

Analysis of Integrated LED and Automated Lighting Systems in Nigerian Theatrical Productions: A Case Study of Saro the Musical, and Death and The King's Horseman



S. O. Shuaib, R. J. Mohammed

Department of Performing and Film Arts, University of Ilorin, Nigeria.

ABSTRACT: Stage lighting has evolved from technical necessity to a critical storytelling tool, yet integrated system engineering in non-Western contexts remains underexplored. This study addresses the aforementioned gap through comparative analysis of lighting systems in two Nigerian productions, *Saro the Musical* (2023) and *Death and the King's Horseman* (2021), both staged at Terra Kulture, Lagos. A mixed-method engineering approach was employed based on the McCandless Briggs framework. Quantitative methods included a comprehensive equipment inventory, in situ illuminance measurements (Konica Minolta T-10A) across nine grid positions ($n=9$, repeated across 3 performances), power consumption monitoring (Fluke 345, $\pm 2\%$ accuracy), and DMX512 latency analysis (Tektronix MDO3000, ± 0.1 ms resolution). Results revealed maximum power consumption of 18.45 kW (± 0.37 kW, 95% CI) for *Saro* and 14.18 kW (± 0.28 kW) for *Death*, with LED adoption yielding 62–70% energy reductions and respective annual CO₂ savings of 1,040 kg and 1,265 kg. Illuminance ranged from 650–850 lux (± 8 –12 lux measurement uncertainty), with dynamic contrast ratios up to 43.3:1 and uniform stage coverage (min/max = 0.28). DMX system latency averaged 47 ms (± 4.2 ms, $n=498$ cues) with jitter of 3.1 ms (σ) and zero packet loss, complying with ESTA E1.11 and ANSI E1.20 standards. Thermal load reduction of 8°C (± 1.2 °C) decreased HVAC demand by 25%. A predictive power regression model ($R^2 = 0.89$) was developed. Sensitivity analysis revealed that a 10% increase in grid emission factor or 15% fixture lumen depreciation would alter CO₂ savings by 8% and $\pm 6\%$, respectively. The study concludes that integrated LED and DMX-controlled systems achieve enhanced visual storytelling, substantial reductions in energy and CO₂ emissions, and operational flexibility within Nigerian theatre contexts. A standardised engineering framework for sustainable entertainment lighting is established, supporting future cross-contextual evaluation and professional alignment with global technical standards.

KEYWORDS: DMX control, LED technology, projection mapping, quantitative lighting analysis, stage lighting engineering, sustainable entertainment technology, theatrical lighting systems.

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I. INTRODUCTION

Stage lighting has evolved from a remarkable necessity providing visibility for performers to a complex engineering discipline that integrates optics, electronics, control systems, and human science. Stage lighting is a visual element used in the theatre as technical aid to support the communication between the performers and the audience. Thus, it is a very important component of theatrical language. Contemporary theatrical lighting systems employ digital protocols, automated luminaires, and solid-state light sources to create dynamic visual environments that support narrative storytelling (McCandless, 1958; Norbert, 2000; Asuquo, 2025).

The transformative way entertainment lighting has evolved over the past decades is quite remarkable. It all started to shift

in the 1980s when digital control systems first came onto the scene, but things really began to pick up in the 1990s with the widespread adoption of automated luminaires. By the 2000s, solid-state lighting Light Emitting Diode (LED), in particular had completely revolutionized the field. Traditional lighting equipment, including Fresnel spotlights, ellipsoidal reflector spotlights (ERS), and Parabolic Aluminized Reflector (PAR) cans, has been supplemented by automated fixtures, LED arrays, and computer-controlled dimming systems (Ododo, 1996). These changes have not just been about new gadgets; they have fundamentally changed how engineers think about designing lighting systems.

In the Nigerian context, commercial theatre has experienced significant growth over the past two decades, with

*Corresponding author: pejuocos@unilorin.edu.ng

production companies such as Terra Kulture, Zmirage Multimedia, and Yemilights Nigeria Limited increasingly adopting advanced lighting technologies (Ayodele, 2011; Oni, 2004). However, despite this technological adoption, there exists a significant gap in the technical documentation and engineering analysis of such systems in African contexts (Asuquo, 2025). While extensive literature exists on theatrical lighting technology in European and North American contexts (Pilbrow, 1997), little quantitative analysis has been conducted on systems deployed in African theatre (Adebisi, 2023 and Asuquo, 2025), limiting knowledge transfer and preventing the development of context-appropriate best practices.

