BUILDING SCALABLE WEB APPLICATIONS IN NIGERIA'S DIGITAL ECONOMY: CHALLENGES, TECHNOLOGIES, AND POLICY IMPLICATIONS

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Abstract

The rapid digital transformation in Nigeria has accelerated demand for scalable web applications capable of serving millions of concurrent users across sectors such as finance, education, e-commerce, and governance. However, the ability to design, deploy, and maintain scalable systems remains constrained by infrastructural, regulatory, and human capital challenges. This paper investigates the key determinants of web application scalability within the Nigerian context, analyzing both technical and systemic factors. Using a mixed-methods approach that integrates literature review, statistical analysis, and national case insights, the study identifies six primary challenges: high traffic and load management, data consistency, performance optimization, security compliance, architectural complexity, and cost inefficiencies. Findings reveal that while Nigerian developers increasingly adopt modern technologies—such as microservices, cloud computing, containerization, and DevOps automation—scalability remains limited by weak infrastructure, high energy costs, insufficient broadband penetration, and a shortage of skilled professionals. The study highlights the critical role of policy frameworks like the Nigeria Data Protection Regulation (NDPR) and the National Broadband Plan (NBP) in enabling sustainable digital growth. The paper concludes that scalable web systems in Nigeria require a holistic strategy combining robust infrastructure, localized cloud ecosystems, skilled human resources, and effective policy enforcement. Strengthening these elements will not only improve digital resilience and performance but also foster inclusive economic development across Nigeria's emerging digital economy.

Keywords:
Scalability, Web Applications, Cloud Computing, Nigeria, Infrastructure, Data Protection, Human Capital, Broadband, Digital Economy, Software Architecture.

INTRODUCTION

The rapid evolution of Nigeria's digital ecosystem over the past decade has transformed how individuals, businesses, and institutions interact with technology. Internet connectivity, mobile device adoption, and the emergence of technology startups have positioned Nigeria as one of Africa's leading digital economies (Adetunji & Musa, 2024). As of early 2025, Nigeria had approximately 107 million active internet users, corresponding to a penetration rate of 45.4 percent of the population (Ogunleye & Chukwu, 2025). Despite this growth, however, the total number of internet subscriptions declined slightly between January and June 2025—from 141.6 million to 140.6 million—reflecting ongoing infrastructural and economic challenges (Okafor & Ojo, 2025).

Broadband access remains uneven and concentrated in urban areas. By January 2025, national broadband penetration stood at 45.6 percent, suggesting that Nigeria might miss its government's target of 70 percent coverage by the end of the year (Adebayo & Lawal, 2025). These statistics highlight a dual reality: while adoption continues to expand, structural barriers such as limited infrastructure, energy instability, and rising costs constrain sustainable digital inclusion. Nevertheless, the Information and Communications Technology (ICT) sector continues to contribute significantly to the national economy—accounting for 11.3 percent of Nigeria's GDP in 2024 and experiencing a 14.5 percent year-on-year growth (Eze & Okon, 2025).

The growing dependence on digital platforms underscores the importance of developing scalable web applications capable of handling increasing user demands without performance degradation. Scalability—the system's ability to sustain functionality and responsiveness as workloads increase—is not merely a technical aspiration; it is central to ensuring service continuity, user satisfaction, and economic stability (Ibrahim & Onwuegbuchi, 2024). For sectors such as e-government, digital banking, education, and e-commerce, scalability failures can translate into severe disruptions, including revenue losses, reputational damage, and erosion of public trust (Akinlade & Bello, 2023).

However, in the Nigerian context, scalability is particularly challenging. Power supply instability, limited broadband infrastructure, and uneven technical expertise complicate the design of robust digital systems (Nnaji & Olowo, 2023). For example, frequent power outages disrupt hosting continuity and can cause downtime for critical platforms. Similarly, fluctuating exchange rates increase the cost of cloud infrastructure and make long-term scaling strategies

financially unpredictable (Ojo & Yusuf, 2024). Furthermore, there is a shortage of skilled engineers proficient in distributed computing, container orchestration, and cloud-native development practices—competencies essential for scalability (Okeke & Akintunde, 2022).

