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RESEARCH ARTICLE

Awareness of 3D Printing for Sustainable Construction in an Emerging Economy

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Abstract

3D printing has been popular in the manufacturing industry as a means of automating processes, speeding up production, and reducing waste. It is frequently seen as a relatively new technology, even though it has been in use for more than three decades. This article aims to analyse 3D printing awareness in an emerging economy towards sustainability in the construction industry. A survey research design was used to obtain primary data from the respondents using structured questionnaires. The sample frame for the research survey comprises professionals in construction and consultancy firms such as architects, quantity surveyors, projects managers, and engineers. Mean item score, standard deviation, and factor analysis were used to analyse the data. The findings from this study show that majority of the professionals acknowledged that they were aware of the existence of 3D printing, but most of them attested that they had not utilized this technology before the survey. The study reveals that the professionals in the construction industry of the emerging economy have low awareness of 3D printing technology, therefore its practices in the construction industry of the study area are significantly low. More awareness of 3D printing technology should be raised by bodies shouldered with management and regulation of the construction industry to increase professionals'

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awareness and enlighten them on the benefits of adopting the technology towards sustainable construction.

Keywords

3D Printing; Construction 4.0; Construction Industry; Digital Construction; Sustainable Construction

Introduction

The construction industry suffers from time overruns, project delays, and abandonment, as well as safety issues, budget overruns, inefficiency, design inflexibility, material waste, and a slew of other issues brought on by a lack of essential information. (Kadiri and Shittu, 2013). Growing populations have wreaked havoc on housing for middle- and lower-income families. Only the affluent and powerful can afford homes where they have total influence over the project's design and implementation (Mehar, et al., 2020).

In the construction industry, the development of three-dimensional printing (3D printing) ushered in a new age. 3D printing has been popular in the manufacturing industry as a means of automating processes, speeding up production, and reducing waste (Perkins and Skitmore, 2015). 3D printing is an automated production technique with layer-by-layer control that has seen significant progress over time, most notably in the manufacturing business for decades, but more recently in the construction industry, to print houses and villas (Wu, Wang and Wang, 2016).

3D printing is an additive manufacturing technique that involves the layer-by-layer fabrication of three-dimensional structures. Information is taken from a computer-aided design (CAD) file and translated to a stereolithography (STL) file in additive manufacturing techniques. The drawing created in CAD software is approximated by triangles and slices holding the information for each layer that will be printed during the process (Wong and Hernandez, 2012). A 3D printer, according to Bogue (2013), is an automated additive manufacturing system that can print 3D solid items using computer-aided design (CAD).

Major developments, primarily led by the creation of new, advanced, highly functional, and 3D printable materials, were beginning to lead the technology away from one-off prototypes, models, guides, and other products made of simple plastics and metals, to mass production of complex products, as the technology began to receive full attention from industry, academia, and government (Jakus, 2019). As technology has progressed, 3D printing has expanded to accommodate construction products other than ceramic in recent years. In construction projects, 3D printers can currently produce plastic and nylon components such as plug fixtures, window frame fixtures, and plumbing fittings (Alzarrad and Elhouar, 2019).

The discovery of the 3D printer ushered in a new construction method known as 3D printing building technology. Contour Crafting is a potential process that could transform the construction business soon, according to the latest technology (Hager, Golonka and Putanowicz, 2016). There are numerous advantages to this technology, including cost and time savings, fewer pollutants, and a reduction in casualties. According to Teizer, et al. (2016), the construction sector has lately effectively implemented industrial uses of the technology in a variety of domains, including consecutive layers of concrete. Furthermore, 3D printing's core idea is that the 3D volume is reduced in the computer to large-scale printing of complicated geometric shapes in a sequence of 2D layers.

Although 3D printing has been present since the late 1970s, it is only recently becoming well-known in the second decade of the twenty-first century. Due to a combination of media interest and the growing availability of consumer-level technology, 3D printing has recently spurred a lot of "futuring" activity (Stein, 2017). Because of the sudden and rapid increase in awareness of 3D printing during the fourth period (2005-2012), as well as a lack of understanding of its history, 3D printing is commonly seen as a new technology, even though it has been in use for more than three decades (Jakus, 2019). According to

Teizer, et al. (2016), 3D has recently attracted a lot of public attention and has become a popular topic of discussion.

