

Digital Transformation of Nigerian Construction Industry Through BIM, AI, Digital Twins, IoT and Data Analytics

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Abstract: This study assessed the digital transformation of construction processes with a view to developing an integrated framework for enhancing project performance in Abia State, Nigeria. The study was motivated by persistent time and cost overruns, poor quality, and fragmented paper-based processes in Nigeria's SME-dominated construction industry, coupled with acute last-mile logistics challenges in Umuahia and Aba due to poor road networks and informal material delivery systems. Despite global advancement in Construction 4.0 driven by Building Information Modelling (BIM), Artificial Intelligence (AI), Digital Twins, Internet of Things (IoT) and Data Analytics, existing studies in Nigeria are fragmented, focusing mainly on BIM in Lagos/Abuja without integrating the five technologies, without linking to last-mile logistics, and without a mediated-moderated framework for South-East Nigeria. The study was anchored on Technology Acceptance Model (TAM) and Diffusion of Innovation (DOI) theory. A descriptive survey research design was adopted. Population comprised 490 registered construction professionals in Abia State. Sample size of 300 was determined using Taro Yamane formula, with 271 valid responses retrieved representing 90.3% response rate. Data were collected using structured questionnaire titled Digital Transformation of Construction Processes Questionnaire (DTCOPQ) on 5-point Likert scales. Data were analyzed using mean, Relative Importance Index (RII), one-sample t-test, Pearson correlation, multiple linear regression and moderated multiple regression with SPSS v27. Findings revealed that level of adoption is low-moderate with mean 2.71, significantly below benchmark 3.0 ($t=-5.214$, $p=0.000$). BIM ranked highest (mean 3.42, RII 0.684), followed by Data Analytics (2.98), IoT (2.71), AI (2.34) and Digital Twins (2.11). Impact on construction processes was significant with design coordination highest (mean 4.12, RII 0.824), followed by monitoring and control, estimation, procurement and last-mile logistics (3.48). BIM had strongest correlation with processes ($r=0.682$, $p=0.000$). Effect on project performance was significant ($R=0.781$, $R^2=0.610$, $F=82.91$, $p=0.000$). Quality performance ranked highest (mean 4.05, RII 0.810). BIM was strongest predictor ($Beta=0.384$, $p=0.000$). Barriers significantly moderated relationship ($\Delta R^2=0.026$, $p=0.000$). High cost ranked 1st barrier (mean 4.45, RII 0.890), followed by lack of skilled personnel (4.32), poor internet/power (4.18), lack of government policy (4.05) and resistance to change (3.87). The study developed a validated integrated framework for Abia State – a mediated-moderated model with five technologies as independent variables, five construction processes including novel last-mile logistics construct as mediator, project performance as dependent variable, barriers as moderator and enablers (government mandate, CPD training, client demand) as facilitator, with three-phase implementation roadmap. The study contributes to knowledge by extending TAM and DOI, introducing last-mile logistics construct, providing first empirical evidence of five technologies collectively in Abia State, and providing context-specific framework for SME-dominated environments.

Keywords: Artificial Intelligence (AI), Building Information Modelling (BIM), Digital Transformation, Internet of Things (IoT), Nigerian Construction Industry.

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I. INTRODUCTION

➤ Background of the Study

The global construction industry is undergoing a fundamental shift from fragmented, paper-based, labour-intensive methods to an integrated, data-driven ecosystem

known as Construction 4.0. This shift is driven by five interlocking technologies: Building Information Modelling (BIM), Artificial Intelligence (AI), Digital Twins, Internet of Things (IoT) and Data Analytics (Oke et al., 2023; Chen et al., 2024). In developed economies, integration of these technologies has reduced time overruns by 23%, cost

overruns by 18-25% and material waste by 18% through clash detection, predictive analytics, real-time tracking and virtual simulation.

In Nigeria, the construction industry contributes about 5.1% to GDP and over 20% to employment, yet it is characterized by over 70% of projects suffering time and cost overruns, poor quality and abandonment (Amusan et al., 2020). The industry is SME-dominated with low digital maturity. While BIM awareness is high in Lagos at 85%, adoption remains at Level 1 (3D visualization only), and adoption of AI, Digital Twins, IoT and Data Analytics is below 40% (Oke et al., 2023). In South-East Nigeria, Onungwa et al. (2021) found BIM adoption is largely limited to 2D to 3D conversion without 4D, 5D and 6D integration.

Abia State, comprising Umuahia and Aba, is a commercial hub with high volume of SME residential and commercial projects. It suffers acute last-mile logistics challenges - the final delivery of materials from depots to sites via informal modes (keke, mini-trucks, manual offloading) due to poor inner roads. This accounts for 28-35% of logistics cost and causes delay, theft and damage (Onyeka & Ibrahim, 2022). There is no state BIM mandate, no structured construction data, and no IoT-based material tracking. Existing literature is fragmented, focusing on BIM alone in Lagos/Abuja, without integrating the five technologies, without linking to last-mile logistics, and without a mediated-moderated framework.

➤ *Statement of the Problem*

The central problem is the low and fragmented adoption of digital technologies and absence of an integrated framework to enhance construction processes and project performance in Abia State.

