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Development of an Integrated Drone–IoT Framework for Sustainable and Climate-Resilient Progress Monitoring and Quantity Measurement in Nigerian Construction Projects A Review of Enabling Technologies, Evidence and Implementation Pathways

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ABSTRACT :

Construction progress monitoring and quantity measurement in Nigeria remain predominantly manual, time-consuming, and vulnerable to the disruptive effects of an increasingly volatile climate, including flooding, extreme heat, and erosion. This paper reviews the empirical and conceptual literature on unmanned aerial vehicle (UAV/drone) applications, Internet of Things (IoT) sensor networks, and climate resilience strategies within the Nigerian construction sector to propose an integrated drone–IoT framework for climate-resilient progress monitoring and quantity measurement. Drawing on eight empirical and review sources published between 2023 and 2026, the paper finds that UAV adoption on Nigerian construction sites remains low (approximately one-fifth of surveyed professionals in one case study), despite evidence that adoption measurably accelerates project delivery. The paper identifies technology- and organisation-related factors as the most critical drivers of UAV uptake, while regulatory ambiguity, security concerns, and staff resistance are recurring barriers. Separately, the reviewed climate literature documents substantial projected reductions in the service life of common Nigerian building materials under current climatic trends. The paper proposes a four-layer conceptual framework, comprising field data capture (drone and IoT sensors), connectivity and edge processing, cloud data fusion and analytics, and decision-support reporting, through which drone-derived volumetric and progress data can be fused with continuous ground-based IoT sensing to support both physical progress tracking and climate-risk early warning. The paper concludes that while the constituent technologies are individually well-documented in the Nigerian context, an empirically validated integrated drone–IoT framework has not yet been reported, and sets out directions for its future development and field validation.

Keywords: *unmanned aerial vehicles; Internet of Things; construction progress monitoring; quantity surveying; climate resilience; Nigerian construction industry*

1. Introduction

Construction progress monitoring and quantity measurement are core project-control functions on which cost certification, payment valuation, and schedule management depend. In Nigeria, these functions are still largely performed through manual site inspection, tape and level surveys, and periodic photographic records, methods that are slow, labour-intensive, and prone to human error and dispute. At the same time, Nigeria's construction sector is increasingly exposed to climate-related disruption: rising temperatures, intensifying rainfall in the south, and greater frequency of flood and erosion events are already measurably reducing the service life of common building materials such as concrete, steel, timber and masonry.

Two digital technologies have emerged internationally as candidate solutions to the progress-monitoring challenge. Unmanned aerial vehicles (UAVs, or drones) equipped with high-resolution and multispectral cameras enable rapid, repeatable aerial capture of site conditions, from which photogrammetric 3D models and volumetric quantities can be derived. The Internet of Things (IoT) enables continuous, low-cost ground-based sensing of variables such as temperature, humidity, structural strain, and flood level, complementing the periodic, image-based data drones provide. Internationally, a small but growing body of work has begun to explore the fusion of these two technologies (often termed AIoT-powered drones) for construction monitoring, though this integration remains comparatively under-reported.

Within Nigeria specifically, the literature on UAVs in construction and the literature on climate resilience in construction have so far developed largely in parallel, with limited cross-referencing, and no widely reported study proposes or tests an integrated drone–IoT framework purpose-built for the combined tasks of progress monitoring, quantity measurement, and climate-risk management. This paper addresses that gap. Its objectives are threefold: (i) to review the empirical evidence on UAV adoption, application, and barriers within the Nigerian construction industry; (ii) to review evidence on climate resilience challenges and strategies relevant to Nigerian construction materials and practice; and (iii) to synthesise this evidence into a conceptual, four-layer drone–IoT framework, together with an agenda for its future development and field validation.

2. Materials and Methods

This paper adopts a narrative review design appropriate to synthesising a technologically diverse, still-emerging literature spanning UAV/drone applications, IoT sensing, and climate resilience in construction, and to proposing a conceptual system architecture on that basis.

2.1 Search Strategy and Sources

Peer-reviewed journal articles, conference proceedings, and institutional repository theses addressing UAV/drone use in construction, IoT applications in the built environment, or climate resilience of construction materials and practice, with explicit relevance to Nigeria, were located through academic search and repository platforms. Search terms combined "drone," "UAV," "IoT," "construction progress monitoring," "quantity surveying," "climate resilience," and "Nigeria," together with supplementary terms for specific states and case-study locations. A supplementary, non-Nigeria-specific search located one recent systematic review of AIoT-powered drones in construction globally, included for its methodological and technical relevance to framework design.