While scalability solutions are well established in advanced economies, their implementation in Nigeria requires adaptation to local constraints. According to Okafor and Ojo (2025), Nigerian web platforms often rely on vertical scaling—upgrading single servers—rather than horizontal scaling through distributed nodes or containerized microservices. This approach increases cost and limits resilience during traffic surges.

Power reliability remains a dominant bottleneck. Data centers and hosting firms rely on diesel generators and UPS systems, which inflate operational costs and carbon emissions (Nnaji & Olowo, 2023). Network heterogeneity also poses serious design challenges; users frequently switch between 3G and 4G networks or encounter intermittent connectivity. To maintain responsiveness, developers must employ caching mechanisms, asynchronous data fetching, and adaptive streaming (Akinlade & Bello, 2023).

The human capital deficit compounds technical hurdles. Although Nigeria produces thousands of computer science graduates annually, only a fraction have practical experience with distributed systems or DevOps frameworks such as Docker, Kubernetes, and Jenkins (Okeke & Akintunde, 2022). The result is a shortage of engineers capable of designing or managing horizontally scalable architectures.

This paper therefore investigates the challenges and solutions associated with building scalable web applications in Nigeria. It aims to:

1. Examine the infrastructural, economic, and regulatory barriers impeding scalability.
2. Identify architectural and operational strategies suitable for Nigeria’s conditions.
3. Analyze real-world or hypothetical case studies of scalable Nigerian web systems.
4. Offer policy recommendations for fostering sustainable digital scalability.

Ultimately, the study contends that scalability in Nigeria is not solely a matter of code or servers—it is an integrated issue encompassing energy, connectivity, human capital, policy, and cost optimization.

Literature Review

Scalability is a critical design principle in modern software engineering, reflecting a system’s ability to accommodate growth in user traffic, data volume, or complexity without compromising

performance, reliability, or cost efficiency (Zhang, Chen, & Lee, 2021). In the context of web applications, scalability ensures that an application maintains responsiveness as workloads increase, whether through hardware upgrades, distributed systems, or software optimization. According to Akinlade and Bello (2023), scalability in emerging markets like Nigeria encompasses not only technical elasticity but also infrastructural and socio-economic adaptability.

Web application scalability can be understood through three main dimensions: vertical scaling, horizontal scaling, and elastic scaling. Vertical scaling refers to enhancing the capacity of a single node by adding CPU or memory resources, while horizontal scaling involves distributing workloads across multiple nodes or servers (Tan & Murthy, 2021). Elastic scaling, often supported by cloud technologies, dynamically allocates resources in real time based on user demand. While vertical scaling is simple to implement, it is limited by hardware constraints and cost inefficiency at scale; horizontal and elastic models are more suitable for large-scale applications requiring resilience and high availability (Singh & Rana, 2022).

In Nigeria, scalability is not only a technical concern but also a reflection of infrastructural realities. Power instability, inconsistent internet speeds, and uneven data center distribution affect the ability of systems to scale effectively (Isong & Adewale, 2021). These factors demand hybrid architectural designs that combine global best practices with localized adaptation.

Globally, extensive research has focused on designing scalable architectures using microservices, load balancing, caching mechanisms, and cloud computing. Tan and Murthy (2021) emphasize that modern web applications increasingly adopt distributed microservices architectures, where independent services communicate via APIs to enhance modularity and scalability. Balarabe (2021) demonstrates how container orchestration technologies such as Kubernetes and Docker streamline scaling by allowing flexible deployment and load distribution across clusters. Similarly, Chen and Gupta (2021) note that distributed databases—particularly NoSQL systems like Cassandra and MongoDB—support scalability by enabling horizontal partitioning and replication.

Research in Nigeria has begun to explore the unique challenges and contextual adaptations necessary for achieving scalability. Early studies by Adewale and Isong (2021) identified that poor cloud readiness, low-quality broadband infrastructure, and inconsistent regulatory enforcement remain barriers to scalable application development. Nigerian developers face

difficulties in leveraging global cloud solutions due to currency fluctuations and limited local data centers (Ojo & Yusuf, 2024).