This technique, which is more efficient in the development of 3D building models and is generally thought to be more efficient than traditional approaches, is so underutilized in construction (Teizer, et al., 2016). Until recently, 3D printing has received a warm welcome in industrialized countries, resulting in its expansion and improvement in the building industry over time. This article aims to analyse 3D printing awareness in an emerging economy towards sustainable construction in the construction industry.

Literature Review

Begić and Galić (2021) noted that Construction 4.0 was initially mentioned in 2016, mostly based on construction companies' recognition of the necessity of digitization in the industry. The rapid improvement of 3D printing technology, which is one of the construction 4.0 technologies, according to Mehar, et al. (2020), has changed people's thinking regarding using concrete as a 3D printable material on its own. According to Kothman and Faber (2016), 3D printing concrete can effectively provide several improvements in manufacturing performance, such as shorter lead times, function integration, and material usage reduction, potentially rendering production steps within the construction supply chain obsolete while reducing logistical and production efforts.

Wu, et al. (2018) noted that despite the numerous advantages that 3D printing can provide, construction has a lower adoption rate than other industries. Teizer, et al. (2016) said that the current public awareness of 3D printing helps in pushing it to the forefront, where building corporations begin to investigate alternate construction processes. Furthermore, Jakus (2019) reiterated that the quick spread and mass awareness of 3D printing was mostly due to the alignment of key legal and social events/groups, rather than any big technological breakthrough.

One of the Arsenic and the 2030 Agenda for Sustainable Development is that, by 2030, it must be ensured that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature (Johnston, 2016). Oke, et al. (2018) stated that government loans, adequate power supply, lowering the cost of digital tools, ensuring that every department develops and manages a computerized information system, raising awareness about the use of technology, and promoting local research and development are all seen as critical to strengthening digital technology and encouraging collaboration.

Perhaps as a result of increased global awareness of the technology, as well as what could be considered inaccurate exaggerations about the ability to make anything, 3D printing technology began to be quickly adopted by academic and clinical research institutions, resulting in it becoming not only a vital tool to aid in existing research but also the subject of research itself (Jakus, 2019).

AWARENESS OF 3D TECHNOLOGIES

There are several techniques for 3D printing including Stereolithography, Fused Deposition Modelling, Contour crafting, among others. These technologies are further explained. Stereolithography (SLA), according to Teizer, et al. (2016), is a process that requires repeatedly lowering a platform into a bath of synthetic resin (Polymer-hybrid). The largest machines can hold up to two cubic meters of material. As a result, this technology lends itself well to the creation of architectural models. According to Chen, et al. (2017), despite the benefits of SLA technology, it has two major disadvantages: processing time and part performance (thermo-mechanical), the latter of which is the focus of this study. SLA-printed goods cannot achieve the mechanical properties of their molecular counterparts due to the method's layer-by-layer structure.

Fused deposition modelling (FDM) which is another 3D technology is a process that includes extruding classifiable building material through a heated nozzle (Teizer, et al., 2016). The materials that can be employed in this approach include plastic, wax, concrete paste, and ceramic paste. According to Rett, et al. (2021), FDM, an extrusion-based 3D technology, is a well-known and widely used 3D method since it is low-cost, low-maintenance, and open source.

Contour crafting, according to Khoshnevis (2004), is a variant of this process in which the material is stopped from flowing out freely by an adjustable outside rim. The nozzle is surrounded by a ring made up of parallel slabs or strips that can spin around it. According to Tay, et al. (2017), contour crafting has been in the works for a while and is based on the extrusion of cement-based paste against a trowel to provide the printed object with a smoother surface finish. According to Teizer, et al. (2016), a construction industry expert, for a client to approve concrete walls, the final surface quality must be within millimetres.

3D Concrete Printing (3DCP) employs a combination of digital technology and new materials science insights to enable cost-effective freeform construction without the use of costly formwork. By separating the cost of fabricating a structural component from its shape, the freeform construction would encourage architectural expression while also allowing for greater design flexibility (Nematollahi, Xia and Sanjayan, 2017).

Digital Light Processing is another 3D technology that can be used to make projectors and 3D printers, among other things. Digital micromirrors are laid out on a semiconductor chip in DLP technology. DLP creates 3D models that are more robust and have a higher resolution. It also requires less material, which reduces expenses and waste (Alzarrad and Elhouar, 2019). For constructing a single layer of a 3D object by spatially controlled solidification using a projector light, the digital light processing (DLP) technology employing photocurable resins is fascinating (either UV or white light). This approach makes it simple to make a layer (Stansbury and Idacavage, 2016).

