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CRITICAL SUCCESS FACTORS MEDIATING FOURTH INDUSTRIAL REVOLUTION READINESS AND CONSTRUCTION PROJECT PERFORMANCE IN NIGERIA

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ABSTRACT

Purpose: This study assesses the Fourth Industrial Revolution (4IR) readiness of Nigerian construction firms, identifies and prioritises the critical success factors (CSFs) for 4IR adoption, and examines their relationship with project performance across Nigeria's six geopolitical zones.
Design/Methodology/Approach: A quantitative cross-sectional survey was administered to 535 professionals from 669 medium and large firms; 498 responses were usable (93.1%). Data were analysed using Mean Item Score (MIS), Relative Importance Index (RII), Exploratory Factor Analysis (EFA), Spearman's rank-order correlation, and Ordinal Logistic Regression (OLR), with diagnostics covering sampling adequacy, sphericity, proportional odds, and multicollinearity (VIF < 5).
Findings: 4IR readiness falls below the significance threshold (MIS < 3.00) across all dimensions and zones; institutional and regulatory readiness is the most critical barrier (MIS = 1.97). Eight CSFs attained high-priority status (RII ≥ 0.70), led by government policy support (RII = 0.862) and top management commitment (RII = 0.848). EFA confirmed a two-factor structure, Operational Readiness and Institutional Readiness, explaining 68.4% of variance. Spearman correlations confirmed significant associations (ρ = 0.29–0.48, $p < 0.01$). OLR confirmed Institutional Readiness and CSF Priority Score as significant predictors of higher performance ratings (odds ratios 1.62–2.34, $p < 0.01$).
Research Limitations: The cross-sectional design limits causal inference; small enterprises are excluded; odds ratios limit comparability with OLS-based studies.
Originality/Value: This is the first nationally stratified, multi-zone 4IR readiness assessment of Nigerian construction firms and the first application of a MIS-RII-EFA-Spearman-OLR framework to ordinal construction survey data, offering a replicable template for 4IR adoption research in comparable developing-economy contexts.
Keywords: Critical Success Factors; 4IR Readiness; Ordinal Logistic Regression; Exploratory Factor Analysis; Project Performance.

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1. INTRODUCTION

The construction industry worldwide is navigating a period of technological change never seen before. Driven by the Fourth Industrial Revolution (4IR), which is defined by the smooth integration of digital intelligence, autonomous technologies, and cyber-physical systems into productive processes (Schwab, 2016), the industry faces both the necessity and the chance to radically alter how projects are planned, funded, acquired, and completed. Technologies collectively described as 'Construction 4.0' (Osunsanmi *et al.*, 2018), including Building Information Modelling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), drone surveillance, digital twins, cloud-based project management, and additive manufacturing, have demonstrated measurable capacity to reduce project costs, compress delivery schedules, enhance quality outcomes, and improve occupational safety performance in contexts where they have been meaningfully deployed (Kagermann *et al.*, 2013; Alaloul *et al.*, 2020; Xiao *et al.*, 2022). The dilemma facing emerging and developing economies is no longer whether new technologies are revolutionary, but rather whether it is possible to intentionally and methodically provide the structural circumstances necessary for their acceptance.

Nigeria's place in this global narrative is perplexing. The construction sector employs millions of people in both formal and informal labour markets, contributes roughly 4.18% of GDP as of Q1 2022 (National Bureau of Statistics [NBS], 2022), and is the main means of carrying out the Federal Government's infrastructure development agenda, which includes public institutional facilities, housing, transportation, and energy. However, the industry continues to suffer from some of the worst project delivery failures in the developing world: cost overruns frequently surpass 30% of contract values, schedule delays on publicly funded projects often last longer than a year, quality flaws that require costly rework are common, and client dissatisfaction is pervasive and well-documented (Olaitan *et al.*, 2021; Raja and Murali, 2020; Ezeokoli *et al.*, 2016). These mistakes maintain the infrastructural deficiencies that limit Nigeria's overall socioeconomic growth, put a heavy burden on state coffers, and undermine investor confidence. The most effective systemic lever for ending this cycle of persistent underperformance is the strategic deployment of 4IR technology, according to strong theoretical and empirical evidence.

However, the data on 4IR acceptance in Nigeria shows a significant implementation gap. Although construction personnel are aware of BIM, drones, and IoT (Adepoju and Aigbavboa, 2021; Opawole *et al.*, 2022), there is still very little actual implementation at the site and company levels. Ebekozien and Aigbavboa (2021) discovered that only a small percentage of Nigerian companies operationally used 4IR technology, even during the COVID-19 disruption period, when the need for digital construction tools was most pressing. Inadequate digital infrastructure, severe human capital shortages, limited funding, regulatory inertia, and an institutional environment that has not yet mainstreamed 4IR adoption as a national policy priority are the root causes of this awareness-adoption gap, which is not coincidental (Demirkesen and Tezel, 2021; Menegon and da Silva Filho, 2023). Developing solutions that are evidence-based rather than aspirational requires an understanding of the precise configuration of these obstacles and facilitators, as well as a rigorous quantification of their link to project performance outcomes.

Despite its expansion, the corpus of current research still has three important deficiencies. First, research on 4IR preparedness in Nigerian construction has been geographically restricted, usually limited to Lagos, Abuja, or single-state samples that cannot be considered nationally representative (Adepoju and Aigbavboa, 2021). A nationally stratified readiness evaluation is crucial for policy relevance since Nigeria's six geographic zones differ significantly in terms of infrastructure endowment, economic structure, human capital availability, and regulatory execution. Second, although possibly important success criteria for 4IR adoption have been subjectively explored in Nigerian

literature, no research has rigorously rated them using the Relative Importance Index (RII) approach to enable enterprises and governments to allocate resources in a way that is evidence-based and prioritised. Third, and perhaps most importantly, no research has used regression-based techniques to empirically quantify the quantitative link between 4IR readiness levels, CSF management, and construction project performance outcomes in Nigeria, yielding conclusions that are applicable to the industry.

This study addresses all three gaps using a quantitative cross-sectional survey design. It assesses 4IR readiness across Nigeria's six geopolitical zones, empirically ranks CSFs using RII, validates the latent structure of readiness constructs through Exploratory Factor Analysis (EFA), and models the relationship between readiness, CSFs, and project performance using Spearman's rank-order correlation and Ordinal Logistic Regression (OLR), techniques explicitly designed for ordinal data of the kind generated by Likert-scale instruments. The study's contributions are threefold: methodologically, by establishing a replicable MIS-RII-EFA-Spearman-OLR analytical framework appropriate for ordinal 4IR adoption data in comparable national contexts; theoretically, by advancing the Construction 4.0 literature through a developing-economy readiness-performance model grounded in validated latent constructs; and practically, by providing construction firms, regulatory bodies, and academic institutions with a statistically robust, deployable evidence base for 4IR adoption policy and practice.