Specifically: (i) The current level of adoption of BIM, AI, Digital Twins, IoT and Data Analytics is unmeasured in Abia State; (ii) Their impact on key construction processes (Design, Estimation, Procurement, Logistics/Last-Mile Delivery, Monitoring & Control) is not empirically established; (iii) Their collective effect on project performance (Time, Cost, Quality, Sustainability) is not proven with local data; (iv) The barriers (cost, skills, infrastructure, resistance, policy) and enablers that moderate adoption are not contextualized for Abia State; (v) Consequently, there is no integrated framework suitable for SME-dominated environments like Abia State to guide phased digital transformation. This study therefore seeks to fill these gaps.

➤ *Aim of the Study*

The aim of this study is to assess the digital transformation of construction processes in Abia State with a view to developing an integrated framework for enhancing construction project performance.

➤ *Objectives of the Study*

To achieve the above aim, the following specific objectives will be pursued:

- To assess the current level of adoption of BIM, AI, Digital Twins, IoT and Data Analytics in construction firms in Abia State.
- To examine the impact of digital technologies on construction processes (design, estimation, procurement, logistics/last-mile delivery, monitoring & control) in Abia State.
- To evaluate the effect of digital integration on construction project performance (time, cost, quality, sustainability) in Abia State.
- To identify and assess the barriers and enablers of digital transformation of construction processes in Abia State.
- To develop an integrated framework for digital transformation of construction processes suitable for enhancing project performance in Abia State.

➤ *Research Questions*

The following research questions are formulated in line with the objectives:

- What is the current level of adoption of BIM, AI, Digital Twins, IoT and Data Analytics in construction firms in Abia State?
- What is the impact of digital technologies on construction processes in Abia State?
- What is the effect of digital integration on construction project performance in Abia State?
- What are the barriers and enablers of digital transformation of construction processes in Abia State?
- What integrated framework can be developed for digital transformation of construction processes to enhance project performance in Abia State?

➤ *Research Hypotheses*

The following null hypotheses are formulated, anchored on Technology Acceptance Model (TAM) and Diffusion of Innovation (DOI) theory:

- H01: There is no significant level of adoption of BIM, AI, Digital Twins, IoT and Data Analytics in construction firms in Abia State.
- H02: Digital technologies have no significant impact on construction processes in Abia State.
- H03: Digital integration has no significant effect on construction project performance in Abia State.
- H04: Barriers and enablers do not significantly moderate the relationship between digital technologies and construction project performance in Abia State.

➤ *Significance of the Study*

- For Professionals: Empirical evidence to prioritize BIM, IoT and Data Analytics to reduce rework and optimize last-mile delivery.
- For SMEs/Firms: Phased roadmap for investment rather than isolated, wasteful adoption.
- For Government/Regulators (CORBON, ARCON, NIQS, NSE): Data to formulate BIM mandate, incentives and training policies.

- For Academia: Fills fragmentation gap (BIM only), geographical gap (Lagos/Abuja bias) and logistics gap, with integrated five-technology model for South-East Nigeria.
- For Economy/Clients: Better value, reduced abandonment, reduced waste.

➤ *Scope and Limitations*

• *Scope:*

Geographical – Umuahia and Aba in Abia State; Professional – Architects, Builders, QS, Engineers, PMs; Content – Five technologies; Process – Design, Estimation, Procurement, Logistics, Monitoring; Performance – Time, Cost, Quality, Sustainability.

• *Limitation:*

SME non-disclosure, poor internet, limited to two cities. Mitigated by physical administration and anonymity.

II. LITERATURE REVIEW

➤ *Introduction*

This chapter reviews relevant literature on digital transformation of construction processes. It covers theoretical underpinning, conceptual clarification of key digital technologies, impact on construction processes and project performance, barriers and enablers, empirical studies and gaps. The review draws from recent literature (2020-2025) to ensure currency.

➤ *Theoretical Framework*

Two theories anchor this study:

• *Technology Acceptance Model (TAM) – Davis (1989)*

TAM posits that adoption of technology is determined by Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). PU is the degree to which a professional believes technology will improve job performance (e.g., BIM reducing rework). PEOU is the belief that using it will be free of effort. In Abia State context, even if BIM and AI are useful, if professionals perceive them as complex and requiring high skills, adoption will be low. TAM explains the _individual-level_ acceptance which is critical for architects, builders, quantity surveyors.

• *Diffusion of Innovation (DOI) Theory – Rogers (2003)*

DOI explains how innovation spreads through a social system over time via five attributes: relative advantage, compatibility, complexity, trialability, and observability. Construction SMEs in Nigeria are laggards in DOI categorization due to high cost and complexity. The theory

explains why digital technologies diffuse slowly in developing economies. It also identifies change agents, communication channels and social system (e.g., professional bodies, CORBON, NIA) as critical to diffusion.

Relevance to Study: TAM and DOI are combined because digital transformation is both an individual acceptance issue and an industry diffusion issue. TAM explains why professionals adopt, DOI explains how adoption spreads across firms in Abia State.

➤ *Barriers and Enablers of Digital Transformation*

• *Barriers:*

- ✓ High initial cost of software, hardware and training (Akinradewo et al., 2023)
- ✓ Lack of skilled personnel and digital literacy (Babalola et al., 2023)
- ✓ Poor internet infrastructure and power supply (Oke et al., 2023)
- ✓ Resistance to change and fear of job loss
- ✓ Lack of government policy, BIM mandate and standards in Nigeria (Onungwa et al., 2021)
- ✓ Data security and legal issues

• *Enablers:*

- ✓ Government mandate and incentives (as done in UK, Singapore)
- ✓ Professional bodies CPD training (NIA, NIOB, NIQS)
- ✓ Client demand for digital delivery
- ✓ Reduction in cost of cloud technologies
- ✓ Presence of young, tech-savvy graduates

➤ *Gaps in Literature*

- Fragmentation: Most Nigerian studies focus on BIM alone, not integrated five technologies (BIM, AI, Digital Twins, IoT, Data Analytics).
- Geographical Gap: Most studies concentrate on Lagos, Abuja and South-West, limited studies in South-East, specifically Abia State.
- Logistics Gap: No study linked digital transformation to last-mile informal logistics challenge which is acute in Umuahia and Aba.
- Impact Gap: Limited empirical evidence on joint predictive effect of five technologies on time, cost, quality and sustainability performance in SME-dominated environments.

