Journal of Namibian Studies, 35 S1 (2023): 4594-4610 ISSN: 2197-5523 (online)

Prospects And Challenges Of Emerging Technologies In Architectural Design Practice Within The Nigerian Context

Akande, Ifeoluwa[1]; Alagbe, Oladoyin Taiye[2]
Adebayo, Oluwatoyin Abiodun[3]; Olaosun, Sulaiman[4];
Oyedele, I. Olabode[5]

[1] Department of Architecture, Bells University of Technology, Ota, Ogun State, Nigeria
i_akande@bellsuniversity.edu.ng

[2, 3, 5] Department of Architecture, Bells University of Technology, Ota, Ogun State, Nigeria.

[4] University of KwaZulu-Natal, South Africa

Abstract

The United Nations' Sustainable Development Goal (SDG) 9 (Industry, Innovation,` and Infrastructure) and the fast rise of technological advancements globally demand a need for Nigeria as a third-world country to keep up with this rapid progression of technology. This study examined how these technological advances are affecting Nigerian architectural design practices. It also looked at how architectural design is now practiced vis-a-vis the problems that hinder the total acceptance and use of new technology in the industry. Hence, the research utilised literature review and questionnaires to identify emerging technologies needed for Nigerian architects to be able to participate in the fast-rising global trend such as Computer Aided design (CAD), 3D modeling, Building Information Modelling (BIM), Data-driven design, Artificial Intelligence (AI) and Virtual reality amongst a few others. The literature revealed that the identified technologies have roles such as improved efficiency, conceptual modeling, and articulate visualisation to play. The findings from this research indicate that limited technological knowledge among architects ranks the highest among the challenges in adopting emerging technologies in Nigeria as identified by 72.7% of respondents. This is due to economic factors such as the high cost of procuring technological equipment as well as technical factors such as insufficient technical knowledge. Therefore, it is highly recommended that Architects in Nigeria begin to explore and integrate these technologies into their day-to-day practices so they can begin to enjoy the benefits that

come with it. These benefits include efficiency, reduced error, increased innovations, and data-driven designs.

Keywords: Technological-advancements, Design-practice, Architecture and emerging-technologies.

Introduction

Background of the Study

Technology is essential in the development and day-to-day life of man. Right from the evolution of using stones and bones to carve drawings on the walls and sticks and stones to defend themselves in the early times. Technology continues to grow in importance as a tool to help (Ahmad & Reza, 2018). As such, emerging advances in architecture and technology have begun to work hand in hand for the betterment of human life and design simplification (Piazza, Grioli, Catalano, & Bicchi, 2019). Advanced building technologies such as Building Information Modeling (BIM) and Information Technology (IT) are becoming an integral part of human life today. Due to the emerging application of technology, the trend towards quality has attracted the attention of developing countries more than ever. The trend towards quality and competitive architecture has created a new trend in these countries. Technology as a powerful and growing tool is one of the most discussed issues in architectural engineering and its evolution (Tidd & Bessant, 2020). It is not far off to say that all architects in the field of architecture have considered the issue of technology and its effective role in the growth of modern architecture as an important issue (Claypool & Retsin, 2019). In this new age and current age, a new world is being built, and the advancement of technology in general as well as the field of architecture creates room for questions such as "How is technology applied in the field of architecture and What future does technology build for architecture. Hence, there is a need for Nigerian architects to familiarise themselves with the prospects and challenges of the emerging technologies that affect their practice.

Problem Statement and Research Questions

In the context of the rapidly evolving global technological landscape, the architectural domain in Nigeria stands at a pivotal juncture (Hein, 2016). As the nation strives to keep pace with the relentless march of technological advancements, there arises an acute need to explore, understand, and incorporate emerging technologies that are not only sustainable but also transformative for the architecture profession. This research endeavours to shed light on the challenges and prospects of integrating these innovations within the Nigerian architectural practice, thereby facilitating a nuanced understanding of the new technological evolution and providing answers to the following critical questions:

i. What are the emerging technologies suitable for sustainable architectural practice in Nigeria?

ii. What is the role of the identified promising technologies in the practice of architecture?

iii. What are the challenges to the adoption of emerging technologies for architectural practice in Nigeria?

These questions highlight the need to evaluate and comprehend the dynamic interactions between technological development, sustainable architectural practice, and the nuances that either restrict or facilitate the incorporation of these revolutionary innovations into the Nigerian architectural context. This study looks into these questions to offer insightful information that will help architects adopt these developments and create a more resilient, creative, and sustainable architectural practice in Nigeria.

