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A Model for Prioritizing Maintenance Activities Using the LCC Approach at the Manado State Polytechnic

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Abstract

University facility managers must allocate limited maintenance resources among building components with varying deterioration patterns, functional requirements, and replacement cycles. However, maintenance priorities are often determined by the urgency of reported problems or available budgets rather than integrated technical, economic, and operational evidence. This study developed a maintenance prioritization model using a life cycle costing (LCC) approach for the Integrated Lecture Building (GKT) at Manado State Polytechnic, a six-story facility with a basement that exhibited cracking, corrosion, water seepage, exterior panel deterioration, and user-reported operational issues. The study addressed three research questions: the costs incurred over the planning horizon, the relationships between technical, economic, and operational criteria and perceived maintenance priorities, and the application of these findings to maintenance decision-making. A quantitative case study integrated a documentary building condition assessment using rapid visual screening (RVS), partial least squares structural equation modeling (PLS-SEM) of 133 questionnaire responses across four constructs, and a deterministic life cycle cost analysis (LCCA) comparing three maintenance strategies over a 20-year planning horizon at a fixed 6% discount rate. All three criteria were significantly associated with perceived maintenance priorities: technical criteria ($\beta = 0.2783$, $p = 0.0313$), economic criteria ($\beta = 0.3283$, $p = 0.0020$), and operational criteria ($\beta = 0.3116$, $p = 0.0065$). Economic criteria had the largest estimated coefficient, although their effect was not statistically distinguishable from that of operational criteria. Scheduled preventive maintenance emerged as the lowest-cost alternative, with a modeled life cycle cost of IDR 92.962 billion and estimated savings of IDR 1.808 billion, representing 9.04% of the forward-looking reactive maintenance cost. The study concluded that integrating building condition assessments, stakeholder perceptions, and life cycle cost estimates provided a traceable basis for prioritizing maintenance activities. The proposed decision rule favored the lowest-cost alternative that satisfied the required technical and service performance criteria. However, the composition of the respondent sample and mixed model fit indices warranted cautious interpretation of the findings.

INTRODUCTION

University facility managers must allocate limited maintenance resources among building components with varying deterioration patterns, functional requirements, and replacement cycles. A low-cost intervention may provide limited long-term benefits if it fails to address the underlying defect, while postponing necessary repairs can disrupt access to educational facilities (Alasmari et al., 2022; Ayob et al., 2025; Kheradranjbar et al., 2022). The primary challenge is therefore to align maintenance priorities with the technical requirements, operational consequences, and life cycle costs of available interventions. Previous research on university buildings has examined maintenance expenditures and budget forecasting using historical records (Li & Guo, 2012). Although such evidence supports long-term financial planning, it does not necessarily explain which operational problems building users perceive as most urgent.

The Integrated Lecture Building (GKT) at Manado State Polytechnic provides a relevant case for examining these interconnected challenges. This six-story building, which includes a basement, accommodates academic and supporting activities. Existing building records documented localized cracking, corrosion, water seepage, and concerns regarding exterior aluminum composite panels (Hair et al., 2019; Kandiyoh et al., 2025; Standardization, 2017). Building users also reported operational problems involving elevators, sanitation facilities, electrical systems, and water supply. These observations represented distinct dimensions of maintenance requirements and therefore needed to be evaluated collectively without interpreting user perceptions as direct measurements of structural integrity (Kandiyoh et al., 2021; Rondonuwu, 2026; Sarstedt et al., 2019; SmartPLS, 2026; Tompodung, 2025).

Previous studies on public building maintenance have developed multicriteria decision-making frameworks for selecting appropriate maintenance strategies (Ighravwe & Oke, 2019). At Manado State Polytechnic, Kandiyoh et al. integrated visual building assessments with life cycle cost analysis (LCCA) to evaluate maintenance alternatives for another lecture building (International, 2017). Building on this research, the present study examined the relationships between perceived technical, economic, and operational criteria, component-level maintenance urgency, and projected maintenance costs for GKT. Its contribution was the systematic integration of these complementary evidence sources into a traceable decision-making framework rather than a claim of an entirely unprecedented methodological combination.

