Framework for Adopting Industry 5.0 in the Construction Sector, South-South Region of Nigeria

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Abstract: Industry 5.0 holds transformative potential precisely by placing human capital, local knowledge, and contextual resilience at the center of the modernisation. Still, there is little or no agenda context-specific implementation framework capable of guiding construction stakeholders. The study aims to develop a Framework for the Implementation of Industry 5.0 (FII5.0) in the Nigerian construction industry. Specific objectives include assessing Industry 5.0 awareness, examining adoption drivers and barriers, establishing effective implementation strategies, and developing a contextually validated implementation framework. A positivist, cross-sectional survey design targeted 508 registered construction professionals in the South-South region of Nigeria. Data collected were collected through structured Likert-scale questionnaires, and 258 valid responses were retrieved. Findings revealed that 93% of the fifteen Industry 5.0 components achieved moderate-to-high awareness, with economic inclusion and community-driven infrastructure as the first and second highest ranked. The results further showed that Rivers State exhibits universally higher awareness than Akwa Ibom State. The most significant drivers were identified as global sustainability goals and climate change adaptation needs, while the significant barriers were high investment costs and inadequate digital infrastructure, with Akwa Ibom State experiencing greater severity. Monitoring and feedback mechanisms and upskilling programs ranked as the highest-priority strategies. FII5.0, an Integration Definition for Function Modelling (IDEF0)-modelled seven-phase cyclical framework validated by ten domain experts (DOI score: 4.24/5.00), projects 20–40% productivity gains and 70% delay reductions. The study recommends prioritising digital infrastructure investment, targeted upskilling, and public-private partnerships to accelerate Industry 5.0 adoption. It advances diffusion theory through ecosystemic moderator evidence, offering the first context-specific Industry 5.0 blueprint for sub-Saharan Africa's construction sector.

Keyword: *Industry 5.0, Integration Definition for Function Modelling (IDEF0), Nigeria, and Construction Sector.*

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I. INTRODUCTION

The construction industry occupies a strategically critical position in Nigeria's socioeconomic architecture, functioning simultaneously as a driver of gross domestic product (GDP) growth, a generator of large-scale employment, and the principal mechanism through which the country's infrastructure deficit is addressed (Ofori, 2012; Ogundeji, 2025). As one of the most resource-intensive and labour-absorbing sectors of the Nigerian economy, the construction industry contributed between 3.4% and 4.0% of real GDP in 2024, sustaining that contribution at approximately 3.6% into 2025, propelled by public expenditure on housing, roads, and critical infrastructure (Oxford Business Group, 2024; Trading Economics, 2025). In the South-South geopolitical zone of Nigeria, encompassing oil-producing states such as Akwa Ibom, Rivers, Delta, Bayelsa, Cross River, and Edo, the construction sector draws additional impetus from petroleum revenues to fund large-scale infrastructure projects, including refineries, transportation networks, and industrial facilities (Rimtip *et al.*, 2025; Oyedele, 2016). Despite this economic centrality, Nigeria's construction sector is beset by a persistent and deepening infrastructure deficit that directly undermines its developmental role. World Bank projections estimate that the country requires approximately $3 trillion in infrastructure investment over a 30-year horizon to close its infrastructure gap. However, only 30% of its 200,000 km road network is currently paved, and federal infrastructure allocations of ₦1.32 trillion in 2024, representing merely 5% of the national budget, fall staggeringly short of the estimated $100 billion in annual needs (Abass, 2025). This gap is further complicated by the persistence of abandoned megaprojects and environmental degradation arising from decades of hydrocarbon extraction, conditions that constrain construction sector performance and suppress sustainable economic diversification (Ezeokoli *et al.*, 2021; Todo *et al.*, 2025).

Historically, successive industrial revolutions have provided the transformative frameworks through which construction industries globally have modernised their processes, enhanced productivity, and improved the quality of built environments. The First Industrial Revolution (IR) introduced steam-powered mechanisation to construction processes; the Second IIR brought electrification and mass-production capabilities; the Third IR enabled automation, computerisation, and early digital workflows; and the Fourth Industry 4.0 integrated cyber-physical systems, the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) into smart, connected construction environments (Schwab, 2016; Kagermann *et al.*, 2013). These successive transitions have progressively transformed construction from a purely manual, labour-intensive undertaking into an increasingly data-driven, technology-enhanced enterprise, particularly in advanced industrialised economies. However, Industry 4.0's predominant orientation toward automation, machine connectivity, and digital efficiency has drawn significant scholarly criticism for subordinating the human element within industrial systems, marginalising workers rather than empowering them, and prioritising efficiency over environmental sustainability and societal resilience (Brettel *et al.*, 2014; Stock and Seliger, 2016). In response to these limitations, the European Commission formally articulated the conceptual foundations of Industry 5.0, a paradigm that reorients industrial systems toward three interlocking pillars: human-centricity, environmental sustainability, and systemic resilience (European Commission, 2021). Unlike its predecessor, Industry 5.0 envisions human workers and intelligent machines as complementary co-creators rather than competitors, with advanced technologies such as collaborative robots (cobots), digital twins, AI-driven analytics, and smart material systems functioning as augmentative tools that amplify human creativity, preserve artisanal knowledge, and embed circularity and ecological stewardship into industrial processes (Musarat *et al.*, 2023; Tunji-Olayeni *et al.*, 2024).

