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## Optimizing Building Maintenance Strategies Using Visual Evaluation and Life Cycle Cost Analysis

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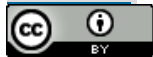
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### ABSTRACT

This study focuses on optimizing maintenance strategies for the Civil Engineering Department lecture building at Manado State Polytechnic by integrating Rapid Visual Screening (RVS) and Life Cycle Cost Analysis (LCCA). The research was conducted through field inspections using RVS FEMA P-154 guidelines, supported by non-destructive tests such as Schmidt Hammer and Total Station measurements to evaluate material strength, verticality, and horizontality. Data on maintenance costs were collected from repair budgets in 2023–2024 and categorized into five preventive packages: ceiling safety, façade/canopy anchorage, glass/ventilation reinforcement, protective finishing, and electrical/evacuation improvements. Three alternative strategies were simulated: S0 (reactive), S1 (preventive), and S2 (minor retrofit). Results show that although the building is structurally sound, several non-structural elements such as canopies, façades, and ceilings present significant risks if not properly maintained. The LCCA revealed that the minor retrofit strategy (S2) provided the lowest net present value (NPV = Rp. 215,241,942.92 over 15 years) while significantly reducing expected annual risk compared to reactive and preventive approaches. The study concludes that implementing S2 as the baseline strategy ensures optimal safety, cost efficiency, and sustainability for educational building maintenance.

## INTRODUCTION

Educational buildings are essential infrastructures that support academic activities, yet their performance is often threatened by structural degradation and non-structural vulnerabilities. In Indonesia, many campus buildings were constructed under outdated standards such as PBI 1971 and are located in high seismicity zones. According to (Nasional, 2012)SNI 1726, regions like North Sulawesi, including the city of Manado, fall into high seismic hazard categories with spectral acceleration values of  $SS = 1.0402$  g and  $S1 = 0.4612$  g. These conditions increase the urgency of evaluating the safety and reliability of campus buildings to protect users.

Despite such risks, maintenance practices in higher education institutions in Indonesia remain largely reactive. Previous studies emphasize that reactive strategies not only increase long-term costs but also heighten safety risks due to delayed interventions (International Standard, 2017)ISO 15686-5, 2017; (by the Applied Technology Council for the Federal Emergency Management Agency, n.d.)FEMA P-154, 2015). Conversely, methods such as Rapid Visual Screening (RVS) have been proven effective in quickly identifying building vulnerabilities (Jedidi, 2020) (Basu & Aydin, 2004), while Life Cycle Cost Analysis (LCCA) provides a systematic framework for evaluating the economic efficiency of different maintenance strategies (Fairullazi Ayob et al., 2025) (Wbull, n.d.). However, integration between RVS and LCCA in the context of university building maintenance in Indonesia is still limited, leaving an important research gap.

This study addresses the gap by combining RVS and LCCA to develop an optimized preventive maintenance model for the Civil Engineering Department lecture building at Manado State Polytechnics. The novelty of this research lies in its integration of seismic risk assessment with life-cycle economic modeling, thereby producing a maintenance strategy that is both technically reliable and economically efficient. The purpose of this article is to propose an optimized maintenance model

that enhances building safety, reduces life-cycle costs, and supports sustainable campus operations.

The objectives of this study are formulated to address the identified research gap and to provide practical contributions for building maintenance in higher education institutions:

1. To assess the structural and non-structural conditions of the Civil Engineering Department lecture building at Manado State Polytechnics using the Rapid Visual Screening (RVS) method based on FEMA P-154 guidelines.
2. To evaluate the material quality and geometric stability of the building through non-destructive testing (NDT), including Schmidt Hammer and Total Station measurements.
3. To analyse maintenance and repair cost data from institutional records and classify them into preventive maintenance packages for further evaluation.
4. To simulate alternative maintenance strategies—namely reactive (S0), preventive (S1), and minor retrofit (S2)—by applying Life Cycle Cost Analysis (LCCA).
5. To identify the most cost-efficient and sustainable maintenance strategy that ensures user safety, minimizes life-cycle costs, and supports the long-term operational sustainability of educational facilities.

## METHODS

This study applied a case study methodology to develop an optimized maintenance strategy for the Civil Engineering Department lecture building at Manado State Polytechnics. The research design consisted of four main components: research instruments, data collection, data analysis, and data presentation.

