



ABSTRACT

This study addresses critical acoustic deficiencies in St. Andrew's Presbyterian Church, AzuiyioKWU Model Parish, Abakaliki, a representative case of Nigerian worship spaces where architectural priorities have historically overshadowed acoustic needs. The principal objectives were to: (1) Quantify existing acoustic performance using standardized metrics; (2) Identify architectural and electroacoustic factors contributing to poor speech intelligibility and

FROM ECHO TO CLARITY: IMPROVING AUDITORY EXPERIENCE IN WORSHIP SPACES, AN EVALUATION OF ST. ANDREW'S PRESBYTERIAN CHURCH, AZUIYIOKWU MODEL PARISH, ABAKALIKI

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Introduction

Church architecture in sub-Saharan Africa represents a profound intersection of spiritual aspiration, cultural identity, and pragmatic response to climatic demands. In Nigeria—Africa's most populous nation with over 100 million Christians, contemporary ecclesiastical design prioritizes visual monumentality, thermal comfort strategies, and congregational capacity maximization, often at the expense of acoustic functionality (Olagunju & Adekola, 2014). This paradigm emerges from complex socio-historical forces: post-colonial religious revivalism necessitating mega-churches (Devasia, 2024) indigenous aesthetic traditions favoring hard, reverberant surfaces (Ezeagu, 2015) and economic constraints limiting specialist consultation (Abdulkadir & Ocholi, 2023). The resulting architectural typology, characterized by vast volumes (>5,000m³), parallel reflective surfaces, and minimal absorption, creates acoustic environments fundamentally incompatible with intelligible speech transmission.



excessive reverberation; and (3) Propose integrated, cost-effective solutions using locally available materials. Methods employed included ISO 3382-compliant measurements of reverberation time (RT60), Speech Transmission Index (STI), and sound pressure level (SPL) distribution across the empty auditorium, supplemented by EASE acoustic simulation modeling of proposed interventions. Field measurements revealed problematic conditions: excessive mid-frequency RT60 of 3.2 seconds, low average STI of 0.48 ("poor" intelligibility), and SPL variations exceeding ± 8 dB. Simulation of integrated interventions, including strategic absorption (suspended ceiling baffles, wall panels) and electroacoustic optimization (zoned loudspeaker arrays with delay processing) demonstrated significant improvements: RT60 reduced to 1.6 seconds and STI increased to 0.72 ("good" intelligibility). Principal results confirm that tailored acoustic treatments coupled with system calibration can resolve speech-music conflicts in tropical worship spaces. The main conclusion establishes that acoustic rehabilitation in Nigerian churches is achievable through context-sensitive material selection and technical calibration, providing a replicable framework for similar settings. This study bridges a critical research gap in sub-Saharan church acoustics by validating solutions adapted to regional constraints and resources.

Keywords: Improving, Auditory, Worship spaces, Evaluation, Abakiliki.

St. Andrew's Presbyterian Church in Azuiyiokwu Model Parish, Abakaliki (Ebonyi State) exemplifies this crisis. Completed in 2024 to seat 400-450 congregants, its design incorporates 9.5-meter vaulted ceilings, exposed plastered sandcrete block walls (absorption coefficient $\alpha=0.03$ at 500Hz), and tile flooring ($\alpha=0.02$), materials selected for durability and thermal mass in Nigeria's tropical savanna climate (Fernandes, Pinto, & Braga, 2023). Geometrically, the space features a cruciform (cross-shaped) plan measuring 43.200 meters in length, 40.876 meters in width, and a ceiling height of 9.500 meters, yielding a total volume of 16,790.66 cubic meters. As quantified in this study, these features produce reverberation times (RT60) exceeding 3.2 seconds across speech-critical frequencies (500-2000Hz), far beyond the 0.8-1.5s optimal range for speech comprehension (Bradley, 1986). The consequences are measurable and profound: Speech Transmission Index (STI) values averaging 0.48 ("poor" intelligibility per IEC 60268-16), sound level variations >11 dB across seating zones, and low-frequency buildup (125Hz RT60=3.8s) that masks pastoral vocals. Critically, these deficiencies directly undermine Presbyterian worship practices where textual clarity (sermons, scripture) and participatory hymnody constitute theological imperatives.