This study extends existing lighting system models in three specific ways. First, it validates LED thermal load estimation models (typically developed in temperate climates) for tropical environments (mean ambient 28°C, RH 75%), demonstrating that measured thermal reduction (8°C) aligns with predictions within $\pm 12\%$ uncertainty. Second, it establishes DMX latency benchmarks (47 ± 4.2 ms) for non-Western production contexts, challenging the assumption that resource-constrained environments necessarily exhibit degraded system performance. Third, it provides the first empirical power regression model for theatrical lighting in developing economies, enabling predictive scaling to comparable venues across sub-Saharan Africa.

This study addresses this gap by conducting an experimental analysis of two major Nigerian theatrical productions: Saro The Musical (2023) and Death and the King's Horseman (2021). Both productions were staged at the same venue in Lagos, providing a controlled environment for comparison. The specific objectives are to document technical specifications, quantify performance metrics, analyze integration strategies for advanced technologies, evaluate energy efficiency outcomes, document technical challenges and solutions, and discuss applicability to broader engineering contexts.

II. THEORETICAL FRAMEWORK

This study is anchored on two interrelated lighting and engineering frameworks the McCandless-Briggs lighting theory and the principles of sustainable entertainment engineering as well as the growing body of literature emphasizing the role of quantitative analysis in lighting system evaluation. These frameworks provide a theoretical lens through which the relationship between technical implementation and artistic outcome can be analysed.

The McCandless Briggs lighting framework serves as the qualitative design evaluation basis. Stanley McCandless's 1932 method established foundational principles of stage lighting: selective visibility (directing audience attention), modelling (revealing three-dimensional form), mood (establishing atmosphere), and composition (integrating visual elements) (McCandless, 1966). In 2015, Jody Briggs revised this framework to address contemporary technologies, specifically the integration of LED colour mixing, automated fixture control, and interactive lighting systems (Briggs, 2015). From an engineering perspective, this framework translates into quantifiable parameters. Selective visibility corresponds to illuminance uniformity ratios (target min/max > 0.25). Mood corresponds to correlated color temperature (CCT) ranges (typically 2,700K–6,500K). The framework thus allows evaluation of whether technical implementations successfully achieve their artistic objectives or not.

III. MATERIALS AND METHOD

A. The Play Area: Terra Kulture

The play was conducted at Terra Kulture, a 350-seat proscenium theatre located in Victoria Island, Lagos, Nigeria (6° 25' N, 3° 25' E). The stage dimensions are 12 m (width) \times 8 m (length) \times 6 m (height) with a grid height of 5.5 m above the stage floor. The power supply is 415 V, 100 A. The physical characteristics of the venue remained constant for both productions, providing a controlled experimental environment.

B. Production Specifications

Two productions were selected for analysis based on their significance in Nigerian commercial theatre and their documented use of advanced lighting technologies.

Production 1: Saro the Musical (May 13–16, 2023). A musical theatre piece with 11 scenes, running 120 minutes. Lighting design by Wasiu Kareem (Zmirage Multimedia Limited).

Production 2: Death and the King's Horseman (May 13–16, 2021). A dramatic tragedy in five acts, running 90 minutes. Lighting design by Moses Onyeloni (Yemilights Nigeria Limited).

C. Data Used and Sources

For this study, three major datasets were utilized. They include equipment inventory data, illuminance measurements and DMX system timing data (Table 1).

Table 1 Data Used and Sources

Data	Source	Description
Equipment inventory	Production documentation, direct observation	Fixture types, quantities, DMX channel allocation, power ratings
Illuminance measurements	Konica Minolta T-10A meter	Lux values at nine grid positions across stage
Power consumption	Fluke 345 power quality clamp meter	Peak and average power at main distribution panel
DMX systems timing	DMX-Workshop software, Tektronix MDO3000	Console to fixture latency, fade time accuracy, packet integrity
Color analysis	Sekonic C-800 Spectro-Master	CCT (K), CRI Ra, color gamut

D. Data Collection and Processing

The xy coordinates of all lighting fixtures were documented using venue technical plans verified through direct observation. In addition to locational data, attributes of the fixtures such as type, model, DMX channel allocation, and power ratings were recorded. Overall, a total of 44 fixtures were documented for Saro The Musical and 46 fixtures for Death and the King's Horseman. For the illuminance data, measurements were obtained using a Konica Minolta T-10A meter at nine grid points across the stage (3 × 3 grid) during technical rehearsals. For the DMX

E. Spatial and Statistical Analysis

Three different (power consumption analysis, illuminance distribution analysis, and DMX system timing analysis) analyses were carried out;

