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EXPLORING TRENDS ON AUTOMATION OF CONSTRUCTION PROCESSES: EXTENT AND ENABLERS IN NIGERIA

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Abstract: This study investigates the extent and enablers of automation of construction processes in Nigeria with a view to improving project performance in developing economies. Despite increasing global adoption of automation technologies, there remains a lack of empirical quantification of automation levels in developing countries. Adopting a positivist paradigm and quantitative research design, data were collected from 198 built environment professionals across Lagos and Abuja using a structured questionnaire. Descriptive and inferential statistical tools, including mean score analysis, t-test, and ANOVA, were employed. Findings reveal that automation adoption in the Nigerian construction industry is low (MS = 2.194), with relatively higher implementation in the pre-construction phase. Significant regional disparities were observed, with Lagos exhibiting higher automation levels than Abuja. Critical enablers identified include stable electricity, technical expertise, and supportive government policy. The study contributes to knowledge by providing implications for Diffusion of Innovation Theory, Technology Acceptance Model, Unified Theory of Acceptance and Use of Technology, and Construction 4.0 through the introduction of environmental feasibility as a key determinant of adoption. Furthermore, a Construction Automation Readiness Framework (CARF) is developed to guide policy and implementation in resource-constrained environments. The findings provide a robust empirical and theoretical foundation for advancing automation in developing economies.

Keywords: Automation, construction processes, enablers, project performance, robotic and Nigeria

1. INTRODUCTION

The execution of construction projects in developing countries has largely remained analog, characterized by crude methods and limited mechanization (Osunsanmi et al. 2020, Olatunde et al. 2022) . Consequently, project performance has been consistently poor, particularly with respect to cost overruns, delays, health and safety issues, and low stakeholder satisfaction (Okorie and Olatunde 2018, Olatunde and Odeyinka 2021). In contrast, advancements in automation and robotics in developed countries have demonstrated significant potential in addressing these challenges, thereby improving construction efficiency and delivery outcomes. This widening technological gap highlights the urgent need for developing economies such as Nigeria to adopt innovative approaches that enhance project performance.

Despite rapid technological progress globally, the construction industry continues to lag behind sectors such as manufacturing, banking, and automotive in adopting automation (Aghimien et al. 2022). While these sectors have leveraged automation to improve productivity and competitiveness, the construction industry—particularly in developing countries—has experienced minimal integration of such technologies (RECM and Holt 2020). For instance, KPMG (2017) reports that fewer than 10% of construction firms globally utilize real-time project management tools, while many rely on fragmented systems. Similarly, over 60% of construction organizations continue to depend on traditional tools such as Microsoft Excel for project monitoring (Hwang et al. 2022). Although research into construction robotics spans over four decades, its practical application has only recently gained momentum, predominantly in developed economies (Balaguer and Abderrahim 2008). The adoption of automation and robotics offers a viable pathway to addressing persistent challenges in construction. Automation can significantly enhance productivity, improve safety, and optimize project management processes (Maskuriy et al. 2019). For example, the deployment of robotic technologies can substantially reduce construction-related accidents, which are reported to be significantly higher than in manufacturing industries (Okorie and Olatunde 2018, Bell and Healy 2006). Furthermore, automation can mitigate delays caused by labour-related issues such as absenteeism, fatigue, and industrial actions, thereby improving adherence to project timelines (Olatunde and Alao 2017, Ye et al. 2022). It also minimizes errors associated with human input, leading to improved quality and efficiency (Oke et al. 2019, Ojha et al. 2022).

In Nigeria, construction project performance remains particularly concerning. Empirical evidence indicates that only a small proportion of projects are completed within budget and on schedule, especially in public and private tertiary institutions (Olatunde and Alao 2017). This underscores the urgent need for technological transformation within the Nigerian Construction Industry (NCI). Although studies have examined barriers, drivers, and strategies for automation adoption (Oke et al. 2023a–c), there is a notable lack of empirical research quantifying the current level of automation across construction processes. Additionally, limited attention has been given to regional disparities in automation readiness within the country. This study addresses these gaps by investigating the extent of automation in construction processes within the NCI, identifying key enablers, and examining regional variations in adoption trends. It also responds to the need for a context-sensitive framework that accounts for the infrastructural and institutional realities of developing economies. By providing empirical insights and proposing a Construction Automation Readiness Framework (CARF), this research aims to inform policy and support the strategic advancement of automation in Nigeria's construction sector. Ultimately, enhancing automation adoption is critical for improving project performance and aligning the industry with global best practices (Huang et al., 2022, Yap et al. 2021).

