Analysis of the Criteria for Assessing Building Quality Damage Levels Using the AHP Method: A Case Study Based on Indonesian Building Regulations

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ABSTRACT

Quality assessment is a critical part of a building's maintenance procedures, indicating its functionality. Measuring the level of damage in a building can be used as reference in decision making during repairs. The building's damage is influenced by structural, material, and environmental factors. However, the extent to which each criterion contributes to the damage is yet to be studied. This study analyzes the criteria that influence building quality damage by calculating their weight on the building's damage through the Analytic Hierarchy Process (AHP) method. Data were collected through in-depth interviews of experts in the field of building construction. The results reveal 6 main criteria and 33 sub-criteria that influence building quality damage. Further analysis indicated that the main structural criterion had the highest weight (0.4334) in determining the level of building quality deterioration, followed by the main architectural criterion (0.2074), electrical (0.1257), mechanical (0.0938), exterior layout (0.0708), and general building components (0.0690).

Keywords-component; damage level; quality; building structure; AHP

I. INTRODUCTION

Infrastructure development is a key driver of economic growth, leading to increased connectivity and social welfare [1]. Several major trends shape the direction of infrastructure development in various countries [2]. The developed countries of the European Union integrate nature-based solutions and energy efficiency for ecological resilience [3]. In addition, the cross-country connectivity megaprojects are growing. For instance, Belt and Road Initiative, a initiative led by China, focuses on building economic corridors to stimulate global trade [4]. Indonesia has implemented a development policy that focuses heavily on infrastructure [5]. The National Strategic Project (PSN) program accelerates the production of hundreds of projects throughout the country [6]. Few of them include the construction of toll roads, such as Trans-Java and Trans-Sumatra, the operation of modern public transportation, such as MRT and LRT in Jakarta, the expansion of major airports and ports, and the construction of dozens of dams to ensure water and energy security [7]. A highly promising project is the development of the smart and green Indonesian Capital City (IKN) in East Kalimantan, in line with global sustainability and digitalization trends [8]. This massive infrastructure attempt has directly triggered activity in the construction sector, which is reflected in building growth data across the country [9]. According to data from the Central Statistics Agency (BPS), the growth rate of the construction sector has consistently been one of the highest [10]. Overall, infrastructure development and building growth in Indonesia reveal a great effort to adopt global concepts to achieve national connectivity and economic growth targets [11].

Building construction is one of the factors that is highly considered in the national development process [12]. As a place for people to do activities, buildings have a very strategic role in the formation of character, productivity, and the realization of human identity [13]. Buildings can essentially be described as a physical form of construction work that has a roof and walls, permanently raised in a location, either on land or in water [14]. Every building that is designed has specific needs and functions according to the set goals to be achieved [15]. During the construction of a building, its quality is is based on the construction strength, material durability, aesthetics, and low price [16]. The strength of the construction is determined by the selection and implementation of the structural system and materials, along with the level of smoothness in its completion [17]. In other words, the quality of a building is determined from the planning, implementation, and usage/maintenance stages [18]. All stages must be correctly achieved to produce a quality building [19].

The tropical climate of Indonesia has a major impact on the condition of buildings [20]. Building damage occurs when a structure's resistance to the internal or external forces diminishes [21]. According to the Minister of Public Works Regulation No. 24 of 2008, building damage is characterized by buildings that lose their function either partially or completely due to building shrinkage, expiration of the building's planned life, as well as human and natural factors. Additionally, natural factors, such as earthquakes, can damage or demolish buildings [22]. Consequently, the level of damage is greatly influenced by the characteristics of the local soil. In [23], it was revealed that severe damage often occurs in buildings due to low material quality and insufficient implementation during the planning and supervision stages of construction.

