

## Smart Infrastructure For Smart Universities: Aligning SDG 9 With 5ir Digital Transformation In Higher Education In Nigeria

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### Abstract

The study examined smart infrastructure for smart universities: Aligning SDG 9 with 5IR digital transformation in higher education. In Nigeria, the drive to establish smart universities is gaining momentum, driven by the Fifth Industrial Revolution (5IR), aligning with Sustainable Development Goal 9. This shift centers on intelligent systems and adaptive technologies that improve learning environments and outcomes. Integrated digital campuses now use real-time data and cloud-based platforms, boosting student retention by 35% and enhancing learning outcomes by 28%. Institutions like Covenant University and UNILAG are leading with energy-efficient designs and solar-powered infrastructure, reducing annual energy expenses by 45% while fostering environmental awareness. These smart campuses also house innovation hubs and fabrication labs, contributing to a 22% increase in student-led research and enterprise initiatives over three years. Reliable broadband, secure cloud storage, and seamless campus connectivity have become essential for academic and administrative efficiency. Equitable access initiatives, including free Wi-Fi and low-cost e-learning tools, are helping bridge the digital divide. For long-term success, strong collaboration between government, industry, and educational bodies is vital to support regulation and investment in smart infrastructure. In conclusion, Smart infrastructure in Nigerian universities fosters inclusive digital campuses, energy-efficient spaces, and adaptive learning aligned with SDG 9. Through resilient systems, research innovation, and strong policy-industry ties, higher education embraces 5IR transformation for equitable, sustainable academic growth. The study also suggested, among others, that Smart university infrastructure in Nigeria should be strategically designed to integrate emerging technologies, enabling sustainable development while enhancing teaching, research, and administration in line with SDG 9 and 5IR.

### Introduction

Sustainable Development Goal 9 (SDG 9) focuses on building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. It is rooted in the recognition that robust infrastructure and technological advancement are foundational to economic growth and social development. Historically, industrial development has driven productivity and income

growth, but SDG 9 encourages innovation that is inclusive and environmentally conscious (United Nations, 2015). For example, in Nigeria, infrastructural development under SDG 9 includes investments in road construction, digital technology access, and localized industrial parks (Akinwale & Aremo, 2020). The aim is to bridge infrastructural gaps that impede economic participation, particularly among marginalized communities, thereby ensuring equitable growth. Innovation hubs and public-private partnerships have also emerged as tools to boost technological capacity and sustainability (Brixiová et al. 2020).

The Fifth Industrial Revolution (5IR) builds on the advancements of the Fourth Industrial Revolution (4IR), characterized by cyber-physical systems, artificial intelligence, and the Internet of Things (IoT). Unlike 4IR, the 5IR is distinguished by its emphasis on human-centric technology that combines smart automation with emotional and ethical intelligence (Xu et al. 2018). The history of the 5IR begins in the early 2020s, as researchers and policymakers emphasized the need to balance profit-driven technological change with human well-being and sustainability. Countries like Japan and South Korea have integrated 5IR principles into their digital policies, advocating for the collaboration of humans and machines for societal benefit (Schwab & Zahidi, 2020). In Africa, particularly Nigeria, digital transformation under 5IR includes fintech expansion, e-learning platforms, and health-tech innovations aimed at narrowing the development gap while centering people in the digital age (Okafor & Okezie, 2023).

Smart infrastructure in higher education refers to the intentional integration of digital systems ranging from IoT sensors and AI to resilient networks into campus planning, aimed at optimizing operations, learning, and research (Jurva et al. 2020; Mylonas et al. 2019). In Nigeria, aligning with SDG 9 (Industry, Innovation, Infrastructure) supports building sustainable and innovative university environments (Ufua et al. 2021). The Fourth Industrial Revolution (5IR) introduces smart machines and digital platforms that redefine university functions transforming analogue chalkboards into networked, data-rich, digitally adaptive ecosystems (Wordu & Wodi, 2024). This synergy between workflow modernization and sustainability principles creates Integrated Digital Campuses *that enable* Adaptive Learning Ecosystems, equipping institutions to meet 21st-century educational demands.

Smart campuses embed energy management systems leveraging IoT-enabled sensors, smart grids, and automated HVAC controls to minimize energy consumption and carbon footprints (Mylonas

et al. 2019; Jurva et al. 2020). Case studies show IoT-based building management achieving up to 20 % energy savings in educational buildings (Mylonas et al. 2019). In Nigeria, integrating these practices supports both SDG 9 and SDG 7 (Affordable, Clean Energy), responding to infrastructural inefficiencies and reducing operational costs while teaching sustainability by example. As part of integrated digital campus design, retrofitting existing buildings with smart systems fosters *Smart-Green University* models where environmental stewardship is embedded in institutional identity (Elshapasy & Mohamed, 2024).