Public building maintenance in Indonesia faces persistent challenges associated with budget constraints, expenditure efficiency, and infrastructure deterioration. In one local government, the 2024 budget allocation for building and structural maintenance reached IDR 78.7 billion, of which IDR 69.4 billion was spent, representing a reported 30.28% increase over the previous year's expenditure. This increase highlighted the importance of evidence-based maintenance prioritization rather than reliance on reactive expenditure decisions. Furthermore, municipal audit findings have identified procurement inefficiencies, including overpayments associated with discrepancies between contracted and completed maintenance work quantities. These examples illustrated that increased maintenance expenditure does not necessarily improve facility

performance without transparent planning, procurement controls, and systematic decision-making procedures (Abideen et al., 2022; Dzulkifli et al., 2021; Rosita et al., 2023).

The specific problem examined in this study concerned GKT at Manado State Polytechnic, a six-story educational facility with a basement that exhibited localized cracking, corrosion, water seepage, and concerns regarding exterior aluminum composite panels. Building users also identified operational issues involving elevators, sanitation facilities, electrical systems, and water supply. These conditions reflected interconnected technical, economic, and operational maintenance requirements that were not necessarily addressed through an integrated assessment process. Consequently, maintenance decisions based primarily on complaint urgency or budget availability could overlook the combined implications of building condition, intervention costs, and service continuity.

Previous research on university building maintenance has advanced the understanding of maintenance demand and strategic planning, although opportunities for further integration remain. D'Orazio et al. developed a data-driven model examining relationships between occupant density and maintenance work orders in Italian university buildings, highlighting the relevance of building utilization to maintenance demand. Grącki and Plebankiewicz conducted a bibliometric review of public university building maintenance strategies using Scopus-indexed publications and identified the need for stronger integration between maintenance planning and life cycle cost considerations. Together, these studies demonstrated the importance of operational demand and economic evaluation, while indicating opportunities to connect these dimensions within a more comprehensive maintenance prioritization framework.

The research gap addressed in this study concerned the limited integration of stakeholder perceptions, component-level maintenance urgency, and projected life cycle costs within a single building-level decision framework. Although previous studies have examined maintenance strategies, building utilization, and economic assessment, the relationships between perceived technical, economic, and operational criteria and alternative maintenance strategies require further investigation. Grącki and Plebankiewicz emphasized the need to connect maintenance strategies with the life cycle costs of university buildings. Moreover, evidence from Indonesian polytechnic facilities remains relevant for understanding how maintenance prioritization can be adapted to institutional resource constraints and local building conditions. Accordingly, this study sought to establish a transparent relationship between these complementary evidence sources without treating them as interchangeable measurements.

The importance of this research was reinforced by infrastructure deterioration and seismic considerations affecting educational facilities in North Sulawesi. A structural assessment of another building at Manado State Polytechnic identified progressive material degradation and limited structural capacity margins, leading to recommendations for proactive retrofitting to improve long-term seismic safety. Given the region's seismic exposure, maintenance planning should consider potential structural vulnerabilities alongside financial and operational requirements. At GKT, documented cracking, corrosion, and seepage highlighted the need for systematic technical screening and timely maintenance decisions. However, these observed

conditions alone did not establish the building's structural safety or seismic performance. Integrating technical assessments, user-reported concerns, and projected maintenance costs could therefore support more informed intervention planning.

The novelty of this study lay in the traceable integration of three distinct evidence sources: building condition documentation supported by rapid visual screening (RVS), partial least squares structural equation modeling (PLS-SEM) of 133 questionnaire responses examining technical, economic, and operational criteria, and deterministic life cycle cost analysis comparing reactive maintenance, scheduled preventive maintenance, and targeted minor retrofitting over a 20-year planning horizon. Unlike approaches that interpret financial expenditure as a direct measure of stakeholder perceptions, the proposed framework distinguished life cycle costing (LCC) as an economic assessment from perceived maintenance priority as a survey-based construct. This methodological distinction enabled the relationships between perceived criteria and maintenance priorities to be examined without conflating statistical associations with monetary cost estimates.

