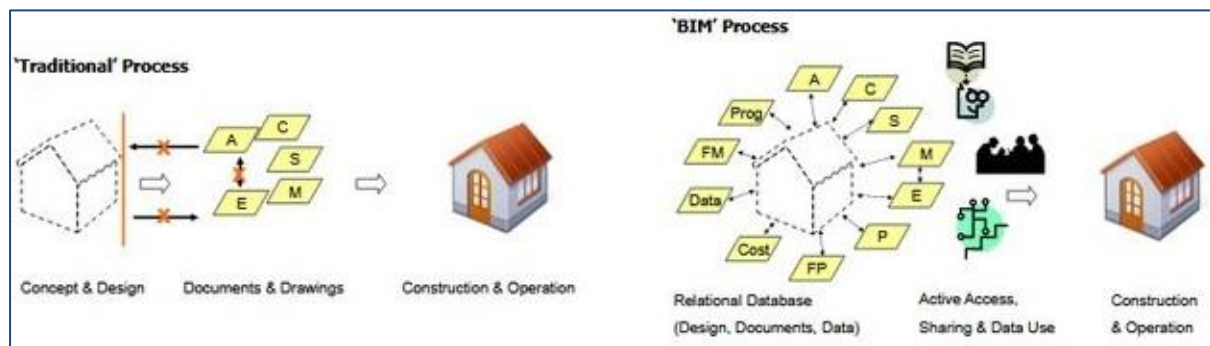


Fig. 12 Traditional process vs BIM process¹⁷

It applies to new construction projects, but more importantly, it supports the built environment's repair, maintenance, and upkeep, which makes up the majority of the industry. (Sategna, 2019; ECSO, 2019). BIM is undoubtedly the most developed and widely utilized digital construction technology (ECSO, 2021). It acts as the hub for collaborative design, modeling, planning, and engagement, allowing all parties involved to access and interact with a digital representation of a building's characteristics across the course of the building's life (Poljanšek, 2017). Nevertheless, taking an eagle view approach on the various definitions and opinions of BIM, the following points are common:

¹⁷ Source: Xuling Ye (2019); Combining BIM with smart contract and blockchain to support digital project delivery and acceptance processes.

BIM process results in the creation of a CAD generated model that contains information from various team involved in the building project. This creates a Common Data Environment (CDE) which helps to avoid data loss and clash.

- (i) It is a process.
- (ii) It encompasses 3D models
- (iii) It enhances interoperability between the industry players and stakeholders
- (iv) It relies on sophisticated soft wares and applications
- (v) It provides a detailed replica of a project in a digital and interactive environment
- (vi) BIM integrates high volumes of data and information for project delivery
- (vii) BIM application cut across the life-cycle of a project/ construction

There had been misconception many a times as to the exact meaning of BIM as interpretation varies by users. According to Besenyoi, Z. (2022), the term BIM is used to describe: Building Information Model, Building Information Modeling and Building Information Management.

- As a model, BIM is a digital file, a 3D design - the digital representations of physical and functional characteristics of places. It contains both graphical (geometric) information and alphanumeric information and topology
- As modelling, BIM is a technological process or method involving the generation and management of digital representations of physical and functional characteristics of places.
- At the managemnet application level, BIM is the process of managing Collaboration between different parties (such as Owners, Engineers, Architects, Authorities, Facility Manager) within the construction industry. Building Information Management does not only involves the overall process of Building Information Modelling but indicates and regulates the long-term utilization of the digital twin through the whole life cycle of the building (Besenyoi, 2022).

These reveals the level of usability of BIM based on user expertise, user role and position, and project demand. One of the factors responsible for the high application and adoption of BIM technology within the architecture, engineering, building and construction industry is its extensive usage from the earlist stage of a project through its entire life cycle.

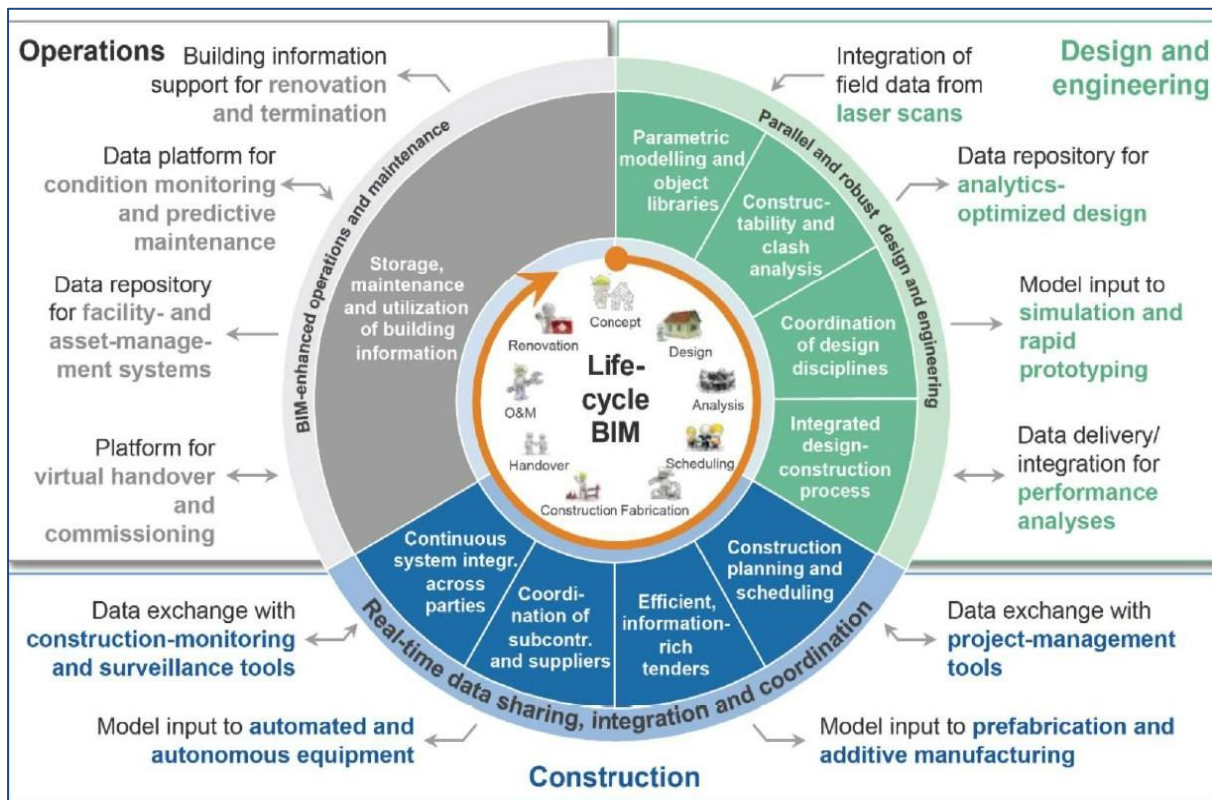


Fig. 13 BIM application along the different phases of Construction¹⁸

As noticed with other modern technologies, there is a significant variation in the adoption and sophistication of BIM varies between countries and companies, depending on their size and place in the value chain. BIM is now part of business for some large engineering firms, but most small businesses across the value chain have limited experience with it. Some of the largest contractors, in fact, have never used BIM on any of their projects (Poljanšek, 2017).

Survey and study undertaken by previous writers and researchers on the global adoption of BIM in the construction industry particularly by regions share reoccurring similarities. Fig. 15 below shows the distribution by region and countries of BIM adoption across the world. McAuley, Hore, & West (2017) generated a map showing global representation of BIM adoption and Africa is one of the continents with no record. Intriguingly, national lessons were intended to be learned, particularly

¹⁸ Source: Shaping the Future of Construction

regarding their respective adoption trends. Many nations have been working to protect the shift to digital technology. (Hamma-adama & Kouider, 2019).

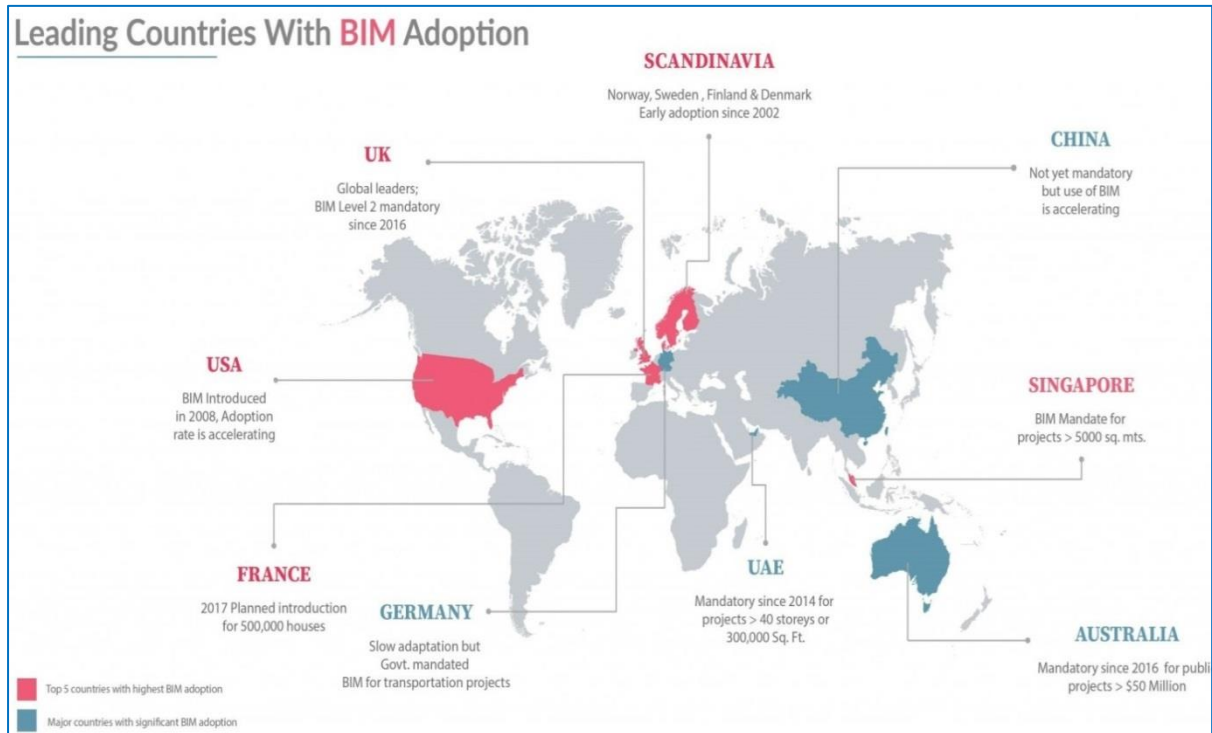


Fig. 14 BIM Adoption by region and country across the world¹⁹

The top countries at the frontier of BIM adoption and growth are; United States, United Kingdom, France, Scandinavian region (Finland, Sweden, Norway, Denmark), China, Singapore, Australia, Germany and United Arab Emirates (United-BIM, 2020). In a study undertaken by Al Hammoud (2021), his discovery further support the positions of European countries, United Kingdom and the U.S as top users followed by Asian countries. Noteworthy is the fact that governments, as stakeholders, in most of these countries have helped to drive the growth of BIM through policy designs and implementation frameworks that mandates companies and contractors to utilize BIM for public projects and certain capital projects. ECSO (2021) noted that BIM adoption among EU member states is promoted by the legislative framework in place. While other Member States either have a BIM requirement in their public procurement processes applying to all projects or projects of a specified threshold,

¹⁹ Source: United-BIM

scope, or kind, Austria and the Netherlands are the only two MS with an Open BIM standard mandate. Ayinla & Adamu (2018) research expounded on the famous technology adoption models in relation to BIM adoption and diffusion in the AEC industry as a verified entrant for countries and countries that are either new to new technologies or at an infant stage, as in the case of Nigeria.

Within Construction processes, the application of BIM has grown to integrate diverse field and increasingly emerging requirements. The ability of BIM-based software and tools to enable continuous modification and improvements further proves the sustainability properties engrained in its development. This resulted in the development of the updated multi-dimension of BIM functions. BIM dimensions can be defined as the precise method through which various types of data are connected to an information model. Users can begin to have a better idea of your building project by adding more dimensions of data, like how it will be supplied, how much it will cost, how it should be maintained, etc (Indovance, 2021). Today, a single model can come with higher dimensions of time, cost, sustainability, facilities management, safety, lean and industrial construction.

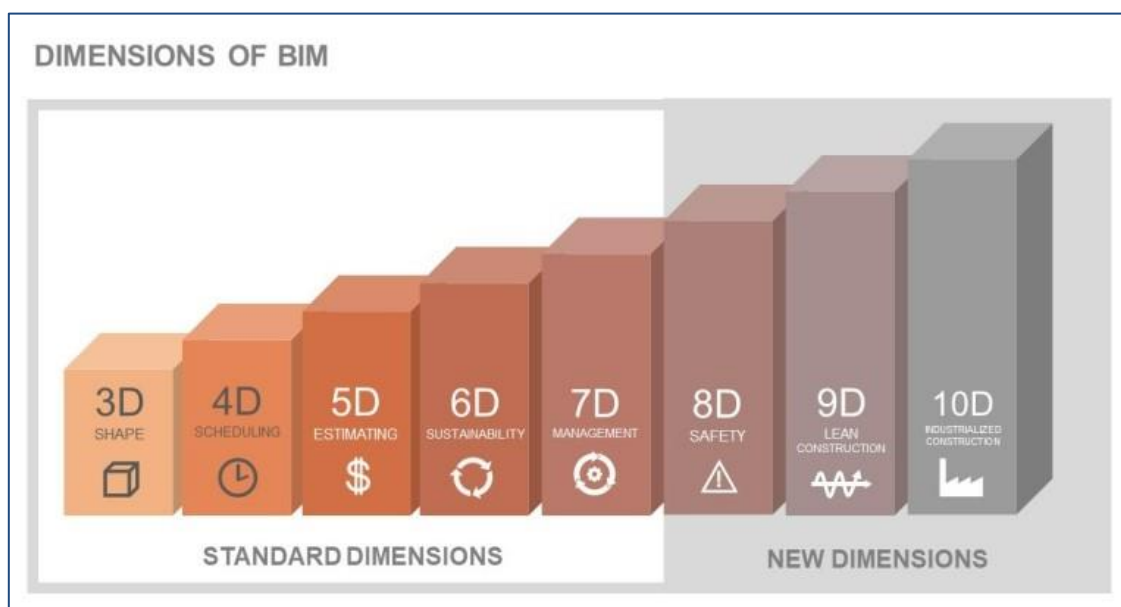


Fig. 15 Breakdown of BIM Dimensions (updated)²⁰

²⁰ Source: BibLus

The levels of BIM development over time is described by Poljanšek, M. (2017) as BIM Maturity. BIM maturity is defined as the ability to transition smoothly from a traditional modeling approach to an open BIM approach. The transition must be handled gradually, as though ascending a stairwell one step at a time. BIM maturity is frequently depicted as a "wedge." In comparison to the UK wedge, several levels (Level 0 and Level 3) have been subdivided, and a new level (Level 4) has been added. Indicators have been established to determine which wedge level is attained. These indicators track four different aspects: content, digitization, interoperability, and collaboration (Poljanšek, 2017).

