



3D-Based building damage assessment and visualization for sustainable maintenance planning: A case study of the Universitas Muhammadiyah Sukabumi rectorate building

Nia Kartika*

Universitas Muhammadiyah
Sukabumi, Universitas
Islam Sultan Agung
Semarang, INDONESIA

Pratikso

Universitas Islam Sultan
Agung, INDONESIA

Henny Pratiwi Adi

Universitas Islam Sultan
Agung, INDONESIA

Article Info

Article history:

Received: July 30, 2026

Revised: Sept 15, 2026

Accepted: October 12, 2026

Keywords:

Building Damage Assessment;
3D Modeling;
Damage Visualization;
Handling Cost Estimation.

Abstract

Background: Effective building maintenance requires systematic damage assessment and integrated condition information to support informed decisions and sustainable infrastructure management. However, conventional inspection reports often lack spatial visualization, limiting the identification and management of damaged building components.

Aims: This study aims to assess building damage and develop a three-dimensional (3D) visualization model integrating damage characteristics, severity classifications, repair recommendations, and cost estimates to support sustainable maintenance planning.

Method: A descriptive case study was conducted at the Universitas Muhammadiyah Sukabumi Rectorate Building through regulatory reviews, technical documentation, field inspections, damage severity analysis, and 3D modeling using Autodesk Revit 2025.

Results: The assessment identified 108 damage instances involving architectural components, comprising 77 minor, 19 moderate, and 12 severe cases. The overall building damage level was 11.01%, indicating minor damage. The developed 3D model linked damaged components with spatial locations, damage dimensions, severity levels, repair recommendations, and cost estimates. The total estimated repair cost reached IDR 149,175,912.

Conclusion: Integrating damage assessment with 3D visualization facilitates structured damage documentation, component identification, and maintenance prioritization, providing a practical foundation for more systematic and potentially resource-efficient building maintenance planning.

To cite this article: Kartika, N., Pratikso, & Adi, H. P. (2026). 3D-Based building damage assessment and visualization for sustainable maintenance planning: A case study of the Universitas Muhammadiyah Sukabumi rectorate building. *Journal of Advanced Sciences and Mathematics Education*, 6(4), 80-101.

INTRODUCTION

Building maintenance plays a fundamental role in ensuring the safety, functionality, durability, and sustainability of infrastructure throughout its operational lifespan. Within the building lifecycle, the operation and maintenance (O&M) phase represents a substantial financial commitment, accounting for approximately 60% of total lifecycle expenditures (Alavi et al., 2022). These recurring expenditures frequently exceed initial construction investments, emphasizing the importance of systematic maintenance strategies and effective resource management (Abideen et al., 2022). As buildings age, their structural and architectural components experience progressive deterioration resulting from environmental exposure, material degradation, and continuous operational demands (Lhara et al., 2024). Consequently, systematic building condition assessments are essential for identifying physical deterioration, evaluating damage severity, and determining appropriate maintenance interventions (De Fino et al., 2023; Faqih & Zayed, 2021; Lupășteanu et al., 2022; Matos et al., 2021; Nazri et al., 2025). Such assessments generate structured information regarding component conditions, damage classifications, and repair requirements, providing a

*Corresponding author:

Nia Kartika, Universitas Muhammadiyah Sukabumi, Indonesia
niakartika@ummi.ac.id ✉

reliable foundation for maintenance planning and resource allocation (Wardach et al., 2023). Building maintenance should therefore be considered an ongoing responsibility throughout the operational phase rather than an intervention undertaken exclusively after significant deterioration occurs. Furthermore, inspection procedures must accommodate the characteristics and functional requirements of individual building components to ensure accurate and context-sensitive evaluations (Pereira & Silva, 2024). Comprehensive damage assessment involves examining technical conditions, identifying deterioration mechanisms, evaluating damage severity, and determining appropriate remediation strategies (Prusov et al., 2024). Accordingly, systematic building condition evaluation contributes to maintaining structural reliability, operational functionality, and long-term infrastructure sustainability (Rapiński et al., 2025).