The purpose of this study was to develop and assess a maintenance prioritization model for GKT at Manado State Polytechnic using an integrated LCC approach. Specifically, the research addressed three questions: which costs were included over the defined planning horizon, how technical, economic, and operational criteria were associated with perceived maintenance priorities, and how the resulting evidence could inform maintenance decisions. The study did not attempt to solve a constrained optimization problem involving individual maintenance packages. Instead, it proposed a conceptual decision rule that prioritized the lowest-cost alternative among those satisfying the required technical and service performance criteria.

The study offered methodological and practical contributions to maintenance planning in educational facilities. Methodologically, it demonstrated how survey-based PLS-SEM findings and deterministic LCCA results could be interpreted together while preserving their distinct analytical purposes and limitations. The analysis also acknowledged the predominance of student respondents and the absence of a formal statistical test comparing the economic and operational path coefficients. Practically, the findings provided facility managers at Manado State Polytechnic with component-level maintenance urgency assessments and comparative cost estimates to support maintenance scheduling, budget planning, and intervention selection. These outputs were intended to inform decision-making rather than establish the effectiveness of maintenance interventions through observed post-implementation outcomes.

METHOD

Case and evidence base

This study employed a quantitative case study design integrating documentary building condition assessments, questionnaire survey data, and deterministic life cycle cost analysis (LCCA). The analysis drew on the underlying thesis (Grącki & Plebankiewicz, 2024) and supporting research materials, including questionnaire datasets, a SmartPLS project file, an expert analysis report, rapid visual screening (RVS) records, and LCC calculation workbooks. Sample sizes and questionnaire responses were verified against the original datasets. Present value

calculations were independently checked using the recorded annual cost components to verify cost aggregation and discounting, although the underlying cost assumptions and external spreadsheet links were not independently reconstructed. Partial least squares structural equation modeling (PLS-SEM) estimates were adopted from the existing expert analysis report without reestimating the statistical models.

Table 1. Evidence used in the model

Evidence	Thesis-reported scope	Role
Condition assessment	RVS inspection dated 4 June 2025; six storeys and basement	Identify concerns requiring technical follow-up
Survey results	133 analytical cases; 56 core items	Explain user maintenance priority
Element urgency	15 facility items	Describe objects of user concern
LCCA	Base year 2026; 2027–2046; fixed 6%	Compare three maintenance strategies
Work classification	Six packages P1–P6	Connect findings to maintenance scope

Table 2. Technical profile of GKT

Parameter	Adopted description	Source
Building area	Approximately 10,500 m²	Tompodung, Section 3.1
Storeys	Six above ground and one basement	RVS record
Construction timeline	Started 2014; completed 2020; use began 2021	Tompodung, Section 3.1
Structural classification	C1 concrete moment-resisting frame as selected on the form	RVS record
Soil category	C as recorded in the screening form	RVS record; geotechnical confirmation not supplied
Inspection and score	4 June 2025; Level 1 score 2.0	RVS record

Respondents and measurement

The verified SmartPLS text input contains 133 records, 133 distinct respondent IDs, and 56 core indicators. Its project metadata also records 133 cases. The questionnaire workbook contains 133 numeric response rows beneath three header rows; its Data_Model sheet contains 133 records. The author confirms 133 final respondents. Although an earlier run was described as involving 135, the supplied archive does not establish a 135-case estimation. The descriptive composition is 105 students, 14 lecturers, and 14 technicians. A separate 132-case SPSS report is not treated as the sample size of the current SEM model.

The core model comprises 14 technical items, seven economic items, 31 operational items, and four maintenance-priority items, using response values from one to five. Six additional supporting items in Data_Model are outside this core set. A comparison aligned by respondent ID and indicator name found 899 differing values across 70 respondents between SmartPLS_Inti and the archived project text. Accordingly, SEM estimates are attributed to the project and expert report, while descriptive element urgency is attributed to Data_Model. These files are not treated as interchangeable replication inputs. The predominance of students limits interpretation of the aggregate rankings as equally representative of all user groups.

Statistical model and estimation

M1 denotes the four-construct model containing KT, KE, KO, and UP. M2 denotes the hierarchical model reported as final in the thesis. M1 supplies the more complete measurement, structural, fit, and prediction tables. M2 supplies the final main-path estimates and hierarchical relationships. M1 diagnostics are not relabelled as M2 results.

