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Research Article

Key Barriers to 3D Printing Technology Adoption for Sustainable Project Delivery in Nigeria

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Abstract

Adopting 3D printing technology has the potential for sustainable construction practices and mitigating environmental impacts. There are challenges to its adoption in developing countries. Hence, this study evaluates the barriers to adopting 3D printing technology in Nigeria. A post-positivist philosophical approach guided a quantitative research methodology towards a questionnaire survey. The population comprises stakeholders who focus on 3D printing technologies and are involved in sustainable development. Using snowball sampling, 380 questionnaires were distributed online; 253 copies were retrieved, screened, and analysed using descriptive and inferential analysis. The mean scores range from 3.09 to 3.46, with key barriers such as limited technical expertise, inadequate regulatory frameworks, and cultural resistance. The Kruskal-Wallis H test outcome revealed that the respondents' opinions differed significantly for the variables since their p-values were less than 0.05. It is recommended that there is a need to enhance awareness of 3D printing technology through workshops, seminars, and demonstration projects that engage construction professionals and industry stakeholders. The study suggests developing technical skills through vocational training programs and certifications for a robust 3D printing workforce.

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Highlights

- The Key barriers to 3D concrete printing in Nigeria includes expertise, regulation, and culture.
- Stakeholder opinions on the adoption barriers to 3D concrete printing, differ significantly by group.
- Training and awareness campaigns are critical for enabling the adoption of 3D printing.

1 Introduction

In recent decades, the construction industry has been more interested in creative ways to improve construction performance in terms of cost, time, and the environment by using three-dimensional printing (3D printing) (Tay et al., 2017; Buchanan & Gardner, 2019). Time overruns, project delays, abandonment, safety concerns, budget overruns, inefficiency, rigid design, material waste, and other problems caused by a lack of critical information plague the construction sector. Shittu and Kadiri (2013). Housing for middle-class and lower-class families has been severely impacted by population growth. Homes with complete control over the project's design and execution are only accessible to the wealthy and influential (Mehar et al., 2020). The advancement of 3D printing brought about a new era in the construction business. In the manufacturing industry, 3D printing has gained popularity in automating procedures, increasing output, and cutting waste (Perkins & Skitmore, 2015). With its layer-by-layer control and automated production capabilities, 3D printing has advanced significantly over the years, mainly in the industrial sector for decades and, more recently, in the building sector for printing homes and villas (Wu, Wang, and Wang, 2016). 3D printing is an additive manufacturing process that creates three-dimensional structures layer by layer. Using additive manufacturing techniques, data is extracted from a computer-aided design (CAD) file and converted into a stereolithography (STL) file. Triangles and slices that include the data for each layer, which will be printed during the procedure, correspond with the drawing made in CAD software (Wong & Hernandez, 2012). Bogue (2013) defines a 3D printer as an automated additive manufacturing system that uses computer-aided design (CAD) to print 3D solid items. Significant advancements, mainly due to the development of new, sophisticated, highly functional, and 3D printable materials, were starting to move the technology away from one-off prototypes, models, guides, and other products made of simple plastics and metals to mass production of complex products such as industry, academia, and government began to fully focus on the technology (Jakus, 2019). In recent years, 3D printing has expanded to include construction products other than ceramics, including plug fixtures, window frame fixtures, and plumbing fittings (Alzarrad & Elhouar, 2019). The invention of the 3D printer led to the development of 3D printing building technology, a new construction approach. According to the newest technology, contour crafting can revolutionise the building industry soon (Hager, Golonka, and Putanowicz, 2016). This technology has several benefits, such as saving time and money, reducing pollution, and reducing casualties. Teizer et al. (2016) stated that the construction industry has recently and successfully applied industrial applications of 3D printing technology in several fields, such as successive concrete layers. Furthermore, the fundamental concept of 3D printing is that complex geometric designs can be printed on a huge scale using a series of 2D layers by reducing the 3D volume in the computer.