In the context of Nigeria's construction sector, Industry 5.0 holds transformative potential precisely by placing human capital, local knowledge, and contextual resilience at the centre of the modernisation agenda. The South-South region is vulnerable to climate hazards, including coastal flooding, soil erosion, and environmental pollution, rendering Industry 5.0's sustainability and resilience pillars directly germane to the imperatives of localised infrastructure development (Tunji-Olayeni *et al.*, 2024). Nevertheless, scholarly engagement with Industry 5.0 in the Nigerian construction context remains nascent and geographically incomplete. Existing studies have offered foundational assessments of Industry 5.0 awareness among construction professionals in Nigeria (Rimtip *et al.*, 2025), highlighted digital infrastructure constraints and skills gaps as primary barriers to fourth and fifth industrial revolution adoption (Ezeokoli *et al.*, 2021; Onyia, 2025), and examined broader patterns of digital transformation in sub-Saharan Africa's built environment (Ikudayisi *et al.*, 2023). However, these contributions have not produced a validated, context-specific implementation framework capable of guiding construction stakeholders through a structured, phased adoption of Industry 5.0 principles, particularly within the South-South geopolitical zone. The study is designed to address the gap by developing an empirically grounded and regionally calibrated Framework for the Implementation of Industry 5.0 (FII5.0) in the Nigerian construction sector. To achieve this aim, the objectives are considered: (a) investigate the level of awareness of Industry 5.0 in project delivery among construction professionals; (b) examine the drivers and barriers facilitating the adoption of Industry 5.0 in the study area; (c) establish strategies for the effective adoption of Industry 5.0; and develop a framework for the implementation of Industry 5.0 in the construction industry.

II. REVIEW OF RELATED LITERATURE

➢ *Key Aspects of Knowledge Base and Awareness in Industry 5.0*

Industry 5.0 marks a paradigm shift by prioritizing human-centric, sustainable, and resilient industrial systems, necessitating a robust knowledge base and awareness to facilitate its adoption. In the context of South-South Nigeria’s construction sector, understanding these aspects is crucial for aligning technological advancements with regional needs and challenges. This section explores five key aspects of Industry 5.0’s knowledge base and awareness: human-machine collaboration, sustainability focus, resilience, complementing Industry 4.0 through critical thinking, and technology integration with ethical/societal concerns, with their sub-factors relevant to the study’s focus. Human-machine collaboration is a cornerstone of Industry 5.0, emphasising the synergy between human creativity and advanced technologies to enhance productivity and innovation (Xu *et al.*, 2021). In Nigeria’s construction sector, this collaboration can transform traditional practices by empowering local artisans. Awareness of technologies like collaborative robots (cobots) and digital twins is limited among South-South Nigeria’s workforce, with only 5% of professionals trained in advanced tools (Olugboyega *et al.*, 2023). Awareness campaigns can highlight how technology complements rather than replaces local expertise, fostering adoption. In the Niger Delta, where 65% of workers feel excluded from technology-driven projects, this knowledge can drive inclusive practices, enhancing employability and community cohesion (Aghimien et al., 2020).

Industry 5.0 places sustainability at its core, requiring a knowledge base that prioritizes ecological responsibility in construction, especially in ecologically fragile regions (Breque *et al.*, 2021). Resilience in Industry 5.0 focuses on creating systems that withstand socio-economic and environmental shocks (Nahavandi, 2019). In South-South Nigeria, where unemployment is 20% above the national average, awareness of Industry 5.0’s potential to employ local youth can strengthen economic resilience (Oyedele, 2016). Critical thinking informs the design of solutions that complement Industry 4.0, such as using IoT for safety and reducing accidents by 25% while prioritizing human roles (Alaloul *et al.*, 2023). Knowledge of Industry 5.0’s emphasis on human creativity encourages critical thinking to innovate beyond Industry 4.0’s efficiency focus. Industry 5.0 integrates technology with ethical and societal

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considerations, requiring a knowledge base that ensures advancements benefit communities without causing harm (European Commission, 2021). Awareness of ethical implications is important; for example, ensuring cobots do not replace but assist workers prevents job losses, where automation has already marginalized 65% of workers (Aghimien *et al.*, 2020). Awareness campaigns can promote technologies that respect these values, reducing resistance and enhancing societal acceptance (Wang et al., 2019). Table 1 reveals the reviewed measures for assessing awareness of Industry 5.0 in project delivery.

Table 1 Reviewed the Measures for Assessing Awareness of Industry 5.0 in Project Delivery

S/N	Knowledge-based aspects of Industry 5.0	Cited authors
A	***Human-machine collaboration***	
	Upskilling for technology use	Wang *et al.*, 2019; Xu *et al.*, 2021
	Preserving traditional skills	Olawale and Sunmola, 2022
	Worker empowerment	Frey and Osborne, 2017
B.	***Sustainability focus***	
i.	Green technology awareness	Olawumi and Chan, 2019; Alaloul *et al.*, 2023
ii.	Circular economy principles	Leng *et al.*, 2022
iii.	Climate-resilient design	Olawumi and Chan, 2019; IPCC, 2021
C	***Resilient***	
i.	Community-driven infrastructure	Leng *et al.*, 2022; Olawale and Sunmola, 2022
ii.	Economic resilience through inclusion	Aghimien *et al.*, 2020
iii.	Disaster preparedness	Ebekozien *et al.*, 2020; IPCC, 2021
D	***Complementing Industry 4.0 through Critical Thinking***	
i.	Evaluating Automation's Limits	Frey and Osborne, 2017; Aghimien *et al.*, 2018
ii.	Designing Human-Centric Solutions	Adegbite et al., 2021
iii.	Fostering Innovation:	Ebekozien et al., 2020
E.	**Technology Integration with Ethical/Societal Concerns**	
i.	Ethical Technology Use:	Nahavandi, 2019
ii.	Societal Inclusion	Frey and Osborne, 2017
iii.	Cultural Sensitivity**:**	Wang et al., 2019

➢ *Drivers and Barriers Towards the Adoption of Industry 5.0*

In the construction sector, several drivers propel the adoption of Industry 5.0, thereby creating opportunities to modernise the industry, enhance resilience, and support developmental goals. The need to align with international frameworks, such as the United Nations' Sustainable Development Goals (SDGs), drives Industry 5.0 adoption by promoting sustainable construction practices. In South-South Nigeria, environmental degradation from oil exploration necessitates waste minimization and carbon reduction. For instance, adopting recycled materials can reduce construction waste by 30%, addressing ecological challenges in the Niger Delta (Olawumi and Chan, 2019). Frequent flooding and erosion in the Niger Delta necessitate resilient infrastructure, a key driver for Industry 5.0's climate-adaptive designs. Technologies like digital twins enable real-time structural adjustments, ensuring durability in flood-prone areas like Bayelsa and Delta (Ebekozien et al., 2020). Training artisans to use collaborative robots (robots) or Building Information Modeling (BIM) can enhance creativity and productivity and also reduce unemployment (Oyedele, 2016).

