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Leveraging Smart Technologies for Efficiency and Cost-Effectiveness in Nigeria's Construction Sector

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ABSTRACT

This study aimed to explore the implementation of smart technologies and project delivery within the Nigerian construction sector. Population of the study comprised of the 2695 construction professionals in the selected firms. The paper utilized the proportionate stratified random sampling to determine sample size in each department from which 128 instruments were retrieved after distribution. SPSS (ver.26) was used to generate frequencies, means, multiple regression and ANOVA. Result indicated 71.9% and 28.1% of the sample were males and females respectively, indicating the dominance of male employees in the construction, of which 60.9% have spent at least 5 years. It was indicated that, Building Information Modeling (M=2.60, sd=1.05) is the most widely adopted smart technology. Also, BIM was shown to be the most significant leading technology in terms of impact on on-time (p-val=0.00, B=0.352) and quality (0.340) project delivery, closely followed by AVR (B=0.264) and SW (B=0.198), respectively. BIM's potentials for a better visualization and planning, and early detection of clashes, which helps to reduce unnecessary costs, seem to fuel its significant adoption and impact. Based on these findings, the study concluded that implementing smart technologies in the selected firms improved efficiency and optimized overall competitiveness. Consequently, establishing platforms that foster partnerships with tech providers with the provision of seminars or workshops for professionals within construction sector. Also, the provision of incentives for technology adoption such as tax reliefs by the government to curb barriers like cost of implementation, lack of expertise, and infrastructure limitations, is recommended.

Key words: Smart Technologies, Building Information Modeling (BIM), Internet of Things (IoTs), Cloud Computing, Augmented and Virtual Reality (AVR), Construction, Nigeria

1. INTRODUCTION

Construction project delivery in Nigeria, has been a significant parameter in determining the competency of constructions firms [1]. It refers to the entire process of planning, executing, and completing a construction project from inception to completion. It encompasses various stages and involves multiple stakeholders, including owners, architects, engineers, contractors, and subcontractors [2]. For decades, contractors have lagged behind in delivery time and quality of construction projects owing to too many factors such as poor planning, lack of experience, financial constraints, supply chain issues, and regulatory delays, to which until recently, adoption of improved project planning and management, increased funding and investment, regulatory reforms, and the adoption of construction 4.0 or smart technologies [3] are deemed to be the critical factors that would abate these unending issues resulting late delivery and poor quality of projects.

The twenty-first century is witnessing a rapid global acceleration of technological breakthroughs and inventions, which is having an impact on the features of buildings and other infrastructures in our cities [4]. Over the past ten years, the Fourth Industrial Revolution—which brought about smart technologies—has had a significant impact on the building sector. The adoption of these smart technologies presents a compelling potential for enhancing the construction industry's performance [5]. However, [6][7] clearly pointed out the adoption of these technologies in the Nigerian construction industry is considerably low.

Construction 4.0 is a transformative framework integrating IoT, drones, AI, robotics, AR/VR, blockchain, and big data analytics to enhance industrial production, cyber-physical systems, and digital technology in the construction industry. With the utilization of automation and cutting-edge technologies, it transforms conventional building methods to increase productivity, efficiency and sustainability [8]. This framework enhances industrial production and cyber-physical systems by improving efficiency, accuracy, and data management in the construction industry. These technologies facilitate data-driven decision-making, automated processes, and real-time monitoring, leading to optimized project management, reduced errors and hazards [9], and raising overall productivity. Studies conducted on the building sector in developing nations reveal that the adoption of smart building concept is still low, and this is largely due to the fact that construction professionals are not well-versed in it [10]. However, a study conducted in Lagos, Nigeria by [11] revealed that construction professionals were found to be widely aware of smart building concept.

