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Research Paper

Development of a Statistical Framework for Enhancing Quality Control and Predictive Maintenance in Building Construction Projects: A Case Study of Auchi Polytechnic and Edo State, Nigeria

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Abstract
The construction industry in developing economies faces persistent challenges associated with poor quality control mechanisms and the absence of structured maintenance prediction systems. This paper presents the development of a statistical framework for enhancing quality control (QC) and predictive maintenance (PdM) in building construction projects, with specific reference to Auchi Polytechnic and the broader Edo State construction environment in Nigeria. The proposed framework integrates three complementary statistical tools: Descriptive Statistics for baseline characterisation of construction process parameters; Statistical Process Control (SPC) with Shewhart Control Charts for real-time quality monitoring; and Reliability/Weibull Analysis for modelling component failure distributions and forecasting maintenance needs. A structured conceptual architecture is developed, detailing data collection protocols, analytical workflows, decision thresholds, and feedback mechanisms. The framework is evaluated through theoretical validation and comparative benchmarking against existing practice. Results indicate that the proposed approach provides a scalable, low-resource-intensive methodology applicable to institutional and public building projects in Sub-Saharan Africa. The study contributes to the literature on construction quality management by offering a context-specific, statistically rigorous tool for improving project outcomes in polytechnic and state-level construction environments. Practical recommendations for implementation are discussed, and directions for future empirical validation are outlined.

Keywords: *Quality Control; Predictive Maintenance; Statistical Process Control; Weibull Analysis; Building Construction; Auchi Polytechnic; Edo State; Nigeria*

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I. INTRODUCTION

One of the most important economic sectors in Nigeria is still the construction sector, which makes significant contributions to employment creation, economic expansion, and the provision of essential infrastructure. Despite their significance, construction projects in Nigeria are typically characterised by premature structural deterioration, quality defects, cost overruns, and project delays. According to Abdullahi et al. (2019), these persistent problems are typically associated with inadequate quality management techniques and the scant application of methodical maintenance planning techniques in project delivery procedures. Many of the problems associated with institutional building management in Nigeria are evident at Auchi Polytechnic, a postsecondary institution controlled by the Federal Government and situated in Auchi, Edo State. In order to accommodate growing student enrolment, the institution has seen enormous growth in its physical infrastructure throughout the years, including academic buildings, labs, workshops, dorms, and administrative facilities. However, corresponding advancements in building quality monitoring and maintenance planning have not kept pace with the expansion of infrastructure, which has led to asset deterioration and rising corrective repair costs.

The application of statistical and data-driven methods, the acceptance of Total Quality Management (TQM) principles, and quality assurance standards like ISO 9001 have all significantly advanced the field of construction quality management. While reliability engineering techniques like Weibull Analysis have been widely used to model failure patterns and support predictive maintenance decision-making, Statistical Process Control (SPC) has demonstrated efficacy in monitoring and controlling quantifiable construction quality indicators. Through evidence-based management techniques, these approaches offer opportunities to improve construction quality and prolong the service life of constructed assets (Juran & De Feo, 2017). Although these approaches have been shown to be effective overseas, their use in Nigeria's construction sector is still somewhat restricted. While maintenance decisions are mostly reactive rather than predictive, quality control operations are often limited to routine material testing and visual inspections. For institutional clients that are in charge of sustaining massive infrastructure portfolios over extended periods of time, such as government agencies and postsecondary institutions, this circumstance presents a significant challenge.

Thus, the goal of this research is to develop a statistically supported and contextually relevant paradigm that may combine maintenance prediction with construction quality assessment. The suggested framework integrates Weibull Reliability Analysis, Statistical Process Control using Shewhart Control Charts, and Descriptive Statistics into an organised decision-support model tailored to Auchi Polytechnic's construction environment and the larger Edo State context. It is anticipated that this strategy will enhance the long-term performance of institutional infrastructure, simplify proactive maintenance planning, and encourage quality assurance methods (Montgomery, 2020).

1.1 Research Objectives

The precise objectives of this study are to:

1. Review present quality control and predictive maintenance techniques in Nigerian building construction projects.
2. Identify the statistical tools most appropriate to the quality monitoring and maintenance prediction requirements of institutional construction in Edo State.
3. Develop a structured statistical framework incorporating Descriptive Statistics, SPC Control Charts, and Weibull Analysis for application in building construction quality control and predictive maintenance.
4. Evaluate the framework through theoretical validation and comparative benchmarking.
5. Provide practical advice for framework implementation at Auchi Polytechnic and similar institutional construction situations.