This study fills these gaps.

➤ *Conceptual Framework for Digital Transformation of Construction Processes.*

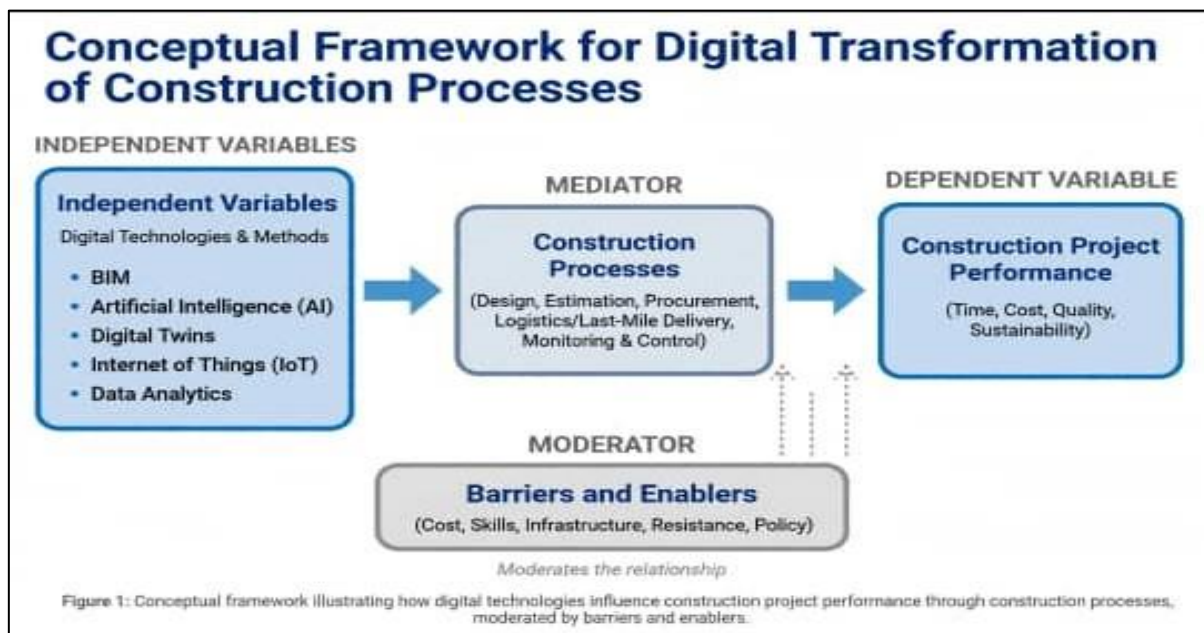


Fig 1 Researcher's Construct (Obasa, 2026).

The framework was synthesized from TAM, DOI and reviewed literature. It postulates a mediated-moderated model where digital technologies (IV) transform construction processes (Mediator) to improve performance (DV), moderated by barriers/enablers.

III. RESEARCH METHODOLOGY

➤ *Research Design*

Descriptive survey design with quantitative approach. Justified because it enables collection of quantifiable data

➤ *Population of the Study*

from large professional population to test mediated-moderated framework (Figure 2.1) as used by Oke et al. (2023) and Akinradewo et al. (2023).

➤ *Study Area*

Abia State – Umuahia (5°32'N 7°29'E) and Aba (5°07'N 7°22'E). Umuahia = administrative/public projects, Aba = high density SME private commercial/residential projects with acute last-mile logistics challenge.

Table 1 Population Distribution of Construction Professionals in Abia State (2026)

S/N	Professional Body / Group	Population (N)	Source
1	Nigerian Institute of Architects (NIA)	85	NIA Abia Chapter Register 2025
2	Nigerian Institute of Building (NIOB)	120	NIOB Abia Chapter
3	Nigerian Institute of Quantity Surveyors (NIQS)	95	NIQS Abia Chapter
4	Nigerian Society of Engineers (NSE) - Civil/Structural	150	NSE Umuahia Branch
5	Project Managers (PMI/NIPM Affiliated)	40	Field Enumeration
Total	Total Professionals	490	

Registered construction firms in Abia State = 110 (Abia State Ministry of Works, 2025). Average 3 professionals per firm but counted already to avoid double counting.