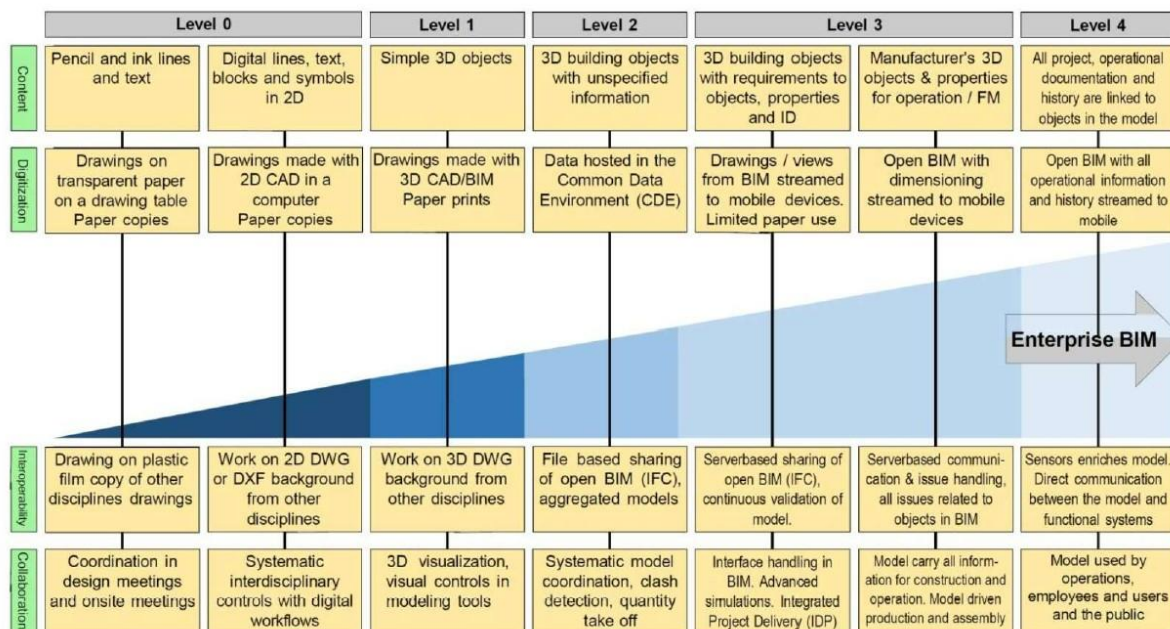


Fig. 16 BIM Maturity Levels²¹

As governments and organizations continue to explore the capabilities of BIM to its full extents, the outcome of their decisions continue to yield evident benefits. According to Poljanšek (2017) report, it is confirmed that by maintaining the integrity and transparency of information throughout the life cycle of built assets, BIM, in conjunction with more collaborative types of contracts, is assisting in resolving the issue of project team members and other stakeholders not having timely access to accurate, complete, and relevant information. Projects that use BIM are more

²¹ Source: (Poljanšek, 2017).

productive, reliable, and profitable.. According to Business Wire (2017), European BIM market was valued at approximately EUR 1.80 billion in 2016 and it is predicted to grow by 13% in 2023, generating the equivalent of EUR 2.1 billion. EUBIM Task Group in her 2018 handbook reported the possibility of ramping up savings in global infrastructure from 15% to 25% by 2025 should there be a wider adoption of BIM within the across markets. BIM's widespread adoption across Europe "would create an additional €130 billion for the €1.3 trillion market if it [delivers] 10% savings to the building sector." (EUBIM Task Group, 2016).

In 2016, 78 percent of Danish design firms became familiar with BIM and utilized it to create 3D visualisations, undertake BIM performance analysis, and to detect clashes. Over 30% have handed models on to individuals in charge of building facility management, demonstrating that BIM implementation extends to the operation and maintenance phases of construction (ECSO, 2019). In 2017, France's BIM adoption rate reached 38 percent, while BIM awareness among enterprises in the construction and real estate industries increased from 22 percent to 35 percent between 2016 and 2017. Furthermore, although just 12 percent of construction projects require a digital model³⁷, 26% of project owners have begun imposing BIM on projects. In fact, this resulted in the BIM-assisted construction of 500,000 homes in 2017 (ECSO, 2019).

2.9.2 Current Situation and Challenges of BIM Usage in Nigeria

BIM use has progressed significantly in most developed countries as earlier mentioned but this is not the same with the rest of the world. In Nigeria, and in fact Africa at large, BIM adoption is still a challenge. Hamma-adama & Kouider & Salman, (2018) opined that BIM acceptability and awareness in Nigerian architecture, engineering, and construction was incredibly poor. (AEC) and research into embracing this breakthrough has gotten relatively little attention. Although BIM Africa (2020) in their report revealed that there is an increasing advocacy efforts from various stakeholders, within the Africa market, leading to a widespread drive for implementation and deployment. To understand the situation further, previous study

and research did reveal that professionals (this include architects, engineers and designers) make use of BIM tools. Existing studies (Babatunde, Udejaja & Adekunle, 2020; Ibe, Uwakonye, Akpoiroro, Somtochukwu, & Oke, 2018) accent to the fact that BIM is actually in use in Nigeria. The deeper perspective into this facts was however captured by other researchers. According to Hamma-adama, Salman & Kouider (2017), the current adoption may be traced back to an organization's level, which is referred to as "a lonely BIM" and operate at Stage 1 BIM (check Fig. 17). This means that structural and service designs are still created using a traditional CAD (2D) system, with just a handful (mainly Architects) using a 3D CAD system for visualization or as a presentation drawing. Kori & Kiviniem (2015) noted that large and medium businesses are leading the way in terms of BIM adoption in the Nigerian AEC²² sector, but small businesses are less advanced in terms of policy and procedural adherence, resulting in lower acceptance.

The claim of growing awareness and high usage of BIM as recorded in previous researches can be described to be a latent phenomenon. Babatunde, S.O. et. al (2020) confirms that BIM awareness is relatively higher than its usage among AEC firms. Ugochukwu, Akabogu & Okolie (2015) also found that although just a small percentage of Nigerian construction professionals have adopted BIM into their processes, at least 67% of them are aware of it. Hence, the implementation of BIM is far below the extent to which it is understood and explored in other developed countries of the world. In Nigeria's case, high awareness doesn't translate into high number of usage and the current rate of usage doesn't translate to high expertise in the implementation of BIM and BIM tools to their full capabilities.

Quite a handful of existing literatures have discussed the topic of BIM challenges in Nigeria. These expositions share a lot of opinions and findings in common, revealing the extent of influence the reoccurring identified problems have on the development of BIM practices in Nigeria. To better understand the nature of these challenges, a previous report by NBS (2018) categorized the barriers to BIM adoption into internal and external, from organizational stand point. Ademci & Gundes (2018) grouped barriers to BIM adoption into five categories namely; personal, legal, management,

²² AEC means Architecture, Engineering and Construction

cost and technical for convenience in analysis. Though these classifications were done for the outcome of research carried out in developed countries, they are however applicable and valid for use in the Nigerian construction context. Common barriers and challenges attached to the adoption of BIM in Nigeria listed by previous researchers (Hamma-adama, & Kouider, 2019; Gyang, 2020; Ibem et al., 2018; Hamma-adama, Kouider & Salman, 2018; Babatunde, Udejaja, & Adekunle, 2020; Olugboyege & Aina, 2016) are as follows;

S/No	Challenges	Category
1	Lack of expertise within the organization	Internal
2	Lack of expertise within the project team	Internal
3	Lack of standardization and implementation framework	Internal and External
4	Lack of demand from client	External
5	Lack of Government's interest in BIM adoption	External
6	Pressumed high cost of investment on new technology and tools	Internal
7	Industry's resistance nature to change or adopt new technology	External
8	Lack of infrastructure	Internal
9	Lack of government's policy	External

Tab. 5 Common challenges (barriers) of BIM in Nigeria²³

Organization's perception towards BIM adoption, based on their size, is also a prominent reason for the unpopular condition of BIM process within the Nigerian building construction industry. Majority of construction companies in Nigeria are regarded as small to middle sized company, operating a contracting form of business. Kori & Kiviniemi (2015) stated that while medium and large scale architectural firms in Nigeria significantly use BIM software technologies to enhance their practices, small firms only use them for visualization due to a lack of understanding on the use

²³ Source: Own tabulation

of BIM software technologies for collaboration and integration. Small architectural firms in Nigeria view BIM software technologies as a mere technological transformation without any accompanying benefits, they opined.

2.9.3 3D Construction Printing Technology

Charles Hull is widely known as the pioneer of 3D printing. He created the first 3D printer in 1984 while working for his company, 3D Systems Corp (Bhandari & Regina, 2014). The stereolithography (STL) technology for creating solid images and the STL file format, which is still the most widely used format for 3D printing today, were both invented by Charles Hull. Along with the development of 3D printing, he also started commercial fast prototyping (Raji, 2017). However, the idea for 3D concrete printed buildings was originally developed to directly tackle very worrisome construction industry related issues; waste generation, green house gases emission, sustainable practices, increasing urbanization and shortage of adequate shelter globally. This also align with the opinion of Nadarajah (2018), who noted that the construction industry's need for a quick and affordable means of prototype manufacturing is what gave rise to 3D printing technology. The idea of 3D printing concrete with a contour crafting system has advanced significantly since Khoshnevis's creation in 2006. The digital model of the building or object, such as a CAD file, serves as the starting point for the process of layering materials until the material is ready. According to WEF report (2016), 30% of global greenhouse gas emissions are produced by buildings and urban areas around the world are growing by 200,000 people every day, and everyone needs access to affordable housing. These trends come with challenges and opportunities and the global construction industry is responding gradually with new disruptive innovations such as 3D construction printing. Realizing that tremendous opportunities abound through the application of new technologies, materials and tools, 3D printing became a direct product of this matrix. 3D construction printing is one of many creative solutions that are already being used on a modest scale or in a few countries. However, a large-scale implementation or a better adaption of recent technology advancements are still required for the sector (WEF, 2016).

3D concrete printing (also known as additive manufacturing) is the process of applying layers of material (such as plastic, metal, or concrete) on top of one another under computer control and utilizing a Computer-Aided Design (CAD) or BIM file to direct the 3D printer's nozzle (ECSO, 2019). Different 3D concrete printed buildings have been constructed in places like Zurich, Switzerland; Dubai, Germany, United States, United kingdom, China and in some African countries like Malawi and Kenya. The working model starts with a 3D model, using a CAD software and later transferred to the 3D printer. Solid Edge and Solid Works are two of the popular 3D printing design tool (Huthman, 2017). As a starting phase, a scan of an existing artifact is also an option. The model is "sliced" into layers during the printing phase, which converts the design into a file readable by the 3D printer, following the designing phase (Oko Institute for Applied Ecology, 2013). Each layer of the object is formed by the 3D printer by carefully arranging the material. According to the design and technique, the 3D printer typically layers the material being processed (Raji, 2017)

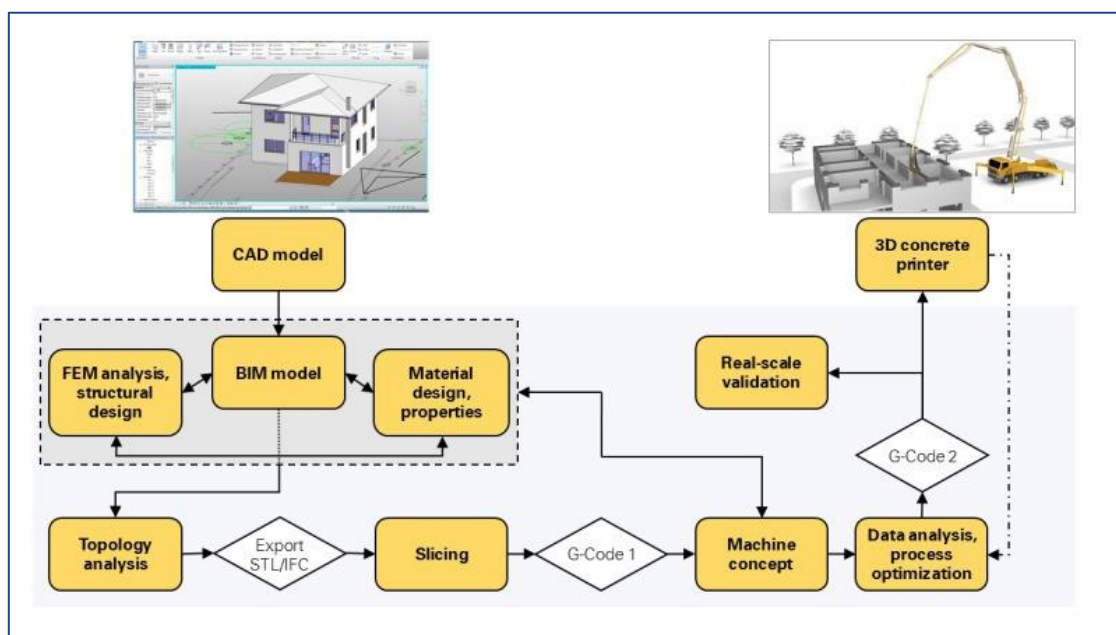


Fig. 17 3Dconcrete printing system²⁴

²⁴ Source: Sesetti, Lalithya, & Kumar (2022). 3D Concrete Printing in Construction Industry—A State of the Art. 3D is achieved through the three components of a Computer and CAD software, 3D printer and printing materials.