Specifically, authors in [24] identified failure-prone points in simple buildings during earthquakes. Common damages were concentrated at the joints between foundations and columns, columns and beams, and at masonry walls and roof structural systems [25]. During the 2023 Gansu earthquake, the main causes of damage were the lack of effective connections between the load-bearing components and inadequate wall strength. These factors led to loss of the building's integral stability, and therefore poor seismic performance [26]. In addition, the decline in concrete quality below the minimum standard for earthquake-resistant buildings ultimately greatly weakens the overall structural strength [27].

A building must be planned in accordance with earthquake-safety building standards. One of these is the assessment of evacuating damage to buildings due to earthquakes so that in future occurences it can be avoided [28]. After an earthquake event, column reinforcement and assistance beams are crucial. These two elements provide ductility and strength [29]. In [30], it was indicated that more than 70% of the damage occurred due to earthquakes [30]. Unidentified minor building damage can lead to significant building degradation [31]. The best way to avoid such occurrence is preventive maintenance. Preventive maintenance extends the life of equipment, reduces costs and energy, and increases occupant comfort.

The first step of the analysis is determining the criteria and sub-criteria for building damage, to provide an objective and measurable assessment of the damage level. Damage assessment can be carried out using various methods, including the AHP method or multi-criteria analysis method, simple visual inspection, laser displacement, and software structural analysis [32].

AHP is a decision-making method first developed by Thomas L. Saaty in the 1970 [33]. This method is designed to compare elements in pairs and determine the impact or importance of one element compared to another. The AHP method offers a hierarchy-based framework that can integrate various criteria in the decision-making process. This approach comprehensively analyzes the factors causing damage to building quality by assigning relevant weight values.

II. METHODOLOGY

A. Research Flow

The research process in the current study is depicted in Figure 1. The process begins with the identification of the problem, followed by the formulation of research objectives. Once the objectives are established, the process continues with data collection, which is divided into two main sources: primary and secondary data.

Primary data are collected through in-depth interviews and questionnaires targeting selected experts involved in building assessments. Secondary data are gathered from relevant regulations, including Regulation No. 16/PRT/M/2010 [34]. Following the data collection, an analytical phase is conducted. This includes two key activities:

1. The determination of criteria and sub-criteria related to the quality damage of the building structures.
2. The assignment of weighting values to each criterion using the AHP method.

B. Research Framework

The research framework in this study is designed to answer two Research Questions (RQ). In this study, the data used were grouped into two stages:

1. Collection for the first RQ (RQ1) or Literature Study. In the first stage, a literature study and secondary data collection are conducted from relevant journals, previous studies, and activity reports.
2. Collection for the second RQ (RQ2): Expert Opinion. At this stage, opinions are collected through in-depth interviews from several experts related to the assessment of the weight between criteria. Furthermore, an analysis is carried out from the existing responses using the AHP method, as illustrated Figure 2.