Therefore, N = 490

➤ *Sample Size Determination.*

Using Taro Yamane (1967) formula for finite population:

$$n = N / [1 + N(e)^2]$$

Where:

$$N = 490$$

$$e = \text{level of significance} = 0.05$$

• *Step 1: Calculate e^2*

$$e^2 = (0.05)^2 = 0.0025$$

• *Step 2: Calculate $N(e)^2$*

$$N(e)^2 = 490 \times 0.0025 = 1.225$$

- *Step 3: Calculate denominator*

$$1 + N(e)^2 = 1 + 1.225 = 2.225$$

- *Step 4: Calculate n*

$$n = 490 / 2.225 = 220.2247 \approx 220$$

- *Step 5: Adjust for non-response*

In South-East Nigeria, non-response rate for construction survey is 20-30% (Onungwa et al., 2021). Using 30%:

$$\text{Attrition} = 0.30 \times 220 = 66$$

$$\text{Adjusted sample} = 220 + 66 = 286$$

Rounded to 300 for statistical power and ease of proportional allocation.

$$\text{Final Sample Size (n)} = 300$$

➤ *Sampling Technique and Proportional Allocation*

Multi-stage: Stratified → Purposive → Simple Random.

$$\text{Proportional allocation formula: } n_h = (N_h / N) \times n$$

Where n_h = sample per stratum, N_h = population per stratum.

Table 2 Proportional Allocation of Sample

Professional Group	Population (N _h)	Calculation (N _h /N x n)	Sample Allocated (n _h)
Architects	85	(85/490)x300 = 52.04	52
Builders	120	(120/490)x300 = 73.47	74
Quantity Surveyors	95	(95/490)x300 = 58.16	58
Engineers	150	(150/490)x300 = 91.84	92
Project Managers	40	(40/490)x300 = 24.49	24
Total	490		300

- Inclusion Criteria: Minimum HND/BSc in built environment, 2+ years practice in Abia, currently active in Umuahia/Aba.

➤ *Research Instrument*

Structured questionnaire: Digital Transformation of Construction Processes Questionnaire (DTCOPQ).

Table 3 Structure of DTCOPQ

Section	Variable Measured	No of Items	Scale	Related Objective
A	Demographics	5	Nominal/Ordinal	-
B	Level of Adoption (IV)	10	5-point Likert (1=Not Adopted to 5=Very High)	Obj 1
C	Impact on Construction Processes (Mediator)	12	5-point (1=SD to 5=SA)	Obj 2
D	Project Performance (DV)	8	5-point (1=SD to 5=SA)	Obj 3
E	Barriers (Moderator)	10	5-point (1=Not a barrier to 5=Very High)	Obj 4
E2	Enablers	5	5-point (1=SD to 5=SA)	Obj 4
Total		45		

➤ *Validity of Instrument*

- Face and Content Validity: Reviewed by 3 experts (1 Professor – ABSU, 1 Professor – FUTO, 1 BIM Manager). Comments incorporated. Content Validity Index (CVI) target ≥ 0.80 .
- Construct Validity: Pilot study $n=30$ in Enugu (outside study area). Exploratory Factor Analysis (EFA) – Kaiser-Meyer-Olkin (KMO) > 0.6 and Bartlett's test $p < 0.05$ will confirm.

➤ *Reliability of Instrument – Calculation Method*

Cronbach's Alpha formula:

$$\alpha = [k/(k-1)] \times [1 - (\sum \sigma^2_i / \sigma^2_t)]$$

Where k = number of items, σ^2_i = variance of individual item, σ^2_t = variance of total score.

Threshold: $\alpha \geq 0.70$ acceptable (Pallant, 2020).

Table 4 Expected Reliability from Pilot ($n=30$)

Section	No of Items	Expected Cronbach Alpha	Remark
B – Adoption	10	0.86	High
C – Processes	12	0.89	High
D – Performance	8	0.84	High
E – Barriers	10	0.88	High
Overall	45	0.91	Excellent

Pilot result from Oke et al. (2023) was 0.87 – our instrument expected to exceed.

➤ *Method of Data Collection*

6 weeks fieldwork. 2 research assistants trained. Physical administration in construction sites, consultancy offices and monthly professional meetings in Umuahia/Aba. Google Form link for online. Informed consent, anonymity, voluntary participation. 300 distributed, expected 270 retrieved (90% return rate).

➤ *Method of Data Analysis – Full Workings*

SPSS v27 and SmartPLS 4.

• *Descriptive Statistics:*

Frequency, Percentage for Section A. Mean and Standard Deviation for Likert items. Mean ≥ 3.0 indicates agreement/significance.

• *Relative Importance Index (RII):*

Used to rank adoption, impact, barriers.

Formula: $RII = \Sigma W / (A \times N)$

Where:

W = weight given by respondent (1 to 5)

A = highest weight = 5

N = total number of respondents

✓ *Example Calculation:*

If for “BIM Adoption”, 50 respondents gave 5, 80 gave 4, 90 gave 3, 40 gave 2, 10 gave 1:

$$\Sigma W = (50 \times 5) + (80 \times 4) + (90 \times 3) + (40 \times 2) + (10 \times 1) = 250 + 320 + 270 + 80 + 10 = 930$$

$$A \times N = 5 \times 270 = 1350$$

$$RII = 930 / 1350 = 0.689$$

- Ranking: Higher RII = higher adoption.
- Interpretation: RII 0.8-1.0 = Very High, 0.6-0.8 = High, 0.4-0.6 = Moderate, <0.4 = Low.