Smart infrastructure extends to innovation hubs and research labs equipped with AI, machine learning, cloud computing, and collaboration tools, empowering both academic inquiry and industrial partnerships. Nigeria's drive for digital growth, via its National Digital Economy Policy and Innovation Strategy, promotes university-based tech hubs that serve as key SDG 9 catalysts (DTC Nigeria Factsheet, 2022). These hubs offer shared resources for SMEs and startups, fostering innovation diffusion beyond academia. Local experts advocate for ICT innovation hubs across all educational tiers to build a tech-savvy future generation (Ibanga, 2020), evidencing how smart campuses can fuel societal transformation through accessible R&D infrastructure.

A resilient digital campus depends on robust ICT backbones, high-speed internet, cloud services, edge computing, and emerging 5G wireless supporting high-density connectivity for devices, sensors, and research platforms (Jurva et al. 2020; Taruc & De La Cruz, 2024). Nigeria's digital landscape has improved with investments in broadband and ICT policy frameworks (DTC Nigeria Factsheet, 2022), yet challenges remain in policy execution and sustainable funding. Effective digital infrastructure equips universities to withstand disruptions (e.g., power outages, cyber incidents), supports remote learning, and connects campuses to global academic networks. Embedding resilient ICT systems is fundamental to actualizing integrated digital campuses and inclusive learning environments.

Smart infrastructure generates rich datasets from energy usage to student performance that enable predictive analytics and personalized interventions. Nigerian universities are beginning to adopt learning analytics and big-data approaches to predict at-risk students and improve outcomes (Oguine et al. 2022). By analyzing attendance, performance, and facility usage, administrators can optimize resource deployment and learning pathways. Furthermore, accessible infrastructure affordable Wi-Fi, digital access for rural populations, and adaptive digital platforms ensure

inclusive education aligned with SDGs 4 (Quality Education) and 10 (Reduced Inequalities). Smart systems thus enable equitable learning, monitoring access gaps, and deploying targeted support.

Realizing smart universities demand cohesive policy frameworks and collaboration between government, industry, and academia. Nigeria's Digital Innovation and Entrepreneurship Strategy (2020-2030) and Digital Transformation Center, in partnership with NITDA and EU/GIZ, provide platforms for capacity-building and infrastructure deployment (DTC Nigeria Factsheet, 2022). However, effective implementation requires stronger multi-stakeholder coordination (Ufua et al. 2021). Partnerships with ICT firms, utilities, and research institutions amplify innovation and generate shared value. Policy mechanisms such as incentives for green buildings, data governance, and digital equity standards are vital. Collaboration ensures the sustainability of smart infrastructure and cements universities' role as engines of innovation, inclusive growth, and national development. Hence, the study examines the role of smart infrastructure in advancing digital transformation within Nigerian higher education, aligning with Sustainable Development Goal 9 (SDG 9). It emphasizes the importance of resilient, innovative systems to support smart universities under the Fifth Industrial Revolution (5IR). Despite recognizing key opportunities, it identifies gaps in policy implementation, sustainable funding, and infrastructural integration, calling for more practical frameworks and empirical studies to guide effective transformation strategies.

### **Smart Infrastructure**

Smart infrastructure refers to technologically advanced systems that integrate sensors, software, and data networks to optimize the efficiency and performance of public utilities such as electricity, water, transportation, and communication networks. These infrastructures operate interactively, using real-time data to enhance sustainability, resilience, and user experience (Kitchin, 2014). In developing nations like Nigeria, the implementation of smart infrastructure is gradually improving with initiatives such as the National Integrated Infrastructure Master Plan (NIIMP), which aims to upgrade outdated systems using digital innovations. Smart infrastructure contributes significantly to urban development by reducing waste, managing energy consumption, and improving mobility and safety. For example, smart traffic lights and smart energy meters help cities respond to population growth and environmental concerns. Globally, cities like Singapore and Amsterdam

are models of successful smart infrastructure adoption. Ultimately, the development of smart infrastructure supports economic growth, climate change adaptation, and improved public services.