The region's reliance on oil and construction underscores the need for innovation to diversify the economy. IoT sensors can improve safety by reducing accidents by 25%, while BIM enhances project efficiency, though adoption remains low at 15% due to infrastructural gaps (Adegbite et al., 2021). Clients, including government and private investors, increasingly demand sustainable and efficient construction solutions. Collaborations could introduce affordable technologies like low-bandwidth digital twins, addressing infrastructural gaps and enhancing training programs (Ajayi and Oyedele, 2018). Therefore, there is an urgent need to address climate change impacts, such as flooding in the Niger Delta, drives Industry 5.0's sustainable practices. Climate-resilient designs, like permeable pavements, protect infrastructure while AI-driven analytics reduce material waste, aligning with environmental goals (Idoro, 2012). The literature review identified ten drivers facilitating the adoption of Industry 5.0, and they are used for data collection. Those drivers include global sustainability goals, demand for resilient infrastructure, abundant human capital, economic growth imperatives, technological advancements, client demand for innovative solutions, government policy and incentives, cultural and community alignment, global and regional collaboration, and climate change adaptation needs (Aghimien et al., 2018; Oke et al., 2018; Eneh, 2019; Aghimien et al., 2020; Ebekozien et al., 2020; Adegbite et al., 2021: Olawale and Sunmola, 2022; Olugboyega et al., 2023)

Despite its potential, adopting Industry 5.0 in the construction sector faces significant barriers rooted in technological, economic, social, infrastructural, and operational challenges. These obstacles impede the seamless integration of human-centric and sustainable systems, necessitating targeted strategies to overcome them. Issues with interoperability between new Industry 5.0 systems (e.g., cobots, digital twins) and existing systems (e.g., legacy

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software or manual processes) create technical challenges, as integrating disparate technologies often requires costly upgrades or retraining (Eastman et al., 2011). A shortage of professionals trained in Industry 5.0 technologies such as BIM or digital twins limits the sector's capacity to implement these solutions (Olugboyega et al., 2023). Unreliable electricity and weak digital connectivity undermine the deployment of smart construction tools like IoT sensors or AI analytics, which require consistent power and internet access (Adegbite et al., 2021). High initial costs for Industry 5.0 technologies such as cobots or renewable energy systems pose a financial barrier for small and medium-sized construction firms (Olawale and Sunmola, 2022).

Weak enforcement of safety, environmental, and technological standards in Nigeria's construction sector hampers Industry 5.0's implementation (Alaloul et al., 2023). Without supportive policies, firms lack incentives to adopt sustainable or human-centric practices (Breque et al., 2021). The absence of industry-wide standardization for Industry 5.0 technologies creates challenges in ensuring consistency, compatibility, and quality across projects. Without standardized protocols for technologies such as digital twins or cobots, firms in South-South Nigeria face difficulties in integrating these tools into their workflows, leading to inefficiencies and reluctance to adopt (Kagermann et al., 2013). The literature scan reviewed nine barriers hindering the adoption of Industry 5.0 in the construction sector. They include limited technological integration, skills gap, infrastructure constraints, funding constraints and lack of incentives, cultural resistance, regulatory deficiencies, concerns about data security and privacy risks, lack of industry-wide standardization, and limited client involvement in technology adoption initiatives (Aibinu and Jagboro, 2002; Oyedele, 2016; Osborne, 2017; Kagermann et al., 2013; Nahavandi, 2019; Ebekozien et al., 2020; Akinradewo et al., 2022; Frey and Leng et al., 2022).

- *Strategies for the Effective Adoption of Industry 5.0*

To overcome barriers and harness the drivers, implementing and adopting Industry 5.0 in the construction sector requires strategic interventions tailored to the region's socio-economic, environmental, and operational context. These strategies aim to integrate human creativity, societal benefits, and sustainability into the industry's framework while addressing concerns such as data security, cultural resistance, and limited client involvement. Establishing vocational training centers and partnerships with universities to teach Industry 5.0 skills, such as operating cobots or using BIM, can bridge the skills gap, where only 5% of professionals are trained in advanced technologies in Nigeria (Olugboyega et al., 2023). Mobile training units could reach rural artisans, enhancing human creativity and employability. Collaborations between government, construction firms, and tech companies can fund the adoption of Industry 5.0 technologies, such as AI or renewable energy systems, addressing funding constraints (Olawale and Sunmola, 2022). This can encourage wider adoption by showcasing tangible benefits like a 40% reduction in material waste (Alaloul et al., 2023). Developing policies that incentivise sustainable construction, for example, offering tax breaks and subsidies for using recycled materials or adopting smart technologies, can drive Industry 5.0 adoption (Breque et al., 2021).

Introducing affordable, region-specific tools like solar-powered cobots or low-bandwidth digital twins can address infrastructure constraints, interoperability issues, and cultural resistance (Leng et al., 2022). This strategy can facilitate gradual adoption, aligning with the incremental implementation approach. Involving local communities and clients in planning and design, using AI to incorporate their needs (e.g., flood-resistant housing), fosters societal acceptance and resilience (Nahavandi, 2019). Awareness campaigns can highlight Industry 5.0's benefits, reducing cultural resistance among traditional builders and management, while encouraging client involvement by educating them on the long-term benefits of innovative, sustainable solutions (Ebekozien et al., 2020). To mitigate concerns about data security and privacy risks, firms should adopt robust cybersecurity measures, such as encryption and secure data storage, when implementing smart technologies like IoT and AI (Leng et al., 2022). The reviewed literature revealed eight strategies that promote effective adoption of Industry 5.0 in the construction sector. They include upskilling and training programs, public-private partnerships (PPPs), policy and regulatory support, localized technology deployment, community and client engagement, incremental implementation and adoption, addressing data security and privacy and monitoring and feedback mechanisms (United Nations, 2015; Tao et al., 2018; Wang et al., 2019; Xu et al., 2021; European Commission, 2021; Leng et al., 2022; Akinradewo et al., 2022; Alaloul et al., 2023).