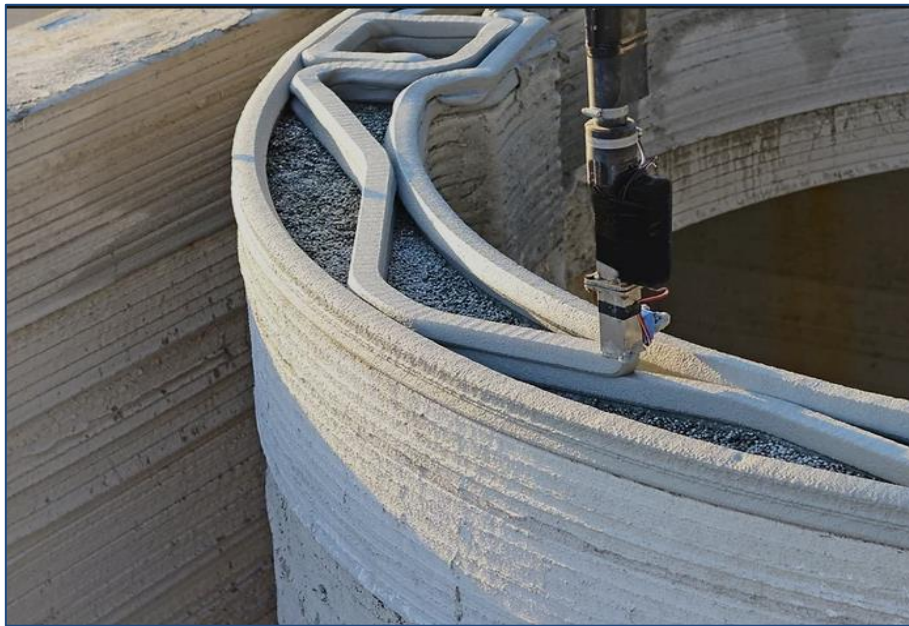


Fig. 18 A 3D Concrete printer at work²⁵

Due to the introduction of 3D printing, the construction industry is expected to undergo a considerable transformation. The technique makes it possible to create custom shapes that are impossible to create using any other method. It also promises significant waste reduction and productivity increases of up to 80% for specific applications. Some buildings' construction times may be cut from weeks to hours, and specially made parts could be purchased for a lot less money (WEF, 2016). For example, leveraging on the technology, WinSun (China) has been able to build 10 houses daily using 3D-printed building components winning them a deal with the Egyptian government for 20,000 single-storey houses (WEF, 2016).

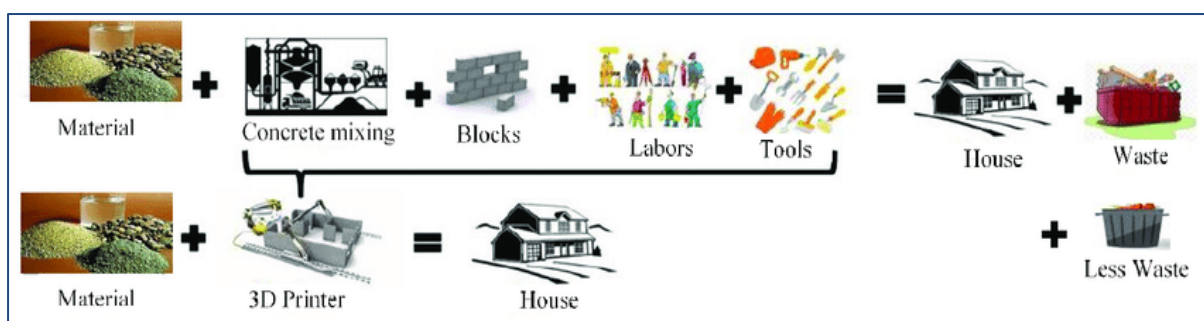


Fig. 19 Comparative illustration of conventional building methods to 3D concrete printing²⁶

²⁵ Source: apis-cor.com

Not only can 3D printing replace conventional production techniques, but it may also produce unusual patterns and shapes that are more difficult to create using conventional techniques (ECSO, 2019). 38% of all construction in the world is for residential dwellings. In order to contribute to a healthier interior environment, increased sustainability, and lower cost, value must be improved in the construction and material quality. Any effort made in this direction will provide positive results, whether it be for people purchasing their first private property or for governments starting a massive infrastructure project (WEF, 2016). Many companies are optimistic in this area and cite other industries like aviation where mass production of 3D-printed components is already prevalent. Concrete can be printed for homes and villas using additive manufacturing, which has greater prospects than building huge constructions (Wu, P., Wang, J. and Wang, X., 2016).

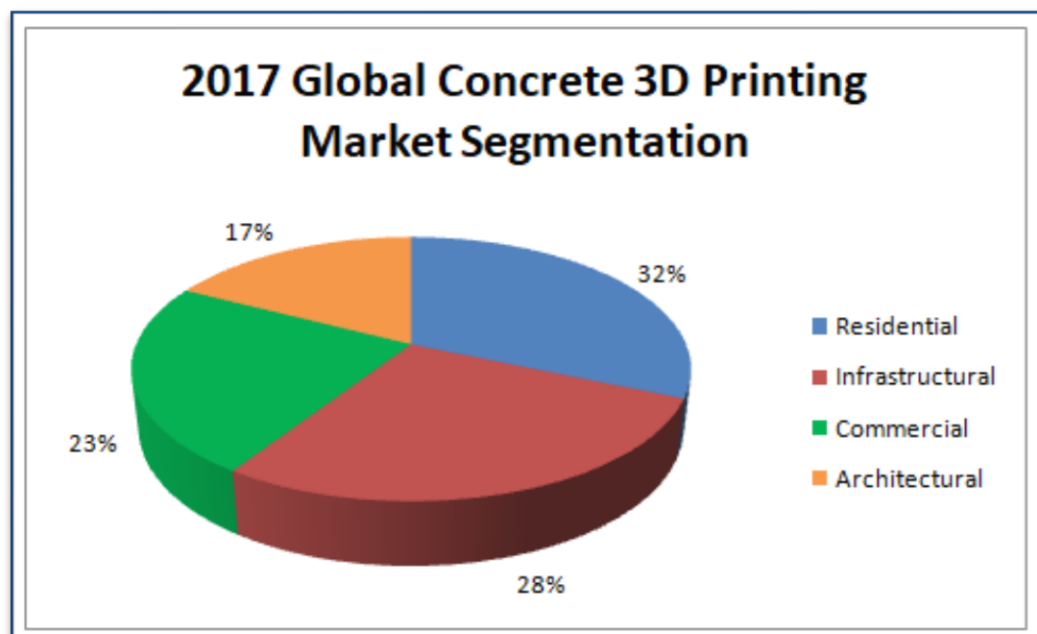


Fig. 20 Shows the distribution of 3DCP by Construction division.²⁷

²⁶ Source: https://www.researchgate.net/figure/Conventional-construction-vs-3D-printing-construction-process-derived-from-41_fig1_344664926

²⁷ Source: <https://www.fabbaloo.com/2019/06/a-concrete-example-how-3d-printing-can-create-housing-and-infrastructure>

Within a short period, there has been a significant progress in automated technologies and robotics in the Construction industry (Md. Aslam et al., 2020). 3D printing has evolved in method, machinery and material and continues to evolve through R&D. The market continues to grow and record higher value year on year as it attracts more players along its value chain. There are companies that manufacture the robotic machine, some build and print the machine while some do both. The three common techniques for 3D concrete printing as described by Lim et al. (2011) are; contour crafting, concrete printing and D-shape. Contour crafting is done by ejecting a cementitious paste against a trowel that allows a fine surface finish created through the build-up of subsequent layers. Concrete printing technique is based on the extrusion of cement mortar, but the extrusion technique is more focused on maintaining three-dimensional freedom with fine material deposition, allowing for more control of internal and external geometries. With D-shape method, layers of powder are placed and then selectively hardened with a binder. Once printing is complete, the printed object needs to be dug out of the loose powder bed.

Based on machinery type, the two commonest types are gantry system printers and robotic arm printer systems. In general, the advantages of robot printers over gantry printers include being more mobile and moveable and being able to print specific prints thanks to the 6 axis mobility that gantry printers would find challenging. On the other hand, gantry printers often offer advantages in terms of cost and stability, allow for larger prints, and can even print entire structures in a single pass. Gantry printers are significantly easier to handle and don't need highly competent programmers for non-continuous printing, which is necessary when printing huge buildings (3D Printhuset, 2018). A careful study of this report reveals that the gantry printing system is most suitable for use in the Nigeria case for mass housing projects based on affordability and ease of usage. Most of the 3D printed houses we have today are built with the gantry system printers.



Fig. 21 Types of 3D concrete printing system

Left: Gantry system printer²⁸. Right: Robotic arm system printer²⁹

The number of companies building houses with 3D concrete printers is on the rise and gradually becoming the a new sensation within the industry globally. The global stock of 3D printed houses continue to rise as it is being pushed as a more sustainable way of meeting rising global demand for housing. Famous Italian architect Mario Cucinella constructed a two-room house entirely out of clay, a reusable and recyclable material mined from the surrounding terrain. (Amadu, 2020). One of the earliest application of 3D printing in scale was a neighbourhood project undertaken by ICON and NewStory in a joint venture at the rural area of Tabasco, Mexico. (Amadu, 2020). According to Amadu(2020), the neighborhood made it possible for 50 families with an average daily income of 3\$ to live comfortably in tidy homes with two bedrooms, a living room, and a bathroom. The houses were constructed using a large-scale construction 3D printer, which can produce the walls of a house like this in just 24 hours, cutting the time needed to construct a full-edged home in half. The printer used, called Vulcan 1, was designed by ICON, an Austin-based construction company, and it is modeled as a gantry system

²⁸ <https://3dprintingindustry.com/news/cobod-demonstrates-construction-technology-with-live-3d-printing-of-4-small-houses-168613/>

²⁹ <https://static.politico.com/dims4/default/c1285cb/2147483647/resize/1160x%3E/quality/90/?url=https%3A%2F%2Fstatic.politico.com%2Ffc0%2Fbe%2F64a73b6c49a2a1e56b140cd8256d%2Fchen-3dhome.led.jpg>



Fig. 22 Vulcan 1 Printer by ICON is a gantry system printer used for building small size family homes in Mexico³⁰



Fig. 23 World first 3D printed community by ICON and NewStory³¹

Winsun, a China-based company, is another leading construction company that continues to push the 3D printing technology beyond boundary. With an in-house

³⁰ <https://www.3dprintingmedia.network/icon-35-million-construction-3d-printing/>

³¹ https://static01.nyt.com/images/2021/09/28/business/28printed-village-01/merlin_194752176_e51ed689-4100-418e-820e-e6e11e5f60f4-videoSixteenByNine3000.jpg

manufactured printer, the company specializes in building entirely 3D-printed residential homes both inside and outside of China. A single house can be purchased for as little as USD 4,000, depending on its size, layout, and interior furnishings. The priciest models come with solar panels and have furnishings, air conditioning, a bathroom, and a shower. A flat can currently be rented for about \$150 or \$200 per month. They are most known for the printing of 10 within a day. They built the houses out of recycled materials, resulting in a total cost of less than 5,000\$ per unit (Blain, 2014). This has encouraged other governments around the world to consider and adopt 3D concrete printing in solving their housing deficit challenges. Other successful 3D printed building projects around the world include;

(i) Germany's first two storey residential building in Beckum: The first 3D-printed residential building in Germany was constructed in Beckum, North Rhine-Westphalia, by PERI GmbH. The standalone two-story home has about 80 square meters of living area per level. The 3D house is receiving a subsidy of 200,000 euros from the state government of North Rhine-Westphalia, which is specifically supporting investments in the building industry's innovation engine. The 3D printers utilized by PERI was BOD2 models, manufactured by the Danish company COBOD. The Beckum BOD2 printer is a gantry printer, meaning that the print head travels along three axes on a firmly fixed iron frame (PERI GmbH, 2020).



Fig. 24 *Left:* Printer installation on site. *Right:* Ariel view of the completed printed building³²

³² PERI GmbH

(ii) **Dubai Municipality Building:** For the Dubai Municipality, Apis Cor 3D printed the wall structures of a two-story administrative building. It is currently the largest 3D-printed building in the world, standing 9.5 meters tall and covering 640 square meters. Without any additional assembly labor, the building's structure was constructed right there on the site. The building's overall area is 640 square meters, which is more than the space available for printing while the printer is stationary. Hence, with a crane, the printer was repositioned at various position through out the entire construction period (Apis Cor, 2019). The structure was printed on regular foundations while the casing for column were printed around rebars. The printer used is a robotic arm model.