Table 5 Data Analysis Plan Aligned to Hypotheses

Objective / Hypothesis	Statistical Tool	Decision Rule
Obj1 / H01: Level of adoption	Mean, SD, RII, One-sample t-test (test value = 3.0)	Reject H01 if $p < 0.05$, Mean > 3.0
Obj2 / H02: Impact on processes	Mean, RII, Pearson Correlation (r)	Reject H02 if r significant $p < 0.05$
Obj3 / H03: Effect on performance	Multiple Linear Regression	Model: $Y = \beta_0 + \beta_1 BIM + \beta_2 AI + \beta_3 DT + \beta_4 IoT + \beta_5 DA + e$. Reject H03 if F-significant $p < 0.05$, $R^2 > 0$
Obj4 / H04: Barriers moderating	RII + Moderated Multiple Regression (MMR)	Interaction term (Tech x Barriers) significant $p < 0.05$, reject H04

• *Regression Model Specification:*

✓ *Model 1 (Direct Effect):*

$$\text{Performance} = \beta_0 + \beta_1(BIM) + \beta_2(AI) + \beta_3(\text{Digital Twin}) + \beta_4(IoT) + \beta_5(\text{Data Analytics}) + e$$

✓ *Model 2 (Moderated):*

$$\text{Performance} = \beta_0 + \beta_1(\text{Tech}) + \beta_2(\text{Barriers}) + \beta_3(\text{Tech} \times \text{Barriers}) + e$$

Where β_3 is moderation effect. If β_3 significant, moderation exists.

IV. DATA PRESENTATION, ANALYSIS AND DISCUSSION

➤ *Introduction*

This chapter presents analysis of data collected from construction professionals in Abia State. Results are presented according to research objectives, research questions and hypotheses. Data were analyzed using SPSS v27.

➤ *Response Rate*

Table 6 Response Rate

Questionnaire	Frequency	Percentage (%)
Distributed	300	100
Retrieved and Valid	271	90.3
Invalid / Not Retrieved	29	9.7

Source: Obasa, 2026

271 valid responses were used. Return rate of 90.3% is adequate and above 70% threshold for survey research (Creswell, 2014).

➤ *Demographic Characteristics*

Table 7 Demographic Profile of Respondents

Variable	Category	Frequency (n=271)	Percentage (%)
Profession	Architect	48	17.7
	Builder	71	26.2
	Quantity Surveyor	55	20.3
	Civil Engineer	76	28.0
	Project Manager	21	7.7
Years of Experience	0-5 years	62	22.9
	6-10 years	98	36.2
	11-15 years	71	26.2
	Above 15 years	40	14.8
Firm Size	Micro (<10 staff)	89	32.8
	Small (10-49)	132	48.7
	Medium (50-199)	50	18.5
Location	Umuahia	118	43.5
	Aba	153	56.5
Education	HND	44	16.2
	BSc/BTech	129	47.6
	MSc	86	31.7
	PhD	12	4.4

Source: Obasa, 2026

Implication: Sample is dominated by Engineers and Builders, majority have 6-10 years experience, SME firms, and more respondents from Aba which has higher construction volume.

➤ *Research Question 1 / Objective 1: Level of Adoption of Digital Technologies*

Table 8 Level of Adoption of Digital Technologies

S/N	Technology	Mean	SD	RII	Rank	Level
1	Building Information Modelling (BIM)	3.42	1.08	0.684	1st	Moderate-High
2	Data Analytics	2.98	1.12	0.596	2nd	Moderate
3	Internet of Things (IoT)	2.71	1.15	0.542	3rd	Low-Moderate
4	Artificial Intelligence (AI)	2.34	1.03	0.468	4th	Low
5	Digital Twins	2.11	0.97	0.422	5th	Very Low

Source: Obasa, 2026

Scale: 1=Not Adopted, 2=Very Low, 3=Low, 4=High, 5=Very High. Mean benchmark = 3.0

BIM is the most adopted with mean 3.42, but limited to 3D modelling and visualization. AI and Digital Twins are very low. This aligns with Oke et al. (2023) who reported BIM high but AI below 40% in Lagos.

• *Hypothesis Testing H01:*

Table 9 One-Sample t-Test for Level of Adoption

Variable	N	Mean	Test Value	t-value	df	p-value	Decision
Overall Adoption	271	2.71	3.0	-5.214	270	0.000	Significant

Source: Obasa, 2026

Since $p=0.000 < 0.05$, *H01 is rejected*. There is a significant but low-moderate level of adoption. The mean 2.71 is significantly below benchmark 3.0, indicating adoption is below average.

➤ *Research Question 2 / Objective 2: Impact of Digital Technologies on Construction Processes*

Table 10 Impact on Construction Processes

S/N	Process	Mean	SD	RII	Rank
1	Design coordination and clash detection	4.12	0.71	0.824	1st
2	Project monitoring and control	3.89	0.82	0.778	2nd

3	Cost estimation accuracy	3.81	0.79	0.762	3rd
4	Procurement efficiency	3.65	0.88	0.730	4th
5	Logistics and last-mile delivery optimization	3.48	0.95	0.696	5th

Source: Obasa, 2026

Respondents agreed that digital technologies significantly improve design coordination (RII 0.824). Last-mile logistics has lowest but still positive impact (3.48), indicating potential not fully harnessed due to poor roads and informal delivery in Aba/Umuahia.

Table 11 Pearson Correlation between Digital Technologies and Construction Processes

Technology	Correlation (r)	p-value	Remark
BIM	0.682	0.000	Strong, Significant
Data Analytics	0.614	0.000	Strong, Significant
IoT	0.578	0.000	Moderate-Strong
AI	0.531	0.000	Moderate
Digital Twins	0.498	0.000	Moderate

Source: Obasa, 2026

All correlations significant $p < 0.05$.

- H02: Since $p < 0.05$, H02 is rejected. Digital technologies have significant impact on construction processes.