- *Framework Conceptualisation and Modelling Approach for Industry 5.0*

This framework integrates five skill clusters—human-machine interface, sustainability focus, resilience, critical thinking, and technological/societal concerns—directly to Industry 5.0's pillars of human creativity, societal resilience, and environmental sustainability, enabling professionals to collaborate with cobots, BIM, IoT, and digital twins while embedding eco-friendly and ethical practices. The Framework for the Implementation of Industry 5.0 (FII5.0) was developed through a multi-stage conceptualisation process. In the first stage, a systematic mapping was conducted between the empirical findings and the extant literature on Industry 5.0 adoption frameworks in construction and related sectors (European Commission, 2021; Rimtip et al., 2025; Ikudayisi et al., 2023). This mapping identified seven critical implementation phases — from initial awareness and assessment through policy and infrastructure development, technology adoption, human-machine collaboration training, pilot implementation, full-scale implementation and monitoring, to sustain and scale — as the logical sequential architecture of the framework, grounded in both the DOI Theory's innovation decision process and the specific contextual barriers and strategies identified empirically.

In the second stage, the Integration Definition for Function Modelling (IDEF0) technique was selected as the modelling methodology for the FII5.0 framework. IDEF0, developed under the Integrated Computer-Aided Manufacturing (ICAM) programme and widely applied in systems engineering, process improvement, and construction project management contexts, was chosen for three specific reasons: its capacity to represent complex, multi-phase processes with clear input-output-control-mechanism relationships; its iterative, cyclical modelling logic that accommodates the feedback loops and decision points central to Industry 5.0's human-centric approach; and its visual clarity, which supports communication of the framework to diverse stakeholder audiences including practitioners, policymakers, and academics (Empowered Automation Solutions, 2024; Onyia, 2025). In the third stage, the IDEF0 model was populated with contextually specific inputs, controls, outputs, and mechanisms derived from the empirical findings.

III. RESEARCH METHODOLOGY

The study is focused on developing a framework for the Implementation of Industry 5.0 (FII5.0) in the Nigerian construction sector. To achieve this aim, the following objectives were considered: (a) investigate the level of awareness of Industry 5.0 in project delivery among construction professionals; (b) examine the drivers and barriers facilitating the adoption of Industry 5.0 in the study area; (c) establish strategies for the effective adoption of Industry 5.0; and develop a framework for the implementation of Industry 5.0 in the construction industry. The study was conducted in the South-South geopolitical zone of Nigeria because it has experienced significant infrastructural development, with high-rise buildings, flyovers, railroads, airports, and real estate serving as a major source of revenue in Nigeria. This region comprises six States, namely Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers. Of the six states, Akwa Ibom and Rivers States. Randomly, two states were selected for this study, namely Rivers and Akwa Ibom States.

The target population consists of registered construction professionals, including Quantity Surveyors, Architects, Builders, and Engineers, who are directly involved in project delivery and play a key role in Industry 5.0 adoption. The population frame is drawn from registration councils for these bodies (QSRBN, ARCON, CORBON, COREN), which provide detailed membership data, reflecting the most recent records as of 2024. The total population across the two states is 631 professionals. According to Kothari (2017), small units can be used to represent a larger population using a sampling method.

The sample size was calculated using the Yamane formula, and 508 respondents were included in the survey. The study explores the research onion approach as stipulated by Yamane (1967)**,** which includes philosophy, approach to theory development, methodological choice, strategies, time horizon, and procedures/techniques. The research adopts a positivist philosophy, which aligns with its aim to objectively measure and quantify perceptions, attitudes, and readiness for Industry 5.0 adoption among construction professionals in South-South Nigeria.

The study adopts a multi-methods quantitative survey to obtain opinions, narratives, interpretations, and perceptions of respondents to convey the realities. According to Ogwueleka (2011), the use of a questionnaire was considered adequate for the field survey because of the ease of obtaining standard data appropriate for achieving the research objectives. There are two sections in the questionnaire: the first section uncovers the sociodemographic factors of respondents, while the second section involves four categorical questions, which investigate the level of awareness of Industry 5.0 in project delivery among construction professionals; examine the drivers and barriers facilitating the adoption of Industry 5.0 in the study area; and establish strategies for the effective adoption of Industry 5.0. For the level of awareness, 15 measures were identified under the five key knowledge areas of Industry 5.0, 10 drivers and 9 barriers to Industry 5.0 adoption were reviewed, while 8 strategies for promoting Industry 5.0 adoption were also identified. A five-point Likert scale was adopted to collect responses from the respondents. The questionnaire was distributed to 508 respondents through either an online survey or in-person contact. The respondents were given four weeks to respond to the questionnaire. A total of 373 questionnaires were retrieved, and only 258 were properly filled, which accounts for a 50% response rate. For data analysis, the decision rule adopted for the study states that a mean score of less than 2.50 is considered a low level, 2.50 - 3.49 is a moderate level, while 3.50 and above indicates a significant or an effective level.

IV. RESULTS AND DISCUSSION

➢ *Respondents' Characteristics*

The study assessed four sociodemographic factors of the respondents, which focused on educational qualification, professional affiliation, industry experience, and location of the respondents as shown in Table 2. The results showed the highest educational qualification of the respondents, with 58.9% having first degree (HND/BSc) qualifications, while 41.1% possess postgraduate degrees (MSc/PhD) qualifications. These results portrayed that all the respondents were knowledgeable on the subject matter. Of the professional affiliations of the respondents, 19.8% were architects, 13.6% were builders, 35.3% were engineers, and 31.4% were quantity surveyors. Furthermore, the results showed the working experience of the respondents, with 20.9% of the respondents having been in practice between 1–10years, 20.2% practised between 11-20years, 27.9% practised between 21- 30 years, and 31.0% have been practicing over 30years. The results also displayed the geographical location of the respondents, with 28.3% residing and operating in Akwa Ibom State and 71.7% of the respondents operating in Rivers State, Nigeria. The majority of the respondents possess considerable knowledge and could give reliable information for the study.