Fig. 25 *Left:* Apis Cor Robotic arm printing system at work. *Right:* The completed printed building

2.9.4 Overview of 3D Printing Market Outlook Globally and In Nigeria.

Analysis from early researchers revealed that residential building leads every other type of construction in the utilization of 3D construction printing. This is corroborated by a projection from MarketsandMarkets (2018) which disclosed that the Building Sector is the industry with the quickest rate of growth for 3D concrete printing.. In this industry, the demand for intricate construction structures and affordable housing is anticipated to be the main drivers of 3D concrete printing demand. By maintaining structural integrity while producing lightweight components like walls and panels, this

method lowers handling and transportation costs. This exposes the immense opportunity in this technology for both current and new companies and players within the AEC space. It provides a direction to where investments would yield the most returns based on global market demand. According to an analysis undertaken by MarketsandMarkets in 2017, the market for 3D concrete printing will increase by USD 1,480.5 million by 2023, at a CAGR of 317.3 percent, from USD 1.2 million in 2018 (MarketsandMarkets, 2018).

According to DataM Intelligence (2022) report available online, Asia Pacific has the largest 3D concrete printing market globally, where the construction industry is expanding at a respectable rate and is anticipated to contribute to the market's expansion through population growth, increased per capita income, and expansion. The report further explains that the main driver of the Asia Pacific 3D Concrete Printing Market is increasing infrastructure construction activities. In Europe, where the demand for the global market in the Europe area is being boosted by the rise in unique residential construction structures and the rise in demand for sophisticated building activities at affordable rates, Germany takes the lead in the application and development of 3D construction printing (DataM Intelligence, 2022).

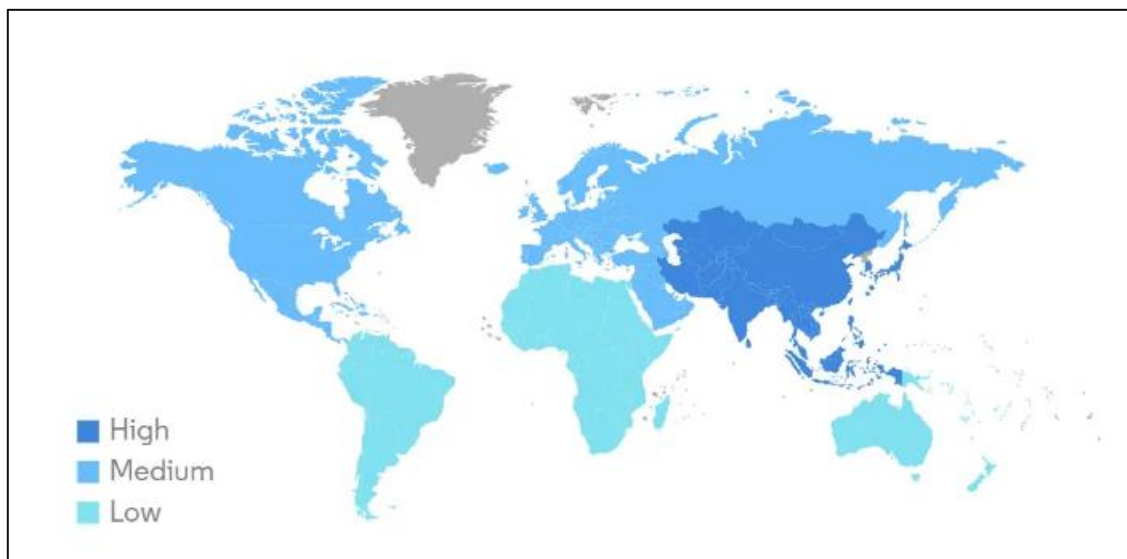


Fig. 26 Showing the 3D Concrete Printing Market Growth by region (2021-2027)³³

³³ Source: Mordor Intelligence

A careful study of previous research on 3D concrete printing by region leaves the entire African continent out due to obvious reasons; unavailability of significant data. For fairness however, Africa is considered alongside the Middle East as a singular region. Albeit, 3D printing has had its footprint in just Malawi, Kenya, Angola and South Africa- with the ambitious plan to scale commercially and transform the African construction industry eventually. So far, the only presence of 3D printing technology in Nigeria is within the manufacturing industry. By the foregoing, 3D concrete printing provides a sustainable and viable opportunity for Nigeria to solve her housing challenge and also overcome some of the categorical factors (technical, administrative, financial) responsible for the problem. The common modular housing model usually constructed by both the governments and private investors, as earlier discussed in this chapter, creates a more usability case for 3D construction printing within Nigeria, especially the real estate developers and government- the major clients by market share.

2.9.5 Benefits of 3D Construction Technology

By using more time- and material-efficient machinery, 3D printing plays a major role in the construction phase, helping to reduce overall construction costs. Existing materials (Panda, Tay, Paul & Tan (2018); Olsson, Shafqat, Arica & Økland, 2019; Md. Aslam, Altynay, Suvash & Jong, 2020 ;WEF, 2016) on the benefits of 3D concrete printing technology all align along the same list of benefits, namely; reduction in site injury, reduction in material usage and waste generation, faster construction time, construction precision, construction of flexible and complex design, better durability and overall construction cost savings. As can be seen, conventional building requires human resources at various phases, which takes time and money. The finished product also contains a sizable amount of construction trash. On the other hand, 3D printing is largely automated and produces structures from a computer-aided (CAD) design without the use of tools formworks or fixtures.

Consequently, this technique lessens the amount of labor needed, manual processes, and material waste (WEF, 2016).

For a Construction industry like Nigeria's- largely occupied by indigenous mid-sized companies, these benefits will enable faster project completion and value retainship should they consider to diversify and embrace 3D concrete printing technology. Mass housing projects commonly undertaken by the government and real estates companies can be easily constructed and delivered for a fraction of time and cost expendable on previous similar projects.

2.9.6 Challenges to 3D Printing Construction Globally and in Nigeria

Globally, the use of 3D printing in the construction sector is still in its infancy (ECSO, 2019). Large-scale printing is still hampered by the trade-off between speed and scale, which keeps printing at a slow pace since standard 3D printers are constrained by their size, resolution issues (large-scale printing typically produces chunky, sloppy output), and expensive costs. Currently, low-volume, high-value products are the main applications for 3D printing. It remains to be seen if businesses will be able to reduce costs and obtain economies of scale, as well as how quickly they will be able to solve the major technological challenges (WEF, 2016). Currently, 3D printing is only used for very small-scale applications; printing larger parts and using several materials are still difficult to do (European Construction Sector Observatory, 2019). According to a research report by DataM Intelligence (2022), the market for 3D printed concrete is significantly hampered by the enormous cost required for the printer, maintenance, and OS. Another drawback that prevents market expansion is the restrictions on printing size and height. High-rise sculptures can be 3D printed in concrete, but moving the printer from one location to another involves a significant setup. The main variables influencing the growth of the 3D concrete printing market are access to a knowledgeable personnel, 3d printing materials, and capital investment in the technology.

Zhang et al. (2019) also listed several significant drawbacks to the use of 3D concrete printing, including the 3D printer's limited capacity for high-rise buildings,

the lack of printing materials (particularly for load-bearing components), the lack of customization, the complexity of the information processing from design to tangible object, etc. However, this technology has proven to be a tangible development in Construction engineering and has so continued to attract more interest via investment in research for development of new products (printing materials) , machinery and methods. Digital technologies won't ultimately reach their full potential unless they are broadly embraced as the standard in the industry. It is essential to foster an atmosphere that is conducive to the digitalization of the E&C sector. That is the responsibility of the government in any given nation, which serves as a project owner, regulator, and incubator.

In a developing country like Nigeria, there is a myriad of hindrances to the adoption and development of 3D concrete printing; lack of infrastructures such as stable power supply, inefficient data storage system, poor research and development culture, unstable economy, lack of required skilled workforce, lack of adequate government policy in support of modern technology, high cost of acquiring a printer, availability of printable materials and beaurucratic issues around awarding of projects. Nevertheless, Nigeria can begin to explore a similar adoption model the EU has set in place for the development of modern technologies such as BIM and 3D concrete printing among its member states.

2.10 Chapter Summary

The Nigerian building construction industry has not evolved so much- a situation largely noticed on a global scale due to the resistant nature of the industry to changes. In efforts to solve her own share of the global housing deficit, the Nigerian government through its ministries and agencies had made various attempts to proffer effective solutions- all of which fail to improve the housing condition in the country. In recent times, digitalization is now believed to hold potentials that can help solve existential challenges within the construction industry. The global construction industry has finally embraced digitalization and, as such, began to experience disruptive transformation across various economies, though slowly and unevenly. Modern technologies such as BIM and 3D concrete printing, among many other

innovations, are greatly helping to improve productivity and fill the long-existing gap. However, more investments are yet still required to make the Construction industry catch up with other sectors such as automobile, manufacturing, retail and logistics, both globally and regionally.

In the chapter, Building Information Modeling (BIM) is defined from various perspectives for wider understanding . The BIM idea has existed since the 1970s but didn't receive wider attention and development until the early 2000s. It is unarguably the most discussed modern component of the Construction industry. So far, the benefits of implementing BIM speak for themselves- helping public and private, small and large-sized users to produce projects faster, safer and more efficiently. However, BIM acceptance and implementation remain incredibly low from the standpoint of the Nigerian building sector. Even though, the understanding of BIM is misunderstood as a mere tool because there is more awareness than application. As a result, it has not been utilized to its full potential.

If not for extremely particular and limited jobs or in projects specifically designed for their use, robotics and 3D printing are still in the development stage and have not yet been widely adopted by businesses in the industry. However, it is believed that the construction industry's need for a quick and affordable means of prototype manufacturing gave rise to 3D printing technology. 3D concrete printing (also known as additive manufacturing) is the process of repetitively adding layers of specially mixed mortar on top of one another under computer control and utilizing a Computer-Aided Design (CAD) or BIM file to direct the 3D printer's nozzle. Though much criticized and undergoing wider research for development, the technology boasts of benefits such as faster construction time, construction precision, flexible and complex design construction, better durability and overall construction cost savings. More importantly, its model is viable for the Nigerian government and real estate investors to provide more housing units for her growing population within a short time and with less cost- making it more affordable for low and middle-income earners in the country.

INTRODUCTION TO CHAPTER THREE

This chapter acquaints you with the methodology employed for carrying out the research. Research methodology is the process engaged to obtain relevant data that will help to provide verifiable and reliable answers to the research questions. Here, the question of 'how' is provided. While there are different kinds of tools available for this, they are all categorized under the quantitative analysis approach and qualitative analysis approach. For this research, two tools were used; a survey questionnaire and case study. These two generally provide qualitative understanding into our research work.

At the end of this chapter, you will learn;

- the different types of data analysis process commonly used
- the data capturing tools used for this research
- further explanation on the structure and nature of the tools

RESEARCH METHODOLOGY

Analytical methods commonly adopted for academic purposes were utilized to establish validity for this research. This research uses a qualitative approach- a case study and questionnaire. This was because the less mathematical analysis was needed, as commonly attributed to quantitative approaches. As defined by (Jansen & Warren, 2020), Quantitative data analysis is analysing data based on numbers that can be quickly "translated" into numbers without losing significance. On the other hand, Bryman (2001) defines qualitative content analysis as a method that uses textual data to produce emerging themes. As a result, the ideas are inspired and formed by how respondents' comments are interpreted (Wood, 2001). Interview, via a customized questionnaire, formed the medium through which professional perspectives were collated and observed. Relevant details were also extracted from journals and research reports related to this topic, which all form the primary source of information. This approach was influenced by understanding the nature of the research problem.

3.1 Survey by Questionnaire

A questionnaire is any text-based tool that provides survey participants with a series of questions to answer or statements to reply to by marking a page, writing a number, or checking a box, for example, on paper or online (Brown, 2001). In the social sciences, questionnaires are still the most popular survey tool and are frequently employed as a research instrument (Breakwell, Hammond, Fife-Schaw, & Smith, 2006). The primary data collection method was a structured questionnaire survey. The focus of the questionnaire's design was mainly on the use of BIM and knowledge of 3D printing in buildings. Because it was designed with a specific objective, the system only accepts responses from users who provided meaningful and relevant information. The nature of the study topics and the necessity to reach as many professional respondents as quickly as possible prompted the use of a questionnaire survey to gather primary data.

The target population for the survey include only individuals within the Architecture, Engineering, Construction, Real Estate, Manufacturing and Academic sector. The structure of the questionnaire is as follows:

- i. Contains 20 non-sectioned questions
- ii. The first part collects personal and professional details of respondents, such; as name, age, years of experience, practising sector, etc.
- iii. The middle part focuses on respondents' knowledge of 3D, both individually and organizationally
- iv. The latter part focuses on respondents' knowledge and usage of BIM

A sample of this questionnaire is available as appendix B. The survey was designed on March 7 and retrieved on July 1 with 55 respondents in total.

3.2 Case Study

Using a case study approach, we can measure the success of our focused solution as well as data obtained from the questionnaire through the lens of an already existing sample. By nature, case studies allow for more intensive, in-depth study. Even though case study is perceived as lacking in rigour and objectivity compared with other social research methods, they may offer insights that might not be achieved with other approaches (Rowley, 2002). In order to obtain corroboration among various sources of evidence, a descriptive framework was developed, as recommended by Rowley (2002), to extract evidences that were gathered within pertinent themes, analysed, and contrasted in specific categories. (Zainal, 2019) opined that in their simplest form, case studies analyze and investigate modern-day phenomena by thoroughly contextualizing a small number of circumstances or occurrences and their connections. In her conclusion, Zainal (2019) noted that while case study research methodologies are criticized for their inability to generalize their findings, one of its benefits is that they present data from real-life circumstances and give deeper insights into the specific behaviours of the individuals of interest. For this research, a multiple-case design is adopted depending on the issue in question.

The application of multiple-case design helps to raise the level of confidence in the method's robustness (Zainal, 2019).

Two case studies were adopted for this research. The first is a family size house printed by 14trees in October 2021 at Athi River, Machakos County on the outskirts of Nairobi. 14Trees is a joint venture company between Lafarge-Holcim, a global leader in sustainable construction solutions, and CDC Group, the UK Government's impact investor (14trees, 2022). The 56m² 3D printed house was printed and completed to serve first as a showcase of the achievement of the technology and its possibilities of exceeding every requirement expected of a traditionally built house and secondly, as a prototype for a much larger proposed construction of 52 units of a low cost housing estate (14trees, 2022). At completion, the modest two-bedroom family-sized house is estimated to cost 2.3million Kenyan shillings, an equivalent of around 18,415euros.