Research Justification and Scope

The characteristics of the 4th Industrial Revolution era require that every member of the architectural design practicing team be vast in digital and Building Information Modeling Technologies (Gokhale, Bhat, & Bhat, 2018). The emergence of technology and its quick extension has changed the way of life of human beings (Nordmann, 2020). Architecture is no exception to this change. As the rise in the utility of technological advancements is eminent in architecture, the study of the future possible outcomes of this phenomenon is to be looked out for. The topic "Prospect and Challenges of Emerging Technologies in Architectural Design Practice in Nigeria" is worth researching for several reasons. Emerging technologies are causing considerable changes in the architectural design sector (Sima, Gheorghe, & Subi, 2020). This pattern is not exclusive to Nigeria. Therefore, it's crucial to look into how these new technologies are influencing Nigerian architecture practice.

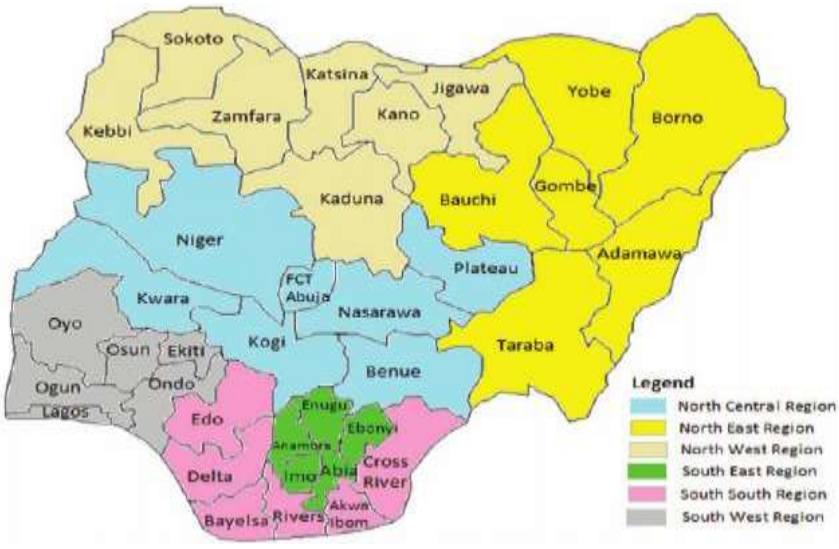
Emerging technologies give architects new tools and methods to create buildings more successfully and efficiently, such as Building Information Modeling (BIM), Virtual Reality (VR), and Augmented Reality (AR). The study will examine the adoption and use of these technologies by Nigerian architects to improve their work. The study will also point out the difficulties that architects encounter when incorporating emerging technologies into their work. This will assist in highlighting areas in which further assistance and funding are required to motivate Nigerian architects to use these new technologies. The study will offer information on how new technologies can affect Nigeria's architectural design sector, including if they might lead to the creation of jobs, boost the sector's level of competition, or raise building standards. The content of this study will focus mainly on emerging technologies in the field of architecture, engineering, and construction (ACE), with emphasis on architecture as a focus. The idea is to see how professionals in the field of architecture can

harness technological revolution and advancements. The study will also see how the professionals can handle the challenges that may come with its adoption. Geographically, the research study will focus on the Lagos state area of Nigeria. This is because Lagos harbors the highest number of architecture practice firms in the South Western part of Nigeria, and probably in Nigeria (Adebisi & Adeoye, 2018).

Study Location

Nigeria, which is officially known as the Federal Republic of Nigeria, is located in West Africa and is the most populated in the continent with a population of over 200 million as of the United States Census Bureau on July 1st, 2022 (Akanle & Shittu, 2022). Nigeria as of January 2022 has about 5000 registered architects (Obiadi, Onuorah, Mba, Okafor, & Kikanmen, 2022). Geographically, it is found between the Sahel to the north, and the Gulf of Guinea to the south of the Atlantic Ocean. Nigeria has a total land area of 923,769 square kilometers. Nigeria is a country with 36 states as shown in Figure 1. With Abuja as its capital. Lagos is the largest city in Nigeria and it is located in the southwestern region of Nigeria. It is bounded by the Ogun state to the north the Bight of Benin to the south, and the Republic of Benin to the west. Lagos covers an area of a total of 1, 171, 28 square kilometers. Lagos is one of the major technological and financial centers in Nigeria and houses one of the largest and best seaports on the continent.

Figure 1: Map of Nigeria showing the 36 states



Source: (Adebisi & Adeoye, 2018)

Literature Review

Technology in Architectural Design

The use of scientific knowledge for practical applications might be summed up as technology (Cargill & Connor, 2021). This corresponds to the use of numerous tools and procedures to help in the design, construction, and upkeep of structures in the context of architecture. The design process has been faster, more effective, and more accurate thanks to technology, which includes building information management systems and 3D modeling software. Computer-aided design (CAD) software is one of the most important ways that technology has changed architecture. These technologies enable architects to rapidly and simply experiment with alternative options, build virtual models of their designs, and make revisions (Rao, Barkley, França, & Yanai, 2021). Time is saved, and the design may be explored in greater detail, resulting in better client and contractor engagement. Using new materials and construction methods is another way technology is altering the face of architecture. The creation of new and improved building materials, such as super-strong and lightweight composites, that can be utilised to produce more creative and sustainable buildings has been facilitated by developments in materials science and engineering. Similar to this, technology has made it possible to adopt new building techniques like 3D printing and prefabrication, which can expedite the building process and cut waste (Adamopoulou, Moussiades, & Springer, 2020). The final alteration brought about by technology is how individuals interact with the built environment. People may now control their environment using their smartphones and other devices thanks to the development of the Internet of Things (IoT) and smart building technology.