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Table 2 Sociodemographic Factors of Respondents

Categories	Variables	Frequency	Percentage
Highest Educational Qualification	First degree	152	58.9%
	Postgraduate	106	41.1%
Professional Affiliation	NIA	51	19.8%
	NIOB	35	13.6%
	NSE	91	35.3%
	NIQS	81	31.4%
Years of Experience in the Industry	1-10years	54	20.9%
	11-20years	52	20.2%
	21-30years	72	27.9%
	Above 30years	80	31.0%
Location of Respondents	Akwa Ibom State	73	28.3%
	Rivers State	185	71.7%

- *Level of Awareness of Industry 5.0 in Project Delivery in South-South Nigeria*

The results are presented in Table 3, showing the level of awareness of Industry 5.0 in project delivery. In Akwa Ibom State, components of Industry 5.0 with mean scores above 3.00 account for 66% of the level of awareness. The results ranked community-driven infrastructure, economic inclusion, automation, human-centric solutions, and climate-resilient designs 1st–5th, respectively. In Rivers State, industry 5.0 components with mean scores above 3.00 account for 100% level of awareness, with economic inclusion, upskilling, human-centric, societal inclusion, and community-driven infrastructure ranked 1st–5th, respectively. The results revealed that professionals in Rivers State are more aware of Industry 5.0 when compared to Akwa Ibom State.

Table 3 Level of Awareness of Industry 5.0 in Project Delivery

	Akwa Ibom State		**Rivers State**		**Aggregated Sample**		
Industry 5.0 Components	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Remarks**
Economic inclusion strengthens project resilience	3.46	2nd	3.62	1st	3.54	1st	High
Community-driven infrastructure meets local needs	3.49	1st	3.53	5th	3.51	2nd	High
Human-centric solutions enhance Industry 5.0 tools	3.36	4th	3.57	3rd	3.46	3rd	Moderate
Evaluating automation limits improves project outcomes	3.41	3rd	3.42	12th	3.41	4th	Moderate
Upskilling enhances technology use in project delivery	3.15	7th	3.62	2nd	3.38	5th	Moderate
Circular economy principles minimize waste	3.24	6th	3.49	7th	3.36	6th	Moderate
Empowering workers through human-machine collaboration fosters innovation in project execution.	3.15	7th	3.49	7th	3.32	7th	Moderate
Climate-resilient designs address regional challenges	3.31	5th	3.29	14th	3.30	8th	Moderate
Green technologies reduce environmental impact	3.13	9th	3.43	11th	3.28	9th	Moderate
Traditional skills are preserved in Industry 5.0	3.05	10th	3.45	9th	3.25	10th	Moderate
Societal inclusion aligns projects with community needs	2.93	13th	3.55	4th	3.24	11th	Moderate
Critical thinking fosters innovative project delivery	2.91	14th	3.51	6th	3.21	12th	Moderate
Ethical technology use ensures fair project practices	2.84	15th	3.45	9th	3.14	13th	Moderate
Cultural sensitivity supports technology adoption	2.97	11th	3.32	13th	3.14	13th	Moderate
Disaster preparedness enhances infrastructure durability	2.95	12th	3.03	15th	2.99	15th	Moderate

- *Drivers Facilitating the Adoption of Industry 5.0 in the Construction Sector*

Table 4 shows the descriptive perceptions of the respondents regarding drivers facilitating the adoption of Industry 5.0. From the decision rule, the analysis reveals that all drivers are significant in both states. In Akwa Ibom State, global sustainability goals, climate change adaptation needs, global and regional collaboration, government policy and incentives, and abundant human capital are ranked 1st – 5th. In Rivers State, drivers ranked 1st – 5th are global sustainability goals, climate change adaptation needs, global and regional collaboration, cultural and community alignment, and abundant human capital.

Table 4 Drivers Facilitating the Adoption of Industry 5.0 in the Construction Sector

	Akwa Ibom State		**Rivers State**		**Aggregated Sample**		
Drivers of Industry 5.0	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Remarks**
Global sustainability goals	4.01	1st	3.82	1st	3.92	1st	Significant
Climate Change Adaptation Needs	3.93	2nd	3.78	2nd	3.85	2nd	Significant
Global and Regional Collaboration	3.72	3rd	3.68	3rd	3.70	3rd	Significant

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Abundant human capital	3.71	5th	3.67	5th	3.69	4th	Significant
Economic growth imperatives	3.68	7th	3.65	7th	3.66	5th	Significant
Cultural and Community Alignment	3.63	10th	3.68	3rd	3.65	6th	Significant
Demand for resilient infrastructure	3.64	8th	3.67	5th	3.65	6th	Significant
Client demand for innovation	3.69	6th	3.62	8th	3.65	6th	Significant
Government Policy and Incentives	3.72	3rd	3.55	9th	3.63	9th	Significant
Technological advancements	3.64	8th	3.50	10th	3.57	10th	Significant

- *Barriers Hindering the Adoption of Industry 5.0 in the Construction Sector*

The results presented in Table 5 show the descriptive perceptions of the respondents regarding the barriers hindering the adoption of Industry 5.0 in the construction sector. The results established that all nine barriers had a mean above 3.50, signifying that the barriers hindering the adoption of Industry 5.0 are highly significant. This also implies that these variables in this range critically affect the level of adoption of Industry 5.0 in both states. In Akwa Ibom state, the study ranked high investment cost and inadequate digital infrastructure as first with an MIS of 4.04, data security and privacy risks ranked second with a MIS of 4.00, followed by weak regulatory enforcement with a MIS of 3.97 as third. In River State, the analysis ranked high investment costs first with a mean of 3.77, ranked second is inadequate digital infrastructure with a mean of 3.74, while data security and privacy risks, and weak regulatory enforcement are both ranked third with a mean of 3.81.