Fig. 27 Tree House No 0. The first 3D printed house in Kenya. Built by 14trees³⁴

To obtain a more robust understanding into this project, a questionnaire form was sent to the manager in charge of the project and answers were received for further examination. This is attached in Appendix C.

³⁴ Source: <https://www.constructionkenya.com/8874/lafargeholcim-3d-printing-houses/>

Why this case study? Housing deficit, among other challenges, is expected in Nigeria and Kenya. The report from various sources (14trees, 2022; Habitat for Humanity, 2022; World Bank, 2017) but Kenya's housing deficit at over 2 million. Data shows that less than 50,000 housing units are currently produced annually, much below the desired level. This results in a housing shortage of more than 2 million units, with approximately 61 per cent of urban households residing in slums. This shortfall is still growing because of inherent limitations on both the demand and supply side, which are made worse by the 4.4 per cent urbanization rate, and 500,000 additional people in the city annually (World Bank, 2017). This is very much like the Nigerian situation except for higher figures. The Kenyan government is currently maximizing the potential of 3D concrete printing by providing faster, more affordable, more sustainable housing solutions. This case study provides a practical and viable case for the key players within the Nigerian Construction industry to consider this growing technology in solving its housing challenges.

The second case study is a 50 3D printed homes community in a village on the outskirts of Nacajuca, in the Tabasco state of Mexico..



Fig. 28 Vulcan II Printer on site³⁵

³⁵ <https://www.nytimes.com/2021/09/28/business/3D-printing-homes.html>



Fig. 29 One of the houses printed in Mexico³⁶

Newstory, a non-profit organization, teamed up with ICON, a construction company, to provide shelter for the homeless. In the summer of 2019, construction began on site and have since been handed to the local residents - most of which are low income earners, after completion. The complete printing process took about 24 hours from beginning to end per building. The 26.25 square meter apartment has two bedrooms, a living area, a kitchen, and a bathroom. Every house has been seismically authorized to withstand an earthquake and can endure hurricanes (Young & McMahon, 2020). The families received the houses with zero-profit mortgages, no interest, and they will pay 400 pesos (\$20) per month for seven years while New Story and private donors cover the remaining expenses (Ramirez, 2019). The printer used on site was a gantry printer system, named Vulcan II, and provided by the technical partner, ICON.

The objective of this research is the significant influence on the structure and type of questions asked. The outcomes collated are then checked and analysed to basic

³⁶ <https://www.wbur.org/hereandnow/2020/02/06/worlds-first-3d-printed-neighborhood-mexico>

descriptive interpretation. This is because, as explained by Jansen, D. and Warren, K., (2020), the study interest is mainly in understanding the attributes of the sample (respondents).

3.3 Summary

Through this chapter, it is learnt that a qualitative analysis approach was used to gather and interpret results. The survey questionnaire was targeted at professionals within the Nigerian construction industry for obvious reasons. The case study comprises of two separate 3D printed buildings at Kenya and China. Eventually, the take away from this chapter are:

- quantitative analysis approach are more mathematical than qualitative analysis approach and hence often involve special formulas and tools
- the survey questionnaire and case studies were used for data collection
- the structure of the survey questionnaire was designed to focus of respondents knowledge of BIM and 3D concrete printing
- the questions in the survey were entirely influenced by the objective of this research

INTRODUCTION TO CHAPTER FOUR

Chapter Four is the part of this research report with results and discussion. The actual work done is elaborately discussed here. The question of 'what then happened' is answered here. This chapter opens up readers to have insight and clear understanding into the actual research exercises, the outcomes of the exercises and how they were able to prove the points for the relevance of this research work. In this chapter, readers will be able to:

- relate with the structure and content of the questionnaire
- understand the feedbacks, reports and data obtained
- relate with the case studies
- see how the questionnaire and case studies aligns
- see the limitations of the methodology through the answers generated

RESULT AND DISCUSSION

The findings of this study are explained in three orderly sections; analysing and discussing the result from the questionnaire, extracting descriptive details from the case study and combining both outcomes to check for alignments and discrepancies, which will then form a base for the final chapter (conclusion and recommendation).

4.1 Questionnaire

A questionnaire survey, designed using google form, was the method employed to collect data. The questionnaire covered interests on the respondents experience and knowledge of BIM and 3D concrete printing. At the end of the feedback period, 55 responses was received. The survey contains both closed ended and open ended questions. The nature of the closed ended questions is such that the responses from the preset optionsa can be easily obtained and described without implementing special analytical tools. The open ended nature seek to obtain direct detailed and valuable information from the responders. This approach enable this research to have raw insight into the responder's knowledge and attitude towards BIM and 3D concrte printing. Hence, all the data are qualitative data.

Through the survey structure, the respondents were categorized by age group, profession, years of experience and their knowledge of the new technologies. This gives us insights into the most relevant information about them which also have much influence on answering the research questions.

The age group provided was in 5 categories; 20-30, 31-40, 41-50, 51-60 and over 60. The most represented age group are those within 31-40 years, with 58.2% of the total respondents. This is followed by age group 20-30, with 30.9%. Respondents over 60 years represent only 1.8% of the total respondents. This align and further support an existing fact that the country has a very young demographic, with a median age of 18.4 according to World Population Review (2022). As a result, rate of awareness is higher among the younger population (age 20-40).

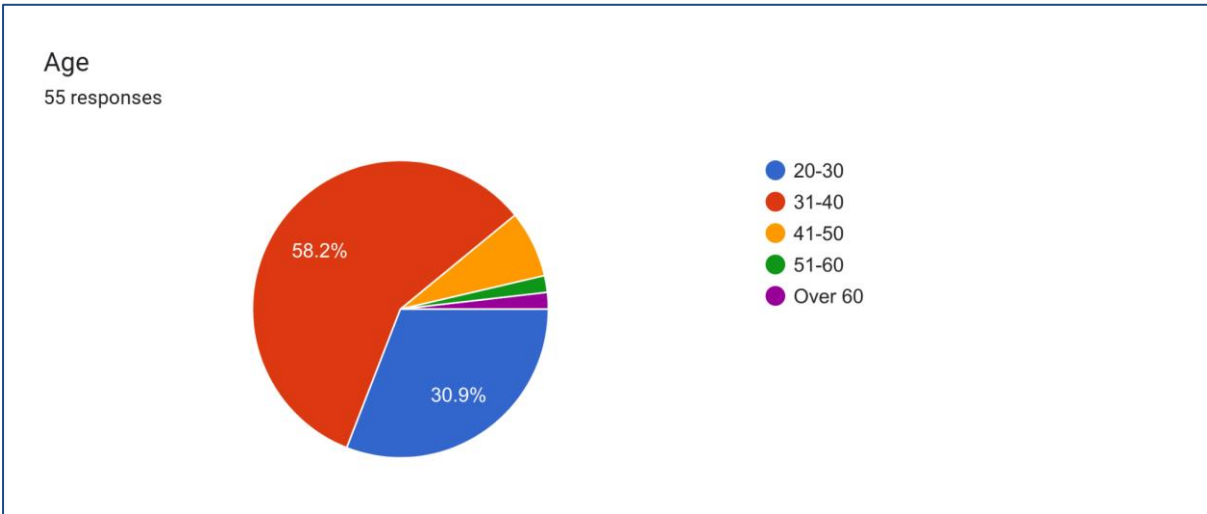


Fig. 30 Age distribution of respondents

This survey was targeted mainly at professionals within the construction sector in Nigeria. Consequently, few respondents, five(12.6%), from other professions participated. 52.7% were from the building construction sector, 9.1% from Highway construction sector, 9.1% from Consultancy, 9.1% from academics and 7.3% from real estates sector.

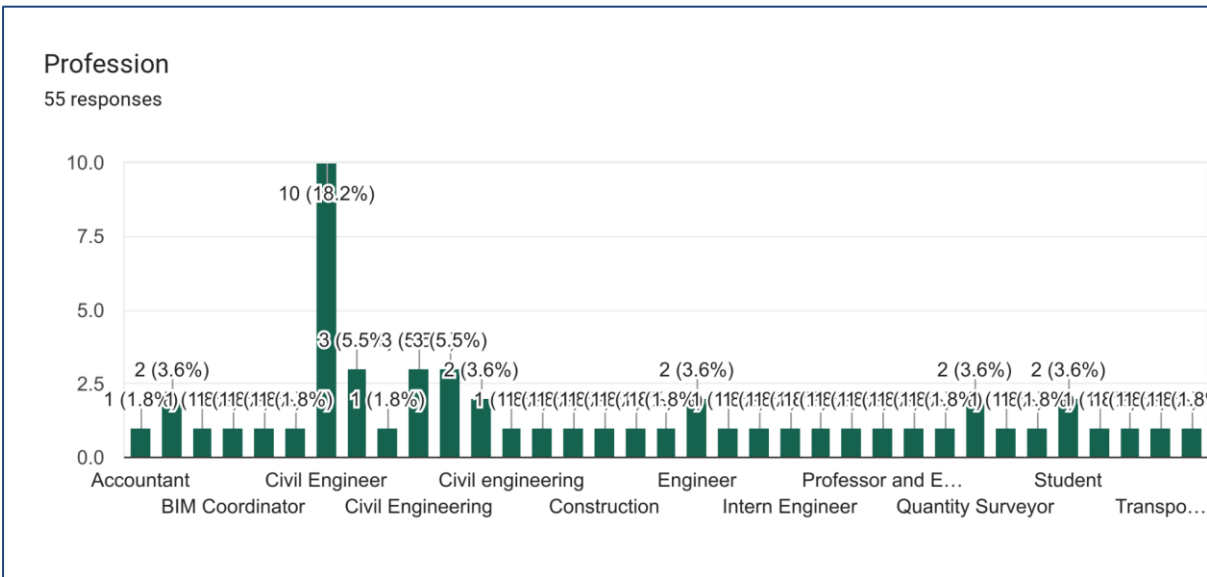


Fig. 31 Professional composition of respondents

43.6% of respondents have less than 6 years working experience in the construction industry, 36.4% have between 6-10 years, 10.9% has worked for 10-15 years, 5.5% have a working experience for between 16-20 years and finally, the number of respondents with over 20 years of working experience within the construction industry represent only 3.6%. This shows that the construction industry is characterized with early stage professionals. This is a direct reflection that there are a lot of young individuals working within the construction industry.

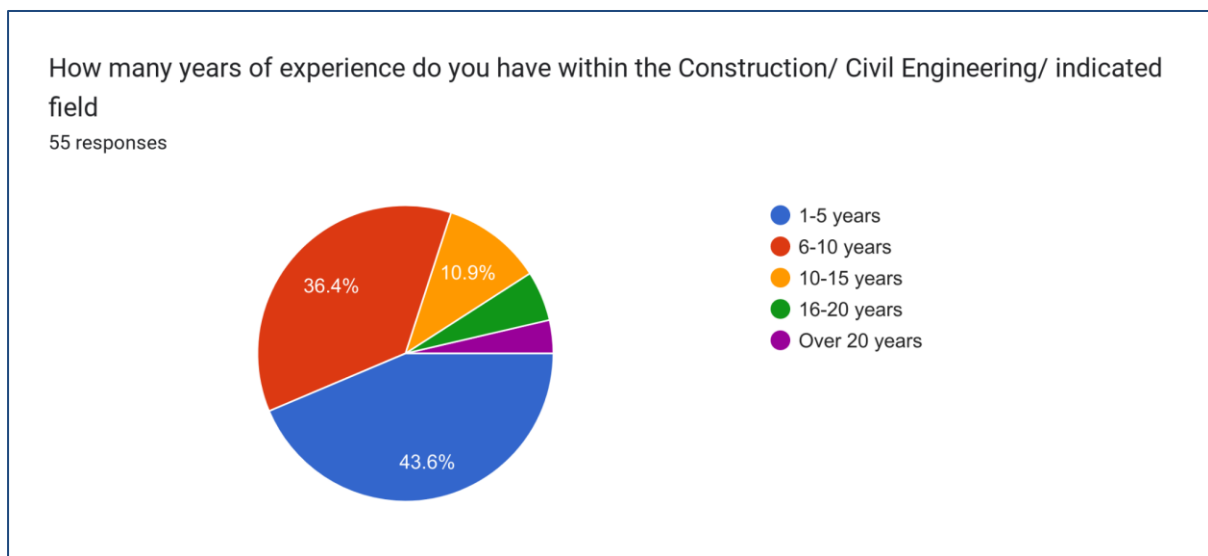


Fig. 32 Years of experience of respondents

81.8% of the respondents know about 3D printing as well as 3D concrete printing while 18.2% do not know about the technology. The awareness of this 81.8% on 3D concrete printing comes from different sources as follows; personal research (32.7%), from a colleague (20%), social media/ internet (18.2%), and from workplace (12.7%).