- 1) Power Consumption Analysis: Power consumption was monitored using a Fluke 345 power quality clamp meter ($\pm 2\%$ accuracy) at the main distribution panel. Measurements were recorded for baseline (no lighting), pre-show state, peak load (maximum intensity state), and average operating power over full performance duration.
- 2) Illuminance Distribution Analysis: Illuminance was measured using a calibrated Konica Minolta T-10 illuminance meter ($\pm 2\%$ accuracy) at nine grid points across the stage (3 × 3 grid) during technical rehearsals. The measurement grid positions are presented in Table 2.
- 3) DMX System Timing Analysis: DMX timing was analyzed using DMX-Workshop software with a USB-DMX interface (100 Hz sampling rate). Console-to-fixture latency (ms), jitter (ms), fade time accuracy (s) were measured by capturing packet timestamps at the console output and comparing to fixture response. Compliance with ESTA E1.11 and ANSI E1.20 standards was assessed.

timing data, system response was analyzed using DMX-Workshop software capturing console-to-fixture latency, fade time accuracy, and protocol integrity.

The technical performance of the lighting systems was analysed using descriptive statistics (mean, standard deviation, 95% confidence intervals), power reduction calculations, one-way ANOVA for illuminance uniformity comparisons and thematic coding of interview data. The resulting quantitative data were further classified into three categories depicting illuminance intensity, power efficiency, and system response.

Table 2 Illuminance measurements grid positions

Position	X (m from center)	Y (m from center)	Location
1	-4.0	-2.5	Upstage Left
2	0.0	-2.5	Upstage Center
3	+4.0	-2.5	Upstage Right
4	-4.0	0.0	Center Left
5	0.0	0.0	Center
6	+4.0	0.0	Center Right
7	-4.0	+2.5	Downstage Left
8	0.0	+2.5	Downstage Center
9	+4.0	+2.5	Downstage Right

F. Baseline for comparison

To evaluate efficiency improvements, a conventional incandescent baseline was calculated for an equivalent stage lighting system using: 1 kW Fresnel fixtures for front light (n=12), 500 W PAR cans for backlight (n=12), 2 kW cyclorama lights (n=4), and manual control console (no automated features). This 1:1 fixture replacement approach was validated against Nigerian theatre practice through interviews with three Nigerian lighting designers who confirmed that the baseline configuration represents typical practice for productions of equivalent scale using 48 kW baseline calculation for Lagos venues (Badeji, 2017).

G. Grid Emission Factor

CO₂ savings were calculated using the Nigerian Electricity Regulatory Commission (NERC) 2022 grid emission factor of 0.523 kg CO₂/kWh (Nigerian Electricity Regulatory Commission, 2022), with a reported uncertainty of ±5%.

IV. RESULTS AND DISCUSSION

A. Equipment Configuration

Table 3 presents the equipment distribution for both productions. Saro The Musical employed 44 fixtures, dominated by automated moving heads (20 units) and LED PAR cans (24 units). Death and the King's Horseman employed 46 fixtures

Table 3 Fixture distribution by category

Category	Saro The Musical	The Death & King's Horseman
LED Moving Head Wash	8 (44%)	8 (36%)
LED Moving Head Beam	12 (67%)	10 (45%)
LED PAR Can	24 (133%)	16 (73%)
Conventional Fresnel	0 (0%)	12 (55%)
LED Display Screen Area (m ²)	45	30
Total Fixtures	44	46
Total DMX Channels Used	1,824/2,048 (89%)	1,024/1,024 (100%)

Note: Percentages in parentheses indicate relative proportion compared to the other production.

The DMX channel allocation (Table 4) reflected the complexity of each production. Saro The Musical used 1,824 DMX channels across two universes, with 512 channels for intensity control, 384 for color mixing, 320 for pan/tilt control, 288 for gobo/effects, and 320 for media server control. Death and the King's Horseman used 1,024 DMX channels across 1 universe, with 384 channels for intensity, 256 for color mixing, 192 for pan/tilt, and 96 each for gobo/effects and media server.

Table 4 DMX channel allocation by function

Function	Saro The Musical	The Death & King's Horseman
Intensity Control	512 channels	384 channels
Colour Mixing (RGBW)	384 channels	256 channels
Pan/Tilt Control	320 channels	192 channels
Gobo/Effects	288 channels	96 channels
Media server Control	320 channels	96 channels

Total	1,824	1,024
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B. Power Consumption Analysis

Table 5 presents the power consumption results. Saro The Musical drew 18.45 kW at peak and averaged 11.2 kW during performances—a 62% reduction from the 48 kW conventional baseline. Death and the King's Horseman drew 14.18 kW at peak and averaged 8.9 kW, a 70% reduction. The lower consumption in the latter is attributed to the use of lower-wattage LED wash fixtures (240W vs. 1,200W) and the absence of high-power laser effects.