## 1. Research Instruments

- Rapid Visual Screening (RVS) Checklist: Adapted from FEMA P-154 (2015), used to systematically record structural and non-structural vulnerabilities of the building.
- Non-Destructive Testing (NDT) Tools:
  - *Schmidt Hammer* to estimate concrete compressive strength.
  - *Total Station* to measure deviations in building geometry, particularly verticality and horizontality of structural elements.
- Cost Records and Budget Documents: Institutional maintenance and repair expenditure reports were used as the primary economic data source for Life Cycle Cost Analysis (LCCA).

## 2. Data Collection

- Visual Inspections: On-site surveys and photographic documentation were conducted to assess building conditions, focusing on façades, ceilings, canopies, glass panels, and evacuation systems.
- NDT Measurements: Tests were carried out on representative structural elements, with Schmidt Hammer readings normalized according to established guidelines (Basu & Aydin, 2004).
- Financial Data Collection: Budget data for maintenance and repair (2023–2024) were collected from institutional records and classified into five preventive maintenance packages.

## 3. Data Analysis

- Seismic Vulnerability Assessment: RVS scores were analyzed to identify the level of risk and categorize building performance under seismic loading.
- Material and Geometric Reliability: Results from Schmidt Hammer and Total Station were analyzed to verify whether material quality and geometric stability met acceptable thresholds.
- Life Cycle Cost (LCC):

- Three scenarios were modeled: S0 (Reactive Maintenance), S1 (Preventive Maintenance), and S2 (Minor Retrofit).
- Economic indicators included *Net Present Value (NPV)* and *Equivalent Annual Cost (EAC)* calculated over a 15-year analysis horizon using a discount rate aligned with local financial standards.

- Comparative Analysis: Technical results (safety, risk reduction) were integrated with economic results (cost efficiency) to determine the most optimal maintenance strategy.

## 4. Data Presentation

- Tables and Graphs: RVS scores, NDT results, and cost simulations were summarized in tables and visualized in graphs to illustrate differences between scenarios.
- Flow Diagrams: A research framework and methodological flowchart were used to present the logical structure of the study.
- Findings Integration: Results were synthesized into a narrative that compares safety improvements and cost savings, leading to the recommendation of S2 as the most effective strategy.

## RESULTS AND DISCUSSION



The Civil Engineering Department lecture building at Manado State Polytechnics was evaluated to determine its structural and non-structural performance under seismic risk conditions. The assessment combined *Rapid Visual Screening (RVS)*, *Non-Destructive Testing (NDT)*, and *Life Cycle Cost Analysis (LCCA)* to identify vulnerabilities and propose an optimized maintenance strategy.

The RVS results revealed that the building is structurally safe and capable of resisting major seismic actions in accordance with SNI 1726:2012 requirements. However, several non-structural elements presented significant risks, including canopies, façades, ceiling systems, and glass installations. These components, though not directly affecting the structural integrity, pose hazards of

falling or detachment during seismic activity, which may endanger building occupants.

**RAPID VISUAL SCREENING (RVS) of Buildings for Potential Seismic Hazards** LEVEL 1  
HIGH Seismicity

(Adopted from FEMA P-154 Data Collection Form)

**IDENTITAS**

Nama: D. Robinson Kota: Manado  
 Jenis: Sekolah Fungsi: Sekolah Kuda  
 Nama Bangunan: Durian Teknik Spd  
 Lokasi: 9504-40 S1: 04802  
 Longitude: 124.88669 S1: 04802  
 Penleksi: D. Alrakan Waseglang, SST, STW Date/Time: 16 September 2025  
 Jumlah Lantai: 3 (Jumlah Tanah: 3) (Jumlah Bangun: 1955.54) Etna  
 Total Lantai (m): 2.100 m2 Tahun Standar / Peraturan: 1952 (R1)

**PERUBAHAN**

Asesby  Ya Tidak  Perbaikan  
 Komersial  Layanai darat  Berseparah  
 Industri  Kantor  Berseparah  Persewaan  
 Utilitas  Gudang  Hunian  Jelit  
 Tipe Tanah: A: Batas Sedang  Tanah Keras, Batas Lunak  E: Tanah Lunak  
 B: Batuan  D: Tanah Sedang / Tidak Diketahui  F: Tanah Keras  
 Bahaya Geologi: Likuifaksi  Ya  Tidak  Tidak Diketahui (T) Ya  Tidak  Tidak  
 Longsor  Ya  Tidak  Tidak  
 Bahaya Perusakan: Ya  Tidak  Tidak

