

Exploring Adoption Benefits of Three-Dimensional (3D) Printing in Construction

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Abstract: Three-Dimensional (3D) printing has evolved from being a demonstration technology to being deployed on construction projects. However, most of the evidence supporting this shift comes from developed countries in the Global North. The studies in developing economies have focused mainly on feasibility, materials and barriers to adoption. The benefits that practitioners expect to achieve are not well documented. This paper explores those benefits using Nigeria as the case study. A quantitative approach was used. Structured questionnaires were given to 171 construction professionals working in contracting and consulting firms in Lagos State. From these 73 usable responses were collected, giving a response rate of 42.7%. The data were analyzed using descriptive statistics and exploratory factor analysis. All eighteen benefits examined were rated significant. Improved affordability ranked highest, followed by construction safety, reduced manpower, improved productivity and increased precision; construction without formwork, reduced waste, sustainability, improved quality and design flexibility followed closely. Factor analysis resolved the benefits into three dimensions: sustainability and quality control, resource management, and construction accuracy and reputation, which together explained 66.58% of the total variance. The contribution is a straightforward one. Existing work has mainly addressed the applications and drivers of 3D printing adoption. This study establishes an empirically grounded framework of adoption benefits as perceived by practitioners in a developing economy. Construction organizations, professional institutions and government agencies can use that structure when appraising the technology. The findings also indicate that realized benefits depend on how well the technology is understood and on the strength of the institutional and industrial environment supporting it.

Keywords: 3D printing; additive manufacturing; construction 4.0; digital construction; Nigeria.

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1. Introduction

The construction industry is judged against a familiar set of performance problems. Productivity gains have been modest compared to other production sectors. Costs and labor demands stay high, delivery times resist compression, and safety and quality outcomes vary widely from one project to the next. Conditions of this kind have sustained a long search for delivery technologies capable of improving project performance, and Industry 4.0 has supplied much of the recent impetus, introducing digitally enabled technologies into the design, production and management of construction projects (Osunsanmi et al., 2018). Among them, Three-Dimensional (3D) printing stands out. It changes how building components and structures are made, not merely how they are planned.

Three-dimensional printing, also termed additive manufacturing, builds components and structures directly from digital models by depositing material in successive layers (Cameli, 2019; El-Sayegh et al., 2020). Geometry is instructed digitally rather than realized through molds and formwork. That difference explains the cluster of gains reported for the process. Integrated with building information modeling, 3D printing has been linked to higher productivity, greater design flexibility, more reliable cost prediction, improved quality, faster construction and better project coordination, together with fewer design errors and shorter production times (Sakin and Kiroglu, 2017). Comparative work has begun to quantify these effects. Batikha et al. (2022) reported savings of around 95% of construction time, cost reductions of at least 32%, and a carbon footprint lower by at least 32%. Evidence of this kind positions the technology as a route to more sustainable, resource-efficient construction and to more cost-effective housing delivery (Sakin and Kiroglu, 2017; Afolabi et al., 2019).

The argument for its adoption is strongest where construction resources are scarce. Developing economies face urban growth, poor infrastructure and housing shortages while operating with limited construction capacity. Therefore, any technology that reduces project time, uses materials and requires fewer workers is naturally appealing. Notwithstanding, whether these advantages actually happen depends on local conditions. Labor costs, material supply, current construction methods, rules and regulations, skills, infrastructure and market features all affect what a technology can deliver. These conditions differ significantly from those in which most research has been conducted. Developing economies, therefore, need to evaluate and adapt such innovations against their own building challenges rather than import conclusions reached elsewhere.