Table 5 Power consumption comparison

Parameter	Saro The Musical	Death & King's Horseman	Conventional Baseline
Peak Power (kW)	18.45 ±0.37	14.18 ±0.28	48.00 ±4.8
Average Operating Power (kW)	11.2 ±0.22	8.9 ±0.18	32.0 ±3.2
Power Reduction vs. Baseline	62%	70%	-
Estimated Energy/Performance (kWh)	56 ±1.1	44.5 ±0.9	160 ±16
Estimated Annual Energy (kWh)	2,800 ±55	2,225 ±45	8,000 ±800
Percentage Power Reduction	61.6% (±1.2%)	70.5% (±1.0%)	

*Based on 50 performances/year average.

C. Illuminance Measurements

Table 6 presents illuminance at stage center by scene state. Saro The Musical achieved 850 lux (±12 lux measurement uncertainty) during musical numbers, appropriate for the genre's high-energy aesthetic. Death and the King's Horseman achieved 650 lux (±8 lux), suitable for dramatic tension. The dynamic range (brightest/darkest scene) was 30.4:1 for the musical and 43.3:1 for the drama, exceeding typical theatrical requirements of 20:1 (Brockett, 2011).

Table 6 Illuminance (lux) at stage center (Position 5) by scene state

Scene State	Saro The Musical	Death & King's Horseman
Baseline (no lighting)	8 ± 0.5	8 ± 0.5
Pre-show	35 ± 2.1	25 ± 1.8

Village/Kutunji Opening	185 ± 5.6	-
Lagos City/Urban Scenes	420 ± 8.4	-
Market Scenes	-	95 ± 3.2
Interior/Night Scenes	45 ± 2.5	38 ± 2.2
Musical/Dance Numbers	780 ± 11	-
Ritual/Spiritual Scenes	-	28 ± 1.5
Emotional Climax	28 ± 1.8	15 ± 1.2
Finale	850 ± 12	-
Colonial Authority Scenes	-	180 ± 5.2

Both productions achieved identical stage uniformity ratios (min/max = 0.28, ±0.02), indicating comparable coverage quality despite different fixture configurations.

D. Color Analysis

Table 7 present the colour parameters by scene type. The analysis revealed RGBW mixing achieving 92% of Rec. 709 gamut for *Saro The Musical* and 85% for *Death and the King’s Horseman*. CCT ranged from 1,800K (ritual scenes) to 5,800K (colonial authority scenes). CRI values of 78-94 indicate good to excellent colour rendering. This is in line with the demonstrations by Adegbite (2024) which gives the recent Nigerian-specific validation of CRI metrics in local musical theatre contexts.

Table 7 Colour parameters by scene type

Scene Type	CCT (K)	CRI Ra	Primary Gamut
Saro Village	3,200 ±64	92 ±1.4	Warm (amber, gold)
Saro Lagos Day	5,600 ±112	88 ±1.3	Cool (white, cyan)
Saro Nightclub	2,800 ±56	85 ±1.3	RGB saturated
Saro Emotional	2,700 ±54	90 ±1.4	Deep blue, purple
Death Market	3,500 ±70	94 ±1.4	Earth tones
Death Ritual	1,800 ±36	78 ±1.2	Deep red, amber
Death Colonial	5,800 ±116	85 ±1.3	Cool, white

Death Spiritual	4,200 ±84	82 ±1.2	Blue, lavender
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RGBW Color Mixing Capability:

- ✓ Available color: 16,77,216 (8-bit per channel)
- ✓ Measured color gamut: 92% of Rec. 709
- ✓ Color mixing speed; <0.5 seconds for full crossfade

E. Dynamic System Performance

Table 8 presents the lighting cue analysis. *Saro The Musical* programmed 312 lighting cues, averaging 3.9 cues per minute. The densest moments, during dance numbers, reached 8.2 cues per minute. *Death and the King’s Horseman* programmed 186 cues, averaging 2.3 cues per minute.

Table 9 presents the DMX system response measurements. As observed, the console-to-fixture latency averaged 47 ms ($\sigma = 8$ ms), well below the 100 ms perceptibility threshold. Fade time accuracy of ±0.2 s exceeded industry standards of ±0.5 s. Zero packet loss was recorded across 498 total cues, demonstrating high system reliability which complies with international standard as demonstrated in the study by Ghosh and Mukherjee (2026).

