Analysis of building operational and maintenance risks in Padang City

Gusni Vitri[1], *Akhmad* Suraji[2*], *Taufika* Ophiyandri[2], and *Dewi* Larasati[3]

[1]Doctoral Program Student, Civil Engineering Department, Faculty of Engineering, Universitas Andalas, Padang, Indonesia
[2]Doctoral Program, Civil Engineering Department, Faculty of Engineering, Universitas Andalas, Padang, Indonesia
[3]School of Architecture, Planning and Policy Development, Bandung Institute of Technology, Bandung, Indonesia

Abstract. High-rise buildings in urban areas face significant operational and maintenance (O&M) challenges, particularly in developing cities where construction growth frequently exceeds the capacity of structured asset management. This study examines O&M risks in high-rise buildings in Padang, Indonesia, using a systematic hazard identification and classification approach. Risks were categorized into five groups: force majeure, structural, architectural, electrical, mechanical, and plumbing. This research uses a mixed method approach, collecting primary data from questionnaires and focus group discussions. Secondary data were obtained from building maintenance records, building design documents, and relevant regulatory. Data validation from relevant experts to ensure reliability the risks identification. The risk assessment and analysis process identified 64 distinct risks, which were subsequently classified into three levels of severity. The majority (42 cases) were categorized as very low risk, followed by 18 cases in the low-risk category, and 4 cases identified as medium risk. This distribution indicates that most hazards within the evaluated scope pose minimal potential impact. The results underscore the importance of preventive maintenance by aligning with international standards such as ISO 15686 on life-cycle costing and ISO 31000 on risk management, the study provides empirical evidence to support risk-informed decision-making for sustainable building management.

1 Introduction

The infrastructure life cycle begins with the identification of infrastructure needs, followed by the stages of planning, design, and construction. Once the infrastructure is completed, it proceeds to the utilization phase, during which it is operated and maintained. Periodic evaluations are essential during this phase to support the formulation of annual infrastructure programs. Under certain circumstances, infrastructure may be decommissioned when it no longer fulfils its intended function [1]. Throughout the building life cycle, the required investment by the owner comprises capital expenditure (capex) and operational expenditure (opex), collectively referred to as life cycle costing (LCC). Notably, operation and maintenance costs constitute a major component of operational expenditure (capex).

Rapid urbanization and limited land availability have intensified the development of high-rise buildings in Indonesian cities. While these structures address spatial constraints, their long-term performance depends heavily on effective operation and maintenance (O&M). Research indicates that O&M expenditures frequently surpass initial capital investment (capex) across a building's life cycle, underscoring the economic significance of this phase [2, 3]. However, O&M is inherently vulnerable to risks such as equipment breakdowns, natural hazards, regulatory shifts, and human error, all of which may disrupt building functionality and increase overall costs [4].

Identifying and assessing these risks is essential for developing robust management strategies. Prior studies highlight that insufficient consideration of risk-related factors often leads to cost overruns, reduced service life, and compromised building performance [5]. In this context, the present study focuses on high-rise buildings in Padang, Indonesia, with the objective of systematically identifying and categorizing O&M risks. By establishing a structured framework, the study contributes to advancing sustainable building asset management practices.

Currently, there is no official data published by either government agencies or the private sector regarding the exact number of high-rise buildings in Padang City. Preliminary estimates indicate the presence of approximately ten high-rise structures functioning primarily as hotels, while government-owned buildings generally do not exceed four stories. This study seeks to identify and analyze the operational and maintenance risks associated with high-rise buildings, using planning data from a 13-story building in Padang City as a case study. The objective is to provide the building owner with an understanding of the potential operational and

* Corresponding author: akhmad.suraji@eng.unand.ac.id

maintenance risks that may influence cost expenditures throughout the building's service life.

2 Literature review

2.1 Operation and maintenance in building

Operation and maintenance (O&M) are fundamental to preserving the performance, safety, and long-term value of high-rise facilities. Effective O&M practices not only ensure service reliability but also reduce total expenditure across a building's life cycle. Studies have shown that systematic O&M management can extend service life while minimizing operational disruptions and unplanned costs [6]. The classification of components in building structures [6] is illustrated in Figure 1 below.