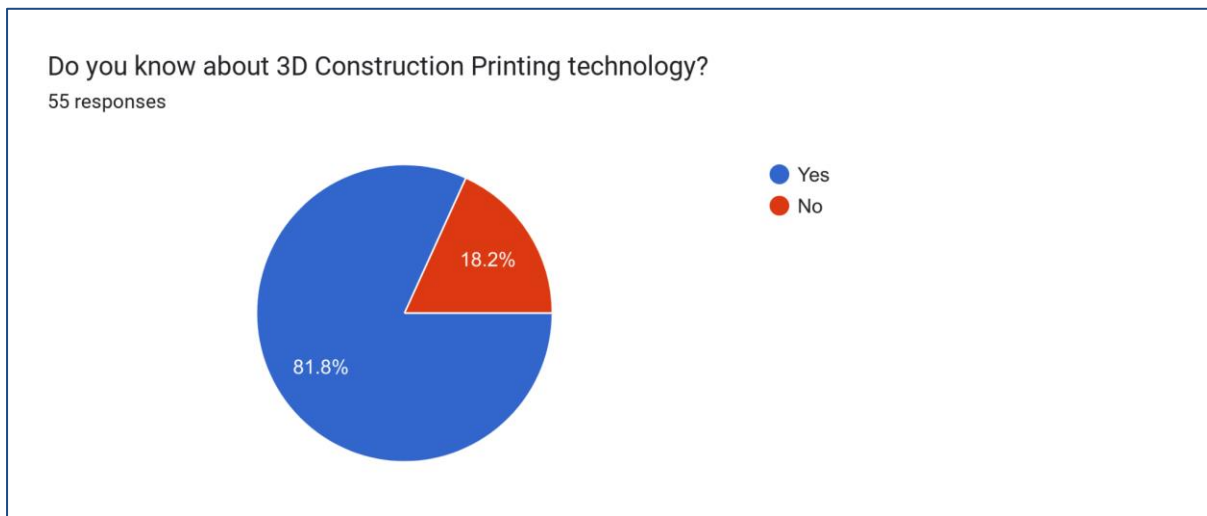


Fig. 33 Respondents knowledge on 3D Technology

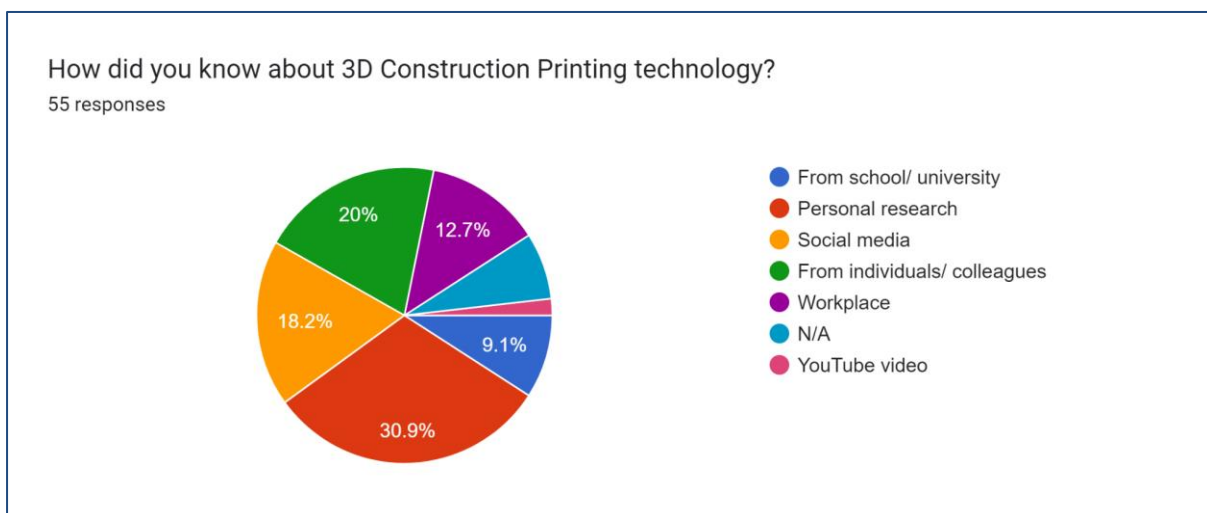


Fig. 34. Sources of 3D knowledge for respondents

Using the 5-point linear scale with 5 as the highest rank and 1 the lowest, the respondents were asked to rate their depth of knowledge on 3D concrete printing technology. 36.4% have an average knowledge of what the technology is and how it works. 25.5% rated their knowledge 2 out of 5, 23.6% have little knowledge about it. Only 5.5% have much knowledge of it. However, the extent of what each of these category know was not explored to have a full understanding of their claims. Going by this, there is clearly a limited or insufficient knowledge about the 3D concrete printing among industry professionals. This is an obvious factor that could hinder the

growth and implementation of the technology within the construction industry, particularly Building Construction.

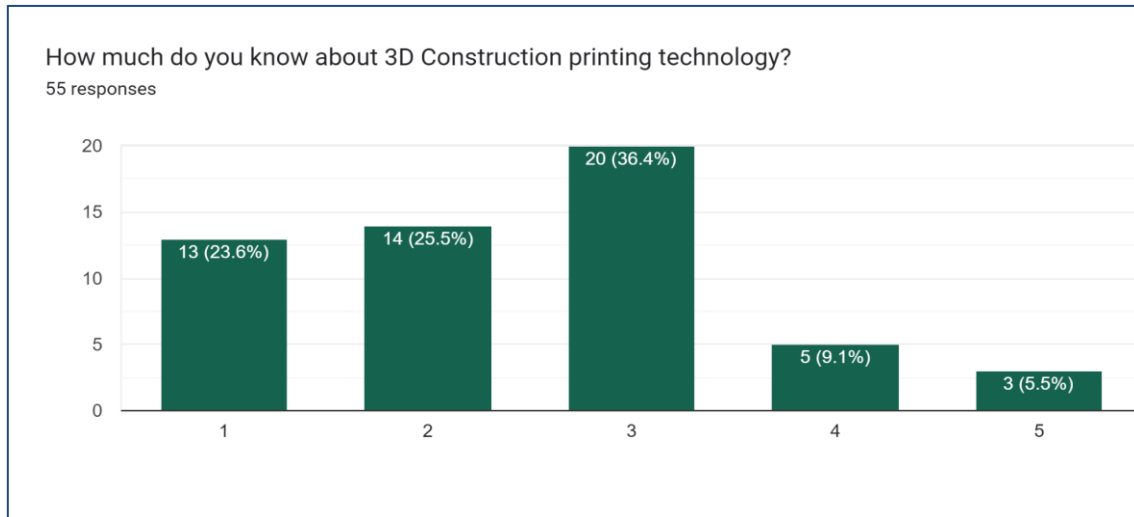


Fig. 35 Respondents rating of their 3DCP knowledge

When asked if the Nigeria construction industry have enough technological resources and readiness to adopt and implement 3D concrete printing at scale, 50.9% of respondents answered no, 25.5% said yes and 23.6% were unsure.

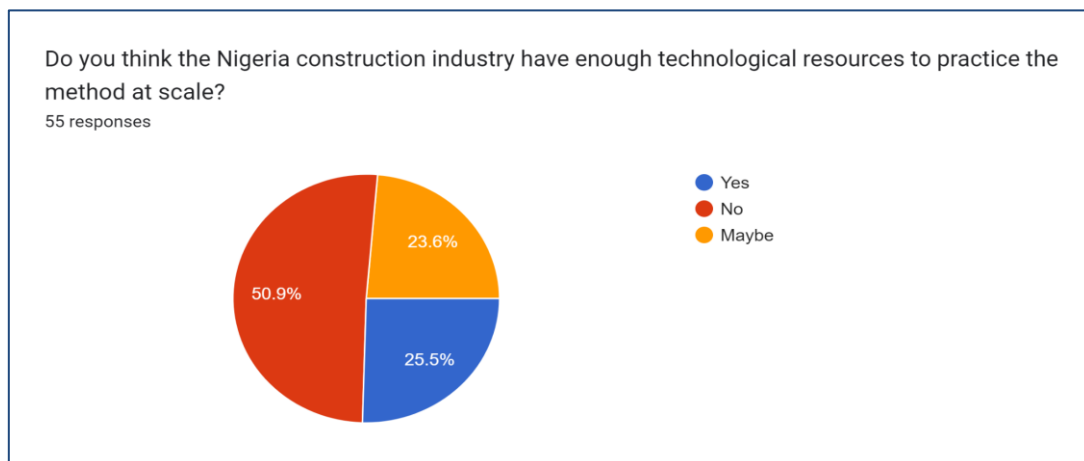


Fig. 36 Respondents opinion on use of 3DCP at scale

With a very large percentage holding the belief that this method is impracticable, there are therefore serious indications that the industry's technological condition is low and suffers a setback with latest disruptive technologies (listed in Chapter 2) driving productive transformation of the construction industry in other countries of the

world, especially the developed nations. The understanding that influences this response is however not covered by this research.

Study of previous literatures highlighted some challenges faced by the Nigerian construction industry which has continually hindered the improvement of the sector and every efforts, particularly by the government, in providing adequate and sufficient housing for her growing population. However, to understand the respondents perception of what the challenges of the construction industry are, particularly those which could hinder the adoption of of 3D Construction printing within the Nigerian Construction industry.

Challenges	Frequency
Corruption	2
Funding/Capital	4
Land Use Act	1
Political instability	2
Low awareness and non readiness for adoption	11
Cost of Acquisition	7
Inadequate infrastructure	10
Bad policies	2
Poor economy	3
Unavailability of tech-skilled personnel	7
Lack of training and research	11
Availability of printing material	6

Tab. 6 Challenges to 3DCP submitted by respodents

When asked if the respondents organization supports the practise of 3D printing, 52.7% of the response was yes and 47.3% says no. This implies that a significant portion of the respondednts work with organization that prefers traditional construction methods above emerging alternative methods. However, this survey didn't go further to confirm how the former category show their support for the new method. There is a likelihood of supporting the new technology without a plan to promote, adopt or invest in it.

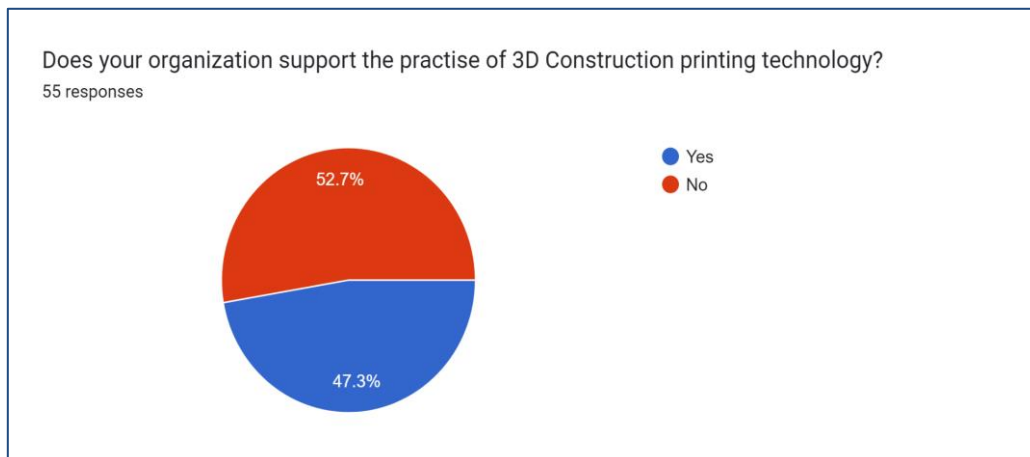


Fig. 37 Respondent's support for 3DCP

56.4% of the respondents revealed that their organization do have an existing or future plan to teach or adopt 3D printing technology. 43.6% answered in the negative. Should this plan remain in effect, this means over the next few years, the Nigerian construction industry will begin to experience land breaking transformation through the adoption of 3D concrete printing technology in providing housing solutions for Nigerians and hence maximise the potentials of the technology to help the Nigerian governments and private clients and investors close the gap of housing deficit in the country.

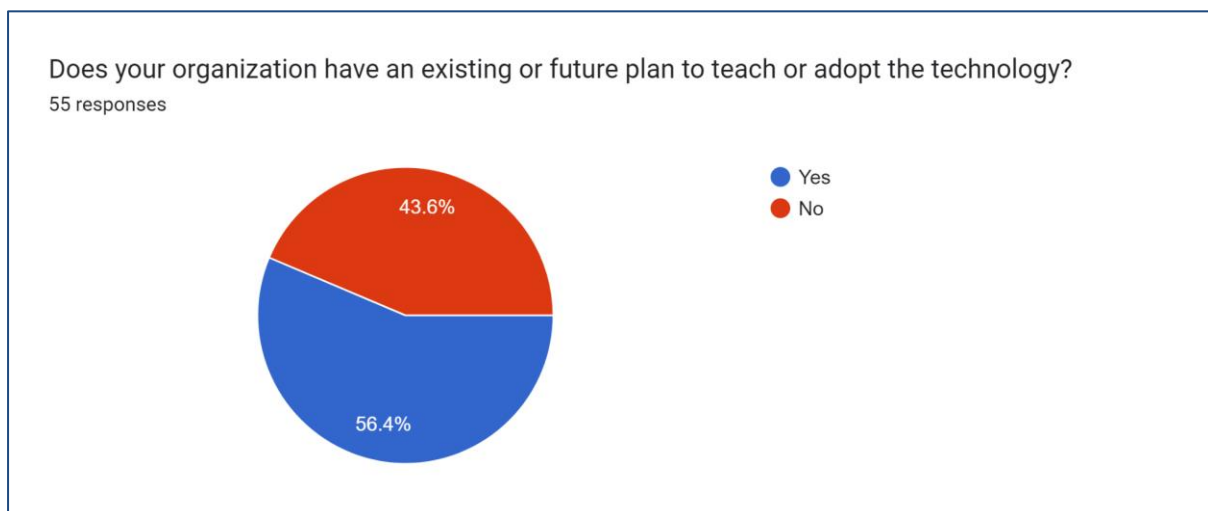


Fig. 38 Respondent organization's plan for 3DCP

The advantages and benefits of this technology to the the Nigerian construction industry, as highlighted by the respondents are tabulated below.

Benefits of 3D concrete printing	Frequency
Affordable building	2
Faster project delivery	21
Reduced environmental impact	6
Increased Productivity	4
Improved Local reputaion and standard	2
Economic growth	3
Design and construction flexibility	5
Improved building quality	7
Easier construction methods	7
Construction Cost saving	4
Ease of mass housing production	1
Technological exposure and transfer	5

Tab. 7 Respondents opinion on benefits of 3DCP

Over the topic of BIM, the following were gathered;

72.7% of the respondents know about BIM while 27.3% do not. Superficially, this provide a positive base for the expansion of BIM usage and growth in the industry. As the most developed digitalized process, BIM knowledge is essential for taking the construction industry through fully a digitalized transformation. However, it is important that the remaining 27.3% get BIM education, at the least, to enhance a faster change.