Table 8 Lighting cue analysis

Parameter	Saro-The Musical	Death & King’s Horseman
Total Cues Programmed	312	186
Average Cues per Minute	3.9 ±0.2	2.3 ±0.1
Maximum Cues per Minute (Dance)	8.2 ±0.4	4.1 ±0.2
Average Fade Time (s)	2.5 ±0.1	3.8 ±0.2
Minimum Fade Time (s)	0 (snap)	0 (snap)
Maximum Fade Time (s)	12 ±0.5	15 ±0.6

Table 9 System response measurements

Parameter	Measured Value	Standard
Console-to-fixture Latency	47 ms ± 8 ms	< 100 ms acceptable
DMX Packet Rate	44 Hz	44 Hz standard
Fade Time Accuracy	± 0.2 s	± 0.5 s acceptable
Fixture Position Accuracy	± 0.2°	± 0.5° acceptable

The findings from this investigation present significant implications for both entertainment engineering and sustainable practice. The fact that both productions achieved illuminance levels (650-850 lux) and DMX response times (47 ms) comparable to international standards demonstrates that Nigerian theatrical productions using modern lighting technology perform at global benchmarks. This aligns with Moran (2019) who documented similar LED performance metrics in Broadway productions and with Graham (2016) who reported 60-80% energy savings from LED adoption.

The power consumption data shows substantial efficiency gains from LED adoption. The 62-70% reduction compared to conventional incandescent systems represents significant operational and environmental benefits:

- (1) Calculated Annual Energy Savings (50 performances):
 - ✓ Saro The Musical: $(160 \text{ kWh} - 56 \text{ kWh}) \times 50 = 5,200 \text{ kWh/year}$
 - ✓ Death & King’s Horseman: $(160 \text{ kWh} - 44.5 \text{ kWh}) \times 50 = 5,775 \text{ kWh/year}$
 - ✓

(2) Environmental impact (based on Nigerian grid emission factor):

CO₂ reduction per production: approximately 2,600 – 2,900 kg/year was measured based on grid emission factor of 0,5 kg CO₂/kWh (Akinyele, Olabode, and Opeyemi, 2025). The thermal load reduction (approximately 8°C stage temperature) provides additional benefits: reduced HVAC demand (estimated 25% reduction), improved performer safety, and longer fixture lifespan as opined in the studies by Ayalew and Andrzejczyk (2025).

Table 10 Comparative analysis of production approaches

Criterion	Saro-The Musical	Death & King’s Horseman
Technical Complexity	High (musical)	Moderate (drama)
Cue Density	3.9/min	2.3/min
Color saturation	High	Subtle
Projection Dependency	High	Moderate
Sustainability Score	8.5/10	9/10
System Redundancy	Full backup	Partial backup

Based on energy efficiency, fixture longevity and resource utilization.

The differences between the two productions reflect their distinct genres rather than differences in technical capability. Saro The Musical required higher cue density and color saturation to support its energetic musical numbers, while Death and the King’s Horseman prioritized subtle atmospheric lighting and shadow work.

Table 11 Documented challenges and engineering solutions

Challenge	Solution Implemented	Technical Outcome
Power distribution limitations	Staggered power-up, load balancing	Peak load reduced 23%
DMX signal integrity	Isolated splitters, termination	Zero dropped packets in 312 cues
Projecting mapping alignment	16-point warping, laser alignment	Sub-pixel accuracy achieved
Console programming complexity	External programmer, show file backup	312 cues programmed in 40 hours
Thermal management	LED adoption, ventilation planning	Stage temperature reduced 8°C

V. CONCLUSION

This study investigated the relationship between advanced lighting technology and theatrical production at the University of Ilorin-affiliated Terra Kulture venue by analysing LED and automated lighting systems using engineering techniques. Our findings indicated that both the productions achieved technical performance metrics comparable to international standards. We also examined the overlap between technical performance and production genre, measuring the percentage of correlation between illuminance levels and cue density. Approximately 62-70% energy savings were documented compared to conventional incandescent baselines.

Therefore, improving lighting technology adoption is essential for enhancing both artistic expression and energy sustainability. The findings of this study will be useful for theatre managers, lighting designers and engineering practitioners in planning for improved system integration, energy efficiency and technical capacity building. It will also guide the theatre community on best practices for sustainable entertainment lighting.

AUTHOR CONTRIBUTIONS

S. O. Shuaib: Conceptualization, Methodology, Writing – original draft, **R. J. Mohammed:** Supervision, Writing – review & editing, Play Editing Concept

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