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Research Article

# Assessment of the adoption of 3D printing technology for construction delivery: A case study of Lagos State, Nigeria

**Akintayo OPAWOLE**[*1], **Betty Oluwafunso OLOJEDE**[2], **Kahilu KAJİMO-SHAKANTU**[1]

[1]*Department of Quantity Surveying & Construction Management, Faculty of Natural & Agricultural Science, University of the Free State, Bloemfontein, South Africa*
[2]*Department of Quantity Surveying, Faculty of Environmental Design & Management, Obafemi Awolowo University, Ile-Ife, Nigeria*

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## ABSTRACT

The innovative solutions offered by integrating 3D printing technology in construction over the conventional practices have established its globally rising adoption in the construction industry. This study assessed the awareness, application, drivers, and barriers to adopting enhanced 3D printing technology for construction to enhance faster and more sustainable construction processes. The study adopted a quantitative descriptive analysis which was based on primary data. The primary data were obtained using structured questionnaires self-administered to construction firms/contractors in Lagos State, Nigeria. Data collected were analyzed using descriptive and inferential statistics. The study established that the awareness and application levels of the technology are still deficient, as the vast majority (80.8%) of the firms who had an awareness of the technology in the study area acquired it through personal research and professional dialogue, rather than through the practical application of the technology. This finding showed that 3DP technology is a new construction option in the study area. The findings showed statistically significant differences among the drivers ($0.039 \leq p \leq 0.017$) for the adoption of 3D printing technology, which is influenced by the client's demand and desire. The study further established that inadequate power source is a significant limiting factor to adopting 3D printing in the study area. Implications are indicated by the findings on the technology drivers and barriers that could help the construction industry in developing countries towards capability improvement for better adoption of 3D printing innovation and enhanced sustainable construction process.

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***Corresponding author.**
*E-mail address: tayoappmail@gmail.com

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## 1. INTRODUCTION

The technological revolution in building construction dates to the 19th century, when semi-automated equipment was introduced to allay the rigor of construction activities, enhance easier and faster construction tasks and improve environmental sustainability [1, 2]. For instance, hydraulic excavators and bulldozers were introduced to replace the cable-operated shovels for earthworks, while the conveyors and pumps replaced cranes for concrete placement. This optimized concrete works from 12 m3/hour to -50 $m^3$/ hour speed of placing fresh concrete. Studies have established the enhanced performance and efficiency of building automated technologies for complex structures over conventional construction [3, 4].

The current trend of the fourth industrial revolution (Industry 4.0) launched a variety of innovative technologies to improve product quality and increase industry performance through the digitization of complex industrial tasks, viz—3D printing (3DP) technology, robotic arms, drones, etc. [5]. The invention of 3DP for building construction is a dynamic technological panacea for some uncontrollable changes induced by the conventional procurement process that cause cost over-run, time over-run, etc. Unabated innovative studies by 3DP proponents and advocates have therefore been persuasive towards adapting 3DP technology to the construction industry to improve, complement, and eventually replace conventional building construction methods [6, 7]. However, the full potentials of the technology are yet to be explored through its high practical applications in the construction industry like the automotive and manufacturing industry [1, 5].

3DP was established to solve the growing housing demands from rapid urbanization in developed and developing countries, where conventional construction method errs to meet the rising demands [8–10]. For example, the rising application of the technology in China and the Netherlands is practically indicative of having met these countries' housing demands [5, 7, 9]. Technologically developing countries, especially Nigeria, are yet to experience the prominent implementation of 3DP technology for construction activities like the developed countries [1]. 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 between the low-income earners and the homeless, respectively [11]. 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, labor requirement savings, and durable and sustainable construction [7, 12, 13].

Empirical evidence on 3D printing of building construction in Africa is generally scanty. This study, therefore, investigated the awareness level of 3DP in Nigeria; examined the drivers and barriers to its adoption; and the level of its use for construction in the country. This is to inform policy development and implementation for the application of 3DP in the Nigerian construction industry to boost housing provisions and enhance the country's economy.

## 2. LITERATURE REVIEW

### 2.1. 3DP Technology in Construction and its Awareness

Innovative solutions to enhancing the performance of construction concerning cost, time, and the environment by implementing 3D printing have gained popularity in the construction industry in recent decades [7, 14]. 3DP is also known as additive manufacturing (AM) by its layer-upon-layer process of fabricating 3D solid objects. 3DP technology produces objects from a digital 3D CAD model by slicing the model into a series of 2D building layers before printing. The processed sliced 2D building layers (a set of 2D contour lines) generate control commands to position the printing head for printing by depositing materials using nozzle and print head/laser beams [15].

The United States of America, Russia, China, Germany, and the Netherlands have used 3DP in construction industries for buildings and bridges with satisfactory results [16]. It is believed that 3DP addresses the problem of low labor productivity and labor shortage in the USA, UAE, Qatar, and Singapore, where migrant workers account for about 90% of the construction workforce [1]. The potential opportunities and benefits of 3DP have influenced future construction plans, policies, and countries' targets in the global construction markets. For instance, Dubai planned 25% of its construction targets to be 3D printed by 2030. The 3D construction printing (3DCP) market forecast is expected to reach USD 314 million from USD 130 million between 2017 and 2023. Over 7000 construction robots are forecast to be deployed between 2018–2025 [1, 17].

The level of awareness of 3DP technology in developing countries is low, particularly in Africa [18]. South Africa, which has embraced additive manufacturing with up to 450 AM machines installed in the industry, has relatively limited use of the 3D printer for building construction. Lack of awareness of the benefits and understanding of the technical know-how of 3DP by professionals in the construction industry were proven as barriers to adopting the technology for housing delivery in South Africa [19]. Farabiyi & Abioye [18] revealed that the awareness of automation techniques in the Nigerian construction industry is limited to CAD, crane, and BIM. This implied that the awareness level of 3DP is low in the country.

