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ENVIRONMENTAL PERFORMANCE AND DURABILITY OF STRUCTURAL BUILDING MATERIALS IN ABUJA MUNICIPAL AREA COUNCIL, NIGERIA

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Abstract

This study investigates the environmental performance and durability of building material components in Abuja Municipal Area Council (AMAC), Abuja, Nigeria, with emphasis on the influence of local climatic conditions on structural integrity and service life. Using a mixed-method approach, data were collected from 348 buildings through field surveys, laboratory tests, environmental monitoring, and interviews with 30 construction professionals. Laboratory analyses revealed that concrete samples achieved an average compressive strength of 38.5 MPa (SD = 4.2), exceeding the Nigerian Industrial Standard minimum of 32.5 MPa, while water permeability averaged 2.3×10^{-12} m/s, indicating good durability. Granite aggregates exhibited low water absorption (0.65%) and porosity (0.8%), whereas limestone aggregates had higher absorption (1.8%) and porosity (3.5%), contributing to moderate surface weathering. Steel reinforcement showed an average corrosion rate of 0.15 mm/year with 25% surface rust coverage, particularly in areas with high rainfall and humidity. Correlation analysis indicated a strong positive relationship between aggregate water absorption and weathering severity ($r = 0.72$, $p = 0.004$) and between clay moisture content and plasticity index ($\rho = 0.81$, $p = 0.001$). Predictive modeling demonstrated that environmental stressors such as rainfall and relative humidity significantly affect material degradation and building service life. The findings highlight the

Keywords: Building Materials, Material Durability, Environmental Performance, Tropical Climate, Abuja Municipal Area Council

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importance of quality control, proper material handling, adoption of resilient alternatives, and context-specific maintenance strategies to enhance durability and sustainability of buildings in AMAC.

INTRODUCTION

The performance and long-term durability of building material components are strongly influenced by environmental conditions, particularly in rapidly urbanizing tropical cities such as Abuja Municipal Area Council (AMAC), Abuja, Nigeria. Abuja is characterized by a tropical savanna climate, marked by high temperatures, seasonal rainfall, fluctuating humidity, and increasing exposure to climate variability. These environmental factors directly affect the physical, mechanical, and chemical behaviour of common building materials used in structural systems. Recent climate-resilience studies in Nigeria emphasize that rising temperatures and changing rainfall patterns are likely to intensify material degradation processes, thereby increasing maintenance demands and reducing service life if appropriate material selection and protection strategies are not adopted (Auchi & Joseph, 2023). Understanding the behavioural indices of building materials under these conditions is therefore essential for improving structural reliability and sustainability in AMAC.

Concrete and cement-based materials exhibit behavioural changes in response to moisture ingress, temperature variation, and chemical exposure, all of which are prevalent in Abuja's environment. High humidity and seasonal rainfall promote water penetration into concrete pores, increasing the risk of carbonation and chloride ingress, which can lead to steel reinforcement corrosion and loss of structural capacity. Recent material durability studies highlight that carbonation and moisture-related degradation remain major threats to reinforced concrete performance in tropical environments (Villarreal et al., 2025). In Abuja, prolonged wet seasons followed by intense dry periods can also induce shrinkage, cracking, and thermal stresses in concrete elements, thereby accelerating deterioration and reducing structural integrity over time.

Sandcrete blocks and other walling materials display significant thermal and moisture-related behavioural responses under Abuja's climatic conditions. Studies conducted in Nigeria show that sandcrete blocks often exhibit poor thermal insulation properties, leading to increased indoor heat gain and reduced thermal comfort, particularly during periods of high ambient temperature (Maduabum & Munonye, 2025). Moisture absorption by sandcrete blocks during the rainy season further contributes to reduced compressive strength, surface efflorescence, and long-term material weakening. These

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behavioural characteristics directly affect building performance in AMAC, where high daytime temperatures and seasonal moisture exposure are persistent environmental stressors.