2.2 Inclusion and Exclusion Criteria

Sources were included if they (a) examined UAV/drone use, IoT sensing, or climate-resilience practice within a construction or built-environment context, (b) reported an identifiable empirical finding, review synthesis, or conceptual model, and (c) were either set in Nigeria or, in the single global-review case, directly informed the technical design of the proposed framework. Eight sources meeting these criteria, published between 2023 and 2026, form the evidence base summarised in Table 1.

2.3 Analytical Approach

For each included source, the setting, method, and principal finding were extracted and tabulated. Findings were grouped into two thematic strands, UAV/drone application and adoption on one hand, and climate-resilience challenges and strategies on the other, and used to derive a functional mapping of monitoring requirements against drone and IoT capabilities (Table 2). This mapping, together with the identified technical and organisational barriers, was then used to construct the four-layer conceptual framework presented in Figure 1 and the descriptive comparison of reported UAV adoption and application emphasis presented in Figure 2.

3. Results

3.1 Overview of the Reviewed Evidence Base

Table 1 summarises the eight sources retained for synthesis. Five sources report primary empirical data collected in Nigeria (Enugu, Akwa Ibom, Abuja and Benin City), one is a Nigeria-focused systematic literature review, one is a global systematic review of AIoT-powered drones included for its technical relevance, and one is a materials-science analysis of Nigerian Meteorological Agency (NIMET) climate data. No source in the reviewed set reported an integrated drone–IoT system implemented and tested on a Nigerian construction site, confirming the framework gap this paper addresses.

Table 1. Summary of Reviewed Studies on UAV/Drone Applications and Climate Resilience in Nigerian Construction

Study (Author, Year)	Focus / Setting	Method	Key Finding Relevant to This Review
Okaka, Ajaelu & Ezeokolie (2023)	Quadcopter drones for monitoring/reporting building construction stages, Enugu Metropolis, Nigeria	Descriptive survey; 242 respondents (Taro Yamane); site observation	Only 21% of professionals used drones; adoption significantly fast-tracked project delivery ($p = 0.0019$)
Aliu, Aghimien, David & Oke (2024)	Critical drivers of UAV deployment for construction in Nigeria	Questionnaire survey; Technology-Organization-Environment (TOE) framework; Fuzzy Synthetic Evaluation	Technology- and organization-related factors are the most critical drivers; construction monitoring and site surveying are priority UAV application areas
Etimi, Amade, Enyinna & Muhammad (2024)	Challenges of UAV application in construction project monitoring, Akwa Ibom State, Nigeria	Qualitative descriptive cross-sectional design; interviews with project managers/engineers	Lack of policy, security concerns, and staff resistance are the main barriers to UAV deployment on site.
Sajid, Ullah, Qayyum, Masood, Inam & Maqsoom (2025)	AIoT-powered drones in the construction industry (global systematic review)	PRISMA-guided systematic review of 33 articles (Scopus, Web of Science)	Identifies quality/progress monitoring, site surveying, logistics, and disaster management as core AIoT-drone application clusters; integration with IoT remains under-reported

Unegbu, Yawas, Dan-asabe & Alabi (2024)	Climate resilience in Nigerian construction: systematic review of strategies and outcomes	Systematic review of 50 sources (journal articles, conference papers, official reports)	Flood barriers, green roofs and sustainable materials mitigate climate risk, but financial, regulatory and awareness gaps persist.
Okotete (2026)	Impact of climate change on durability of building materials in Nigeria	Analysis of 60 years (1965–2024) of NIMET meteorological data across three climatic zones	Concrete, steel, timber and masonry all show accelerated degradation (20–50% service-life reduction) under current climatic trends, especially in southern Nigeria
Ebekozien, Aigbavboa, Samsurijan, Ahmed, Adekunle, Akinradewo & Awo-osagie (2024)	Construction practitioners' preparedness to mitigate climate change in Nigeria	Qualitative interviews with 17 practitioners in Abuja and Benin City	Preparedness among practitioners remains low; recommends stakeholder sensitisation and integration of climate interventions into contract administration

3.2 UAV Adoption, Drivers and Barriers

The Enugu Metropolis case study found that only 21% of surveyed construction professionals had used drones on site, against 76% who had not, indicating generally low adoption; nonetheless, statistical testing in the same study rejected the null hypothesis that drone use does not fast-track project delivery ($p = 0.0019$), indicating a measurable positive effect where adoption does occur. The Technology-Organization-Environment analysis of UAV deployment drivers found that technology- and organisation-related factors, rather than external/environmental factors, were the most critical determinants of adoption, with construction monitoring and site surveying identified as priority application areas. The Akwa Ibom State study, examining UAV application specifically for construction project monitoring, found that lack of clear policy, security concerns, and employee resistance were the principal barriers reported by senior project managers and engineers. These findings are illustrated in Figure 2.