Another type of 3D technologies is Stick Dispenser. A depth camera and a projector guide the stick dispenser in real-time. By projecting a basic colour code, both of these technologies assist in notifying where the chopsticks will be placed. To operate the projector, printing must be done in low-light situations (Tay, et al., 2017).

Powder injection moulding (PIM) is a known technique for mass-producing metal and ceramic components. PIM eliminates the machining stage, cutting overall production costs (Basso, et al., 2019). PIM's potential lies in its ability to combine plastic injection moulding's design flexibility with powder metallurgy's nearly endless material alternatives, allowing several elements to be created.

The Digital Construction Platform (DCP) is a compound robotic arm system that combines a 5-axis Altec hydraulic mobile boom arm and a 6-axis KUKA robotic arm in development. Using rapid cure polyurethane foam, insulative formwork in double-curved geometry may be produced quickly and without the usage of support material. Early foam strength, print speeds, resolution, and preliminary economic statistics have all validated the project's promise (Keating, et al., 2014).

The WASP 2040 is a 3D printer that uses material extrusion (Bhardwaj, et al., 2019). This printer's build volume was cylindroconical in shape. The cylindrical component measured 200mm in diameter and 400mm in height. At the top of the construction volume, the distance between the bottom of the cylinder and the tip of the cone was 430mm. A 3-litre material container with a compressed air-operated plastic piston was provided with the printer. The G-code for printing was generated using the Cura software. To address this demand, several AM technologies that can produce ceramic parts are currently available (Travitzky, et al., 2014).

D-Shape is a method that employs a binder to selectively spray on the printing material, similar to inkjet powder beds. D-Shape is a powder-bed 3D printer with a production gantry that can produce architectural structures up to 6 x 6 x 6 meters long. Compressive strengths of goods printed using the D-shape technique range from 235 to 242MPa (Wu, Wang and Wang, 2016). D-Shape technology was created primarily for the manufacture of structural elements with complicated geometry in the factory (off-site) (Gosselin, et al., 2016).

Since the 1990s, Rapid Prototyping Technique (RP) methods have been used in medicine to create complicated 3D models (Swan, 1996). Medical diagnosis and surgical treatment planning are now both aided by the RP model. Wax patterns for prostheses, all-ceramic crowns, metal prostheses (in clouding FPDs and framework for removable partial dentures), and prosthetic casts are all covered in this review. (Sun and Zhang, 2012). The virtual phase (modelling and simulating) and the physical phase (building) are the only two phases of RP (fabrication), according to Wang and Shaw (2006). The practice of building a model through a dynamic, interactive simulation is known as virtual prototyping. The development of a physical model begins with the creation of a 3D physical model using CAD software.

The Flow-based Fabrication process is a patented extrusion-based additive manufacturing technique for yield stress material that is constantly reinforced. As a result, it is possible to build a part layer by layer using a continuous deposition of material along a specific robotic path based on the geometry of the finished part. Bi-extrusion and pultrusion are the two primary alternatives. The method for applying the mechanical force required for continuous reinforcing deposition is the key distinction (Ducoulombier, et al., 2020).

A welding robot (an articulated arm mounted on a track) was utilized to build a steel net that could be used as a permeable formwork for concrete that would be poured later [HAC 14, HAC 15]. This method is intriguing because it allows for the production of steel-reinforced wall parts that behave similarly to regular reinforced concrete (Perrot and Amziane, 2019). The mesh increases the concrete's tensile strength, making it a viable alternative to standard steel reinforcement (Tay, et al., 2017).

Minibuilders has presented a novel method for creating three-dimensional concrete. The system employs three small mobile robots. The first robot follows a specified course while laying the concrete foundation with the help of a sensor. The second robot is put on the foundation and grasped with rollers before printing further concrete layers and building the structure. The final robot uses suction cups and pressurized air to print vertically up the printed structure and strengthen it, which was previously just horizontally stacked (Zhang, et al., 2018).

Standard tessellation language format is a 3D printing technology. The three-dimensional representation of the surface geometry, also known as stereolithography, gives birth to unimportant information for printing such as texture or colour, resulting in its popularity in the industry (Sakin and Kiroglu, 2017). Standard tessellation language, as defined by Alharbi, et al. (2016), is a format for 3D digital files that be scanned and exported utilizing 3D systems into 3D printers.

SUMMARY OF 3D PRINTING TECHNOLOGIES

This section highlighted and discussed existing studies on 3D printing technologies. The summary is made in table 1.