Even though 3D printing has been around since the late 1970s, it has only recently gained popularity in the second decade of the twenty-first century. Due to media attention and the increasing availability of consumer-level technology, 3D printing has recently sparked a lot of "futuring" activity (Stein, 2017). As a result of the abrupt and rapid increase in awareness of 3D printing during the fourth period (2005-2012) and a lack of knowledge about its history, 3D printing is often viewed as a new technology, even though it has been around for more than thirty years (Jakus, 2019). Though generally regarded as more efficient than traditional methods, this technique is underutilised in the construction industry (Teizer et al., 2016). Until recently, industrialised countries welcomed 3D printing, which led to its gradual expansion and improvement in the building industry. In developing countries, especially in Africa, there is a lack of awareness of 3DP technology (Farabiyi & Abioye, 2017). Even South Africa, which has embraced additive manufacturing, has a relatively low utilisation rate of 3D printing for building construction. The adoption of 3DP technology for housing delivery in South Africa has been hampered by the building industry's experts ' lack of knowledge of the technology's technical capabilities and advantages (Aghimien et al., 2020). Construction has a lower adoption rate than other industries, according to Wu et al. (2018), despite the many benefits that 3D printing can offer. According to Teizer et al. (2016), building companies are looking into alternative construction methods due to the increased public knowledge of 3D printing. Furthermore, Jakus (2019) reaffirmed that, rather than any significant scientific advancement, the rapid proliferation and widespread awareness of 3D printing were mostly caused by the synchronisation of important legal and social events/groups. According to Johnston (2016), one of the goals of the 2030 Agenda for Sustainable Development and Arsenic is to guarantee that everyone on the planet has access to the necessary knowledge and awareness for sustainable development and environmentally friendly lifestyles by that year. According to Oke et al. (2018), strengthening digital technology and fostering collaboration can be achieved through government loans, a sufficient power supply, reducing the cost of digital tools, ensuring that every department creates and maintains a computerised information system, increasing awareness about technology use, and supporting local research and development. It can be ascertained that prevalent construction methods in Nigeria are characterised by inefficiencies such as high labour costs, substantial material wastage, lengthy project timelines, and significant carbon emissions.

Despite global advancements in 3D printing technology offering solutions such as enhanced precision, reduced material wastage, and shortened construction times, its adoption within Nigeria's construction industry remains minimal. It is critical to obtain a thorough understanding of the challenges associated with 3D printing technology adoption; this will guide policymakers and industry stakeholders in developing effective strategies and policies that will promote the technology's adoption. There is inadequate research that has explored the challenges to adopting 3D printing technology in the Nigerian construction industry. Hence, this study aims to evaluate the barriers to adopting 3D printing technology for sustainable project delivery in Nigeria.

2 Research Methodology

This study used empirical data and a post-positivist philosophical approach to evaluate the barriers to 3D printing technology adoption in Nigeria's construction industry. This philosophical perspective influenced a quantitative research methodology using a questionnaire survey. According to Creswell (2014), quantitative research gathers numerical data that may be classified, ranked, or evaluated using measurement units. To gather information from the target population for this study, a closed-ended questionnaire was developed using data from the studied literature on the obstacles to implementing 3D printing technology. The questionnaire was divided into two sections. Section A gathered background data from respondents, while Section B focused on the barriers to 3D printing technology adoption in Nigeria's construction sector. According to Oke et al. (2020), the questionnaire has been used extensively in most studies about construction and can swiftly cover a large range of respondents. Respondents indicated their agreement or disagreement with the criteria using a 5-point Likert scale. According to Joshi et al. (2015), a 5-point Likert-type scale improved response quality and rate while lowering respondents' annoyance. Due to the statistical methodology of the study, the target population consisted of 3D printing technology researchers, architects interested in designing sustainable buildings, construction managers in Nigeria, policymakers involved in sustainable development or construction regulations, and civil engineers with experience in sustainable construction. Due to their direct involvement in the building and decision-making processes of the built environment, several professional groups were chosen.

The study's design required a snowball sampling technique—a method of gathering data in which research participants help recruit new study participants. Research using hardly identifiable respondents has employed this method (Mould-Millman et al., 2017; Akinradewo et al., 2022; Ebiloma et al., 2024). The snowball sampling was selected for this study because the need for 3D printing technology in the Nigerian construction industry is novel and innovative; hence, there is a need to obtain the needed information from industry stakeholders, professionals, and other relevant officers who are well-grounded in sustainable construction practices and research. Four sustainable construction professionals from academia and industry were chosen to achieve this, as they assisted in identifying, referring, and recruiting the professionals and stakeholders who satisfied the requirements and were eligible to participate in the study. 253 copies of the 380 online surveys that were distributed were recovered. Every recovered questionnaire was examined and determined to be appropriate for analysis.