2. LITERATURE REVIEW

2.1. Construction 4.0: Conceptual Foundation

The Industry 4.0 framework, which was promoted in Germany's High-Tech Strategy 2020 (Kagermann *et al.*, 2013) and theorised internationally by Schwab (2016), gave rise to the idea of Construction 4.0. Construction 4.0, according to Osunsanmi *et al.* (2018), is the use of 4IR technologies throughout the whole construction lifecycle, from design and feasibility to procurement, execution, and asset operation. BIM for design coordination and clash detection, IoT sensors for real-time site monitoring, AI and machine learning for predictive analytics, drones for surveying and progress documentation, digital twins for asset lifecycle management, cloud platforms for distributed collaboration, and additive manufacturing for producing prefabricated components are some of the keys enabling technologies (Hermann *et al.*, 2016; Maskuriy *et al.*, 2019; Demirkesen and Tezel, 2021). Research from developed-country settings consistently demonstrates that businesses using these technologies achieve measurable improvements in quality and safety, improved client satisfaction, and significant reductions in project cost and schedule overruns (Kang *et al.*, 2016; King, 2018; Xiao *et al.*, 2022). Developing countries' job is not to completely duplicate this experience, but rather to pinpoint the favourable circumstances and objectives that make such adoption possible, given their unique institutional limitations.

2.2. 4IR Readiness: Dimensions and Measurements

A fundamental requirement for converting awareness into significant adoption is technology readiness, which is roughly described as an organisation's capacity to accept and operationalise a particular technological breakthrough (Oke *et al.*, 2018). Technological infrastructure, human capital capabilities, financial investment capacity, and institutional/regulatory environment have generally been included as essential evaluation elements in Industry 4.0 readiness frameworks (Adepoju and Aigbavboa, 2021; Menegon and da Silva Filho, 2023). Hermann *et al.* (2016) highlighted connectivity, virtualisation, and decentralised decision-making as fundamental pillars of preparedness. Singapore's Smart Industry Preparedness Index operationalises these across eight key aspects. While Ebekozien and Aigbavboa (2021) identified regulatory barriers to ICT procurement, resistance to change, and management inertia as the main structural impediments, Adepoju and Aigbavboa (2021) documented moderate levels of technology knowledge but critically low levels of practical training among construction professionals

in Nigeria. Together, these results show that Nigeria's deficiencies in building preparedness are multifaceted and accumulating, necessitating comprehensive, institutionally rooted repair techniques as opposed to technology-only initiatives.

2.3. Critical Success Factors for 4IR in Construction

According to Soni and Kodali (2016), critical success factors (CSFs) are those circumstances whose successful management is essential to accomplishing organisational 4IR adoption goals. Government policy and regulatory support (Schwab, 2017); top management commitment and digital leadership (Gledson *et al.*, 2024); ICT infrastructure availability (Lou *et al.*, 2019); workforce reskilling (Adepoju and Aigbavboa, 2021); supply chain collaboration (Osunsanmi *et al.*, 2020); financial access (Ebekozien and Aigbavboa, 2021); and organisational innovation culture (Demirkesen and Tezel, 2021). Although similar factors have been qualitatively identified in Nigeria by Osunsanmi *et al.* (2020) and Ezeokoli *et al.* (2016), no study has used the Relative Importance Index, a validated, widely published ranking method widely used in Scopus-indexed construction management research (Alaloul *et al.*, 2020), to confirm their relative priority in the Nigerian context. This divide prevents politicians and construction companies from setting evidence-based priorities.

2.4. 4IR Technologies and Project Performance

The performance of construction projects is often evaluated in terms of cost, time, and quality; client happiness, safety results, and sustainability are added in recent literature (Raja and Murali, 2020). The evidence base in emerging countries is still in its infancy, despite the fact that 4IR-performance links are well-established in developed markets. According to Castagnino *et al.* (2016), a large portion of the building productivity gap in developing nations may be linked to a lack of use of digital technology. In South Asian construction environments, Xiao *et al.* (2022) showed statistically significant increases in safety performance from IoT use. Nevertheless, this work covers a methodological vacuum by using multiple regression analysis to explore the association between composite 4IR preparedness, CSF management, and project performance outcomes in Nigeria.

2.5. Analytical Framework

Likert-scale survey instruments generate ordinal data: response categories are ranked but the intervals between them cannot be assumed equal (Hair *et al.*, 2019). Mean Item Score (MIS) and Relative Importance Index (RII) remain appropriate descriptive tools for ordinal data, as both summarise central tendency and relative ranking without assuming interval-level measurement (Ogbu and Olatunde, 2019). However, inferential techniques that assume interval/ratio measurement and multivariate normality, such as Pearson correlation and ordinary least squares (OLS) multiple regression, are not directly appropriate for ordinal Likert composites without strong justification (Hair *et al.*, 2019). This study therefore adopts a three-stage analytical framework suited to ordinal data: (i) Exploratory Factor Analysis (EFA) to empirically validate the latent dimensional structure of the readiness and CSF constructs before forming composite scores; (ii) Spearman's rank-order correlation (ρ), which assesses monotonic association without assuming linearity or interval measurement; and (iii) Ordinal Logistic Regression (OLR), which models the odds of a respondent reporting a higher performance category as a function of readiness and CSF predictors, without requiring the dependent variable to be continuous. This combination directly addresses concerns regarding the statistical fit of Pearson correlation and OLS regression to Likert-derived construction management survey data, while preserving the descriptive value of MIS and RII established in prior research (Alaloul *et al.*, 2020; Demirkesen and Tezel, 2021).

3. METHODOLOGY

Based on the positivist epistemological tradition that predominates in construction management research on technology adoption and project performance, a quantitative cross-sectional survey approach was adopted (Alaloul *et al.*, 2020). This methodology is suitable for assessing predictive correlations using statistical inference as well as for determining prevalence, distribution, and inter-construct linkages within a defined population at a certain moment in time (Borden and Abbott, 2011). Lagos (South-West), Abuja-FCT (North-Central), Akwa Ibom (South-South), Enugu (South-East), Kaduna (North-West), and Gombe (North-East) are the six geopolitical zones of Nigeria where the study was carried out, with one representative state in each zone. The target audience consisted of 669 construction companies classified as medium (50–200 people) and big (>200 employees) by the Bank of Industry (Ogbu and Olatunde, 2019). A total target sample of 535, spread over the six states, was obtained using stratified purposive sampling with strata calculated using Taro Yamane (1967) at a 5% significance level (Table 1 in Section 4 below). The following topics were covered in a structured five-section questionnaire: (A) respondent demographics and firm profile; (B) 4IR technology awareness and usage using a five-point Likert scale (1 = Very Low to 5 = Very High); (C) 4IR readiness across four dimensions using 24 validated items; (D) importance of 23 potential CSFs using a five-point importance scale; and (E) project performance outcomes. Three construction management academics attested to the content's authenticity. Clarity and face validity were verified by pilot testing (n = 30). Internal consistency was confirmed using Cronbach's Alpha ($\alpha > 0.70$ criterion). All data were analysed in SPSS Version 25. MIS (threshold ≥ 3.00) summarised awareness and readiness item responses, and $RII = \Sigma W/(A \times N)$ ranked the 23 CSF items. Prior to forming composite readiness scores, Exploratory Factor Analysis (EFA) with principal axis factoring and oblique (direct oblimin) rotation was conducted on the 24 readiness items to empirically determine the latent dimensional structure, with sampling adequacy assessed via the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. Mann-Whitney U-tests ($p \leq 0.05$) compared perceptions across firm size and geopolitical zone for the resulting factor scores. Spearman's rank-order correlation (ρ) assessed monotonic associations between readiness factors, the CSF priority score, and the four project performance outcomes. Ordinal Logistic Regression (OLR), estimated via the cumulative link (proportional odds) model, modelled each project performance outcome, retained in its original five-category ordinal form, as a function of the readiness factors and CSF priority score. The proportional odds assumption was tested for each model using the test of parallel lines, and multicollinearity among predictors was assessed via VIF (threshold < 5).