Research Method

For this study, a quantitative research approach was used. Through the use of structured questionnaires, a survey research approach was employed to acquire primary data from the respondents, which included several project players in Lagos state, Nigeria (an economically growing area in West Africa). The survey's sample frame includes experts from construction and consulting firms in Lagos, such as architects, quantity surveyors, project managers, and engineers. Table 2 shows an overview of the sample size for the study. Convenient sampling was used to choose one hundred and seventy-one (171) respondents where respondents were picked based on convenience considering their availability, accessibility and proximity. The sampling size for this study was obtained using the Yamane formula adopted by Olatunji, et al. (2014) for each of the sample frames.

Table 1. Variables and coded authors on awareness of 3D printing techniques in the construction industry

S/N		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	TL
1	3D concrete printing	✓	✓																														2
2	Contour crafting			✓	✓	✓																											3
3	WASP						✓	✓																									2
4	Sterolithography					✓			✓																								2
5	Fused deposition modelling					✓				✓	✓																						3
6	D- shape technology											✓	✓	✓																			3
7	Rapid prototyping														✓	✓	✓	✓															4
8	Standard tessellation language format																		✓	✓													2
9	Digital light processing																				✓	✓											2
10	Digital construction platform																						✓	✓									2
11	Flow-based fabrication																								✓								1
12	Mesh-mould																									✓	✓						2
13	Minibuilders																											✓					1
14	Stick dispenser																										✓		✓				2
15	Inject power printing																													✓	✓	✓	3

A- (Nematollahi, et al., 2017); B- (Gardiner, 2011); C- (Khoshnevis, 2004); D- (Tay, et al., 2016); E- (Teizer, et al., 2016); F- (Bhardwaj, et al., 2020); G- (Travitzky, et al., 2014); H- (Chen, et al., 2017); I- (Pannerselvam, Raghuraman and Krishnan, 2021); J- (Rett, Traore and Ho, 2021); K- (Wu, Wang and Wang, 2016); L- (Lim, et al., 2012); M- (Gosselin, et al., 2016); N- (Swan, 1996); O- (Zhang, 2012); P- (Sun and Zhang, 2012); Q- (Wang and Shaw, 2006); R- (Sakin and Kiroglu, 2017); S- (Alharbi, Osman and Wismeijer, 2016); T- (Alzarrad, et al., 2019); U- (Stansbury, et al., 2016); V- (Keating, 2012); W- (Saulters and Scarr, 1985); X- (Ducoulombier, et al., 2020); Y- (Perrot and Amziane, 2019); Z- (Yi Wei, et al., 2017); AA- (Zhang, et al., 2018); AB- (Yoshida, et al., 2015); AC- (Alberto, et al., 2019); AD- (Hausnerová, 2011); AE- (Tandon, 2008)

Table 2. Sampling Size of the Respondent.

Respondents	Sample Frame	Sample Size	Retrieved
Architects	1700	43	12
Builders	700	42	31
Engineers	1850	43	13
Quantity surveyors	1080	43	17
Total	5330	171	73

Source: Nigerian Institute of Quantity Surveyors (NIQS), Nigerian Institute of Architects (NIA), Nigerian Society of Engineers (NSE), Nigerian Institution of Building (NIOB), 2020

Questionnaires in hard copy printed forms were distributed to the respondent accordingly for proper assessment. Of the 171 questionnaires distributed to the professionals in the construction industry who have limited time and organized office in the study area, 73 were retrieved. This was due to many forms being misplaced, while other respondents were lost track of. The retrieved forms were used for the analysis of this research work. Data was collected and analysed using descriptive statistics, which was done with the help of a statistical package for social science (SPSS). The data were analysed using mean item score, standard deviation, and factor analysis.

Results

In this section, the data collected from the field survey were systematically presented, analysed with inferences made in a bid to assess the level of awareness of 3D printing towards sustainable construction in Lagos, a city with an emerging economy.

BACKGROUND INFORMATION OF THE RESPONDENTS

This section reveals the general statistical information of the targeted respondents used for this research. The result of the survey presented in Table 3 shows the numbers of qualified professionals certified and registered according to the principles and guidelines of the professions with QSRBN having 30 frequency and 41.1% of the data collected, ARCON having the frequency of 17 and 23.3% of the respondents, CORBON having 13 frequency and 17.8 % of the respondents, COREN having respondents of 13 and 17.8 percent of the data collected and professionals with no professional qualifications amount to the frequency of 18 and 17.3% of the population. This result shows that all the respondents are certified and registered members of a professional body.