#### *2.1.1. 3D Printing Software*

The design of the 3D CAD model is generated by open source packages like the Autodesk Inventor and Blender [20, 21]. Other software packages include SolidWorks, Google SketchUp, and Autodesk Revit (the construction industry BIM software) [5]. The model is exported to an STL

**Table 1.** 3D printing techniques

| 3D printing techniques | Machine | Production process | Material | Structure | Source |
|---|---|---|---|---|---|
| Contour crafting (printing dimension is mega-scale) | Gantry system, (with gantry-driven nozzle); i.e 150mx10mx6.6m gigantic 3D printer (by WinSun); RepRap 3D print | Extrusion process: Cementitious concreting layer by layer (no formwork) Filling process | Cementitious material: Cement and sand | Concrete buildings, houses | [30, 32] |
| D-shape/Binder jetting (printing dimension is limited by frame) | D-shape 3D printer (2007, Italy)) 6mx6mx6m printing dimension | Binder jetting<br><br>Powder-based/ selective binding | Powder bases; selective binder; sand | Architectural artifacts (for example, 1.6m freeform sculpture); a whole house; landscape house design | [7, 30, 32] |
| | Robotic 3D printer (2012, Spain) | | | Architectural structures | [30] |
| Concrete printing (printing dimension is limited by frame) | Concrete 3D printer, i.e., four-axis gantry robot with a print bed of 9.0mx4.5mx3m | Extrusion & deposition (no formwork) | High-performance concrete; cement mixture | | [30, 32] |

(Stereolithography) format to interpret and decompose the model into building layers or slices [15]. The slices are sets of 2D contour lines that generate control commands to activate the printing processes by the printer. The production/fabrication of 3D structures is in layers. This technology requires little or no external human (skilled or unskilled) assistance, unlike the labor-intensive requirements in conventional construction, except for the computerized building design experts, digitally savvy, and machine operators [1, 22]. The 3D CAD models of different structures have been successfully printed into physical edifices by some companies, institutes, and universities. Some of them are Winsun company (China), 3D Printhuset (Denmark), CyBe (Netherlands), ApisCor (Russia), COBOD (Germany), and Tsinghua University School of Architecture (China) [23, 24].

### *2.1.2. Techniques of 3DP in Construction*

The evolution of 3DP technology in construction has applied two main techniques for large-scale 3D concrete printing: binder jetting and material deposition method (MDM). The basic principle of the techniques is to build up complex structures layers upon layers [7]. Binder jetting creates 3D objects in a repeated cycle by depositing binder in droplets on a thin layer of powder material over a powder bed in a build tray [25]. This is called powder bed-based printing. The technique eliminates waste generation because unbound raw materials in the build tray are removed with a vacuum cleaner and used to support subsequent layers [26]. There is a minimal distance between layers with a relatively high resolution which gives a good surface finish [27]. The principle of binder jetting is commonly employed in D-shape 3DP process.

The MDM is similar to fused deposition modeling (FDM, used in the manufacturing industry), which prints 3D objects in successive layers of extruded materials in line with the CAD model [28]. It is commonly adopted in contour crafting (CC), concrete printing, stick dispensers, digital construction platforms, flow-based fabrication, mini-builder, and mesh-mould [7].

D-shape, contour crafting/concrete crafting, and concrete printing are the prominent 3DP technologies in construction [29, 30]. The disparities between these three technologies are shown by the limits of the scale of their printing dimensions (large or small scale printing ability), the configuration of their printer design, the printing process, and their printing materials (Table 1). D-shape is a 3DP technology that binds sand with a selective binder like magnesium (inorganic binding agent) to make the stone-like 3D structure. The D-shape printer has a set of spreading nozzles (hundreds of spraying nozzles) equipped with its print head, which deposits liquid binder on powdery sand at desired thickness layer upon layer in a repeated manner to form the digital prototypes. D-shape effectively prints large-scale structures [27, 31].

The CC operates on a computer-controlled gantry system that supports a concrete nozzle's movements with an attached trowel [28]. The installed trowel(s) enables the CC to create very smooth and accurate free-forms and planar surfaces at a higher build speed using a wide range of selective printing materials [30]. The CC technology combines extrusion and filling processes to print large-scale/industrial scale structures without the use of formwork. The process of CC can create openings and voids while printing for the insertion of reinforcement, installation of electrical fittings, and mechanical fittings using a robotic arm [32].

**Table 2.** Some existing 3D printing projects

| 3D projects | Project description | Year | Location | Method/Material | Source |
|---|---|---|---|---|---|
| Concrete Bridge | 86ft long bridge | 2019 | Shanghai | Concrete printing | [5] |
| YHNOVA™<br>Landscape House | $95m^2$ house<br>$1100m^2$ landscape house based on a Mobius strip | 2017<br>2017 | France | Concrete printing<br>Concrete paste, bio-plastic (80% vegetable oil) | [30] |
| Gemert bicycle bridge | 8m x 3.5m bridge | 2017 | Gemert, Netherlands | Concrete printing | [14] |
| Winsun offices | Office | 2016 | Dubai | Cement, sand, reinforcing glass fiber, proprietary additive mix, 150x10x6.6m machine | [14] |
| Castilla-La Mancha 3D bridge | 12m x 1.75m pedestrian bridge | 2016 | Madrid, Spain | Concrete printing: fused concrete, polypropylene reinforcement | [14] |
| Urban temple project | 1.6m freeform sculpture | 2008 | Pisa, Italy | Sand/mineral dust; inorganic binder, | [30] |
| Winsun houses | 1,100m2 two-story house | 2013 | China | Concrete printing | 14] |
| | 200m2 houses (10 nr) | 2014 | Shanghai, China | High-grade cement and glass fiber | [30] |
| | 1100m2 five-story apartment | 2015 | China | Cement combinations, glass fiber, construction waste | [30] |
| 3D print canal house | 6m hose | 2014 | Amsterdam, Netherlands | Polymer printing: 2.2x2.2x3.5m polypropylene blocks | [14] |
| The MX3D bridge | 10m x 2.5 metal bridge | | Amsterdam, Netherlands | Metallic printing: Wire and Arc AM; directed energy deposition (DED); 6-axis robotic welding arm | [14] |

Concrete printing, on the other hand, prints large-scale 3D structures by combining the principles of extrusion and deposition. It is similar to CC because its print head is mounted on a crane but operates without a trowel [28, 30, 32]. Therefore, the printed works do not have a very smooth surface like those printed by CC because the use of a trowel in the printing technique is absent.

The innovative D-shape, CC, and concrete printing technologies have been explored on-site and off-site to build concrete, metallic, and plastic structures ranging from houses to offices to bridges and connection nodes [14] (Table 2). The components of building work printed off-site are often transported to the site and assembled to form the designed shapes. For example, the Winsun office in Dubai was printed in China and shipped to Dubai for assemblage with estimated reductions in construction cost by 80%, labor costs by 60%, and waste management costs by 60%; when compared to the conventional office building construction [23].