For construction companies, implementing smart technology is a challenging and reactive process, however, [12] highlighted the necessity of implementing smart technology in construction projects to enhance efficiency. Implementing this strategy is crucial in addressing challenges like low productivity, construction delays, lack of technological awareness, and environmental issues in a developing country like Nigeria [13]. The intelligent features surrounding smart technology have several advantages when it comes to building design and construction [14]. These features include real-time monitoring for tracking project progress and performance, automation that streamlines processes such as scheduling and quality control, and data analytics for informed decision-making. Smart technologies can further help in handling stakeholders' conflict and competing interest in construction projects [15] by improving communication, collaboration, transparency, and decision-making processes, as real-time visualization of project's success is made available through augmented and virtual reality.

For something as beneficial as smart technology not to be fully adopted, there are inhibitors to its adoption. And these inhibitors could vary according to specific smart technologies, while some would be generalized. Some of the inhibitors to its (IoT) adoption include security, privacy, safety, maintainability, scalability and portability [12]. Similarly, the lack of managerial commitment is a critical factor inhibiting the adoption of smart technology in the construction industry [13]. This industry faces several challenges when considering the implementation of such technologies, including limited technical expertise, high costs associated with smart and sustainable materials and equipment, and resistance to departing from conventional methods. These practical, financial, and economic difficulties persist despite the numerous advantages that smart technologies offer [14][15]. Therefore, the absence of robust leadership to drive the change exacerbates these obstacles and impedes the industry's advancement in incorporating cutting-edge technologies.

Extant research [9][11][16][17][18][19][20] has not assessed the impact of implementing smart technologies on on-time and quality project delivery in Nigeria's construction sector. This gap prompted the current study, as findings will be a pedestal on which construction firms will base their decisions as to whether or not adopt smart technologies when on-time and quality delivery is a priority. This study therefore aims to investigate leveraging on smart technologies for efficiency and cost-effectiveness in Nigeria's construction sector, with specific objectives to: (1) assess the level of adoption of smart technologies in the Nigerian construction industry (2) determine the impact of smart technologies on on-time delivery of construction projects and (3) examine the impact of smart technologies on construction project quality. The conceptual framework of this study is portrayed in Figure 1.

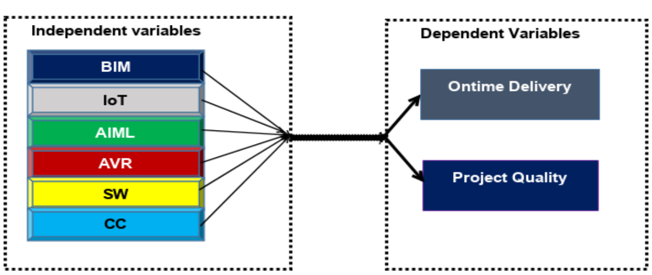

Figure 1: The hypothesized relationship between implementation of smart technologies and Project Delivery (Source: Author's construct).

2. RESEARCH METHODOLOGY

The study utilized questionnaires to obtain primary data from construction professionals in three construction firms in Lagos State; Dutum Group Construction Company, Julius Berger Nigeria Plc, and China Civil Engineering Construction Corporation, using purposive sampling technique [21], while proportionate stratified random sampling [22] was deployed to determine sample size in each department and to form the desired sample size of 200 from which 128 instruments were retrieved after distribution. The data was analyzed using descriptive and inferential statistical tools, including frequency, Mean-Item-Score, standard deviation, multiple regression and ANOVA. The instrument was designed based on four-point Likert-scale, in which Strongly Agreed (SA) weighs 4, Agreed (A) weighs 3, Disagreed (D) weighs 2, and Strongly Disagreed (SD) weighs 1.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + e_i \quad (1)$$

Where:
$Y = (y_1, y_2)$= Project Delivery
y_1= on-time delivery; y_2= Project Quality, x_1 = BIM, x_2 =IoT, x_3 =AIML, x_4 = AVR, x_5 = SW
x_6 = CC, β_0 =constant, e_i =random error.
The formula for proportionate stratified random sampling technique is given as:

$$n_j = \frac{n}{N} \times N_j \quad (2)$$

Where:

n_j= sample size from department, N_j= Department size, n=sample size, and N=population size.