The result of the analysis presented in Table 3 shows the highest level of academic qualification attained by each of the respondents. From the result, the majority (54.8%) of the respondents are bachelor's degree holders, while some of them (34.2%) have attained a Master's Degree from their university of choice, with few (6.8%) having obtained a Higher National Diploma (HND) from a polytechnic. Meanwhile, 2.7% of the respondents have attained a PhD in their area of specialization, while 1.4% of the respondents had a National Diploma certificate to practice their profession

The result of the survey carried out on the years of experience of the respondents is presented in Table 3. From the result, it can be deduced that most of the professionals (61.6%) had between 5 to 10 years of professional experience, while 32.9% of the respondents had 11 to 15 years of professional experience in their respective professions. Furthermore, 2.7% of the respondents who are professionals in the construction

Table 3. Demographic characteristics of the respondents

Variables	Characteristics	Frequency	Percentage (%)
Professional qualification	Architects Registration Council of Nigeria (ARCON)	17	23.3
	Council of Registered Builders of Nigeria (CORBON)	13	17.8
	The Council for the Regulation of Engineering in Nigeria, COREN	13	17.8
	Quantity Surveyors Registration Board of Nigeria (QSRBN)	30	41.1
Highest Education Attained	National Diploma (ND)	1	1.4
	Higher National Diploma (HND)	5	6.8
	Bachelor's degree (B.Sc/B.Tech)	40	54.8
	Master's degree (M.Sc/M.Tech)	25	34.2
	Doctor of Philosophy (PhD)	2	2.7
Years of experience	Less than 5 years	2	2.7
	5 to 10 years	45	61.6
	11 to 15 years	24	32.9
	16 to 20 years	2	2.7

industry had less than 5 years of professional, 2.7% had long years of experience between 16 to 20 years respectively.

AWARENESS OF 3D PRINTING IN THE CONSTRUCTION INDUSTRY

The result of the survey carried out to inquire if the respondents are aware of 3D printing in the construction industry is presented in Table 4. According to the results, 65.8% of respondents said they were aware of 3D printing in the construction business. Alternatively, 24.7 percent of respondents were unaware of 3D printing, while 9.6 percent were unsure whether or not they were aware. The findings indicate that certain construction industry experts in the research region were unaware of 3D printing.

Table 4. Awareness of 3D printing

Variables	Response	Frequency	Percentage (%)
Aware of 3D Printing?	Yes	48	65.8
	No	18	24.7
	Maybe	7	9.6
Participated in 3D printing?	Yes	26	35.6
	No	28	38.4
	Maybe	19	26.0

Further analysis reveals that 35.6% of the respondents had participated in 3D printing while others had not participated, although 26% of the respondents were not sure whether they had participated or not. From the result, it can be deduced that the participation of professionals in the construction industry in 3D printing is low.

LEVEL OF AWARENESS OF 3D PRINTING TECHNOLOGIES

Table 5 shows the reliability statistics of the 5-point Likert scale from "very low" to "very high" was used for the survey. From the result, the Cronbach's alpha is 0.930 which indicates a very high level of internal consistency for the scale of the items of the level of awareness of 3D printing technologies.

Table 5. Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	No of Items
0.930	0.930	15

Table 6 shows the analysis of the Item-Total Statistics of the level of awareness of 3D printing technologies. Column 5 present the value that Cronbach's alpha would be if that particular variable was deleted from the scale. From the result, we can see that removal of any variable would result in a lower Cronbach's alpha. Therefore, we would not want to remove any of the variables.

Table 6. Item-Total Statistics

Variables	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
3D concrete printing	35.22	78.562	0.701	0.655	0.925
Contour crafting	35.58	80.692	0.591	0.440	0.928
WASP	35.22	80.785	0.602	0.538	0.927
Stereolithography	35.42	76.331	0.720	0.616	0.924
Fused deposition modelling	35.53	77.252	0.701	0.715	0.925
D-shape technology	35.40	81.187	0.576	0.520	0.928
Rapid prototyping technique	35.51	77.281	0.722	0.663	0.924
Standard tessellation language format	35.51	78.753	0.651	0.610	0.926
Digital light processing	35.53	78.780	0.692	0.702	0.925