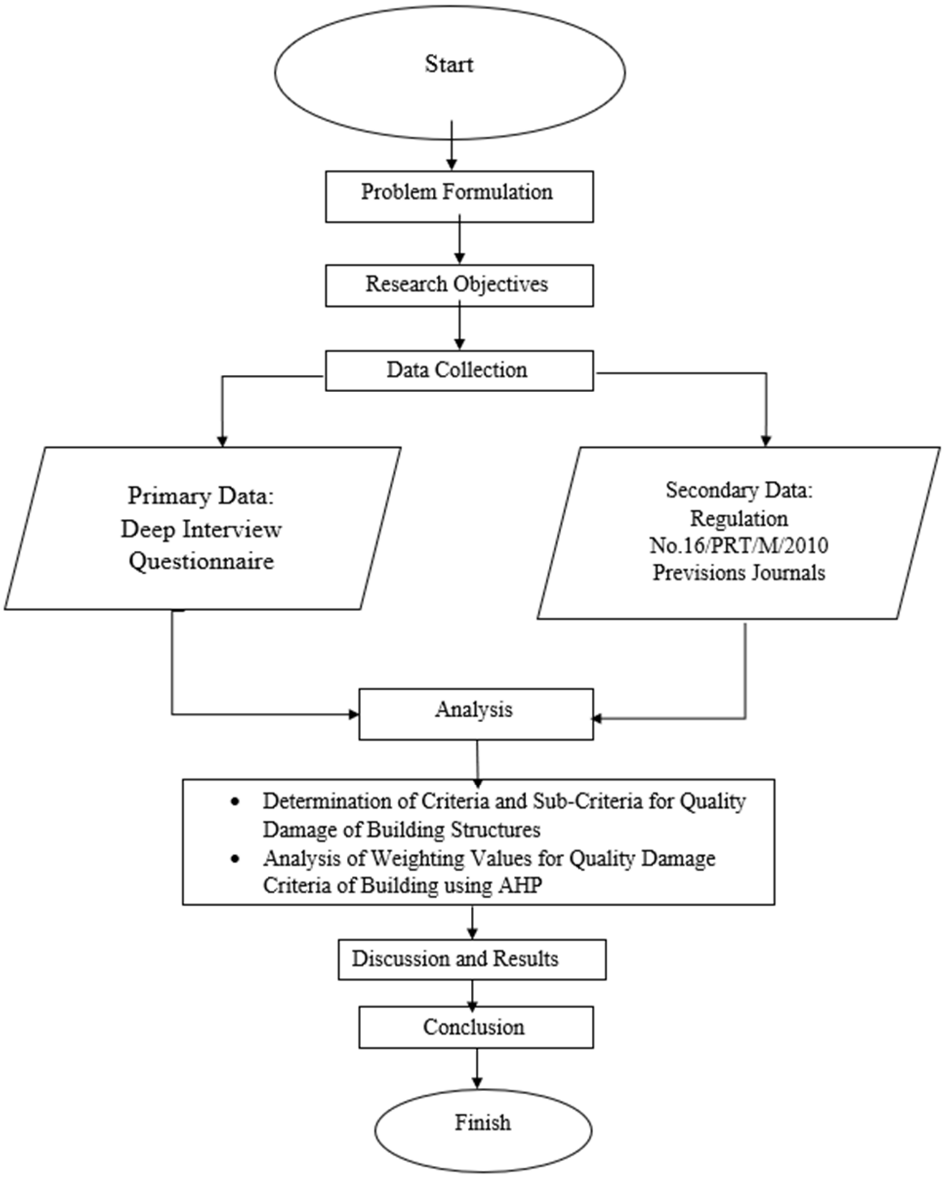

Fig. 1. Research flowchart.

C. AHP Stages

The first stage includes the definition of the criteria and the creation of a hierarchical structure. From the defined problem, the relevant criteria are determined. In a later stage the criteria will be processed, and their weight values will be obtained. Questionnaires are distributed and expert opinions are gathered. The filled questionnaires are combined using the geometric mean equation, which is an average value closer to the data obtained from the respondents. The geometric mean can be calculated by:

$$GM = \sqrt[n]{(X_1)(X_2)\dots(X_n)} \quad (1)$$

where GM refers to the geometric mean, X_1 to the first expert, X_2 to the second expert, and X_n to the n^th^ expert.

During the second stage, the element weight is calculated. The objective is to determine the level of interest of the relevant parties in the problem concerning the criteria and structure of the hierarchy or system. The initial step in determining the priority of the criteria, involves comparing in pairwise form all criteria for each hierarchical subsystem. The comparison is then transformed into a pairwise comparison matrix for numerical analysis.