$$n_1 + n_2 + n_3 \ldots . + n_j = n \quad (3)$$

$$N_1 + N_2 + N_3 + \cdots + N_j = N \quad (4)$$

Table 1: Distribution of sample across Departments

Strata	Sratum size (N_j)	Sample size (n_j)
Project Manager/Contractor	1835	136
Quality Assurance and Quality Control Engr.	206	15
Architect and Quantity Surveyor	186	14
Project Engr.	320	24
Safety Engr.	148	11
Total	**2695**	**200**

The selection of Project managers/contractors, QA/QC Engr., Architect / Quantity Surveyor, Project Engr., and Safety Engr., was due to their direct dependence on smart technologies for job delivery, making them most relevant. Also, the limitation of the scope to these few specific roles was to focus more on experience or facts, than guess responses, thus, reducing bias in data. In Nigeria, concerns over data privacy and security remains one of the reasons why most private firms are reluctant to release their data, following the weakness in enforcement of Nigeria Data Protection and Regulation (NDPR). The figures are rough estimates garnered from the staff of these firms under study.

3. RESULTS

3.1 Demographics

After 200 questionnaires were distributed, only 128 instruments were retrieved from the respondents, as the instrument either got lost, torn or were never attended to. The retrieved 128 instruments formed the data for this study.

Table 2: Demographics of respondents

Variable		Frequency	Percent
Gender	Male	92	71.9
	Female	36	28.1
Experience	1-5 years	50	39.1
	6-10 years	23	18.0
	11-15 years	34	26.6
	Above 15 years	21	16.4
Profession/ Job Role	Project Manager/Contractor	69	53.9
	QA/QC Engr.	17	13.3
	Architect/Quantity Surveyor	13	10.2
	Project Engr.	19	14.8
	Safety Engr.	10	7.8

Following the distribution in Table 1, Table 2 is showing that, 128 respondents participated in the survey (n = 128), of which 71.9% and 28.1% were males and females respectively, indicating the dominance of male employees in the construction industry. Experience in the construction industry ranged from 1 – 5 years to above 15 years. From the result, about 39.1% of the respondents have not spent more than 5 years in the industry. This somewhat indicates that employment in the construction industry has not dropped amidst the economic hardship facing the country. This is closely followed by those whose years of practice in the industry fall within 11 to 15 years (26.6%), 6 to 10 years (18.0%), and least, are those whose experience is more than 15 years (16.4%). Roles in the construction industry is almost inexhaustible, this study therefore focused on a few roles critical and much relevant to the topic of interest, for which majority of the respondents (53.9%) comprised of project managers and contractors, with another 14.8% who are project engineers, 13.3% comprising Quality assurance and control Engineers (13.3%), Architects and Quantity Surveyors (10.2%), and Safety Engineers (7.8%). This shows that the respondents are competent enough to attempt the questions pertaining to implementation of smart technologies and project delivery. Given a majority being male, that indicates the representation aligns with the industry's workforce composition. Also, given that a significant proportion have experience of more than 5years, that would be considered a plus, as it suggests proven experience in the industry. Also, the inclusion of the stakeholders makes it even more outstanding as they are considered to have a verse for practical implications of smart technology adoption for timely and quality project delivery.

3.2 Adoption of Smart Technologies amongst Professionals in Construction Industry

Table 3: Adoption of smart technologies amongst professionals in the construction industry

The following smart technologies are incorporated during construction projects	SA	A	D	SD	Rank	$\bar{x}$	sd
Building Information Modeling (BIM) creation of detailed 3D models that include precise geometry and relevant data needed for construction	25	31	42	30	1	2.60	1.05
Internet of Things (IoT) Tracking of equipment and personnel movements, and collection of real-time data to enhance decision-making and proactive maintenance.	47	30	42	9	6	2.10	.986
Artificial Intelligence and Machine Learning (AIML) Automation of routine tasks, such as scheduling and resource allocation are done with AI and ML	37	45	33	13	4	2.17	.964
Augmented and Virtual Reality (AVR) Overlay of digital information onto the physical site, aiding workers with real-time guidance and instructions.	32	38	44	14	2	2.31	.970
Smart Wearable (SW) Workers are equipped with smart helmets, vests, and glasses can monitor worker health, track location, and provide real-time safety alerts	36	46	31	15	3	2.19	.980
Cloud Computing (CC) Initiation of platforms for the storage, sharing, and real-time access of project data from anywhere	49	33	28	18	5	2.11	1.07