2. LITERATURE REVIEW

Theories of Innovation and Automation Adoption: The theoretical foundation for understanding innovation and automation adoption plays a critical role in shaping research, policy, and implementation strategies in the construction industry. Key theories include the Diffusion of Innovation Theory (Rogers 1962), which explains how technologies spread through communication channels over time within a social system. The theory classifies adopters into innovators, early adopters, early majority, late majority, and laggards. However, its assumption that awareness naturally leads to adoption is often unrealistic in developing countries, where infrastructural and institutional deficiencies—such as unreliable electricity, shortage of skilled labour, and weak policy enforcement—can hinder diffusion. To address this limitation, Hossain (2018) proposed a pre-diffusion phase that incorporates environmental readiness as a prerequisite for adoption. The Technology Acceptance Model (TAM) (Davis 1989) further explains adoption behaviour through perceived usefulness and perceived ease of use. It has been applied to construction technologies such as drones, mobile monitoring systems, and automation tools (Park et al. 2020). Nonetheless, TAM primarily emphasizes individual cognitive factors and overlooks external constraints. To overcome this, Venkatesh and Bala (2008) extended the model to include social and facilitating conditions. In developing countries, additional contextual variables—such as infrastructure availability, regulatory support, and skilled workforce—are essential for accurately explaining adoption (Oke et al. 2023b).

The Construction 4.0 framework integrates Industry 4.0 technologies—including the Internet of Things, artificial intelligence, robotics, building information modelling, and additive manufacturing—into construction processes to improve efficiency and sustainability (Oesterreich and Teuteberg 2016, Pramod 2022). However, it assumes a level of technological and institutional maturity that is often absent in developing economies. Aghimien et al. (2022) therefore argue for a phased implementation approach in Africa, beginning with foundational enablers such as stable electricity, skills development, and supportive policies before full automation can be achieved.

Automation of Construction and Project Performance: Extant literature demonstrates that automation and robotics are effective solutions to persistent construction project performance challenges (Yap et al. 2021). Robotics enhances productivity, particularly in repetitive and complex tasks (Liel et al. 2019), while automation improves project outcomes in terms of time, quality, and efficiency (de Soto and Skibniewski 2020). Technologies such as unmanned aerial vehicles (drones) have enabled construction activities in hazardous or inaccessible environments (Aghimien et al. 2020). They also support site surveying, environmental monitoring, and project planning (Oke et al. 2023a), while automated trucks facilitate material transportation (Ragbir et al. 2020). Additionally, drones integrated with building information modelling enable remote monitoring and accurate measurement of construction parameters (Golizadeh et al. 2019; Oke et al. 2023a). Health and safety challenges, a major concern in construction, can also be mitigated through automation. Technologies such as exoskeletons reduce physical strain associated with labour-intensive tasks, improving worker safety and productivity (Carra et al., 2018; Delgado et al., 2019; Ebekozien et al. 2023). The industry's poor safety record has been linked to heavy reliance on manual labour, unlike more automated sectors such as manufacturing (Aghimien et al. 2022). Exoskeletons and related technologies enhance human capabilities, reduce fatigue, and create safer work environments (Oke et al. 2023a).

Enablers of Automation of Construction: Construction 4.0 has been widely recognized as a major driver of automation and robotics adoption across the construction industry (Pramod 2022). The emergence of automation represents a key technological advancement aligned with the fourth industrial revolution, with the potential to transform operational efficiency (Oke et al. 2023c). Enablers, defined as factors or resources that facilitate the achievement of specific goals (McIntosh 2015), are critical to this transformation. Core technological enablers of construction automation include Internet of Things, big data analytics, cybersecurity, augmented reality, building information modelling, cloud computing, additive manufacturing, blockchain, and automated equipment (Oesterreich and Teuteberg 2016, Guoping et al. 2017, Olatunde et al. 2022). Additional enablers include machine learning, simulation tools, smart decision-support systems, gamification, quantum computing, smart sensors, and interconnected systems (Awodele et al. 2024). Beyond technology, foundational conditions such as stable electricity supply, technical expertise, supportive government policies, and effective regulatory frameworks are essential for enabling automation adoption (Aghimien et al. 2022). Without these critical enablers, the transition towards automated construction processes in developing countries may remain constrained.