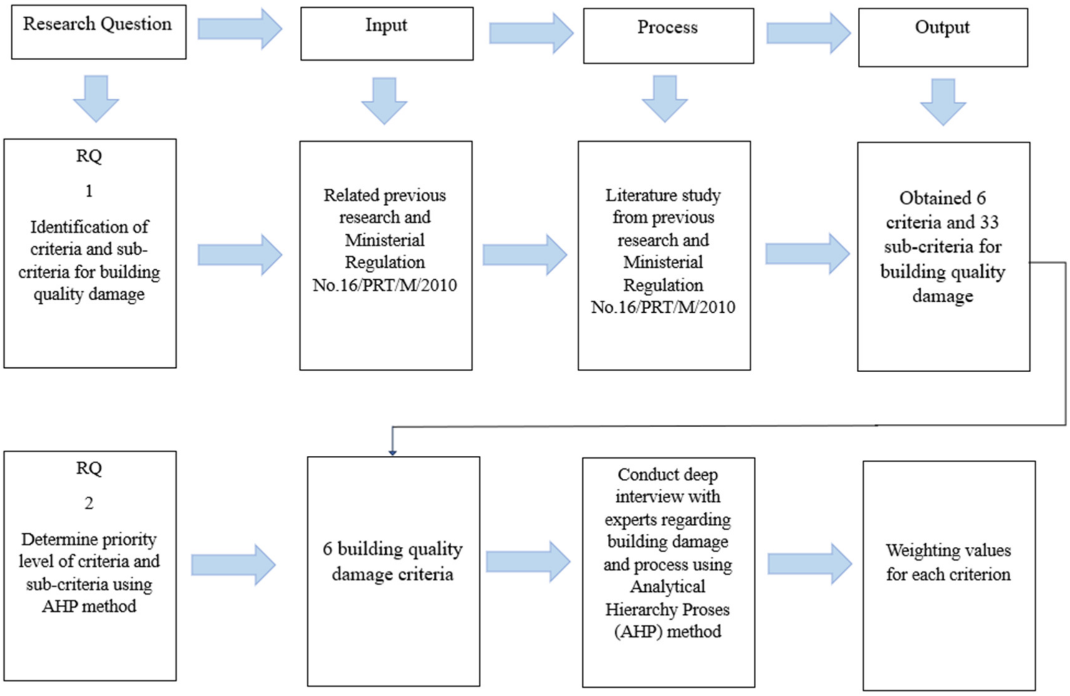

Fig. 2. Research framework.

During the criteria weighing, to find out the dominant criteria, a comparison matrix is prepared at each level. Matrix is a collection of objects consisting of rows and columns and arranged in a rectangular shape. Usually, the matrix consists of m rows and n columns. The matrix is considered square if m is equal to n and the scalars are in the i-th row and j-th column, being called the entry matrix. A vector of n dimensions is a regular arrangement of elements in the form of n numbers, arranged according to rows, from left to right, or according to columns, from top to bottom.

To determine the value of each element within the matrix, the total value of each column is compared against its corresponding matrix value. These are summed for each row. Subsequently, the total row value of the derived matrix is aggregated. Priority values are determined by comparing the total row value in the matrix with the total calculated column value. The eigenvalue is then obtained by multiplying the priority values within the matrix and comparing this product to the overall priority value. The eigenvalue itself is the sum of the individual eigenvalues divided by the matrix order (n). This matrix effectively illustrates the relative contribution or influence of each element concerning the objective or criterion positioned one level above it. For instance, the comparative value of element A_1 to element A_2 is denoted as a_{12}.

What distinguishes AHP from other decision-making methods is the absence of absolute consistency requirements. AHP uses the decision maker's perception as its input, so inconsistencies may occur, especially when comparing the number of criteria. Based on these conditions, decision makers can express their opinions freely without having to think about whether they will be consistent or not in the future.

III. RESULTS AND DISCUSSION

A. RQ1 Analysis: Identification of Criteria and Sub-Criteria for Building Quality Damage

Based on the Minister of Public Works Regulation No. 16/PRT/M/2010, building maintenance consists of components, including architecture, structural, mechanical, electrical, and exterior layout. The following is a description of the criteria and sub-criteria, along with the indicators that affect the quality of the building damage, as presented in Tables I-Table V.