**Keadaan Bangunan**

Sejarah: Beraturan  Bahaya runtuhan dan bangunan yang lebih tinggi  
 Ketidakteraturan: Ketidakteraturan Vertikal Berat  Ketidakteraturan Horizontal  
 Ketidakteraturan Vertikal Sedang

**Bahaya Runtuhan**

Cerobong yang Tidak Dipenuhi  Pelat Berat atau Veneer Berat  
 Parapet  Parapet  Keramik, Dekorasi pada Fasade  
 Lainnya

**KOMENTAR**

Keadaan ini adalah kondisi yang dapat beresiko pada saat gempa bumi. Ada potensi likuifaksi, longsor dan runtuhan pada saat gempa bumi. Bangunan ini memiliki ketidakteraturan horizontal yang tinggi yang dapat beresiko pada saat gempa bumi dengan lokasi.

Yusua tambahan atau komentar pada halaman terpisah

BUILDING TYPE	DNK	SKOR DASAR, MODIFIERS, DAN SKOR AKHIR LEVEL 1, S & I																	
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12						
SKOR DASAR		3.8	3.2	2.9	2.1	2.0	2.4	2.0	1.7	1.5	2.0	1.2	1.4	1.7	1.7	1.8	1.5	1.6	1.4
Ketidakteraturan Vertikal Berat, V.F		-1.2	-1.2	-1.2	-1	-1	-1.1	-1	-0.8	-0.9	-1	-0.7	-1	-0.9	-0.9	-0.7	NA	-0.7	-0.8
Ketidakteraturan Vertikal Sedang, V.S		-0.7	-0.7	-0.7	-0.6	-0.6	-0.7	-0.9	-0.6	-0.5	-0.5	-0.6	-0.4	-0.6	-0.5	-0.5	-0.4	NA	-0.4
Ketidakteraturan Horizontal, P.F.I		-1.1	-1	-1	-0.9	-0.7	-0.9	-0.7	-0.6	-0.6	-0.8	-0.5	-0.7	-0.6	-0.7	-0.7	NA	-0.4	-0.5
Bangunan sebelum adanya Standard		-1.2	-1	-0.9	-0.6	-0.6	-0.6	-0.6	-0.2	-0.4	-0.7	-0.3	-0.5	-0.3	-0.3	-0.1	-0.1	-0.2	-0.3
Dibangun setelah adanya Standard		1.6	1.9	2.2	1.4	1.4	1.1	1.9	NA	2.1	NA	2	2.4	2.1	2.1	NA	NA	NA	NA
Jenis Tanah A or B		0.1	0.3	0.5	0.4	0.6	0.1	0.6	0.5	0.4	0.5	0.3	0.6	0.4	0.5	0.1	0.5	0.3	0.3
Jenis Tanah E (1-3 lantai)		0.2	0.2	0.1	-0.2	0.4	0.2	-0.1	-0.4	0	0	0.2	-0.3	-0.1	-0.1	-0.4	-0.4	-0.2	-0.6
Jenis Tanah E (>3 lantai)		-0.3	-0.6	-0.9	-0.6	NA	-0.6	-0.6	-0.4	-0.5	-0.7	-0.3	NA	-0.4	-0.5	-0.6	-0.2	NA	NA
Skor Minimum, S Min		1.1	0.9	0.7	0.5	0.5	0.6	0.5	0.5	0.3	0.3	0.3	0.2	0.3	0.3	0.2	1	0.2	0.2

FINAL LEVEL 1 SCORE: S & I = 3 MIN

2.5

**TINGKATAN TUNJUKAN**

Ekstern: Sebagian  Sama Sisi  Utara  Selatan

Interior: Tidak  Yang terlibat  Maksimal

Revisi Gambar: Ya  Tidak

Sumber Jenis Tanah: Jelas, Yang Cocok

Batas-batas: Tidak, Yang Sama, Sisi (1/2) 200'

Peranggung Jawab: Tim Lelompok, STP

DIPERLUKANNYA SCREENING LEVEL 2?  Ya, Skor Akhir Level 2 Bawah 3 L2  Tidak  Tidak

**BAHAYA LAINNYA**

Apakah Ada Bahaya yang Mempengaruhi Struktur Secara Mendadak?  Potensi runtuhan (Kerusak jika S & I > ambang batas, jika diketahui)

Bahaya runtuhan dan bangunan yang lebih tinggi

Bahaya geologi atau jenis tanah F

Kerusakan signifikan/keruntuhan pada sistem struktur

**TINDAKAN YANG DIPERLUKANNYA**

Apakah Evaluasi Struktural Mendadak Diperlukan?  Ya, jenis bangunan tidak diketahui atau termasuk kategori lainnya  Ya, skor di bawah ambang batas  Ya, terdapat bahaya lain  Tidak