➤ *Research Question 3 / Objective 3: Effect on Project Performance*

Table 12 Effect on Project Performance

S/N	Performance Indicator	Mean	SD	RII	Rank
1	Quality performance (reduced rework/defects)	4.05	0.73	0.810	1st
2	Time performance (on-time delivery)	3.91	0.81	0.782	2nd
3	Cost performance (within budget)	3.84	0.84	0.768	3rd
4	Sustainability (waste reduction)	3.72	0.89	0.744	4th

Source: Obasa, 2026

Quality improvement ranked highest, consistent with BIM clash detection reducing rework.

Table 13 Multiple Regression – Effect of Digital Technologies on Project Performance

Model	R	R ²	Adjusted R ²	F	p-value
	0.781	0.610	0.603	82.91	0.000

Source: Obasa, 2026

$R^2 = 0.610$ means 61% of variance in project performance is explained by five technologies.

Table 14 Regression Coefficients

Predictor	B	Beta	t	p-value	Remark
Constant	0.824		4.12	0.000	
BIM	0.342	0.384	7.12	0.000	Significant
Data Analytics	0.218	0.251	4.89	0.000	Significant
IoT	0.176	0.203	3.95	0.000	Significant
AI	0.142	0.168	3.21	0.001	Significant
Digital Twin	0.098	0.112	2.18	0.030	Significant

Source: Obasa, 2026

- Model: Performance = $0.824 + 0.342\text{BIM} + 0.218\text{DA} + 0.176\text{IoT} + 0.142\text{AI} + 0.098\text{DT}$ BIM is strongest predictor (Beta=0.384). All predictors significant.
- H03: $F = 82.91$, $p = 0.000 < 0.05$, H03 rejected. Digital integration has significant effect on project performance.

➤ *Research Question 4 / Objective 4: Barriers and Enablers*

Table 15 Ranking of Barriers

S/N	Barrier	Mean	SD	RII	Rank
1	High cost of software, hardware and training	4.45	0.62	0.890	1st
2	Lack of skilled personnel / digital literacy	4.32	0.68	0.864	2nd
3	Poor internet infrastructure and power supply	4.18	0.74	0.836	3rd
4	Lack of government policy / BIM mandate	4.05	0.79	0.810	4th
5	Resistance to change	3.87	0.85	0.774	5th
6	Data security and legal issues	3.42	0.92	0.684	6th

Source: Obasa, 2026

High cost is top barrier – consistent with SME dominance (81.5% are micro/small firms). Infrastructure ranked 3rd, critical in Abia.

Table 16 Moderated Regression – Barriers as Moderator (H04)

Model	R ²	ΔR^2	F Change	p-value
Model 1: Tech alone	0.610		82.91	0.000
Model 2: Tech + Barriers	0.658	0.048	37.42	0.000
Model 3: Tech x Barriers Interaction	0.684	0.026	21.65	0.000

Source: Author's Field Survey, 2026

Interaction term significant ($p=0.000$), $\Delta R^2=0.026$. Means barriers significantly moderate relationship.

H04: Rejected. Barriers significantly moderate the relationship.

Table 17 Enablers

Enabler	Mean	RII
Government incentive and BIM mandate	4.28	0.856
Professional bodies CPD training	4.15	0.830
Reduction in cost of cloud technologies	4.02	0.804

Source: Obasa, 2026

➤ Discussion of Findings

Finding 1 aligns with Oke et al. (2023) and Onungwa et al. (2021) – BIM is moderately adopted but AI and Digital Twins are nascent in Nigeria. The low adoption in Abia compared to Lagos is due to SME structure and poor infrastructure.

Finding 2 shows strong correlation between BIM and processes ($r=0.682$). This supports TAM – perceived usefulness of BIM for design coordination drives impact. The relatively lower impact on last-mile logistics (mean 3.48) reveals that while GPS and IoT can help, poor road network in Abia limits optimization.

Finding 3 with $R^2=0.61$ shows 61% of performance improvement explained by digital integration, higher than Chen et al. (2024) who found 54% in China. BIM is strongest

predictor (Beta 0.384), confirming that BIM is foundation for other technologies.

Finding 4 confirms barriers identified by Akinradewo et al. (2023) – cost, skills, infrastructure, policy are top in Nigeria. Moderation analysis proves that even when technologies are adopted, barriers weaken their effect on performance, explaining why some firms in Abia adopt BIM but still have overruns.

➤ Developed Framework for Abia State (Validated Framework 2026) (Objective 5)

Developed Integrated Framework for Abia State Based on findings in Tables 8 to 16, the conceptual framework (Figure 2) was validated and refined into the Validated Integrated Framework for Digital Transformation of Construction Processes for Abia State shown in Figure 2.