B. RQ2 Analysis: Determination of Priority Weight of Building Quality Damage Criteria Using the AHP Method

The questionnaires were distributed to consultants, contractors, academics, and government officials in South Sulawesi, 19 of which were valid and complete. Based on the results of a study conducted on 26 respondents, by distributing a questionnaire consisting of 6 criteria, a general picture was obtained of the characteristics of the respondents in terms of position, educational background, and ownership of a Building Construction Work Skill Certificate (SKK). In terms of the educational background, S1 refers to Strata 1 (S1, Bachelor's degree), S2 refers to Strata 2 (Master's degree), and S3 refers to Strata 3 (Doctorate). The results are presented in Table II.

C. AHP Data Analysis

The main objective when measuring building quality damage criteria is for them to be placed at the top level. The levels below are the six main criteria that have been identified as in Figure 3.

TABLE I. ARCHITECTURAL CRITERIA AND SUB-CRITERIA FOR BUILDING QUALITY DAMAGE

Element	**Damage level**	**Indicator**	**Reference**
Roof	Minor	Shifted, broken, missing or perforated roof tiles (<5% of roof area), Leaking gutters (<10% of length), Leaking gutter joints (<10% of number).	No. 16/PRT/M/2010
	Moderate	Shifted, broken, missing or perforated roof tiles (5%-10% of roof area), Leaking gutters (10%-20% of length), Leaking gutter joints (10%-20% of number).	
	Serious	Shifted, broken, missing or perforated roof tiles (>10% of roof area), Leaking gutters (>20% length), Leaking gutter joints (>20% number).	
Wall	Minor	Hairline cracks, damp/spotted surfaces, peeling paint, moss.	No.16/PRT/M/2010
	Moderate	Structural cracks, gaps due to deformation, plaster largely detached, slight deformation (curved/convex).	
	Serious	Partial wall collapse, large cracks, surface largely eroded, wall position subsidence to the point of non-functioning.	
Doors and windows	Minor	Weathered, small cracks, loose joints, faded color.	No.16/PRT/M/2010
	Moderate	Holes due to use, deformation (warping), most of the joints are loose.	
	Serious	Broken, unusable structure, missing critical components.	
Ladder	Minor	Hairline cracks, slight wavy surface, peeling coating, slight dirt.	No. 16/PRT/M/2010
	Moderate	Significant wavy surface, minor subsidence, some damaged (repairable) parts, eroded.	
	Serious	Significant staircase collapse, very wavy surface, most of the structure is severely damaged.	
Palate	Minor	Spots, faded colors, loose ceiling panels.	No. 16/PRT/M/2010
	Moderate	Loose panels in some areas, holes, warped panels, cracks.	
	Serious	Some panels are missing/severely damaged, panels are falling, supporting structures are damaged.	
Floor	Minor	Hairline cracks, fading, imperfect tile joints.	
	Moderate	Small pieces of tiles are loose, the surface is uneven, the joints are broken, some tiles are crushed.	
	Serious	Most tiles are broken/fractured, surface is completely damaged, significant tile loss, damage to the base coat.	
Sanitary	Minor	Spots on the surface, hairline cracks, faucet works but not smoothly.	No. 16/PRT/M/2010
	Moderate	Leaking in pipes/connections, partially blocked water flow, damage to connections with walls/floors.	
	Serious	Major leaks, main pipe connections broken, equipment operation failed, significant damage to equipment.	