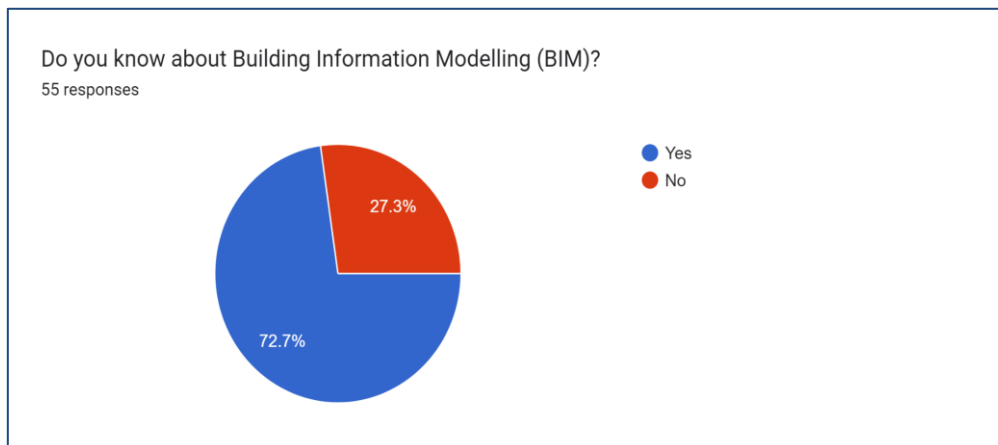


Fig. 39 Respondents awareness with BIM

49.1% of respondents engage BIM processes in their project while 50.9% do not. This infer that awareness do not translate to usage or engagement. Objectively, this figure is most useful for a technical analysis of BIM usage than awareness. However, a step further is to examine to what extent these professionals utilize BIM. With the majority of respondents (43.6%) having a work experience of less than 5 years (early stage level), this percentage is justifiable.

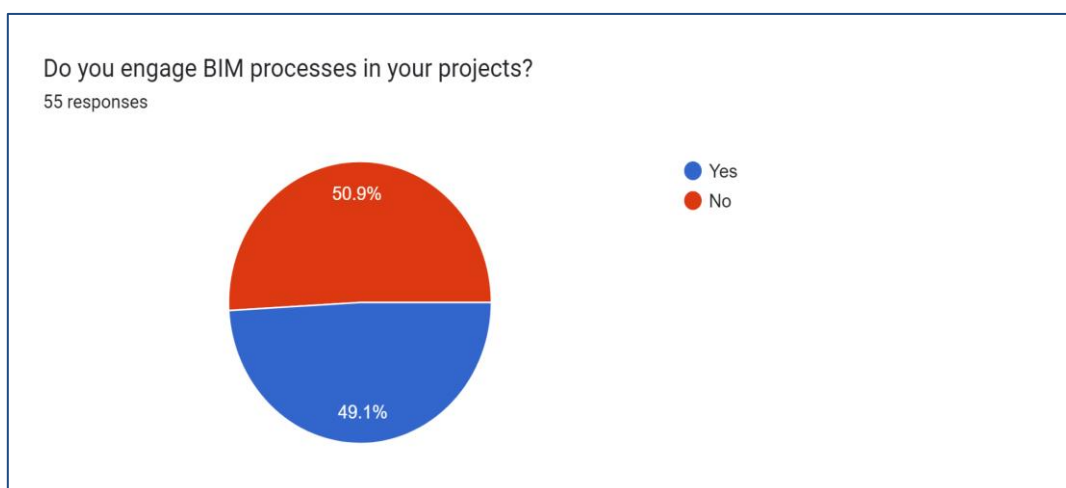


Fig. 40 Respondent's engagement with BIM

When asked of their years of experience using BIM process, 92.6% have used BIM for between 1-5years, 5.6% have used it for 6-10 years. Only 1.9% have used it for atleast 15 years. Going by the earlier percentage of those who uses and do not use BIM, it was later realized that the 94.1% also covers for those with no experience

using BIM process. Nevertheless, with majority having less than 5 years of BIM experience, it is evident that the Nigerian industry is indeed at the infancy stage of the digitalization and technological transformation some of the developed countries have been experiencing since the beginning of the millennium. This also explain the the slow readiness of the Nigerian counstruction industries to embrace digitalization over the current construction practices which has has not helped in solving its wideneing challenges.

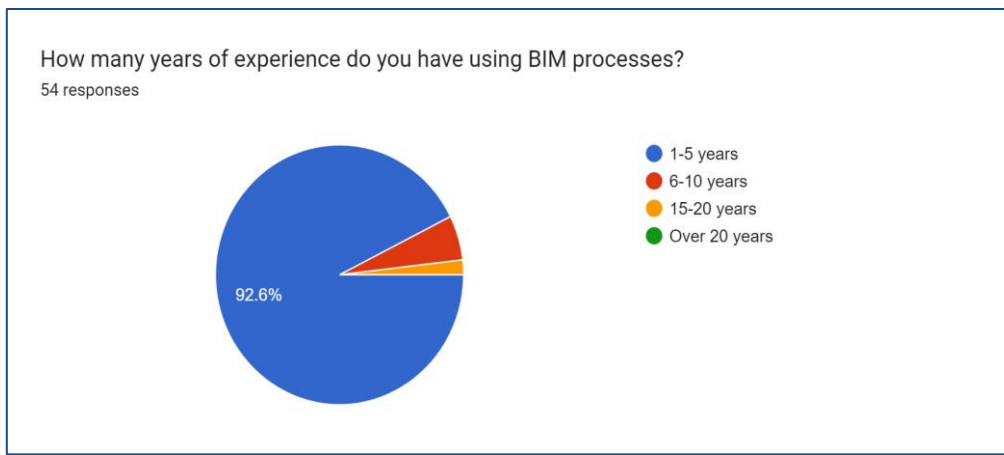


Fig. 41 Respondent's years of experience with BIM

The BIM tools used by the respondents who indicated they use BIM processes for their projects include:

BIM Tools	Frequency	Vendor
ArchiCAD	10	Nemetschek
Artlantis	1	Artlantis
AutoCAD	6	Autodesk
Bluebeam	1	Bluebeam+Nemetschek
Civil 3D	3	Autodesk
Edificus	1	ACCA Software
Home Designer	1	Chief Arhitect Architectural
Infraworks	2	Autodesk
MidasGen	1	MidasIT
Naviswork /BIM 360	7	Autodesk
Orion	3	CSC
Planswift	1	ConstructConnect

ProtaStructure	1	Prota Software
R.Design	1	R.Design
Revit	18	Autodesk
Revitzo	2	Vizerra SA
Solibri	2	Nemetschek
Staadpro	2	Bentley
Tekla Structure	1	Trimble
Vectorworks Archiitect	1	Nemetschek

Tab. 8 Lists of Softwares used by respondents

Autodesk Revit is the most used BIM tool by the respondents, followed by ArchiCAD, Naviswork and AutoCAD. This corresponds with the research undertaken by Ibem et. al (2018) who identified Revit and AutoCAD as the most predominant tools used by Architects in Lagos State, Nigeria. By primary function, these softwares perform one or more of these functions; 2D plan drafting, 3D model designing and visualization, rendering, building element analysis, cost estimation and so on.

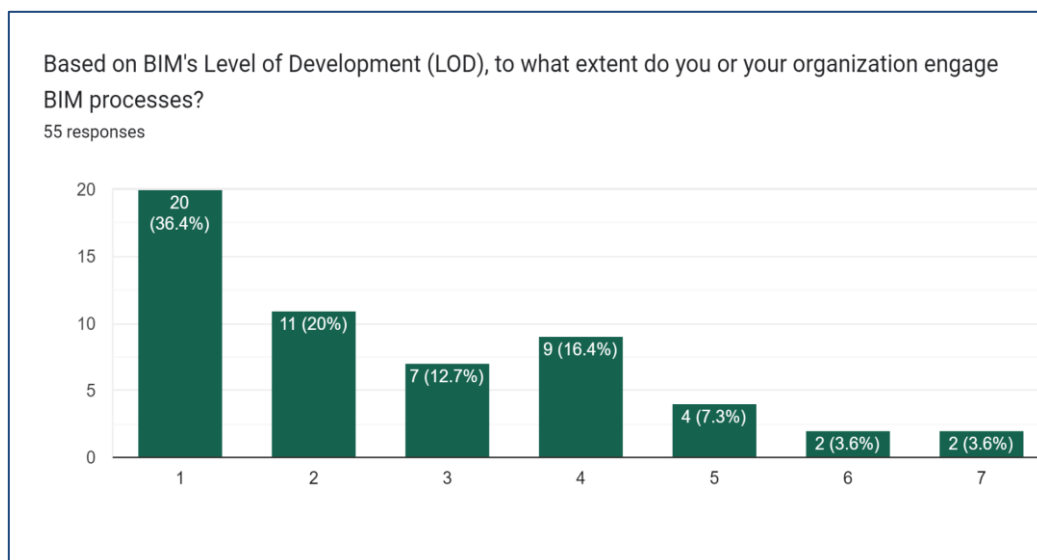


Fig. 42 Respondent's rating of their extent of BIM usage

Interestingly, as the dimensions of BIM process upgrades to accommodate new industry-required updates, these tools (or softwares) are also developed into newer version with expanded functions and capabilities. This results in increase of level of

details integratable into a model design. By this, the dimensions of BIM have expanded to ten (check Fig. 15).

Adopting the UK LOD definition has recorded in PAS 1192³⁷, the LOD profile of the respondents indicates that 36.5% uses their BIM tools only at pre designing stage – LOD 100. 21.2% use BIM up to schematic designing stagewise 13.5% and 17.3% engages BIM process up to building design and construction stages respectively. The BIM's Level of Detail (LOD) explains how the building model's 3D geometry might result in various levels of sophistication. It serves as a gauge for the necessary service level (Indovance, 2021). With majority of the respondents using BIM processes below LOD 200, data insufficiency and high loss of construction data are liable to occur. This effect may be less on a small private project but not so in the kind of large scale public mass housing projects usually undertaken by the government. With only 3.8% indicating the use of BIM processes up to LOD 700 (project in-use stage), the Nigerian construction industry obviously performs poorly in maintaining project quality and data through out their lifecycle, further contributing to loss of old houses as in the case discussed earlier in Chapter two.

This therefore answers the question of how the Nigerian Construction Industry is faring technologically; poor. If 3D concrete printing will record a huge and evident success in Nigeria, professionals within the sector must improve on their technical know-how and explore the usage to its full capabilities. Understanding the principle of its operations, 3D printing is generally dependent on 3D BIM model for output.

4.2 The Case Studies

The following information was gathered both from primary sources- interviews and secondary sources- online as follows;

4.2.1 Construction Time

The traditional method of construction in Kenya of using earth-compressed bricks for constructing a house design of the same floor area would take about two weeks on

³⁷ Source: <https://biblus.accasoftware.com/en/what-are-lod-and-loin-in-bim-and-what-are-they-for/>

average. However, to print the entire exterior and interior walls of Trees House 0, the COBOD printer spent only 15-18hrs, cutting construction time by 96.42% and for the Tabasco community houses, 24hrs. In Nigeria, the construction of walls for this same building using hollow sandcrete blocks will take about a week, should all factors remain unaltered. This means a replica of 3D printing of this building in Nigeria will cut construction time by at least 92.85%. Faster construction time will translate to higher productivity and faster project completion and delivery. Therefore, the inability of the government to produce a targeted number of houses through different housing schemes and programs in previous years can be diminished through the deployment of modern construction technologies. Consequently, this is the most mentioned benefit by respondents from the questionnaire survey.

4.2.2 Affordability

House Tree 0 was constructed using special print material, most of which were locally sourced. At completion, the two bedroom family sized house was valued at 2.3million Kenyan shillings (18,415euros). According to Habitat for Humanity (2022), affordability is a significant issue in Kenya, with so many people unable to buy or construct their housing. In addition, only 2% of the officially built homes are intended for families with lower incomes. As of 2021, Kenya's annual average wage earning is 827,441.200 Kenyan Shillings (68,953.43 euros) (CEIC, 2021). Though, the income scale for the residents at the Tabasco community is very low, yet a payment structure that will enable the locals own the house was introduced. The average annual salary in Nigeria is currently pegged at an equivalent of 13,080euro, far above what is obtainable in the Mexican village case study. This imply, that the challenge of affordability on the part of the low to medium income earners within the country can be easily solved through the provision of 3D concrete printed houses.

4.2.3 Building Quality

Improved building quality is the second most mentioned benefit of a 3D printed house by the respondents. Creation of a BIM 3D model for a building before commencing its printing enables all the relevant stakeholders to walk through the project and access all the necessary details about it, eben unto operational phase.

This helps to reduce errors usually caused manually in traditional building methods. In the construction of mass housing projects, such as undertaken by the Nigerian government in different administrations, it is a common place to see the building units vary in construction and finishing quality due to human error. The construction of Trees house 0 in Kenya (and other 3D printed buildings) followed the automated print-as-designed with very little or no variation in the expected quality of the final print. 3D concrete printing also gives flexibility to print complex shapes and multi-geometric designs without compromising on structural properties. The common hollow blocks used in Nigeria for building construction is liable to quality variation due to human error and limited in achieving flexible curves and shapes. Poor quality have led to quick deterioration of buildings in Nigeria. All of these challenges are solved in 3D concrete printing.