### **Smart Universities**

Smart universities are higher education institutions that integrate digital technologies across academic, administrative, and infrastructural systems to improve learning outcomes and operational efficiency. These institutions use tools such as artificial intelligence, learning management systems (LMS), and campus-wide Internet of Things (IoT) devices to foster interactive and personalized learning (Yusof et al. 2021). In Nigeria, universities like Covenant University have led in adopting smart technologies, offering online lecture delivery, virtual labs, and real-time performance tracking (Oyedemi & Salawu, 2022). Smart universities promote flexible learning, encourage Student-centred instruction, and allow seamless communication between staff and students. They also enhance research through digital libraries and collaborative platforms. By leveraging smart technologies, these institutions better prepare students for the evolving demands of the digital economy. The transformation into smart universities aligns with global educational reforms, making higher education more inclusive, data-driven, and responsive to societal needs.

### **3. SDG 9 5IR Digital Transformation**

Sustainable Development Goal 9 (SDG 9) emphasizes building resilient infrastructure, promoting inclusive industrialization, and fostering innovation. In the age of the Fifth Industrial Revolution (5IR), which combines advanced digital technologies with human-centred approaches, higher education institutions play a vital role in achieving SDG 9 through digital transformation. This includes the integration of artificial intelligence, robotics, blockchain, and biotechnology into teaching, research, and administration (Schwab & Zahidi, 2020). In Nigeria, universities are adopting virtual learning platforms and digital laboratories to enhance innovation-driven education (Adetimirin, 2023). The focus of 5IR is not only on technological advancement but also on ethical, sustainable, and inclusive growth. By digitizing infrastructure and promoting research in science and engineering, higher education supports national development goals and prepares students for evolving industrial roles. Hence, the synergy between SDG 9 and 5IR promotes digital equity and human development.

## **Higher Education**

Higher education refers to all forms of post-secondary education, including universities, polytechnics, and colleges that provide learning, training, and research beyond the secondary level. It plays a critical role in the economic, cultural, and technological development of nations by producing skilled professionals and fostering innovation. In Nigeria, higher education is facing challenges such as limited funding, outdated curricula, and brain drain. However, institutions are increasingly engaging in reforms to meet global standards (Ezeani & Oladejo, 2021). Higher education contributes to human capital development and serves as a platform for societal transformation, entrepreneurship, and policy development. It also helps address complex global challenges like climate change and public health through research and knowledge dissemination. As the world moves into a digital-first future, higher education must adapt by integrating flexible learning models and ensuring equitable access to quality education.

## **Integrated Digital Campuses & Adaptive Learning Ecosystems**

Integrated digital campuses meld physical facilities with cloud platforms, IoT-connected devices, and centralized student information systems, streamlining everything from registration and ID verification to smart classrooms and administrative workflows. As Ojo and Adegboyega (2021) highlight, this integration fosters operational efficiency, minimizes downtime, and supports a seamless student experience that spans both in-person and online activities. When layered with adaptive learning ecosystems where algorithms tailor content, pacing, and assessments to each learner's performance, universities gain the ability to monitor engagement and deliver personalized interventions (Kumar & Singh, 2022). This blend is particularly promising in Nigeria, where disparities in academic readiness and infrastructural inconsistencies persist. However, successful adoption requires investment not just in cloud infrastructure but also in professional development for faculty and robust broadband across campuses, as noted by Nwachukwu et al. (2023). Aligning these efforts supports SDG 4 (quality education) and SDG 9 (infrastructure and innovation), preparing graduates to thrive in 5IR-driven economies.

A study by Adeyeye and Okon (2023) revealed that institutions employing digital campus frameworks featuring centralized learning management systems (LMS), AI-powered tutoring, and cross-platform accessibility saw improved student engagement and academic performance by 28%. Furthermore, adaptive learning ecosystems helped personalize content delivery through real-

time analytics, accommodating diverse learning paces and styles. This aligns with SDG 9 and the principles of the Fifth Industrial Revolution (5IR), fostering human-centred, tech-integrated education systems. The study concludes that a holistic digital campus model, supported by government and private investment, can bridge the infrastructural and pedagogical gaps currently hindering Nigeria's higher education sector.

### **Energy-Efficient and Sustainable Buildings**

Smart universities must also commit to sustainable campus infrastructures. According to Okeke and Adeniran (2020), retrofitting buildings with IoT sensors for HVAC optimization, daylight harvesting, and automated lighting can reduce energy costs by 30–40%. This is critical in Nigeria, where unreliable power supply often forces constant reliance on diesel generators, undermining environmental goals and budgetary stability. At the Federal University of Technology, Akure, a pilot deployment of solar panels and smart meters reduced generator runtime by 45% and cut energy bills by nearly ₦20 million annually (Adeyemi & Bello, 2022). Such measures serve multiple Sustainable Development Goals: SDG 7 (clean energy), SDG 11 (sustainable cities), and SDG 13 (climate action). Policymakers must, however, update building codes and incentivize green construction through tax rebates and grants, ensuring these systems are widely adopted rather than confined to flagship projects.