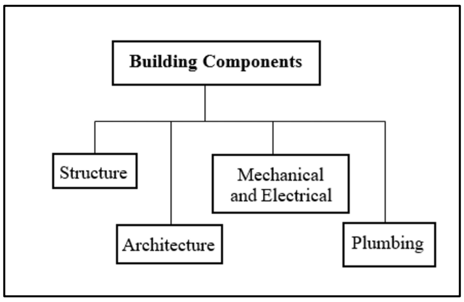

Fig. 1. Building components

The building components are:

1. Structure
   - Foundations
   - Beams
   - Columns
   - Floor slabs
   - Stairs
2. Architecture
   - Walls
   - Walls coverings
   - Floor coverings
   - Roof Coverings
   - Windows
   - Doors
   - Frames
3. Mechanical and Electrical
   - Air conditioning systems
   - Building transportation systems
   - Fire prevention and extinguishing systems
   - Electrical installation systems
   - Communication systems
4. Plumbing
   - Clean water installation system
   - Dirty water installation system
   - Waste water installation system
   - Sanitation Equipment

2.2 Risks in building operation and maintenance

The O&M phase is exposed to a wide range of risks that may originate internally or externally. Internal risks typically involve equipment deterioration, system malfunctions, or human error, whereas external risks are driven by environmental hazards, regulatory changes, or socio-economic conditions [7]. In regions such as Padang, which are vulnerable to seismic activity and hydrometeorological events, environmental risks including earthquakes, floods, and extreme rainfall constitute major threats to building operations [8].

Risk management is a field of study that studies how an organization maps various existing problems using a comprehensive and systematic management approach. Risk management is also defined as the policies and procedures an organization has in place to manage, monitor, and control risks [9]. According to International Standard [10], the risk management process is described in Figure 2 below.

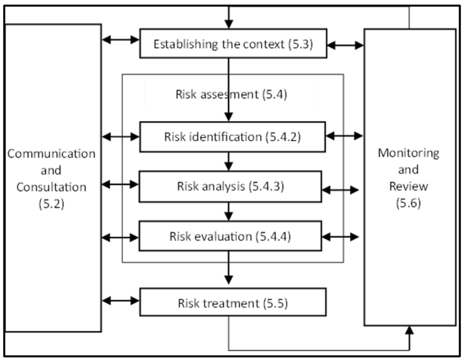

Fig. 2. Risk management process

2.3 Frameworks for risks identification

Structured approaches such as hazard identification (Hazid) and risk categorization are widely applied to assess O&M vulnerabilities. These frameworks enable systematic classification of risks and facilitate the development of mitigation strategies. International standards provide additional guidance: ISO 15686 emphasizes integrating life-cycle cost considerations into building management, while ISO 31000 outlines comprehensive principles for risk governance in asset operations. Together, these standards form a foundation for risk-informed decision-making in building management.

Building on the literature, a conceptual framework was developed to link operation and maintenance (O&M) functions, associated risks, and the standards used to manage them (Table 1). The framework integrates three key elements:

1. O&M Objectives – sustaining building functionality, safety, and service life.
2. Risk Domains – internal risks (equipment failure, human error, material degradation) and external risks (natural disasters, regulatory changes).
3. Risk Management Standards – ISO 15686 for life-cycle cost integration and ISO 31000 for structured risk governance.

This framework emphasizes that identifying, categorizing, and integrating risks into building management decisions enhances resilience and sustainability, particularly in disaster-prone contexts such as Padang.

Table 1. Conceptual framework for building O&M risk identification

O&M Function	Examples	Relevant Standards	Management Strategy
Equipment & Systems	HVAC malfunction, elevator breakdown	ISO 15686 (Life-cycle costing)	Preventive maintenance, performance monitoring
Building Materials & Structure	Roof leakage, facade corrosion	ISO 15686	Regular inspection, durability planning
Human Resources	Human error, unsafe maintenance practices	ISO 31000 (Risk management)	Training, safety protocols
External Environment	Earthquakes, flooding, extreme rainfall	ISO 31000	Disaster preparedness, resilience design

The Risks identification detailed is depicted in Table 2 below:

Table 2. Work Breakdown Structure (WBS) of operational and maintenance risks in buildings