Factors Influencing the Application of Technology in Architectural Design

Certain factors play a role in the application of technology in architectural designs, these factors can deter the idea of utilising technology. They can be categorised into three factors which are: economic factors, technical factors, and personal factors.

i. Economic Factors

Cost is a significant determinant of how technology is used in architectural design. It can be expensive to procure and integrate technology, such as hardware and software, especially for smaller architectural firms with tighter budgets (Ghobakhloo & Ching, 2019). For instance, the cost of obtaining and using BIM software, which is necessary for many contemporary architectural projects, can be high. Recurring licensing fees, education expenses, and hardware expenses (such as those for potent computers and graphics cards) are all associated with BIM software. Because both software and hardware must continue to work, the cost of upkeep and updates is another factor. As a result, architectural enterprises could face ongoing expenses that put pressure on their finances. The usage of technology in design is significantly influenced by cost (Ahuja, Sawhney, Jain, Arif, & Rakshit, 2020).

ii. Technical Factors

The level of competency and mastery of the tools and processes used in design and construction are determined by technical talent, which is another important component in the application of technology in architecture (Sony & Naik, 2020). CAD software and advanced fabrication techniques are two examples of technology that architects with excellent technical abilities can use to generate high-quality and effective designs (Zhao, 2020). Without the necessary technical expertise, architects may find it difficult to properly incorporate technology into their work, which could result in mistakes, inefficiencies, and lower-quality outcomes. How much technology is employed in architecture depends significantly on how skilled architects, engineers, and other members of the built environment are (Zhang, Liu, Kang, & Al-Hussein, 2020). Implementing technologies like Building Information Modeling (BIM), 3D printing, and other digital tools requires a high level of technical ability. It might be challenging for unfamiliar architects and engineers to use these technologies effectively, which could lead to errors and increased costs.

iii. Personal Factors

The application of technology in architecture is significantly influenced by individual choices. These preferences are influenced by several variables, such as a person's cultural and ethical background, degree of education, and technological experience. For instance, persons with strong technical expertise are more likely to adopt new technologies and apply them to design than those with less experience. Similarly to this, individuals from more traditional cultural backgrounds might be less likely to utilise new technology or might favor using them more conventionally. This may be a significant deciding element in how technology is applied to architecture (Battaglio, P, P, & N, 2019). More educated people might be more open to experimenting with and learning about new technologies, whereas less educated people are more likely to stick with a believed simpler ideas. It is a complicated and varied topic when it comes to how technology and human decision-making interact in architectural design (Berg & Vance, 2017).

Technology Advancements in Architectural Design Practice

The constant evolution of man has brought about advancements to facilitate the process and outcome of architectural designs in the world globally (Schjoldager, Narimatsu, Joshi, & Clausen, 2020). The use of new tools, materials, technologies, and methods to enhance building design, construction, and use is referred to as technical advancement in architecture. Buildings that are more effective, sustainable, and aesthetically pleasing are made by applying scientific knowledge and engineering concepts. Technological advancements have greatly impacted the field of architecture and have changed the way architects

design and construct buildings. Some of the key technological advancements in architecture include:

i. Building Information Modeling (BIM)

BIM is a digital depiction of the building that offers a thorough and interactive platform for collaboration between architects, engineers, and contractors. BIM software enables architects to generate extremely accurate and realistic virtual representations of buildings, allowing them to simulate and evaluate various design elements (Zhao, 2020). An integrated database of information on a building project, including design data, details on the materials and construction, and requirements, is provided by BIM in architecture (Bechthold & Weaver, 2017). The use of this data is necessary at every stage of the design and construction process, from concept generation and visualization to cost estimation, planning, and facility management. BIM is a crucial tool for contemporary architecture, giving designers, builders, and other building professionals a more thorough and integrated approach to the planning, execution, and management of building projects.

ii. Computer-Aided Design (CAD)

In the domains of architecture and other engineering, CAD (Computer-Aided Design) is a digital drafting and design technique that is widely employed (Shivegowda, Boonyasopon, Rangappa, & Siengchin, 2022). Instead of creating their plans and drawings by hand, architects and designers can now electronically generate, edit, and record them using CAD software. Computer-aided design (CAD) is a type of digital technology that enables architects to create, edit, and store their designs and drawings electronically. With the aid of CAD, architects may create 2D or 3D drawings, mark them up, take precise measurements, and share their work with others. CAD is now a crucial tool for architects, allowing them greater precision, efficiency, and flexibility in their work because of the industry's extensive use of this tool for architects, giving them more precision, efficiency, and flexibility in their work.