Research on 3D printing in construction has expanded quickly, though unevenly. One body of work has examined the obstacles to implementation: technological compatibility, implementation complexity, quality assurance, materials, logistics and wider impacts (Besklubova et al., 2021; Mujeeb et al., 2022; Schuldt et al., 2021). A second study has documented the advantages of building information modeling-enabled 3D printing and its potential contribution to sustainable construction, including in developing economies (Sakin and Kiroglu, 2017; Afolabi et al., 2019). Between them, these strands establish that the technology works, that identifiable barriers impede its diffusion, and that its environmental credentials are plausible. What they have not produced is practitioner-derived evidence on the benefits themselves. Benefits surface as by-products of feasibility assessments, laboratory investigations or narrative reviews. They are rarely the object of inquiry, and they are rarely measured, ranked or grouped in ways that would support an adoption decision. Empirical work of this kind in developing economies is limited, and the underlying evidence is scarce. Construction organizations, professional institutions and policymakers in these settings are consequently asked to appraise 3D printing without knowing which of its reported advantages their own professionals regard as significant, how those advantages rank against one another or whether they cluster into a smaller number of decision-relevant dimensions. This study addresses that gap. Its purpose is to examine the benefits of adopting 3D printing technology in construction from the perspective of construction professionals in a developing economy, with Nigeria as the empirical setting. Data were gathered through a questionnaire survey. The result is a demonstration of how construction professionals derive benefits from adopting 3D printing technology and how they perceive and rate these benefits in their day-to-day application. These findings equally include the underlying factors that support such ratings.

2. Literature Review

A growing body of literature agrees on what 3D printing brings to construction. Reported benefits include improved construction times, lower labor needs, reduced material use and waste, improved productivity and safety, cost savings, greater design flexibility, enhanced accuracy and greater environmental sustainability (Aghimien et al. 2020). Studies by Weng et al. (2020) revealed a considerable difference in productivity between the traditional and precast methods. The benefit reported by Hager et al. (2016) lies in the method itself, as the geometry is created additively, enabling increasingly complex designs with less formwork and waste. In this reading, efficiency of resources is not merely an incidental of the technology but a result of the way the technology creates material. The difference is significant in rapidly urbanizing developing economies, where the rapid growth of cities, inadequate infrastructure, housing shortages and limited construction resources make efficient project delivery a structural issue.

The evidence base nonetheless remains fragmented, and in a particular way. Much of the research has concentrated on technical applications, materials, implementation challenges, adoption drivers and feasibility rather than on systematically establishing the benefits construction stakeholders can derive from adoption (Besklubova et al., 2021; Mujeeb et al., 2022). When benefits have been directly discussed, they have usually come from review articles. Schuldt et al. (2021) listed sustainability, cost efficiency, productivity, geometric freedom, safety and waste reduction as advantages. However, most of these findings come from developed nations, laboratory experiments, manufacturing contexts or theoretical thinking. As a result, reported benefits are often inferred from results rather than measured through the perspectives of the people who would actually implement them.

There is little real data on how construction professionals in developing economies see, rank and prioritize these benefits. This gap is important because benefits derived from a technology are not fixed facts; they depend on contextual conditions such as labor availability, material access, established building practices, laws and regulations, skill levels, infrastructure and market behavior. Reduced labor costs may be highly contextual, where labor is expensive and hard to get, with little or no significance where labor is cheap and readily available. Similarly, benefits established in controlled experimental settings might not hold up when applied to supply chains or in settings with limited technical support. Therefore, benefits established in one setting cannot be assumed to have the same relevance or significance in another. The question that matters for adoption decisions is not whether the technology works, but which of its advantages practitioners in a given economy consider significant.

Research in developing countries has largely reproduced the wider pattern, focusing on the potential, challenges, and problems of 3D printing rather than on the benefits from the industry users' perspective. The present study takes that perspective as its starting point. Responses from construction professionals are used to identify the principal benefits of adopting 3D printing, and factor analysis is employed to establish the dimensions underlying them. Benefits understood in this way can serve as an empirical basis for evaluating the technology, and the resulting classification can help construction companies, policymakers and other industry players appraise the value of 3D printing technologies and develop a supportive environment for their adoption. Twenty publications addressing the adoption benefits of 3D printing were reviewed, and the benefits were recorded. Table 1 summarizes the results, with benefits arranged in descending order of frequency of occurrence across the reviewed sources.