Table 1: Sample distribution by state and firm size

State	Zone	Population	Medium Firms (Sample)	Large Firms (Sample)	Total
Lagos	South-West	228	127	38	165
Abuja (FCT)	North-Central	182	107	32	139
Akwa Ibom	South-South	87	62	14	76
Enugu	South-East	47	34	7	41
Kaduna	North-West	62	44	12	56
Gombe	North-East	63	45	12	57
TOTAL		669	419	115	534

4. PRESENTATION AND DICUSSION OF RESULTS

4.1. Respondents Characteristics

Out of the 535 questionnaires that were issued, 498 were returned, resulting in a response rate of 93.1%, which is higher than the 75% threshold that is advised for construction survey research (Tan and Yeoh, 2011). A combined profile of all

respondents in six demographic and professional categories, geopolitical zone distribution and response rate, professional designation, educational background, years of experience, business type, and firm size is shown in Table 2. Specific conclusions are drawn from each category in the discussion that follows.

Table 2: Respondents' profile (n=498)

Category / Variable	Sub-category	Frequency	% of N
A. Geopolitical Zone and Response Rate	State	Returned	RR (%)
	Lagos (South-West)	159	96.4
	Abuja-FCT (North-Central)	131	94.2
	Akwa Ibom (South-South)	71	93.4
	Enugu (South-East)	39	95.1
	Kaduna (North-West)	53	94.6
	Gombe (North-East)	55	96.5
	Total	498	93.1
B. Professional Designation		Frequency	% of N
	Project Manager / Site Engineer	305	61.2
	Quantity Surveyor	112	22.5
	Senior Management / Director	81	16.3
	Total	498	100.0
C. Educational Qualification		Frequency	% of N
	Higher National Diploma (HND)	109	21.9
	B.Sc. / B.Tech.	211	42.4
	Postgraduate Diploma (PGD)	62	12.4
	Master of Science (M.Sc.)	96	19.3
	Ph.D.	20	4.0
	Total	498	100.0
D. Years of Professional Experience		Frequency	% of N
	1 – 5 years	62	12.4
	6 – 10 years	134	26.9
	11 – 15 years	148	29.7
	16 – 20 years	99	19.9
	Above 20 years	55	11.0
	Total (Mean = 14.6 yrs)	498	100.0
E. Firm Type		Frequency	% of N
	Indigenous Nigerian Firm	358	71.9
	Foreign-Affiliated Firm	140	28.1
	Total	498	100.0
F. Firm Size	Employees	Frequency	% of N
	Medium Firm	50 – 200	358
	Large Firm	201+	140
	Total		498

Note: RR = Response Rate. N = 498 usable responses from 535 distributed

A thorough professional and demographic summary of the 498 respondents that made up the successful research sample is given in Table 2. The data reveal a number of analytically significant patterns that directly affect the validity, representativeness, and interpretative breadth of the study's conclusions. The national response rate for geopolitical zone distribution (Panel A) was 93.1%, which is much higher than the minimum 75% level advised for construction survey research (Tan and Yeoh, 2011). All six states achieved response rates over 93%. This high response rate lowers the possibility of non-response bias skewing zone-level comparisons and improves the inferential reliability of the results. The stratified purposive sampling approach, which purposefully adjusted strata sizes to the relative density of construction business activity in each zone rather than mandating equal allocation, is seen in the rather uniform distribution across

zones, with 39 respondents in Enugu and 159 in Lagos. The increased prevalence of medium-sized and large construction companies in Nigeria's main economic hubs is well reflected in the bigger Lagos and Abuja samples (NBS, 2022).

According to the professional designation distribution (Panel B), the majority of respondents (61.2%) are project managers and site engineers, followed by quantity surveyors (22.5%) and senior management (16.3%). Project managers and site engineers are the most reliable sources of information about 4IR readiness obstacles and the effects of adoption or non-adoption at the site level because they have the most direct, day-to-day operational knowledge of technology deployment conditions and project performance outcomes. While the senior management cohort (16.3%) offers strategic and organisational readiness insights that supplement the operational perspectives of site personnel, the inclusion of quantity surveyors (22.5%) adds perspectives from professionals who regularly quantify project expenditure deviations to the cost performance data.

A total of 64.3% of respondents had first-degree or higher credentials (B.Sc./B.Tech: 42.4%; M.Sc.: 19.3%; Ph.D.: 4.0%), while 21.9% have Higher National Diplomas and 12.4% have Postgraduate Diplomas, according to the educational qualification profile (Panel C). This qualification distribution verifies that the sample is taken from the segment of Nigeria's construction workforce with formal education. This cohort is the most likely to have encountered 4IR technology concepts through industry engagement, professional training, and continuing education, making them the most trustworthy informants on awareness, readiness, and adoption intentions. A cohort with the analytical ability to offer nuanced, trustworthy evaluations of complex dimensions like institutional preparation and CSF prioritisation is further suggested by the presence of 23.3% postgraduate-qualified respondents (PGD, M.Sc., Ph.D). Since mid-career and senior professionals are more likely to have personally experienced the performance consequences of both adopting and failing to adopt emerging construction technologies, the experiential profile (Panel D), with a mean of 14.6 years and 70.6% of respondents having 6–20 years of industry experience, further supports the breadth and validity of the insights offered. In terms of firm characteristics (Panels E and F), the predominance of indigenous Nigerian firms (71.9%) and medium-sized firms (71.9%) reflects the true makeup of Nigeria's registered construction sector. This guarantees that the study's conclusions are ecologically valid and directly applicable to the majority of firms operating in the national market rather than being biased towards the minority of large, foreign-affiliated firms that might already have a greater capacity to adopt new technology.

4.2. 4IR Technologies Awareness and Usage

A consistent and statistically significant pattern can be seen in Table 3: whereas awareness levels are comparatively greater for a selection of 4IR technologies, actual use ratings for all twelve technologies evaluated are significantly lower than both the awareness numbers and the 3.00 criterion. Nigerian construction companies are in an awareness-adoption transition zone, where technologies are known in theory but not operationally integrated into project delivery practices, as demonstrated by this uniform sub-threshold usage pattern. The results are consistent with Ebekozien and Aigbavboa's (2021) conclusion that practical use of digital construction tools remained low throughout Nigerian construction sites, even during the COVID-19 era, when the efficiency reasons were strongest.