No	Category	Sub-component	Risk Identification
I	Force majeure	Natural events	- Earthquake - Tsunami - Storms/strong winds
		Human-related events	- Explosion - Vandalism - Fire - Power outage/blackout
II	Structural	Column	- Cracking of columns
		Beam	- Cracks - Spalling of mortar
		Slab	- Hairline cracks
		Roof frame	- Roof frame damage
		Staircase	- Floor screed and hardener deterioration
III	Architectural	Wall	- Hairline cracks - Dampness/mold - Faded paint - Plaster peeling - Partition fading - ACP fading
		Floor finish	- Broken tiles/flooring
		Ceiling	- Loose ceiling frame - Mold/discoloration - Leakage/holes - Loose ceiling trims
		Doors and windows	- Cracked aluminum frames - Broken windows - Broken glass - Cracked doors - Faulty hinges - Loose/corroded bolts - Malfunctioning locks
		Roof covering	- Corrosion and perforation of metal roof
		Toilet & kitchen fittings	- Cracked sink - Worn-out faucet parts - Leaking faucets - Floor drain leakage - Faulty flush buttons - Seal/gasket leakage in sink
IV	Electrical	Electrical installations	- Burnt switch contacts - Damaged sockets - Panel short circuits (SDP, PP, MDP) - Cable faults - Burnt feeder cables - Lamp failure
		Systems & equipment	- Malfunctioning sound system - Fire alarm failure - Non-recording CCTV - Lift module replacement - Lift malfunction - Generator overheating - Transformer terminal failure - Corrosion of lightning protection grounding - Projector failure
V	Mechanical & Plumbing	Water and HVAC systems	- Leakage in clean water pipes - Faulty or jammed gate valves - Leakage in wastewater/vent pipes - Damaged rainwater gutters - Hydrant failure - Damaged AC pipes/brackets - AC chiller breakdown - Refrigerant replacement - Sewage treatment plant (STP) failure - Tank leakage - Pump malfunction

3 Methodology

This research employed a mixed-method approach, integrating qualitative and quantitative techniques to systematically identify operational and maintenance (O&M) risks in high-rise buildings. The process combined document analysis, expert interviews, and hazard identification (Hazard) to ensure both empirical and contextual relevance [11]. A mixed-method approach was applied, combining structured interviews and questionnaire surveys with building management personnel in Padang, Indonesia. Both public and private facilities were considered to capture a representative perspective of O&M practices.

3.1 Data collection

Secondary data were obtained from building maintenance records, architectural and structural design documents, and relevant regulatory frameworks such as regulation from Ministry of Public Works on building maintenance [12]. Primary data were collected through expert consultation and validated using a focus group discussion (FGD) with practitioners, including engineers, facility managers, and safety officers.

Interviews were conducted with key informants directly involved in building operation and maintenance, such as engineering managers, functional administrators, and facility coordinators. These interviews provided qualitative insights into hazard types, management challenges, and risk mitigation strategies. To complement this, questionnaires were distributed to building managers to collect quantitative data on hazard occurrence and management practices, ensuring triangulation of data sources.

General respondent information is summarized in Table 3, which includes the type of building, position of the respondent, and building age. The selected cases covered both office buildings and hotels, with building ages ranging from 4 to 17 years.

Table 3. General information of respondents

No	Building type	Respondent role	Building age (years)
1	Four-storey office building	Functional administrator, Building and Housing Division	10
2	Four-storey office building	General affairs sub-division staff	11
3	Nine-storey hotel	Assistant Chief Engineering	17
4	Ten-storey hotel	Engineering and accounting manager	4

3.2 Risks identification and categorization

The HAZID approach was applied to systematically identify potential risks. Identified risks were grouped into four categories adapted from international guidelines [2, 10]:

1. Equipment-related risks (e.g., HVAC malfunction, elevator failure)
2. Material-related risks (e.g., façade corrosion, roof leakage)
3. Worker-related risks (e.g., unsafe practices, human error)
4. Environmental risks (e.g., flooding, earthquakes)

The criteria for the likelihood of a risk occurring can use a probability approach, frequency of occurrence per unit of time or expert judgment [13]. Scale of risk probability, score from 1 until 5 [14] is shown in Table 4.