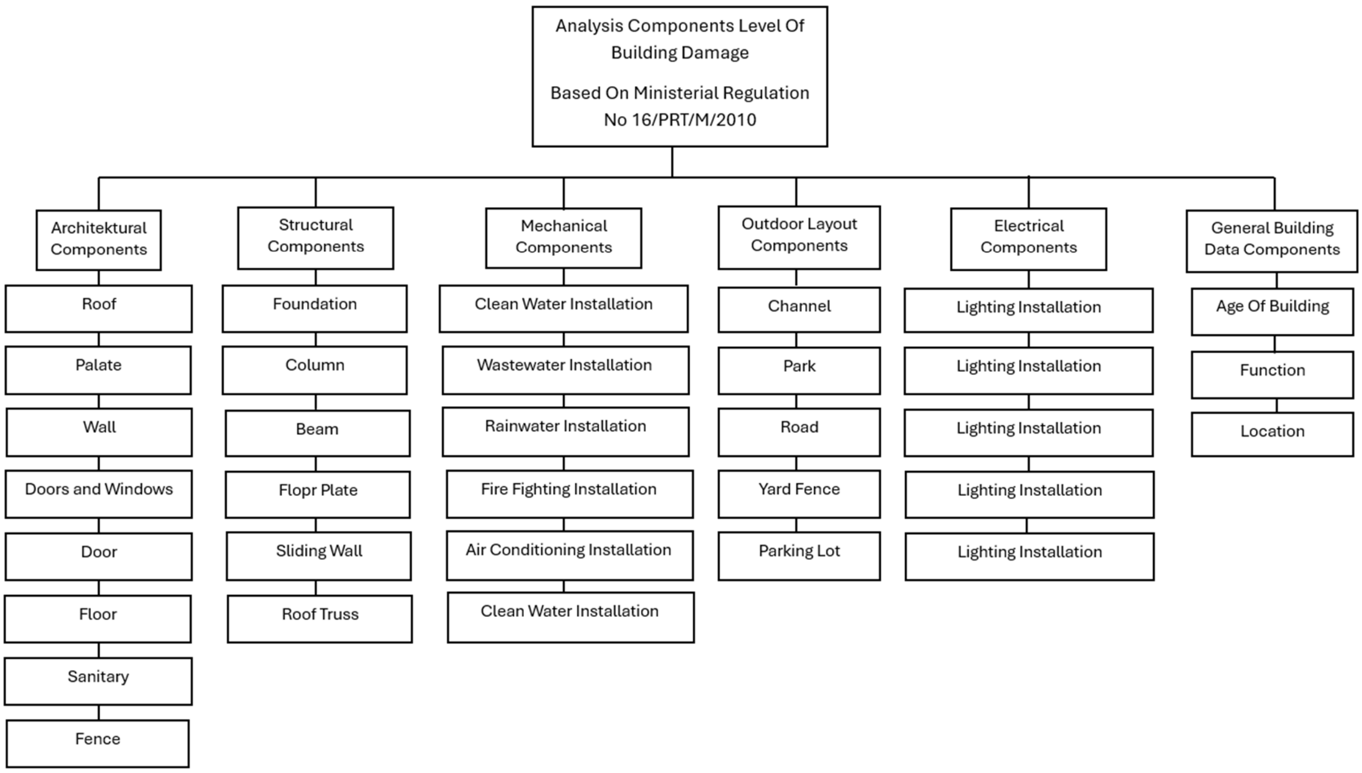

Fig. 3. Hierarchy of building damage level analysis components.

TABLE II. STRUCTURAL CRITERIA AND SUB-CRITERIA FOR BUILDING QUALITY DAMAGE

Element	Damage level	Indicator	Reference
Foundation	Minor	Minor cracks, slight waviness, minor leaks at joints.	No 16/PRT/M/2010
	Moderate	Moderate structural cracks, uneven land subsidence, moderate leakage.	
	Serious	Significant decline, large cracks, severe leaks.	
Column	Minor	Hairline cracks, slight surface warping, slight corrosion on reinforcement.	No. 16/PRT/M/2010
	Moderate	Moderate structural cracks, column shifts, severe corrosion, misaligned/cracked column-beam connections.	
	Serious	Broken columns, porous reinforcement, large settlement, partial collapse.	
Beam	Minor	Hairline cracks, small peeling of concrete layer, slight wavy surface.	No. 16/PRT/M/2010
	Moderate	Moderate structural cracks, corrosion of reinforcement, cracked beam-column joints.	
	Serious	Large cracks/breaks, severe damage to joints, heavy corrosion, significant deterioration.	
Floor plates	Minor	Hairline cracks, slight surface warping, minor leaks.	No. 16/PRT/M/2010
	Moderate	Medium dimensional cracks, moderate leaks, peeling concrete skin, sagging surface.	
	Serious	Broken/crushed, damaged surface, visible reinforcement, large deformation.	
Roof frame	Minor	Corrosion at joints, wood rotting, loose fittings, light sagging.	No. 16/PRT/M/2010
	Moderate	Heavy corrosion, warped frames, loose joints, rotting wood.	
	Serious	Most of the frame broke, unable to support the load, the main joints came loose, the frame collapsed.	
Sliding wall	Minor	Slight bending, hairline cracks, slight plaster loosening.	No. 16/PRT/M/2010
	Moderate	Moderate structural cracks, extensive plaster damage, leaks, joints with other elements cracked.	
	Serious	Large gaps, loose wall coverings, unstable walls, overall damage.	