AI/machine learning (gap = 1.25), drones/UAVs (gap = 1.13), and 3D printing/additive manufacturing (gap = 1.34) have the biggest awareness-use gaps, which are calculated as the arithmetic difference between a technology's awareness MIS and its usage MIS. These large gaps indicate that while professional, media, and academic discourse have raised awareness of these technologies, major structural obstacles, such as the cost of purchasing equipment, the need for specialised knowledge, and unclear regulations, have prevented their practical application. Cloud computing, on the other hand, shows the smallest disparity (0.49), which is explained by the reduced entry costs,

the accessibility of commercial subscription platforms, and the pandemic-driven normalisation of remote collaboration tools even in Nigerian professional practice.

BIM is the most advanced technology on the adoption spectrum among Nigerian construction enterprises, as evidenced by its greatest awareness (MIS = 3.61) and utilisation (MIS = 2.74). This result is in line with Adepoju and Aigbavboa's (2021) conclusion that BIM has the longest history in Nigerian professional development and construction education programs, providing it an advantage in raising awareness and putting it into practice. Even so, BIM's utilisation score of 2.74 remains well below the significance level, suggesting that its adoption is limited and project-specific rather than institutionally ingrained. The rank reversal observed for cyber-physical systems, ranked 12th in awareness but 8th in usage, warrants attention: it suggests that firms using CPS are doing so as part of broader operational integration rather than as a standalone technology, which may reflect the embedded nature of CPS within broader IoT or automation investments.

Table 3: MIS for awareness, usage, and awareness-usage gap of 4IR technology

4IR Technology	Awareness MIS	Usage MIS	Gap	A. Rank	U. Rank	Sig.*
Building Information Modelling (BIM)	3.61	2.74	0.87	1	1	✓
Drones / UAVs	3.44	2.31	1.13	2	3	✓
Cloud Computing Platforms	3.38	2.89	0.49	3	2	✓
Artificial Intelligence (AI)	3.12	1.87	1.25	4	7	✓
Internet of Things (IoT)	3.05	1.92	1.13	5	6	✓
Big Data Analytics	2.89	1.71	1.18	6	9	✗
3D Printing / Additive Manufacturing	2.97	1.63	1.34	7	10	✗
Augmented / Virtual Reality	2.84	1.68	1.16	8	11	✗
Robotics and Automation	2.81	1.61	1.20	9	12	✗
Digital Twins	2.63	1.44	1.19	10	13	✗
Blockchain Technology	2.58	1.42	1.16	11	14	✗
Cyber-Physical Systems (CPS)	2.74	1.54	1.20	12	8	✗

Note: Scale: 1=Very Low to 5=Very High. Significance threshold: MIS ≥ 3.00 (✓ = aware; ✗ = not significant). A. Rank = Awareness Rank; U. Rank = Usage Rank.

The study's ensuing preparedness and performance analyses are directly impacted by the overall pattern in Table 3. The fact that usage scores consistently fall short of the 3.00 threshold indicates that 4IR adoption in Nigerian construction is a sector-wide issue rather than a firm-specific shortcoming, and that readiness and CSF-based interventions need to be planned to address the entire range of technologies rather than giving priority to specific tools. Sustained awareness-building campaigns are likely to lower adoption barriers over time, according to the correlation between higher awareness scores and smaller awareness-usage gaps (r = -0.61 across technologies). This finding bolsters the argument for structured professional development and curriculum reform as long-term adoption enablers.

4.3. 4IR Readiness Assessment

The results of Table 4, which offers the most geographically thorough 4IR readiness assessment of Nigerian construction companies to date in the published literature, are both in line with earlier theoretical predictions and highlight subtleties that earlier, geographically constrained studies were unable to identify. Most importantly, regardless of location, firm size, or industry specialism, all four readiness parameters fall below the 3.00 significance threshold at both the zonal and national levels, indicating that Nigerian construction companies remain ill-prepared for major 4IR implementation. Nigeria is well below the readiness criteria seen in similar middle-income economies in East and Southern Africa, with a national composite readiness score of 2.16, which indicates a mid-to-low preparedness level (Aigbavboa *et al.*, 2022).

Table 4: 4IR readiness assessment

Readiness Dimension	Lagos	Abuja	Akwa Ibom	Enugu	Kaduna	Gombe	National MIS	Rank
Technological Infrastructure	2.87	2.76	2.21	2.18	2.10	1.94	2.41	1
Human Capital / Skills	2.63	2.54	2.07	2.01	1.97	1.92	2.19	2
Financial Capacity	2.44	2.37	1.98	1.94	1.87	1.86	2.08	3
Institutional / Regulatory Env.	2.31	2.26	1.89	1.88	1.82	1.79	1.97	4
Composite Readiness Index	2.56	2.48	2.04	2.00	1.94	1.88	2.16	—

Note: Significance threshold: MIS ≥ 3.00. All dimensions and zones fall below the threshold. Composite = mean of four dimensions.

There is significant analytical value to the dimensional ranking: technical infrastructure (2.41) > human capital (2.19) > financial capacity (2.08) > institutional/regulatory environment (1.97). In line with the cloud computing usage finding in Table 3, the technological infrastructure's comparatively higher score demonstrates the gradual penetration of fundamental ICT technologies (cloud computing, project management software) into Nigerian construction enterprises. The most significant finding in this table, however, is that the institutional/regulatory environment is the weakest dimension (1.97). This suggests that the lack of a stable, incentive-driven regulatory environment will continue to limit the translation of investment into performance improvement, even if technology equipment is purchased and workforce training is provided. In line with Schwab's (2017) contention that 4IR diffusion in resource-constrained economies necessitates catalytic state action before private-sector adoption can scale, this finding directly supports the recommendation for a national Construction 4.0 Policy Framework as the highest-priority intervention.

A distinct metropolitan-periphery gradient that is both practically meaningful and statistically significant (Mann-Whitney U, $p < 0.05$) is shown by the geopolitical zone analysis. The concentration of digital infrastructure, human resources, financial services, and regulatory competence in Nigeria's main economic hubs is reflected in Lagos and Abuja's consistently high composite readiness ratings (2.56 and 2.48). Gombe (1.88) and Kaduna (1.94) had the lowest composite scores, which is in line with the North-East and North-West zones' lower densities of technically skilled construction workers and more constrained infrastructure endowment. This gradient has direct policy implications: rather than merely strengthening the current metropolitan advantage, a uniform national policy response is unlikely to be ideal, and geopolitically differentiated implementation strategies, such as more intensive capacity-building investment in peripheral zones, are required to achieve national industry transformation.

In all four readiness dimensions, large firms score significantly higher than medium firms ($p = 0.003$), which is in line with Menegon and da Silva Filho's (2023) conclusion that smaller construction companies encounter disproportionate readiness barriers due to limited capital budgets, thinner management layers, and more restricted access to professional development infrastructure. This finding suggests that policy and industry association interventions should be tailored to the limitations of medium-sized indigenous firms rather than being based on the capabilities of large contractors, since medium-sized firms make up 71.9% of the study sample and are representative of the industry's structural majority.

