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LEAN CONSTRUCTION PRACTICES AND FIRM PERFORMANCE IN NORTH EAST NIGERIA: THE MEDIATING ROLE OF TECHNOLOGY ADOPTION

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ABSTRACT

Lean construction is expected to improve firm performance, but the mechanism through which it does so, and whether technology adoption forms part of that mechanism, is rarely tested in developing-country, post-conflict settings. This study evaluated the effect of lean construction practices (LCP) on the performance of construction firms (FP), examined the mediating role of technology adoption (TA), and validated a structural model linking the three constructs. A cross-sectional survey of contractor and consultant firms in Adamawa, Bauchi, and Borno States, North East Nigeria, yielded 149 valid responses from a proportionate stratified random sample of 187 firms (82.4% response rate). The model was estimated with Partial Least Squares Structural Equation Modelling in SmartPLS 4.0. The measurement model met reliability and validity criteria ($\alpha = 0.908$ to 0.934; CR = 0.923 to 0.945; AVE = 0.597 to 0.648). LCP had a significant positive effect on FP ($\beta = 0.341$, $p < 0.001$) and on TA ($\beta = 0.623$, $p < 0.001$), and TA significantly improved FP ($\beta = 0.487$, $p < 0.001$). The indirect effect through TA was significant ($\beta = 0.303$, 95% CI [0.168, 0.438]), and the variance accounted for was 47.05%, indicating partial mediation. The model explained 52.7% of the variance in FP and 38.8% in TA, with acceptable fit (SRMR = 0.061) and predictive relevance. The LCP to TA path was stronger in large firms. The results show that lean practices and technology adoption are complementary routes to performance, and that firms should pursue them together.

Keywords: lean construction; technology adoption; firm performance; mediation; PLS-SEM; North East Nigeria

1. INTRODUCTION

Nigerian construction firms are repeatedly criticized for cost overruns, delays, and quality deficiencies, and the burden is heavy in the North East, where firms are central to post-conflict reconstruction (Bala et al., 2021; Tijani et al., 2023). Lean construction promises to reduce waste and improve flow and value in project delivery (Koskela, 2000), and studies in several countries link it to better performance (Aziz & Hafez, 2013; Bajjou & Chafi, 2018; Demirkesen & Tezel, 2022). Parallel work shows that digital technologies, and BIM in particular, interact with lean practices in ways that can strengthen both (Sacks et al., 2010; Dave et al., 2013).

Most existing studies, however, test the direct lean–performance link. Few examine whether technology adoption is part of the mechanism, and, to our knowledge, none do so for Nigerian firms. The most closely related evidence comes from Indonesian construction firms, where lean practices improved performance partly through business model innovation (Arifin et al., 2025). This paper tests an analogous mechanism in which technology adoption is the mediator, using data from contractors and consultants in Adamawa, Bauchi, and Borno States.

The study pursued three objectives: (i) to evaluate the effect of lean construction practices on firm performance; (ii) to examine the mediating role of technology adoption in that relationship; and (iii) to develop and validate a structural model linking lean practices, technology adoption, and performance.

2. THEORETICAL BACKGROUND AND HYPOTHESES

The model draws on five perspectives. The Transformation–Flow–Value (TFV) theory explains how lean improves performance by reducing transformation inefficiency, smoothing flow, and focusing on value (Koskela, 2000). The Resource-Based View treats lean routines and digital tools as capabilities that give firms an advantage (Barney, 1991). Diffusion of Innovation Theory (Rogers, 2003) and the Technology–Organisation–Environment framework (Tornatzky & Fleischer, 1990) explain why firms with stronger organisational routines are better placed to take up new technology. Socio-Technical Systems theory holds that performance is best when the social subsystem (processes, culture, practices) and the technical subsystem (tools, technology) are jointly optimised (Trist, 1981). Together, these suggest a dual pathway from lean practice to performance: a direct route through process improvement and an indirect route through technology.

Four hypotheses followed:

- **H1:** Lean construction practices have a significant positive effect on firm performance.
- **H2:** Lean construction practices have a significant positive effect on technology adoption.
- **H3:** Technology adoption has a significant positive effect on firm performance.
- **H4:** Technology adoption significantly mediates the relationship between lean construction practices and firm performance.