Effective building maintenance management requires accurate documentation, accessible technical information, and systematic coordination between inspection findings and subsequent repair activities. Conventional facility management practices frequently rely on two-dimensional computer-aided design (2D CAD) drawings, inspection reports, and tabulated inventories to document building conditions and maintenance requirements (Su et al., 2011). Although these conventional approaches provide essential technical records, their limited spatial representation may complicate the identification of damaged components and the interpretation of deterioration patterns. Furthermore, separating inspection results from geometric building information can create challenges in retrieving component-specific data and coordinating maintenance interventions. Advances in digital engineering have introduced three-dimensional (3D) modeling as an alternative approach for representing building geometry and organizing technical information within an integrated digital environment. Three-dimensional modeling enables the visualization of building components and their spatial relationships, potentially improving the interpretation of physical conditions and maintenance requirements (Su et al., 2011). When integrated with structured databases, digital building models can associate geometric representations with component identities, technical specifications, inspection records, and relevant maintenance information. Building Information Modeling (BIM) provides a digital information management framework that supports the organization and retrieval of building-related data throughout different stages of the infrastructure lifecycle (Azhar, 2011). This integration allows facility managers to access component-specific information through spatially referenced digital representations rather than relying exclusively on conventional drawings and inspection documentation. Therefore, incorporating 3D modeling into building condition assessment offers opportunities to strengthen damage information traceability, technical communication, and the systematic organization of maintenance-related data.

The application of 3D modeling to building damage assessment provides opportunities to integrate physical inspection findings with spatial visualization and maintenance-related information. Unlike conventional documentation methods, component-based digital models can associate individual building elements with damage characteristics, affected dimensions, severity classifications, and recommended repair interventions. The integration of technical drawings, original component quantities, and field inspection records within a structured database enables building condition information to be organized according to identifiable elements and their corresponding spatial locations. Such information management capabilities are consistent with the application of BIM as a digital repository supporting building documentation and facility management throughout the operational lifecycle (Azhar, 2011). Furthermore, incorporating Work Breakdown Structure (WBS) information, material specifications, component parameters, and inspection results into a 3D environment can facilitate the organization of maintenance activities and associated technical requirements. The inclusion of measured damage quantities and relevant unit prices also enables inspection findings to be connected with preliminary repair cost estimates, supporting more informed maintenance budgeting. These capabilities are particularly relevant to

aging institutional buildings, where accumulated deterioration must be systematically documented while maintaining the continuity of administrative and educational activities. The Rectorate Building of Universitas Muhammadiyah Sukabumi (UMMI), constructed in 1925, represents an existing institutional facility requiring comprehensive damage assessment and structured maintenance information management. In this context, Autodesk Revit 2025 provides a modeling environment for representing building geometry and linking individual components with inspection-derived damage attributes and maintenance information. Accordingly, integrating building damage assessment with 3D visualization offers a practical approach to organizing deterioration records, identifying maintenance requirements, and supporting more systematic and potentially resource-efficient building maintenance planning.

Recent developments in building condition assessment and digital infrastructure management have encouraged the adoption of computational technologies to improve damage identification, visualization, and maintenance decision-making. Previous investigations have explored automated building damage detection using remote sensing, deep learning, and information fusion techniques, particularly for post-disaster condition evaluation (Hong et al., 2024; Zhang & Pan, 2022; Zheng et al., 2021). Other studies have examined machine learning applications and strategic maintenance frameworks to enhance facility management, operational performance, and sustainability-oriented maintenance practices (Villa et al., 2022). Meanwhile, BIM-based approaches have demonstrated applications in three-dimensional infrastructure visualization, rehabilitation quantity take-off, and lifecycle information management (Abuhussain et al., 2024; Liu et al., 2021). More recent investigations have extended these approaches through seismic damage assessment, repair cost estimation, degradation prediction, and predictive maintenance optimization (Li et al., 2026; Nageeb et al., 2026; Sanrı Karapınar et al., 2026). Although these developments demonstrate the potential of digital technologies for infrastructure management, their different methodological objectives and application contexts highlight the need for further investigation into practical approaches that integrate field-based damage assessment with component-level spatial visualization and maintenance planning. In particular, connecting measured damage dimensions, severity classifications, repair recommendations, and estimated costs within a unified 3D representation remains a relevant area for applied research on aging institutional buildings. Furthermore, conventional damage assessment records require systematic transformation into spatially traceable digital information while preserving the accuracy and consistency of field-based evaluation procedures. Addressing these considerations, the present study integrates building damage assessment with 3D modeling using Autodesk Revit 2025 to establish a structured representation of deterioration conditions and associated maintenance requirements. This integration provides a practical framework for connecting inspection-derived damage information, component-level visualization, and preliminary repair cost estimation to support evidence-informed maintenance planning.