According to the thesis, estimation used path weighting, a maximum of 3,000 iterations, a stopping criterion of 10^{-7}, and standardized estimates. Bootstrapping used 5,000 subsamples, two-sided tests at 5%, and percentile 95% confidence intervals. PLSpredict used ten folds and ten repetitions. The original software version and random seed should accompany the archived analysis files.

The reported M2 diagram directs KT and KE towards their dimensions. Within KO, several dimensions point towards KO, while KO points towards the service-impact dimension. This configuration is retained as reported and is not described as uniformly reflective. Confirmation of the intended higher-order specification and its corresponding diagnostics remains necessary. The structural summary is UP = 0.2783KT + 0.3283KE + 0.3116KO + ε, with standardized construct scores and a residual term.

Cost scenarios and decision rule

The cost model uses a 20-year horizon and a fixed 6% rate adopted by the researcher as a rounded analytical assumption. It is not represented as the exact average BI policy rate or as a Fisher-derived real rate. The scenario workbook directly applies 6%. The separate building workbook currently applies a Fisher-derived rate of 4.9193%; for consistency with the research specification, its stored annual net costs were discounted independently at 6%, reproducing the thesis total. The workbooks themselves were not altered. No sensitivity analysis is reported. Historical and source-year prices have not all been normalized to 2026, so totals are reported as pro forma costs at recorded prices without escalation, rather than verified constant-2026-price estimates.

For scenario s, $NPC_s = I_0 + J_s + \Sigma_{t=1}^{20}(C_{st} + D_{st} - V_{st})/(1 + r)^t$, where I_0 is common historical initial cost, J_s is additional intervention at year zero, C_{st} comprises operating, maintenance, and replacement costs, D_{st} is terminal demolition expenditure, and V_{st} is residual value. $EAC_s = NPC_s \times r/[1 - (1 + r)^{-20}]$. The capital-recovery factor is approximately 0.087184557.

S0 represents reactive maintenance, S1 scheduled prevention, and S2 targeted minor retrofit plus the S1 programme. The proposed operational rule is to choose the lowest-cost alternative

among those meeting the required technical and service conditions. This is a conceptual decision rule; the study has not solved a package-level constrained optimization problem.

RESULTS AND DISCUSSION

Condition screening

The RVS record reconstructs a Level 1 score of 2.0 from a C1 basic score of 1.0, a plan-irregularity modifier of −0.4, and a post-benchmark modifier of +1.4. The form records “No” for detailed structural evaluation and Level 2 screening. These are screening decisions, not certification that all components are safe. Cracking, corrosion, seepage, and external-panel concerns remain relevant to local investigation and maintenance. Tompodung (Plebankiewicz & Grącki, 2024) reports an approximate building area of 10,500 m², adopted here for the descriptive profile. The inconsistent RVS floor-area entry is not used for area-normalized cost calculations.

Measurement and structural evidence

Table III presents the available M1 measurement results. All reported AVE values exceed 0.50. The thesis reports HTMT values between 0.2879 and 0.7194. Reliability is high, although values above 0.95 for several constructs warrant examination of item redundancy rather than an unqualified claim of superior measurement.

Table 3. Measurement results for M1

Construct	AVE	Alpha	Composite reliability
KT	0.6262	0.9541	0.9590
KE	0.8322	0.9664	0.9720
KO	0.6062	0.9783	0.9794
UP	0.7135	0.8662	0.9088

The hierarchical main paths in Table IV support the three stated hypotheses under the reported testing procedure. Economic criteria have the largest point estimate, but their coefficient is close to that of operational criteria. No coefficient-difference test is available, so economic criteria are not claimed to be statistically more influential than operational criteria.

Table 4. Main paths reported for M2

Path	β	t	p	95% confidence interval
KT → UP	0.2783	2.153	0.0313	0.0073–0.5084
KE → UP	0.3283	3.094	0.0020	0.1231–0.5394
KO → UP	0.3116	2.723	0.0065	0.1116–0.5488

For M1, R^2 is 0.5641 and adjusted R^2 is 0.5539. These values concern variation in perceived priority, not physical deterioration or expenditure. SRMR is 0.0743, whereas NFI is 0.6382. Thus, fit evidence is mixed. Current SmartPLS guidance also distinguishes approximate fit from other

model-assessment requirements (Obradović et al., 2024). An acceptable SRMR alone does not validate every feature of the model.