3. METHODOLOGY

A quantitative, cross-sectional survey design was adopted within a positivist paradigm (Saunders et al., 2019; Creswell & Creswell, 2018). The study covered Adamawa, Bauchi, and Borno States, three states of the North East geopolitical zone that are the focus of post-conflict reconstruction (Bala et al., 2021). The target population was all registered contractor and consultant firms operating in the three states. A sampling frame of 350 firms (Adamawa 77, Bauchi 142, Borno 131) was compiled from the registers appropriate to each category: for contractors, the membership directories of the Federation of Construction Industry, the registers of the Bureau of Public Procurement and state procurement agencies, and the contractor lists of state ministries of works; for consultants, the registers of the Council for the Regulation of Engineering in Nigeria, the Architects Registration Council of Nigeria, the Quantity Surveyors Registration Board of Nigeria, and the Nigerian Institute of Quantity Surveyors; and, for building contractors and consultancies, the Nigerian Institute of Building and the Council of Registered Builders of Nigeria. Entries were merged, de-duplicated and verified against the Corporate Affairs Commission register.

Proportionate stratified random sampling was used, with states as strata and simple random selection within each state. Yamane's formula (Uakarn et al., 2021) gave a sample of 187 firms, allocated as 41 (Adamawa), 76 (Bauchi), and 70 (Borno). One senior key informant per firm (managing director, general manager, principal partner, head of practice, project manager, or lead consultant) completed the questionnaire (Kumar et al., 1993). The questionnaire was administered electronically by email and an online form, with two reminders and telephone follow-up over six months. In all, 154 questionnaires were returned (82.4%), and 149 were valid after multivariate outliers were removed. Table 1 gives the profile of the valid sample.

Table 1: Profile of Respondent Firms (N = 149)

Characteristic	Category	n	%
Firm type	Contractor	83	55.7
	Consultant	66	44.3
Firm size (SMEDAN, 2019)	Small (< 50 employees)	87	58.4
	Medium (50–199 employees)	42	28.2
	Large (≥ 200 employees)	20	13.4
State	Adamawa	30	20.1
	Bauchi	63	42.3
	Borno	56	37.6

Source: Field survey (2026).

The questionnaire measured three constructs. Lean construction practices (LCP) were measured with 24 items covering eight practice areas (value stream mapping, pull planning, JIT delivery, continuous improvement, visual control, teamwork, supply chain integration, and waste reduction); technology adoption (TA) with 12 items on digital tools from project management software to artificial intelligence; and firm performance (FP) with 16 items covering cost and financial performance, time efficiency, quality outcomes, and client satisfaction, rated as change over the preceding three years. Items were adapted from Koskela (2000), Aziz and Hafez (2013), Bajjou and Chafi (2018), Sacks et al. (2010), Olanrewaju et al. (2020), Chan and Chan (2004), and Doloi (2013). All constructs were specified as reflective, and the items load directly on their constructs. Content validity was established by five experts, and a pilot with 30 firms returned Cronbach's alpha values of 0.824 to 0.901. Data were screened for missing values (under 5%, replaced by item means), five multivariate outliers (Mahalanobis distance, $p < 0.001$, removed), and normality (skewness and kurtosis within ±2). Common method bias was assessed with Harman's single-factor test (23.7% of variance, below 50%) and full-collinearity VIF values (1.412 to 1.563, below 3.3; Kock, 2015).

The model was estimated in SmartPLS 4.0 following the two-stage procedure of measurement and structural model evaluation (Hair et al., 2021). Path significance was

tested with bias-corrected and accelerated (BCa) bootstrapping with 5,000 resamples. The indirect effect was tested following Preacher and Hayes (2008), and the type of mediation was classified with the variance accounted for (VAF): below 20% none, 20% to 80% partial, above 80% full. Explanatory power was judged by R^2, effect sizes by f^2 (Cohen, 1988), predictive relevance by Q^2 through blindfolding, and fit by the standardised root mean square residual (SRMR < 0.08; Hu & Bentler, 1999). Permutation-based multi-group analysis (5,000 permutations) compared paths across small, medium, and large firms, and importance–performance map analysis (IPMA) identified priority lean practice areas.

4. RESULTS

4.1 Measurement model

Table 2 shows that all constructs were reliable and valid. Cronbach's alpha ranged from 0.908 to 0.934, composite reliability from 0.923 to 0.945, and AVE from 0.597 to 0.648, all above the usual thresholds of 0.70 and 0.50 (Fornell & Larcker, 1981; Hair et al., 2021). Outer loadings ranged from 0.724 to 0.897. Discriminant validity held under the Fornell–Larcker criterion, as the square root of each AVE (0.773 to 0.805) exceeded the inter-construct correlations (0.623 to 0.698), and the HTMT ratios (LCP–TA 0.721; LCP–FP 0.754; TA–FP 0.798) were all below 0.85 (Henseler et al., 2015).