iii. 3D Printing

By adding layers of material, 3D printing, also known as additive manufacturing, produces three-dimensional items (Bhargav, Sanjairaj, Rosa, Feng, & Fuh, 2018). By using 3D printing to produce physical models of building plans and full-scale building components, architects and builders may more quickly, accurately, and efficiently visualize, test, and build their projects. A crucial instrument in the world of architecture, 3D printing offers designers fresh, creative ways to bring their visions to life (Nadagouda, Rastogi, & Ginn, 2020). By using 3D printing to produce actual models of building designs, architects, and designers may perceive their designs in a way that is more concrete and realistic. Scales ranging from small, intricate prototypes to full-scale mockups of building components can be produced using 3D printing.

By eliminating the time and expense involved with conventional model-making techniques, this technology also enables architects to modify their designs and produce new prototypes quickly and easily (Oztemel & Gursev, 2020).

iv. Artificial Intelligence

According to Ngarambe, Yun, and Santamouris (2020), artificial intelligence (AI) in architecture refers to the application of sophisticated computer tools and algorithms to improve many parts of the architectural design and building process. AI can automate repetitive jobs, enhance BIM processes, provide design options, help with construction planning, and improve building performance assessments. Artificial Intelligence (AI) has the potential to revolutionise the field of architecture.

v. Building Performance Analysis

The process of assessing and projecting how well a building or structure will perform in terms of variables like energy efficiency, sustainability, occupant comfort, and safety is known as building performance analysis in architecture (Nordmann, 2020). Building performance analysis aims to find areas where the building's design and operation can be improved while also making sure that it satisfies the needs and objectives of the client and other stakeholders. Building performance evaluation is a vital component of the architectural design process because it helps architects construct structures that are more environmentally friendly, long-lasting, and comfortable for occupants. Architects may make sure that their designs fulfill the desires and objectives of clients and stakeholders and contribute to a more sustainable and livable built environment by using reducing tools and methodologies to predict and assess building performance (Gokhale, Bhat, & Bhat, 2018).

vi. Virtual and Augmented Reality

Virtual Reality (VR) and Augmented Reality (AR) are a technology that beautifies the way architects and architects can visualise and interact with building designs (Alizadehsalehi, Hadavi, & Huang, 2020). Virtual Reality (VR) creates a much-simulated environment that may be interacted with in a seemingly real or physical manner. In structure, VR can be used to create immersive and interactive visualisations of constructing designs, allowing architects to revel in their designs as if they have been in the building itself. This technology can assist in identifying ability layout issues, communicate layout ideas to stakeholders, and provide an extra immersive and attractive reveal for customers (Balali, Zalavadia, & Heydarian, 2020).

vii. Digital Twin Technology

A virtual depiction of a real building, system, or procedure is known as a "digital twin" in architecture (Botn-Sanabria et al., 2022). It is made with the use of cutting-edge digital technology, including computer simulation

and building information modeling (BIM), and is intended to mimic the behavior of its physical equivalent in the real world. Real-time monitoring, analysis, and optimization of building performance are all made possible by the digital twin for architects and building managers. This technology can be used to simulate different scenarios and test how a building will perform under different conditions, such as changes in occupancy, weather, or energy demand (Moazami, Nik, Carlucci, & Geving, 2019). This information can be used to make informed decisions about building operations and maintenance, as well as to identify potential issues.

Research Methodology

Research Design, Instrument, and Respondents

Table 3.1: Summary of Research Design

Research Question	Data Gathering	Data Analysis
What are the emerging technologies suitable for sustainable architectural practice in Nigeria?	Questionnaire	Thematic analysis
What is the role of the identified promising technologies in the practice of architecture?	Questionnaire	Narrative analysis
What are the challenges to the adoption of emerging technologies for architectural practice in Nigeria?	Questionnaire	Descriptive statistics

Source: Author's device (2023)

Lagos state, Nigeria has been established to host the largest number of architectural design practicing firms in Nigeria with about 350 registered firms (Adebisi & Adeoye, 2018). To determine the sample size for the study, Yamane's formula sample calculation was used and the sample size used was 99. The instrument adopted for the study to corroborate the literature review was a questionnaire survey. These 4 sectional questionnaires were designed to obtain specific information related to the research questions. The first one; is to identify the demography of the respondents. The second one; is a set of questions that is directed specifically towards the identification of the emerging technologies in the field of architecture. The third one; is a set of questions aimed at understanding the role of the identified emerging technologies. The fourth part seeks to gather information on the challenges of the adoption of the identified emerging technologies.