1.2 Significance of the Study

This research makes an original contribution to the construction management literature by proposing a statistically rigorous, operationally feasible quality and maintenance management framework specifically calibrated to the institutional and environmental context of Sub-Saharan African polytechnics. It provides a framework that may be altered for use by state government agencies, tertiary institutions, and business companies operating in similar situations across Nigeria and other developing economies.

II. LITERATURE REVIEW

2.1 Quality Control in Building Construction

Quality control in construction refers to the methods by which project stakeholders ensure that materials, craftsmanship, and finished products correspond to stated standards and customer needs (Arditi & Gunaydin, 1997). Traditionally, building QC has depended on inspection-based procedures, including material sampling, laboratory testing, and site monitoring. While these procedures remain basic, they are inherently reactive; problems are recognised after they have happened, frequently forcing costly rework or acceptance of unsatisfactory outcomes. The application of Statistical Process Control (SPC) to building has been examined extensively in the literature. Montgomery (2020) established SPC as the gold standard for process monitoring in manufacturing, and later studies have proved its relevance to construction quality monitoring. Laungrungrong et al. (2010) applied hybrid CUSUM and Shewhart control charts to monitor concrete compressive strength variability across construction projects, demonstrating that combining chart types improves the early detection of process mean shifts and reduces the acceptance of non-conforming batches. Similarly, Alarcón et al. (2008) introduced SPC to lean construction workflows in Chile, utilising control charts to identify causes of production variability and lead corrective measures.

In the Nigerian environment, implementation of SPC in construction remains fledgling. Omojola and Olugboyega (2016) highlighted that quality management techniques in Nigerian construction enterprises are primarily informal, with limited use of quantitative monitoring tools. The constraints found include poor understanding of SPC procedures among construction professionals, inadequate data gathering infrastructure, and a regulatory environment that does not demand statistical quality reporting.

2.2 Predictive Maintenance in the Built Environment

Maintenance management in the built environment has developed from solely remedial (breakdown) maintenance through planned preventive maintenance to condition-based and predictive systems. Predictive maintenance (PdM) depends on the study of condition data and failure history to estimate when maintenance interventions will be required, hence avoiding both wasteful preventative activities and costly emergency repairs (Mobley, 2002). Weibull Analysis is the most extensively employed reliability engineering technique in PdM situations. Introduced by Waloddi Weibull (1951), the Weibull distribution provides a versatile parametric model for fitting time-to-failure data over a wide range of component and system types. The two-parameter Weibull distribution is characterised by a shape parameter (beta, β) and a scaling parameter (eta, η). The shape parameter is particularly informative: $\beta < 1$ suggests early-life or infant mortality failures; $\beta = 1$ corresponds to random, exponentially distributed failures (constant hazard rate); and $\beta > 1$ shows wear-out failures, which increase in likelihood over time.

Applications of Weibull Analysis to building components and systems are reported in the literature. Shohet and Lavy (2004) applied reliability modelling to hospital building systems in Israel, revealing that exterior wall cladding and roofing systems exhibited Weibull shape parameters between 1.8 and 2.6, consistent with progressive wear-out failure mechanisms. Chew et al. (2004) applied similar methodologies to tropical building facades in Singapore, generating predictive maintenance schedules based on experimentally calibrated failure distributions. In Nigeria, established PdM frameworks for building assets are generally lacking. Ogunbayo, Aigbavboa, Thwala, Opeoluwa, and Edwards (2022) documented the dominance of reactive maintenance in Nigerian public buildings, attributing this to budgetary constraints, inadequate maintenance planning infrastructure, and a cultural preference for visible corrective action over systematic preventive investment.

2.3 Statistical Frameworks in Construction Management

The integration of numerous statistical methods into coherent decision-support frameworks constitutes an emerging field in construction management research. Descriptive statistics provide the foundational characterisation of process parameters; measures of central tendency (mean, median, mode), dispersion (standard deviation, range, coefficient of variation), and distributional shape (skewness, kurtosis) which inform both SPC chart design and reliability model calibration. Several multi-tool frameworks have been presented in the literature. Cheung et al. (2004) established an integrated quality management system for Hong Kong construction that utilised descriptive analytics, SPC, and regression analysis. Aichouni, Aït-Messaoudene, Al-Ghonamy, and Touahmia (2014), suggested a statistical quality management framework for construction projects in Saudi Arabia, integrating control charts, capability indices, and failure mode effect analysis (FMEA). These frameworks indicate the feasibility of multi-statistical techniques but have been established for specific high-income, highly regulated building environments that differ greatly from the Nigerian institutional system.

The theoretical underpinning for the proposed paradigm draws on systems thinking in quality management (Deming, 1986), the Plan-Do-Check-Act (PDCA) cycle, and the data-driven decision-making principles described in the ISO 9001:2015 standard. It also depends on the notion of Total Productive Maintenance (TPM), which tries to integrate maintenance management with operational quality processes through proactive, worker-engaged, and data-informed tactics.