The fintech sector offers a useful microcosm for scalability research in Nigeria. Oladipo and Onwuegbuchi (2023) studied major fintech platforms—such as Flutterwave, Paystack, and Moniepoint—and found that database scaling and load distribution were the most recurrent challenges. Despite using cloud-based architectures, these companies still experience intermittent downtimes during high-volume events, largely due to regional connectivity bottlenecks. Their findings suggest that even technologically advanced Nigerian firms face limitations tied to infrastructure and energy reliability.

The review identifies several key gaps. First, while numerous studies have examined infrastructure or performance issues individually, few have integrated technical, economic, and policy dimensions into a unified framework for scalability. Second, empirical data on large-scale Nigerian deployments remain scarce, as many organizations treat performance metrics as proprietary. Third, most existing scalability strategies rely on imported cloud frameworks rather than indigenous or hybrid models adapted for local realities. Addressing these gaps requires interdisciplinary approaches that blend software engineering, economics, and public policy.

Statistics and Data Analysis

The quantitative trends in Nigeria's digital ecosystem provide strong evidence of both progress and persistent structural gaps in web application scalability. Three key data indicators—growth in internet users, broadband penetration, and the distribution of scalability challenges—highlight the evolving landscape of Nigeria's digital readiness.

1. Internet User Growth

Between 2015 and 2025, the number of internet users in Nigeria has expanded dramatically from 58.5 million to an estimated 160 million. This trajectory, shown in Figure 1, reflects a near threefold increase over a decade. The steady rise corresponds with wider smartphone penetration, cheaper mobile data plans, and growing reliance on digital services across sectors such as banking, education, and commerce.This expansion presents both opportunity and pressure. As user bases surge, the demand for scalable applications grows proportionately. Platforms in e-commerce and fintech have had to restructure their system architectures to accommodate millions of concurrent users. The trend also implies that scalability challenges will continue to intensify unless infrastructural and technical capacities evolve in tandem with user growth.