M1 Q^2predict values for the four UP indicators range from 0.3015 to 0.4320. Reported PLS prediction errors are below the linear-model benchmark for each indicator. These results support predictive performance within the reported cross-validation design. They do not establish transferability to another campus, and no equivalent complete predictive table is available for M2.

The structural summaries in Figure 1 distinguish M1 from M2. Only the main construct paths are shown; the hierarchical dimensions are omitted. M2 R^2 is displayed approximately as 0.553 in the supplied algorithm image, while the complete numerical M2 R-square table remains unavailable.

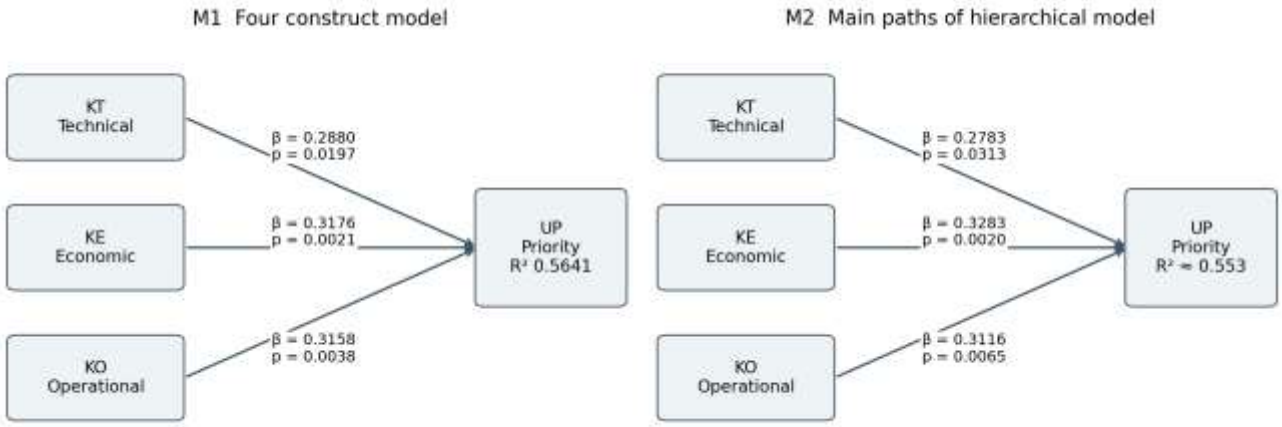


Figure 1. Main paths of M1 and M2 reconstructed from the expert report; M2 R^2 is the rounded image value.