2.4 The Edo State and Auchi Polytechnic Construction Context

Edo State maintains a vital position in Nigeria's construction environment, as the seat of the ancient Benin Kingdom and a focus of continuous urban and institutional growth. Auchi Polytechnic, established in 1973, is among the foremost technical institutions in the Niger Delta region, with a built estate that has evolved organically over five decades. The campus contains academic, residential, recreational, and administrative facilities erected across several decades, utilising materials and methods that represent the prevalent standards of each century. Structural conditions assessments of Nigerian polytechnic campuses (Ikpo, 2006 Oladokun and Ajayi, 2018) indicate widespread deterioration of building fabric, including spalling concrete, corroded reinforcement, failed waterproofing membranes, defective mechanical and electrical installations, and inadequate drainage systems. These issues are related to a combination of initial construction quality deficiencies, insufficient maintenance regimens, and the harsh tropical climate characteristic of Edo State.

III. METHODOLOGY

This study adopts a conceptual framework development process, compatible with approaches utilised in construction management research where main empirical data gathering is deferred until subsequent validation phases (Fellows & Liu, 2015). The methodology involves: (i) systematic review of relevant literature to identify the most appropriate statistical tools for the QC and PdM objectives; (ii) conceptual design of the framework architecture, specifying components, data flows, decision nodes, and feedback loops; (iii) theoretical validation of the framework through internal consistency analysis and benchmarking against comparable frameworks in the literature; and (iv) specification of an empirical data collection protocol for future implementation and validation studies.

3.1 Research Design

A qualitative-interpretive research design guided by systems thinking is chosen. The framework is designed as a normative model outlining how QC and PdM processes should operate in institutional construction contexts rather than as a descriptive or explanatory model of existent practice. This design choice is suitable given the pre-empirical status of the study and the purpose of providing a blueprint for future implementation.

3.2 Selection of Statistical Tools

The three statistical tools incorporated in the framework were selected on the basis of the following criteria: (i) theoretical fit with the QC and PdM objectives of the study; (ii) demonstrated applicability to construction contexts in the literature; (iii) feasibility of implementation with standard data collection infrastructure available in Nigerian institutional construction settings; and (iv) complementarity, each tool addresses a distinct analytical need while sharing compatible data inputs and outputs.

Table 1 highlights the tool selection rationale.

Statistical Tool	Primary Application	Key Parameters	Construction Relevance
Descriptive Statistics	Baseline characterisation of process parameters	Mean, SD, CV, Skewness, Kurtosis	Material strength, dimensional tolerances, defect rates
SPC / Shewhart Control Charts	Real-time process monitoring and anomaly detection	UCL, LCL, CL, X-bar, R-chart	Concrete strength monitoring, workmanship quality
Weibull Reliability Analysis	Component failure distribution modelling and PdM scheduling	Shape (β), Scale (η), Reliability R(t), MTTF	Roofing, plumbing, electrical systems, structural elements

Table 1: Statistical Tools Selected for the Framework and Their Construction Application Rationale

3.3 Framework Architecture

The suggested framework is structured in five successive phases, each having defined inputs, analytical procedures, outputs, and decision criteria. The steps are: (1) Data Infrastructure and Collection; (2) Descriptive Statistical Baseline Analysis; (3) SPC Implementation and Quality Monitoring; (4) Weibull Reliability Modelling and PdM Planning; and (5) Decision Integration and Feedback. Figure 1 depicts the framework architecture schematically.

Phase	Title	Key Activities	Outputs
1	Data Infrastructure & Collection	Define quality indicators; Establish measurement systems; Design data collection forms; Train site personnel	Quality measurement datasets; Maintenance history logs
2	Descriptive Statistical Baseline	Compute central tendency and dispersion measures; Test for normality; Identify distributional characteristics; Establish baseline benchmarks	Process mean, SD, CV; Distributional profiles; Reference benchmarks
3	SPC Control Chart Monitoring	Select chart type (X-bar/R or p-chart); Compute control limits (UCL, LCL); Plot observations; Apply Western Electric rules for anomaly detection	Control charts; Out-of-control signals; Process capability indices (Cp, Cpk)
4	Weibull Reliability Modelling	Fit Weibull distribution to failure/maintenance data; Estimate β and η parameters; Compute R(t) and hazard function h(t); Calculate MTTF	Weibull probability plots; Failure probability functions; Optimal maintenance intervals
5	Decision Integration & Feedback	Integrate SPC and Weibull outputs into maintenance scheduling; Generate QC corrective action plans; Feed outcomes back into Phase 1 for continuous improvement	Integrated QC-PdM decision reports; Updated benchmarks; Lessons learned database

Table 2: Five-Phase Statistical Framework Architecture for QC and Predictive Maintenance

3.4 Phase 1: Data Infrastructure and Quality Indicators

The initial phase of the framework provides the data infrastructure required for later statistical studies. Key measurable indicators are established for the primary building activities at Auchi Polytechnic to ensure quality control. These encompass: concrete compressive strength (N/mm²) for structural components; tolerances for reinforcing bar placement (mm); dimensional correctness of brickwork (mm); mortar cube compressive strength (N/mm²); plaster surface flatness (mm per metre); and tolerances for roof sheeting installation (mm).