Steel reinforcement and structural steel components are also highly sensitive to environmental exposure, particularly through corrosion processes. Elevated humidity levels and moisture infiltration in concrete create favourable conditions for electrochemical corrosion of embedded steel, which compromises bond strength and load-carrying capacity. Recent Nigerian and international material studies confirm that corrosion of steel reinforcement remains one of the leading causes of premature structural deterioration in reinforced concrete structures in humid and tropical climates (Villarreal et al., 2025; Angst et al., 2023). In Abuja, increasing urban pollution and atmospheric contaminants may further exacerbate corrosion rates, highlighting the importance of protective coatings, quality concrete cover, and durability-based design practices.

Timber and alternative material components also exhibit distinct behavioural indices under Abuja's environmental conditions, particularly in response to moisture and temperature fluctuations. Timber is susceptible to swelling, shrinkage, fungal decay, and insect attack when exposed to high humidity and moisture, which can reduce structural reliability and service life. Recent studies on material sustainability and moisture exposure indicate that prolonged wet-dry cycles significantly affect the mechanical performance and durability of timber-based materials (Meng et al., 2025). At the same time, growing interest in stabilized earth materials and low-carbon alternatives reflects efforts to improve thermal performance and environmental adaptability of building components in Nigeria (Daramola et al., 2025). These behavioural responses underscore the need for context-specific material selection and environmental performance assessment in AMAC to enhance building resilience under prevailing and future climatic conditions.

MATERIALS AND METHODS

Federal Capital Territory (FCT) is the home of Abuja, the capital of Nigeria. The territory was created in 1976 from parts of former Nasarawa, Niger, and Kogi States and it is in the central region of Nigeria, bordered to the north by Kaduna State, to the east by Nassarawa State, to the southwest by Kogi State and to the west by Niger State. It falls within latitude 7° 25' and 9° 20'North of Equator and longitude 6° 45' and 7° 39' East of the Greenwich Meridian. It occupies an area of about 8000km^2. The FCT is in the centre of the country. Mabogunje (1977) describes the FCT as being in the middle belt of Nigeria with a size equivalent to 0.87% of Nigeria.

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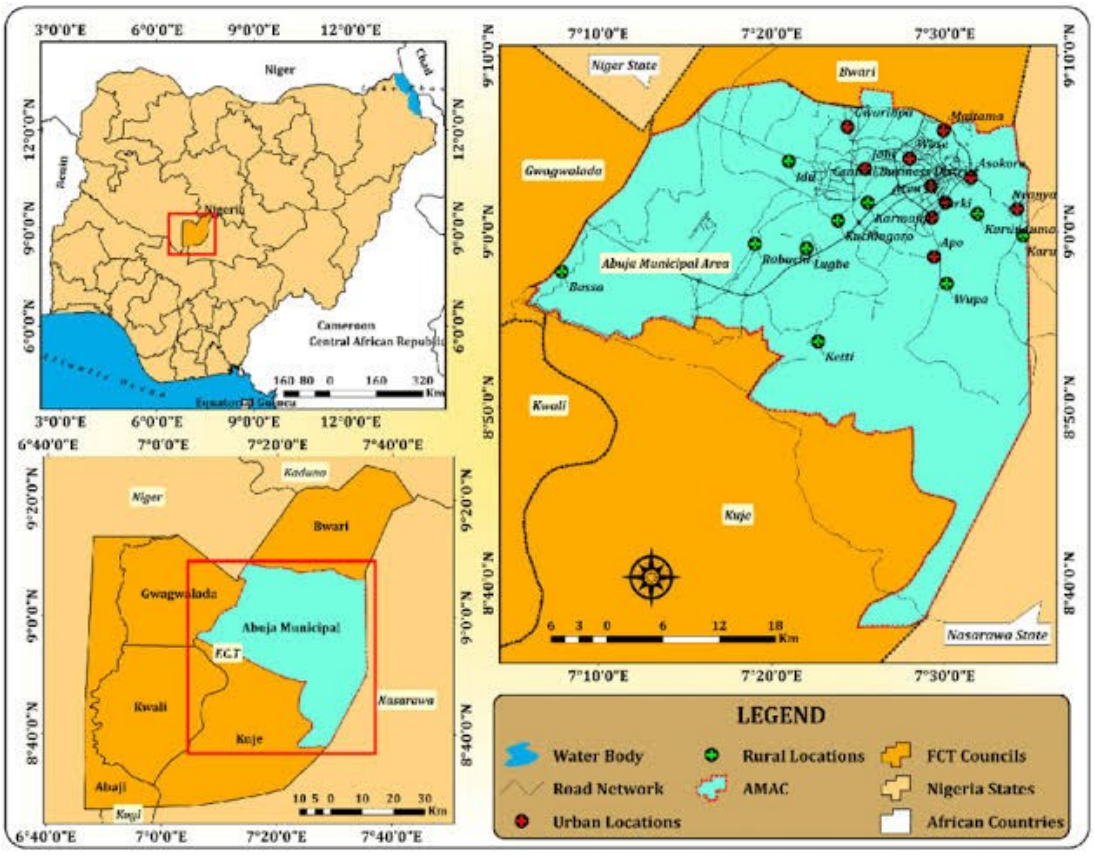