Table 5 Barriers Hindering the Adoption of Industry 5.0

	Akwa Ibom State		**Rivers State**		**Aggregated Sample**		
Barriers Hindering the Adoption of Industry 5.0	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Remarks**
High investment costs	4.04	1st	3.77	1st	3.90	1st	Significant
Inadequate digital infrastructure	4.04	1st	3.74	2nd	3.89	2nd	Significant
Data security and privacy risks	4.00	2nd	3.70	3rd	3.85	3rd	Significant
Weak regulatory enforcement	3.97	3rd	3.70	3rd	3.83	4th	Significant
Lack of industry standardization	3.94	4th	3.69	5th	3.81	5th	Significant
Stakeholder resistance	3.80	5th	3.64	7th	3.72	6th	Significant
Limited client involvement	3.78	7th	3.62	8th	3.70	7th	Significant
Insufficient digital skills	3.72	8th	3.67	6th	3.69	8th	Significant
Limited technological integration	3.79	6th	3.52	9th	3.65	9th	Significant

- *Strategies for Effective Adoption of Industry 5.0 in the Construction Industry*

Table 6 shows the hierarchy of 8 strategies based on MIS; the results suggest that all eight strategies, accounting for 100%, are effective in enhancing the adoption of Industry 5.0. In Akwa Ibom, the first ranked is upskilling and training programs with a mean of 3.82, monitoring and feedback mechanism ranked second with a mean of 3.72, and the third ranked is public-private partnership with a mean of 3.68. In Rivers State, the monitoring and feedback mechanism is ranked first with a mean of 3.60, upskilling and training programs are ranked second with a mean of 3.32, and the third ranked is community and client engagement with a mean of 3.17.

Table 6 Strategies for Effective Adoption of Industry 5.0 in the Construction Industry

	Akwa Ibom State		**Rivers State**		**Aggregated Sample**		
Strategies for Implementing and Adopting Industry 5.0	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Remarks**
Monitoring and feedback mechanisms	3.72	2nd	3.60	1st	3.66	1st	Effective
Upskilling and training programs	3.82	1st	3.32	2nd	3.57	2nd	Effective
Public-private partnerships	3.68	3rd	2.64	8th	3.16	3rd	Effective
Community and client engagement	3.06	4th	3.17	3rd	3.11	4th	Effective
Data security and privacy measures	3.04	5th	3.14	4th	3.09	5th	Effective
Incremental implementation	2.91	7th	3.12	5th	3.01	6th	Effective
Localized technology deployment	2.84	8th	3.08	6th	2.96	7th	Effective
Policy and regulatory support	3.00	6th	2.88	7th	2.94	8th	Effective

- *Framework Development for Implementing Industry 5.0 in the Nigerian Construction Industry*

This framework adopts IDEF0 (Integration Definition for Function Modelling), a technique developed under the Integrated Computer-Aided Manufacturing (ICAM) program to produce the Framework for the Implementation of Industry 5.0 (FII5.0). This technique assisted in identifying major implementation obstacles and offered focused solutions to overcome them. With a focus on human-machine collaboration, sustainability, and resilience, this method

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produces an organised, iterative flowchart that is customised to local issues, including power shortages, informal labour markets, and skills gaps (See Figure 1). FII5.0 progresses through seven interrelated phases, which are connected by decision points, feedback loops, and forward arrows: (1) awareness and assessment; (2) policy and infrastructure development; (3) technology adoption; (4) training for human-machine collaboration; (5) pilot implementation; (6) full-scale implementation and monitoring; and (7) sustain and scale. In contrast to Industry 4.0's linearity, its design embodies Industry 5.0's cyclical, human-centred ethos (Empowered Automation Solutions, 2024; Onyia, 2025). Before moving toward policy initiatives like 5G rollout and training hubs, the process begins with evaluations of skills gaps and infrastructure amid inconsistent power and informal labour (Rimtip et al., 2025). Before KPI-monitored scaling (for instance, 30% waste reduction), it incorporates technologies such as AI, IoT, cobots, and digital twins, along with reskilling, to address job anxieties. These technologies were verified in low-risk projects like modular housing.