Two features of the distribution deserve comment. Reduced waste heads the list, followed by increased customization, design variation and flexibility, construction safety, enhanced sustainability and reduced production cost, each cited by five or more sources. A middle band appears in three or four sources: improved efficiency, rapid prototyping, increased productivity, education and training, time-saving, reduced formwork, and reduced manpower. At the lower end sit enhanced quality performance, improved quality of life and welfare, ease of component recycling, component precision, creation of new markets, simplification of the supply chain, reduced construction errors and risk reduction, each reported only once or twice. The literature, then, emphasizes material- and design-related advantages over those concerning labor, organization and risk. It also draws predominantly on developed economies, so the frequency with which a benefit is reported indicates what has attracted scholarly attention rather than what practitioners in a developing economy would prioritize. Their relative importance in such a setting remains an open empirical question. It is the question this study takes up.

3. Method

The study adopted a quantitative approach, gathering data directly from respondents through a structured questionnaire. The design suited the objective. What was required was a measure of the significance construction professionals attach to a defined set of adoption benefits, their relative ranking, and the structure underlying those measurements, not an exploration of the meanings practitioners give to the technology. Lagos State, Nigeria, provided the study setting. It is the most populous and fastest-growing city in a developing economy, with a wide variety of ongoing mega construction projects. The sample included quantity surveyors, architects, engineers and project managers working in construction firms in Lagos. The number of professionals in each group registered with their professional bodies in 2025 was used to determine the sample size for each category. The Yamane formula in Equation (1) was applied to the sample.

$$n = \frac{N}{1+N(e)^2}. \quad (1)$$

The study's sample size was calculated using Equation (1), where "n" represents the sample size, "N" is the total population, and "e" is the desired level of precision (Olatunji et al., 2014). After calculating the required sample size, convenience sampling was used to select 171 respondents with experience working on 3D-printing construction projects. The reason behind this choice is simple: professionals who have worked on projects understand the technology better and are in a stronger position to judge its advantages.

The questionnaire was administered in hard copy to allow for effective evaluation. It was sent to respondents with offices in the study area who had time to complete it. Seventy-three were successfully retrieved, a response rate of 42.7%, which is not uncommon in construction and social sciences research (Dosumu et al., 2023). Twenty-four items related to the benefits of adopting 3D printing in construction comprised the instrument.

Analysis proceeded in two stages. Descriptive statistics, the mean item score, and standard deviation established the significance of each benefit and its relative ranking. Inferential analysis then used factor analysis to establish the dimensions underlying them, and the factor structure of the 24 items was assessed through exploratory factor analysis (EFA). Two-factorability tests preceded extraction. The Kaiser-Meyer-Olkin (KMO) measure is a test of factor homogeneity, commonly used when the partial correlations between variables are as low as possible (Sharma, 1996); the minimum value for successful factor analysis is 0.6, with a range of 0 to 1. Bartlett's test of sphericity was applied to determine whether the correlation matrix differed significantly from the identity matrix, with a p-value below 0.05 considered significant (Kineber et al., 2021). Components were then extracted by principal component analysis; those with eigenvalues above 1 were retained, and the solution was rotated to aid interpretation of the resulting benefit groups.

4. Results and Discussion

This section presents and scientifically evaluates the primary data obtained from the field survey to assess the advantages of implementing 3D printing technology in the construction industry. Table 2 shows the distribution of data collected from construction professionals. Respondents registered with the Quantity Surveying Registration Board of Nigeria (QSRBN) accounted for 41.1% of the sample. The Architects Registration Council of Nigeria (ARCON) accounted for 23.3%, the Council of Registered Builders of Nigeria (CORBON) for 17.8% and the Council of Registered Engineers in Nigeria (COREN) for 17.8%. A bachelor's degree was the highest educational qualification of the majority (54.8%), with a master's degree second at 34.2%; the Higher National Diploma (HND) accounted for 6.8%, the Doctor of Philosophy (Ph.D.) for 2.7% and the National Diploma (ND) for 1.4%. Most professionals (61.6%) had 5 to 10 years of experience, and 32.9% had 11 to 15 years of experience. The remainder is split evenly between 2.7% with less than 5 years' experience and 2.7% with 16 to 20 years' experience. The sample is thus professionally registered and academically qualified, and 97.3% of respondents have at least five years of industry experience, a profile that supports the reliability of their assessments of construction technology.