Table 4. Risk probability scale (Jakarta Provincial Governor Regulation No. 122/2020)

Scale	Probability (P)	Description
1	Very Small	Very unlikely to occur (Frequency of occurrence > once every 5 years)
2	Low	Rarely occurs or has never been heard of a similar event (Frequency of occurrence > once every 3 years)
3	Medium	Possible or has been heard of a similar event (Frequency of occurrence > once a year)
4	Large	Very likely to occur (Frequency of occurrence > once a year and a half)
5	Very Large	Frequently occurs (Frequency of occurrence once a month)

The impact classification is based on the possibility of cost losses and its impact on the health and safety of users [15] as can be seen in Table 5.

Table 5. Risk impact scale

Scale	Impact (I)	Description
1	Very Small	No injuries, minor financial loss (x < Rp 1 million)
2	Low	Minor injuries, moderate financial loss (Rp 1 million < x < Rp 10 million)
3	Medium	Moderate injuries, major financial loss (Rp 10 million < x < Rp 100 million)
4	Large	Serious injuries, major financial loss (Rp 100 million < x < Rp 1 billion) and disruption of building use
5	Very Large	Fatal injuries, very major financial loss (x > Rp 1 billion), and cessation of building use

A risk matrix is a matrix used to assess risk levels by considering risk probability and risk impact. The following is a grouping of risk levels, where the risk level is determined by multiplying the risk probability scale by the risk impact scale.

Table 5 presents a risk matrix consisting of two main components: probability and impact. The first component, probability, describes the likelihood of a risk occurring. The second component, impact, indicates the magnitude of the consequences if the risk occurs. These two components are combined into a matrix to map the overall risk level, thus facilitating the process of risk identification and management.

Table 6. Risk impact scale

		Impact				
		1	2	3	4	5
Probability	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Table 7. Risk value

Value R = P x I	Risk Category	Symbol
1 – 4	Very Low	
5 – 8	Low	
10 – 15	Moderate	
16 – 25	Critical	

3.3 Validation Process

To ensure reliability, the identified risks were reviewed and refined through expert consensus during the FGD. This triangulation method increased validity by integrating documentary evidence, practitioner insights, and regulatory compliance [11].

4 Result and discussion

4.1 Risks Identification

The results of data collection, it can be summarized as follows:

1. Risks with Very Low Risk Level

Table 8. Risks with very low risk level

No	Risk identification	Risk score	Risk level
1	Loose ceiling trim	1	Very low
2	Non-functioning flush button (urinal/toilet)	1	Very low
3	Cracked column	2	Very low
4	Cracked beam	2	Very low
5	Cracked aluminium window frame	2	Very low
6	Broken window	2	Very low
7	Broken glass pane	2	Very low
8	Cracked washbasin	2	Very low
9	Short circuit in electrical wiring	2	Very low
10	Damage to the transformer connection terminal	2	Very low
11	Corrosion in the lightning rod grounding system	2	Very low
12	Leaking rainwater gutter	2	Very low
13	Sewage treatment plant (STP) Failure	2	Very low
14	Peeled beams	3	Very low
15	Leakage in the sink seal/gasket	3	Very low
16	Short circuit in the electrical panel (SDP, PP, MDP)	3	Very low
17	Short circuit in the feeder cable	3	Very low
18	Sound system not working	3	Very low
19	Fire alarm not working	3	Very low
20	CCTV camera not recording	3	Very low
21	Water pipe leak	3	Very low
22	Gate valve leaking and stuck	3	Very low
23	Hydrant installation	3	Very low
24	Tank leak	3	Very low
25	Water pump	3	Very low
26	Tsunami	4	Very low
27	Explosion	4	Very low
28	Vandalism	4	Very low
29	Floor slab cracks	4	Very low
30	Roof frame	4	Very low
31	Damage to floor screed and floor hardener	4	Very low
32	Faded ACP	4	Very low
33	Detached ceiling frame	4	Very low
34	Cracked door	4	Very low
35	Door handle loose and rusty	4	Very low
36	Recessed lock not working	4	Very low
37	Metal contacts on the switch burned	4	Very low
38	Cracked or broken socket	4	Very low
39	Elevator not working	4	Very low
40	Generator set overheating	4	Very low
41	Infocus not working	4	Very low
42	Damaged AC chiller	4	Very low

Table 8 presents risks categorized as *very low*, with risk scores ranging from 1 to 4. These risks mainly comprise minor structural, architectural, electrical, and plumbing defects that, while noticeable, pose limited impact on safety or functionality if addressed promptly.