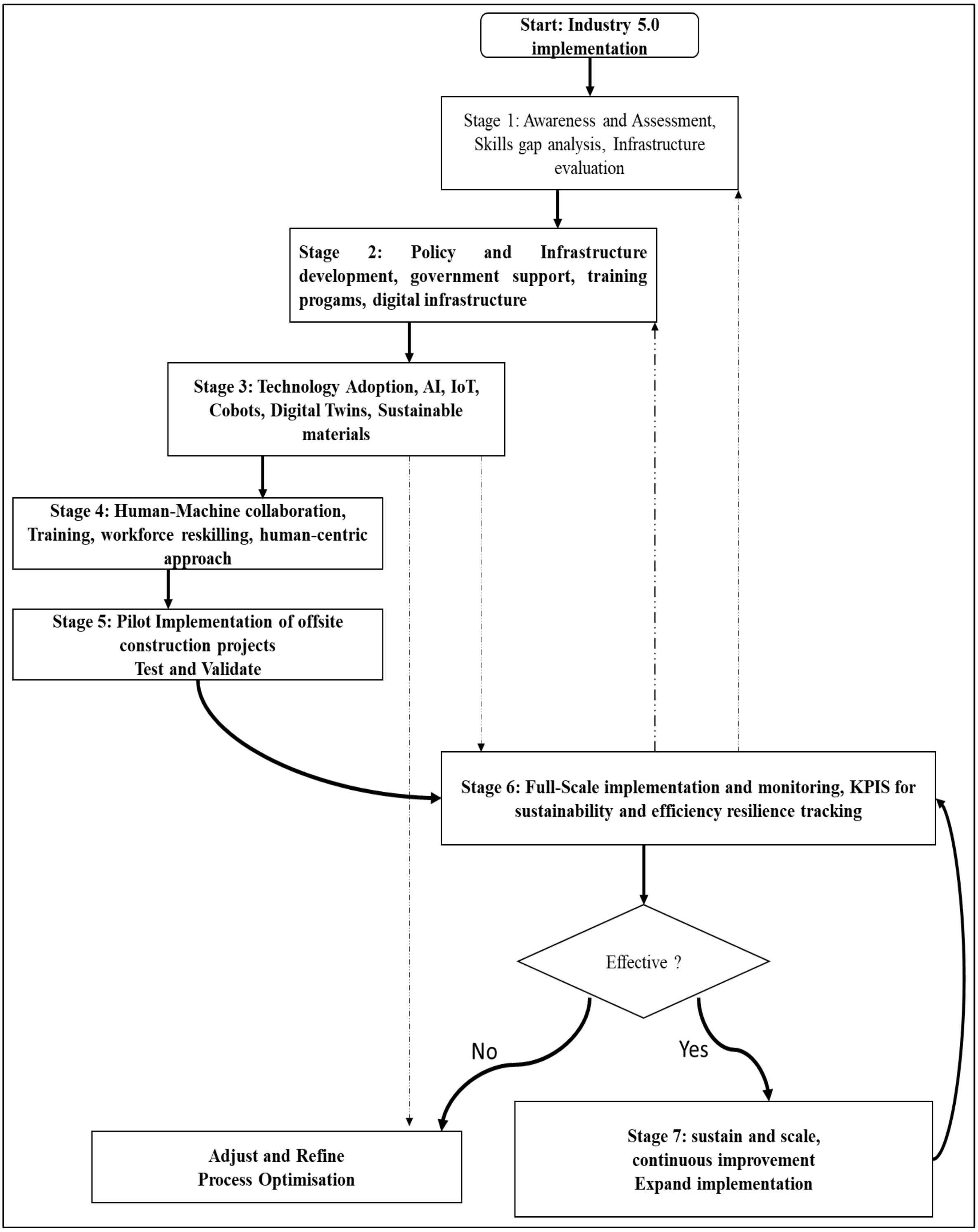

Fig 1 Industry 5.0 Implementation Framework in the Nigerian Construction Industry

➢ *Validation of FII5.0*

A survey of ten stakeholders, six construction professionals, and four academics with expertise in innovation was used to validate the framework. The Diffusion of Innovations (DOI) theory, which assesses the following important constructs: relative advantage, compatibility, complexity, trialability, and observability, provides good validation for the FII5.0 for Nigeria's construction sector (Empowered Automation Solutions, 2024). In the face of infrastructure gaps and sustainability needs, its stepwise flowchart, awareness to sustain and scale, with arrows, feedback loops, and decision points, exhibits theoretical soundness and contextual fit, as indicated in Table 6. In line with empirical models such as scientometric productivity frameworks and Nigeria's offsite construction studies (Mean scores 4.2/5), DOI constructs from Rogers (2003), the benchmark for adoption of construction technology, confirm alignment (Rimtip *et al.*, 2025). Industry 4.0 constraints are addressed by human-centric components (reskilling, cobots, AI/IoT integration), with loops that strengthen resilience to power instability (Onyia, 2025). One of the problems expressed by professionals who verified the methodology is Industry 5.0 performance measurement. However, in creating the framework, the study team recognised that measuring Industry 5.0 performance is still a problem in underdeveloped countries. Emerging issues arise from knowing which physical scale to use and what criteria to use.

Table 7 Feedback and Performance of the FII5.0

Construct	Description	Score (1-5)	Framework Evidence
Relative Advantage	20-40% productivity gain via digitalisation over manual	4.7	Phased adoption cut waste/efficiency boost
Compatibility	Fits sustainability, youth labour, policy evolution	4.2	Training/loops match demographics
Complexity	Phased ease vs. infra hurdles	3.8	Feedback simplifies; demands noted
Trialability	Modular pilots with “Effective?” tests	4.5	Low-risk dedicated phase
Observability	KPI visibility in monitoring	4.0	Real-time loops track results

Based on similar validations, the mean score of 4.24 (21.2/5) indicates strong adaptability (Empowered Automation Solutions, 2024). Compatibility increases green procurement for 2060 net-zero; trialability/observability via loops mimic EU resilient pilots (Ikudayisi *et al.*, 2023). Two categories of expert comments were identified for the created framework, that SME mobile audits are necessary due to complexity and weaknesses. All things considered, the framework, which combines Industry 5.0 with Nigeria's inventiveness to accelerate urbanisation, deserves to be implemented.

V. DISCUSSION OF RESULTS

The level of awareness of Industry 5.0 in both states reveals that above 90 percent penetration rate in the study area. This report surpasses the study conducted by Rimtip et al. (2025), which revealed a benchmark of 35 percent in Nigeria. The South-South region's advantage may stem from sustainability needs in ecologically sensitive areas. While Akwa Ibom state reflects similar dynamics, Rivers state may align with urban-industrial growth observed in Gauteng, South Africa (78%) (Du Plessis and Bam, 2022). Globally, human-centric approaches dominate in the EU (85% high awareness) (European Commission: Directorate-General for Research and Innovation, 2021), reinforcing Nigeria's focus on societal technology needs. In contrast to Germany's 92% adoption driven by policy, Nigeria's 80% moderate clustering mirrors Middle Eastern trends (65-75%), highlighting socio-economic factors over technological ones (Nahavandi, 2019; Rimtip *et al.*, 2025). Recent African parallels, such as Maqbool *et al.* (2023), assert that Ghana affirms the importance of economic inclusion, maintaining a unique uniformity that could support scaling efforts, suggesting that Industry 5.0 may thrive in resource-constrained environments through awareness-building strategies rather than solely through automation.

The results show that all identified drivers of Industry 5.0 adoption in the construction sector are statistically and practically significant, with mean scores above 3.00 and, more importantly, above 3.50, indicating a strong and positive consensus among respondents. Global sustainability goals ranked first, followed by climate change adaptation needs, global and regional collaboration, abundant human capital, and economic growth imperatives, confirming that professionals perceive Industry 5.0 as a strategic response to intertwined environmental, social, and economic pressures rather than a purely technological trend (Ebekozien *et al.*, 2020). This pattern suggests that the transition towards Industry 5.0 in the South-South Nigerian construction context is being driven primarily by high-level sustainability and resilience imperatives, which align with the broader framing of Industry 5.0 as a human-centric, sustainable, and resilient paradigm. The second-ranked driver, climate change adaptation needs, reflects the vulnerability of construction assets and infrastructure to climatic hazards, such as flooding and extreme rainfall, especially in coastal and deltaic regions like Akwa Ibom and Rivers States, where resilient design, low-carbon materials, and adaptive planning are increasingly indispensable. These findings imply that Industry 5.0 will likely be embedded in strategies such as climate-resilient buildings, renewable energy integration, advanced material monitoring, and data-driven risk management in construction projects.