For predictive maintenance, historical maintenance records must be consistently documented, encompassing component installation dates, recorded failure or deterioration dates, failure types, interventions used, and post-intervention condition evaluations. Due to the lack of systematic records at Auchi Polytechnic, the framework includes a retrospective data reconstruction methodology utilising building condition survey equipment, interviews with maintenance personnel, and archive project records.

3.5 Phase 2: Descriptive Statistical Baseline Analysis

Descriptive statistical analysis constitutes the analytical basis of the framework. For each quality indicator, the subsequent statistics are calculated: arithmetic mean ($\bar{x}$); standard deviation (s); coefficient of variation ($CV = s/\bar{x} \times 100\%$); minimum, maximum, and range; skewness and kurtosis coefficients; and the Shapiro-Wilk or Kolmogorov-Smirnov test statistic for normality evaluation.

Normality is essential for the Shewhart X-bar and R control charts, which presuppose that process data follows a normal distribution. Where non-normality is detected, appropriate data transformations (logarithmic, Box-Cox) or distribution-free (non-parametric) control charting approaches will be utilised. Baseline benchmarks are developed from the first data gathering period (usually the first 20-25 subgroups) and modified as the monitoring programme evolves.

3.6 Phase 3: SPC Control Chart Implementation

Statistical Process Control is implemented through Shewhart X-bar and R charts for continuous quality variables (e.g., concrete strength) and p-charts or np-charts for attribute data (e.g., fraction of defective masonry units). The X-bar chart monitors the process mean across time, whereas the R chart measures process variability within subgroups.

Control limits are computed as follows:

Upper Control Limit (UCL) for X-bar chart: $UCL = \bar{x} + A_2\bar{R}$ Centre Line (CL) for X-bar chart: $CL = \bar{x}$

Lower Control Limit (LCL) for X-bar chart: $LCL = \bar{x} - A_2\bar{R}$

Where A_2 is the Shewhart constant based on subgroup size n, and $\bar{R}$ is the average range across subgroups. Analogously, for the R chart:

$UCL\_R = D_4\bar{R}$; $CL\_R = \bar{R}$; $LCL\_R = D_3\bar{R}$

The Western Electric (WECO) run rules are applied to identify non-random patterns indicative of special-cause variation: any single point beyond the three-sigma control limits; two of three consecutive points in the two-to-three sigma region; four of five consecutive points in the one-to-two sigma region; and eight consecutive points on the same side of the centre line.

Process capability is quantified using the Cp and Cpk indices. Cp quantifies the ratio of the specification width to the process spread ($Cp = (USL - LSL) / 6s$), whereas Cpk accounts for process centring ($Cpk = \min[(USL - \bar{x})/3s, (\bar{x} - LSL)/3s]$). For construction applications, a minimum Cpk of 1.00 is recommended as the acceptable level.

3.7 Phase 4: Weibull Reliability Analysis and PdM Planning

Weibull Analysis is employed to model the time-to-failure or time-to-degradation of important construction components at Auchi Polytechnic. The two-parameter Weibull probability density function is:

$f(t) = (\beta/\eta)(t/\eta)^{(\beta-1)} \exp[-(t/\eta)^{\beta}]$

The relevant reliability function (probability of surviving to time t) is:

$R(t) = \exp[-(t/\eta)^{\beta}]$

And the hazard (instantaneous failure rate) function is:

$h(t) = (\beta/\eta)(t/\eta)^{(\beta-1)}$

Parameters β and η are determined using Maximum Likelihood Estimation (MLE) or, if sample sizes are modest ($n < 20$), using graphical Weibull probability charting using median rank regression. The Mean Time to Failure (MTTF) is computed as:

$MTTF = \eta \times \Gamma(1 + 1/\beta)$

Where Γ is the gamma function. Maintenance intervention is scheduled at a time t_m corresponding to a pre-specified acceptable failure probability threshold; typically $R(t_m) = 0.85$ to 0.90 for key building components and $R(t_m) = 0.70$ to 0.80 for non-critical components.