Tables and charts were used to derive statistical conclusions based on their responses. The responses were examined using the Statistical Package for the Social Sciences (SPSS) software and Microsoft Excel. The data was examined to determine percentiles, frequencies, and mean item scores. Percentiles and frequencies were used to examine the respondents' demographic data, and the mean item score was used to sort the variables according to the respondents' answers. In addition to the descriptive analysis, an inferential examination of the differences in the viewpoints of the different respondent groups concerning barriers to the use of 3D printing technology in the Nigerian construction sector was conducted. This was accomplished using the Kruskal-Wallis H test, which is suitable for determining the differences in respondents' opinions that belong to more than two groups (Yong & Pearce, 2013). Cronbach's alpha was used to assess the study instrument's reliability; the results showed an alpha value of 0.931, confirming the validity of the data obtained from the questionnaire survey.

3 Research Findings and Discussion

3.1 Demographic Information of Respondents

The results of the characteristics of the respondents gathered from the 253 completed and recovered questionnaires utilised for the study are shown in Table 1. These include occupation, years of experience, and level of education. Table 1 displays the occupations of the study participants. Most participants—34.4%, or 87 respondents—are civil engineers. Construction managers, who comprise 32% of the sample (81 respondents), come next. Another important group is architects, who comprise 19% (48 responders). The representation of other occupations is lower, with policymakers accounting for 5.1% (13 respondents) and researchers for 9.5% (24 respondents). This result suggests that the study sufficiently represented the necessary and pertinent professionals.

Table 1: The demographic characteristics of the respondents (Source: Author's findings)

Respondents' characteristics	Frequency (n = 253)	Percentage
Years of experience		
1-5 years	62	24.5
6-10 years	114	45.0
11-15 years	55	21.7
16-20 years	14	5.5
Above 20 years	8	3.2
Educational status		
OND	8	2.5
HND	15	4.8
B.Sc.	135	43.0
B.Tech.	6	1.9
M.Sc.	53	16.9
PhD	36	11.5
Occupation		
Construction Manager	81	32.0
Architect	48	19.0
Civil Engineer	87	34.4
Researcher	24	9.5
Policy Maker	13	5.1

Table 1 summarises the respondents' distribution according to the years they worked in the construction business. The data shows that, with 114 respondents, or 45% of the sample, the largest category consists of respondents with 6–10 years of experience. Next in line are those with 1–5 years of experience (24.5%) and those with 11-15 years of experience (21.7%), respectively (62 respondents). Just 8 respondents (3.2%) have more than 20 years of experience, whereas 14 respondents (5.5%) have 16–20 years. This indicates that fewer respondents have substantial experience. Given that 3D printing technology is a recent development in the Nigerian construction sector, this indicates that the study's findings are sufficient. The respondents' distribution according to their level of education is displayed in Table 1. Most participants, or 43.0% (135 respondents) of the sample, had a B.Sc. Respondents with

M.Sc. degrees come next, who comprise 16.9% of the sample (53 respondents). Interestingly, 36 participants, or 11.5% of the answers, hold a PhD, suggesting that the sample contains highly educated professionals. Additional credentials consist of an Ordinary National Diploma (OND) for 2.5% (8 respondents) and a Higher National Diploma (HND) for 4.8% (15 respondents). Six responders (1.9%) have a B.Tech degree. This demonstrates that the respondents have the experience, knowledge, and training to supply the data required for the study. This also indicated that the respondents have obtained the academic capacity on the subject matter and associated fields.

3.2 Barriers to 3D Printing Technology Adoption for Sustainable Project Delivery in Nigeria

The evaluation of challenges to using 3D-printed concrete in the Nigerian construction industry is presented in Table 2. This table summarises the mean scores for various identified challenges based on responses from 253 participants. The mean scores range from 3.09 to 3.46, indicating varying levels of concern regarding these challenges. Using the Kruskal-Wallis H test, Table 2 also displays the results of the disagreements among the respondents. Asymp. Sig. scores below 0.05 in the Kruskal-Wallis H test suggest that respondents' opinions differ significantly. The highest mean score of 3.46 is associated with the challenge of "lack of building codes." This suggests a significant perception among respondents that the absence of established regulatory frameworks hinders the adoption of 3D printing technology in construction. Following closely, the statement "inadequate power supply" received a mean score of 3.43. This highlights a critical concern regarding the reliability of electricity, which is essential for the operation of 3D printing machinery. The challenge of "insufficient investment cost" was perceived with a mean score of 3.40, indicating that financial constraints pose significant barriers to adopting 3D concrete printing. This concern is crucial as substantial initial investment is often required for technology acquisition and implementation. Respondents also highlighted "worker resistance to new technology," which received a mean score of 3.34. This suggests that a cultural hesitance to embrace innovative technologies may impede the integration of 3D printing in construction processes.