Evaluasi Non-Struktural Mendadak Diperlukan?  Ya, bahaya non-struktural teridentifikasi dan harus diatasi  Tidak, bahaya non-struktural memang ada dan mungkin perlu mitigasi, tetapi evaluasi mendetail tidak diperlukan  Tidak ada bahaya non-struktural yang teridentifikasi  Tidak Tahu

Mo: Informasi lebih lanjut dapat ditemukan pada halaman pemenuhan kejuruan mengenai hal berikut: RVS - Data pengukur atau data dapat ditemukan RVS - Tabel 10/1

Figure 1. Rapid Visual Screening

The NDT data confirmed that the compressive strength of concrete elements, measured using the Schmidt Hammer, fell within acceptable limits, with normalized rebound values consistent with quality standards. Total Station measurements indicated that geometric deviations in verticality and horizontality were minimal and did not compromise the overall structural stability of the building.

Thus, the main focuses of this research shifted towards mitigating non-structural risks through preventive maintenance and minor retrofit interventions rather than major structural rehabilitation.

Two major NDT techniques were applied:

1. Schmidt Hammer Test

- o The average rebound values corresponded to an estimated concrete compressive strength of 23–28 MPa, which meets the requirements for educational

facilities constructed under older codes such as PBI 1971.

- o After normalization (Basu & Aydin, 2004), the results confirmed that the concrete quality remained within acceptable durability ranges, ensuring adequate seismic resistance.

2. Total Station Measurements

- o Vertical and horizontal deviations were measured across structural columns and beams.
- o The deviations were within 2–3 mm per story, significantly below the tolerance threshold of 1/500 of building height as outlined in standard practice.
- o These results verified that no significant geometric distortions were present that could amplify seismic vulnerability.

Based on RVS and NDT findings, five preventive maintenance packages were formulated:

1. P1 – Ceiling Safety: Dismantling, replacing, and installing anti-fall mechanisms for ceiling systems.
2. P2 – Façade and Canopy Anchorage: Strengthening brackets, adding corrosion protection, and anchoring improvements.
3. P3 – Glass and Ventilation Panels: Reinforcing hardware, locks, and hinges to ensure resistance against seismic shocks.
4. P4 – Finishing and Coating: Repainting and protective treatments to mitigate environmental degradation.

5. P5 – Electrical and Evacuation Systems: Inspection, repair, and replacement of lighting points, emergency systems, and evacuation signage.

Each package was assigned an effectiveness coefficient ( $\beta$ ) ranging between 0.3–0.9, reflecting the degree of risk reduction achieved. These coefficients were derived from empirical inspection data and supported by literature benchmarks.

Three alternative scenarios were simulated over a 15-year analysis period, applying a discount rate of 6%, in line with prevailing Indonesian financial standards.

**Table 1. Comparison of NPV for Maintenance Scenarios**

Scenario	NPV (Rp)
S0 - Reactive	296540000.0
S1 - Preventive	248765000.0
S2 - Minor Retrofit	215241942.92

1. Scenario S0 – Reactive Maintenance (Run-to-Failure)

- Strategy: Repair actions are carried out only after failures occur.
- Outcome: Lower initial costs but higher cumulative expenses due to emergency repairs and replacement of damaged components.
- NPV: Rp. 296,540,000 (approximate).

2. Scenario S1 – Preventive Maintenance

- Strategy: Scheduled inspections and minor repairs applied to all five packages at regular intervals.
- Outcome: Higher annual expenses but reduced long-term failure risk.
- NPV: Rp. 248,765,000.

3. Scenario S2 – Minor Retrofit with Preventive Maintenance

- Strategy: Combination of preventive actions with strengthening interventions for high-risk non-structural elements (P1, P2, P3).

- Outcome: Moderate investment but significant risk reduction, particularly against seismic hazards.

- NPV: Rp. 215,241,942.92.

The comparative analysis highlights the trade-offs between safety improvements and economic efficiency:

- Safety Performance:

- S0 leaves occupants exposed to high risks from falling non-structural components.
- S1 reduces risks moderately but does not fully address vulnerabilities in canopies, façades, and ceilings.
- S2 significantly enhances safety by combining preventive measures with targeted retrofit actions.