The importance of global and regional collaboration as the third driver underscores that the diffusion of Industry 5.0 technologies in developing countries depends heavily on inter-organisational and cross-border partnerships, knowledge sharing, and joint ventures, especially where local capacity and infrastructure remain constrained (Rimtip *et al.*, 2025). This is in line with literature showing that collaborative frameworks between government, industry, and academia are crucial to overcoming financial, technical, and regulatory barriers to IR 5.0 readiness. Abundant human capital being ranked highly suggests that, despite infrastructural and funding constraints, there is a strong professional base capable of being upskilled for human–machine collaboration, cobotics, and advanced digital workflows, echoing studies that highlight human competencies and craftsmanship as central assets in Industry 5.0 (Rimtip *et al.*, 2025). Economic growth imperatives, while ranked fifth, still exhibit high mean scores, indicating that respondents recognise Industry 5.0's potential to enhance productivity, unlock new business models, and support macroeconomic development in Nigeria's construction sector.

Statistical evidence suggests that these barriers are not experienced equally; Akwa Ibom faces more severe constraints compared to Rivers State, indicating a locational effect on Industry 5.0 readiness. The primary barriers include high investment costs, inadequate digital infrastructure, data security and privacy risks, weak regulatory enforcement, and lack of industry standardisation, aligning with both international and Nigerian research on Industry 4.0/5.0 and digital transformation in the construction sector. Notably, the high costs associated with advanced technologies such as AI, IoT, robotics, and cyber-physical systems are critical constraints, especially for small and medium-sized firms operating on limited margins and access to funding. Additional barriers, such as insufficient client involvement, limited digital skills, and inadequate technological integration, further emphasise that the resistance to Industry 5.0 is complex and multi-dimensional. The prominence of inadequate digital infrastructure and weak regulatory enforcement aligns closely with prior Nigerian and broader Global South evidence that links technology adoption to enabling ecosystems rather than firm-level willingness alone (Adegbite *et al.*, 2021). Poor IT networks, unreliable electricity supply, and limited access to secure data centres have been shown to hinder the deployment of real-time data platforms, BIM-integrated cyber–physical systems, and collaborative human–robot environments typical of Industry 5.0 (Eastman *et al.*, 2013; Akinradewo *et al.*, 2022). At the same time, the perception of weak regulatory enforcement and lack of industry standardisation suggests that professionals are acutely aware of institutional weaknesses, such as the absence of clear guidelines for data governance, interoperability standards, and safety protocols for advanced automation, which can increase perceived risk and discourage investment (Breque *et al.*, 2021; Alaloul *et al.*, 2023). Concerns about data security and privacy risks mirror findings in recent Industry 5.0 and digital construction studies that highlight cybersecurity threats and unclear liability regimes as critical obstacles to cloud-based collaboration and AI-driven decision support tools (Leng *et al.*, 2022).

The findings are consistent with global research on Industry 5.0 adoption, highlighting the importance of monitoring and feedback mechanisms as outlined by Xu *et al.* (2021), which are critical for enhancing adaptive and resilient cyber-physical systems. This approach is being applied in construction to optimise prefabrication and IoT-enabled site monitoring, reducing downtime by up to 20%, as evidenced in European studies (Nahavandi, 2019). Furthermore, the emphasis on upskilling mirrors firms' view that workforce readiness is a major barrier to Industry 4.0/5.0 implementation, which is particularly pronounced in Africa due to digital literacy challenges. In contrast, the low emphasis on public-private partnerships (PPP) deviates from trends observed in India and Brazil, where such collaborations have notably enhanced technology adoption. This suggests that Nigerian professionals might favour building internal capacity over depending on inconsistent public funding.

VI. CONCLUSION

This study sets out to address a critical gap in the construction management and industrial innovation literature. The absence of an empirically grounded, contextually validated framework for the implementation of Industry 5.0 in the Nigerian construction sector, with specific focus on the South-South geopolitical zone is a crucial aspect. By pursuing five discrete but interrelated objectives which are assessing Industry 5.0 awareness among construction professionals, examining adoption drivers, evaluating adoption barriers, prioritising implementation strategies, and developing a validated implementation framework. the study generated a comprehensive body of empirical evidence that advances both theoretical understanding and practical guidance in one of sub-Saharan Africa's most consequential built environment contexts. Based on the study findings, it is concluded that Industry 5.0 is not an imported luxury but an indigenous opportunity for South-South Nigeria's construction sector to leapfrog conventional modernisation trajectories and position itself as a vanguard of human-centric, sustainable, and resilient industrialisation in sub-Saharan Africa. The study pioneers FII5.0 as the first empirically derived, expert-validated, contextually calibrated framework for Industry 5.0 implementation in the Nigerian construction sector. The study contributes as a deployable practical artefact and a set of theoretically enriched insights that can advance the global Industry 5.0 discourse in developing countries' construction contexts.

RECOMMENDATIONS

➢ *Based on these Findings of the Study, the Study Recommends the Following:*

- Establish joint Industry 5.0 awareness programmes between Akwa Ibom and Rivers States, leveraging Rivers State's megaproject knowledge spillovers.
- Embed economic inclusion as a mandatory criterion in public construction procurement specifications, prioritising Industry 5.0-compliant firms for contract awards.
- Enact and enforce national Industry 5.0 interoperability standards and data governance regulations applicable to all public construction contracts.

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- Partner with polytechnics and professional bodies to deliver modular Industry 5.0 training, targeting 500,000 construction workers reskilled in digital tools by 2030.
- Adopt and deploy FII5.0 immediately as the standard implementation blueprint for Industry 5.0 in South-South Nigeria's construction sector, beginning with pilot projects.

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