This study aims to assess building damage and develop a three-dimensional (3D) visualization model to support sustainable maintenance planning for the Rectorate Building of Universitas Muhammadiyah Sukabumi (UMMI). Specifically, the research seeks to identify deteriorated building components through systematic field inspections and document their physical characteristics, locations, and affected dimensions. The study also evaluates the severity of identified damage using component-based assessment procedures and applicable Indonesian building maintenance regulations. Furthermore, the recorded defects are classified into minor, moderate, and severe categories to establish a structured representation of building conditions. The resulting assessment data are subsequently integrated into a digital 3D building model developed using Autodesk Revit 2025. Within this model, individual building components are associated with identification codes, damage characteristics, dimensional measurements, severity classifications,

and supporting inspection documentation. The research additionally incorporates recommended repair interventions and preliminary cost estimates calculated from measured damage quantities and relevant unit prices. Through this integration, the study examines the application of 3D visualization for organizing, locating, and retrieving building damage information within a unified digital environment. The developed model is intended to provide facility managers with structured information for identifying maintenance requirements, considering repair priorities, and preparing preliminary maintenance budgets. Ultimately, this research contributes to digital building condition assessment by demonstrating an integrated approach that connects field-based damage evaluation, spatial visualization, and repair cost information to support systematic and potentially more sustainable building maintenance planning.

LITERATURE REVIEW

Building damage assessment constitutes a fundamental process in infrastructure management, providing systematic information regarding the physical condition, deterioration characteristics, and functional performance of building components. The assessment process generally involves identifying visible defects, measuring affected areas, evaluating damage severity, and determining appropriate repair interventions based on established technical standards (Pereira & Silva, 2024; Prusov et al., 2024). Building deterioration may result from material aging, environmental exposure, operational activities, and inadequate maintenance, making periodic inspections essential for maintaining building serviceability (Lhara et al., 2024). Systematic condition evaluation enables facility managers to distinguish between minor, moderate, and severe deterioration while establishing a measurable basis for maintenance planning (Wardach et al., 2023). Furthermore, integrating damage characteristics with component-specific information can improve the consistency and accessibility of inspection records. Recent developments in automated damage identification have introduced computer vision, deep learning, and information fusion techniques to enhance building condition evaluation, particularly following natural disasters (Zhang & Pan, 2022; Hong et al., 2024). Nevertheless, field-based inspections remain relevant for documenting component-level deterioration and obtaining dimensional measurements required for repair planning. The reliability of damage assessment depends on consistent inspection procedures, clearly defined classification criteria, and accurate documentation of observed defects. Consequently, building condition assessment provides the analytical foundation for identifying maintenance requirements and allocating repair resources. These considerations establish the importance of integrating conventional damage evaluation procedures with digital information management technologies to support systematic building maintenance.

Three-dimensional (3D) modeling has become an important technological approach for representing building geometry, spatial relationships, and component characteristics within digital environments. Unlike conventional two-dimensional drawings, 3D representations enable building elements to be visualized spatially and associated with relevant technical information, facilitating more comprehensive building documentation (Su et al., 2011). Building Information Modeling (BIM) extends these capabilities by integrating geometric representations with structured information concerning building components, specifications, and lifecycle management requirements (Azhar, 2011). The application of BIM in facility management provides opportunities to organize inspection records, technical drawings, and maintenance information within an accessible digital framework (Abideen et al., 2022). Digital building models can also accommodate component identification codes, dimensional attributes, material characteristics, and inspection-related information to support systematic data retrieval. Previous research has demonstrated the application of BIM-based

approaches to building condition assessment and infrastructure information management (Alavi et al., 2022; Wardach et al., 2023). Furthermore, integrating 3D visualization with digital information systems enables the spatial representation of infrastructure conditions and supports the interpretation of component-level deterioration (Artus et al., 2022; Liu et al., 2021). The effectiveness of these applications depends on the accuracy of geometric representations and the consistency of information associated with individual building elements. Within maintenance management, component-based digital models can serve as structured repositories that connect building geometry with inspection-derived condition information. Accordingly, 3D modeling and BIM provide a technological foundation for integrating building damage assessment results with spatial visualization and maintenance-related documentation.