4.2.4 Reduced Construction Cost

Project financing has been one of the major challenges that confronts the Nigeria Construction Industry. Developing countries like Nigeria and Kenya with severe economic instability are poised to achieving much with less through the adoption of BIM and 3D concrete printing technology in their Construction Industry. Governments, private organizations, contractors and private clients are able to spend either lesser or achieve more in increasing the housing stock in the country. The construction company that built the case study, 14trees, reported to have spent less than 10,000\$ to complete the building. Reduction of waste, labor, and delay all contribute to the ability of these innovations to help reduce the cost expendable in building projects. Hence, a percentage of an initial construction cost can be saved through the use of 3D concrete printing. Also, earlier cost estimations is made possible through 5D BIM and hence increases the chances of cost manipulations and inflations- a common occurrence within both public and private sector.

Therefore, seeing the outcome of the 3D printed case study built in a market environment similar to Nigeria, it can be inferred that BIM driven 3D concrete printing offer itself as a viable technological method that can replace the existing conventional methods and generate better results. Mass housing projects

undertaken by the government and private investors can be achieved faster, cheaper and without compromise on quality and safety.

4.3 Limitations of Research Methodology

It is obvious that open-ended inquiries provide greater details and in-depth responses but they are more difficult to examine. There are other important questions the questionnaire didn't capture. This is because the responses would not have provided a direct contribution to our research questions and aim. For example, the respondents were asked if they know about 3D concrete printing and from through what channel. However, the extent of the full understanding of their claims was not questioned. However, this provides an avenue for further extensive study in understanding the conditions of new technologies in Nigeria.

The use of two case studies provides a limited insight into the benefits of 3D concrete printing. Even though many 3D printed buildings are available to be considered, there is no sufficient information on them to create a comprehensive academic discourse.

4.4 Summary

At the end of this chapter, the following can be understood;

- the structure of the survey questionnaire is a mixture of open ended and closed ended questions
- the nature of the questions asked required no use of special statistical tools for analysis
- the data collated were basically interpreted through descriptive approach
- the limitations of the adopted method
- the correlation between the opinions of the respondents on BIM and 3D concret printing and the insights drawn from the case studies.

INTRODUCTION TO CHAPTER FIVE

This is the concluding part of this research work. Here, insights from previous researchers, materials and the outcomes of the research been done funneled together into a list of consice points that shows new ideas and discoveries from the entire research, relatively to the research topic. In this chapter, you will learn;

- the conclusions of this research
- the recommendations from the research

CONCLUSION AND RECOMMENDATIONS

This study was undertaken to investigate the benefits of BIM and 3D concrete printing to the Nigeria Construction industry. The approach adopted examined the level of awareness of these technologies among relevant professionals as key factor of maximizing the potentials in them to solve current housing problems in Nigeria. The following conclusions were drawn.

5.1 Conclusions

- (i) Inadequate technological implementation has never been recognized as a factor inhibiting the successful completion of projects in Nigeria, hence the little interest attributed to adopting new processes and methods.
- (ii) From this research, it is evident that the adoption of BIM and 3D concrete printing will contribute positively to solving the challenge of housing and building construction through the highlighted means. BIM and 3D concrete printing will enable both public and private projects to be completed faster and in record time. This is the benefits most identified from the feedbacks submitted by the respondents.
- (iii) Secondly, the increasing need of affordable housing by Nigerians can be met with the adoption of 3D concrete printing. It offers a better option for the Nigerian governments to construct and provide affordable housing for her low to middle income earners dominated population. Various researches had identified affordability as a big factor that has contributed to the housing deficit in Nigeria. As 3D printed houses cost less, up to 50% in many locations around the world compared to an existing conventional method, ownership rate will increase in Nigeria with the adoption of this new technology based building construction method.
- (iv) The dominance of young professionals within the Nigerian construction industry offers a great opportunity for all stakeholders to develop and implement a long term BIM utilization framework. Early stage professionals will help to lead a more technological construction industry on the backdrop of policy, training and infrastructure.

- (v) The level of knowledge and awareness of 3D concrete printing among construction professionals is significantly low, hence posing and hence posing an hinderance to its technological growth with the industry
- (vi) The Nigeria construction professionals are conversant with the use of various BIM modelling tools. Although the level of usage is higher within the lower BIM capabilities.
- (vii) From the feedback of the methodologies, 3D printing will greatly suffer infrastructural setbacks ahead of wider adoption within the Nigeria construction industry.

5.2 Recommendations

- (i) The Nigerian government should consider to adopt 3D concrete printing as a viable alternative to the current conventional method of building and providing housing for her increasing population, especially in the urban areas. The method is more affordable and enables faster project delivery.
- (ii) Capacity building in the area of optimizing the various BIM tools in construction practice is required within thee industry. This is because in comparison to their use for design and drafting, the use of BIM tools for analyses is somewhat underutilized. This is crucial in order to maximize the advantages of BIM.
- (iii) Professional organizations, governmental authorities, and non-governmental organizations both locally and globally should seize this oppourtunity to push for a massive awareness of BIM and 3 concrete printing within the Nigeria Construction Industry.
- (iv) BIM implementation should be supported by suitable government regulations and policies in developing countries like Nigeria
- (v) Modern technologies such as BIM process and 3D concrete printing process should be incorporated into the academic curricula of architecture, engineering, and construction related programs in higher institutions
- (vi) To enable middle the proliferation of the implementation of this new technology within the Nigerian construction industry and to also make it affordable, stakeholders must show more support tthrough research and development and work

closely with leading organizations. Cost of acquisition of printers is a major uphill that must be surmounted to see 3DCP grow in Nigeria.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Location, Date

Signature of the student

Consent of publishing the Master`s Thesis

I consent to the publishing of this Master`s Thesis at the HTW Berlin library

Appendix

Appendix A: Impact of New Technology across Industries

Task	Enabling technology	Result
Intelligent design and planning	BIM, Significant Data	Reduction in design errors and enhancement in the quality of the design and engineering processes through virtual and digital simulation (i.e. digital twin).
Fleet management	Internet of Things, Big Data	Remote monitoring through the use of sensors and analytics of status and location of construction equipment (i.e. work vehicles) so as to reduce costs, improve energy efficiency and limit idle time of machines.
Predictive maintenance	Internet of Things, Big Data, AI	Monitoring of the condition of machines through the use of sensors and analytics with the aim of conducting preventive maintenance and to reduce potential failures.
Innovative fabrication methods	Internet of Things, Big Data, AI, BIM, Drones	Rethinking construction processes and operations in a "smart perspective" leveraging the information gathered through data collection and analytics to speed up processes, reduce costs, improve energy efficiency and operators' safety.
Monitoring and Evaluation of Resilience	BIM, Internet of Things, Big Data, AI, Drones	Better "real-time" surveying in all of the phases of the project such as providing adequate support to on-site operators as well as monitoring resilience of infrastructure following the end of the project.
Autonomous equipment and driverless vehicles	Internet of Things, Big Data, Robotics	Introduction of driver-assistance systems and autonomous driving to improve construction processes and reduce physical workload on the construction site.

Appendix B: Questionnaire shared with respondents

04/07/2022, 00:34 3D Construction Printing Technology

3D Construction Printing Technology

This survey is developed to gather data and opinion for a research that primarily focus on the technological condition of the Nigerian construction industry as to enable the adoption, practice and growth of 3D printing construction method. 3D printing (also referred to as Additive Manufacturing) is the use of machines to produce real life objects directly from a CAD model using specially formulated printable materials through extrusion. This process has finally found its way into Construction and its being used to build houses with simple and complex geometries. In less than 5 minutes, kindly fill in this survey. Thanks

*** Required**

1. Name *

2. Age *

Mark only one oval.

20-30

31-40

41-50

51-60

Over 60

3. Profession *

<https://docs.google.com/forms/d/1rgJWUN9sZpcsJFpWRxGWyrHaNizs2CYtAcwE2qLFoXg/edit> 1/6

04/07/2022, 00:34

3D Construction Printing Technology

4. Sector *

Mark only one oval.

- Architecture, Engineering and Construction- Building
- Architecture, Engineering and Construction - Highway
- Architecture, Engineering and Construction- Consultancy
- Academic and Research
- Manufacturing
- Real Estate
- Other: _____

5. Position within Organization *

6. How many years of experience do you have within the Construction/ Civil Engineering/ indicated field *

Mark only one oval.

- 1-5 years
- 6-10 years
- 10-15 years
- 16-20 years
- Over 20 years

7. Do you know about 3D Printing technology? *

Mark only one oval.

- Yes
- No

04/07/2022, 00:34

3D Construction Printing Technology

8. Do you know about 3D Construction Printing technology? *

Mark only one oval.

- Yes
 No

9. How did you know about 3D Construction Printing technology? *

Mark only one oval.

- From school/ university
 Personal research
 Social media
 From individuals/ colleagues
 Workplace
 N/A
 Other: _____

10. How much do you know about 3D Construction printing technology? *

Mark only one oval.

- | | | | | | | |
|--------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------|
| | 1 | 2 | 3 | 4 | 5 | |
| Little | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | Much |

11. Do you think the Nigeria construction industry have enough technological resources to practice the method at scale? *

Mark only one oval.

- Yes
 No
 Maybe

04/07/2022, 00:34

3D Construction Printing Technology

12. What are the challenges you think can hinder the adoption of 3D Construction printing within the Nigerian Construction industry? *

13. Does your organization support the practise of 3D Construction printing technology? *

Mark only one oval.

- Yes
 No

14. Does your organization have an existing or future plan to teach or adopt the technology? *

Mark only one oval.

- Yes
 No

15. What advantages/benefits do you think this Construction method can add to the AEC industry in Nigeria? *

04/07/2022, 00:34

3D Construction Printing Technology

16. Do you know about Building Information Modelling (BIM)? *

Mark only one oval.

Yes

No

17. Do you engage BIM processes in your projects? *

Mark only one oval.

Yes

No

18. How many years of experience do you have using BIM processes? *

Mark only one oval.

1-5 years

6-10 years

15-20 years

Over 20 years

19. Which software(s) do you use for your BIM processes? Kindly list below. *

04/07/2022, 00:34

3D Construction Printing Technology

20. Based on BIM's Level of Development (LOD), to what extent do you or your organization engage BIM processes? *

LOD 100 – Pre-designing stage. LOD 200 – Schematic designing stage. LOD 300 – Building design development. LOD 350 - Construction documentation. LOD 400 – Construction stage. LOD 500 – As-built stage. LOD 600 & 700 – In-use and Re-use stages.

Mark only one oval.

	1	2	3	4	5	6	7	
LOD 100	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	LOD 700

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Google Forms

Appendix C: Interview Questions

Interview Questions

Research Thesis Case Study: Trees House No 0 (TH-0), Kenya

1. Kindly introduce yourself.
Francois Perrot, 14Trees Managing Director
(francois.perrot@14trees.com)
2. Tell us about your organization, 14trees.
14Trees is a JV between Holcim, world leader in building materials, and British International Investment, the UK Government's impact investor. We are the leader in the use of 3D printing in Africa, building homes and schools across the continent
3. Kindly tell us about the 3D printed house project in Kenya.
The house printed in Nairobi is a show house used to promote a 52 unit project which will soon start to be printed on the coast of Kenya.
4. What motivated this project?
There is a huge housing deficit in Kenya and we believe that 3D printing can help clear that backlog by delivering efficient, fast and sustainable buildings.
5. What challenge/problem is this project solving or going to solve in Kenya?
Availability of affordable houses. Sustainability of those houses.
6. Compared to the traditional construction methods in Kenya, what are the advantages and disadvantages of a 3D printed house such as this?
Much faster, reduced quantity of materials, more limited environmental footprint. Our 3D project in Kenya is EDGE certified. 3D printing is already competitive compared to other technologies costs, and we believe it can become cheaper by up to 20% vs other methods.
7. How long did it take to print TH-0 and how long does it take to complete the entire building?
It takes 15-18 hours to print the walls of the house. Rest of the building is conventional (though we are working on several innovations which will be introduced progressively as part of the 52 unit project)
8. What is the total floor area of the building?
56m²
9. How many manpower was engaged during the on-site printing of the building?

10. What materials were used for the printing and how were they sourced? We used Holcim Tector print 3D ink.
11. How much did it cost to complete the building of the house?
12. What is the market value TH-0? For a similar size, how much would it cost if it was built using traditional methods?
For the total cost of the building, including land + utilities, please refer to mvulegardens.com
13. Is a 3D printed house such as this affordable for a low or middle class income earner in Kenya or Nigeria? Yes we believe it is affordable for the low to middle income class earner in Kenya. For Nigeria, we are working on cost estimates and designs.
14. What challenges did you experience during the construction? Our main challenges were logistical (getting the printer in the country) and related to the weather (we had to print during very hot days as a Covid related curfew was in place at that time and we could not print during the nights as we usually do)
15. In Sub sahana Africa, what challenges do you think could hinder the growth of this building technology (3D concrete printing)? Cost of printers is definitely a limitation and cheaper printers are needed so that this technology can be massively adopted.
16. In Nigeria, previous government housing schemes failed to achieve their targets of mass housing production. Reasons for this are political, financial, technical and administrative in nature. How can 3D concrete printing help to solve that? I cannot comment on Nigeria sorry.
17. Did Building Information Modeling (BIM) play any role during this project? How did that happen? Not yet but the fact that we use digital fabrication already contributes to improving the project preparation and design.
18. What is your opinion or assessment of the knowledge of African construction professionals on new technologies such as BIM and 3D concrete printing? We believe African contractors are ready to use new technologies and provided 3DP continues to improve and deliver on performance, it can be the technology of choice to make an impact in Africa on a large scale.
19. What must be done across board (public and private) to promote the growth of these technologies?

20. Has work commenced on the proposed Mvule Housing Project? A lot of work has been done and we have secured several commercial deals, which will allow construction to start in the coming weeks.

21. If yes, what is the current state of the project? If no, why has it not commenced?

22. Do you think 3D concrete printing can help solve the housing deficit challenge in countries like Kenya and Nigeria? Yes, this is why we are actively working on it 😊

Please, kindly share with me the plans for TH-0 (floor plan, elevations) of the 3D printed house (early, middle and final printing stages) and if possible, a plan of one of the proposed building for Mvule project. Sorry we can only share publicly available information which is available on our website mvulegardens.com

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