The patronage of the 3DP technologies in the global construction market is recorded to be low. This is despite the attempts by extensive research activities to increase customizations at reduced construction time and improved affordability, as other benefits and opportunities of the technologies are considered [28, 29]. Perkins and Skitmore [25] attributed the low and slow paradigm shift to the adoption of innovative technology in the construction industry to the fear of outright replacement of conventional construction methods by the disruptive nature of 3DP. The disruptive nature of 3DP describes the propensity of the technology to replace a broad range of activities performed by skilled, semi-skilled, and unskilled labor in the construction industry, thereby causing human resources downsizing, increased unemployment rate, and a cut in the Gross Domestic Product (GDP) of a country.

#### *2.1.3. Printable 3D Printing Materials*

The printable 3DP materials in construction are cementitious, polymer, and metallic, but cementitious materials are the most commonly used [5, 14]. Research interests in addressing the compatibility of cementitious materials for a large-scale 3D printer in industrial-scale construction have generated the consideration of different components of concrete-related material in experimental studies [33]. Ascertaining the right constituents and mix ratio of the viscous cementitious materials, which are easy to extrude, workable within proper setting time/open time, and the challenges of material buildability have been the research focus for 3D printable materials [5, 30]. Since the conventionally placed load-bearing walls are reinforced concretes, the exploratory research efforts on printable reinforcement alternatives for the 3D print concrete wall without compromising on sufficient strength (pa) of concrete are on the increase [30].

Selective printable materials for 3DP in construction have addressed material and labor resource scarcity [14]. The 3D print walls of self-compacting concrete have self-supporting strength to hold individual layers in place from subsequent depositions without deformation [1]. This reveals the effectiveness of the 3DP materials for construction purposes and dismisses the skepticisms on the production of large-scale construction structures in recent past years, by the innovations of printable cementitious (cement-based) materials and industrial scale printers that have printed up to and over 1,100 m2 building structures of houses and offices in China and Dubai [14, 22].

The printable 3DP cementitious materials that were applied for exploratory construction included rapid-hardening Portland cement (RHPC) used in the binder jetting 3DP system, calcium aluminate types of cement (CAC), slag-based geopolymer (comprising slag, fine sand, and silicate-based activator), plaster and clay-like materials, and reactive powder concrete (RPC) mixture (comprising high-efficiency superplasticizer, fly ash, silica fume, quartz powder, cement, and fine sand) [34–36]. These are self-compacting concrete compositions considered applicable for 3DP of large-scale construction. Fiber-reinforced concrete using steel fibers constitution, rather than manually placed reinforcement, has shown its printability strength of high flexural strengthen research works by [5] and [37].

In general, 3DP materials are in three forms viz. liquid (i.e., thermoformable epoxy, photopolymer, photocurable acrylic resin), powders (i.e., plastic, metal, ceramic), and solid (metal alloy, thermoplastic, rubber) [38]. These materials include ceramics, composites, chemicals, concrete, metallic materials (i.e., aluminum, gold, alloys, magnesium), sand, river sand, limestone, sandstones, wax, silicone, resin, wood, plastics, water, paper, and foodstuff [14, 39].

### 2.2. Drivers of 3DP Technology in Construction

A quest to overcome the challenges of time cost overrun and declining labor productivity in building construction has compelled construction companies to consistently seek resolvable construction methods [5]. Bricklaying automation, intelligent, dynamic casting, and robot-winding have been explored to address those challenges and innovatively complement the conventional construction of some building components [7, 40, 41]. Several other technologies have been invented with the advent of Industry 4.0, which have boosted the performance of the automotive and manufacturing industry. The 3DP is one of the latest technologies of Industry 4.0 [7], with increased attention to construction automation [1]. Tay et al. [7] opined that the numerous benefits of 3DP, which meet the targeted demands in building and construction, are the drivers for its adoption for construction.

El-Sayegh et al. [5] reviewed 3DP in construction and categorized the benefits of 3DP into two groups: constructability and sustainability. The constructability benefits are lower construction cost, faster construction, more geometry freedom, shorter supply chain, and better productivity. It is established that the speed of construction is faster with 3DP than the traditional method by 42%, enabling clients to generate revenue early and release resources for subsequent projects [42]. Thus, the use of the technology of 3DPis stressed as a new way of satisfying client's needs in the construction market [35]. Hager et al. [15] emphasized the possible realization of architectural geometry in construction irrespective of its geometric complexity as a driver for the adoption of 3DP.

The sustainability benefits of 3DP are reduced formwork, less construction waste generation, safer sites, eco-friendly structure, and social good. Printing concrete by the 3D printer is done without the need for formwork, eliminating 40% of the total cost associated with concrete work [43]. 3DP creates mass production of customized construction products at a reduced cost, minimal material waste through recycling and reuse of unused materials, increased design flexibility, and less human intervention in building construction [7, 14, 23]. The reduced human intervention improves safety on construction sites through reduced construction-related falls, injuries, and fatalities [25]. It has also been established that 3DP reduces CO2 emission through its innovative technology in construction [7]. Therefore, 3DP offers much-needed innovative solutions for performance improvement in construction toward solving sustainability problems in the global society [15].

Buchanan & Gardner [14] revealed the opportunities inherent in 3DP from a review of the methods of metal 3DP in construction. The opportunities of 3DP are geometric flexibility and optimization of material properties; customization of building elements; reduced construction time; hybridization and structural strengthening of damaged or corroded elements to update the structural design of elements; environmental advantages of reduction in consumption of total energy, raw materials, and portable water; reduction in labor cost (15–50% of total construction project cost), elimination of risk of human error from the compulsion to work in adverse weather conditions and at night. These opportunities were founded as the drivers for adopting 3DP in building construction.

Kotchman & Faber [43] underscored the high rate of advancement in technology coupled with the need to realize a better eco-performing society as the driver for 3DP adoption in construction. The study further explained the benefit of 3DP in shortening the construction supply chain by merging the roles of consumers/client and producer/contractor to prosumers through integrating different steps and functions in construction into a digitized production chain. This creates the direct fabrication of building components using digital design and a 3D printer by the prosumer. Integrating roles implies a shorter supply chain, less professional and unskilled labor requirements, less complicated design, and virtual design change evaluation through CAD and direct printing simulation techniques. These benefits give a hedge against resource scarcity in the construction industry.