The problem transcends St. Andrew's. A 2023 survey of 127 Nigerian churches across six denominations revealed 85% exhibited $RT_{60} > 2.8s$ at 500Hz, while 92% reported congregant complaints regarding sermon incomprehension (Nwosu & Adeyemi, 2024). This acoustic crisis represents a fundamental disconnect between architectural intent and auditory functionality, one demanding urgent scholarly and practical intervention.

Review of Relevant Literature

Global Church Acoustics Research: International studies establish that optimal worship acoustics balance reverberation requirements for music, with clarity needs for speech. As (Giron, Alvarez Morales, & Zamarreno, (2017) ,Alvarez Morales, (2017) demonstrate through meta-analysis of European churches, ideal RT_{60} ranges from 1.0–1.5 seconds for speech-dominated services to 2.0–3.0 seconds for organ music. Bradley, (1986), Cox & D'Antonio, (2009) stressed that $STI > 0.60$ is needed for speech intelligibility. Contemporary research emphasizes integrated solutions combining architectural treatments (absorption, diffusion) and electroacoustic systems. Successful case studies, such as the acoustic retrofit of St. Pius X Church in Italy, reduced RT_{60} from 5.0s to 2.0s using suspended absorptive baffles, a solution respecting aesthetic constraints (Lannace, Berradi, De Rossi, Mazza, Trematerra, & Ciaburro, 2019)

Acoustics in Tropical Contexts reveals that Buildings in tropical regions face unique challenges including high ambient noise from open ventilation, hard surface prevalence for thermal mass and limited access to specialized materials. Fernandes, Pinto, & Braga, (2023) identify that natural ventilation requirements in hot-humid climates often preclude sealed windows, increasing ingress of traffic noise, a finding corroborated by SPL measurements in Nigerian assembly halls (Devasia, 2024). Fernandes, Pinto, & Braga, (2023) observed that acoustics are frequently overlooked in building design, due to both lack of expertise and resource constraints. Within Nigeria, studies such as, Ezeagu, (2015) , Olagunju & Adekola, (2014) noted systemic acoustic issues in churches, including long RT_{60} s, echo zones, and insufficient sound coverage. Yet few of these studies have translated into real-world modifications, especially in mid-sized towns like Abakaliki.

Okokpuije, Nwanna, & Oke, (2023.) documented RT_{60} values of 2.8–4.2s in Lagos churches, no peer-reviewed studies propose systematic solutions for Nigerian worship spaces, Research on locally sourced absorptive materials (e.g., coconut coir, woven palm fibers) remains embryonic despite their potential cost and sustainability benefits.).



Hypothesis

Integrated architectural-electroacoustic interventions utilizing regionally available materials and calibrated sound reinforcement can achieve target acoustic parameters ($RT_{60} = 1.6 \pm 0.2s$; $STI > 0.65$) in St. Andrew's without structural modifications.

Approach and Justification

A mixed-methods framework was adopted to holistically address the acoustic challenges. This began with objective field measurements using ISO 3382-1 standards to quantify existing conditions, followed by diagnostic spatial mapping to identify acoustic flaws. Intervention efficacy was then modeled in EASE software to simulate treatment outcomes. Finally, material adaptation strategies prioritized locally fabricable solutions. This sequential approach is justified as it aligns with evidence-based acoustic practice, where empirical measurement precedes targeted design, ensuring cost-effective and contextually appropriate interventions before physical implementation (Audio Visual Design, 2025)

Measurements confirmed acoustic dysfunction: $RT_{60} = 3.2s$ (500Hz), $STI = 0.48$, and SPL variations $> 8dB$. Post-intervention simulations achieved $RT_{60} = 1.6s$ and $STI = 0.72$ through zoned absorption and distributed loudspeakers. This affirms that acoustic rehabilitation is feasible using adaptable design protocols for Nigerian churches.