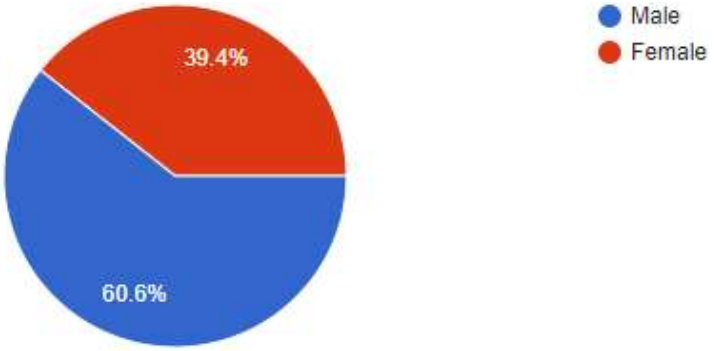
Results and Discussions

Gender of Respondents

Figure 4.1 indicates a higher majority of the respondents are male. Male respondents of 60.6% of the sample while the female percentage is

39.4%. The study tries to maintain a gender balance even though the profession is a male-dominated one. However, this does not imply the aim of this research and its result.

Figure 4.1 Gender of Respondents

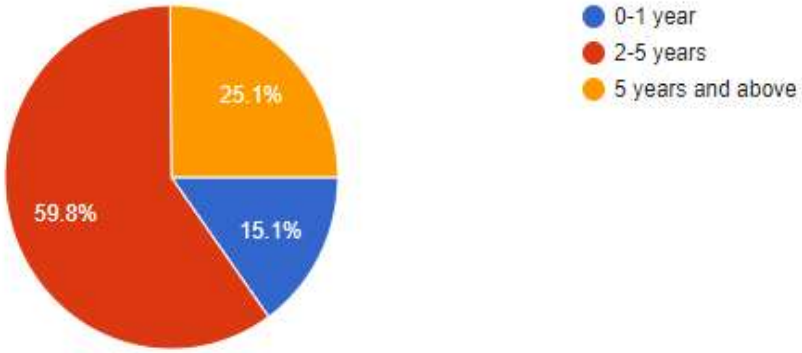


Source: Author's field survey (2023)

Respondents Years of Architectural Design Practice

According to the survey taken, figure 4.2 indicates that the majority of respondents have 2-5 years' experience in architectural design practice with a sum of 59.8% while respondents with 5 years and above make a sum of 25.1% and respondents with 0-1 year sum up to 15.1% respectively.

Figure 4.2 Respondents' Years of Architectural Design Practice



Source: Author's field survey (2023)

Respondents Familiarity with Emerging Technologies in Architecture

Figure 4.3 below indicates that Computer-aided design (CAD) ranks highest in respondent familiarity with 91.4% of respondents affirming to be familiar with it, Building Information Modeling (BIM) Ranks second with a 70.2% familiar rate, next comes 3D printing with 66.7% then virtual reality with 57.1%familiarity rate among respondents. This indicates that Computer Aided Design is the Most Familiar amongst respondents.

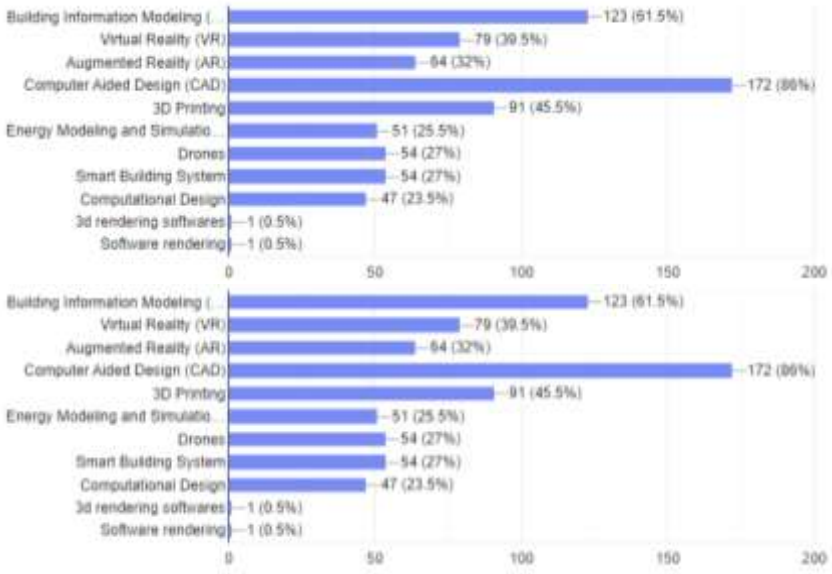
Figure 4.3: Respondents' Familiarity with Emerging Technologies

Source: Author's field survey (2023)

Encountered Technologies of Respondents

Figure 4.4 indicates that Computer-aided design (CAD) ranks first on the poll with 86% of respondents affirming to have encountered it, Building Information Modeling (BIM) comes next with 61.3%, 3D printing follows with 45.5%, virtual reality comes in next with 39.5%, and Augmented reality with a 32% encounter rate by respondents. Computer-aided design is the most encountered technology according to respondent's responses conducted from the survey.