Table 2: Reliability and Validity of the Constructs

Construct	Items	A	CR	AVE	√AVE
Lean construction practices (LCP)	24	0.921	0.938	0.621	0.788
Technology adoption (TA)	12	0.908	0.923	0.597	0.773
Firm performance (FP)	16	0.934	0.945	0.648	0.805

Source: Field survey (2026). Correlations: LCP–TA 0.623; LCP–FP 0.671; TA–FP 0.698.

4.2 Direct effects (H1 to H3)

All three direct paths were positive and significant (Table 3). Lean practices had a significant effect on firm performance ($\beta = 0.341$, $t = 4.372$, $p < 0.001$; $f^2 = 0.152$, a medium effect), supporting H1. Lean practices strongly predicted technology adoption ($\beta = 0.623$, $t = 10.213$, $p < 0.001$; $f^2 = 0.634$, a large effect), supporting H2. Technology adoption significantly improved performance ($\beta = 0.487$, $t = 5.798$, $p < 0.001$; $f^2 = 0.284$), supporting H3.

Table 3: Structural Model Path Coefficients (5,000 BCa Bootstrap Resamples)

Path	B	SE	t	p	95% CI	Hypothesis
LCP → FP	0.341	0.078	4.372	< 0.001	[0.189, 0.493]	H1 supported
LCP → TA	0.623	0.061	10.213	< 0.001	[0.503, 0.743]	H2 supported
TA → FP	0.487	0.084	5.798	< 0.001	[0.322, 0.652]	H3 supported

Source: Field survey (2026).

4.3 Mediation (H4)

The indirect effect of lean practices on performance through technology adoption (0.623 × 0.487) was β = 0.303 (p < 0.001; 95% BCa CI [0.168, 0.438]), which excludes zero. The total effect was 0.644 (95% CI [0.503, 0.785]). Because both the direct and indirect effects were significant and VAF was 47.05%, which lies between 20% and 80%, technology adoption partially mediated the relationship, and H4 was supported. About 52.95% of the total effect was direct and 47.05% was indirect (Table 4).

Table 4: Direct, Indirect, and Total Effects of LCP on FP

Effect	β	95% BCa CI	Share of total (%)
Direct (LCP → FP)	0.341	[0.189, 0.493]	52.95
Indirect (LCP → TA → FP)	0.303	[0.168, 0.438]	47.05
Total	0.644	[0.503, 0.785]	100.00

Source: Field survey (2026). VAF = 47.05%, partial mediation.

4.4 Model validation

Table 5 summarizes the quality of the model. The model explained 52.7% of the variance in firm performance and 38.8% in technology adoption. Q^2 values of 0.331 and 0.224 were above zero, showing predictive relevance, and SRMR of 0.061 was below 0.08, indicating good fit. The Normed Fit Index (0.872) was slightly below 0.90, which is a common outcome in models with many indicators, and SRMR is the primary fit criterion in PLS-SEM (Hair et al., 2021). The conceptual model linking lean practices, technology adoption, and performance was therefore judged empirically valid.

Table 5: Model Quality Indices

Index	Value	Threshold	Decision
R^2 (firm performance)	0.527	–	Moderate to strong
R^2 (technology adoption)	0.388	–	Moderate
Q^2 (firm performance)	0.331	> 0	Predictive relevance
Q^2 (technology adoption)	0.224	> 0	Predictive relevance
SRMR	0.061	< 0.08	Good fit
NFI	0.872	> 0.90	Approaching threshold

Source: Field survey (2026).

4.5 Differences by firm size and priority practices

The multi-group analysis (Table 6) showed positive paths in all three size groups. The LCP → TA path was significantly stronger in large firms (β = 0.728) than in medium (β = 0.663) and small firms (β = 0.541), p = 0.041. The direct LCP → FP path (p = 0.187) and the TA → FP path (p = 0.076) did not differ significantly, although both rose with firm size. The VAF rose from 41.2% in small firms to 47.8% in medium and 53.6% in large firms.

Table 6: Multi-Group Analysis by Firm Size

Path	Small	Medium	Large	Permutation p
LCP → TA	0.541	0.663	0.728	0.041
LCP → FP (direct)	0.298	0.367	0.412	0.187
TA → FP	0.423	0.516	0.589	0.076
Mediation VAF (%)	41.2	47.8	53.6	–

Source: Field survey (2026). Coefficients are standardised path coefficients (β).