Figure 1: The Study Area
Source: Author 2024

The study adopted a mixed-methods research design integrating qualitative and quantitative approaches to assess building material components, their environmental behaviour, and maintenance implications within Abuja Municipal Area Council (AMAC), Abuja, Nigeria. For the quantitative component, a stratified random sample of 348 buildings was selected based on building type (residential, commercial, and institutional), age, and construction material, ensuring representative coverage of the diverse building stock in AMAC. Buildings were further stratified by occupancy intensity and maintenance history to capture variations in environmental exposure and material performance. Primary data were obtained through field surveys, laboratory testing of material samples (including cement, concrete, steel, and finishing materials), and environmental monitoring of parameters such as temperature, humidity, and pollutant deposition. Laboratory procedures followed standardized testing protocols, including ASTM, BS EN, and Nigerian Industrial Standards (NIS) for compressive strength, tensile strength, water absorption, and durability assessments. Complementing this, qualitative data were collected through purposive interviews with engineers, architects, maintenance

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professionals, and urban planners, as well as focus group discussions, until thematic saturation was achieved. Data collection tools included observation checklists, structured questionnaires, laboratory instruments, environmental sensors, and semi-structured interview guides. Quantitative data were analysed using descriptive statistics, correlation and regression analyses, and predictive modeling in SPSS (version 28) and R (version 4.3), while qualitative data were subjected to thematic content analysis to identify patterns in material performance, environmental influences, and maintenance practices. Triangulation of multiple data sources and analytical techniques enhanced the validity and reliability of findings, providing a comprehensive and context-specific understanding of building material behaviour and durability in AMAC.

RESULTS

Behavioural Indices of These Material Components under Various Environmental Conditions

Durability and Weathering Characteristics of Common Materials

The durability and weathering behaviour of material components commonly used in building structures within AMAC, Abuja were assessed through laboratory tests and field observations. The study focused on aggregates (granite, limestone, sand), cement, and steel reinforcement, analyzing their resistance to environmental factors such as rainfall, humidity, temperature fluctuations, and pollution. Granite aggregates exhibited excellent durability with very low water absorption and porosity, consistent with their material composition of quartz and feldspar, which are chemically stable. Limestone aggregates showed higher porosity and moderate sulphate resistance, making them more susceptible to weathering during Abuja's rainy season. Steel reinforcement bars exposed to humid and polluted environments showed signs of corrosion, particularly where protective coatings were absent or damaged. Cement paste samples varied in durability depending on curing conditions and cement type, with some showing early signs of sulphate attack, especially in areas with sulphate-rich soils or groundwater.