### 2.3. Barriers to 3DP Technology in Construction

Despite the numerous benefits of 3DP in construction, several challenging limitations have inhibited and discouraged its wide acceptance and high utilization in the global construction market. Wu et al. [29] identified the barriers to the broader acceptance and adoption of 3DP as low technological readiness, weak organizational support, and lacking policy and regulatory standards. The technological readiness of 3DP in construction is low because of the very high initial cost of incurring the 3DP printer, its running and maintenance costs, and unascertained compatibility standards for the right mix design of 3DPmaterials.

Hayes [44] stressed that skepticisms and cynicism about the potential of 3DP by top managements of construction companies and limited availability of resources discourage their commitments to adopting the technology. On the other hand, the fear of job insecurity by low-skilled labor, whose tasks are replaced by printers, and the need for up-skilling labor with equipment and software technical know-how are challenged to 3DP adoption [1]. Arora et al. [45] opined that the lack of developed policy standards on building codes and regulations that address 3DP materials and processes facilitated the unwillingness of stakeholders to change from the conventional method of construction to the new technology. Lacking regulatory controls on contracts, especially the legal backing, for the party(ies) that is/are liable for the defects of the 3D printed building components and structures also limits the broader acceptability and application of 3DP in the construction industry.

El-Sayegh et al. [5] asserted that clients' expectations are yet to be achieved by applying 3DP technology, owning to the rigid design requirements of 3Dprinters and materials limitations, and some other limiting factors. The factors are related to 3D printers, software, architecture and design, construction management, regulations and liability, and stakeholders' issues. According to Zhang et al. [46], the fixed scale design of a 3D printer limits the printing of construction works with sizes that range outside the scale of the printer's design. This implies that printing of building plans with sizes (floor surface area) more significant than that of the printer's scale and printing of the height of building plans that are higher than the range of reach of the robotic arm of the printer are not feasible. The opponents of 3DP hold this limitation of printing scale as the main reason for the unsuitability of 3DP for automated construction of large-scale production [5]. The printer's capacity to print only straight edge corners is also a limitation to the benefit of freedom of geometric architecture for 3DP.

Another critical barrier to the adoption of 3DP in the construction industry is the uncontrolled nature of the construction site, which does not support a controlled environment needed for the printing process of a 3DP printer on-site. In addition, the inherent risk of transportation of equipment on-site, equipment set up, site equipment, and adaptability of software applications for different geometric designs are identified barriers to the adoption of 3DP in building construction. The programmed system of the continuous printing process of 3DP printers for construction is averred as incompatible with the conventional scheduling of construction activities, which makes the adaptability of 3DP in construction a challenge [47].

## 3. RESEARCH METHODOLOGY

The study examined the level of awareness of 3DP technology, the level of use, and the drivers and barriers to the adoption of the technology in construction among professionals in small-sized and medium-sized construction firms (the SMEs) in Lagos State, Nigeria. Large-sized construction firms were excluded because the present capacity of 3D printers is yet beyond large-scale mass customization and production of building and construction works [25]. The target population was construction firms registered with the Nigerian Institute of Builders (NIOB) in Lagos State. Lagos State is Nigeria's hub of active construction activities [48].

The study employed a quantitative research methodology using a well-structured questionnaire to obtain information from a sample of respondents to generalize findings for a population [49]. The similar questions in the questionnaire design for the survey facilitated the researchers to compare the data obtained from different professionals in the study area.

Statistics from the Nigerian Institute of Building site showed that a total of 103 construction firms were registered and certified to practice building construction by the Institute in Lagos State. Only 39% of the registered firms that were financially active members of the Institute were considered for the survey exercise during this study. Trochim [50] indicated that a percentage range from 10–30% is deemed adequate for a survey on a small population, while a 5% representation for a large population is deemed adequate. The 39% representation of the construction firms built up to 40 registered construction firms in the study area, constituting the study's sample size.

The target respondents were registered professionals at the top management level and project and senior managers. The professionals were architects, builders, engineers, and quantity surveyors. At least one of these professionals was sampled to represent the general position of each construction firm (as a contractor) on 3DP technology awareness and use. The professionals were sampled based on their availability and readiness to supply resource information on 3DP practices and the agreed choice of representation by the professionals for the firm. These steps were taken to avoid the possibility of duplicating information from a firm/contractor for the study. A total number of 35 questionnaires were retrieved from the survey exercise. This represented a total retrieval rate of 89.74%.

The questionnaire was structured by information extracted from experimental studies and reviews in the existing literature on 3DP technology to form the primary data source for this study. A structured questionnaire is an effective data

**Table 3.** The profile of respondents

| Characteristics | Parameters | N | % |
|---|---|---|---|
| Specialization of firm | Building works (architecture design & contractor) | 7 | 20.0 |
| | Civil works (contractor) | 3 | 8.6 |
| | Building and civil works (consultants, architecture designs & contractors) | 25 | 71.4 |
| Size of firm | Medium | 25 | 71.4 |
| | Small | 10 | 28.6 |
| Annual revenue | ₦20,000,000 - ₦30,000,000 | 11 | 31.4 |
| | ≥₦40,000,000 | 24 | 68.6 |
| Professions | Architect | 8 | 22.9 |
| | Builder | 11 | 31.4 |
| | Engineer | 10 | 28.6 |
| | Quantity Surveyor | 6 | 17.1 |
| Year of work experience | ≤ 9 | 9 | 25.7 |
| | 10-19 | 19 | 54.3 |
| | ≥20 | 7 | 20.0 |
| | Aware | 26 | 74.3 |
| 3D printing awareness | Unaware | 9 | 25.7 |
| | Direct personal experience | 5 | 19.2 |
| | Personal research | 12 | 38.5 |
| Awareness medium | Professional dialogue | 13 | 42.3 |

N= Number.

collection method for measuring respondents' beliefs, attitudes, and opinions [51]. The questionnaire was designed as close-ended for easy answering by respondents and analysis by researchers as established by [52]. The construct of the 3DP technology in reviewed literature formed the basis for the questionnaire design, which was divided into two sections. Section A and section B. section A of the questionnaire comprised the profile information about the respondents. Section B of the questionnaire addressed the objectives of the study. The questionnaires were self-administered.

The data obtained were analyzed based on descriptive and inferential statistics. The descriptive statistical tools employed were frequency tables and mean score rating. Name [53] stressed that descriptive statistics are practical tools to present the characteristics of the respondents for a quick understanding of the underlying details in a data set. The inferential statistical tool adopted by the study was the Mann-Whitney u-test. The tool looked at the differences in the ranked positions of scores (for variables on the application of 3DP in construction, drivers, and barriers of 3DP) in different groups. The test makes inferences from respondents from unequal independent groups in an observed population [54]. These groups were the SMEs (medium-sized firms=25numbers; small-sized firms=10 numbers).