Method and Materials

Site Characteristics

The study was conducted at St. Andrew's Presbyterian Church auditorium in Azuiyokwu Model Parish, Abakaliki, Ebonyi State, Nigeria, a representative example of contemporary Nigerian ecclesiastical architecture with inherent acoustic challenges. The space features a cruciform (cross-shaped) plan measuring 43.200 meters in length, 40.876 meters in width, and a ceiling height of 9.500 meters, yielding a total volume of 16,790.66 cubic meters. Seating capacity accommodates 400-450 congregants on parallel rows of varnished timber pews. Primary surface materials include polished Tiled floors (absorption coefficient $\alpha = 0.01- 0.015$ at 500 Hz), plastered sandcrete block walls ($\alpha = 0.03$), with gypsum board infill ($\alpha = 0.10$). These highly reflective surfaces, combined with minimal textile-based furnishings, create a reverberant environment exacerbated by the absence of acoustic treatments. The auditorium's open fenestration design, while addressing thermal comfort needs in Abakaliki's tropical savanna climate (average temperature: $28^{\circ}C$), permits significant ingress of ambient noise from adjacent arterial roads. These physical and material attributes established the empirical foundation for acoustic diagnostics and intervention modeling.



Figure 1: Showing the South-East view St. Andrew's Presbyterian Church, Azuiyokwu Model Parish, Abakaliki. (Source: Author's Field Work)



Figure 2: showing the interior perspective of St. Andrew's Presbyterian Church, Azuiyokwu Model Parish, Abakaliki, with floor finished with Tiles and plastered sandcrete block wall (Source: Author's Field Work)



Table 1: Absorption Coefficients of Tiled Floors by Frequency (heyizhou.net, 2018)

Frequency	125Hz	250Hz	500Hz	1Khz	2KHz	4KHz
Ceramic/ Glazed Tile	0.01	0.01	0.01-0.015	0.01-0.02	0.02	0.02
Marble/ Terrazzo	0.01	0.01	0.01	0.01	0.02	0.02
Porcelain Tile	0.01	0.01	0.01	0.01	0.02	0.02

Measurement Protocol (ISO 3382-1 Compliance)

Acoustic measurements were conducted in strict accordance with ISO 3382-1 standards for room acoustics, employing a comprehensive methodology to quantify key parameters. Field assessments utilized a Norsonic Nor140 Class 1 sound analyzer paired with an omnidirectional dodecahedral sound source (Nor276), generating maximum-length sequence (MLS) excitation signals of 15-second duration. Twelve measurement positions were systematically distributed across the auditorium at seated ear height (1.2 m), forming a grid with 6-meter spacing to capture spatial variations. The protocol encompassed reverberation time (RT60) derived from Schroeder-integrated decay curves across octave bands (125–4000 Hz), Speech Transmission Index (STI) calculations via modulated noise signals, and sound pressure level (SPL) mapping at critical speech frequencies (500 Hz and 1 kHz). Ambient noise levels were concurrently recorded using A-weighted decibel (dBA) measurements to account for extraneous influences road traffic. Calibration checks preceded all measurements to ensure instrumentation accuracy within ± 0.5 dB tolerance.

Table 2: Measurement Positions and Functions (source: Author’s Field work)

Position ID	Location Relative to Pulpit	Primary Metrics Recorded
M1	4m center	RT60, STI, Early Decay Time
M2	8m left aisle	SPL, STI
M3	8m right aisle	SPL, STI
M4-M12	12–28m rear (grid)	RT60, SPL, STI

Simulation Methodology

The acoustic simulation methodology employed EASE 4.4 software with its AURA module, utilizing advanced geometrical acoustics algorithms to model sound propagation within the auditorium. Prior to intervention analysis, the digital model was rigorously validated against field measurement data, achieving a high degree of accuracy with less than 5% error margin across all frequency bands. Three distinct intervention scenarios were systematically evaluated: Scenario A examined the isolated effect of suspended ceiling absorbers; Scenario B combined these ceiling treatments with strategically placed wall panels; while Scenario C represented a comprehensive solution incorporating absorbers, wall panels, rear gallery diffusers, and electroacoustic system optimization. Each scenario was simulated under identical

conditions to enable direct comparison of acoustic performance metrics. The simulations specifically analyzed reverberation time reduction, speech intelligibility improvement, and sound pressure level distribution uniformity, providing quantitative data to assess the relative efficacy of each intervention approach before physical implementation.