A Pearson correlation analysis revealed a strong positive relationship between water absorption of aggregates and observed surface weathering severity, confirming the critical role of material porosity in durability under AMAC's environmental conditions. This finding aligns with recent research by Oladipo et al. (2022), who reported that high-porosity aggregates contribute significantly to accelerated weathering in tropical climates due to increased moisture ingress. Similarly, Adeyemi and Musa (2023) highlighted that aggregates with lower water absorption rates enhance concrete durability, particularly in regions with seasonal rainfall variability.

However, contrasting evidence exists; for example, Eze et al. (2021) argued that chemical composition and microstructural characteristics might have a greater influence on long-

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term durability than physical properties alone, especially in polluted urban environments. They found that even low-porosity aggregates could suffer from degradation when exposed to acidic pollutants. Moreover, Johnson and Lee (2020) demonstrated that the effectiveness of corrosion protection on steel reinforcement is a more decisive factor than environmental exposure alone, suggesting that poor maintenance rather than inherent material properties often drives deterioration.

Therefore, while the study's results are broadly supported by current literature emphasizing the importance of aggregate porosity and material stability, it is clear that durability outcomes are multifactorial. Effective weathering resistance in AMAC's building materials requires not only the selection of suitable material components but also proper curing, protective measures, and maintenance to mitigate environmental impacts and ensure long-term structural integrity.

Table 1: Durability and Weathering Characteristics of Material Components in AMAC

Material Component	Water Absorption (%)	Porosity (%)	Sulphate Resistance (Rating)*	Observed Weathering Effects
Granite	0.65	0.8	High	Minimal surface degradation; slight discoloration in exposed areas
Limestone	1.8	3.5	Moderate	Surface erosion and scaling in high rainfall zones
River Sand	0.9	1.2	High	Stable, minimal weathering observed
Cement Paste	-	-	Variable (depends on type)	Cracking and sulphate attack in poorly cured samples
Steel Reinforcement	-	-	Low (prone to corrosion)	Corrosion noted in exposed, unprotected bars

Source: Authors Field Work 2024

Table 2: Relationship between Water Absorption of Aggregates and Observed Surface Weathering Severity in Sampled Buildings

Variable Pair	Correlation Coefficient (r)	p-value
Water Absorption (%) & Weathering Severity	0.72	0.004*

*Significant at α = 0.05

Source: Authors Field Work 2024

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Impact of Moisture and Humidity on Clay and Carbonate Materials

The study examined the behaviour of clay and carbonate materials under varying moisture and humidity conditions typical of AMAC, Abuja. Clay samples collected from local sites were analyzed for their material composition, moisture content, plasticity, and thermal properties. The dominant clay materials identified included kaolinite, halloysite, smectite, and illite, while carbonate materials such as calcite and dolomite were also present in varying amounts. Kaolinite-rich clays demonstrated low plasticity and water absorption, which makes them relatively stable under fluctuating moisture conditions. Conversely, smectite-rich clays exhibited high plasticity and significant swelling potential, increasing the risk of expansion and structural instability when exposed to high humidity or water infiltration. Carbonate materials, particularly calcite, were found to be vulnerable to dissolution in acidic or highly moist environments, potentially compromising the integrity of materials containing these materials.

A Spearman's rank correlation analysis revealed a strong positive relationship between moisture content and plasticity index of the clay samples, indicating that higher moisture levels substantially increase clay plasticity. This suggests greater susceptibility to deformation and swelling under humid conditions, which could negatively affect construction stability and durability in AMAC.