Table 1. Benefits of adopting 3D printing in construction

Benefits	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Total
Reduced waste	✓	✓		✓	✓	✓		✓		✓	✓			✓					✓		10
Increased customization		✓				✓				✓			✓		✓	✓		✓			7
Design variation and flexibility	✓				✓	✓	✓			✓			✓								6
Construction safety	✓	✓	✓											✓					✓		5
Enhanced sustainability	✓						✓		✓						✓				✓		5
Reduced production cost	✓	✓		✓	✓														✓		5
Improved efficiency	✓			✓	✓	✓															4
Rapid prototyping	✓					✓				✓	✓										4
Increased productivity		✓	✓				✓														3
Education and training						✓				✓										✓	3
Time saving		✓		✓															✓		3
Reduced formwork				✓			✓												✓		3
Reduced manpower												✓	✓				✓				3
Improved productivity		✓	✓				✓														3
Enhanced quality performance		✓		✓																	2
Improved quality of life and welfare		✓					✓														2
Ease of components recycling									✓												1
Component precision	✓																				1
Creation of new market																	✓				1
Simplification of supply chain										✓											1
Reduces construction error					✓																1
Risk reduction													✓								1

A- (Hager et al., 2016), B- (Aghimien et al., 2020), C- (Sakin and Kiroglu, 2017), D- (Perkins and Skitmore, 2015), E- (Wu et al., 2018), F- (Hardaway, 2023), G- (Weng et al., 2020), H- (Wu et al., 2018), I- (Mehar et al., 2020), J- (Toinette, 2023), K- (Rood, 2024), L- (Wickstrom, 2025), M- (Pearson, 2018), N- (Ellis, 2022), O- (Ross, 2024), P- (Bashyal, 2024), Q- (Singha, 2022), R- (Blasquino, 2024), S- (Lotfi and Sameh, 2020), T- (Ghisays, 2023).

The benefits studied, and their significance, are shown in Table 3. The results reveal that all eighteen items received a score above 3.5, meaning every single one falls within the significant range under the decision rule. The ranking reveals that Improved affordability came out first (mean = 4.27), followed by construction safety (4.25), reduced manpower (4.12), improved productivity (4.10), and increased precision (4.05). Construction without formwork, reduced waste and sustainability were the next, with ratings between 3.97 and 4.03. Development, without formwork, reduced waste. Sustainability was next, with ratings ranging from 3.97 to 4.03. Some of the lowest-ranked items were also deemed important, such as reduced construction time (3.71), reduced construction flaws (3.63), and increased customization (3.62). The standard deviations ranged from 0.811 to 1.110, indicating reasonable agreement among the respondents. Professionals do not question whether the benefits exist; they clearly see them. What they differ on is how important each one is, placing greater weight on cost, safety, and labor-related gains than on design-based benefits, which are often highlighted in published reviews.

Table 2. General information about the respondents

Demography	Characteristics	Frequency	Percentage (%)
Professional qualification	Architects Registration Council of Nigeria	17	23.3
	Council of Registered Builders of Nigeria	13	17.8
	Council for the Regulation of Engineering in Nigeria	13	17.8
	Quantity Surveyors Registration Board of Nigeria	30	41.1
Total		73	100
Academic Qualification	National Diploma	1	1.4
	Higher National Diploma	5	6.8
	Bachelor of Science	40	54.8
	Master of Science	25	34.2
	Ph.D.	2	2.7
Total		73	100
Years of experience	below 5 years	2	2.7
	5 - 10 years	45	61.6
	11 - 15 years	24	32.9
	16 - 20 years	2	2.7
Total		73	100