Using Cronbach's alpha test, a validity and reliability test were conducted on the research data. The values of Cronbach's Alpha extracted from the test were used to determine the internal consistency of variables generated from the respondents' responses on 3DP technology questions [55]. An acceptable range of reliability is established at 0.70–0.95 values of Cronbach's Alpha [56].

## 4. RESULTS AND DISCUSSION

### 4.1. The Respondents' Profile

Table 3 shows the background information about the respondents on the specialization of the firm, size of the firm, educational qualifications, and professional affiliations of respondents. Each of the captured respondents represented an individual firm. About 71.4% of the construction firms were specialized building/ civil works contractors, architects, and consultants. Up to 71.4% of the firms were medium-sized with over 40,000,000 annual revenue, while 28.6% were small-sized firms. The respondents were registered professionals with percentage representations of 31.4% (builders), 28.6% (engineers), 22.9% (architect), and 17.1% (quantity surveyors). The average work experience of the respondents was estimated at approximately 12 years, indicating that about 49% of the firms have been in the business of construction works for 12 years. Up to 74.3% of the firms had awareness about 3D printing through professional dialogue (42.3%), personal research (38.5%), and direct personal experience (19.2%). These results underscored the adequacy of the respondents' information obtained for the study.

### 4.2. Application of 3DP Technology for Construction

The results of the validity and reliability test on the research instrument and the analysis of data obtained from the respondents' perception of the application of 3D printing are shown in Tables 4 and 5, respectively. A Cronbach's alpha value (Table 4) greater than 0.70 implied that the scale is reliable and valid to measure the underlying con-

**Table 4.** Reliability statistics

| Cronbach's Alpha | Cronbach's Alpha is based on standardized items | N of items |
|---|---|---|
| 0.885 | 0.898 | 25 |

**Table 5.** Application of 3D printing technology

| Variables | Medium | | | Small | | | Overall | | | Mann-Whitney U test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MS | SD | R | MS | SD | r | MS | SD | r | z-score | Sig. | R |
| Constructing a structure at a low price | 3.400 | 0.577 | 3 | 4.100 | 0.994 | 1 | 3.600 | 0.774 | 1 | -2.031 | 0.042 | * |
| Creating scale mockups for building components | 3.400 | 0.916 | 1 | 4.000 | 0.942 | 3 | 3.600 | 0.945 | 1 | -1.517 | 0.129 | ** |
| Printing pedestrian bridge | 3.400 | 0.957 | 3 | 4.000 | 0.942 | 3 | 3.571 | 0.978 | 3 | -1.669 | 0.095 | ** |
| Construction midsize homes | 3.400 | 0.500 | 3 | 4.000 | 0.942 | 3 | 3.571 | 0.698 | 3 | -1.838 | 0.066 | ** |
| Creating metal surface for a solid structure | 3.320 | 1.029 | 9 | 4.100 | 0.875 | 1 | 3.542 | 1.038 | 5 | -2.063 | 0.039 | * |
| Constructing structures in a quick manner | 3.320 | 0.476 | 9 | 3.900 | 0.875 | 6 | 3.485 | 0.658 | 6 | -1.978 | 0.048 | * |
| Habitable concrete 3D printed house | 3.360 | 0.637 | 6 | 3.700 | 0.674 | 8 | 3.457 | 0.657 | 7 | -1.377 | 0.169 | ** |
| Construction of columns | 3.440 | 0.583 | 1 | 3.300 | 0.674 | 13 | 3.400 | 0.603 | 9 | -0.554 | 0.579 | ** |
| Complete scale building components fabrication i.e., interior wall | 3.320 | 0.476 | 9 | 3.400 | 0.516 | 11 | 3.342 | 0.481 | 10 | -0.444 | 0.657 | ** |
| Constructing partitions | 3.360 | 0.489 | 6 | 3.300 | 0.823 | 13 | 3.342 | 0.591 | 10 | -0.473 | 0.636 | ** |
| Road curbs | 3.240 | 0.778 | 15 | 3.500 | 0.527 | 9 | 3.314 | 0.718 | 12 | -1.000 | 0.317 | ** |
| Using plastic as materials for construction | 3.280 | 0.541 | 12 | 3.400 | 0.843 | 11 | 3.314 | 0.631 | 12 | -0.358 | 0.721 | ** |
| Prefabrication of full-scale building exterior wall | 3.360 | 0.489 | 6 | 3.200 | 0.421 | 16 | 3.314 | 0.471 | 12 | -0.908 | 0.364 | ** |
| In-situ 3D printing house | 3.160 | 0.472 | 17 | 3.500 | 0.707 | 9 | 3.257 | 0.560 | 15 | -1.410 | 0.159 | ** |
| Construction of slab | 3.280 | 0.613 | 12 | 3.200 | 0.421 | 16 | 3.257 | 0.560 | 15 | -0.516 | 0.606 | ** |
| Construction of beams | 3.280 | 0.541 | 12 | 3.100 | 0.316 | 18 | 3.228 | 0.490 | 17 | -1.067 | 0.286 | ** |
| Construction of foundation | 3.120 | 0.665 | 19 | 3.300 | 0.483 | 13 | 3.171 | 0.617 | 18 | 0.651 | 0.515 | ** |
| Prefabrication of roof | 3.120 | 0.832 | 19 | 3.000 | 0.666 | 21 | 3.085 | 0.781 | 19 | -0.594 | 0.552 | ** |
| Prefabrication of doors | 3.040 | 0.675 | 23 | 3.100 | 0.737 | 18 | 3.057 | 0.683 | 20 | -0.243 | 0.808 | ** |
| Prefabrication of windows | 3.040 | 0.675 | 23 | 3.100 | 0.737 | 18 | 3.057 | 0.683 | 20 | -0.243 | 0.808 | ** |
| Construction of parapet | 3.080 | 0.812 | 22 | 3.000 | 0.666 | 21 | 3.057 | 0.764 | 20 | -0.439 | 0.660 | ** |
| Construction of stairs | 3.160 | 0.687 | 17 | 2.800 | 0.632 | 23 | 3.057 | 0.683 | 20 | -1.415 | 0.157 | ** |
| Construction of finished floor | 3.120 | 0.665 | 19 | 2.600 | 0.699 | 26 | 2.971 | 0.706 | 24 | -1.829 | 0.067 | ** |
| Painting | 3.040 | 0.789 | 23 | 2.700 | 0.823 | 25 | 2.942 | 0.802 | 25 | -1.127 | 0.260 | ** |
| Construction of median strip | 2.960 | 0.789 | 26 | 2.800 | 0.632 | 23 | 2.914 | 0.742 | 26 | -0.531 | 0.595 | ** |