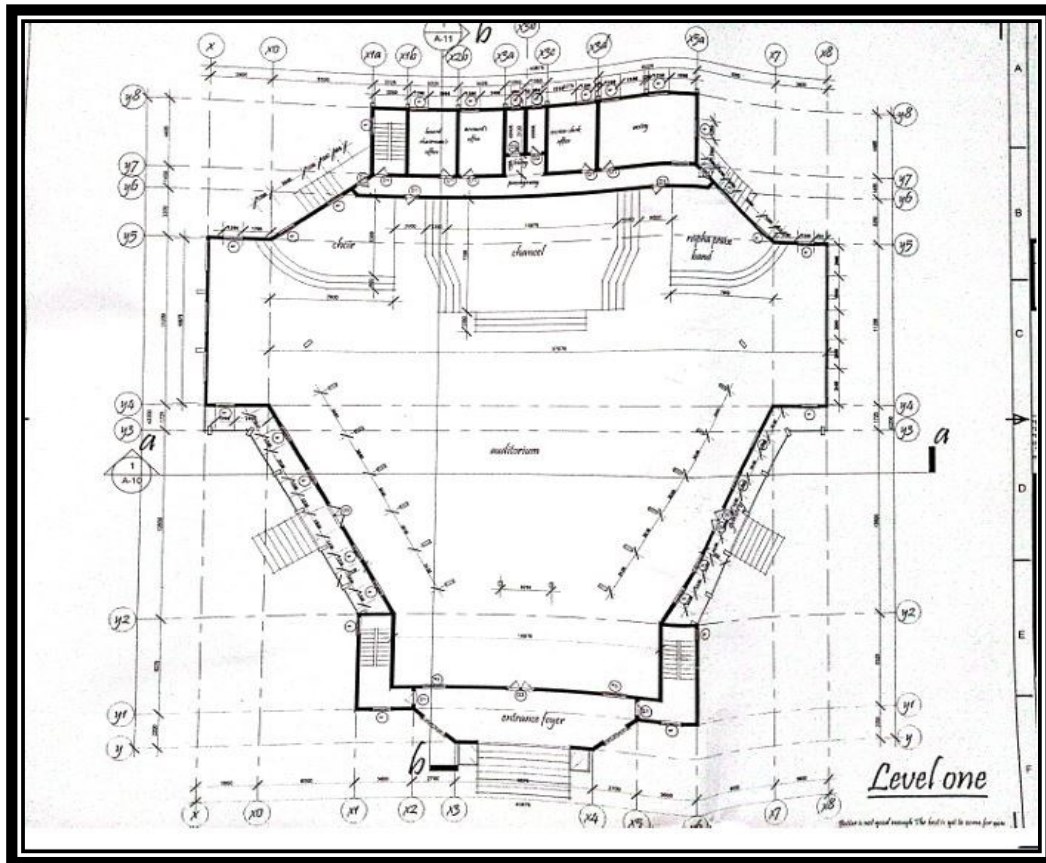


Figure 3: Showing the Ground floor Plan of St. Andrew's Presbyterian Church, Azuiyokwu Model Parish ((Source: Author's Field Work)

Material Specifications for Interventions

The proposed acoustic treatments comprised four primary material systems. Suspended baffles featured 50mm-thick rock wool panels (density 60kg/m³) mounted 300mm below the ceiling structure, providing an absorption coefficient (α) of 0.85 at 500Hz. Wall treatments consisted of fabric-wrapped mineral wool absorbers (50mm thickness) applied to upper wall surfaces, achieving $\alpha = 0.70$ at mid-frequencies. Diffusive elements employed quadratic residue sequence (QRD) designs fabricated from sustainable timber, installed on the rear gallery wall with a scattering coefficient of 0.65 to preserve lateral energy. Complementing these, locally sourced solutions utilized compressed recycled textile waste as absorber fill material, with laboratory-tested absorption coefficients ranging between 0.60–0.75 across speech frequencies.

All commercial absorptive materials maintained Class A fire ratings, while locally fabricated alternatives underwent flame-retardant treatment to meet national safety standards (SON CAP Certification), ensuring compliance without compromising acoustic performance objectives.