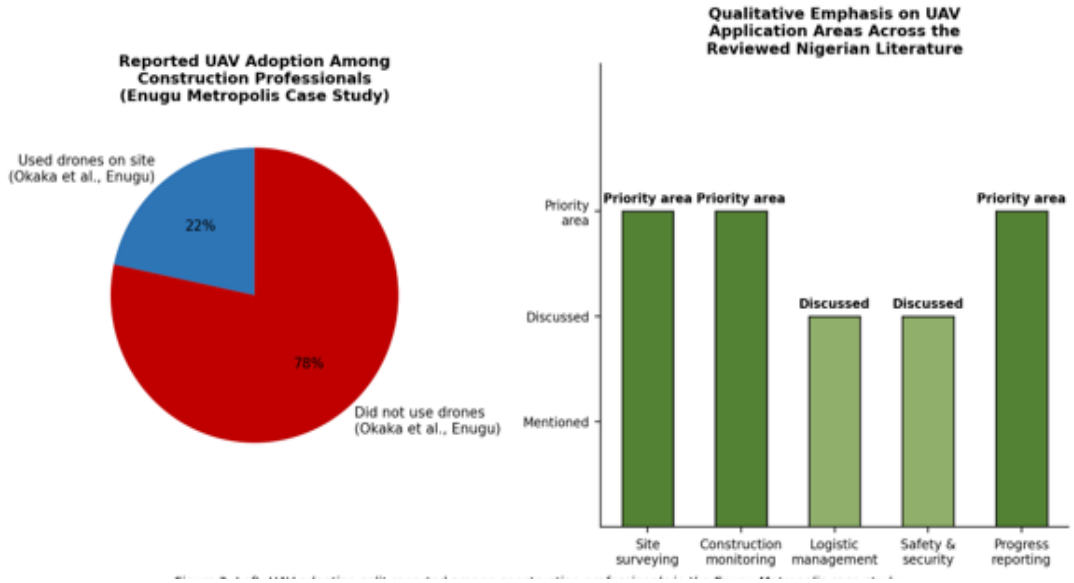


Figure 1 above compares the reported UAV adoption split from the Enugu Metropolis case study with a qualitative synthesis of the emphasis placed on different UAV application areas across the reviewed Nigerian literature.

3.3 Climate Resilience Evidence Relevant to Construction Monitoring

The Nigeria-focused systematic review of climate resilience strategies, synthesising 50 sources, found that flood barriers, green roofs and sustainable materials are effective mitigation measures, but that financial constraints, regulatory gaps and low awareness continue to limit their adoption. The 60-year NIMET climate-trend analysis found that concrete, steel, timber and masonry, the four building materials it examined, all face accelerated degradation under current climatic conditions relative to historical design assumptions, with reported service-life reductions ranging from approximately 20% to 50% depending on material and zone, and with southern Nigeria experiencing the most severe combined effects. Separately, qualitative interviews with practitioners in Abuja and Benin City found generally low preparedness among construction professionals to mitigate climate-change impacts on their projects. Taken together, these findings indicate a clear and growing need for continuous, sensor-based environmental monitoring integrated directly

into construction project-control systems, rather than reliance on periodic manual inspection or historical climate assumptions alone.

3.4 A Proposed Integrated Drone–IoT Framework

Building on the functional requirements identified above, and on the systematic review of AIoT-powered drones internationally (which identifies quality/progress monitoring, site surveying, logistics and disaster management as core application clusters but notes that AI-IoT-drone integration remains under-reported), this paper proposes the four-layer conceptual framework shown in Figure 1: a field data-capture layer (drone imagery plus ground IoT sensors and static ground-control references); a connectivity and edge-processing layer; a cloud data-fusion and analytics layer combining BIM/4D model comparison with AI-based volumetric quantity take-off; and a decision-support layer producing progress dashboards, automated quantity/payment certificates, and climate-risk early-warning alerts, with a feedback loop back to site operations and subsequent capture missions.