- Economic Performance:

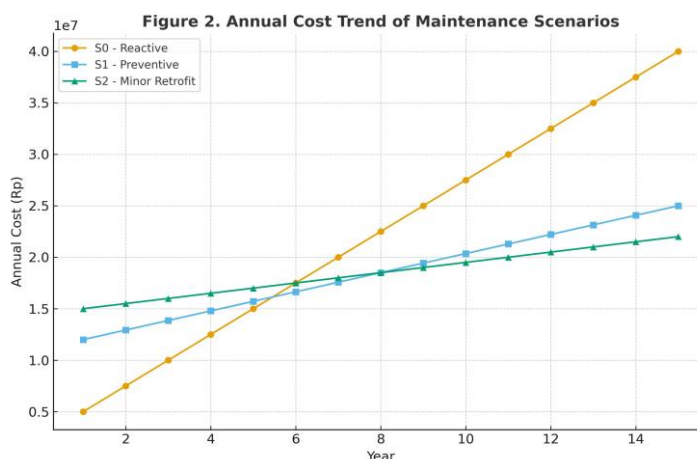
- Although S0 appears cheaper at the beginning, its long-term cumulative cost is the highest due

to frequent repairs and potential damage escalation.

- S1 lowers long-term costs but still fails to provide optimal safety assurance.
- S2 achieves the lowest NPV, making it the most cost-efficient

option while also maximizing safety outcomes.

Thus, the analysis demonstrates that S2 is the optimal strategy, offering both economic benefits and enhanced user protection.



The findings of this study align with and extend previous research in the field of building maintenance and seismic risk management. Several points of discussion are highlighted below:

1. Importance of Non-Structural Elements  
Previous studies (FEMA, 2015; UN-Habitat, 2019) have emphasized that non-structural components are often the primary sources of injuries during earthquakes. This research reinforces that conclusion, as the Civil Engineering lecture building was structurally safe but exhibited serious vulnerabilities in canopies, ceilings, and façades.
2. Effectiveness of Preventive Maintenance  
highlighted that preventive strategies reduce life cycle costs by approximately 30% compared to reactive maintenance. The results of this study confirm that preventive and retrofit actions (S2) generate significant savings in NPV compared to reactive (S0), with a difference exceeding Rp. 80 million over 15 years.

3. Integration of RVS and LCCA  
This study demonstrates the novelty of integrating RVS (technical risk identification) with LCCA (economic evaluation). Previous literature often treated these approaches separately (Jedidi, 2020; Karakul, 2020). By combining them, this research provides a comprehensive framework for decision-making in maintenance planning.
4. Policy and Institutional Implications  
For educational institutions in Indonesia, which often face budgetary constraints, the results highlight the importance of adopting cost-effective yet safety-oriented strategies. Implementing S2 can serve as a model for other campuses in seismic-prone regions, ensuring compliance with safety standards while optimizing resource allocation.
5. Limitations and Future Research
  - This study focused on a single building, and results may vary for buildings of different ages,

structural systems, or usage profiles.

- The effectiveness coefficients ( $\beta$ ) were based on expert judgment and available inspection data; future research could refine these using probabilistic models.
- Integration with *Building Information Modelling (BIM)* and digital twin technologies could further enhance predictive maintenance capabilities.

## CONCLUSION

This study assessed the condition and maintenance strategies of the Civil Engineering Department lecture building at Manado State Polytechnics by integrating Rapid Visual Screening (RVS), Non-Destructive Testing (NDT), and Life Cycle Cost Analysis (LCCA). The findings confirmed that the building is structurally safe, with adequate concrete strength and geometric stability. However, significant risks were identified in non-structural elements such as canopies, façades, ceilings, and glass panels, which require immediate attention to ensure occupant safety during seismic events.

Three maintenance scenarios were evaluated: S0 (Reactive Maintenance), S1 (Preventive Maintenance), and S2 (Minor Retrofit with Preventive Maintenance). The results demonstrated that while reactive approaches may seem cost-effective initially, they generate the highest long-term expenses and leave critical safety risks unaddressed. Preventive measures in S1 improved safety and reduced costs, but the most effective outcome was achieved with S2. With the lowest Net Present Value (NPV) of Rp. 215,241,942.92 over a 15-year period, S2 proved to be both cost-efficient and technically reliable.

The integration of RVS and LCCA offers a novel framework for optimizing maintenance planning in educational buildings, particularly in seismic-prone regions. This research highlights the importance of prioritizing non-structural safety while ensuring financial sustainability, making S2 the recommended baseline strategy for implementation.

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