3. RESEARCH METHODOLOGY

This study adopts a positivist research approach to examine the extent and enablers of automation in construction processes in Nigeria. The positivist paradigm emphasizes objectivity through empirical observation and scientific methods, making it suitable for quantitative investigation. Accordingly, a quantitative research design was employed to enable objective measurement and minimize bias through numerical analysis (Oke et al, 2023a). Data were collected from two major Nigerian cities—Abuja (North) and Lagos (South)—to provide a comprehensive and geographically diverse perspective. These cities were selected due to their historical significance as current and former federal capitals, as well as their high volume and sophistication of construction activities. This selection enhances the representativeness and generalizability of the findings across regions. Additionally, built environment professionals residing in these cities but with recent experience in other parts of Nigeria were included to provide broader comparative insights.

A convenience sampling technique was used to select respondents, including Architects, Engineers, Builders, and Quantity Surveyors. This approach reduces selection bias and ensures representation of key stakeholders involved in construction decision-making and implementation. Data were collected using a structured questionnaire, chosen for its efficiency in gathering large volumes of data within a short time and its simplicity in administration. Unlike qualitative methods such as interviews, which prioritize depth, the questionnaire approach aligns with the study's objective of obtaining a wide range of responses (Flick 2014). The questionnaire comprised two sections: the first captured respondents' demographic information, while the second addressed the study objectives. Items in the second section were measured using a five-point Likert scale, consistent with prior studies (Oke et al. 2023c, Olatunde et al. 2022, Pacchini et al. 2019). The development of questionnaire items was informed by extant literature to ensure alignment with established theoretical constructs in automation and innovation research.

In addition to reliability assessment, construct validity was considered to ensure that the questionnaire items adequately represented the theoretical constructs investigated in the study. Construct validity was established through an extensive review of existing literature on automation adoption, Construction 4.0, and innovation diffusion theories, from which the questionnaire items were adapted (Oke et al. 2023a–c; Olatunde et al. 2022). This process ensured theoretical alignment between the measurement items and the underlying constructs of automation extent and automation enablers.

To further strengthen content and construct validity, face validation was conducted by three independent experts —two senior academics and a professional fellow of the Nigerian Institute of Quantity Surveyors. Their feedback improved the clarity, relevance, and comprehensiveness of the instrument. The multidisciplinary nature of the validators further strengthened content validity. The questionnaire was distributed via online platforms, including LinkedIn and professional webpages, enabling access to a technologically aware population relevant to the study focus. A total of 198 responses were obtained, comprising 61 from Abuja, 53 from Lagos, and 84 from other regions. Reliability and validity of the data were assessed using Cronbach's alpha, while the Shapiro–Wilk test was applied to evaluate normality assumptions for parametric analysis. Descriptive statistics, including frequency, percentage, and mean item score, were used to summarize respondent characteristics and responses. Inferential analysis was conducted using t-tests and ANOVA. The t-test compared differences in automation extent between Lagos and Abuja, while ANOVA assessed variations across multiple groups. All analyses were performed using the Statistical Package for Social Sciences (SPSS).

4. RESULTS

Table 1 shows Cronbach's Alpha coefficient for the reliability and internal consistency of the data collected. The result indicated that the Cronbach Alpha coefficient for the extent of automation and enablers of automation is 0.904 and 0.964 respectively. This implies high reliability and internal consistency, and low random errors within constructs since the values are very close to 1.00. This claim is justified when the figures are compared with the 0.6 benchmark set by Cho and Kim (2015) for a data set to be statistically reliable.

Before using independent sample t-test and one-way ANOVA a test of assumption of normality for parametric tests was examined for the composite scales used in the analysis (extent of automation and enablers of automation). The Shapiro–Wilk test was employed due to the moderate sample size ($n = 198$). Results indicated that the data for the "extent of automation" variable did not significantly deviate from normality ($W = 0.971$, $p = 0.069$), suggesting that the assumption of normality was met. Similarly, the "enablers of automation" scale also passed the normality test ($W = 0.968$, $p = 0.081$).