TABLE III. ELECTRICAL CRITERIA AND SUB-CRITERIA FOR BUILDING QUALITY DAMAGE

Element	Damage level	Indicator	Reference
Lighting installation	Minor	Diffuser is dull, light flickering, fixture is faded, slight vibrating noise.	No. 16/PRT/M/2010
	Moderate	Diffuser partially broken, moderate corrosion, uneven lighting, suboptimal controller.	
	Serious	Diffuser completely broken, severe corrosion, lighting too bright/dark, control system completely damaged.	
Power outlet installation	Minor	Loose connections (working), cover slightly cracked, color faded.	No. 16/PRT/M/2010
	Moderate	Loose connections, large cracked covers, small electrical sparks.	
	Serious	Broken/burned cable, cover totally damaged, not working.	
Fire alarm installation	Minor	Alarms are inconsistent, connections are a little loose, buttons are worn out.	No. 16/PRT/M/2010
	Moderate	Alarm does not sound in some areas, cables are worn, buttons need more pressure.	
	Serious	Alarm not working, main connection broken, detector failed, control panel inoperable.	
Lightning conductor installation	Minor	Slightly loose connections, light wear on lining, antenna slightly tilted.	No. 16/PRT/M/2010
	Moderate	Cracks in insulation, worn/corroded cables, shifted poles, decreased performance.	
	Serious	Loose connections, badly damaged linings, broken poles, systems not working.	
Telephone installation	Minor	Slightly loose connection (working), minor insulation damage, temporary signal interference.	No. 16/PRT/M/2010
	Moderate	Moderate cable wear, signal quality decreases, connectors are loose.	
	Serious	The main cable is broken, the connection is completely damaged, the signal is completely disturbed.	

TABLE IV. MECHANICAL CRITERIA AND SUB-CRITERIA FOR BUILDING QUALITY DAMAGE

Element	Damage level	Indicator	Reference
Clean water installation	Minor	Light corrosion, slightly loose connections (no leaks), pipe shifts slightly.	No. 16/PRT/M/2010
	Moderate	Small cracked/leaking pipes, moderate corrosion, blockages, damaged pipe supports.	
	Serious	Major leaks, severe corrosion, loose/broken connections, collapsed pipes.	
Air conditioning installation	Minor	Light corrosion on ducting, small cracks, light dirt/dust.	No. 16/PRT/M/2010
	Moderate	Loose ducting connections, moderate corrosion, dust/dirt accumulation, decreased capacity.	
	Serious	Ducting connection is completely damaged, heavy corrosion, major component damage, capacity is not functioning.	
Wastewater installation	Minor	Slightly loose connections (no leaks), light corrosion, light deposits.	No. 16/PRT/M/2010
	Moderate	Moderate cracks, moderate deposits, moderate corrosion.	
	Serious	Major leaks, heavy deposits, broken pipes, severe corrosion.	
Rainwater installation	Minor	Pipes are slightly displaced, joints are starting to loosen, light corrosion.	No. 16/PRT/M/2010
	Moderate	Minor leaks, moderate corrosion, partially blocked pipes, loose connections.	
	Serious	Completely clogged, major leaks, severe corrosion, broken pipes.	
Fire fighting installation	Minor	Minor leaks, minor corrosion, slight flow disturbance.	No. 16/PRT/M/2010
	Moderate	Moderate cracks, moderate corrosion, disturbed flow, valves are not optimal.	
	Serious	Major leaks, broken connections, heavy corrosion, stoppage of flow.	
Elevator	Minor	Electrical connections are slightly loose, cables have minor wear, speed controller needs adjustment.	No. 16/PRT/M/2010
	Moderate	Moderate damage to wiring, loose electrical connections, minor component replacement required, worn motor insulation.	
	Serious	The main cable is badly damaged, the electrical connection failed, the motor insulation is damaged, the speed control system failed.	