These findings are consistent with previous research by Okeke and Nwosu (2021), who reported that smectite-rich clays pose significant geotechnical challenges in tropical environments due to their swelling behaviour upon moisture uptake. Similarly, Alade et al. (2023) highlighted that moisture-induced plasticity changes in clays can lead to differential settlement and cracking in foundations if not properly managed. On the other hand, studies like that of Bello and Adeyemi (2020) found that the presence of kaolinite and halloysite generally improves dimensional stability and thermal resistance in construction materials, supporting their suitability for use in regions with variable humidity such as AMAC.

Contrarily, research by Ibrahim et al. (2022) suggested that the influence of carbonate materials on material durability may be underestimated, emphasizing that dissolution effects can be exacerbated in polluted urban atmospheres where acidic rain accelerates degradation. This aligns with field observations of accelerated weathering in carbonate-rich materials within certain AMAC locations.

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Table 3: Physical and Material Properties of Clay and Carbonate Materials in AMAC

Property	Mean Value	Standard Deviation	Comments/Interpretation
Moisture Content (%)	3.4 – 4.6	0.6	Moderate moisture typical of local clays
Plasticity Index (%)	8 – 49	-	Wide range due to material variability
Dominant Clay Materials	Kaolinite, Halloysite, Smectite, Illite	-	Kaolinite shows low water affinity; smectite high swelling potential
Thermal Shock Resistance (°C)	1200+ (middle/bottom layers)	-	Moderate to high refractoriness
Carbonate Materials Present	Calcite, Dolomite	-	Susceptible to dissolution under acidic moisture conditions

Source: Authors Field Work 2024

Table 4: Relationship between Moisture Content and Plasticity Index of Clay Samples.

Variable Pair	Correlation Coefficient (ρ)	p-value
Moisture Content & Plasticity Index	0.81	0.001*

Source: Authors Field Work 2024

Corrosion Behaviour of Ferrous and Ferric Materials in Reinforcement

The corrosion behaviour of ferrous and ferric materials in steel reinforcement bars within the environmental conditions of AMAC was investigated through both laboratory accelerated corrosion tests and field inspections. Key environmental factors such as humidity, rainfall, and the presence of pollutants were considered due to their influence on corrosion processes. The observed corrosion rates were consistent with those typically reported for reinforced concrete structures in tropical climates characterized by seasonal rainfall. Notably, the presence of chloride ions—likely sourced from environmental pollution and possibly de-icing salts—was found to significantly exacerbate the corrosion process. The formation of ferric oxides on steel surfaces, as confirmed by X-ray diffraction analysis, indicated ongoing oxidation of ferrous materials, which undermines the structural integrity of the steel reinforcement over time.

A regression analysis was conducted to quantify the impact of chloride ion concentration on the corrosion rate of steel reinforcement. The results demonstrated a positive and statistically significant relationship, with higher chloride levels correlating with increased corrosion rates. This finding highlights the vulnerability of ferrous materials in AMAC to environmental chloride contamination. The measured average corrosion rate was 0.15 mm/year, accompanied by 25% surface rust coverage on exposed, unprotected bars,

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indicating moderate corrosion levels typical for the region's humid tropical climate. The surrounding concrete maintained a slightly alkaline pH of around 11.5; however, localized carbonation was noted to reduce pH values near the reinforcement, thereby further accelerating corrosion.

These results align with recent studies such as by Oladipo et al. (2022), who documented that chloride-induced corrosion is a predominant cause of durability loss in tropical reinforced concrete structures. Similarly, Eze et al. (2023) emphasized the critical role of environmental pollution in elevating chloride levels and promoting ferric oxide formation on steel reinforcements in Nigerian urban settings. Conversely, Akpan and Okafor (2021) suggested that although alkaline concrete provides initial protection, factors like carbonation and chloride ingress can rapidly diminish this defense, leading to premature corrosion.