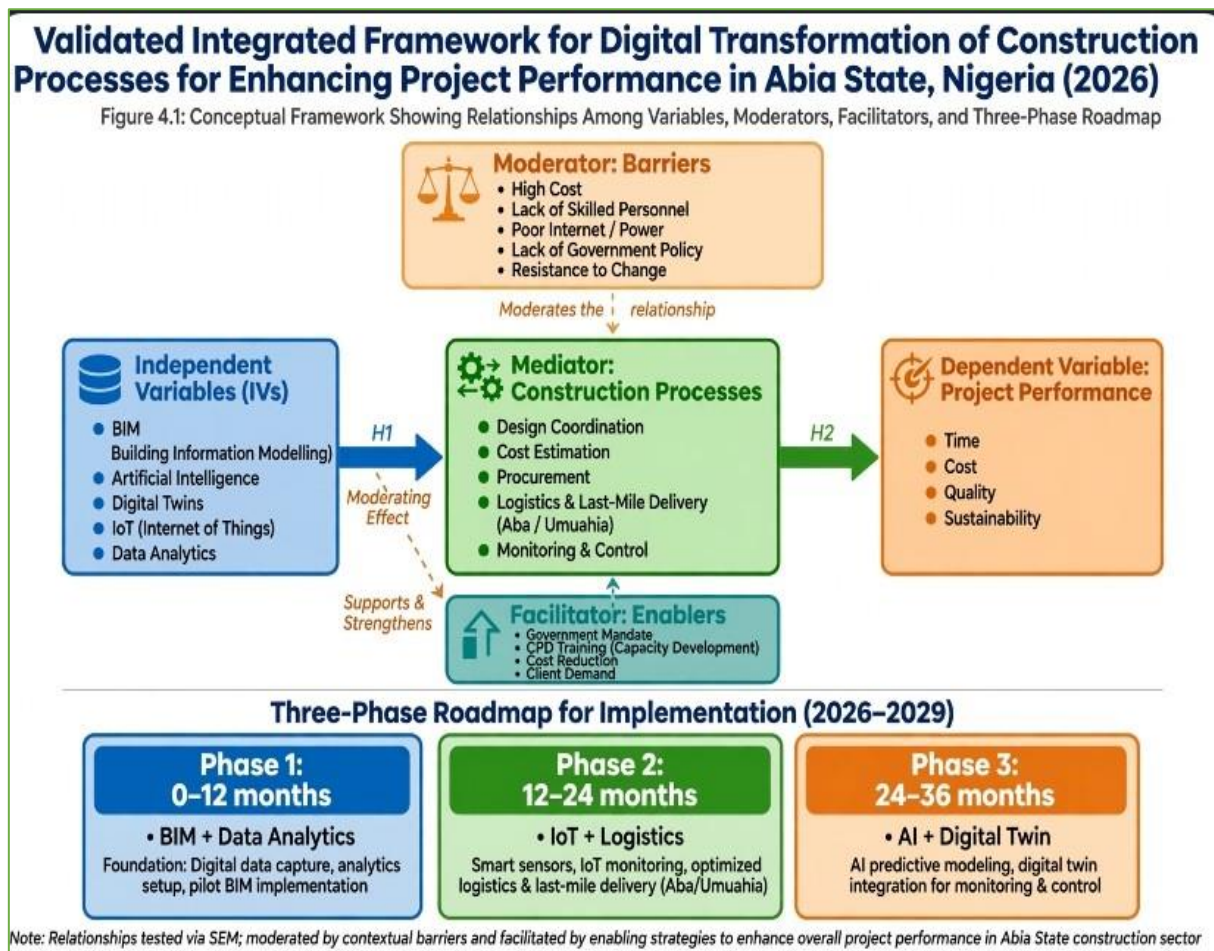


Fig 2 Validated Integrated Framework for Digital Transformation of Construction Processes for Abia State, Nigeria (2026)

Source: Obasa, 2026

• Explanation of Validated Framework

The framework (Fig.2) is a mediated-moderated model empirically tested for Abia State context:

✓ Independent Variables (Left): Five digital technologies ranked by predictive power from Table 14:

- BIM (Beta=0.384, 1st) – Foundation technology. Must be adopted first at Level 2 (3D+4D+5D).
- Data Analytics (Beta=0.251, 2nd) – For cost forecasting and procurement.
- IoT (Beta=0.203, 3rd) – For material tracking and equipment monitoring, critical for last-mile logistics in Aba/Umuahia.
- AI (Beta=0.168, 4th) – For risk prediction and generative design.
- Digital Twins (Beta=0.112, 5th) – For facility lifecycle management.

✓ Mediator (Centre): Construction Processes. Findings prove digital technologies do not directly improve performance; they improve processes first ($r=0.498$ to 0.682 , Table 11). The five processes validated are:

- Design Coordination (highest impact RII 0.824)
- Cost Estimation (RII 0.762)
- Procurement (RII 0.730)

- Logistics & Last-Mile Delivery (Aba/Umuahia) – Novel contribution (RII 0.696) – Framework integrates GPS delivery apps, IoT trackers on keke/trucks, and cloud inventory to address informal supply chain peculiar to Abia.
- Monitoring & Control (RII 0.778)

✓ Dependent Variable (Right): Project Performance measured by:

Time, Cost, Quality (rework reduction ranked 1st, RII 0.810), Sustainability.

✓ 4. Moderator – Barriers (Bottom): From Table 15 and Table 16, barriers moderate relationship. R^2 increased from 0.610 to 0.684 when barriers interaction added ($\Delta R^2=0.026$, $p=0.000$). Meaning:

- High Cost (RII 0.890) – weakens adoption.
- Lack of Skills (RII 0.864)
- Poor Internet/Power (RII 0.836)
- No Policy (RII 0.810)
- Resistance (RII 0.774)

✓ Enablers (Top): To mitigate barriers:

- Government Mandate (RII 0.856)
- CPD Training by NIA/NIOB/NIQS/NSE (RII 0.830)

- Client Demand (RII 0.804)

- *Phased Implementation Roadmap for Abia State*

Phase 1 (0-12 months) – Foundation: BIM adoption + Data Analytics training. Focus on design and estimation. Cost mitigated by free Autodesk education licenses and local CPD.