The integration of building damage information with 3D visualization represents an important development in transforming conventional inspection documentation into spatially organized digital records. Traditional inspection reports commonly present damage descriptions, photographs, and measurement results separately from building drawings, potentially complicating the identification and interpretation of deteriorated components (Adamopoulos & Rinaudo, 2021; Chew & Gan, 2022; De Fino et al., 2023; Sjölander et al., 2023). Integrating these records into a 3D model enables damage information to be associated with identifiable building elements and their corresponding spatial locations (Artus et al., 2022). Component-based damage visualization can incorporate information regarding defect types, affected dimensions, severity classifications, and supporting inspection documentation. Such integration facilitates the representation of building deterioration through geometric models supplemented by structured condition attributes. Previous investigations have explored digital damage representation, information integration, and BIM-based visualization to improve the accessibility and interpretation of infrastructure condition data (Alavi et al., 2022; Liu et al., 2021). Furthermore, the application of digital modeling in building rehabilitation has demonstrated opportunities to connect geometric information with inspection records and construction quantities. However, the practical organization of damage information requires consistent component identification, standardized attribute structures, and reliable connections between field observations and digital representations. A structured 3D damage information model can therefore support the retrieval of component-specific conditions and facilitate communication among inspectors, engineers, and facility managers. These capabilities highlight the relevance of integrating field-based damage assessment with spatial visualization to establish a more systematic information framework for building maintenance planning.

Sustainable building maintenance planning emphasizes the systematic management of existing infrastructure to preserve functionality, extend service life, and support the efficient allocation of maintenance resources. Effective maintenance strategies require reliable information regarding component deterioration, repair priorities, intervention requirements, and associated financial implications (Villa et al., 2022). Building condition assessment provides essential inputs for maintenance decision-making by identifying defects and evaluating their severity across different building components. Integrating damage assessment results with maintenance planning enables facility managers to organize repair activities according to observed conditions and operational requirements. Recent studies have explored predictive maintenance frameworks, degradation modeling, and optimization approaches to improve maintenance scheduling and infrastructure management (Li et al., 2026; Nageeb et al., 2026). In addition to condition evaluation, repair cost estimation is necessary for determining financial requirements and preparing preliminary maintenance budgets. BIM-based approaches have demonstrated potential for integrating geometric information with quantity take-off and cost estimation procedures in building rehabilitation and damage assessment applications. The estimation process generally involves calculating repair quantities from measured damage dimensions and applying relevant unit prices to determine

anticipated intervention costs. Incorporating these estimates into a 3D information model can establish a connection between physical deterioration, recommended repair measures, and financial planning. Consequently, integrating damage visualization with repair cost information provides a practical basis for more transparent, systematic, and potentially resource-efficient building maintenance planning.

The application of integrated 3D-based damage assessment is particularly relevant to institutional buildings that require continuous operational functionality and systematic maintenance management. Aging educational and administrative facilities may exhibit deterioration across architectural and structural components, requiring accurate inspection records and clearly defined maintenance interventions (Cardinal et al., 2020; Dahuri et al., 2025; Ferreira et al., 2021). Conventional assessment procedures provide essential information regarding building conditions but may not fully support spatially integrated documentation and component-level information retrieval. Combining field-based damage evaluation with digital modeling offers opportunities to connect physical inspection findings with geometric representations and maintenance requirements (Alavi et al., 2022; Artus et al., 2022). Recent research on digital maintenance frameworks for educational buildings has highlighted the potential of integrated information systems to support infrastructure management and sustainability-oriented decision-making (Nageeb et al., 2026). However, implementing such approaches in existing buildings requires consideration of available technical drawings, inspection data quality, component identification systems, and modeling resources. Autodesk Revit provides a digital modeling environment in which building elements can be represented geometrically and associated with structured information attributes. Integrating damage classifications, affected dimensions, repair recommendations, and cost estimates within this environment can support the organization and interpretation of component-specific maintenance information. In the context of the Universitas Muhammadiyah Sukabumi Rectorate Building, this approach provides a framework for transforming field inspection records into a spatially traceable representation of building deterioration and associated repair requirements. Therefore, the integration of damage assessment, 3D visualization, and preliminary cost estimation establishes a practical foundation for evidence-informed maintenance planning while providing opportunities for further development toward sustainable digital infrastructure management.