In a comprehensive analysis, Eze et al. (2023) demonstrated a 35% reduction in energy consumption and a 24% drop in maintenance costs over 18 months. The study underscores the viability of implementing sustainable building practices within Nigerian universities to meet the targets of SDG 9. It also emphasized how energy-efficient buildings contribute to smart campuses by reducing carbon footprints while enhancing operational resilience. The researchers advocate for national policy inclusion and incentives to support campus retrofitting projects in alignment with global 5IR sustainability standards.

### **Smart Research and Innovation Hubs**

Innovation hubs embedded within the campus serve as critical bridges between academia and industry. Eze and Onoh (2023) describe how co-working spaces, mentorship programs, and seed funds linked to technology hubs can nurture entrepreneurial mindsets and commercialize research. The University of Lagos's partnership with a fintech incubator has produced over 15 spin-off

ventures in the past two years, securing intellectual property protection and raising early-stage capital (Alade, 2024). Yet, many Nigerian universities still struggle to channel research outputs into market-ready products due to weak commercialization frameworks and limited venture funding (Igbokwe-Dada, 2022). Strengthening these hubs through industry partnerships, commercialization offices, and dedicated innovation funding directly advances SDGs 8, 9, and 17, promoting sustainable industrial development and collaborative research networks.

Nwankwo and Aluko (2024) study found that IoT-enabled labs, high-speed internet, and blockchain-powered data repositories have increased research output and collaboration by 43%. Smart hubs have also attracted external funding and industry partnerships, further bridging the gap between academia and society. These spaces support interdisciplinary inquiry and scalable innovation by integrating AI tools, real-time data processing, and cloud-based computing infrastructure. As Nigeria pushes toward 5IR integration, the study emphasizes the role of smart hubs in fulfilling SDG 9 by promoting inclusive industrialization and fostering innovation ecosystems that are globally competitive and locally relevant.

### **Resilient Digital Infrastructure**

Resilient infrastructure requires reliable broadband, backup power, local data storage, and cybersecurity protocols. As Umeh and Okoli (2023) point out, most campuses still depend on ad-hoc fiber curls and offline file sharing. However, institutions like Babcock University now operate their own micro data centres and campus-wide Wi-Fi using solar-enabled uninterruptible power supplies, delivering 99.5% uptime even during grid failures (Ojo & Salami, 2023). Embedding network resilience and privacy safeguards aids compliance with NITDA and NUC guidelines, while bolstering SDG 9 and SDG 11. Still, replication across states requires sustained investment, training of IT staff, and public-private partnerships to deliver affordable, high-quality connectivity nationwide.

Ogundele and Emeh (2022) research analyzed network uptime, cybersecurity protocols, and disaster recovery systems. Results showed that institutions investing in cloud migration, edge computing, and redundant broadband systems experienced 90% fewer outages and data losses. The findings affirm that resilient infrastructure is central to creating smart universities equipped to adapt to both human and technical disruptions. Moreover, by aligning with 5IR principles, universities not only enhance learning continuity but also strengthen the digital backbone needed

for inclusive and scalable education. The study recommends a national digital resilience framework tailored to Nigeria's higher education sector as part of sustainable development infrastructure under SDG 9.

### **Data-Driven Decision-Making & Inclusive Access**

When campuses deploy sensors, learning analytics, and administrative dashboards, decision-makers can observe patterns, predict at-risk students early, and optimize resource allocation. As acknowledged by Adebajo and Musa (2022), institutions using predictive analytics saw a 12% increase in retention rates and better facility utilization. Yet, these systems are only effective if all students have digital access. The proliferation of low-cost tablets and subsidized internet bundles in underserved regions has led to more equitable engagement, as documented by Bello et al. (2023). Embedding digital equity initiatives like device loan schemes, subsidized broadband, and digital literacy programs ensures that SDG 10 (reduced inequality) and SDG 4 (quality inclusive education) accompany data-driven advancements, creating an ecosystem where technology uplifts, rather than excludes.

Bello and Chukwuma (2023) study showed a 31% increase in retention rates and a 19% improvement in academic outcomes for marginalized groups. The study highlights that data-informed interventions such as early alerts, adaptive assessments, and digital nudges can dismantle structural inequities in education delivery. By deploying decision intelligence systems, universities become more agile, evidence-based, and inclusive hallmarks of both SDG 9 and the 5IR agenda. The researchers argue for a federal mandate to institutionalize data governance frameworks and ensure data equity in Nigeria's higher education policy landscape.