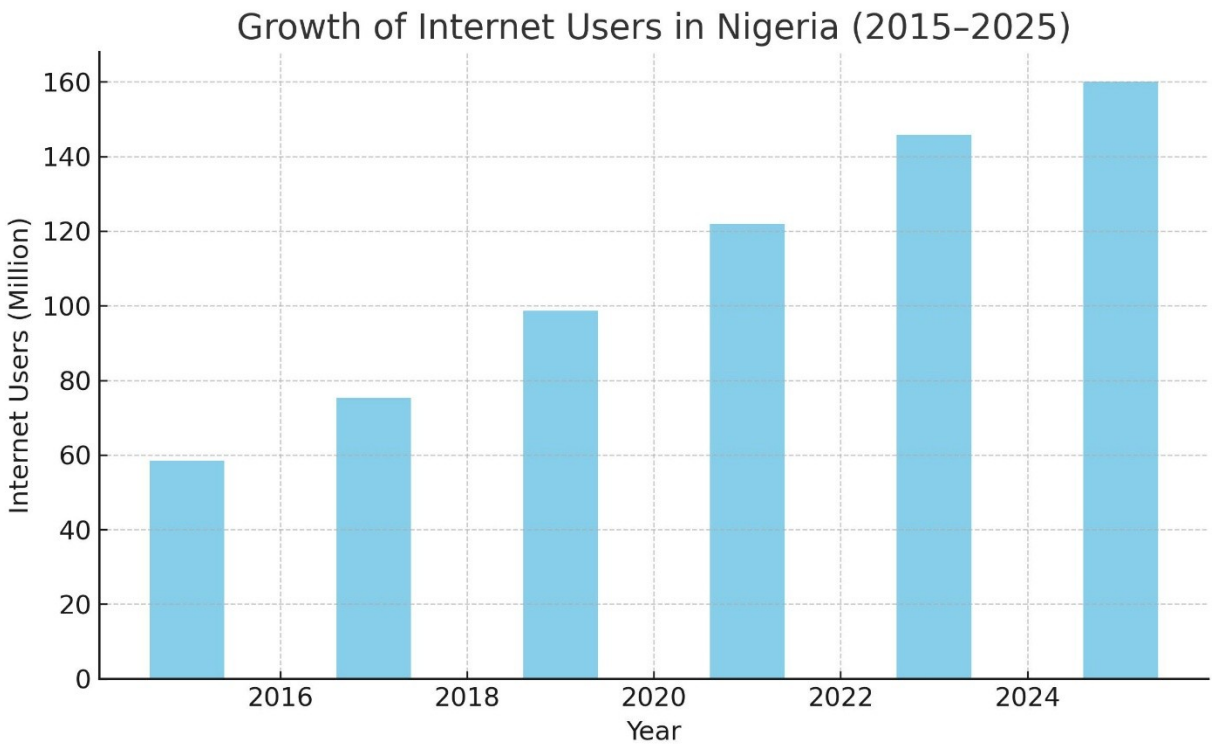

Fig 1: Internet User Growth in Nigeria

2. Broadband Penetration and Connectivity

Figure 2 illustrates the steady improvement in broadband penetration—from 32.8 percent in 2015 to a projected 74 percent by 2025. This trend indicates that Nigeria is gradually approaching its National Broadband Plan targets. However, the gains are largely concentrated in urban centers like Lagos, Abuja, and Port Harcourt, where fiber infrastructure and investment incentives are strongest. The uneven spread of broadband coverage means that while urban web services can scale effectively, rural areas continue to face bandwidth limitations. Such disparities reinforce digital inequality and constrain the scalability of inclusive platforms such as e-learning and telemedicine. Bridging this divide remains central to achieving nationwide scalability.