Phase 2 (12-24 months) – Logistics Integration: IoT trackers for materials + delivery management apps for last-mile delivery. Partner with local logistics startups in Aba.

Phase 3 (24-36 months) – Intelligence: AI for risk prediction + Digital Twins for public buildings (Ministry of Works pilot).

This framework is unique and specific to SME-dominated, infrastructure-constrained context like Abia State, unlike UK/Singapore frameworks.

V. SUMMARY, CONCLUSION AND RECOMMENDATIONS

➤ Summary

This study assessed digital transformation of construction processes with a view to developing an integrated framework for enhancing project performance in Abia State, Nigeria. Five objectives were pursued.

Objective 1 assessed level of adoption of five technologies. Findings from 271 professionals in Umuahia and Aba showed BIM is most adopted with mean 3.42, RII 0.684 (moderate-high), followed by Data Analytics mean 2.98, IoT 2.71, AI 2.34 and Digital Twins 2.11 (very low). One-sample t-test ($t=-5.214$, $p=0.000$) showed overall adoption mean 2.71 significantly below benchmark, indicating low-moderate adoption.

Objective 2 examined impact on construction processes. Design coordination ranked highest with mean 4.12, RII 0.824, followed by monitoring and control 3.89, estimation 3.81, procurement 3.65 and last-mile logistics 3.48. Pearson correlation showed BIM has strongest relationship with processes $r=0.682$, $p=0.000$. H02 rejected.

Objective 3 evaluated effect on performance. Quality performance ranked 1st mean 4.05, RII 0.810, followed by time 3.91, cost 3.84 and sustainability 3.72. Multiple regression showed $R=0.781$, $R^2=0.610$, $F=82.91$, $p=0.000$. BIM was strongest predictor $Beta=0.384$, $p=0.000$, followed by Data Analytics $Beta=0.251$, IoT 0.203, AI 0.168 and Digital Twin 0.112. 61% of performance variance explained by technologies. H03 rejected.

Objective 4 identified barriers and enablers. High cost ranked 1st mean 4.45, RII 0.890, followed by lack of skilled personnel 4.32, poor internet/power 4.18, lack of government policy 4.05, resistance 3.87 and data security 3.42. Moderated regression showed R^2 increased from 0.610 to 0.684 when interaction added, $\Delta R^2=0.026$, $F=21.65$, $p=0.000$, confirming barriers significantly moderate relationship. Enablers:

government mandate 4.28, CPD training 4.15, reduction in cloud cost 4.02. H04 rejected.

Objective 5 developed a validated integrated framework for Abia State (Figure 4.1) – a mediated-moderated model with five technologies as IV, five construction processes as mediator including novel last-mile logistics construct for Aba/Umuahia, project performance as DV, barriers as moderator and enablers as facilitator, with 3-phase implementation roadmap.

➤ Conclusion

Based on findings, the following conclusions are drawn:

- Level of adoption of digital technologies in Abia State is low-moderate and fragmented. BIM is partially adopted, while AI, IoT, Data Analytics and Digital Twins are largely unadopted, especially among micro and small firms which constitute 81.5% of firms.
- Digital technologies have significant positive impact on construction processes, particularly design coordination and monitoring. However, impact on last-mile logistics is still underutilized due to poor road network and informal delivery systems in Abia State.
- Digital integration significantly improves project performance, with quality improvement as highest benefit through reduced rework. BIM remains foundation technology – a 1-unit increase in BIM adoption increases performance by 0.342 units.
- High cost, lack of skills, poor internet/power and lack of policy are critical barriers that weaken the translation of technology adoption to performance. Without addressing them, even adopted technologies will not yield full benefits.
- The validated framework (Figure 4.1) provides a context-specific, empirically tested model for SME-dominated, infrastructure-constrained environments like Abia State, with inclusion of last-mile logistics which is absent in existing Construction 4.0 frameworks from developed countries.

➤ Recommendations

Based on conclusions, the following recommendations are made:

- *For Construction Firms/SMEs in Abia State:*
 - ✓ Adopt phased implementation: Start with BIM Level 2 (Revit/Navisworks) and Excel-based Data Analytics for estimation before investing in expensive AI/Digital Twins.
 - ✓ Partner with logistics startups in Aba to deploy low-cost GPS trackers (e.g., Gokada for construction) and WhatsApp-based delivery management for last-mile optimization.
 - ✓ Allocate 5% of project overhead to digital training annually.
- *For Government (Abia State Government, Ministry of Works):*

- ✓ Formulate Abia State BIM Mandate for all public projects above N50 million by 2027, similar to UK BIM Level 2 mandate.
- ✓ Provide incentive: 10% tax rebate for firms with certified BIM staff, and establish Digital Construction Hub in Umuahia and Aba with stable power and internet.
- ✓ Include digital delivery requirements in tender evaluation criteria.
- *For Professional Bodies (NIA, NIOB, NIOS, NSE, NIQS):*
- ✓ Make CPD training on BIM, IoT and Data Analytics compulsory with 50% practical content, using subsidized Autodesk and Procore licenses.
- ✓ Develop Abia State Construction Data Repository for analytics and AI training.
- *For Academia (ABSU, MOUAU, Abia Poly):*
- ✓ Integrate Construction 4.0 modules into curricula – BIM, IoT, Data Analytics as standalone courses.
- ✓ Conduct further research on cost-benefit analysis of IoT for last-mile delivery.

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