Table 1: Reliability Statistics

Extent of Automation		Enablers of automation	
Cronbach's Alpha	No. of Items	Cronbach's Alpha	No. of Items
0.904	16	0.964	29

Table 2 indicates the demography of the respondents to the questionnaire. The respondents cut across the main build environment practitioners and engineers have the highest number of respondents (33.3%). This is expected because engineers are more in population than other professionals in Nigeria. All the respondents are members of their various professional organizations. While 64.1% were corporate members, 9.1%were Fellows in their professional associations. Regarding work experience, 66.2% of the respondents have more than ten years of experience in the Nigerian construction industry, 22.7% have between 5 and 10 years of work experience, while only 11.1% have work experience of less than 5 years in the Nigerian construction industry. Many of the respondents (44.4%) were holders of master's certificates, 26.3% were holders of bachelor's degree certificates, and 19.7% were PhD holders. The distribution of the respondents across the study area shows that 30.8% were from Abuja, 26.8% were from Lagos and 42.4% have been practicing from other locations in Nigeria in the last five years. The analysis of the background of the respondents indicated that they were qualified to supply the information requested from them as they possessed the work experience needed, and academic qualifications, were an adequate mix of built environment professionals, were spread across the study area, and were professionally qualified. Hence, it could be deduced that the data gathered from them is reliable and could be used for informed decision-making.

Table 2: Demography of Respondents

Category	Classification	Frequency	Percentage
	Quantity surveyor	46	23.2
	Engineer	66	33.3
Profession	Builder	33	16.7
	Architect	53	26.8
	Total	**198**	**100**
	NIQS	42	21.2
	NSE	65	32.8
	NIOB	35	17.7
Membership of Professional Bodies	NIA	47	23.7
	Others	9	4.5
	Total	198	100.0
	Graduate	19	9.6
	Probationer	34	17.2
	Corporate	127	64.1
Type of Membership	Fellow	18	9.1
	Total	**198**	**100.0**
	1-5	22	11.1
Years of experience	6-10	45	22.7
	11-15	40	20.2

	16-20	51	25.8
	21 and above	40	20.2
	Total	**198**	**100.0**
	HND	15	7.6
	PGD	4	2.0
	B.Tech/B.Sc	52	26.3
	M.Tech/M.Sc	88	44.4
Highest academic Qualification	PhD	39	19.7
	Total	**198**	**100.0**
	Lagos	53	26.8
	Abuja	61	30.8
Location	Others	84	42.4
	Total	**198**	**100.0**

Table 3 shows the extent of automation in the construction phases. The result indicated that the extent of automation is low (MS= 2.194). However, the extent of automation of construction in the pre-construction phase was ranked first (MS=2.283). The standard deviation in the opinion of the respondents on all the phases of construction processes was less the 1.00 which implies that there is little variability in the opinions of the respondents in the way they rated the extent of automation in the study area. The result of the ANOVA shows that there was unanimity in the rating of the respondents on the extent of automation in the pre-construction phase (P-Value=0.051), while there were significant differences in their opinions on the construction phase (p-value=0.005) and the post-construction phases (p-value=0.010). Overall, there is no significant difference in the opinion of the respondents on the extent of automation in Nigeria (p-value=0.074).

Table 3: Extent of Automation on Construction Phases

Construction phases	Mean score	Standard deviation	Rank	F-stat	P- Value
Pre-construction phase	2.283	.727	1	3.027	0.051
Construction phase	2.147	.664	3	5.487	0.005
Post construction phase	2.152	.703	2	4.677	0.010
Overall Average	2.194	0.698		4.397	0.074

Table 4 depicts the extent of automation on the various sub-phases of construction processes. Results indicated that the overall extent of automation based on the respondents' rating on the sub-phases of construction processes is very low (overall MS=1.939). The pre-construction phase of the construction processes appears to have a little increase in rating as compared to the other phases hence, planning and design, bidding and procurement, and project initiation respectively were ranked 1st, 2nd, and 3rd. The standard deviation for all the sub-phases of construction processes was less than 1.00 indicating a little variability in the opinions of respondents. The result of the ANOVA shows that the opinions of the respondents were unanimous on 7(54%) variables (P-values greater than 0.05) of the 13 items measured, while there is a significant difference in their opinions on 6(46%) items (P-values less than 0.05). Overall, there is no significant difference in the opinion of the responses on the extent of automation within the study area based on the rating of the sub-phase of construction processes (p-value=0.191).