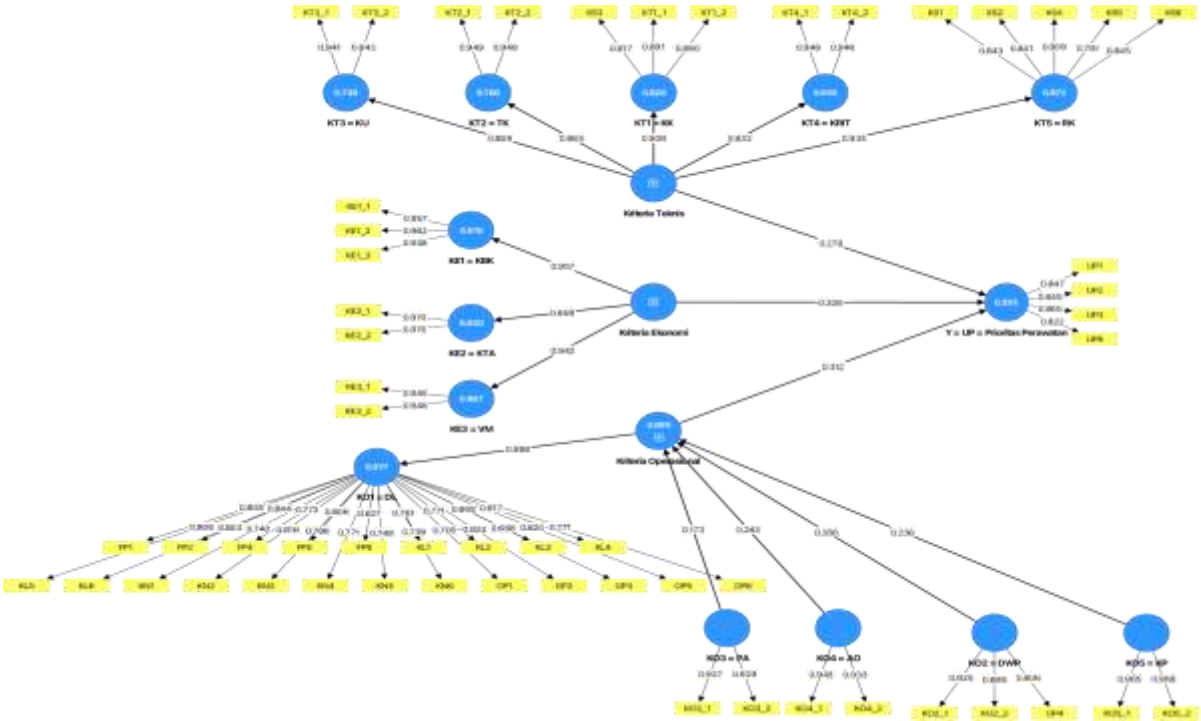


Figure 2. Main paths of M2 reconstructed from the expert report; M2 R^2 is the rounded image value.

Scenario costs

Table V reports the thesis's scenario totals in IDR billion. S1 is the least costly alternative under the stated cash-flow structure. Removing the common historical cost leaves the ranking unchanged but gives a more relevant denominator for an existing-building decision.

Table V. Twenty-year scenario comparison

Scenario	Total NPC	EAC per year	NPC excluding common historical cost
S0 Reactive	94.770	8.262	20.008
S1 Preventive	92.962	8.105	18.200
S2 Minor retrofit plus preventive	93.525	8.154	18.764

The exact saving of S1 relative to S0 is IDR 1,808,060,787.32, equivalent to approximately 1.91% of inclusive S0 cost or 9.04% of forward-looking S0 cost. The change in percentage is entirely attributable to the denominator. The separate building-level LCC total of IDR 90,799,554,011.71 uses a different maintenance and inventory scope and is not substituted for S0.

Several assumptions explain the ranking. S0 concentrates corrective expenditure and replacement in year one. S1 has no additional corrective-cost entry. S2 retains the preventive

programme while adding IDR 259,168,418.29 initially and IDR 304,381,735.62 in discounted corrective expenditure. Their sum, about IDR 563.550 million, explains S2's premium over S1. Demolition is a common hypothetical terminal cost of 10% of historical initial cost in year 20. Scenario salvage is 5% of an inventory basis of IDR 3,140,128,764.49, yielding IDR 157,006,438.22 at year 20 and a present deduction of IDR 48,955,349.59. It is not 5% of the entire building cost. No monetized reduction in failure losses or downtime offsets the S2 premium; the ranking therefore applies to the specified cost structure.

From user urgency to maintenance actions

Users assign the highest mean urgency to the lift (3.4586), followed by cleanliness and environmental health (3.2707). Electrical installations and sanitation share the next rank at 3.2556; water provision follows at 3.2406. These are descriptive ranks without tests of differences between element means. They identify service concerns for follow-up, not a complete engineering work order.

The lift maps to P5, electrical installations to P4, and sanitation and plumbing to P6. Cleanliness spans operational services and should not be counted again as a new maintenance package without a distinct scope. Other packages cover ceilings and façades (P1), openings and glazing (P2), and walls and finishes (P3). Package numbers are identifiers rather than priority positions. Site-specific hazards can require action even where the corresponding element has a lower survey mean.