Table 3. Significant benefits of adopting 3D printing

Benefits	Mean	Std. Deviation	Rank
Improved affordability	4.27	0.870	1
Construction safety	4.25	0.940	2
Reduced manpower	4.12	0.999	3
Improved productivity	4.10	1.043	4
Increased precision	4.05	0.941	5
Construction without formwork	4.03	1.067	6
Reduced waste	4.01	1.007	7
Sustainability	3.97	1.054	8
Improved quality	3.97	1.040	9
Design flexibility	3.97	0.957	10
Design variation	3.93	1.110	11
Reduced material cost	3.88	1.027	12
Enhanced public image	3.84	1.028	13
Enhanced quality performance	3.81	0.811	14
Construction efficiency	3.79	0.816	15
Reduced construction time	3.71	0.920	16
Reduced construction flaws	3.63	1.007	17
Increased customization	3.62	0.922	18

Note: Not Significant = < 1.5, Slightly Significant = 1.5 – 2.49, Averagely Significant = 2.49 – 3.49, Significant = 3.5 – 4.49, Very Significant = > 4.49.

The data were then tested for suitability for factor analysis, with the results reported in Table 4. The Kaiser-Meyer-Olkin measure of sampling adequacy returned 0.883, indicating that 88.30% of the collected data were appropriate for factor analysis (Kineber et al., 2021). Bartlett's test of sphericity yielded 1423.451 with 276 degrees of freedom. The result is highly significant ($p < 0.001$) and successfully rejects the null hypothesis that the correlation matrix is an identity matrix. Collectively, these statistics confirm a significant correlation among the listed items at the 5% significance level and indicate that the dataset is highly appropriate for EFA (Oke et al., 2021).

Table 4. KMO and Bartlett's test of sphericity

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.883
Bartlett's Test of Sphericity	Approx.	1423.451
	Chi-Square	
	Df	276
	Sig.	0

Table 5 presents the total variance explained by the benefits of 3D printing adoption in construction. Principal component analysis found three components with eigenvalues above 1. After extraction, these accounted for 22.94%, 21.91%, and 21.74% of the variance, respectively, and cumulatively for 66.58%. The five highest components are shown. Their contributions are almost equal. No single dimension dominates the benefit structure, and the advantages professionals associate with 3D printing are distributed across three comparably weighted domains.

Table 5. Total variance explained on the benefits of 3D printing adoption

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.124	54.684	54.684	5.505	22.937	22.937
2	1.686	7.026	61.711	5.257	21.905	44.842
3	1.169	4.872	66.583	5.218	21.741	66.583
4	0.979	4.078	70.661			
5	0.802	3.343	74.004			

Fig. 1 shows the scree plot of the benefits of adopting 3D printing. Inspection indicates a definite break after the second component, and because the curve levels off at this juncture, the visual analysis supports the extraction of three underlying components (factors). The scree criterion, therefore, corroborates the eigenvalue criterion reported in Table 5.

The rotated component matrix is shown in Table 6. Three distinct benefit groups emerged, effectively modeling the benefits associated with the adoption of 3D printing in the construction industry of developing economies. Each item was assigned to the component on which it loaded highest, and every retained item met the 0.50 threshold on that component. Six items also loaded at or above 0.50 on a second component improved quality, construction without formwork, reduced manpower, enhanced public image, reduced material cost and increased customization, so the assignment for these rests on the dominant loading rather than on a clean, simple structure. Enhanced quality performance was a different case. Examined across all three factor groups, its loadings fell below the 0.50 threshold on every one, so it did not load sufficiently on any factor and was excluded from the factor structure. The resulting classification is set out in Table 7. Table 7 presents the advantages of 3D printing in the construction industry, as identified through factor analysis. The results identified 18 benefit items influencing the adoption of 3D printing, which were classified into three groups: sustainability and quality control (seven items), resource management (four items), and construction accuracy and reputation (seven items). A Kaiser-Meyer-Olkin value of 0.883 and a highly significant Bartlett's test of sphericity ($p < 0.001$) confirmed the suitability of the dataset for this analysis. The reliability values for these three extracted factors had values from 0.415 to 0.604.