Table 4: Extent of Automation on sub- phases of construction Processes

Construction phases	Mean score	Standard deviation	Rank	F-stat	P- Value
Project Initiation	2. 136	.642	3	6.915	0.001
Planning & Design:	2.313	.729	1	13.488	0.000
Bidding & Procurement:	2.167	.711	2	4.508	0.012
Site Preparation:	2.101	.540	7	4.188	0.017
Foundation work	2.015	.750	12	10.417	0.000
Superstructure Construction	2.061	.538	8	2.922	0.056
Mechanical, Electrical and plumbing installation	2.081	.701	7	0.284	0.753
Interior and Exterior Finishes	2.035	.694	10	3.243	0.410
Landscaping and Site Work	2.030	.697	11	4.100	0.018
Inspection and Testing:	2.121	.642	5	2.746	0.067
Commissioning	2.126	.747	4	2.626	0.075
Handover:	2.105	.738	6	1.005	0.368
Closeout	2.056	.774	9	0.351	0.705
Overall Average	**1.939**	0.623		1.511	0.191

Table 5 shows the result of the comparison of the extent of automation on construction processes in Lagos and Abuja. The results indicated that the extent of automation in Lagos is rated higher than that of Abuja on all construction phases and the sub-construction phases used. Overall, while the extent of automation in Lagos is low (MS=2.209), that of Abuja is very low (MS=1.939). The results of the t-test show that there is a significant difference in the opinion of the respondents on 56% of the variables, while they were unanimous in their rating of the other 44% of the variables. Overall, there is a significant difference in the opinion of the respondents on the extent of automation of construction processes in Lagos and Abuja (P-value=0.003).

Table 5: Extent of Automation in Lagos and Abuja Compared

Construction phases	Extent of automation		T-Statistics	P-value
	Lagos	Abuja		
Pre-construction phase	2.2642	1.9344	2.189	0.031
Project Initiation	2.1698	1.7705	2.899	0.005

Planning & Design:	2.5094	1.9344	4.452	0.000
Bidding & Procurement:	2.3774	1.9836	3.156	0.002
Construction phase	2.2642	1.9180	2.978	0.004
Site Preparation:	2.0000	1.9434	0.396	0.693
Foundation work	2.0377	1.6885	2.934	0.004
Superstructure Construction	2.2075	1.8852	2.408	0.018
Mechanical, Electrical and plumbing installation	2.1321	2.0328	0.761	0.448
Interior and Exterior Finishes	2.1509	1.8525	2.279	0.025
Landscaping and Site Work	2.0377	1.8361	1.603	0.112
Post construction phase	2.1887	1.9344	2.116	0.037
Inspection and Testing	2.1509	1.9672	1.623	0.107
Commissioning	2.3019	1.9836	2.352	0.020
Handover	2.2453	2.0492	1.334	0.185
Closeout	2.3585	2.2459	0.750	0.455
Overall	**2.209**	**1.939**	**2.900**	**0.003**

Table 6 shows the enablers of the automation of construction processes. The results indicated that the most important enabler of automation of construction processes is stable electricity (MS=4.197) ranked 1st. Other important enablers of the automation of construction processes are technical expertise (MS=4.076) and ranked 2nd and government policy (MS=3.985) and ranked 3rd. Respondents pinioned that all the enablers of automation of construction are important hence, all the enablers were moderate with a Mean score greater than 3.0. The results of the ANOVA indicated that the opinion of the respondent only differed significantly on 17% of the enablers of automation measured while there is concordance in their rating of 83% of the enablers of automation. Overall, there is no significant difference in the opinions of the respondents on the enablers of automation in the study area (p-value=0.138).

Table 6: Enablers of Automation of Construction processes

Enablers of Automation	**Mean Score**	**Rank**	**F-Stat**	**P- Value**
Stable electricity	4.197	1	.676	.510
Technical expertise	4.076	2	.832	.437
Government policy	3.985	3	.870	.421
Smart decision support systems	3.970	4	4.425	.013