The main contribution is a model that connects explanatory, descriptive, and financial evidence while preserving their different units. SEM supports consideration of technical, economic, and operational criteria; urgency ratings identify the elements users notice; and LCCA supplies the cost implications of alternative programmes. The model consequently avoids interpreting the economic-path coefficient as a percentage budget allocation or treating a facility-wide survey mean as a condition score for an individual component.

The S1 finding is compatible with a scheduled-maintenance baseline but does not justify deferring necessary local interventions. The earlier campus study reported an advantage for S2 in a different building and cost-risk structure. The difference is informative: strategy labels alone do not determine economic performance. Included benefits, replacement timing, and preventive or corrective assumptions determine the result. For GKT, the additional value of local retrofit must be assessed against the specific defect and service requirement rather than rejected on the aggregate cost ranking.

The study is limited by its single-building, cross-sectional evidence and by the difference between the questionnaire workbook and archived SEM input. The 6% assumption has no sensitivity analysis, and source prices are not fully harmonized to one year. Some replacement formulas in the scenario workbook refer to an external workbook; the discounted totals were verified using the stored annual components, not a full refresh of those links. Complete M2 reliability, discriminant-validity, collinearity, fit, and prediction outputs remain unavailable in the supplied report. No before-and-after implementation data are available. These limits define a case-based decision-support model with reported associations and conditional scenario costs.

CONCLUSION

The study concluded that maintenance prioritization at the Integrated Lecture Building of Manado State Polytechnic could be systematically structured by integrating three distinct sources of evidence rather than relying on a single assessment approach. Level 1 rapid visual screening (RVS) yielded a reconstructed score of 2.0 but did not constitute a comprehensive structural evaluation. Consequently, the identified cracking, corrosion, water seepage, and exterior panel concerns remained unresolved and required further site-specific investigation. Partial least squares structural equation modeling (PLS-SEM) supported all three research hypotheses, demonstrating statistically significant positive associations between perceived maintenance priorities and technical criteria ($\beta = 0.2783$, $p = 0.0313$), economic criteria ($\beta = 0.3283$, $p = 0.0020$), and operational criteria ($\beta = 0.3116$, $p = 0.0065$). Although economic criteria exhibited the largest estimated path coefficient, their association was not established as statistically stronger than that of operational criteria because no formal coefficient-difference test was conducted. The 20-year life cycle cost analysis (LCCA), conducted using a fixed 6% discount rate, identified scheduled preventive maintenance (S1) as the lowest-cost alternative, with an estimated present value of IDR 92.962 billion. Compared with reactive maintenance (S0), this strategy yielded estimated savings of IDR 1,808,060,787.32, equivalent to approximately 1.91% of total inclusive costs or 9.04% of forward-looking costs. These findings supported a proposed decision rule that favored the lowest-cost maintenance alternative among those satisfying the required technical and service performance criteria. However, mixed model fit indicators (standardized root mean square residual [SRMR] = 0.0743; normed fit index [NFI] = 0.6382) and the predominance of student respondents (105 of 133) limited the generalizability of the stakeholder-based findings across different building user groups.

Future research should address the methodological and data limitations identified in this study. First, the higher-order construct specification of the M2 model should undergo formal validation and comprehensive diagnostic reporting, particularly because the existing configuration combined formative and reflective measurement specifications and the complete coefficient of determination (R^2) results were unavailable. Second, a formal statistical test comparing path coefficients should be conducted to determine whether economic criteria were significantly more strongly associated with perceived maintenance priorities than operational criteria. Third, the LCCA model should incorporate sensitivity analyses for alternative discount rates, adjustments of historical costs to constant 2026 prices, and reconciliation of inconsistent floor-area data to improve the reliability and comparability of estimated life cycle costs. Fourth, discrepancies between the SmartPLS_Inti dataset and the archived project data, involving 899 differing values across 70 respondents, should be resolved through a documented data reconciliation procedure before model replication. Finally, subsequent studies should include more representative stakeholder groups, obtain independent structural engineering assessments of the exterior panel deterioration and water seepage concerns, and evaluate the applicability of the proposed prioritization model across other polytechnic buildings and campuses in seismically active areas

of North Sulawesi. These improvements would strengthen the model's methodological robustness, economic reliability, and practical relevance for maintenance decisions involving both financial efficiency and building safety.

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