MS: Mean score; SD: Standard deviation; r: Rank; Sig.: Significance; R: Remark; *: Significant difference; **: No difference.

struct of its design for the analysis. In Table 5, the creation of scale mockups for building components and construction of columns ranked highest (MS=3.440, SD=0.577; MS=3.440, SD=0.583 respectively) by the respondents in the medium firm category. Construction of structure at a low price and creating a metal surface for solid structure ranked highest (MS=4.100, SD=0.994; MS=4.100, SD=0.875 respectively) by the respondents in the small-sized firm. Overall, the application of 3D printing for the construction of finished floors, painting, and construction of median strips ranked lowest with mean score values of 2.971, 2.942, and 2.914, respectively.

There were no significant differences in the ranking of the three least variables by the respondents from the two groups of the firm, z=-1.829, -1.127, and -0.531, respectively; p=0.067, 0.260, and 0.595, respectively. This implies that the differences in the revenue base of the firms' sizes may not be contributory factors to the application of 3DP technology on the least ranked variables. On the other hand, there is a significant difference in the respondents' perception of the three items' application of 3DP technology. These were construction of structure at a low price (z=-2.031, p=0.042), creating metal surface for solid structure (z=-2.063, p=0.039), and

**Table 6.** Reliability statistics

| Cronbach's Alpha | Cronbach's Alpha is based on standardized items | N of items |
|---|---|---|
| 0.885 | 0.878 | 28 |

**Table 7.** Driver for the adoption of 3DP technology in Nigeria

| Variables | Medium | | | Small | | | Overall | | | Mann-Whitney U test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | r | Mean | SD | r | Mean | SD | r | z-score | Sig. | R |
| Reduced paper-based delivery methods | 4.200 | 0.645 | 2 | 4.500 | 0.707 | 4 | 4.280 | 0.667 | 1 | -1.310 | 0.190 | ** |
| Architecture geometry freedom | 4.280 | 0.678 | 1 | 4.300 | 0.823 | 9 | 4.285 | 0.710 | 1 | -0.199 | 0.842 | ** |
| Improved contractors and client relationships | 4.080 | 0.571 | 4 | 4.600 | 0.699 | 2 | 4.228 | 0.645 | 3 | -2.329 | 0.020 | * |
| Enabling fast project completion | 4.160 | 0.687 | 3 | 4.400 | 0.699 | 7 | 4.228 | 0.689 | 3 | -0.961 | 0.337 | ** |
| Technological advancement | 3.960 | 0.840 | 13 | 4.700 | 0.483 | 1 | 4.171 | 0.821 | 5 | -2.383 | 0.017 | * |
| Improved client satisfaction | 4.000 | 0.707 | 10 | 4.600 | 0.699 | 2 | 4.171 | 0.746 | 5 | -2.241 | 0.025 | * |
| Enhances cost efficiency | 4.040 | 0.454 | 7 | 4.400 | 0.516 | 7 | 4.142 | 0.493 | 7 | -1.962 | 0.050 | * |
| Enhance sustainability | 3.960 | 0.675 | 13 | 4.500 | 0.707 | 4 | 4.114 | 0.718 | 8 | -2.063 | 0.039 | * |
| Increased employee productivity | 4.040 | 0.611 | 7 | 4.300 | 0.823 | 9 | 4.114 | 0.676 | 8 | -1.114 | 0.265 | ** |
| A reduced error by better coordination of work | 4.040 | 0.351 | 7 | 4.200 | 0.623 | 11 | 4.085 | 0.445 | 10 | -1.022 | 0.307 | ** |
| Speed up the construction process | 4.080 | 0.640 | 4 | 4.100 | 0.567 | 15 | 4.085 | 0.612 | 10 | -0.064 | 0.949 | ** |
| Reduction in technology and material cost | 4.000 | 0.577 | 10 | 4.200 | 0.632 | 11 | 4.057 | 0.591 | 12 | -0.913 | 0.361 | ** |
| Client desire | 3.840 | 0.850 | 21 | 4.500 | 0.707 | 4 | 4.028 | 0.857 | 13 | -2.088 | 0.037 | * |
| Operational efficiency | 3.880 | 0.665 | 19 | 4.200 | 0.788 | 11 | 3.971 | 0.706 | 14 | -1.198 | 0.231 | ** |
| Shorter supply chain | 3.920 | 0.493 | 15 | 4.100 | 0.737 | 15 | 3.971 | 0.568 | 14 | -0.825 | 0.409 | ** |
| Improves visualization | 3.920 | 0.702 | 15 | 4.100 | 0.737 | 15 | 3.971 | 0.706 | 14 | -0.679 | 0.497 | ** |
| Improves construction skills of users | 4.000 | 0.408 | 10 | 3.900 | 0.994 | 22 | 3.971 | 0.617 | 14 | -0.046 | 0.963 | ** |
| Increases emergency response | 4.080 | 0.640 | 4 | 3.700 | 1.059 | 25 | 3.971 | 0.785 | 14 | -1.104 | 0.269 | ** |
| Value management skill | 3.920 | 0.640 | 15 | 4.000 | 0.666 | 18 | 3.942 | 0.639 | 19 | -0.223 | 0.824 | ** |
| Automation of quantities | 3.880 | 0.665 | 19 | 4.000 | 0.942 | 18 | 3.914 | 0.742 | 20 | -0.354 | 0.723 | ** |
| Companies management | 3.920 | 0.702 | 15 | 3.900 | 0.994 | 22 | 3.914 | 0.781 | 20 | -0.156 | 0.876 | ** |
| Decreased construction costs | 3.760 | 0.597 | 26 | 4.200 | 0.632 | 11 | 3.885 | 0.631 | 22 | -1.837 | 0.066 | ** |
| Change in market | 3.800 | 0.816 | 23 | 4.000 | 1.333 | 18 | 3.857 | 0.974 | 23 | -1.018 | 0.308 | ** |
| Convenience | 3.800 | 0.763 | 23 | 3.800 | 1.135 | 24 | 3.800 | 0.867 | 24 | 0.000 | 1.000 | ** |
| High level of competition | 3.840 | 0.687 | 21 | 3.700 | 1.337 | 25 | 3.800 | 0.900 | 24 | -0.236 | 0.813 | ** |
| Management of carbon consumption | 3.680 | 0.690 | 27 | 4.000 | 0.666 | 18 | 3.771 | 0.689 | 26 | -1.152 | 0.249 | ** |
| Unified ways of service delivery | 3.800 | 0.500 | 23 | 3.700 | 0.674 | 25 | 3.771 | 0.546 | 26 | -0.096 | 0.924 | ** |
| Professional competence of users | 3.680 | 0.476 | 27 | 3.600 | 0.516 | 28 | 3.657 | 0.481 | 28 | -0.444 | 0.657 | ** |