The importance–performance map analysis identified supply chain integration, pull planning, JIT delivery, and value stream mapping as the practice areas with high importance for performance but below-average performance (59.6% to 68.2% on the rescaled 0 to 100 scale), and hence as priorities for improvement. Continuous improvement and waste reduction scored well on both and should be maintained.

4.6 Distribution of technology adoption

Table 7 shows how far the 149 firms used each of the 12 technologies, rated from 1 (never) to 5 (always). Because extent of use was rated on this scale, adoption is reported as mean scores and not as the percentage of firms using each technology. The composite mean was 3.06 (SD = 0.968), a moderate level, and adoption fell into three tiers.

Table 7: Extent of Technology Adoption among Respondent Firms (N = 149)

Technology	Mean	SD	Rank	Adoption level
Project management software	3.64	1.087	1	Moderate-high
Mobile applications for site communication	3.52	1.124	2	Moderate-high
Digital documentation systems	3.41	1.156	3	Moderate
Cloud-based collaboration tools	3.28	1.189	4	Moderate
Automated scheduling software	3.15	1.203	5	Moderate
Cost estimation software	3.09	1.227	6	Moderate
Integration of technology across project phases	2.97	1.254	7	Moderate-low
Building Information Modelling (BIM)	2.84	1.298	8	Low-moderate
Drones for site monitoring and surveying	2.71	1.326	9	Low
IoT sensors for equipment tracking	2.53	1.347	10	Low
Augmented reality (AR) for visualization	2.38	1.289	11	Low
Artificial intelligence (AI) for project planning	2.21	1.234	12	Very low
Overall technology adoption composite	**3.06**	**0.968**	**–**	**Moderate**

Source: Author (2026).

The first tier consists of foundational tools: project management software (M = 3.64), mobile applications for site communication (M = 3.52), and digital documentation systems (M = 3.41). The second tier, made up of cloud-based collaboration tools (M = 3.28), automated scheduling software (M = 3.15), cost estimation software (M = 3.09), and technology integration across project phases (M = 2.97), showed moderate but more variable use, with standard deviations of 1.189 to 1.254. The third tier comprises advanced

technologies that remain marginal: BIM (M = 2.84), drones (M = 2.71), IoT sensors (M = 2.53), augmented reality (M = 2.38), and artificial intelligence, which had the lowest mean of all 12 items (M = 2.21, SD = 1.234).

Adoption also rose with firm size ($F(2, 146) = 13.42$, $p < 0.001$, $\eta^2 = 0.155$). Large firms (M = 3.81) used technology significantly more than medium firms (M = 3.34, $p < 0.01$) and small firms (M = 2.76, $p < 0.001$), and medium firms used it significantly more than small firms ($p < 0.01$).

5. Discussion

5.1 The direct effect of lean practices

The significant positive effect of lean practices on performance ($\beta = 0.341$) supports TFV theory: firms that improve transformation efficiency, flow, and value generation perform better (Koskela, 2000). It agrees with studies in other countries that link lean practice to performance (Aziz & Hafez, 2013; Bajjou & Chafi, 2018; Demirkesen & Tezel, 2022), and the medium effect size is plausible because lean is one of several influences on performance. Plausible mechanisms are lower material waste and rework, better scheduling and coordination, higher quality through standardisation and continuous improvement, and closer attention to client needs. These mechanisms were not measured directly. The result also suggests that partial implementation brings benefits, which is encouraging for small firms.

5.2 Why lean practices drive technology adoption

The large effect of lean on technology adoption ($\beta = 0.623$, $f^2 = 0.634$) is the strongest relationship in the model. It suggests that lean routines create readiness for digital tools: structured meetings, visual control, standard procedures, and a habit of measurement give firms the process discipline and analytical capacity to evaluate and use technology effectively (Sacks et al., 2010; Dave et al., 2013). This interpretation implies that lean practice may be a precondition for getting returns from technology investment, although a cross-sectional design cannot establish the direction of causality, and technology may also reinforce lean (see 5.4).

5.3 Partial mediation and the socio-technical reading

The partial mediation result is the main contribution. Close to half of the effect of lean practice on performance (47.05%) passes through technology adoption, while a significant direct effect remains. This is consistent with Socio-Technical Systems theory (Trist, 1981): lean practices represent improvement of the social subsystem, technology adoption improvement of the technical subsystem, and performance is best when both are advanced

together. The share is close to the 47.5% VAF reported for business model innovation as a mediator among Indonesian construction firms (Arifin et al., 2025), which suggests that mediation of about this magnitude may be a general feature of the lean–performance relationship. Lean also strengthens technology: just-in-time delivery works best with digital tracking, visual management with real-time dashboards, and continuous improvement with data analytics (Sacks et al., 2010).