Figure 4.4: Encountered Technologies of Respondents

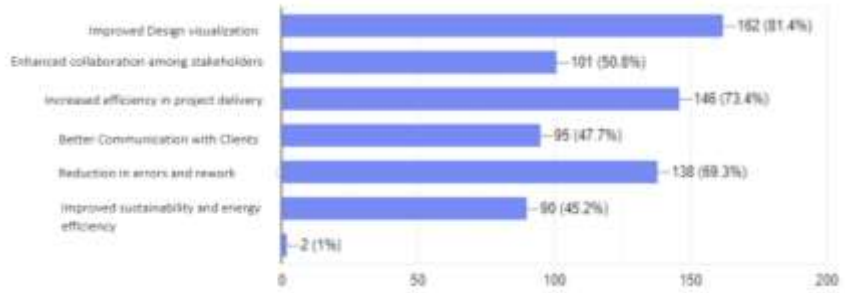


Source: Author's field survey (2023)

Main Benefits of Technology Observed by Respondents

Figure 4.5 below indicates the respondent's statistical analysis of the respondent's identification of roles and benefits of utilising technology in their architectural design practice. improved design visualisation ranks the highest with 81.4% affirming it as a benefit, increased efficiency in project delivery comes in next with 73.4%, Reduction in errors and rework follows with 69.3%, and better communication with clients with a rate of 47.7% affirmed to it being the roles and benefits of identified technology.

Figure 4.5: Benefits of Technology Observed by Respondents

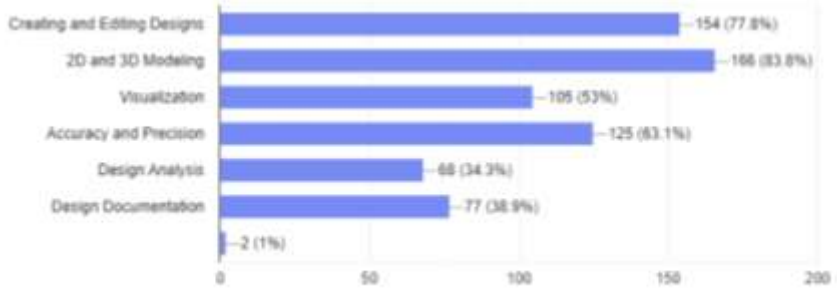


Source: Author's field survey (2023)

Roles of Computer-Aided Design (CAD) to Respondents

Figure 4.6 below indicates that 2D and 3D modeling ranks the highest as the role of computer-aided Design (CAD) to respondents selected by 83.8% of them, Creating and editing designs, and design documentation with 38.9% and 34.3 % utilise it for Design analysis. From this, the majority of respondents identify 2D and 3D modeling as a primary role of Computer-aided design (CAD).

Figure 4.6: Roles of Computer-Aided Design (CAD) to Respondents

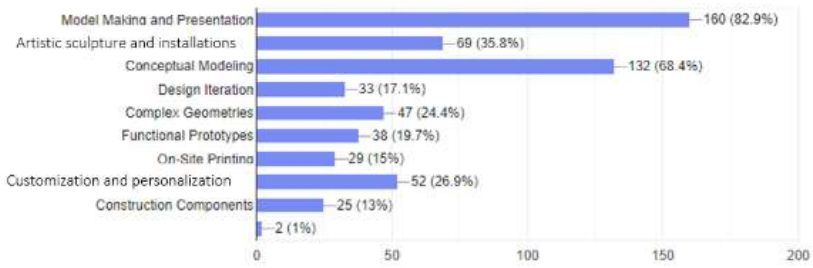


Source: Author's field survey (2023)

Role of 3D Printing to Respondents

Figure 4.7 indicates model making ranks the highest as the role of 3D printing to Architects with 83% of respondents affirming it, conceptual modeling comes in with 68%, and artistic and sculptural installations with 35%.

Figure 4.7: Role of 3D Printing to Respondents

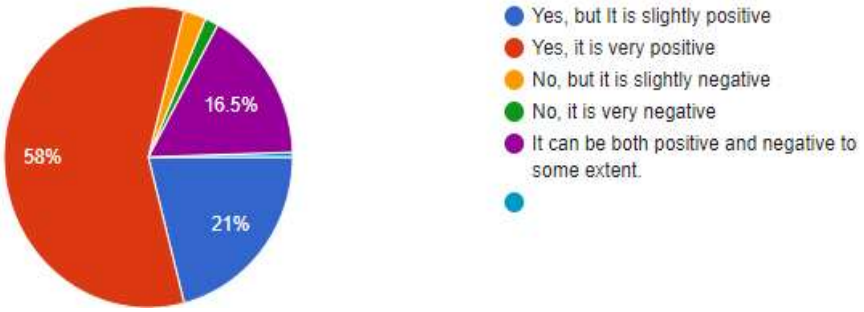


Source: Author's field survey (2023)

Respondents' Perception of Technology on the Architectural Industry in Nigeria

Figure 4.8 below indicates that 58 % of respondents agree that the adoption of emerging technologies will have more of a positive impact on the architectural industry in Nigeria, 20.9% agree that the impacts will be positive but only slightly, 16.9% think it can be positive and negative impacts to some extent.