Relevant laws and regulations	3.955	5	.504	.605
Building information Modelling (BIM)	3.894	6	1.914	.150
modelling and simulation	3.864	7	.757	.470
3D Printing	3.758	8	1.014	.365
Virtual Reality (VR)	3.697	9	1.050	.352
Internet of things	3.682	10	1.972	.142
Smart sensors and connected machines	3.652	11	2.593	.077
Laser Scanning and LiDAR	3.647	12	1.192	.306
Machine learning	3.636	13	.061	.941
Horizontal/ vertical integration	3.632	14	4.338	.014
AI-based Project Management Software	3.621	15	.254	.776
Artificial intelligence	3.591	16	1.022	.362
Cloud computing	3.576	17	.465	.629
Cyber security	3.546	18	4.881	.009
Big data	3.530	19	6.324	.002
Augmented reality	3.455	20	.725	.486
Computer Numerical Control (CNC)Machinery	3.455	21	.106	.900
Automated and robotic equipment	3.428	22	.449	.639
Tele-operated Construction Equipment	3.424	23	.670	.513
Smart Wearables	3.399	24	.935	.394
Human-Robot Collaboration (Cobots)	3.389	25	.464	.629
Quantum computing	3.318	26	.026	.974
Cyber-physical system	3.307	27	1.841	.161
Additive manufacturing	3.303	28	.708	.494
Block chain	3.182	29	4.812	.009

Overall	**1.582**	**0.138**

5. Discussion and Theoretical Contribution

The findings reveal a low level of automation in construction processes, reaffirming the predominantly analog nature of the Nigerian construction industry (Osunsanmi et al. 2020, Olatunde et al. 2022). The limited presence of automation—particularly during construction and post-construction phases—continues to hinder project performance, contributing to time and cost overruns, safety concerns, and quality deficiencies. Although the pre-construction phase exhibits relatively higher automation due to the use of digital tools such as AutoCAD and Revit, core construction activities remain largely manual. This supports earlier studies indicating that awareness of automation does not necessarily translate into adoption (Aliu et al. 2021, Fadamiro and Oke 2019). Furthermore, regional differences observed between Lagos and Abuja highlight uneven adoption levels, with Lagos showing relatively higher automation, likely due to its status as a commercial hub with greater exposure to advanced technologies. Key enablers identified—stable electricity, technical expertise, and government policy—underscore the infrastructural and institutional constraints influencing adoption and carry important theoretical implications.

Extending and Challenging Existing Theories

Diffusion of Innovation Theory (Rogers 1962): The findings challenge the theory's assumption of a linear diffusion process. In Nigeria, automation adoption appears stalled at an early stage, suggesting a disruption of the expected S-curve. This indicates that enabling conditions—such as infrastructure, human capital, and policy—must precede diffusion, necessitating the inclusion of a "pre-diffusion readiness" stage for developing economies.

Technology Acceptance Model (Davis 1989): While TAM emphasizes perceived usefulness and ease of use, this study shows that these factors alone do not drive adoption in Nigeria. Despite positive perceptions of automation, adoption remains low due to environmental constraints. Therefore, the study proposes "Environmental Feasibility (EF)"—capturing infrastructure, expertise, and policy support—as a critical mediating variable, enhancing TAM's applicability in developing contexts.

Unified Theory of Acceptance and Use of Technology (Venkatesh et al. 2003): The study repositions facilitating conditions from a secondary moderating factor to a primary determinant of adoption. In resource-constrained environments, such conditions are foundational rather than supportive. Additionally, regional disparities suggest the need to incorporate context-specific variables such as urbanization and economic clustering into extended models.

Construction 4.0 Framework: Existing Construction 4.0 models assume baseline technological and institutional readiness. However, this study demonstrates that such assumptions are unrealistic in developing economies. A phased, "Foundational-First" approach is therefore advocated, where critical enablers precede the adoption of advanced technologies such as BIM, IoT, and cloud computing.

The proposed Construction Automation Readiness Framework (CARF) is conceptually grounded in the relationship between automation enablers and organizational readiness for technological adoption. While enablers represent the specific technological, institutional, and infrastructural conditions that facilitate automation implementation, readiness refers to the overall capacity of an industry or organization to successfully adopt and sustain automation practices. In this study, the identified enablers are not treated as isolated variables; rather, they are interpreted as underlying readiness conditions that collectively determine the preparedness of the construction industry for automation transformation. For instance, stable electricity and internet connectivity represent infrastructural readiness, technical expertise reflects human capital readiness, while government policy and regulatory support indicate institutional readiness. Similarly, the adoption of BIM, AI, IoT, and related technologies reflects technological maturity readiness. Thus, the CARF was developed by conceptually grouping empirically identified enablers into broader readiness dimensions grounded in technology adoption and innovation theories. This approach provides a more theoretically coherent framework for understanding automation adoption in developing economies, where readiness conditions often determine whether enabling technologies can be effectively implemented.