5. Discussion

The study examined the advantages of 3D printing in the construction industry. In developing countries such as Nigeria, the most notable benefits lie in affordability, construction safety, reduced manpower, improved productivity and precision; the three rated least beneficial for the adoption of the technology were reduced construction time, reduced construction flaws and increased customization. Several of these results have precedents. Improved affordability is consistent with the

findings of Hager et al. (2016), Aghimien et al. (2020), Perkins and Skitmore (2015), Wu et al. (2018), and Lotfi and Sameh (2020). Construction safety aligns with Sakin and Kiroglu (2017). Increased productivity and decreased manpower agree with Weng et al. (2020), Rood (2024), Wickstrom (2025), and Ross (2024). Across many regions, then, improved affordability, construction safety, reduced manpower, and higher productivity and precision emerge as the more significant benefits of adopting 3D printing technology. The findings further corroborate the view of Aghimien et al. (2020), which states that government agencies and private developers would find 3D printing technology useful for making housing schemes and construction projects more affordable. Sakin and Kiroglu (2017) proposed that technology can help prevent injuries and fatalities on construction sites by reducing the number of people needed to perform dangerous tasks. Steenhuis and Pretorius (2017) and Hossain et al. (2020) likewise concluded that 3D printing reduces the construction sector's high labor demand. The prominence of construction safety here is consistent with Sakin and Kiroglu (2017) and suggests a mechanism: the safety benefit appears to be realized through reduced exposure that follows from lower labor intensity, rather than as an independent effect of the technology.

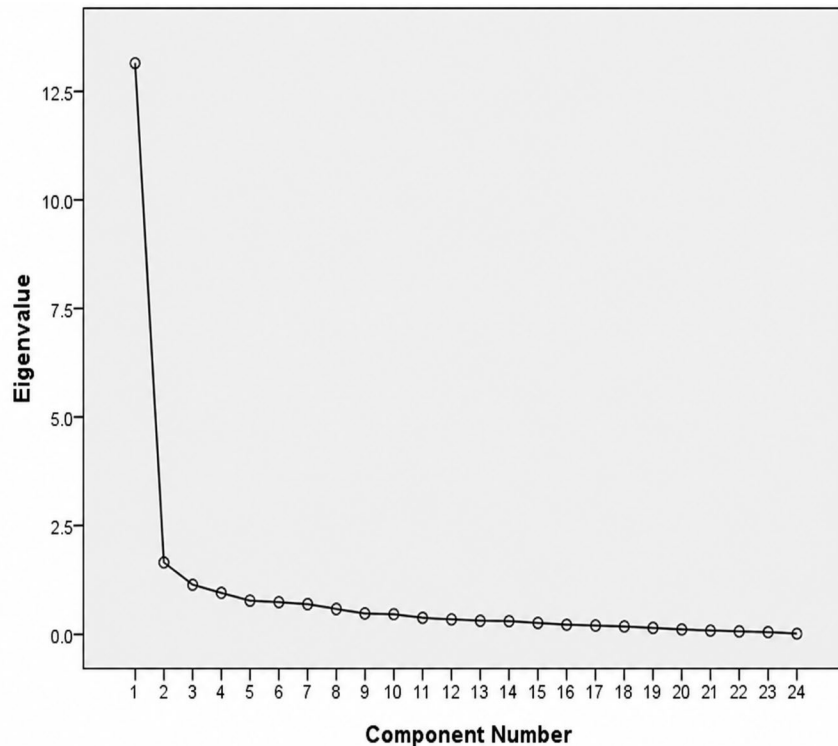


Fig. 1. Scree plot of loading of benefits of 3D printing adoption (source: original)