4.4. Critical Success Factors

The RII rankings of all fourteen evaluated CSFs are shown in Table 5, with eight attaining high-priority status (RII > 0.70) and six being categorised as moderate ($0.55 \leq$ RII < 0.70). A methodological strength that sets this research apart from other qualitative CSF identification studies, which are unable to quantify relative priority, is the RII scale, which is limited between 0 and 1, allowing direct comparison of variables' relative significance as evaluated by a diverse cross-national sample. Successful 4IR adoption in

Nigerian construction is a multi-domain challenge requiring simultaneous intervention across several organisational and institutional fronts, as evidenced by the eight high-priority CSFs forming a coherent cluster that spans regulatory, managerial, infrastructural, human capital, financial, collaborative, cultural, and technical governance dimensions.

Table 5: Critical success factors

Rank	Critical Success Factor	RII	MIS	SD	VR	Priority
1	Supportive government policy and regulatory framework	0.862	4.31	0.51	0.87	High
2	Top management commitment and digital leadership	0.848	4.24	0.55	0.84	High
3	Adequate digital and ICT infrastructure	0.836	4.18	0.58	0.81	High
4	Workforce reskilling and capacity development	0.822	4.11	0.62	0.79	High
5	Adequate and accessible funding/financing mechanisms	0.796	3.98	0.67	0.76	High
6	Stakeholder collaboration and supply chain integration	0.768	3.84	0.71	0.73	High
7	Organisational culture of digital innovation	0.744	3.72	0.74	0.71	High
8	Standards, protocols and interoperability frameworks	0.722	3.61	0.77	0.69	High
9	International partnerships and technology transfer	0.688	3.44	0.81	0.64	Moderate
10	Client awareness and demand for digital delivery	0.642	3.21	0.84	0.60	Moderate
11	University–industry research collaboration	0.631	3.16	0.87	0.58	Moderate
12	Project complexity and digital procurement strategies	0.614	3.07	0.89	0.55	Moderate
13	Availability of local technology vendors	0.597	2.99	0.91	0.52	Moderate
14	Risk management frameworks for digital projects	0.584	2.92	0.93	0.49	Moderate

Note: RII = ΣW/(A×N). High Priority: RII ≥ 0.70. Moderate: 0.55 ≤ RII < 0.70. SD = Standard Deviation. VR = Variation Ratio (SD/MIS).

The most significant conclusion in this table is the importance of government policy support (RII = 0.862, MIS = 4.31). It illustrates the structural reality that public-sector clients, Federal, State, and Local Government projects, dominate Nigerian construction spending, making government-provided fiscal incentives and regulatory stability a prerequisite rather than an enabler of industry-wide digital transformation. This result directly supports the suggestion that a national Construction 4.0 Policy Framework, akin to Singapore's Smart Industry Readiness Index program or Germany's Industrie 4.0 initiative, be developed as soon as possible. It also supports Schwab's (2017) contention that catalytic state intervention is necessary for developing-country 4IR diffusion. This item's low variation ratio (VR = 0.87) also shows that respondents strongly agree on its significance, indicating that sampling error is unlikely to be the cause of this result.

The second-place ranking of top management commitment (RII = 0.848) supports Gledson *et al.*'s (2024) conclusion that the best internal predictor of Construction 4.0 transformation in construction companies is digital leadership. The practical implication is straightforward: companies whose boards and senior management actively support digital transformation will outperform those that assign it to IT departments or treat it as a compliance exercise. In Nigeria, 4IR adoption is more of a leadership challenge than a technology procurement challenge. Because it links Nigeria's technical and higher education system, especially polytechnics that operate under NBTE regulations, to the readiness gap, workforce reskilling (RII = 0.822), which ranks fourth, is analytically significant. Reskilling will continue to be a reactive, ad hoc, and costly industry burden rather than an organised human capital development pipeline if the construction crew is not taught on 4IR technologies as a regular part of professional formation.

International technology transfer alliances, client awareness, university-industry collaboration, and risk management frameworks are among the moderate-priority CSFs (RII < 0.70) that are not insignificant. Instead, when the high-priority fundamental CSFs

are addressed, they serve as enabling circumstances that might hasten adoption. Their lower RII ratings could be a reflection of respondents' belief that, although desired, these variables are either dependent on earlier progress on higher-ranked CSFs or are now outside the immediate control of particular enterprises. Particular attention should be paid to the availability of local technology vendors ranking 13th (RII = 0.597, MIS = 2.99, the only item falling below 3.00). This indicates that respondents believe local 4IR technology providers currently underserve the Nigerian market, which supports the argument for international partnerships and technology transfer programs as medium-term strategic investments.

4.5. Latent Structure, Correlation, and Predictive Analysis of 4IR Readiness, CSFs, and Project Performance

The analyses in this section were designed specifically for the ordinal, Likert-derived nature of the survey data. Three sequential procedures were applied: first, Exploratory Factor Analysis (EFA) was used to empirically validate the latent dimensional structure of the 24 readiness items, rather than assuming the four a-priori dimensions in Table 4 are empirically distinct; second, Spearman's rank-order correlation (ρ) assessed monotonic association between the resulting readiness factors, the CSF Priority Score, and the four project performance outcomes; and third, Ordinal Logistic Regression (OLR) modelled each performance outcome, retained in its original five-category ordinal form, as a function of the readiness factors and CSF Priority Score. This sequence avoids the assumptions of interval-level measurement and multivariate normality required by Pearson correlation and OLS regression, while preserving inferential rigour.

4.5.1 Exploratory Factor Analysis of 4IR Readiness Items

Principal axis factoring with direct oblimin rotation was applied to the 24 readiness items. Sampling adequacy was confirmed (Kaiser-Meyer-Olkin = 0.881, exceeding the 0.60 minimum), and Bartlett's Test of Sphericity was significant ($\chi^2(276) = 5{,}842.17$, $p < 0.001$), confirming that the item correlation matrix was suitable for factor analysis. Contrary to the four-dimensional structure assumed in Table 4, the EFA extracted a two-factor solution based on the Kaiser criterion (eigenvalues > 1) and confirmed by scree plot inspection, jointly explaining 68.4% of total variance.

Table 6: Exploratory Factor Analysis (Rotated Factor Loadings for 4IR Readiness Items)

Readiness Item Cluster (Representative Items)	Factor 1: Operational Readiness	Factor 2: Institutional Readiness	Communality (h^2)
ICT hardware and software availability	0.812	0.184	0.701
Internet connectivity and bandwidth adequacy	0.788	0.201	0.663
Staff digital literacy and technical competence	0.764	0.227	0.635
Availability of trained BIM/CAD operators	0.741	0.198	0.589
Firm-level capital budget for technology adoption	0.718	0.256	0.581
Access to equipment financing/credit facilities	0.689	0.241	0.534
Management's willingness to fund pilot technology projects	0.671	0.312	0.547
Existence of national digital construction policy	0.211	0.831	0.733
Enforcement of BIM/digital standards by regulators	0.198	0.807	0.690
Professional certification requirements for digital skills	0.234	0.779	0.661
Government incentives for technology adoption	0.227	0.762	0.633
Building code provisions for digital construction methods	0.246	0.741	0.610
KMO = 0.881	Bartlett's $\chi^2(276) = 5{,}842.17$, $p < .001$	Variance Explained = 68.4%	Factor Correlation r = 0.49

Note: Extraction: Principal Axis Factoring; Rotation: Direct Oblimin ($\delta = 0$). Loadings < 0.20 suppressed. 12 of 24 items shown as representative.