Table 6. continued

Variables	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Digital construction platform	35.40	81.021	0.604	0.562	0.927
Flow-based fabrication	35.42	79.414	0.645	0.657	0.926
Mesh-mould	35.29	77.263	0.696	0.640	0.925
Minibuilders	35.30	79.991	0.615	0.504	0.927
Stick dispenser	35.62	78.351	0.690	0.679	0.925
Inject powder printing	35.29	77.958	0.701	0.692	0.925

Table 7 shows the results of a survey conducted to determine the respondents' level of awareness about 3D printing processes in the construction industry. With a mean of 2.73, the majority of the respondents are mainly aware of WASP and 3D concrete printing as some of the 3D printing techniques employed in the construction industry, indicating that it is of great relevance to the construction industry. Some respondents are familiar with Injection powder printing and Mesh-mould, each with a mean value of 2.66 and very high importance.

Table 7. Level of awareness of 3D printing

Variable	Mean	Std. Deviation	Rank
WASP	2.73	0.804	1
3D concrete printing	2.73	0.870	2
Inject powder printing	2.66	0.916	3
Mesh-mould	2.66	0.975	4
Minibuilders	2.64	0.856	5
Digital construction platform	2.55	0.782	6
D-shape technology	2.55	0.800	7
Flow-based fabrication	2.52	0.868	8
Stereolithography	2.52	1.015	9
Standard tessellation language format	2.44	0.913	10
Rapid prototyping technique	2.44	0.943	11
Digital light processing	2.41	0.863	12
Fused deposition modelling	2.41	0.969	13

Table 7. continued

Variable	Mean	Std. Deviation	Rank
Contour crafting	2.37	0.825	14
Stick dispenser	2.33	0.898	15

The use and importance of Digital construction platforms, D-shape technology, Stereolithography, Flow-based fabrication, Standard tessellation language format, Rapid prototyping technique, and Digital light processing can be considered to be averagely aware by the respondents. While Stick dispensers can be considered to be low awareness in the construction industry in the study area.

Table 8. KMO and Bartlett's Test for Awareness of 3D Printing

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.871
Bartlett's Test of Sphericity	Approx. Chi-Square	642.448
	Df	105
	Sig.	0.00

Table 9. 3D printing Awareness of Total Variance Explained

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.614	50.761	50.761	4.807	32.047	32.047
2	1.348	8.985	59.747	4.155	27.699	59.747
3	0.937	6.247	65.994			
4	0.822	5.483	71.477			
5	0.688	4.584	76.06			
6	0.591	3.939	79.999			
7	0.586	3.907	83.906			
8	0.508	3.385	87.291			
9	0.47	3.134	90.425			
10	0.359	2.392	92.817			
11	0.281	1.876	94.693			
12	0.263	1.754	96.447			
13	0.233	1.553	98			
14	0.176	1.173	99.173			
15	0.124	0.827	100			

The data received were enough for factor analysis, according to the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO), and Bartlett's Test of Sphericity for correlation adequacy between the variables was very significant, as shown in Table 8. A data collection or sample can be utilized for factor analysis if it passes Bartlett's Test of Sphericity.

The Kaiser-Mayer-Olkin sample adequacy test (KMO = 0.871) revealed that 87.1 percent of the data was eligible for factor analysis. With a degree of freedom of 66 and chi-square of 642.488, it also demonstrates that the p-value utilized is less than 0.05, meaning that the data is appropriate for factor analysis. According to Bartlett's test (p-value = 0.000), the correlation is an identity matrix, meaning that the correlation matrix of all the items presented has a significant correlation at the 5% level, and so exploratory component analysis is suitable in Table 6.

Variance in the total Principal Component Analysis (PCA) found the presence of four components with eigen values greater than one, accounting for 32.04 percent and 27.69 percent of the variance, respectively, in the areas of application of 3D printing in the construction industry.

Figure 1 shows a scree plot of the loading of awareness in the construction industry. After the second component, there was a noticeable split in the scree plot. The number of factors that should be created by the analysis is indicated by the point where the slope of the curve begins to level out.