Figure 4.8: Respondents' Perception of Technology on the Architectural Industry in Nigeria

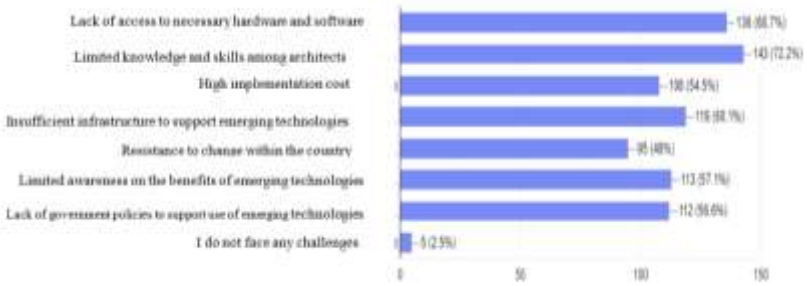


Source: Author's field survey (2023)

Respondents Challenges Faced in the Adoption of Emerging Technologies

Figure 4.9 below indicates that Limited technical knowledge and skills among architects rank the highest by 72.2% of respondents to be a major challenge that is faced by the architectural industry in Nigeria, Lack of access to necessary hardware and software follows next with 68.7% of respondents affirming, Insufficient infrastructure next with 60.1% affirming, Limited awareness and understanding of the benefits of emerging technologies affirmed by 57.1%, 48% affirmed to resistance to change within the industry and 56.6% affirmed to lack of government policies to promote the use of emerging technologies. 2.5% of respondents claim to not face any challenges.

Figure 4.9: Respondents Challenges Faced in the Adoption of Emerging Technologies



Source: Author's field survey (2023)

From the compiled survey results, limited technical knowledge and skills among architects and, lack of access to necessary hardware and software are the major challenges faced in Nigeria in the journey of incorporating emerging technologies in architectural design practice.

Conclusion and Recommendations

The integration of emerging technologies in architectural design practice has become a significant topic of interest in recent years, especially in developing countries like Nigeria. The utilisation of these technologies has the potential to transform the architectural design and construction process by boosting efficiency, reducing costs, and enhancing the quality of design outcomes. This study has accessed the potential and challenges of emerging technology in architectural design practice in Nigeria. This research has highlighted numerous emerging technologies that have the potential to influence architectural design practice in Nigeria. These technologies include Building Information Modeling (BIM), Virtual Reality (VR), and 3D printing. The study has also identified various difficulties that inhibit the acceptance and deployment of these technologies in Nigeria. These difficulties include a lack of technical know-how, a lack of access to technology, and opposition to change.

Emerging technologies have the potential to revolutionise the field of architectural design practice in Nigeria, as such, this study highly recommends that Architects in Nigeria begin to explore and integrate these technologies into their daily practices. By embracing these, architects can begin to look forward to utilising technology and becoming a lot more efficient, creating innovative and data–driven designs that push the limits of possibilities in architecture and designs as a whole. The government and Architectural bodies in Nigeria such as the Architects Registration Council of Nigeria (ARCON) and the Nigerian Institute of Architects (NIA) should provide incentives and funding for architects to acquire the necessary skills and knowledge to use these technologies effectively. The government should also invest in the necessary infrastructure, such as high-speed internet, to enable architects to access these technologies.

Also, architects should be encouraged to be proactive in their approach to technology adoption. Architects should embrace emerging technologies and take the initiative to learn how to use them effectively.