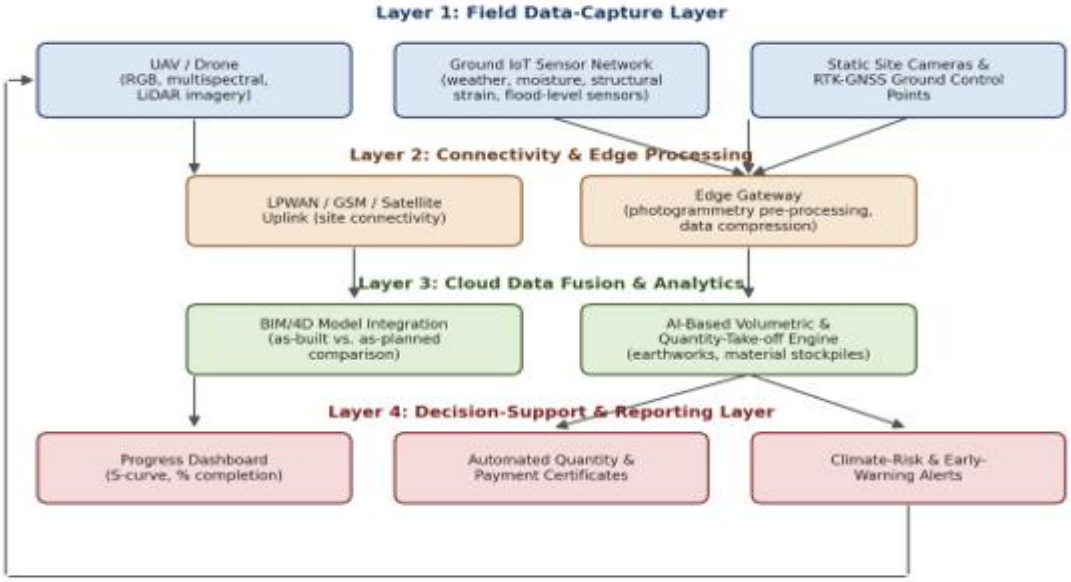


Figure 2 above presents the proposed four-layer drone–IoT framework architecture, from field data capture through to decision-support reporting and the feedback loop to site operations.

Table 2 maps five core monitoring requirements identified in the reviewed literature against the complementary contributions of drone and IoT components within this framework, illustrating why an integrated approach is expected to outperform either technology used in isolation.

Table 2. Mapping of Construction Monitoring Requirements to Drone and IoT Capabilities

Monitoring Requirement	Drone (UAV) Contribution	IoT Sensor Network Contribution
Physical progress tracking	Periodic aerial imagery and photogrammetric 3D models for as-built vs. as-planned comparison	Continuous equipment/asset-location tagging and site-access logging between flights
Quantity / volumetric measurement	Volumetric survey of stockpiles, earthworks and excavation via orthomosaic and point-cloud analysis	Weighbridge/flow sensors and RFID tagging for delivered-material verification
Climate-risk exposure	Post-event aerial damage assessment (flooding, wind, erosion)	Continuous rainfall, temperature, humidity, wind and flood-level sensing for early warning
Material durability/curing conditions	Thermal/multispectral imaging for surface-level moisture and defect indicators	Embedded concrete-temperature, humidity and strain sensors for real-time curing and structural-health data
Safety and site security	Aerial surveillance of hazardous or inaccessible zones	Wearable and perimeter sensors for worker location and intrusion detection

4. Conclusion

The reviewed literature demonstrates that the individual building blocks of an integrated drone–IoT framework are each reasonably well evidenced within Nigeria: UAVs measurably accelerate project delivery where adopted, though adoption itself remains low and constrained by policy, security and organisational barriers; and climate change is already measurably shortening the service life of Nigeria's principal building materials, with construction practitioners' preparedness to respond currently limited. However, no reviewed source reports a Nigerian construction project on which drone-based aerial monitoring and ground-based IoT sensing have been combined into a single, purpose-built progress-monitoring and quantity-measurement system. This paper's proposed four-layer framework, linking field data capture, connectivity, cloud-based data fusion, and decision-support reporting, offers a conceptual bridge between these separately well-documented technologies and Nigeria's stated need for climate-resilient project control. Realising this framework in practice will require addressing the adoption barriers identified in the reviewed literature, particularly regulatory clarity, organisational readiness, and practitioner training, alongside the technical work of framework validation.

5. Research Directions

Building on the gaps identified in this review, four directions for future research are proposed:

1. Field pilot and validation studies. The proposed framework should be implemented and tested on live Nigerian construction projects, comparing drone–IoT-derived progress and quantity measurements against conventional survey methods for accuracy, cost, and time savings.
2. Regulatory and policy research. Given that regulatory ambiguity was identified as a primary barrier to UAV adoption, further work should examine how Nigerian Civil Aviation Authority (NCAA) drone regulations and emerging climate-smart building codes can be harmonised to support routine, integrated drone–IoT deployment on construction sites.
3. Cost-benefit and organisational-readiness studies. Future research should quantify the cost-benefit case for small and medium-sized Nigerian construction firms adopting integrated drone–IoT systems, and examine the organisational and training interventions needed to overcome the staff resistance reported in the reviewed literature.
4. Zone-specific climate-risk calibration. Because reviewed climate-durability evidence shows materially different degradation patterns across Nigeria's climatic zones, future framework development should calibrate the IoT sensing and early-warning thresholds separately for each zone, rather than applying a single national configuration.

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