Table 2: Adoption barriers of 3D printing technology in Nigeria (Source: Author's findings).

Barriers	Mean	Kruskal-Wallis H	Asymp. Sig.	Rank
Lack of building codes	3.46	6.6765	0.1540	1st
Inadequate power supply	3.43	12.3758	0.0148	2nd
Insufficient investment cost	3.40	37.6746	0.0000	3rd
Worker resistance to new technology	3.34	20.3684	0.0004	4th
Inadequate material sourcing	3.32	20.7275	0.0004	5th
Lack of training and local studies	3.30	20.9767	0.0003	6th
Delay in process integration	3.29	20.7550	0.0004	7th
Government discontinuity	3.27	23.6415	0.0001	8th
Lack of quality control system	3.27	15.8716	0.0032	9th
Budgetary and cash flow issues	3.26	5.9791	0.2007	10th
Lack of awareness among stakeholders	3.25	19.3900	0.0007	11th
Lack of equipment maintenance	3.24	16.3194	0.0026	12th
Lack of skilled personnel	3.24	19.8830	0.0005	13th
The dearth of government policies	3.09	14.2710	0.0065	14th

Additionally, the mean score of 3.32 for "inadequate material sourcing" indicates challenges in accessing suitable materials for 3D printing, which is essential for ensuring the quality and sustainability of printed structures. Furthermore, the challenge of "lack of training and local studies" received a mean score of 3.30. This reflects a recognised need for educational initiatives and research to enhance knowledge and skills related to 3D printing technology among industry professionals. The delay in process integration, with a mean score of 3.29, indicates that integrating new technology into existing workflows remains a significant obstacle. The perception of "government discontinuity" as a challenge, with a mean score of 3.27, underscores the importance of stable government policies and support for technological advancements in construction. The same mean score applies to the lack of a quality control system, indicating that respondents believe that ensuring quality in 3D printed constructions is a pressing concern. Additional challenges, such as "budgetary and cash flow issues" (mean = 3.26), "lack of awareness among stakeholders" (mean = 3.25), "lack of equipment maintenance" (mean = 3.24), and "lack of skilled personnel" (mean = 3.24), further illustrate the multifaceted barriers to implementing 3D printing in the construction sector. The relatively close mean scores suggest that these challenges are perceived as interrelated and can compound one another, complicating the transition to innovative construction methods. Lastly, the challenge associated with "the dearth of government policies" received the lowest mean score of 3.09. While this score indicates a recognised issue, it also suggests that respondents may prioritise other challenges more highly. The Kruskal-Wallis H test outcome revealed that the respondents' opinions were inconsistent, variant, and not uniform since most of the p-values were less than 0.05; however, the variables "Lack of building codes" and "Budgetary and cash flow issues" scored greater than 0.05, which showed that the respondents agreed with the variables. This outcome reflects the role of the industry and government in developing regulations, frameworks, and robust funding for the full implementation of 3D printing technology in the construction industry.

3.3 Research Discussion

While the advantages of 3D-printed concrete are compelling, the study highlights several significant challenges that hinder its adoption in Nigeria. These challenges stem from various sources, including technological limitations, economic constraints, regulatory issues, and cultural barriers. The study identified the most critical challenge to be "lack of building codes." This suggests that the absence of established regulatory frameworks hinders the adoption of 3D printing technology in the construction industry. Following closely, "inadequate power supply" ranked next and highlighted a critical concern regarding the reliability of electricity, which is essential for the operation of 3D printing machinery. The challenge of "insufficient investment cost" was among the foremost barriers, indicating that financial constraints pose a significant hindrance to the adoption of 3D concrete printing. This concern is crucial as substantial initial investment is often required for technology acquisition and implementation. The lack of adequate infrastructure to support 3D printing technology presents a formidable barrier to its adoption. The sophisticated equipment and materials required for 3D concrete printing may not be readily available in Nigeria, particularly in rural areas where traditional construction methods are more prevalent (Hager et al., 2016). Moreover, the skill gap within the Nigerian workforce poses a significant hurdle. The successful operation and maintenance of 3D concrete printers necessitate specialised knowledge and expertise currently limited among construction professionals in the country. According to Bos et al. (2016), addressing this skill gap requires comprehensive training programs that teach the technical aspects of 3D printing and promote an understanding of the technology's benefits and applications.