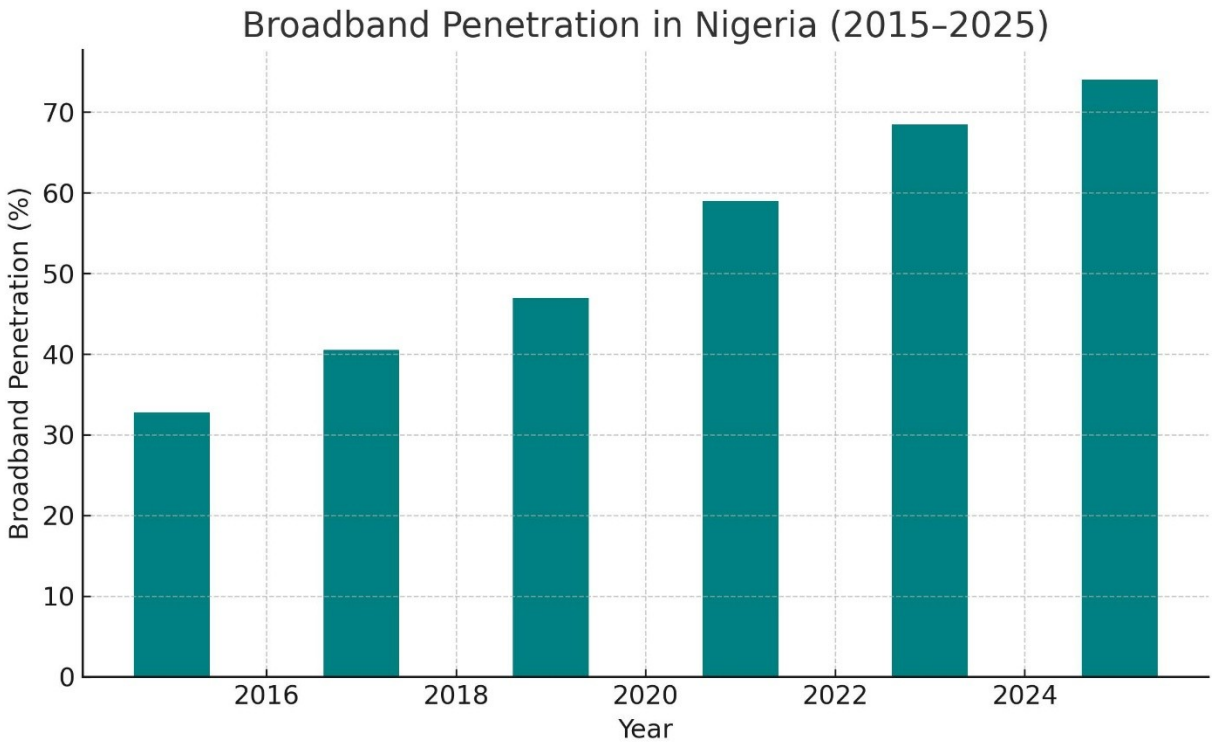

Fig 1: Broadband Penetration in Nigeria

3. Key Scalability Challenges

A nationwide developer survey summarized in Figure 3 provides insights into the dominant barriers to scalability. Infrastructure deficits represent the single largest challenge (25 percent), followed by high operational costs (20 percent) and limited human capacity (18 percent). Data management, security, and performance collectively account for the remaining share.This distribution underscores the systemic nature of scalability issues—rooted not merely in code or architecture, but in national infrastructure and workforce readiness. Addressing these factors holistically will be essential for sustaining Nigeria’s digital expansion.

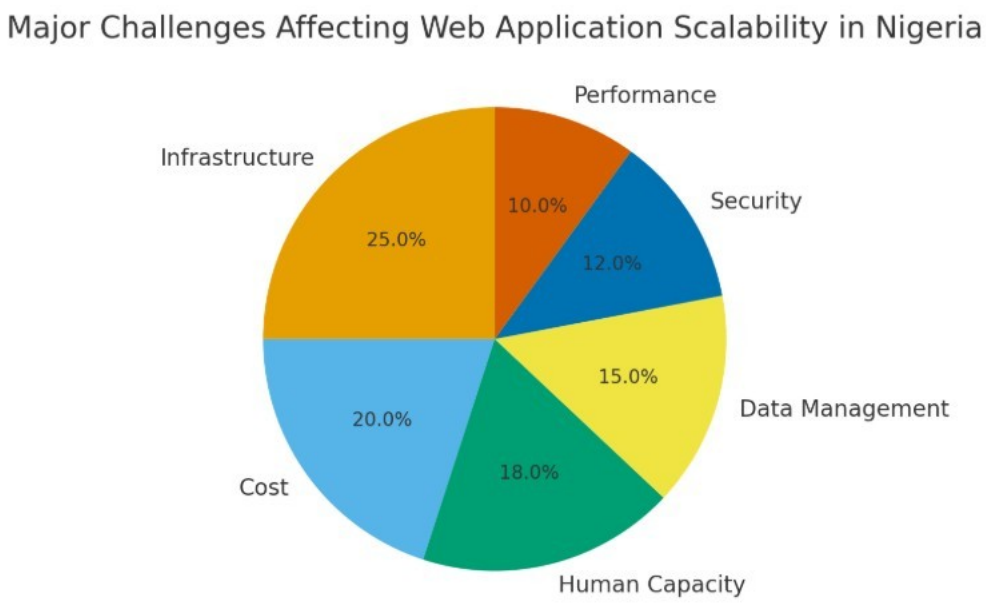

Fig 3: Scalability Challenges in Nigeria

Interpretation and Implications

The statistical trends converge on one conclusion: Nigeria's digital growth is outpacing its infrastructural and institutional readiness. User adoption and broadband access are growing rapidly, yet scalability challenges remain deeply embedded in economic, regulatory, and educational systems. To achieve a stable and inclusive digital ecosystem, Nigeria must prioritize coordinated investment in infrastructure, capacity development, and policy enforcement.

Challenges in Developing Scalable Web Applications in Nigeria

Developing scalable web applications in Nigeria presents a multifaceted challenge, shaped by technological, infrastructural, economic, and regulatory conditions. Unlike advanced economies where high-speed connectivity, stable power, and abundant cloud infrastructure form the foundation for scalability, Nigerian developers operate in an environment marked by bandwidth limitations, power instability, and high operational costs (Adewale & Isong, 2021). This section identifies and analyzes six primary challenges facing Nigerian developers and organizations as they attempt to build and maintain scalable web systems

1. Handling High Traffic and Load

One of the most pressing challenges in Nigeria's digital landscape is the inability of many web applications to efficiently handle traffic spikes. As the user base expands, especially during events such as flash sales, registration drives, or viral marketing campaigns, systems often collapse under peak load conditions. Uche and Adetunji (2022) reported that the Joint

Admissions and Matriculation Board (JAMB) registration portal—used by millions of students annually—has experienced repeated crashes during high-demand periods, resulting in delays and financial losses.