The first category, sustainability and quality control, accounts for 22.94% of the total variance observed. It includes seven areas of benefit: enhanced sustainability in construction, improved productivity, improved affordability, reduced construction flaws, improved construction safety, improved quality, and reduced construction waste. These benefits are considerable, as mean ratings range from 3.63 to 4.27. The results corroborate those of Hager et al. (2016), Mehar et al. (2020), and Aghimien et al. (2020), who affirmed that 3D printing is beneficial for sustainable construction. This includes Wu et al. (2018), who claimed that 3D printing and related technologies can significantly reduce errors in construction processes. The second category is resource management, which accounts for 21.90% of the observed total variance. Four benefits comprise it: reduced construction time, improved construction efficiency, construction without formwork, and design variation. Mean scores were not negligible, ranging from 3.71 to 4.03, demonstrating their significance for 3D printing technology. These findings corroborate the work of Perkins and Skitmore (2015) and Weng et al. (2020), who, respectively, suggested that 3D printing technology could save construction time, improve quality, and enable construction without formwork. The grouping is coherent in practical terms. Eliminating formwork is the mechanism by which program duration and site efficiency gains are achieved together, and the freedom to vary geometry follows from this process. The third category, construction accuracy and reputation, accounts for 21.74% of the observed total variance and includes seven benefits: increased precision, sustainability, reduced manpower, enhanced public image, reduced material costs, design flexibility, and increased customization. Mean scores range from 3.62 to 4.12. These, too, are significant and matter for the adoption of 3D printing technology in developing countries, as Saeed et al. (2021) and Mehar et al. (2020) have posited. Past research points the same way. 3D printing technology is beneficial for printing components with high precision, for managing and reducing material costs through reduced construction waste, and for enabling construction without formwork (Sakin and Kiroglu, 2017). The evidence is consistent on this point. Compared with traditional construction methods, 3D printers achieve high precision in printing large, complex components with intricate geometry (Hager et al., 2016; Yeh and Chen, 2018). The literature also attests that 3D printing technology could deliver products faster, enhance design flexibility, and enable mass customization compared to traditional prefabrication methods (Pan et al., 2021; Rayna and Striukova, 2021). Wider benefits have also been claimed. The adoption of 3D printing in construction could yield tangible benefits through recycling, top-down development, inclusivity, bottom-up grassroots innovation, division of labor, and global

production networks (Birtchnell and Hoyle, 2014). The composition of this factor is notable in two respects. Increased precision carries the highest loading in the entire solution (0.790), consistent with the accuracy label, and enhanced public image sits alongside it, suggesting that practitioners associate technical precision with organizational reputation and thus perceive a commercial return alongside a technical one. Reduced manpower loading here, rather than with resource management points, points the same way: labor reduction appears to be valued for the consistency of output it brings as much as for the savings themselves.

Table 6. Rotated component matrix of the benefit of 3D printing adoption

Benefits	F1	F2	F3
Enhanced sustainable construction	0.779	0.447	0.128
Improved productivity	0.765	0.242	0.367
Improved affordability	0.731	0.189	0.415
Reduced construction flaws	0.702	0.166	0.196
Construction safety	0.675	0.241	0.086
Improved quality	0.595	0.142	0.594
Reduced construction waste	0.559	0.226	0.473
Reduced construction time	0.372	0.687	0.256
Construction efficiency	0.236	0.652	0.277
Construction without formwork	0.370	0.544	0.528
Design variation	0.399	0.512	0.422
Increased precision	0.160	0.301	0.790
Sustainability	0.345	0.333	0.734
Reduced manpower	0.143	0.500	0.653
Enhanced public image	0.604	0.069	0.617
Reduced material cost	0.204	0.512	0.609
Design flexibility	0.365	0.478	0.590
Increase customization	0.158	0.523	0.537