The lack of training and educational initiatives may inhibit the industry's ability to fully leverage the advantages offered by 3D printing. Regulatory barriers further complicate the landscape for 3D printing in Nigeria. The absence of established standards and regulations tailored to 3D-printed structures can hinder the technology's acceptance and implementation. Buswell et al. (2018) noted that a lack of a robust regulatory framework can create uncertainty among stakeholders regarding safety, quality, and compliance issues. Developing clear guidelines that govern the use of 3D printing in construction is essential for instilling confidence in the technology among investors, builders, and the public. The lack of regulatory oversight may result in inconsistent quality control and safety standards, ultimately impacting public trust in 3D-printed structures. Cultural factors also significantly influence the construction industry's resistance to adopting 3D printing technology. Traditional building practices are deeply entrenched in Nigeria, and there may be scepticism or reluctance to embrace new technologies, especially those that significantly alter established construction processes. Overcoming these cultural barriers requires demonstrating the tangible benefits of 3D printing, including its efficiency, cost-effectiveness, and design possibilities. Engaging local communities in pilot projects and educational campaigns can help build trust and acceptance of 3D printing technology (Aghimien et al., 2020). The invention of 3D Printing for construction projects is a dynamic technological solution for some uncontrollable changes induced by the conventional procurement process that cause cost overrun, time overrun, etc. 3D printing was advanced to solve the growing housing demands from rapid urbanisation in developed and developing countries, where conventional construction methods fail to meet the rising demands. For example, the rising application of technology in China and the Netherlands practically indicates that these countries have met their housing demands. Technologically, developing countries, especially Nigeria, have not experienced the prominent implementation of 3D printing technology for construction activities like the developed countries. Whereas 3DP technology has the innovative potential to solve the housing deficit in Nigeria, this is put at 18 million units and 24.4 million units for the low-income earners and the homeless, respectively. Nigeria creates a high market potential for 3DP technology in its construction industry to enhance housing provision while deriving benefits of faster construction, reduced material use and cost, improved safety on site, labour requirement savings, and durable and sustainable construction. The multifaceted challenges associated with adopting 3D printing in concrete highlight the need for a collaborative approach involving various stakeholders, including government bodies, industry leaders, and educational institutions. Recognising these barriers is the first step toward developing targeted strategies to address them and unlock the full potential of 3D printing technology in Nigeria's construction sector.

4 Conclusion and Recommendations

This study has evaluated the barriers to adopting 3D printing technology in the Nigerian construction industry. Despite the clear benefits, the study uncovered a significant gap between awareness and practical application of 3D printing technology among construction professionals in Nigeria. While knowledge of the technology grows, its implementation and thorough understanding remain limited. This discrepancy points to several challenges hindering widespread adoption. The research identified multiple obstacles to integrating 3D printing in Nigeria's construction industry. These include a lack of specialised technical expertise, insufficient government support, and industry-specific building regulations for 3D-printed structures. Additionally, cultural resistance to new technologies plays a role in slowing down adoption rates. To address these hurdles, the study proposes several strategic actions. These include the development of international partnerships to facilitate knowledge transfer, the establishment of local research centres to drive innovation, and organising professional training workshops to build capacity. Moreover, the research emphasises the critical role of government intervention through supportive policies and financial incentives in promoting 3D printing for sustainable construction practices. Furthermore, the establishment of regulatory frameworks tailored to 3D-printed structures is recommended. This step ensures safety, quality, and compliance, fostering industry confidence in the technology. Clear regulations will provide a solid foundation for the widespread implementation of 3D printing in construction projects.

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Ethical Approval Declaration

The study was conducted in accordance with established standards for research integrity and ethics.

Informed Consent Statement

All participants provided informed consent before participating in the study.

Data Availability Statement

Data can be made available upon request to the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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