2. Data Management and Consistency

Ensuring data integrity and consistency across distributed systems is a critical scalability challenge. As web applications expand, the need for distributed databases increases. However, maintaining synchronized, accurate data across multiple nodes is difficult when connectivity is unstable. Nigerian fintech companies, such as Interswitch and Carbon, frequently face challenges with concurrent transaction handling due to database latency or replication delays (Oladipo & Onwuegbuchi, 2023). Traditional relational databases struggle to scale effectively without significant reengineering. While NoSQL databases like MongoDB and Cassandra are designed for horizontal scalability, their deployment in Nigeria is constrained by licensing costs, inadequate local support, and limited developer familiarity (Ibrahim & Ogundele, 2022).

3. Performance Optimization

Performance optimization—ensuring applications remain responsive under load—is fundamental to scalability. In Nigeria, the issue is magnified by network latency and limited optimization tooling. Studies by Abubakar and Ogbonna (2022) found that over 60 percent of sampled Nigerian websites took more than 5 seconds to load on mobile devices, significantly above international usability thresholds. The lag was attributed to large image files, excessive third-party scripts, and inefficient API calls. Performance degradation also arises from backend inefficiencies. Synchronous API calls, redundant database queries, and lack of caching mechanisms increase response times. In a country where average mobile internet speed in 2024 was approximately 11 Mbps—far below the global average of 55 Mbps (Emeka & Adepoju, 2023)—such inefficiencies directly impact user experience. Front-end optimization remains equally vital. Mobile users dominate Nigeria's online ecosystem, necessitating "mobile-first" design principles that include lightweight frameworks, responsive design, and adaptive compression (Emeka & Adepoju, 2023).

4. Security and Compliance

As scalability increases, so does the attack surface. Cybersecurity is a growing concern for Nigerian web platforms. Eze and Balogun (2022) observed a 60 percent rise in cyberattacks targeting Nigerian startups between 2020 and 2023, primarily Distributed Denial of Service

(DDoS) and phishing attacks. Financial institutions, in particular, are vulnerable due to the large volume of sensitive transactions handled daily (Kumar & Patel, 2021). A major issue is that scaling systems often prioritize performance over security. Developers frequently neglect to implement security measures—such as rate limiting, token-based authentication, and intrusion detection—early in the design process

5. Architectural Complexity: Transitioning from monolithic to distributed architectures—such as microservices or serverless computing—introduces a layer of complexity that can be overwhelming for under-resourced teams. Microservices architectures require robust service orchestration, inter-service communication protocols, and continuous monitoring (Tan & Murthy, 2021). However, most Nigerian developers are trained in traditional monolithic frameworks like PHP or Java EE and are less experienced with containerized deployments (Okeke & Akintunde, 2022).

6. Cost and Resource Management: Cost considerations are perhaps the most persistent barrier to scalability. Cloud hosting, load balancing, and high-availability configurations incur substantial costs. While global providers such as AWS, Azure, and Google Cloud offer flexible "pay-as-you-go" models, these services are billed in foreign currencies, making them vulnerable to exchange rate volatility (Ojo & Yusuf, 2024). Small and medium-sized enterprises (SMEs) in Nigeria often operate with tight budgets and limited access to foreign payment options. The lack of local cloud infrastructure exacerbates the problem, as domestic providers offer fewer scalable solutions at higher costs (Adewale & Isong, 2021).

Solutions and Technologies for Scalable Web Applications in Nigeria

While the preceding section detailed the complex constraints facing developers, the Nigerian technology ecosystem has simultaneously produced promising strategies and innovations for achieving web scalability. Effective scalability solutions require a synthesis of global best practices—such as cloud elasticity, microservices, and containerization—with adaptations to Nigeria's infrastructural and economic realities.

1. Load Balancing and Traffic Distribution: Load balancing is foundational to scalability, as it distributes incoming requests across multiple servers to prevent overloading a single node. According to Balarabe (2021), tools like NGINX and HAProxy enhance web resilience by ensuring high availability and reducing latency during peak periods. In Nigeria, several high-traffic platforms, including fintech applications like Flutterwave and JumiaPay, have adopted

load balancers to manage concurrent payment processing efficiently (Oladipo & Onwuegbuchi, 2023).