Bibliography

1. Adamopoulou, E., Moussiades, L., & Springer, C. (2020). In IFIP international conference on artificial intelligence applications and innovations. An overview of chatbot technology, 373-383.
2. Adebisi, D. I., & Adeoye, D. O. (2018). EVALUATION OF RESIDENTIAL-BASED ARCHITECTURAL FIRM FACILITIES TOWARDS REDESIGNING: A CASE STUDY OF SOUTH WEST NIGERIA. LAUTECH Journal of Engineering and Technology, 12(1), 113-133.
3. Ahmad, D., & Reza, M. (2018). The use of technology in English language learning. A literature review. International Journal of Research in English Education, 3(2), 115-125.
4. Ahuja, R., Sawhney, A., Jain, M., Arif, M., & Rakshit, S. (2020). Factors influencing BIM adoption in emerging markets–the case of India. International Journal of Construction Management, 20(1), 65-76.
5. Akanle, O., & Shittu, O. S. (2022). The unending development question of Nigeria. The European Journal of Development Research, 34(1), 321-342.
6. Alizadehsalehi, S., Hadavi, A., & Huang, J. (2020). From BIM to extended reality in AEC industry. Automation in Construction,, 116, 103254.
7. Balali, V., Zalavadia, A., & Heydarian, A. (2020). Real-time interaction and cost estimating within immersive virtual environments. Journal of Construction Engineering and Management, , 146(2), 04019098.
8. Battaglio, J., P, B., P, B., & N, C. (2019). Public Administration Review. Behavioral public administration ad fontes: A synthesis of research on bounded rationality, cognitive biases, and nudging in public organizations, 79(3), 304-320.
9. Bechthold, M., & Weaver, J. (2017). Materials science and architecture. Nature Reviews Materials, 2(12), 1-19.
10. Berg, L. P., & Vance, J. M. (2017). Industry use of virtual reality in product design and manufacturing: a survey. Virtual reality, 21, 1-17.
11. Bhargav, A., Sanjairaj, V., Rosa, V., Feng, L., & Fuh, Y. (2018). Applications of additive manufacturing in dentistry: A review. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 106(5), 2058-2064.
12. Botín-Sanabria, M., Mihaita, S., Peimbert-García, E., Ramírez-Moreno, A., Ramírez-Mendoza, A., & Lozoya-Santos, J. (2022). Digital twin technology challenges and applications: A comprehensive review. Remote Sensing, 14(6), 1335.
13. Cargill, M., & Connor, P. (2021). Strategy and steps. John Wiley & Sons.
14. Claypool, J. G., & Retsin, S. (2019). Robotic building. Architecture in the age of automation. De Gruyter.
15. Ghobakhloo, M., & Ching, N. (2019). Journal of Industrial Information Integration. Adoption of digital technologies of smart manufacturing in SMEs, 16, 100107.

16. Gokhale, Bhat, & Bhat. (2018). Introduction to IOT. International Advanced Research Journal in Science. Engineering and Technology, 5(1), 41-44.
17. Hein, C. (2016). Port cityscapes: conference and research contributions on port cities. Planning Perspectives, 31(2), 313-326.
18. Moazami, A., Nik, M., Carlucci, S., & Geving, S. (2019). Impacts of future weather data typology on building energy performance–Investigating long-term patterns of climate change and extreme weather conditions. Applied Energy,, 238, 696-720.
19. Nadagouda, N., Rastogi, V., & Ginn, M. (2020). A review on 3D printing techniques for medical applications. Current Opinion in Chemical Engineering, 28, 152-157.
20. Ngarambe, J., Yun, Y., & Santamouris, M. (2020). The use of artificial intelligence (AI) methods in the prediction of thermal comfort in buildings: Energy implications of AI-based thermal comfort controls. Energy and Buildings,, 211, 109807.
21. Nordmann. (2020). In The Ethics of Nanotechnology, Geoengineering, and Clean Energy (pp.). Routledge. If and then: A critique of speculative nanoethics, 115-130.
22. Obiadi, B., Onuorah, I., Mba, P., Okafor, C., & Kikanmen, I. E. (2022). The shift in the architecture of the Nigerian cities: the case of rural to urban migration and the consequences in the Built Environment. Irish International journal of Engineering and Scientific Studies, 5 (4).
23. Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. Journal of intelligent manufacturing, 31, 127-182.
24. Piazza, C., Grioli, G., Catalano, M. G., & Bicchi, A. J. (2019). A century of robotic hands. Annual Review of Control, Robotics, and Autonomous Systems, 2, 1-32.
25. Rao, A., Barkley, D., França, G., & Yanai, I. (2021). Exploring tissue architecture using spatial transcriptomics. Nature, 596(7871), 211-220.
26. Schjoldager, K., Narimatsu, Y., Joshi, J., & Clausen, H. (2020). Global view of human protein glycosylation pathways and functions. Nature reviews Molecular cell biology, 21(12), 729-749.
27. Shivegowda, D., Boonyasopon, P., Rangappa, M., & Siengchin, S. (2022). A review on computer-aided design and manufacturing processes in design and architecture. Archives of Computational Methods in Engineering., 29(6), 3973-3980.
28. Sima, V., Gheorghe, I., & S. N. (2020). Influences of the industry 4.0 revolution on the human capital development and consumer behavio. A systematic review. Sustainability, , 12(10), 4035.
29. Sony, M., & Naik, S. (2020). Production Planning & Control. Critical factors for the successful implementation of Industry 4.0: a review and future research direction, 31(10), 799-815.
30. Tidd, J., & Bessant, J. (2020). Managing innovation: integrating technological, market and organizational change. John Wiley & Sons.
31. Zhang, Y., Liu, H., Kang, S., & Al-Hussein, M. (2020). Virtual reality applications for the built environment: Research trends and opportunities. Automation in Construction, 118, 103311.

32. Zhao, X. (2020). Computer-Aided Design and Applications. Application of 3D CAD in landscape architecture design and optimization of hierarchical details, 18(S1), 120-132.