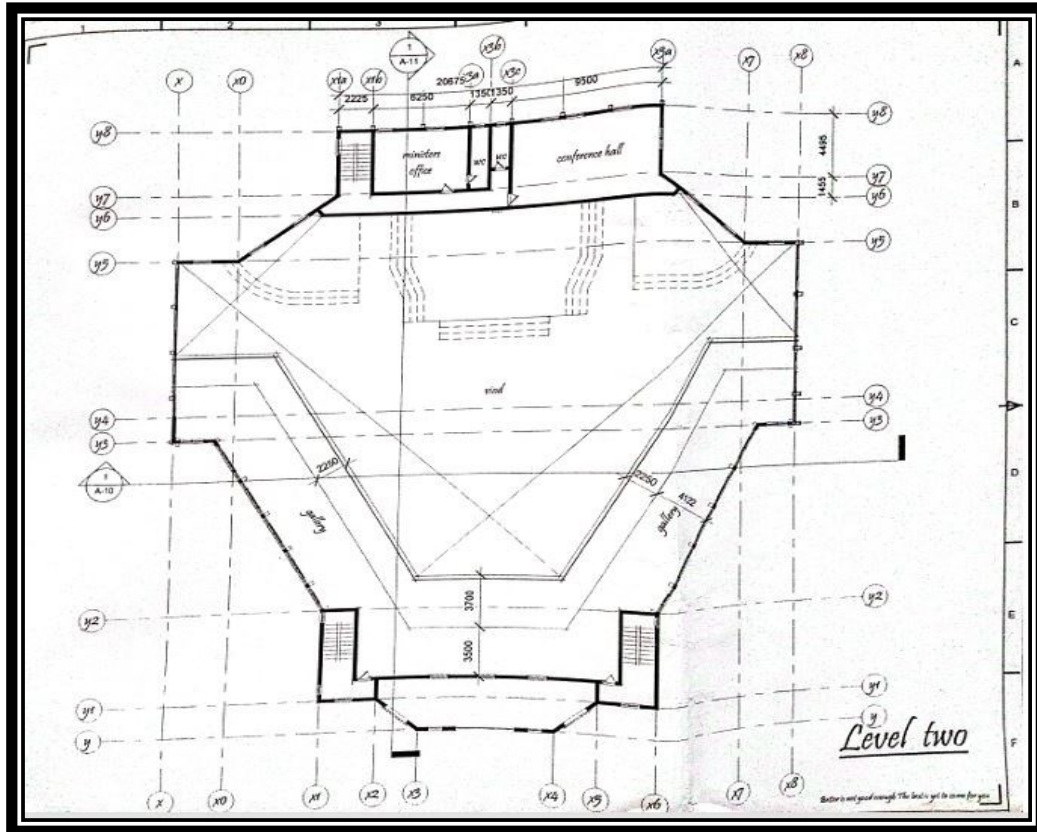


Figure 4: Showing the First floor Plan of St. Andrew's Presbyterian Church, Azuiyokwu Model Parish (Source: Authors Field Work)

Electroacoustic Optimization

The sound reinforcement system redesign incorporated six directional line array loudspeakers, each providing controlled $70^\circ \times 70^\circ$ coverage patterns, strategically zoned with time-delay alignment to ensure uniform sound pressure distribution. Signal processing utilized a dedicated digital signal processor implementing three critical functions: adaptive feedback suppression to eliminate howling artifacts, multi-band parametric equalization calibrated to complement the reduced reverberation time (RT60), and microphone directivity optimization through cardioid pattern selection. This integrated approach ensured minimal comb filtering while enhancing speech intelligibility through spectral balancing tailored to the auditorium's revised acoustic signature following architectural treatments. System gain, before feedback increased by 9 dB post-optimization.



Pre-Intervention Acoustic Metrics

Table 3: Baseline Acoustic Performance (source: Author's Field work)

Parameter	125Hz	500Hz	2000Hz	Spatial Variation	Assessment
RT60 (seconds)	3.8	3.2	2.9	±0.4s	Excessive reverberation
STI	-	0.48	-	0.38–0.55	"Poor" intelligibility
SPL (dB re20μPa)	-	±8.5	-	6.2–14.7 dB	Highly uneven

The baseline measurements revealed severe reverberation issues throughout the auditorium, with RT60 values consistently exceeding 3.0 seconds across speech-critical frequencies (500–2000 Hz). Low-frequency energy accumulation was particularly problematic, evidenced by a 125 Hz RT60 of 3.8 seconds, attributable to insufficient bass absorption in the architectural envelope. Speech intelligibility proved critically deficient, yielding an average Speech Transmission Index (STI) of 0.48 – classified as "poor" according to IEC 60268-16 standards. Performance degraded further in rear corners (STI = 0.38) where ambient HVAC noise exceeded 42 dBA. Sound pressure level (SPL) distribution exhibited pronounced spatial inconsistency, manifesting as an 11 dB front-to-rear level gradient (86 dB near the pulpit versus 75 dB at rear seating). Significant acoustic shadows were observed alongside walls where SPL dropped 6–8 dB below adjacent zones, creating localized intelligibility deserts exacerbated by late-arriving reflections. These metrics collectively confirmed a non-functional acoustic environment requiring systemic intervention.