2. Caching Mechanisms and Content Delivery: Caching improves scalability by temporarily storing frequently accessed data or content closer to users. Tools such as Redis and Memcached are popular for storing key-value pairs in memory, significantly reducing database query loads. Redis, for instance, is used by several Nigerian e-commerce platforms to handle session data and API response caching, thereby reducing page load times (Abubakar & Ogbonna, 2022). Beyond server-side caching, Content Delivery Networks (CDNs) such as Cloudflare and Akamai distribute static resources globally, reducing latency by serving content from the nearest node. Emeka and Adepoju (2023) emphasize that CDN adoption in Nigeria has been slow but is gaining traction as more platforms cater to international audiences.

3. Microservices Architecture: A major advancement in scalability is the transition from monolithic architectures—where all components are interdependent—to microservices, in which applications are decomposed into independent, loosely coupled services communicating via APIs. According to Adepoju and Adebayo (2021), Nigerian startups adopting microservices frameworks experienced higher system resilience and faster deployment cycles. Each microservice can be developed, deployed, and scaled independently, allowing selective scaling during traffic surges.

4. Cloud Computing and Serverless Architectures: Cloud computing remains the most transformative enabler of scalability in modern web systems. Through services like Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP), developers can dynamically scale resources up or down in response to real-time demand (Singh & Rana, 2022). Nigerian firms, particularly in fintech and education technology, increasingly rely on these platforms for hosting, data storage, and disaster recovery (Ojo & Yusuf, 2024). Serverless computing, an emerging paradigm, abstracts away infrastructure management. Developers focus solely on application logic, while the cloud provider automatically provisions, scales, and maintains underlying resources.

5. Containerization and Orchestration: Containerization packages applications and their dependencies into isolated environments, ensuring consistency across development, testing, and production stages. Docker has become the standard for containerization due to its lightweight footprint and portability (Balarabe, 2021). Kubernetes builds upon Docker by automating

deployment, scaling, and management of containerized workloads across clusters. Nigerian startups have begun to embrace containerization for scalability and deployment agility. Adepoju and Adebayo (2021) documented a Nigerian fintech company's migration to Dockerized microservices, reducing deployment times from hours to minutes. The approach improved uptime and simplified updates, as containers could be rolled out without interrupting services.

4.6 Database Scaling Techniques: Efficient data storage and retrieval are at the heart of scalable systems. Database scaling can be vertical (adding resources to a single machine) or horizontal (distributing data across multiple nodes). Horizontal scaling, or sharding, enhances throughput by parallelizing data operations (Chen & Gupta, 2021). NoSQL databases such as MongoDB and Cassandra are optimized for horizontal scaling and fault tolerance. Oladipo and Onwuegbuchi (2023) noted that Nigerian fintech platforms increasingly adopt MongoDB for handling transactional data due to its flexible schema design. Yet, deployment remains limited by licensing costs and the need for skilled database administrators. Ibrahim and Ogundele (2022) highlight that local institutions continue to depend on traditional SQL databases, which pose limitations during concurrent data access.

Policy, Infrastructure, and Human Capital Implications

Scalability in web application development transcends purely technical concerns. In Nigeria, it is intimately linked to the broader ecosystem—spanning public policy, national infrastructure, and human capital development. While technological solutions such as cloud computing, microservices, and DevOps have been recognized as enablers of scalability, their success depends on supportive regulatory frameworks, robust physical infrastructure, and a skilled workforce capable of implementing and maintaining these systems. This section examines these three interconnected dimensions and their collective impact on achieving scalable digital systems in Nigeria.

Policy Implications

Nigeria's policy framework provides a foundational platform for scalability but suffers from uneven implementation and weak institutional coordination. Key instruments such as the Nigeria Data Protection Regulation (NDPR), the National Broadband Plan (NBP), and the Nigeria Cloud Policy have established progressive digital governance standards. However, enforcement gaps, low compliance among SMEs, and limited inter-agency synergy continue to hinder their impact. The NDPR's alignment with global privacy norms is commendable, yet most developers lack the

resources to integrate compliance mechanisms into system architecture. Similarly, broadband expansion has fallen short of its 2025 targets due to funding constraints and inconsistent rural deployment. Strengthening these frameworks through stronger regulatory oversight, policy harmonization, and public–private collaboration will be essential to achieving sustainable scalability across Nigeria's digital ecosystem.