Table 3 shows that, to an extent, smart technologies are deployed on-site to handle various construction tasks. The most readily deployed smart technology is the Building Information

Modeling (M=2.60, sd=1.05), closely followed by Augmented Reality and Virtual Reality (M=2.31, sd=0.97), smart wearable (M=2.19, sd=0.98), Artificial Intelligence and Machine Learning (M=2.17, sd=0.96), Cloud Computing (M=2.11, sd=1.07), and Internet of things (M=2.10, sd=0.98). This finding resonates with [23][24] who noted BIM to be increasingly deployed in various construction applications. This, however, shows the level of adoption of smart technologies for project delivery amongst professionals is still at infancy, although a progress is being made. This finding is in congruence with [20] who noted that the Nigerian construction industry is proficient in global positioning systems, cameras, IoT-enabled HVAC systems, smart homes, and BIM.

3.3 Effect of Smart Technologies on On-time Delivery of Construction Projects

Prior to the use of multiple regression models, normality and multicollinearity assumptions were tested as shown in Figure 2 and Table 4.

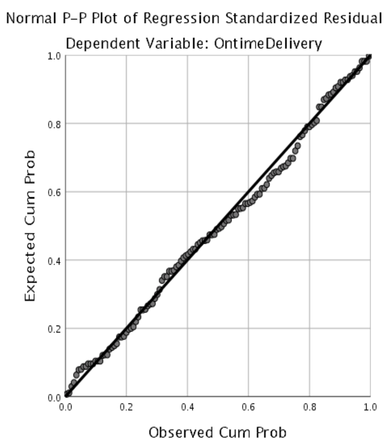

Figure 2: Normality plot for on-time delivery

Table 4: Multicollinearity for on-time delivery

Coefficients^a							
Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	-.696	.150		-4.636	000		
BMI	.409	.059	.352	6.907	000	.544	1.839
IoT	.225	.060	.181	3.757	000	.606	1.650
AIML	.023	.061	.018	.382	703	.608	1.644
AVR	.332	.064	.264	5.219	000	.553	1.810
SW	.167	.053	.134	3.141	002	.778	1.286
CC	.283	.054	.249	5.251	000	.627	1.595
a. Dependent Variable: On-time Delivery							

As shown in Table 4, the variance inflation factor (**VIF**) values were slightly higher than 1.0, implying almost no correlation between the predictors and the response variable exists, hence multicollinearity assumption was satisfied [25]. Additionally, **Tolerance** values were all > 0, implying little to no correlation between the predictors and response variable. Therefore, from Figure 2 and Table 4, it could be seen that normality and multicollinearity assumptions were met by the data.

Table 5: ANOVA for Smart Tech on on-time project delivery

ANOVA^a					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	157.566	6	26.261	97.970	.000^b
Residual	32.434	121	.268		
TotActual	190.000	127			
a. Dependent Variable: On-time Delivery					
b. Predictors: (Constant), CC, SW, IoT, AIML, AVR, BMI					

Table 5 depicts there is a significant effect of smart tech adoption on on-time construction projects delivery, since $F = 97.97$, and $p = 0.00$ at level of significance $(\alpha) = 0.05$.