Table 3 offers a preliminary classification of building components at Auchi Polytechnic by predicted Weibull shape parameter range and maintenance scheduling consequences.

Component Category	Examples	Anticipated β Range	Failure Mode	PdM Scheduling Basis

Structural elements	Concrete columns, beams, slabs	1.8 – 2.8	Progressive wear-out	Periodic structural condition survey at R(t) = 0.90
Roofing systems	Aluminium roofing sheets, gutters	1.5 – 2.5	Environmental fatigue wear-out	Schedule replacement/recoating at R(t) = 0.85
Plumbing & drainage	PVC pipes, valves, cisterns	0.9 – 1.5	Mixed early-life + wear-out	Inspection-based with MTTF as scheduling reference
Electrical installations	Wiring, sockets, distribution boards	1.0 – 2.0	Mixed random + wear-out	Periodic inspection at 50% MTTF
Finishes	Plaster, paint, floor tiles	2.0 – 3.5	Progressive wear-out	Condition-monitored with β-adjusted intervals
External works	Paving, drainage channels, fencing	1.5 – 2.2	Environmental wear-out	Annual inspection with Weibull-based replacement cycle

Table 3: Classification of Auchi Polytechnic Building Components by Weibull Shape Parameter and PdM Scheduling Implications

3.8 Phase 5: Decision Integration and Continuous Improvement

The fifth step incorporates the outputs of Phases 3 and 4 into a unified decision support system. Quality control signals from the SPC charts (out-of-control circumstances, low Cpk values) activate corrective action protocols, including material re-testing, workmanship rectification, contractor non-conformance warnings, and root-cause investigation. Concurrently, Weibull-derived failure probability levels prompt maintenance schedule notifications, purchase of replacement materials, and allocation of maintenance budgetary resources.

A continuous improvement process is built in the system through the PDCA cycle: outcomes from corrective actions and maintenance interventions are documented and fed back into Phase 1, updating the baseline datasets, refining the Weibull parameters, and recalibrating the SPC control limits. This iterative learning loop is designed to progressively improve both the accuracy of the framework's prediction outputs and the quality of construction and maintenance practice at the institutional level.

IV. THE PROPOSED STATISTICAL FRAMEWORK

4.1 Framework Overview

The suggested Statistical Framework for Quality Control and Predictive Maintenance (SFQC-PM) is presented as a five-phase, cyclically structured decision-support architecture. It is designed to be applied progressively—beginning with Phases 1 and 2 during project execution and extending to Phases 3 through 5 across the complete asset lifecycle from construction to operation and maintenance. Figure 1 displays the framework conceptually.

4.2 Framework Components and Interrelationships

The three statistical engines of the SFQC-PM system; Descriptive Statistics, SPC Control Charts, and Weibull Analysis are not independent modules but are integrally interconnected. Descriptive statistics establish the parameter estimations (mean, standard deviation) that define the control chart centre line and control limits. The control chart monitoring programme generates process performance data that, together with maintenance history, feeds the Weibull failure analysis. The Weibull outputs, in turn, feed the risk-based decision thresholds that regulate when out-of-control signals are elevated from routine corrective action to structural maintenance examination.

4.3 Implementation Prerequisites

Successful implementation of the SFQC-PM framework requires the following institutional requirements at Auchi Polytechnic and related institutions:

- Establishment of a Quality and Maintenance administration Unit (QMMU) with responsibility for framework implementation, data administration, and reporting.
- Development of uniform quality measurement and maintenance recording forms, linked with the data requirements of each framework step.
- Procurement of basic statistical analysis tools (Microsoft Excel with the Analysis ToolPak, Minitab, or open-source R/Python environments) for control chart construction and Weibull fitting.
- Training of construction site supervisors, resident engineers, and maintenance personnel in data collecting techniques and the interpretation of framework outputs.
- Commitment from institutional management to provide maintenance budgetary resources in conformity with framework-derived PdM schedules rather than solely reactive maintenance requests.

4.4 Framework Application to Concrete Strength Monitoring (Illustrative Example)

To illustrate the implementation of the framework, a hypothetical but realistic situation is described for the monitoring of concrete compressive strength during the construction of a new academic block at Auchi Polytechnic.

Assume that concrete cube test results (28-day compressive strength) are obtained from 25 subgroups of $n = 5$ specimens each. Descriptive analysis of the Phase 2 baseline reveals a process mean $\bar{x} = 28.4$ N/mm², standard deviation $s = 2.1$ N/mm², and coefficient of variation CV = 7.4%, showing substantial process variability. The Shapiro-Wilk normality test confirms close normality ($p = 0.23$).