2. Risks with Low Risk Level

Table 9 summarizes risks assessed as *low*, with risk scores ranging from 6 to 9. These include recurring maintenance issues such as faded paint, plumbing leaks, and minor equipment failures, which have a limited but non-negligible effect on building performance and user comfort.

Table 9. Risks with low risk level

No	Risk identification	Risk score	Risk level
1	Faded partition wall	6	Low
2	Ceiling mold/discoloration	6	Low
3	Faulty hinge	6	Low
4	Corroded and perforated metal roof	6	Low
5	Worn water faucet spare parts	6	Low
6	Leaking/cracked water faucets	6	Low
7	Leaking floor drains at the joints	6	Low
8	Broken lights	6	Low
9	Elevator module replacement	6	Low
10	Damaged AC pipes and AC brackets	6	Low
11	AC freon replacement	6	Low
12	Fire	8	Low
13	Hairline cracks in walls	8	Low
14	Mold, damp, and moss-covered walls	8	Low
15	Faded wall paint	8	Low
16	Peeling plaster on walls	8	Low
17	Cracked floor coverings	9	Low
18	Leaking dirty, used, and vented water pipes	9	Low

3. Risks with Moderate Risk Level

Table 5 highlights risks classified as *moderate*, each scoring 10 - 15. These risks include natural hazards and utility failures, which, although less frequent, can significantly disrupt operations if not effectively mitigated.

Table 10. Risks with moderate risk level

No	Risk Identification	Risk Score	Risk level
1	Earthquake	12	Moderate
2	Power outage/blackout	12	Moderate
3	Ceiling leakage/holes	12	Moderate
4	Storms/strong winds	12	Moderate

4.2 Risks Analysis

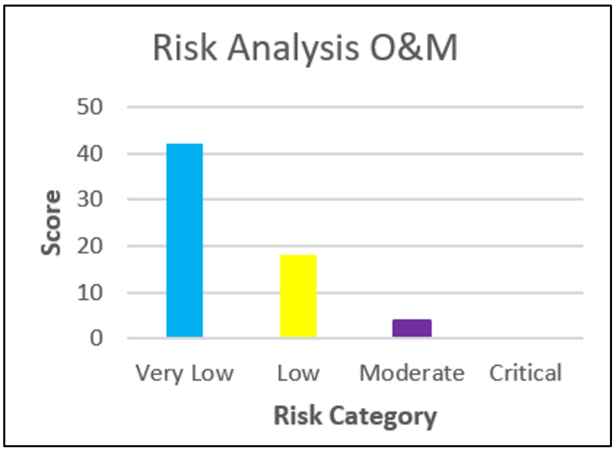

Fig. 3. Risk analysis

 https://doi.org/10.1051/e3sconf/202567701006

The research identified 64 risks in building operations and maintenance, divided into three categories: very low, low, and moderate. No risks were identified in the critical category (See Fig. 3).

Based on the results of the risk analysis, the very low-risk category is predominantly associated with the architectural, electrical, and mechanical plumbing components, which are primarily related to the building's routine operational activities. This distribution is illustrated in the figure below.

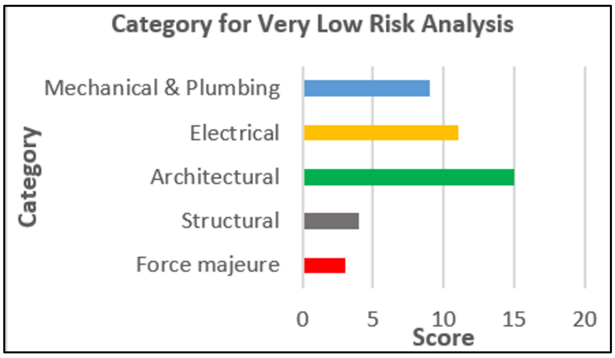

Fig. 4. Category for very low risk analysis

The chart presents the distribution of risks categorized as very low across various building system components. The analysis indicates that the architectural category contributes the largest proportion of very low-risk items, with a score of approximately 15, followed by the electrical and mechanical & plumbing categories, each showing moderate scores. The structural and force majeure categories register minimal contributions. This pattern suggests that most identified risks within the architectural, electrical, and mechanical systems are minor in nature, primarily associated with routine operational conditions rather than critical safety or structural concerns.