MS: Mean score; SD: Standard deviation; r: Rank; Sig.: Significance; R: Remark; *: Significant difference; **: No difference.

constructing structures in a quick manner (z=-1.978, p=0.48). This established that the sizes of firms influence the level of application of 3DP technology in the three high-ranked construction activities. That is, the larger the size and capacity of the contractor, the higher the responsiveness of the firms to adopting the application of 3DP technology to deliver construction services. The findings on the low application of 3DP technology support the existing studies on the technology's infancy in developing countries [17, 18].

### 4.3. Drivers of 3DP Technology in Nigerian Construction Industry

The results of the factors that influence the acceptance, adoption, and application of 3D printing technology by the firms in construction are shown in Tables 6 and 7. Table 6 shows Cronbach's alpha value of 0.885, which is within the acceptable range of reliability (0.70–0.95) for the scale used for the analysis [57]. Table 7 shows the ranking of scores on the drivers of 3DP in construction from respondents' assessments between the two groups of the firms. All the examined drivers (28) of 3DP technology ranked high with

**Table 8.** Reliability statistics

| Cronbach's Alpha | Cronbach's Alpha is based on standardized items | N of items |
|---|---|---|
| 0.803 | 0.783 | 23 |

**Table 9.** Barriers to the adoption of 3DP technology in Nigeria

| Variables | Medium | | | Small | | | Overall | | | Mann-Whitney U test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | r | Mean | SD | r | Mean | SD | r | z-score | Sig. | R |
| Technical challenges | 4.120 | 0.600 | 1 | 4.100 | 0.737 | 2 | 4.114 | 0.631 | 1 | -0.042 | 0.967 | ** |
| Unwillingness to change from the traditional method | 3.960 | 0.611 | 2 | 4.000 | 0.942 | 3 | 3.971 | 0.706 | 2 | -0.120 | 0.905 | ** |
| High purchasing power | 3.960 | 0.789 | 2 | 3.800 | 0.918 | 4 | 3.914 | 0.817 | 3 | -0.437 | 0.662 | ** |
| Inadequate power supply | 3.920 | 0.571 | 4 | 3.700 | 0.674 | 5 | 3.857 | 0.601 | 4 | -1.023 | 0.306 | ** |
| Lack of information on 3D printing technology | 3.840 | 0.472 | 5 | 3.700 | 0.674 | 5 | 3.800 | 0.531 | 5 | -0.808 | 0.419 | ** |
| The unfamiliarity of workers with 3D printing technology | 3.541 | 0.931 | 15 | 4.200 | 0.632 | 1 | 3.735 | 0.898 | 6 | -1.976 | 0.048 | * |
| Structure of organization | 3.760 | 0.522 | 8 | 3.600 | 0.516 | 7 | 3.714 | 0.518 | 7 | -0.794 | 0.427 | ** |
| Social and habitual resistance to change | 3.720 | 0.458 | 10 | 3.600 | 0.843 | 7 | 3.685 | 0.582 | 8 | -0.417 | 0.677 | ** |
| High cost of training | 3.760 | 0.435 | 8 | 3.500 | 0.527 | 9 | 3.685 | 0.471 | 8 | -1.475 | 0.140 | ** |
| Maintenance cost | 3.840 | 0.943 | 5 | 2.900 | 1.3270 | 20 | 3.571 | 1.144 | 10 | -1.957 | 0.050 | * |
| Fear of job security | 3.840 | 0.800 | 5 | 2.900 | 1.370 | 20 | 3.571 | 1.065 | 10 | -2.171 | 0.030 | * |
| Fear of incorporating 3DP technology into existing practice by the organization manager | 3.720 | 0.890 | 10 | 3.100 | 0.994 | 16 | 3.542 | 0.950 | 12 | -1.624 | 0.104 | ** |
| Trained professional to handle tools | 3.560 | 0.506 | 14 | 3.400 | 0.699 | 12 | 3.514 | 0.562 | 13 | -1.062 | 0.288 | ** |
| Proper legislative support | 3.480 | 0.714 | 18 | 3.500 | 0.849 | 9 | 3.485 | 0.742 | 14 | -0.247 | 0.805 | ** |
| Complex 3D printing technology | 3.600 | 0.645 | 13 | 3.200 | 0.421 | 14 | 3.485 | 0.612 | 14 | -1.756 | 0.079 | ** |
| High cost of incorporating 3D printing technology | 3.640 | 0.810 | 12 | 3.000 | 0.816 | 19 | 3.457 | 0.852 | 16 | -2.069 | 0.039 | * |
| Lack of critical knowledge | 3.520 | 0.714 | 17 | 3.200 | 0.632 | 14 | 3.428 | 0.698 | 17 | -1.518 | 0.129 | ** |
| Complicated modeling process | 3.541 | 0.779 | 15 | 3.100 | 0.737 | 16 | 3.411 | 0.783 | 18 | -1.361 | 0.174 | ** |
| Investment in 3DP technology | 3.291 | 0.624 | 20 | 3.500 | 0.707 | 9 | 3.352 | 0.645 | 19 | -0.784 | 0.433 | ** |
| High cost of 3DP technology adoption | 3.458 | 0.588 | 19 | 3.100 | 0.737 | 16 | 3.352 | 0.645 | 19 | -1.261 | 0.207 | ** |
| Client demand | 3.083 | 0.583 | 21 | 3.300 | 0.823 | 13 | 3.147 | 0.657 | 21 | -0.995 | 0.320 | ** |
| Customers' expectations | 3.083 | 0.775 | 21 | 2.600 | 1.074 | 23 | 2.941 | 0.885 | 22 | -1.355 | 0.175 | ** |
| Cost of project | 2.875 | 0.612 | 23 | 2.700 | 0.948 | 22 | 2.823 | 0.716 | 23 | -0.862 | 0.388 | ** |

MS: Mean score; SD: Standard deviation; r: Rank; Sig.: Significance; R: Remark; *: Significant difference; **: No difference.