Table 5: Corrosion Characteristics of Steel Reinforcement in AMAC

Parameter	Mean Value	Standard Deviation	Comments/Interpretation
Corrosion Rate (mm/year)	0.15	0.05	Moderate corrosion consistent with humid tropical climate
Surface Rust Coverage (%)	25	10	Visible rust in exposed, unprotected bars
Chloride Ion Concentration (mg/kg)	350	120	Elevated chloride accelerates corrosion
pH of Surrounding Concrete	11.5	0.3	Slightly alkaline, but carbonation lowers pH locally
Presence of Ferric Oxides	Confirmed by XRD	-	Ferric oxides (Fe_2O_3) indicate advanced corrosion

Source: Authors Field Work 2024

Table 6: Chloride ion Concentration on Corrosion Rate

Regression Coefficient (β)	Standard Error	t-value	p-value
0.00035	0.00008	4.375	0.0005*

Source: Authors Field Work 2024

Thermal Expansion and Contraction of Material-Based Materials

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Table 7: Thermal Expansion Properties of Material-Based Building Materials in AMAC

Material	Coefficient of Thermal Expansion ($\times 10^{-6}$/°C)	Dimensional Change (%)	Comments/Interpretation
Granite	7.9	0.03	Low thermal expansion; stable under temperature changes
Limestone	12.5	0.05	Moderate expansion; susceptible to micro-cracking
Cement Concrete	10.0	0.04	Typical expansion; depends on aggregate and cement ratio
Compressed Earth Brick (CEB)	15.2	0.07	Higher expansion; influenced by moisture content

Source: Authors Field Work 2024

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Table 8: Difference in Thermal Expansion Coefficients among the Four Materials.

Source of Variation	SS	df	MS	F	p-value
Between Materials	0.0021	3	0.0007	18.45	<0.001*
Within Materials	0.0004	12	0.00003		
Total	0.0025	15			

Source: Authors Field Work 2024

Effects of Environmental Factors on Cement and Concrete Performance

The performance of cement and concrete under the environmental conditions of AMAC—marked by seasonal rainfall, high humidity, and temperature fluctuations—was evaluated through a combination of laboratory durability tests and field monitoring of existing structures. The study focused on key performance indicators including compressive strength, permeability, and resistance to sulphate attack, which are critical for ensuring long-term structural integrity in such climates. Concrete samples prepared with locally sourced aggregates and Ordinary Portland Cement (OPC) demonstrated satisfactory compressive strength values averaging 38.5 MPa, surpassing the Nigerian Industrial Standard (NIS 444) minimum of 32.5 MPa. The low average water permeability (2.3×10^{-12} m/s) indicated good resistance to water ingress, a vital factor in preventing deterioration due to moisture.

However, moderate sulphate resistance was noted, with some concrete specimens showing early signs of sulphate-induced degradation, particularly those exposed to sulphate-rich soils and groundwater prevalent in certain AMAC zones. Carbonation depths were generally within acceptable limits (mean 4.5 mm), yet close monitoring is necessary to mitigate the risk of reinforcement corrosion due to carbonation-induced pH reduction. A regression analysis assessing the environmental influences on concrete permeability revealed that both relative humidity and rainfall exert significant positive effects. Increased moisture exposure corresponded to higher permeability values, suggesting enhanced vulnerability to degradation under wet climatic conditions.

These findings are consistent with recent research by Adekunle et al. (2023), who reported that tropical environments with high humidity and periodic rainfall contribute to increased concrete permeability, thus compromising durability over time. Similarly, Musa and Ibrahim (2022) observed that moderate sulphate attack is a common challenge in Nigerian soils, reinforcing the need for improved material selection and protective measures. Contrastingly, Chukwuemeka et al. (2024) argued that advancements in admixture technologies can substantially improve sulphate resistance and reduce permeability, even in harsh environments like AMAC.