The Rotated Component Matrix was used to conduct further analysis on 3D printing awareness in the construction business, and the results are provided in Table 10. The results demonstrate that a model with two applications may be sufficient to represent 3D printing awareness in the construction industry of

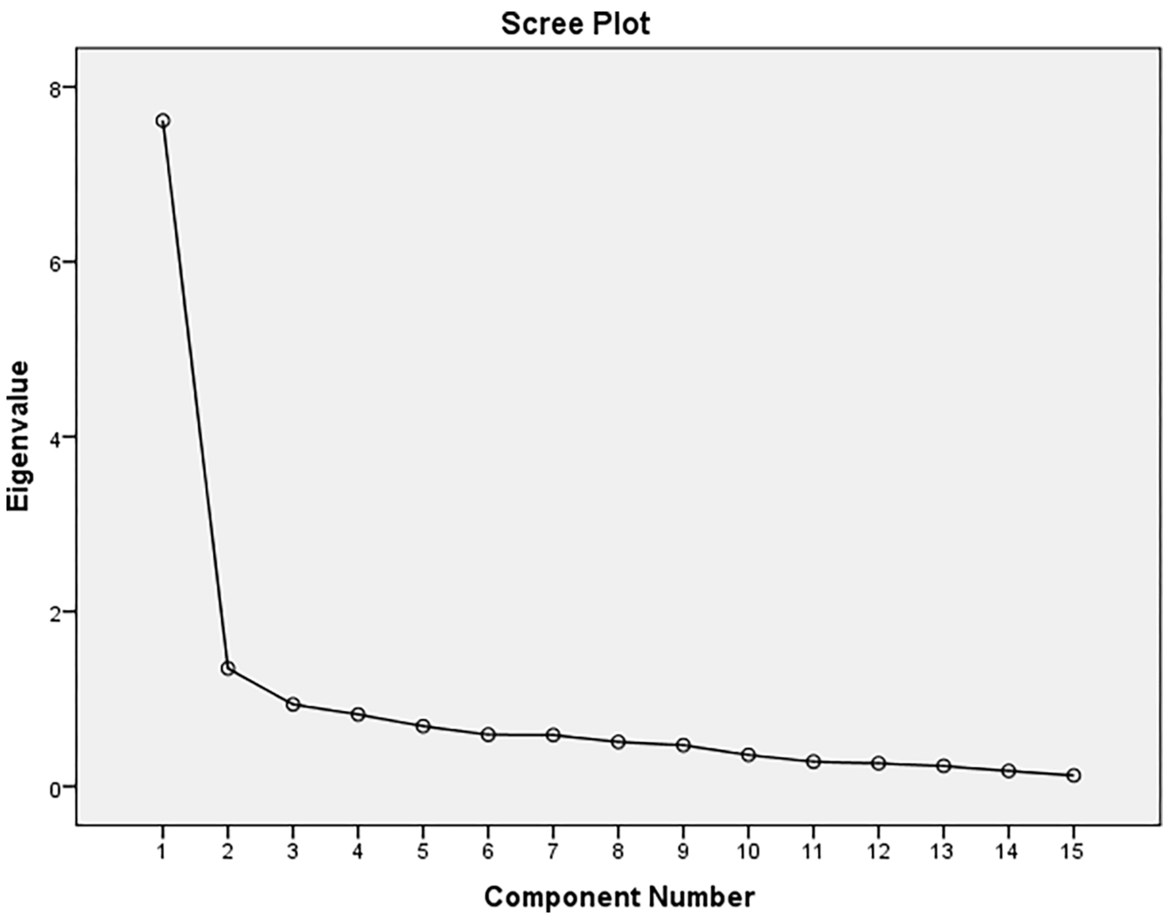

Figure 1. The scree plot of loading of the awareness in the construction industry

Table 10. Awareness of 3D printing Rotated Component Matrix

	F1	F2
Digital light processing	0.848	0.165
Inject powder printing	0.761	0.276
Flow-based fabrication	0.757	0.200
Mesh-mould	0.693	0.344
Stereolithography	0.665	0.408
D-shape technology	0.651	0.219
3D concrete printing	0.604	0.450
Minibuilders	0.578	0.357
WASP	0.573	0.348
Standard tessellation language format	0.220	0.803
Digital construction platform	0.183	0.777
Fused deposition modelling	0.349	0.731
Rapid prototyping technique	0.392	0.711
Stick dispenser	0.372	0.691
Contour crafting	0.256	0.679

emerging economies. Table 8 shows the factor grouping based on the varimax rotation, and each variable has a strong influence on only one of the tool groups. It is necessary to name these factors before interpreting the four major categories.

Table 11 shows the factor analysis, 15 items in factor influencing the awareness of 3D printing which results in a two-factor solution that is Digital and Technical in which optimism cannot be analysed because it's a single variable. The Kaiser- Meyer – Olkin (KMO) value is 0.871 and Bartlett's test of sphericity is significant (p =0.000).