Table 6 presents the rotated factor loadings for the readiness item set. Two clear factors emerged. Factor 1, labelled Operational Readiness, comprises items relating to ICT infrastructure, digital literacy, equipment availability, and firm-level financial capacity for technology adoption, effectively merging the technological infrastructure, human capital, and financial capacity dimensions that were treated as separate constructs in Table 4. Factor 2, labelled Institutional Readiness, comprises items relating to national policy, regulatory enforcement, certification, incentives, and building code provisions, corresponding closely to the institutional/regulatory environment dimension in Table 4. All items loaded above 0.65 on their primary factor with cross-loadings below 0.32, and communalities exceeded 0.50 for all retained items, indicating a well-defined factor structure.

This finding has direct methodological and substantive significance. Methodologically, it demonstrates that the four a-priori readiness dimensions assumed in earlier descriptive analysis (Table 4) are not empirically distinct in the Nigerian sample: technological, human capital, and financial readiness covary so strongly that they form a single latent Operational Readiness construct, while only the institutional/regulatory dimension stands apart as a distinct factor. This is consistent with the relatively high inter-item correlations observed across the technological, human capital, and financial readiness items during preliminary screening, and indicates that entering all four dimensions as separate predictors in a regression model, as in conventional approaches, would have introduced redundant, highly collinear constructs. Substantively, the two-factor structure suggests that 4IR readiness in Nigerian construction is best understood as a function of two distinct levers: firm-level operational capacity (which firms can address through their own investment decisions) and the external institutional environment (which requires policy intervention). The moderate inter-factor correlation ($r = 0.49$) confirms the factors are related but distinct, justifying their use as separate predictors in subsequent analyses. Factor scores for Operational Readiness and Institutional Readiness were computed for each respondent and carried forward as the readiness predictors in Sections 4.5.2 and 4.5.3.

4.5.2 Spearman's Rank-Order Correlation Analysis

Spearman's rank-order correlation (ρ) was computed between the two readiness factors, the CSF Priority Score, and the four project performance outcomes. Spearman's ρ was selected over Pearson's r because all variables are derived from ordinal Likert-scale items, and ρ assesses monotonic association without requiring linearity or interval-level measurement, directly addressing the measurement-level concern that motivated the present re-analysis.

Table 7: Spearman's Rank-Order Correlation Matrix (Readiness Factors, CSF Priority Score, and Performance Outcomes)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Operational Readiness	1.00						
(2) Institutional Readiness	0.49**	1.00					
(3) CSF Priority Score	0.41**	0.46**	1.00				
(4) Cost Performance	0.34**	0.38**	0.29**	1.00			
(5) Schedule Performance	0.31**	0.35**	0.27**	0.61**	1.00		
(6) Quality Performance	0.37**	0.42**	0.32**	0.64**	0.58**	1.00	
(7) Client Satisfaction	0.33**	0.39**	0.30**	0.59**	0.55**	0.62**	1.00

Note: ** $p < 0.01$ (two-tailed). Spearman's ρ reported throughout; appropriate for ordinal Likert-derived variables.

Table 7 presents the Spearman correlation matrix, providing an initial assessment of monotonic association before the ordinal regression analysis. Both readiness factors and the CSF Priority Score are positively and significantly correlated with all four performance outcomes ($\rho = 0.27–0.42$, $p < 0.01$), providing a first inferential indication that higher readiness and CSF prioritisation are associated with better project performance ratings. Institutional Readiness shows consistently stronger correlations with performance outcomes ($\rho = 0.35–0.42$) than Operational Readiness ($\rho = 0.31–0.37$), foreshadowing its stronger role in the ordinal regression models that follow.

The inter-correlation between the two readiness factors ($\rho = 0.49$) is moderate and consistent with the EFA finding of related but empirically distinct constructs (Table 6); this value is well below the 0.80 threshold that would indicate redundancy. The CSF Priority Score correlates most strongly with Institutional Readiness ($\rho = 0.46$), consistent with the observation that several top-ranked CSFs (government policy, standards and interoperability frameworks) are themselves institutionally anchored. Among performance outcomes, cost and quality performance show the strongest intercorrelation ($\rho = 0.64$), reflecting the established empirical relationship in construction project management between quality management investment and downstream cost savings through reduced rework and defect rectification. All reported correlations are interpreted as monotonic associations rather than linear relationships, consistent with the ordinal measurement level of the underlying variables.

4.5.3 Ordinal Logistic Regression Analysis

Ordinal Logistic Regression (OLR), estimated via the cumulative link (proportional odds) model, was used to model each of the four project performance outcomes, retained in their original five-category ordinal form (1 = Very Poor to 5 = Excellent), as a function of Operational Readiness, Institutional Readiness, and the CSF Priority Score. OLR estimates the odds that a respondent's performance rating falls at or above a given category, expressed as odds ratios (OR); an OR > 1 indicates that higher values of the predictor are associated with greater odds of a higher performance rating. The proportional odds assumption, that predictor effects are constant across all category thresholds, was tested for each model using the test of parallel lines, and multicollinearity among predictors was assessed via VIF.

Table 8: Ordinal Logistic Regression Cost Performance

Predictor	**Estimate (B)**	**SE**	**Odds Ratio (Exp B)**	**Wald χ^2**	**Sig.**
Operational Readiness	0.512	0.097	1.668	27.84	.000
Institutional Readiness	0.612	0.101	1.844	36.71	.000
CSF Priority Score	0.481	0.108	1.617	19.85	.000
−2 Log-Likelihood = 1142.6	Model $\chi^2(3) = 138.42$, $p < .001$		Nagelkerke $R^2 = 0.287$	Test of Parallel Lines: $\chi^2(9) = 11.84$, $p = .222$	
Max VIF = 1.39	Goodness-of-Fit (Pearson) $p = .184$		—	—	

Note: DV = Cost Performance (5-point ordinal). Link function = Logit. Non-significant parallel lines test ($p > .05$) supports the proportional odds assumption.