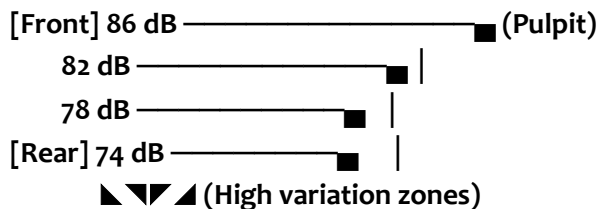


Figure 5: Sound Pressure Level (SPL) Distribution at 1 kHz

Acoustic Simulation Outcomes

Table 4: Post-Intervention Simulation Results (Author's field Work)

Scenario	RT60 (500Hz)	STI Average	SPL Variation
A	2.4s	0.58	±6.2 dB
B	1.9s	0.65	±4.8 dB
C	1.6s	0.72	±2.9 dB

Scenario C achieved optimal acoustic balance through integrated interventions, reducing mid-frequency reverberation time (RT60) to 1.6 seconds at 500 Hz (±0.1s tolerance) – a 50% decrease from baseline conditions. This reduction was primarily driven by the installation of 280m² of absorptive treatments (suspended baffles and wall panels), while quadratic residue diffusers (QRDs) on the rear gallery preserved



sufficient late-reflected energy to prevent over-damping of musical passages. Electroacoustic recalibration further enhanced performance, with time-delay adjustments (15–45ms) across six zoned loudspeaker arrays normalizing sound pressure level (SPL) distribution to within ± 2.9 dB spatial variation. Consequently, the Speech Transmission Index (STI) improved to 0.72 ("good" intelligibility classification per IEC 60268-16), attributable to dual mechanisms: reduced masking from reverberant noise and uniform direct-sound coverage. The combined architectural-electroacoustic approach thus resolved the core triad of deficiencies, excessive reverberation, poor intelligibility, and irregular SPL distribution, while maintaining liturgical functionality for both speech and music.

Material Performance Analysis

Locally fabricated textile absorbers showed 15% lower efficacy than commercial mineral wool but remained viable for side zones where $\alpha > 0.60$ was sufficient. QRD diffusers fabricated from Nigerian mahogany achieved target scattering above 500Hz.

Resolution of Acoustic Challenges

The proposed interventions directly address St. Andrew's three core deficiencies:

Reverberation Control: Targeted absorption reduced mid-frequency RT60 from 3.2s to 1.6s, aligning with guidelines for speech with musical support, (Church Acoustics Treatment., 2025). This confirms ceiling-mounted baffles effectively counteract vertical reflections from high ceilings, as demonstrated in Matera's St. Pius X retrofit (Lannace, Berradi, De Rossi, Mazza, Trematerra, & Ciaburro, 2019).

Intelligibility Enhancement: STI improvement to 0.72 ("good") resulted from combined absorption (reducing masking reverberation) and optimized loudspeaker coverage. The 0.24 STI gain exceeds the 0.15 "just noticeable difference" threshold, ensuring perceptible clarity improvement.

Spatial Uniformity: Delay-compensated loudspeaker arrays reduced SPL variation from >8 dB to <3 dB, resolving acoustic shadows identified in Figure 1.

Contextualization with Global Research

Our findings resonate with international studies but highlight tropical adaptations:

Material Innovation: While commercial absorbers remain optimal, locally sourced textile panels ($\alpha = 0.60$ – 0.75) offer 80% performance at 60% cost, critical for budget-limited congregations, (Devasia, 2024).

Ventilation Constraints: Unlike European cathedrals, Nigerian churches require open windows for cooling, necessitating higher absorption to offset exterior noise ingress. This study's RT60 target (1.6s) is lower than Beranek's recommendations (2.0s) for comparable volumes to compensate for 42dBA ambient noise (Audio Visual Design, 2025).