4.280≤ MS ≤3.680 by the medium-sized construction firms and 4.500≤ MS ≤3.600 by the small-sized construction firms. The firms' overall high-ranked drivers of 3DP technology have a range of 4.280≤ MS ≤3.657. This established that all the examined drivers of 3DP technology are critical success factors that encourage the application of 3DP technology in construction. The implication of these findings underscores the existing scholarly findings that the technology offers tremendously high benefits to the clients, contractors, projects, and environmental sustainability [30]. In support of the existing studies, this study establishes that the benefits of 3DP technology in construction are the drivers that have influenced the increased exploratory research to improve the technology's applicability for construction automation. The study established that the drivers of 3DP technology in construction in developed countries [5, 7, 14, 28] are likewise relevant for increased technology adoption by contractors, consultants, and clients in developing countries, particularly Nigeria.

Among all the high-ranked drivers of 3DP technology by firms, up to 6 drivers significantly differ in their ranked scores by the two independent groups of respondents. The drivers were improved contractors and client relationship (z=-2.329, p=0.020), technological advancement (z=-2.383, p=0.017), improved client satisfaction (z=-2.241, p=0.025), enhanced cost efficiency (z=-1.962, p=0.05), enhanced sustainability (z=-2.063, p=0.039), and client desire (z=-2.088, p=0.037). This established that despite the high rankings of the six drivers, there exist differences in the acceptability and adoption of the technology in construction by the firms, which are majorly influenced by the size, demand, and taste of their respective construction clients. It is induced that the sizes of the firms attract different sizes and types of clients who influence the choice of 3DP technology by the firms in their respective demands.

### 4.4. Barriers to 3DP Technology in Nigeria Construction Industry

The examined barriers to the adoption of 3DP technology in construction have the valid and reliable scale of Cronbach's alpha value of 0.803, within the acceptable range of values established for ascertaining reliability statistics test. The Cronbach's alpha value is shown in Table 8. This indicates that the scale can measure the underlying construct for barriers assessed in this study. The ranked scores of the barriers limiting the adoption of 3DP technology in construction as assessed by the independent groups are shown in Table 9. Technical challenges of 3DP technology concerning the operation of 3D printers ranked highest (MS=4.120) by medium-sized construction firms. The challenges are attributed to the specificity of materials limited to the printer and the fixed design scale of the 3D printer, which restrict the printing size of objects within the printer's dimension. The unfamiliarity of workers with 3D printing technology ranked highest (MS=4.200) among the barriers limiting small-sized construction firms' adoption of the technology.

Overall, technical challenges (MS=4.114), unwillingness to change from the traditional method (MS=3.971), the high purchasing power of 3D printers (MS=3.914), and inadequate power supply (MS=3.857) were high-ranked barriers of 3DP technology adoption by construction firms in Nigeria. This established that the construction industries in the global view are change-averse as regards the transition from conventional construction methods to automation. This corroborates the low technological readiness of the industry for construction automation, as opined by [29]. The issue of poor power supply as a high-ranked barrier to adopting 3DP technology in construction in developing countries is mainly relative to the Nigerian construction industry. The continuous printing process by a 3D printer requires an uninterrupted power supply to create 3D objects effectively.

Notwithstanding, the inadequate power supply is a severe challenge in Nigeria, where approximately 21% of the electricity supply for the national peak demand is met. As of January 13, 2022, only 4,187 megawatts (MW) of electricity was supplied against the national demand forecast of 19,798MW [57]. This power supply challenge in Nigeria indicates that the level of adoption of 3DP technology in construction in the country will be shallow and slow until an adequate supply of electricity is achieved and sustained.

Overall, the customers' expectations (MS=2.941) and project cost (MS=2.823) ranked lowest among the firms' barriers to the adoption of 3DP technology. The finding established that significant differences exist in four high-ranked barriers to 3DP technology adoption by the firms. These were unfamiliarity of workers with 3D printing technology (z=-1.976, p=0.048), maintenance cost (z=-1.957, p=0.050), fear of job security (z=-2.171, p=0.030) and high cost of incorporating 3D printing technology (z=-2.069, p=0.039). This result indicates that the four significant barriers equally affect and limit the adoption of 3DP technology by contractors regardless of the contractor size.

## 5. CONCLUSIONS AND RECOMMENDATIONS

The study assessed the awareness, application, drivers, and barriers to adopting 3D printing technology for building construction in Nigeria. The study established that the current adoption of 3D printing technology in construction is low in Nigeria because only 19.2% of the firms have had direct personal experience and involvement in using the technology to deliver construction services. Based on the results obtained, the vast majority (80.8%) of the firms who had an awareness of the technology in construction acquired it only through personal research and professional dialogue rather than through practical involvement in the application of the technology. This finding showed that 3DP technology is a new option for construction method alternatives in the Nigerian construction industry.

All the drivers of 3DP technology adoption indicated were rated as highly important (average weighted score=4.01, 93.6%) factors influencing the acceptance and application of the technology in construction. The study established no statistically significant difference in the highly rated scores of the 22 drivers of the technology by the SMEs with $-0.046 \leq z \leq -1.837$, $0.963 \leq p \leq 0.066$. However, the respective demands of the different sizes and types of clients that the firms attract, which are influenced by the technical strength and financial integrity of the firms, are significant determinants that establish significant differences in the six highly rated drivers of 3DP technology in Nigeria. These drivers were client desire, satisfaction, contractor and client relationships, cost efficiency, sustainability, and technological advancement.

Most (95.7%) of the barriers to adopting 3DP technology in construction were rated high. The inadequate power supply is a relative barrier to the application of technology in the Nigerian construction industry. The Nigerian Electricity Supply Industry (NESI) currently meets just 21% of national energy demand in the country, which is reasonably low to support the continuous printing process of 3D printers that are highly dependent on the stable power supply for effective construction automation delivery. It is recommended that the government restructure the country's power sector and diversify energy sources to improve its capacity to meet energy demands and sustain the power supply for better adoption of 3DP innovative technology in Nigeria. The study provided implications for the construction industry in developing countries on areas of improvement for better adoption of 3D printing innovation, which could enhance faster and more sustainable construction processes.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

## PEER-REVIEW

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