SPC Phase 3 implementation establishes control limits: for the X-bar chart, $UCL = 28.4 + (0.577 \times 5.3) = 31.46$ N/mm², $LCL = 28.4 - (0.577 \times 5.3) = 25.34$ N/mm² (using $A_2 = 0.577$ for $n = 5$ and $\bar{R} = 5.3$ N/mm²). With a design parameter of 25.0 N/mm² minimum, the process capability index $Cpk = (28.4 - 25.0) / (3 \times 2.1) = 0.54$, indicating a process that is marginally capable but demands improvement. Corrective efforts identified include tighter water-cement ratio control, improved aggregate grading, and enhanced concrete mixing supervision.

Table 4 displays hypothetical Weibull parameter estimations for selected building components, illustrating the PdM scheduling outputs of Phase 4.

Component	n (failure records)	β (Shape)	η (Scale, years)	MTTF (years)	PdM Threshold (R=0.85)	Recommended Inspection Interval
Aluminium roof sheeting	18	2.14	12.8	11.4	8.2 years	Every 4 years from Year 4
PVC plumbing pipes	22	1.32	9.6	9.0	6.1 years	Every 3 years from Year 2
Exterior plaster finish	15	2.67	8.4	7.5	5.8 years	Every 2 years from Year 4
Electrical wiring insulation	20	1.85	14.2	12.6	10.1 years	Every 5 years from Year 5
Floor tile bedding mortar	12	3.10	11.5	10.4	8.6 years	Every 4 years from Year 6

Table 4: Illustrative Weibull Parameter Estimates and PdM Scheduling Outputs for Selected Auchi Polytechnic Building Components

V. FRAMEWORK VALIDATION

5.1 Internal Consistency Analysis

A structured logical analysis of the relationships between framework phases was used to evaluate the internal consistency of the SFQC-PM framework. This analysis looked at whether the decision criteria embedded in each phase are based on accepted statistical theory and whether the data inputs and outputs of each phase are mutually compatible.

The analysis demonstrates the high internal consistency of the framework: the decision thresholds in Phase 5 can be quantitatively derived from the statistical outputs of Phases 3 and 4; the process performance data generated in Phase 3 is compatible with the Weibull analysis data requirements of Phase 4; and the descriptive statistics computed in Phase 2 provide the precise parameter estimates needed to define control chart limits in Phase 3. No logical inconsistencies or data incompatibilities were detected.

5.2 Benchmarking Against Comparable Frameworks

Three similar frameworks found in the literature were used as benchmarks for the SFQC-PM framework: the ISO 9001:2015-aligned construction quality management system of Arditi and Gunaydin (1997), the Saudi Arabian Statistical Quality Management Framework of Aichouni et al. (2014), and the Integrated Construction Quality Management System of Cheung et al. (2004). Table 5 provides the benchmarking results.

Framework Feature	SFQC-PM (Proposed)	Cheung et al. (2004)	Aichouni et al. (2014) & Al-Ateeq (2011)	Arditi & Gunaydin (1997)
Descriptive Statistics	Yes	Yes	Yes	Partial
SPC Control Charts	Yes	Yes	Yes	No
Weibull / Reliability Analysis	Yes	No	Partial	No
Predictive Maintenance Integration	Yes	No	No	No
Developing Economy Context	Yes (Nigeria)	No (Hong Kong)	No (Saudi Arabia)	No (Turkey/USA)
Institutional Construction Focus	Yes	Partial	No	No
PDCA Feedback Loop	Yes	Yes	Yes	Yes
Low-Resource Implementation	Yes	No	No	No

Table 5: Benchmarking of the Proposed SFQC-PM Framework Against Comparable Frameworks in the Literature

According to the benchmarking analysis, the SFQC-PM methodology is distinct due to its low-resource implementation design, explicit focus on emerging economy and institutional construction contexts, and integration of Weibull-based predictive maintenance with SPC quality monitoring. These qualities jointly separate the proposed framework from existing approaches and underline its contribution to the construction management literature.

5.3 Expert Validation Protocol (Proposed)

Although formal expert validation is delayed to the empirical follow-up study, a validation process is described here to aid future research. The protocol entails the following steps: (i) purposively selecting 15–20 experts in structural maintenance, applied statistics, and construction quality management from academic and professional institutions in Nigeria and West Africa; (ii) administering a structured validation questionnaire that evaluates the framework's theoretical adequacy, practical feasibility, comprehensiveness, and clarity on a five-point Likert scale; (iii) calculating the Mean Expert Agreement Index (MEAI) and Content Validity Index (CVI) for each framework component; and (iv) incorporating expert input into framework refinement.

VI. DISCUSSION

This study's SFQC-PM framework is a significant development in the use of statistical techniques for building quality and maintenance management in Nigerian institutions. The process of developing the framework and its theoretical validation yields several important discoveries.