In contrast, the low-risk category is predominantly associated with the architectural components, as illustrated in the Figure 5.

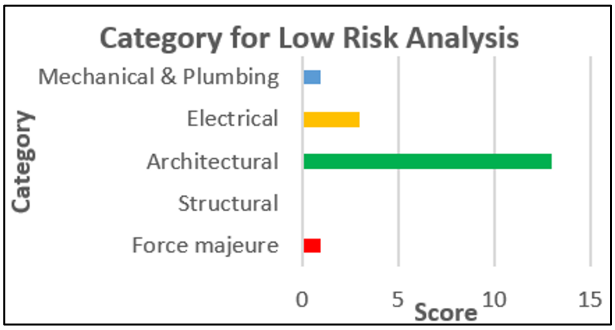

Fig. 5. Category for low risk analysis

The chart illustrates the distribution of risks categorized as low across various building system components. The analysis shows that the architectural category contributes the highest number of low-risk items, with a score of approximately 13, indicating that most minor operational and maintenance risks are associated with architectural elements. The electrical category follows with a moderate score, while mechanical and plumbing, structural, and force majeure categories register only minimal contributions to the low-risk group. This suggests that, within the overall risk profile, architectural components require the most consistent attention during routine maintenance, even though their risk severity remains low.

The Figure 5, illustrates the distribution of risks classified as moderate across different building system categories. The results show that the force majeure category contributes the highest proportion of moderate risks, indicating external and uncontrollable factors as the primary source of potential disruptions. In contrast, the architectural, electrical, and mechanical categories exhibit only a single instance each, reflecting minimal exposure to moderate-level risks. This distribution suggests that environmental or unforeseen events represent the most significant moderate-risk factors in building operation and maintenance within the analyzed context as presented in Fig. 6.

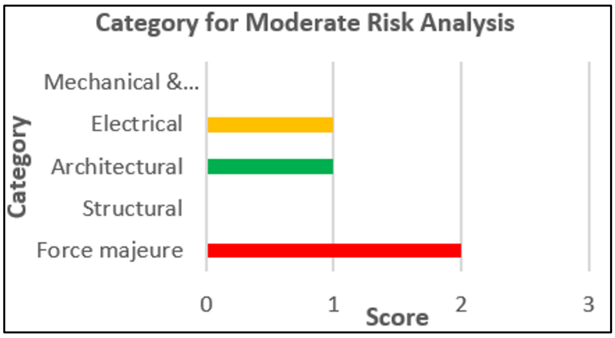

Fig. 6. Category for moderate risk analysis

The findings of the risk analysis are consistent with the four main categories of operation and maintenance (O&M) risks identified as influencing the performance of high-rise buildings in Padang City. Among these, equipment-related risks were identified as the most critical**.** Equipment failures pose frequent and costly disruptions due to the heavy reliance on mechanical and electrical systems in high-rise facilities. Meanwhile, environmental risks reflect Padang's geographic exposure to seismic activity and hydrometeorological hazards, which significantly elevate the vulnerability of urban infrastructure.

These findings align with prior studies that emphasize the dominance of equipment and environmental hazards in building O&M risk profiles. The results underscore the need for preventive maintenance programs and resilience-focused strategies to mitigate both technical failures and disaster-related impacts.

The findings emphasize the necessity of integrating risk considerations into operation and maintenance (O&M) planning for high-rise buildings. The predominance of equipment-related risks reflects the sector's reliance on complex mechanical and electrical systems, where failures can cause significant disruptions and financial implications.

Although worker-related and material-related risks were identified less frequently, they remain critical to building safety and service continuity. Worker-related risks, including human error and unsafe practices, can amplify the severity of equipment or environmental failures, while material-related risks such as façade corrosion or roof leakage compromise structural integrity and long-term durability.