Table 6: Multiple Regression of Smart Technologies on On-time Delivery of Construction Projects

on-time Delivery	**Smart Tech.**	**Standard Beta**	**Sig.**
The adoption of smart technologies during construction projects has led to faster delivery by enhancing efficiency, reducing errors, improving coordination, and enabling proactive management	**BIM**	0.352	000
	IoT	0.181	000
	AIML	0.018	703
	AVR	0.264	000
	SW	0.134	002
	CC	0.249	000
= 0.911, r^2=0.829, Significance=$\boldsymbol{p < 0.05}$			

$$OntimeDeliv = 0.35BIM + 0.18IoT + 0.02AIML + 0.26AVR + 0.13SW + 0.25CC \quad (5)$$

Table 6 shows that 82% total variability in on-time delivery of construction projects is accounted for by the implemented smart technologies. It further depicts the respective effects of the predictors on the response variable (on-time project delivery), and it is evident that, with exception of AIML ($p - val = 0.703$), all the smart technologies under consideration have significant effect on on-time delivery of construction projects in the Nigerian construction sector, with BIM ($B = 0.352$) as leading technology in terms of impact on on-time delivery, followed by AVR ($B = 0.264$), CC ($B = 0.249$), IoT ($B = 0.181$), and SW ($B = 0.134$). This finding connotes with [11], who averred that use of BIM, IoT, and smart devices has revolutionized construction activities, enhancing productivity.

3.4 Effect of Smart Technologies on Quality Delivery of Construction Projects

It is again necessary to conduct test for normality and multicollinearity prior to deploying regression analysis as shown in Figure 3 and Table 7.

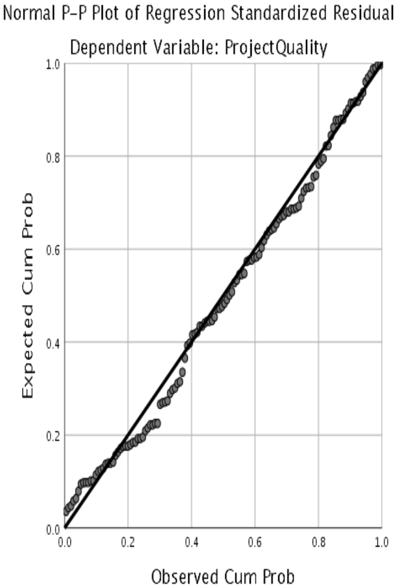

Figure 3: Normality plot for project quality

Table 7: Multicollinearity for project quality

Coefficients[a]							
	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tol	VIF
(Constant)	.032	.241		.134	393		
BMI	.389	.095	.340	4.092	)00	544	839
IoT	.194	.096	.159	2.023	)45	606	650
AIML	.017	.098	.014	.175	362	608	644
AVR	.235	.102	.189	2.299	)23	553	810
SW	.244	.085	.198	2.856	)05	778	286
CC	.077	.087	.069	.893	374	627	595
a. Dependent Variable: Project Quality							

As shown in Table 7, the variance inflation factor (**VIF)** values were close to 1.0, implying almost no correlation between the predictors and the response variable exists, hence multicollinearity assumption was satisfied [24, 25]. Additionally, **Tolerance** values were all > 0, implying little to no multicollinearity. Normality test is also met as shown in Figure 3.

Table 8: ANOVA for Smart Tech and project quality delivery

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	101.199	6	16.867	ŀ.363	.000[b]
Residual	83.769	121	.692		
ıActual	184.969	127			

a. Dependent Variable: Project Quality
b. Predictors: (Constant), CC, SW, IoT, AIML, AVR, BMI

Table 8 shows a significant effect of implementation of smart technologies on quality of construction projects exists, given $F = 24.36$, and $p - val = 0.00$ at $\alpha = 0.05$.

Table 9: Multiple Regression of Smart Technologies on Quality Delivery of Construction Projects

Project Quality	Smart Tech.	Standard Beta	Sig.
Adoption of smart technologies during *construction* ensures long-term durability and performance by enhancing precision, facilitating better planning, enabling real-time monitoring, and optimizing construction techniques.	**BIM**	.340	.000
	IoT	.159	.045
	AIML	.014	.862
	AVR	.189	.023
	SW	.198	.005
	CC	.069	.374

= 0.740, r^2=0.547, Significance = $p < 0.05$

$$Quality = 0.34BIM + 0.15IoT + 0.01AIML + 0.18AVR + 0.19SW + 0.06CC \quad (6)$$

Having established a significant relationship in Table 8, it was deemed necessary to determine the individual impacts of the identified smart techs on project quality, from which Table 8 is showing that firstly, 54% of total variability in project quality is explained by adoption of smart technologies. With exception of AIML ($p - val = 0.86$) and CC (($p - val = 0.37$), BIM (0.340), SW ($B = 0.198$), AVR($B = 0.189$), and IoT ($B = 0.159$), respectively, have a significant effect on quality of construction project delivery, as shown in Table 9. This finding tallies with [16] who posited that smart technology integration has the ability to increase project efficiency and promote sustainable development, even in small-scale building projects. Similarly, [17] assert that the use of smart technologies like IoT significantly enhances the security, privacy, safety, productivity, and performance of construction workers.