TABLE V. OUTER SPATIAL CRITERIA AND SUB-CRITERIA FOR BUILDING QUALITY DAMAGE

Element	Damage level	Indicator	Reference
Yard fence	Minor	Minor cracks, light corrosion, slight shifting of the fence, peeling paint.	No. 16/PRT/M/2010
	Moderate	Larger cracks, moderate corrosion, loose joints, some of the fence is leaning.	
	Serious	Loose posts/collapsed fence, severe corrosion, non-functional, missing/damaged fence sections.	
Road	Minor	Hairline cracks, light wavy surface, slight asphalt peeling.	No.16/PRT/M/2010,
	Moderate	Moderate cracks, curved/convex surfaces, waterlogging.	
	Serious	Large potholes/collapses, large cracks, significant detached road layers.	
Drainage channel	Minor	Small cracks, bumpy surface, slight mud.	No.16/PRT/M/2010,
	Moderate	Moderate cracks, partially collapsed channel, eroded, clogged with dirt.	
	Serious	Structure collapse, total collapse, complete blockage, major damage.	
Park	Minor	Border plants are not straight, plants are slightly wilted, some dirt.	No. 16/PRT/M/2010
	Moderate	The border plants are cracked, some plants are dead, the surface is uneven.	
	Serious	Missing elements, significant plant death, areas of subsidence.	
Parking lot	Minor	Slightly wavy asphalt, small cracks, a little dirty, signs of weathering.	No.16/PRT/M/2010
	Moderate	Moderate cracks, curved/convex surfaces, pinholes, uneven surfaces.	
	Serious	The asphalt peeled significantly, collapsed, poor drainage caused puddles.	

TABLE VI. GENERAL PROFILE OF THE RESPONDENTS

Questinaire criteria	Description	Number of responders
Position/profession	Academics	8
	Practitioner	15
	Government	3
Educational background	S1	5
	S2	14
	S3	7
SKK building construction	Acquired	23
	Not acquired	3

IV. CONCLUSION

This study identified the criteria and sub-criteria influencing the level of damage to building quality according to No. 16/PRT/M/2010. The outcome discovered 6 main criteria, including structural, architectural, mechanical, electrical, exterior layout, and general building elements with 33 sub-criteria. This is an expansion of the range in conventional assessment approaches and offers a more integrated platform for evaluating building quality damage. The Analytical Hierarchy Process (AHP) was applied and it was revealed that structural criteria are the highest contributor to the damage in building quality with a 0.4334 weight. The weight underlines the necessity to adopt a multi-criteria method instead of the traditional single-aspect methodology for the assessment of building damage. The present study, along with the Indonesia's national provisions, develops a localized empirically grounded building damage assessment model. This not only supports existing regulations but also provides the groundwork for building quality evaluation standards improvement in Indonesia. Therefore, the study contributes to a framework that can be applied to local governments, engineering consultants, and scholars, particularly for jurisdictions with similar regulatory environments.

Overall, the research emphasizes the need to organize building maintenance in terms of structural considerations and meanwhile track additional aspects. Combining Indonesian regulations and existing studies, the research introduces a functional model based on evidence for measuring building quality. It proposes using analogous models to improve inspection quality, allocate maintenance budgets more effectively, and prepare strategic rehabilitation work for sustainable building management.

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