5.4 Firm size as a boundary condition

The stronger LCP → TA path in large firms means that large firms convert lean readiness into technology adoption more effectively, which is consistent with their greater capital, digital skills, and formal channels for investment (Barney, 1991). The mediated share of performance rose from 41.2% for small firms to 53.6% for large firms. Small firms, however, still benefited from both pathways, which implies that support for them can pay off. The TA → FP difference was not significant at the 5% level ($p = 0.076$), so the rising pattern should be read as suggestive.

5.5 Contextual barriers and the LCP-TA-FP relationships

The model did not measure the operating environment, yet the relationships among lean practices, technology adoption, and performance are unlikely to be independent of it. Three barriers, namely insecurity, weak infrastructure, and limited skills, are widely reported for construction in Nigeria and especially in the North East (Bala et al., 2021; Aghimien et al., 2022). Their likely influence on each path is discussed below as interpretation, because none of them was measured in this study.

Insecurity is most likely to weaken the direct LCP → FP path. Security risks that affect site access and the movement of personnel, and supply chains that are exposed to disruption, make pull planning, just-in-time delivery, and supply chain integration hard to sustain (Bala et al., 2021). These were the practice areas that the importance–performance analysis found to be important but under-performing, so the operating environment may be part of the explanation. Insecurity may also discourage investment in costly equipment and digital systems, which would reduce the return firms obtain from technology.

Infrastructure deficiencies are most relevant to the TA → FP path. Unreliable electricity and intermittent internet connectivity affect technology adoption in the North East more than in other Nigerian regions (Oke, 2024), and they make cloud-dependent and sensor-based tools unreliable in daily use. This is consistent with the low use of IoT sensors ($M = 2.53$) and the comparatively modest use of cloud-based collaboration tools ($M = 3.28$) in Table 7. Firms that adopt such tools without dependable power and connectivity may not

realise their full benefit, which could be one reason why the indirect effect (β = 0.303) is smaller than the strength of the LCP → TA path (β = 0.623) might lead one to expect.

Skills shortages may affect both the LCP → TA and TA → FP paths. Lean routines build readiness for technology, as argued in Section 5.2, but firms still need staff able to select, operate, and maintain digital tools. Displacement of skilled workers during the conflict has left skills scarce in the region (Bala et al., 2021), lack of lean training is among the most severe barriers to lean implementation in Nigeria (Oke et al., 2022), and skills scarcity is a barrier to adopting advanced tools such as artificial intelligence (Acheampong et al., 2025), the least used technology in Table 7 (M = 2.21). Where skills are scarce, readiness is less likely to become effective adoption and adoption less likely to improve performance. This is consistent with the stronger LCP → TA path in large firms (Section 5.4), which are better placed to recruit and train specialist staff.

Taken together, these barriers may help explain why mediation is partial and not full: lean practices reach performance directly through process improvement, while the technology route depends on conditions that vary across firms and locations. Future studies should measure these barriers and test them as moderators of the three paths. For practice and policy, the findings support pairing technology investment with security-aware project planning, reliable power and connectivity, and targeted training, especially for small firms.

5.6 Implications

For firms, the findings support an integrated lean digital strategy and not a choice between the two. For practice, the priority areas from the importance performance analysis (supply chain integration, pull planning, JIT delivery, and value stream mapping) are where improvement is likely to yield most. For policy, support for technology infrastructure and training, aimed especially at small firms, will strengthen the indirect pathway. For theory, the study applies TFV, the Resource-Based View, Diffusion of Innovation, TOE, and Socio-Technical Systems theory within one tested model and extends them to a post-conflict setting in sub-Saharan Africa.

6. Conclusion

Lean construction practices improve firm performance in North East Nigeria both directly and through technology adoption, which partially mediates the relationship (VAF = 47.05%). The validated model explains over half of the variance in performance and has acceptable fit and predictive relevance. Firms should pursue lean practices and digital technologies together, prioritising the weakest but most important lean practice areas, and

policymakers should support technology infrastructure and skills so that small firms can benefit.

The study has limitations. It is cross-sectional, so causal ordering rests on theory; all constructs were reported by one senior informant per firm, with a risk of perceptual and social desirability bias, although the tests showed no serious common method bias; it covers registered firms in three of the six North East states; and contextual barriers (insecurity, infrastructure, and skills) were not measured, so their role is interpreted and not tested. Future research should use longitudinal or objective performance data, extend the sample, and test these barriers and organisational culture as moderators.

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