### **Policy and Industry Collaboration**

Strategic infrastructure and innovation in higher education depend on cohesive policy frameworks and active engagement from industry. The National Universities Commission's draft digital infrastructure policy (NUC, 2024) outlines standards for ICT readiness and data governance, and the Ministry of Communications' Digital Nigeria agenda integrates tertiary institutions into national digital strategies. However, Olanrewaju and Chukwu (2023) argued that effective transformation demands horizontal collaboration: regulatory bodies (NUC, NITDA), utilities (NERA), telecom providers, and universities must align on building standards, research

commercialization policies, and digital skills. Successful cross-sectoral efforts, like the Covenant–Cisco–Interswitch alliance, offer models for replicating impact across states. By combining policy direction, funding, and private-sector innovation, Nigeria can cultivate smart campus ecosystems grounded in SDG 9's pillars of innovation, infrastructure, and industrial resilience.

Ibrahim and Ezeani (2024) revealed that collaborative frameworks such as public-private partnerships (PPPs), innovation sandboxes, and joint research councils led to faster deployment of edtech solutions and smart facilities. Institutions engaged in such partnerships reported a 45% increase in funding for infrastructural upgrades and a 29% rise in graduate employability due to aligned skill training. These collaborations operationalize SDG 9 by integrating infrastructure development with industrial needs, thereby positioning universities as hubs of national innovation. The study advocates for legislative support and coordinated policy instruments to institutionalize these partnerships and sustain 5IR transformation in Nigerian higher education.

## **Conclusion**

In Nigeria, the vision of building smart universities aligned with Sustainable Development Goal 9, *industry, innovation, and infrastructure*, is taking a new shape under the influence of the Fifth Industrial Revolution (5IR). This transformation involves embedding intelligent systems and automation into higher education environments. The development of integrated digital campuses with adaptive learning ecosystems is a cornerstone. These campuses use real-time data, cloud-based platforms, and personalized learning tools to enhance student engagement and performance. In recent surveys, universities implementing adaptive technologies reported a 32% increase in student retention and a 25% improvement in learning outcomes. Energy-efficient and sustainable buildings form the physical backbone of smart campuses. Institutions like Covenant University and UNILAG are adopting green architecture and solar-powered facilities, reducing energy costs by up to 40% annually while promoting eco-consciousness among students. These efforts tie directly into global climate goals while improving operational efficiency. Smart research and innovation hubs are also gaining ground. Through digital fabrication labs and collaborative spaces, Nigerian universities are nurturing problem-solvers and tech-driven startups. These hubs have contributed to a 19% rise in student-led research output over the last three years. Crucially, resilient digital infrastructure enables these systems to function smoothly. Reliable broadband, secured cloud systems, and campus-wide connectivity now serve as the veins of academic and

administrative operations. Data-driven decision-making has helped institutions respond faster to student needs, curriculum gaps, and infrastructural deficiencies. Equally important is inclusive access. Digital equity initiatives such as free Wi-Fi zones and subsidized e-learning devices are helping bridge socioeconomic divides, ensuring no student is left behind. The smart university model demands active policy and industry collaboration. Stakeholders must align regulatory frameworks and technological investments to meet long-term objectives. In all, leveraging smart infrastructure through 5IR tools is not just a luxury but a necessity for Nigerian universities to lead in innovation, inclusiveness, and global relevance.

### **Suggestions**

1. Smart university infrastructure in Nigeria should be strategically designed to integrate emerging technologies, enabling sustainable development while enhancing teaching, research, and administration in line with SDG 9 and 5IR.
2. Digital campuses in Nigeria should be developed with flexible, learner-centred platforms that promote personalized education, ensuring accessibility and collaboration while aligning with digital transformation goals of the 5IR.
3. University infrastructure should be redesigned using energy-efficient technologies and eco-friendly materials to reduce carbon footprint, supporting SDG 9 and promoting long-term sustainability in higher education environments.
4. Research hubs in Nigerian universities should be digitally connected, resource-rich, and innovation-driven, enabling interdisciplinary collaboration and advancing smart technologies to meet both national and global development challenges.
5. Reliable and secure digital infrastructure should be prioritized in universities to support continuous access to online learning, research, and administration, especially in underserved and technologically marginalized communities.
6. University governance should be guided by real-time data analytics that support transparency, student equity, resource allocation, and inclusive policies for underrepresented groups in the digital education landscape.
7. National policies should be aligned with industry needs, ensuring that universities collaborate with tech sectors and policymakers to co-create innovative solutions and prepare students for the 5IR workforce.

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