4. DISCUSSION OF RESULTS

Results of this study accentuates the transformative potential inherent with smart technologies while raising awareness to its limited adoption in the Nigerian construction industry. BIM emerged as the most readily adopted technology. This is probably because it facilitates better design visualization, resource allocation and detects design clashes early, thereby cutting down costs which is a key incentive in the construction industry, especially in Nigeria. However, adoption is still at its infancy, which tallies with [20][21], who noted the integration of technologies like BIM and IoT-enabled HVAC into project delivery to be limited. While smart technologies were noted to significantly impact on-time delivery of construction projects (F=97.97, p=0.00), BIM was noted to have much more impact compared to AR/VR, CC, IoT, and smart wearable, although AIML showed no significant effect. The insignificance of AIML might be attributed to the notable unavailability of data amongst most Nigerian firms.

Also, BIM, smart wearable, AR/VR, and IoT, respectively have a significant impact project quality in the construction industry, with AIML and CC not making a significant impact. Generally, BIM stands out as the most impactful technology spanning both timeliness and quality dimensions, which resonates with prior studies ([11], [20], [21]) which averred the role of BIM, IoT, and AR/VR in the quest to enhance productivity and quality.

While BIM and AR/VR indicate early application, their significant impact on timely and quality project delivery further portray their potential to transform the construction industry if harnessed. These, however, validates the extant research pointing the improved efficiency and rapid productivity smart technology will bring to the construction industry if embraced.

5. CONCLUSIONS

This study avers that, the level of adoption of smart technologies is still low, although they are quite promising in transforming the construction industry. However, BIM was found to be gain wide adoption closely followed by augmented reality and virtual reality, smart wearable, artificial intelligence and machine learning, cloud computing, and internet of things.
BIM, AVR, CC, IoT, and SW were found to have a significant effect to on-time delivery of construction projects, with exception to AIML. By enhancing planning, communication, resource management, and risk mitigation, these technologies have helped in reducing delays and ensuring that projects are completed within their scheduled timeliness.

Furthermore, project quality was significantly influenced by implementation of smart technologies. This not only has improved project efficiency but also optimized the overall competitiveness of Nigerian construction sector. Implications are that embedding smart technologies in the Nigerian construction sector promises to revolutionize the industry, bringing numerous benefits in terms of efficiency, quality, safety, and sustainability.

6. RECOMMENDATION

1. This paper therefore recommends the adoption of smart technologies as it significantly improves timeliness and quality of construction project delivery in the Nigerian construction industry.
2. Since BIM, AR/AVR and IoT are proved to be most impactful, a focus on their broader implementation is therefore recommended. Establishing platforms that foster partnerships with tech providers with the provision of seminars or workshops for professionals with construction roles.
3. This paper also recommends the provision of incentives for technology adoption such as tax reliefs by the government to curb barriers like cost of implementation, lack of expertise, and infrastructure limitations.
4. Recurrent evaluation should be implemented to oversee progress and identify areas needing improvement. This will hopefully help in refining the existing strategies on which the adoption of smart technologies is based.

7. SUGGESTIONS FOR FURTHER STUDIES

This study acknowledges limitations, including the restricted scope of technology adoption and the lack of comprehensive data on long-term impacts. Future research should explore broader technology applications across various project scales and investigate the long-term effects of smart technology adoption on project outcomes, sustainability, and industry growth. Further studies may want to ascertain smart technologies available and their areas of impact on construction activities for quality delivery.

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