These findings underscore the importance of proactive risk assessment and preventive maintenance, which enable more efficient allocation of resources and strengthen building resilience. Incorporating standards such as ISO 15686 on life-cycle costing and ISO 31000 on risk management into O&M strategies offers a structured pathway to mitigate risks, extend service life, and enhance sustainability in urban building management.

5 Conclusion

This study systematically identified and classified the operational and maintenance (O&M) risks associated with high-rise buildings in Padang. The results of the analysis revealed a total of 64 identified risks, comprising 42 categorized as very low risk, 18 as low risk, and 4 as moderate risk. These findings indicate that the majority of potential risks in high-rise building operations fall within the lower severity levels, reflecting effective management of routine maintenance and operational activities. However, continued monitoring and the implementation of preventive measures remain essential to mitigate the potential escalation of moderate risks and ensure sustainable building performance throughout its service life.

The results of the risk analysis indicate that the operation and maintenance (O&M) risks of the analyzed high-rise building are largely concentrated in the very low and low categories. The architectural components dominate both risk groups, suggesting that most potential issues arise from routine operational and maintenance activities rather than from structural or safety-critical concerns. The electrical and mechanical–plumbing systems contribute moderately to these categories, reflecting manageable risks within standard maintenance practices. In contrast, moderate-risk events are primarily associated with force majeure factors, emphasizing the influence of external and uncontrollable conditions on building performance.

Future research should build upon this study by quantifying the costs associated with identified risks and integrating corresponding mitigation strategies within a life-cycle cost (LCC) framework. Such an approach would enhance the economic foundation for risk-informed decision-making and promote more sustainable and resilient urban infrastructure management.

References

1. H. Suprayitno, and R. A. A Soemitro, Reflection on Basic View of Public Infrastructure for Infrastructure Asset Management in Indonesia, J. Infra. & Fac. Asset Man., **3**(0), 15–24 (2019). https://doi.org/10.12962/j26151847.v3i0.5353.
2. International Standard ISO 15686, Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing. International Organization for Standardization, Geneva (2017).
3. S. K. Fuller, S. R. Petersen, Life-cycle costing manual for the Federal Energy Management Program. (NIST Handbook 135, 1996).
4. International Standard ISO 55002, Asset Management – Management systems – Guidelines for the application of ISO 55001. International Organization for Standardization, Geneva (2018)
5. A. S. Ali, S. J. L. Chua, The role of maintenance in sustainable building management. J. Build. Eng. **25**, 100814 (2019). https://doi.org/10.1016/j.jobe.2019.100814.
6. P. I. Devina, R. Waluyo, and V. H. Puspasari, Building Maintenance Cost Estimation Analysis. Jurnal Teknik Sipil, **17**(2), 95 - 102 (2023). https://doi.org/10.24002/jts.v17i2.6407
7. M. Hallowell, J. Hinze, K. Baud, A. Wehle, Proactive construction safety control: Measuring, monitoring, and responding to risk indicators. J. Constr. Eng. Manag., **142**(10), 04016052 (2016). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001168
8. BNPB, Indonesia Disaster Risk Index. National Disaster Management Agency, Jakarta (2020).
9. I. Arta, et al., Risk management: A theoretical and practical review (1st ed.). (Widina Bhakti Persada Bandung, 2021)
10. ISO 31000, Risk management – Guidelines. International Organization for Standardization, Geneva (2018).
11. J. W. Creswell, Research design: Qualitative, quantitative, and mixed methods approach. (Sage Publications, Thousand Oaks, 2014).
12. Regulation of Ministry of Public Works and Public Housing of The Republic of Indonesia No. 22/PRT/M/2018, Construction of State Building (2018).
13. Minister of Public Works and Public Housing, Guidelines for the Implementation of Risk Management in The Ministry of Public Works and Public Housing, (2021).
14. DKI Jakarta Governor Regulation Number 122, 2020, Implementation of Risk Management in The Government of The Special Capital Region of Jakarta Province, (2020).
15. Risk Management at the Ministry of Finance. Ministry of Finance of the Republic of Indonesia. (2021).