Discussion

The awareness and knowledge of 3D printing technology are grouped into two major groups based on the data analysis of this study: Digital and Technical. The findings from this study show that majority of the professionals acknowledged that they were aware of the existence of 3D printing, but the majority of them attested that they had not utilized 3D printers before the survey. This finding corroborates Xu, et al., (2017) findings that the use of 3D printers in the construction industry is still limited. The low usage of 3D printing technology could be a result of the lack of exposure of the construction industry in developing countries to new technologies and their adoption. Furthermore, the potential challenges and risks envisaged by the professionals seem to have overshadowed the potential benefits of adopting this technology.

More findings of the awareness and usage of the listed 3D printers brought into light that the professionals are not satisfactorily aware of 3D printers and have not been utilizing 3D printers for their

Table 11. Related component of the awareness of 3D printing

Awareness of 3D printing (KMO= 0.871)	Nature item	Description	Factor loading
Digital	1	Digital light processing	0.848
	2	Jet power printing	0.761
	3	Flow-based fabrication	0.757
	4	Mesh- mould	0.693
	5	Stereolithography	0.665
	6	D- shape technology	0.651
	7	3D concrete printing	0.604
	8	Minibuilders	0.578
	9	WASP	0.573
Technical	10	Standard tessellation language format	0.803
	11	Digital construction platform	0.777
	12	Fused deposition modelling	0.731
	13	Rapid prototyping technique	0.711
	14	Stick dispenser	0.691
	15	Contour crafting	0.679

day-to-day operation. It could be concluded from the research of Chen, et al. (2017), Tay et al. (2017), Teizer, et al. (2016) and Wu, et al. (2016), that 3D printing has been underutilized in the construction industry in the emerging economy compared to its prominence in the manufacturing and health industry. The finding of this study in this section aligns with the positions of the reviewed researchers, as this could be as a result of so many factors such as the immaturity of the industry, unavailability of the technology, poor technological advancement, poor research and development team.

From the results of the factor analysis, the first awareness group is labelled 'Digital' which accounts for about 32.05% of the observed total variance and contains nine 3D printers which are: Digital light processing, Jet power printing, flow-based fabrication, mesh-mould, stereolithography, D-shape technology, 3D concrete printing, Minibuilders, and WASP. The printers discovered in this study have a low awareness and are not in use by the professionals in the construction industry of the study area. This can be attributed to the lack of exposure and immaturity of the professionals in the construction industry when it comes to technological innovations adoption. This finding aligns with the positions of Chen, et al. (2017), Tay, et al. (2017), Teizer, et al. (2016) and Wu, et al. (2016).

The second awareness group is labelled 'Technical' which accounts for about 27.70% of the observed total variance and contains six 3D printers which are: Standard tessellation language format, digital construction platform, fused deposition modelling, rapid prototyping technique, stick dispenser, and contour crafting. The printers as identified in this study have a low awareness and have not been used by the construction professionals. This finding aligns with the positions of Chen, et al. (2017), Tay, et al. (2017), Teizer, et al. (2016) and Wu, et al. (2016).

Conclusion

The degree of knowledge of 3D printing in the developing economy's construction industry was disclosed in this study. According to the findings, several construction industry experts were unaware of 3D printing. 3D concrete printing and WASP are two 3D printing technology often employed in the construction sector, according to some of the respondents. As a result of the limited understanding of 3D printing technology among professionals in the developing economy's construction industry, the use of this technology in the construction industry is extremely low. The implication of this is that it will impede the rate of acceptance and integration in the developing economy.

Therefore, more awareness of 3D printing technology should be raised to increase the awareness of the professionals and enlighten them on the benefits of adopting it into the construction industry. All stakeholders, professional bodies in the construction industry, and government agencies are to provide an enabling environment for adequate training and sensitization of all the parties in the construction industry about 3D printing towards sustainable construction in the emerging economy.

The limitation encountered in the study is the discouraging attitude of some of the professionals towards the administration of questionnaires which led to most of the questionnaires not being attempted in the study area. This research has shown the level of awareness of 3D printing among professionals towards sustainable construction in the construction industry. Some of the techniques of 3D printing are known to some of the professionals in the industry. The awareness of 3D printing in the construction industry will bring about its understanding, appreciation, and appropriate implementation, with a resultant sustainable construction in an emerging economy.

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DISCLOSURE STATEMENT

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