Table 8 reports the ordinal logistic regression model for cost performance. The overall model is statistically significant ($\chi^2(3) = 138.42$, $p < 0.001$), and the non-significant test of parallel lines ($\chi^2(9) = 11.84$, $p = 0.222$) confirms that the proportional odds assumption holds; the effect of each predictor on the odds of a higher cost performance rating is consistent across all rating thresholds. All three predictors are statistically significant. Institutional Readiness shows the largest effect (OR = 1.844; $p < 0.001$): for each one-unit increase in the Institutional Readiness factor score, the odds of a respondent reporting a higher cost performance category increase by approximately 84%, holding other predictors constant. Operational Readiness (OR = 1.668) and the CSF Priority Score (OR = 1.617) show smaller but still substantial and statistically significant effects. The Nagelkerke R^2 of 0.287 indicates a moderate level of explained variation in

the ordinal outcome, appropriate for pseudo-R^2 measures in ordinal regression, and the maximum VIF of 1.39 confirms multicollinearity is not a concern.

The primacy of Institutional Readiness as a predictor of cost performance reinforces the CSF findings in Table 5, where government policy support was rated the highest-priority success factor. Both analyses converge on the conclusion that the regulatory and governance environment, procurement frameworks, contract enforcement, anti-corruption measures, and digital standards exert the strongest influence on a firm's capacity to translate 4IR investment into improved cost outcomes, providing methodologically robust support for prioritising regulatory reform as a cost-performance intervention.

Table 9: Ordinal Logistic Regression (Schedule Performance)

Predictor	Estimate (B)	SE	Odds Ratio (Exp B)	Wald χ^2	Sig.
Operational Readiness	0.467	0.096	1.595	23.62	.000
Institutional Readiness	0.571	0.099	1.770	33.21	.000
CSF Priority Score	0.438	0.106	1.550	17.07	.000

−2 Log-Likelihood = 1187.3	Model $\chi^2(3)$ = 121.95, $p < .001$	Nagelkerke R^2 = 0.261	Test of Parallel Lines: $\chi^2(9) = 13.02$, $p = .163$
Max VIF = 1.39	Goodness-of-Fit (Pearson) $p = .211$	—	—

Note: DV = Schedule Performance (5-point ordinal). Non-significant parallel lines test ($p > .05$) supports the proportional odds assumption.

Table 9 extends the OLR analysis to schedule performance. The model is statistically significant ($\chi^2(3) = 121.95$, $p < 0.001$) with the proportional odds assumption satisfied ($p = 0.163$). Institutional Readiness again shows the largest effect (OR = 1.770; $p < 0.001$), followed by Operational Readiness (OR = 1.595) and the CSF Priority Score (OR = 1.550), all statistically significant. The mechanisms linking 4IR readiness to schedule performance are well documented: IoT-based real-time site monitoring reduces reactive response times, AI-driven scheduling optimises resource sequencing, drone-based progress tracking replaces manual surveying, and cloud-based platforms enable concurrent design review and procurement processes (Kang *et al.*, 2016; King, 2018). The significant effect of Operational Readiness alongside Institutional Readiness suggests that schedule benefits depend on both the availability of enabling technology and the regulatory environment within which scheduling decisions are made and enforced.

Table 10: Ordinal Logistic Regression (Quality Performance)

Predictor	Estimate (B)	SE	Odds Ratio (Exp B)	Wald χ^2	Sig.
Operational Readiness	0.549	0.095	1.732	33.43	.000
Institutional Readiness	0.650	0.099	1.916	43.07	.000
CSF Priority Score	0.503	0.105	1.654	23.00	.000

−2 Log-Likelihood = 1098.4	Model $\chi^2(3)$ = 162.77, $p < .001$	Nagelkerke R^2 = 0.329	Test of Parallel Lines: $\chi^2(9) = 10.46$, $p = .315$
Max VIF = 1.39	Goodness-of-Fit (Pearson) $p = .267$	—	—

Note: DV = Quality Performance (5-point ordinal). Non-significant parallel lines test ($p > .05$) supports the proportional odds assumption.

Table 10 presents the model for quality performance, which yields the highest Nagelkerke R^2 (0.329) and the largest model χ^2 (162.77, $p < 0.001$) of the four outcomes, the strongest model in the study. Institutional Readiness again shows the largest effect (OR = 1.916; $p < 0.001$): a one-unit increase in Institutional Readiness is associated with approximately a 92% increase in the odds of a higher quality performance rating. Operational Readiness (OR = 1.732) and the CSF Priority Score (OR = 1.654) are both

significant. Institutional Readiness encompasses the enforcement of building codes, professional certification requirements, and quality-related regulatory oversight, mechanisms that directly govern quality production on Nigerian construction sites. This finding implies that strengthening regulatory enforcement of existing quality standards, independent of new technology procurement, is likely to yield measurable quality improvements, with 4IR-enabled quality monitoring (IoT sensors, drone inspections, AI-driven defect detection) compounding those gains when embedded within a strengthened regulatory framework.

Table 11: Ordinal Logistic Regression (Client Satisfaction)

Predictor	Estimate (B)	SE	Odds Ratio (Exp B)	Wald χ^2	Sig.
Operational Readiness	0.498	0.096	1.646	26.95	.000
Institutional Readiness	0.601	0.100	1.824	36.19	.000
CSF Priority Score	0.466	0.107	1.594	18.97	.000

−2 Log-Likelihood = 1132.9	Model $\chi^2(3) = 145.18$, $p < .001$	Nagelkerke $R^2 = 0.301$	Test of Parallel Lines: $\chi^2(9) = 12.37$, $p = .193$
Max VIF = 1.39	Goodness-of-Fit (Pearson) $p = .228$	—	—

Note: DV = Client Satisfaction (5-point ordinal). Non-significant parallel lines test ($p > .05$) supports the proportional odds assumption.

Table 11 presents the model for client satisfaction, a composite outcome integrating client perceptions across cost, schedule, quality, and responsiveness. The model is statistically significant ($\chi^2(3) = 145.18$, $p < 0.001$; Nagelkerke $R^2 = 0.301$) with the proportional odds assumption satisfied ($p = 0.193$). Institutional Readiness remains the strongest predictor (OR = 1.824; $p < 0.001$), theoretically coherent given that client satisfaction in public construction is particularly sensitive to procurement irregularities, contract variation disputes, and regulatory compliance failures, institutional rather than purely technical phenomena. The significant effect of Operational Readiness (OR = 1.646) suggests that clients value the visible deployment of technologies, BIM-enabled visualisation, drone progress reporting, digital communication platforms, as signals of professional competence, even where full 4IR integration has not been achieved.

Table 12: Summary of Ordinal Logistic Regression Models (Odds Ratios and Model Fit)

Performance Outcome	OR Operational R.	OR Institutional R.	OR CSF Score	Nagelkerke R^2	Sig.
Cost Performance	1.668**	1.844**	1.617**	0.287	p<.001
Schedule Performance	1.595**	1.770**	1.550**	0.261	p<.001
Quality Performance	1.732**	1.916**	1.654**	0.329	p<.001
Client Satisfaction	1.646**	1.824**	1.594**	0.301	p<.001

Note: ** $p < 0.01$. OR = Odds Ratio (Exp B). R. = Readiness. All proportional odds assumptions satisfied ($p > 0.05$). Max VIF = 1.39 across all models.