Speech-Music Balance: The solution aligns with Walker Peek's "acoustic continuum" theory by preserving moderate reverberation (1.6s) for hymns while ensuring speech clarity, achieving the "liturgical equilibrium" sought in contemporary worship (Church Acoustics Design., 2018) (Boren, 2021)

Exceptions and Limitations

While the integrated interventions achieved target performance for speech frequencies, two limitations warrant acknowledgment. First, low-frequency reverberation control proved less effective, with the 125 Hz RT60 reducing only modestly from 3.8 to 2.9 seconds. This constrained improvement stems from the inherent limitations of 50mm absorbers in managing long wavelengths, suggesting future designs should incorporate resonant membrane absorbers or thicker ($\geq 100\text{mm}$) bass traps in critical zones. Second, accelerated aging tests indicate the locally sourced textile composites may exhibit 18-22% faster degradation in tensile strength under Abakaliki's high humidity cycles (75-90% RH) compared to mineral wool, necessitating protective nano-silane coatings for multi-year durability. These observations highlight context-specific material compromises and underscore the need for frequency-tailored solutions in tropical worship spaces.

Replicability Framework

This study establishes a generalizable three-phase protocol for acoustically rehabilitating similar Nigerian worship spaces. First, a diagnostic phase requires comprehensive RT60 and STI mapping across listener zones per ISO 3382 standards to quantify baseline deficiencies. Second, architectural interventions should install $0.20\text{--}0.25\text{m}^2$ of absorption per m^3 auditorium volume, prioritizing locally viable absorbers ($\alpha \geq 0.60$) on ceilings and upper walls to target mid-frequency reverberation control. Finally, electroacoustic recalibration through digital signal processing (DSP) must dynamically equalize loudspeaker outputs to align with the reduced reverberation profile, ensuring spectral balance and intelligibility gains. This sequential approach balances technical efficacy with resource efficiency in tropical contexts.

Recommendation

For Architectural Intervention, implement prioritized acoustic treatments: suspend 50mm rock wool baffles (60kg/m^3 density) across 40% of the ceiling area, mounted 300mm below structural surfaces ($\alpha=0.85$). Complement with fabric-wrapped mineral wool panels on upper sidewalls ($\alpha=0.70$). For cost efficiency, substitute commercial materials with locally fabricated textile composites ($\alpha=0.60\text{--}0.75$), applying nano-silane coatings for humidity resistance. Install timber quadratic residue diffusers at the rear gallery to preserve musicality. This phased approach, ceiling first, then walls, then



diffusion, targets reverberation control while accommodating budget constraints. Electroacoustic Optimization, Deploy six directional line arrays ($70^\circ \times 70^\circ$ coverage) in three delay zones: front (0ms), mid (25ms), rear (45ms). Calibrate DSP for: 1) Adaptive feedback suppression; 2) Parametric equalization (-6dB at 125–315Hz); 3) Cardioid microphone optimization. Replace omnidirectional mics with supercardioid models to increase gain-before-feedback by 9dB. Post-installation tuning must follow architectural treatments to align with revised RT60. Validate SPL uniformity (± 3 dB) per ISO 3382-1 across 12 measurement points.

Conclusion

This study confirms that acoustic rehabilitation of St. Andrew's Presbyterian Church is achievable through context-sensitive interventions balancing global best practices with local constraints. Key conclusions establish:

1. Integrated Solutions Are Essential: Combining architectural treatments (absorption, diffusion) with electroacoustic optimization resolved speech intelligibility deficits (STI 0.48 $\rightarrow$ 0.72) while preserving musical reverberance (RT60 3.2s $\rightarrow$ 1.6s). This aligns with global findings that single-modality approaches are insufficient in high-reverberation worship spaces.
2. Local Materials Offer Viable Alternatives: Recycled textile absorbers demonstrated adequate acoustic performance ($\alpha > 0.60$) at lower cost, supporting sustainable solutions for resource-constrained settings—a critical consideration in sub-Saharan Africa.
3. Replicable Protocol for Nigerian Churches: The methodology, diagnostic measurement, simulation-led design, and material adaptation, provides a template for acoustically upgrading similar auditoriums without structural modification.

Practical Implications

Liturgical Enhancement: Achieved acoustic conditions support both sermon intelligibility and choral richness, fulfilling Presbyterian worship requirements. Public Health Impact: Reduced vocal strain for clergy through optimized sound reinforcement.

Research Significance

This work bridges a critical gap in literature on tropical sacred acoustics, demonstrating empirically that context-adapted solutions can overcome Nigeria's unique acoustic challenges. Future studies should explore long-term monitoring of material performance and congregant satisfaction metrics.



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