F1 = Factor 1; F2 = Factor 2; and F3 = Factor 3

6. Conclusion

This study investigated the benefits of 3D printing technology in the construction industries of developing countries, taking Nigeria as its empirical setting. The most significant benefits of adoption are improved affordability, construction safety and productivity, reduced manpower, construction without formwork and increased precision. All of the positive effects of the 3D printing technology studied are relevant to the construction sector. The results do not, however, fully align with the literature. That body of work ranked the benefits of 3D printing technology in the order of reduced waste, increased customization, design variation and flexibility, construction safety, enhanced sustainability and reduced production costs. The divergence is the more substantive finding. Construction professionals in a developing economy prioritize benefits that address cost, labor, and safety, whereas the reviewed literature, drawn largely from developed economies, emphasizes material- and design-related advantages. Hence, the study posits that the benefits of 3D printing technology adoption in construction may differ across regions. The research also identifies all potential gains from adopting 3D printing in construction, which can be grouped into sustainability and quality control, resource management, and construction accuracy and reputation. Several recommendations follow. Government, private agencies and commercial developers in the construction sector of developing economies should use 3D printing technology in their housing and construction schemes for the following benefits: making housing schemes more affordable, reducing construction time and costs, improving construction safety, increasing productivity and promoting sustainable construction. All construction stakeholders are to collaborate to foster an enabling environment for the adoption of 3D printing in construction projects. Further, 3D printing technology should be integrated into degrees in the built environment program at universities, and professional bodies should raise awareness of its benefits in the construction industry. Finally, adoption in developing countries should be encouraged to avoid a potentially large technology adoption gap, given its rapid uptake in developed countries.

Government, developers, and construction workers can draw practical evidence from these outcomes to encourage the use of 3D printing to make building construction more affordable, safer, more productive, more resource-efficient, and more precise. The identified benefit categories can also inform policies, professional training and curriculum development for integrating 3D printing into construction practice in developing countries. The study has limits. It is confined to construction professionals in Nigeria and examines the perceived advantages of 3D printing among respondents, so the results are not necessarily applicable to other countries or economies and do not serve as a replacement for objectively

measured evidence of performance. Future research in developed and other developing economies can examine regional differences in the benefits of 3D printing.

Table 7. Factor analysis of the benefits of 3D printing adoption

Benefits of 3D printing adoption (KMO = 0.883)	item	Description	Factor loading
Sustainability and Quality Control	1	Enhanced sustainable construction	0.779
Improved productivity	2	Improved productivity	0.765
Improved affordability	3	Improved affordability	0.731
Reduced construction flaws	4	Reduced construction flaws	0.702
Construction safety	5	Construction safety	0.675
Improved quality	6	Reduced waste	0.601
Reduced construction waste	7	Improved quality	0.595
Reduced construction time	8	Reduced construction waste	0.559
Resource management			
Construction without formwork	9	Reduced construction time	0.687
Design variation	10	Improved efficiency	0.652
Increased precision	11	Construction without formwork	0.544
Sustainability	12	Design variation	0.512
Construction accuracy and reputation	13	Increased precision	0.790
Enhanced public image	14	Reduced manpower	0.653
Reduced material cost	15	Enhanced public image	0.617
Design flexibility	16	Reduced material cost	0.609
Increase customization	17	Design flexibility	0.590

Author Contributions

Oluwaseun Sunday Dosumu contributed to conceptualization, methodology, research design, data analysis and interpretation, original draft, reviewing, editing, and supervision. Ayodeji Emmanuel Oke contributed to conceptualization, methodology, literature review, data collection, data analysis and interpretation, original draft writing, reviewing and editing. Nathan Kibwami contributed to conceptualization, literature review, methodology, interpretation of findings, writing, reviewing, editing, and validation. Frederic Nyaminani contributed to data collection, investigation, literature review, data analysis, interpretation of findings, review and editing. Olusegun Emmanuel Akinsiku contributed to conceptualization, methodology, interpretation of findings, reviewing, editing, and validation. Jeanne Uwanyirigira contributed to data collection, investigation, data organization and analysis, literature review, writing original draft, writing review and editing. Nnadi Ezekiel Oluwaseun Ejiofor contributed to conceptualization, methodology, validation, interpretation of findings, construction management expertise, writing review and editing, and supervision.

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Institutional Review Board (IRB) Statement

Not applicable. The study involved a voluntary questionnaire survey of construction professionals. Informed consent was obtained from participants through a screening question presented before the questionnaire commenced. Participation was voluntary, and respondents could decline to proceed. No personally identifiable information was collected, and the confidentiality of responses was maintained.

Declaration of Artificial Intelligence (AI) Tools

ChatGPT was used for language editing and improvement in readability. The authors reviewed and verified all content and take full responsibility for the accuracy and integrity of the manuscript.

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