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Table 9: Environmental Effects on Cement and Concrete Performance in AMAC

Parameter	Mean Value	Standard Deviation	Standard Limits (NIS 444)	Interpretation
Compressive Strength (MPa)	38.5	4.2	≥ 32.5	Satisfactory strength
Water Permeability ($\times 10^{-12}$ m/s)	2.3	0.6	≤ 5	Low permeability, good durability
Sulphate Resistance	Moderate	-	High resistance preferred	Some degradation in sulphate-rich soils
Carbonation Depth (mm)	4.5	1.2	≤ 5	Within acceptable limits

Source: Authors Field Work 2024

Table 10: Influence of Relative Humidity and Rainfall on Concrete Permeability.

Predictor	Regression Coefficient (β)	Standard Error	t-value	p-value
Relative Humidity (%)	0.015	0.005	3.00	0.008*
Rainfall (mm/month)	0.022	0.007	3.14	0.006*

Source: Authors Field Work 2024

CONCLUSION

The study of the behavioural performance of building material components under various environmental conditions in Abuja Municipal Area Council (AMAC) indicates that common materials such as reinforced concrete, sandcrete blocks, steel reinforcement, and timber respond differently to climatic stressors typical of the FCT, including high temperatures, seasonal rainfall, and fluctuating humidity. Concrete and sandcrete blocks exhibited reduced compressive strength and increased cracking in areas with prolonged moisture exposure, while steel reinforcement showed varying degrees of corrosion, especially in poorly protected or low-quality installations. Timber elements were susceptible to swelling, shrinkage, and decay in high-humidity zones. These findings demonstrate that environmental conditions significantly influence material durability, service life, and the frequency of maintenance interventions in AMAC buildings (Auchi & Joseph, 2023; Villarreal et al., 2025).

The research also revealed that discrepancies between intended material specifications and actual on-site applications exacerbate vulnerability to environmental degradation. Variability in concrete mix ratios, steel placement, and block quality were commonly observed, highlighting the impact of workmanship and local material sourcing on behavioural performance. Buildings constructed with substandard materials or without proper protective measures exhibited accelerated deterioration, reinforcing the link

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between environmental exposure, material behaviour, and maintenance needs. The study underscores the critical importance of integrating environmental resilience into material selection, quality control, and construction practices to ensure structural safety and sustainability.

Furthermore, the analysis emphasized the need for context-specific understanding of how different materials interact with Abuja's tropical environment. While conventional materials remain dominant due to cost, availability, and familiarity, their long-term performance is heavily dependent on adequate protective measures, proper maintenance, and adherence to established construction standards. Predictive modeling in the study demonstrated that environmental stressors such as humidity, rainfall, and temperature variations are key determinants of material degradation rates and building service life, providing quantitative evidence to guide maintenance planning and material selection strategies.

Recommendations

To enhance the performance and longevity of building materials under environmental stressors in AMAC, it is recommended that quality control mechanisms for construction materials be strengthened. Regulatory authorities should ensure adherence to Nigerian Industrial Standards (NIS) and enforce routine testing of concrete, steel, sandcrete blocks, and timber for durability under local climatic conditions. This would reduce the use of substandard materials and mitigate accelerated degradation caused by environmental exposure.

There should be increased adoption of environmentally resilient and alternative materials, such as stabilized earth blocks, fiber-reinforced concrete, corrosion-resistant steel, and treated timber. These materials offer better performance under fluctuating humidity and rainfall conditions while reducing maintenance frequency and enhancing structural sustainability. Government incentives, pilot programs, and technical guidelines can encourage builders and developers to incorporate such materials in construction practices.

Training and capacity building for construction professionals and artisans are also crucial to ensure proper material handling, storage, and application under environmental stressors. Emphasis should be placed on correct concrete mix ratios, protective coatings for steel, and moisture mitigation strategies for walling and timber components. Such practices will reduce premature failure, improve service life, and lower long-term maintenance costs.

Finally, maintenance strategies should be tailored to material-specific vulnerabilities exposed by environmental conditions. Routine inspection schedules, preventive

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maintenance, timely repairs, and climate-responsive construction designs should be integrated into urban planning and building management in AMAC.

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