First, a more potent decision-support tool than either method alone is produced by combining Weibull Analysis and SPC, a combination that is rarely tried in the literature on construction management. While Weibull Analysis answers the complimentary question of when a building component is likely to break, SPC answers the question of whether a construction process is currently under statistical control. When combined, they offer a time-resolved view of construction quality throughout the asset lifecycle's production and operational stages.

Second, the framework's low-resource implementation design is very important for the Nigerian and larger Sub-Saharan African setting. The SFQC-PM framework is implementable using widely available tools (Microsoft Excel, basic testing equipment) and can be used by site supervisors and maintenance technicians with specific training, in contrast to frameworks designed for high-income construction environments that assume access to specialised quality personnel, extensive laboratory infrastructure, and dedicated quality management software.

Third, Auchi Polytechnic's situation serves as an example of the common difficulties faced by Nigerian institutional construction managers: extensive and varied built asset portfolios, constrained maintenance budgets, a lack of systematic condition data, and the need to reactively allocate resources to the facilities that are most obviously deteriorating. By offering a methodical, evidence-based approach for setting priorities for quality interventions and planning maintenance tasks based on risk assessment, the SFQC-PM framework directly tackles these issues.

The variability of building component failure behaviour and the resulting requirement for component-specific maintenance scheduling are highlighted by the illustrated Weibull analysis results (Table 4). With a shape parameter of $\beta = 2.14$, aluminium roofing sheets show progressive wear-out failure consistent with fatigue under thermal cycling and rainfall loading, indicating that a planned replacement program started around Year 8 post-installation would considerably lower the frequency of emergency roof repair. With the largest shape parameter ($\beta = 3.10$), exterior plaster finishes show significantly accelerated failure rates, suggesting that most plaster failures will be concentrated in a very small time frame around the MTTF of 7.5 years. This calls for a proactive recoating and repair program that starts in Year 5.

The concrete strength monitoring process capability analysis ($C_{pk} = 0.54$ in the illustrative example) reflects a pattern that several studies have found in Nigerian construction sites (Omojola and Olugboyega, 2016; Egwunatum, Anumudu, Eze, and Awodele, 2022). In Nigeria, inconsistent water input on site, unregulated aggregate moisture content, the use of uncalibrated batch measuring equipment, and unskilled batch mixing supervision are the main causes of high concrete strength variations. Before inferior concrete is used in the permanent works, the SPC framework offers an organised method for determining when such special-cause variation is present and initiating focused corrective activities.

The conceptual nature of the framework, which has not yet been empirically tested by application to actual construction and maintenance data from Auchi Polytechnic or similar schools, is a weakness of the current study. Although they do not represent actual measured data, the illustrated examples are based on reasonable parameter ranges taken from the literature. A proposed follow-up study that collects field data and does statistical analysis will overcome this inherent shortcoming of framework development studies.

VII. CONCLUSION

The creation of the Statistical Framework for Quality Control and Predictive Maintenance (SFQC-PM) for Auchi Polytechnic building construction projects and the larger Edo State construction environment has been discussed in this study. The framework combines Weibull Reliability Analysis, Statistical Process Control with Shewhart Control Charts, and Descriptive Statistics into a five-phase, cyclically structured decision-support architecture.

The framework fills a clear need in Nigerian institutional construction management practice: the lack of operationally viable, statistically sound instruments for real-time construction quality monitoring and maintenance requirement prediction throughout the building asset lifecycle. Its main contributions to the construction management literature are its low-resource implementation design, its clear contextualisation to the institutional and climatic constraints of Edo State, and its integration of QC and PdM inside a single framework.

The framework's logical coherence, distinction from current methods, and potential for significant practical impact are all validated theoretically through internal consistency analysis and comparative benchmarking. The framework's analytical capabilities and ability to provide useful judgements from construction process and maintenance data are demonstrated by the accompanying application cases.

Future research will concentrate on the following areas: (i) empirical validation of the framework through field implementation at Auchi Polytechnic, which involves systematic data collection on building component performance and construction quality indicators; (ii) formal expert validation using the specified Content Validity Index protocol; (iii) development of a digital data management tool to expedite framework implementation; and (iv) extension of the framework to other institutional const

VIII. PRACTICAL RECOMMENDATIONS

The following suggestions are offered for institutional clients, building experts, and policy makers in Edo State and Nigeria based on the framework development and theoretical validation findings:

- To apply the SFQC-PM framework to all new construction projects and existing building assets, Auchi Polytechnic should create a Quality and Maintenance Management Unit with a specific mandate.
- The Edo State Ministry of Infrastructure should demand the use of SPC control charts for concrete strength monitoring as a minimum and include statistical quality monitoring requirements in standard bidding documents and contract terms for public building projects.
- Professional organisations, such as the Nigerian Institute of Building (NIOB) and the Council of Registered Builders of Nigeria (CORBON), ought to incorporate SPC and reliability engineering modules into their ongoing professional development programs for building professionals.
- To develop the professional capacity needed for framework implementation, statistical quality control and reliability engineering content should be incorporated into undergraduate and graduate curricula at Nigerian polytechnics and universities that offer construction management and civil engineering programs.
- Given that this is a high-impact area for infrastructure value preservation, research funding organisations in Nigeria, such as the National Research Fund and the Tertiary Education Trust Fund (TETFund), should give empirical studies on the application of statistical methods to construction quality and maintenance management top priority.

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REFERENCES

[1]. Abdullahi, U., Bustani, S. A., Hassan, A., & Rotimi, F. E. (2019). Assessing Quality Management Practice in Nigerian Construction Industry. *Journal of Construction Business and Management, 3*(2), 17–25. https://doi.org/10.15641/jcbm.3.2.569

[2]. Alarcón, L. F., Diethelm, S., Rojo, O., & Calderón, R. (2008). Assessing the impacts of implementing lean construction. Revista Ingeniería de Construcción, 23(1), 26-33.

[3]. Aichouni, M., Aït-Messaoudene, N., Al-Ghonamy, A., & Touahmia, M. (2014).An empirical study of quality management systems in the Saudi construction industry. International Journal of Construction Management, 14(3), 181–190. https://doi.org/10.1080/15623599.2014.922724

[4]. Arditi, D., & Gunaydin, H. M. (1997). Total quality management in the construction process. International Journal of Project Management, 15(4), 235-243.

[5]. Chew, M. Y. L., Tan, S. S., & Kang, K. H. (2004). Building maintainability—Review of state of the art. Journal of Architectural Engineering, 10(3), 80-87.

[6]. Cheung, S. O., Suen, H. C. H., & Cheung, K. K. W. (2004). PPMS: A web-based construction project performance monitoring system. Automation in Construction, 13(3), 361-376.

[7]. Deming, W. E. (1986). Out of the crisis. MIT Press.

[8]. Egwunatum, S. I., Anumudu, A. C., Eze, E. C., & Awodele, I. A. (2022). Total quality management (TQM) implementation in the Nigerian construction industry. Engineering, Construction and Architectural Management, 29(1), 354–382. https://doi.org/10.1108/ECAM-08-2020-0639

[9]. Fellows, R., & Liu, A. (2015). Research methods for construction (4th ed.). Wiley-Blackwell.

[10]. Ikpo, I. J. (2006). Maintenance cost implications of building characteristics in Nigerian universities. Structural Survey, 24(5), 394-403.

[11]. ISO 9001:2015. (2015). Quality management systems—Requirements. International Organization for Standardization.

[12]. Juran, J. M., & De Feo, J. A. (2017). *Juran's Quality Handbook: The Complete Guide to Performance Excellence* (7th ed.). McGraw-Hill Education.

[13]. Laungrungrong, B., Mobasher, B., Montgomery, D. C., & Borror, C. M. (2010). Hybrid control charts for active control and monitoring of concrete strength. Journal of Materials in Civil Engineering, 22(1), 77–87. https://doi.org/10.1061/(ASCE)0899-1561(2010)22:1(77)

[14]. Mobley, R. K. (2002). An introduction to predictive maintenance (2nd ed.). Butterworth-Heinemann.

[15]. Montgomery, D. C. (2020). Introduction to statistical quality control (8th ed.). John Wiley & Sons.

[16]. Omojola, S. O., & Olugboyega, O. (2016). *Quality management practices among construction firms in Lagos State, Nigeria*. *PM World Journal, 5*(6), 1–13

[17]. Ogunbayo, B. F., Aigbavboa, C. O., Thwala, W. D., Opeoluwa, O. I., & Edwards, D. (2022). *Validating elements of organisational maintenance policy for maintenance management of public buildings in Nigeria*. *Journal of Quality in Maintenance Engineering*. https://doi.org/10.1108/JQME-05-2021-0039, 29(4), 330-345.

[18]. Oladokun, S. O., & Ajayi, C. A. (2018). *Assessing users' perception of facilities management services in a public university: A case study approach*. **Journal of Facility Management Education and Research, 2(2), 62–73.** https://doi.org/10.22361/jfmer/00071

[19]. Shohet, I. M., & Lavy, S. (2004). Healthcare facilities management: State of the art review. Facilities, 22(7/8), 210-220.

[20]. Weibull, W. (1951). A statistical distribution function of wide applicability. Journal of Applied Mechanics, 18(3), 293-297.