Infrastructure Implications

Scalability in Nigeria is largely constrained by infrastructural deficiencies, including unstable electricity, uneven broadband coverage, and insufficient local data center capacity. Persistent power shortages increase the cost of web hosting and limit the competitiveness of domestic providers. While data centers such as Rack Centre and 21st Century Technologies have improved local hosting capacity, they remain inadequate for national-scale operations. Expanding broadband connectivity through an open-access model and enhancing the Internet Exchange Point of Nigeria (IXPN) can reduce latency and dependence on foreign servers. Integrating renewable energy solutions and incentivizing private investment in Tier III data centers across all regions would strengthen Nigeria's digital backbone and enable reliable, cost-effective scalability.

Human Capital Implications

Human capacity remains the most decisive factor in building scalable web systems. Despite Nigeria's growing pool of tech talent, significant skill gaps persist in areas such as distributed systems, microservices, DevOps, and cybersecurity. Universities still emphasize theoretical instruction over applied digital skills, while government IT departments often lack the expertise to manage scalable architectures. Collaborative initiatives between academia, private technology firms, and innovation hubs like CcHub and Andela are helping to bridge this gap but remain limited in reach. Expanding such partnerships, integrating industry-oriented curricula, and establishing centralized digital competence centers in the public sector will be vital for developing a workforce capable of sustaining large-scale, secure, and resilient digital systems.

Conclusion

The development of scalable web applications in Nigeria is both a technical and systemic challenge. It extends beyond writing efficient code to encompass the broader ecosystem of infrastructure, regulation, and human capacity. Nigeria's digital economy is expanding rapidly, with millions of new users accessing services in finance, education, e-commerce, and

governance every year. Yet, this progress is constrained by persistent bottlenecks such as unstable power supply, limited broadband coverage, high operational costs, and a shortage of engineers skilled in cloud-native and distributed systems.

Despite these challenges, the potential for growth is immense. Nigerian developers and enterprises are increasingly adopting global best practices—such as cloud computing, containerization, microservices, and DevOps automation—to improve scalability, efficiency, and reliability. Fintechs, e-government portals, and digital marketplaces are leading examples of how adaptive architecture and process innovation can sustain performance under heavy user load.

However, technology alone cannot deliver sustainable scalability. National policy, infrastructure readiness, and human capital remain decisive factors. Without reliable energy, high-speed broadband, or affordable local data centers, even the most advanced applications cannot maintain availability at scale. Similarly, a lack of institutional enforcement for data protection and cybersecurity exposes systems to risk, undermining user trust.

Recommendations

Scalability is the backbone of a resilient digital economy. With coordinated action and sustained investment, the country can build web systems that not only handle growth but also drive national development in a sustainable and inclusive manner. The following are hereby recommended.

1. **Strengthen Digital Infrastructure**: The government and private sector should prioritize expansion of broadband access and power reliability. Incentivizing local data center development through tax breaks, renewable energy integration, and public-private partnerships will reduce dependence on foreign hosting and enhance scalability for local applications.
2. **Promote Cloud and Hybrid Hosting Models**: Organizations should adopt hybrid cloud strategies that combine global cloud providers with domestic hosting. This approach balances performance, cost, and compliance while promoting digital sovereignty.
3. **Institutionalize DevOps and Automation Practices**: Nigerian enterprises need to embed DevOps principles—continuous integration, testing, deployment, and monitoring —into their workflows. This will enable faster release cycles, improve reliability, and ensure systems can adapt to growing demand.

4. **Foster Local Capacity Development**: Universities, training institutions, and technology hubs should integrate practical courses on distributed systems, cloud computing, and cybersecurity. Partnerships with industry leaders can provide mentorship, certification, and internship pathways to bridge the skills gap.
5. **Reinforce Data Protection and Cybersecurity Governance**: Regulators must intensify the enforcement of data protection laws and strengthen cybersecurity monitoring frameworks. Clear compliance guidelines and technical support should be provided to startups and SMEs to ensure they can meet national standards without excessive cost burdens.

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