Construction Automation Readiness Framework (CARF): Based on these insights, a context-sensitive framework is proposed, comprising four interrelated dimensions: Infrastructure Readiness (electricity and connectivity), Human Capital Readiness (skills and expertise), Policy and Regulatory Readiness (government support and enforcement), and Technological Maturity (extent of digital adoption). This framework provides a more practical tool for assessing automation readiness in emerging economies.

Theoretical Contributions: This study makes several key contributions. First, it challenges the linear assumption of Diffusion of Innovation Theory by emphasizing the role of pre-existing conditions in shaping adoption. Second, it has implications for the Technology Acceptance Model by introducing Environmental Feasibility as a critical determinant. Third, it reinterprets the Unified Theory of Acceptance and Use of Technology by elevating facilitating conditions to a central role in adoption. Finally, it advances Construction 4.0 discourse by proposing a phased implementation approach through the Construction Automation Readiness Framework (CARF), offering a more realistic pathway for automation adoption in developing economies

Construction Automation Readiness Framework (CARF)

Based on the empirical findings and the theoretical interpretation of automation enablers as readiness conditions, a Construction Automation Readiness Framework (CARF) is proposed to guide the assessment and implementation of automation in developing economies. The framework comprises four interdependent dimensions:

- Infrastructure Readiness (availability of stable electricity, internet connectivity, and physical infrastructure)
- Human Capital Readiness (availability of skilled professionals and technical expertise)
- Policy and Regulatory Readiness (government policies, incentives, and enforcement mechanisms)
- Technological Maturity (current level of adoption of digital and automation technologies)

These dimensions interact dynamically to determine the readiness of the construction industry to adopt automation. The framework emphasizes that automation adoption cannot occur in isolation but must be supported by foundational enablers.

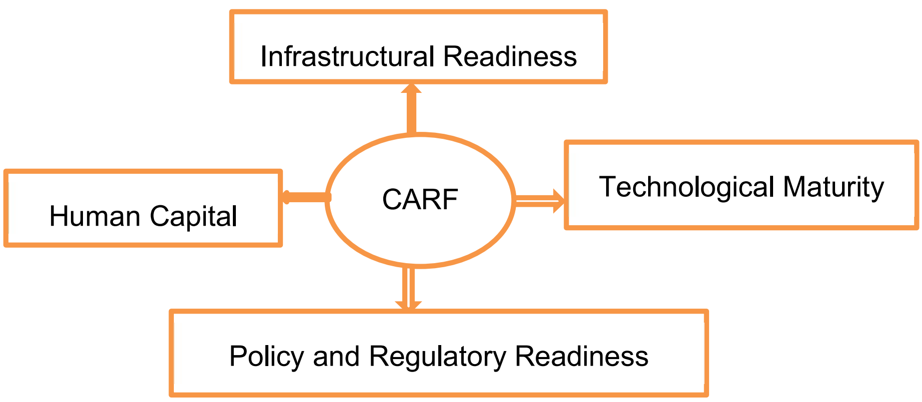

Figure 1: Construction Automation Readiness Framework (CARF).

6. CONCLUSION

This study provides empirical evidence that construction automation in Nigeria remains low, with significant variation across project phases and regions. The findings highlight the critical role of infrastructural, human, and policy-related enablers in shaping automation adoption. The study contributes to theory by proving implications for the existing technology adoption models through the introduction of environmental feasibility as a key determinant. Additionally, the proposed Construction Automation Readiness Framework (CARF) offers a practical tool for assessing and guiding automation adoption in developing economies. For practice, the study underscores the need for targeted policy interventions, investment in infrastructure, and capacity development to facilitate automation adoption. The limitations that may be associated with the study included the reliance on self-reported data which may introduce response bias, as perceptions may not fully reflect actual levels of automation implementation. Also, the study focuses on two major cities—Lagos and Abuja—which, although significant, may not fully represent the diversity of construction practices across all regions of Nigeria. In the same vein, the limitation imposed by lack of validation of the proposed framework was also acknowledged. Future research should explore longitudinal approaches and comparative studies across multiple developing countries to further validate and refine the proposed framework.

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