Table 12 consolidates the four ordinal logistic regression models, enabling cross-outcome comparison. Three overarching inferences emerge. First, Institutional Readiness consistently records the highest odds ratio across all four performance outcomes (OR range: 1.770–1.916), confirming it as the most influential readiness factor for project performance in the Nigerian context, a finding that is robust to the change in analytical method from OLS to ordinal logistic regression, and consistent with the Spearman correlations in Table 7, where Institutional Readiness showed the strongest associations with performance outcomes. Second, the CSF Priority Score is a statistically significant predictor in every model (OR range: 1.550–1.654), confirming that CSF management

exerts an influence on performance odds independent of readiness factor scores. Third, the quality performance model achieves the highest Nagelkerke R^2 (0.329) and the largest model χ^2, indicating that quality outcomes are most systematically associated with the readiness-CSF nexus, prioritising quality management as the area where 4IR adoption investments are likely to yield the most measurable returns. Across all four models, the proportional odds assumption was satisfied, and multicollinearity was minimal (max VIF = 1.39), supporting the validity and robustness of the ordinal logistic regression approach for this dataset.

4.6. DISCUSSION OF RESULTS

The study's findings advance understanding of Construction 4.0 in the Nigerian context across three intersecting analytical planes, each strengthened by the use of analytical techniques appropriate to ordinal survey data. First, the national readiness assessment establishes the most geographically comprehensive diagnostic baseline yet produced in the Nigerian 4IR construction literature. The finding that all four a priori readiness dimensions fall below the 3.00 significance threshold at every geopolitical zone, with institutional/regulatory readiness weakest nationally (MIS = 1.97), confirms that the adoption gap is structurally systemic. The subsequent EFA finding that these four dimensions collapse into two empirically distinct factors, Operational Readiness and Institutional Readiness, sharpens this diagnosis considerably: it is not that firms face four separate readiness deficits requiring four separate interventions, but that they face one firm-level operational capacity deficit and one external institutional deficit, the latter being consistently the more influential of the two across every performance outcome modelled.

Second, the RII analysis provides Nigeria's first rigorously ranked CSF evidence base. The dominance of government policy support (RII = 0.862) reflects the structural reality of public-sector-dominated construction procurement, where policy stability and fiscal incentives are the ultimate arbiters of investment confidence. The strong ranking of workforce reskilling (RII = 0.822) directly implicates technical education institutions, including polytechnics operating under NBTE standards, in the current readiness deficit. The CSF Priority Score's significant independent contribution in every ordinal regression model (OR range: 1.550–1.654) confirms that CSF management is not merely a proxy for readiness but an independently actionable lever, providing a sequenced prioritisation that directs scarce institutional resources to the factors with the greatest leverage.

Third, the ordinal logistic regression results provide statistically robust evidence, appropriate to the ordinal nature of the underlying performance ratings, that higher 4IR readiness and CSF prioritisation are associated with significantly greater odds of higher project performance ratings across all four dimensions. Institutional Readiness consistently shows the largest odds ratios (1.770–1.916), with the quality performance model showing both the largest effect (OR = 1.916) and the best overall fit (Nagelkerke R^2 = 0.329). This has direct procurement policy implications: public project owners who embed 4IR readiness criteria, particularly criteria reflecting institutional/regulatory engagement, in contractor pre-qualification are likely to see measurable improvements in the quality outcomes of the resulting contractor pool. Because all proportional odds assumptions were satisfied and multicollinearity was minimal (max VIF = 1.39) across all four models, these findings rest on a statistically defensible foundation appropriate to the ordinal, Likert-derived nature of the survey instrument, directly addressing the measurement-level concerns that motivated this analytical re-specification..

5. CONCLUSION

This study addressed three persistent gaps in the Construction 4.0 literature for developing economies: the absence of a nationally representative 4IR readiness diagnostic for Nigerian construction firms, the lack of rigorously ranked empirical evidence on the critical success factors governing adoption, and the absence of models linking readiness and CSF management to project performance using techniques appropriate to ordinal

survey data. By deploying a stratified cross-sectional survey across Nigeria's six geopolitical zones and applying an integrated MIS-RII-EFA-Spearman-OLR analytical approach, the findings are simultaneously diagnostic, methodologically robust, and generalisable to comparable construction environments across sub-Saharan Africa and the broader developing world.

The most significant discovery is that 4IR readiness remains consistently below the significance threshold across all assessed dimensions and all six geopolitical zones, with institutional and regulatory readiness recording the lowest national score (MIS = 1.97). Exploratory Factor Analysis subsequently revealed that this apparent four-dimensional deficit is empirically structured as two distinct latent constructs, Operational Readiness and Institutional Readiness, jointly explaining 68.4% of variance in the readiness item set, with Institutional Readiness consistently the stronger of the two in predicting project performance outcomes. This indicates that the adoption gap is fundamentally a governance challenge rather than solely a deficiency in technology acquisition or workforce skills: firm-level investment alone cannot drive industry-wide transformation in the absence of a coherent national Construction 4.0 regulatory framework, enforced quality standards, and digital procurement rules. The RII analysis reinforces this conclusion, identifying government policy support (RII = 0.862) as the highest-priority critical success factor, followed by top management commitment (RII = 0.848), digital infrastructure (RII = 0.836), and workforce reskilling (RII = 0.822), with eight CSFs overall attaining high-priority status (RII $\geq$ 0.70) across regulatory, managerial, infrastructural, financial, and collaborative domains.

The Spearman correlation and ordinal logistic regression analyses provide statistically robust confirmation, appropriate to the ordinal nature of the underlying data, that both readiness factors and CSF prioritisation are significantly associated with higher odds of improved project performance across cost, schedule, quality, and client satisfaction (odds ratios 1.55–1.92, $p < 0.001$ throughout), with Institutional Readiness the consistently strongest predictor and quality performance the most strongly and reliably predicted outcome (Nagelkerke $R^2 = 0.329$). All models satisfied the proportional odds assumption and showed minimal multicollinearity (max VIF = 1.39), lending confidence to the validity of these findings. The clear metropolitan-periphery readiness gradient identified, with Lagos and Abuja scoring highest and Gombe and Kaduna lowest, further indicates that differentiated, zone-specific strategies are required, since uniform national policy responses risk exacerbating existing spatial disparities in 4IR readiness.

The study extends Schwab's (2017) framework with sector-specific, methodologically robust quantification, demonstrating that institutional readiness is the critical factor mediating the relationship between 4IR adoption and project performance in developing-economy construction. Its methodological contribution is a replicable MIS-RII-EFA-Spearman-OLR analytical template explicitly suited to the ordinal survey data generated by 4IR adoption research, applicable to comparable country contexts across South Asia and sub-Saharan Africa. Its practical contribution is an evidence-based, prioritised roadmap for academic institutions, construction firms, and regulatory agencies: policymakers are encouraged to develop a national Construction 4.0 Policy Framework, mandate BIM for public projects exceeding defined contract thresholds, and establish a national certification programme for digital construction skills. Future research should pursue longitudinal designs to track readiness trajectories as such interventions are implemented, and should extend this analytical approach to small construction enterprises, which constitute the structural majority of Nigeria's construction industry and remain its least-studied segment.

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