METHOD

Research Design

This study employed a descriptive quantitative approach integrated with three-dimensional (3D) building modeling to assess physical deterioration and support maintenance planning for the Rectorate Building of Universitas Muhammadiyah Sukabumi (UMMI), Indonesia. The methodological framework combined field-based building inspections, component-level damage assessment, spatial visualization, and preliminary repair cost estimation. Quantitative assessment was conducted using measurements of damaged building components, while Autodesk Revit 2025 was employed to develop a digital representation of building geometry and associated damage information. The research was organized into four sequential stages: preparation and preliminary review, data collection, building damage assessment, and 3D-based damage modeling and repair cost estimation. This sequence was designed to maintain consistency between field observations, damage calculations, and the information represented in the digital model. The overall research procedure is illustrated in Figure 1.

Preparation and Preliminary Review

The initial stage involved reviewing relevant literature, technical references, and regulatory provisions concerning building condition assessment, damage classification, and maintenance planning. Particular attention was given to the Indonesian Minister of Public Works Regulation No. 24/PRT/M/2008, which served as the regulatory reference for evaluating building maintenance and damage conditions. The review established the assessment framework and informed the identification of relevant building components, damage characteristics, measurement requirements, and classification criteria. Existing building documentation was also examined to support the subsequent inspection and modeling procedures. This preparatory stage provided the technical foundation for conducting systematic field assessments and organizing the resulting data into a component-based damage inventory.

Data Collection

Data collection involved primary and secondary sources to obtain the information required for building damage assessment and 3D modeling. Primary data were collected through direct field inspections of the UMMI Rectorate Building, focusing on the identification and documentation of observable deterioration in building components. The inspection activities included identifying damaged elements, recording their locations, determining damage types, measuring affected dimensions, and documenting physical conditions through photographs. The measurements were used to establish the quantities of damaged components and estimate the corresponding repair work requirements. Each inspection finding was organized according to the affected building component to facilitate subsequent damage assessment and integration into the digital model. Secondary data consisted of available architectural drawings and building technical specifications, which provided references for identifying building geometry, component characteristics, and relevant dimensional information. The combination of field inspection records and existing technical documentation established the dataset used for damage analysis, 3D visualization, and preliminary repair cost estimation.

Building Damage Assessment

Building damage assessment was performed by processing the field inspection data according to component type, damage location, defect characteristics, affected dimensions, and damage quantity. The assessment involved determining the extent of deterioration by comparing the measured quantity of damage with the corresponding total quantity of the assessed building component. Depending on the characteristics of the element and the observed defect, damage quantities were expressed using appropriate measurement units, including area or volume. The percentage of damage was calculated using Equation (1):

$$D_i = \frac{V_{d,i}}{V_{t,i}} \times 100\% \dots \dots \dots (1)$$

where D_i represents the percentage of damage to the assessed building component (%), $V_{d,i}$ denotes the measured quantity of damage, and $V_{t,i}$ represents the total quantity of the corresponding component. The numerator and denominator were expressed in consistent measurement units to ensure the validity of the calculated percentage.

The resulting damage percentages were interpreted using the classification thresholds adopted in the study, with reference to the Indonesian Minister of Public Works Regulation No. 24/PRT/M/2008. Damage severity was classified into three categories: minor damage ($\leq 30\%$), moderate damage ($>30\%$ to 45%), and severe damage ($>45\%$). These classifications were used to describe the extent of deterioration and organize the assessment results for subsequent maintenance planning. The assessment also considered the location and physical characteristics of the observed defects to identify the building elements requiring repair interventions. The resulting damage

inventory included component identification, damage type, affected dimensions, calculated damage percentage, and severity classification. These results were subsequently used as the primary information inputs for 3D-based damage visualization and repair planning.

3D-Based Damage Modeling and Repair Cost Estimation

The final stage involved developing a 3D digital model of the UMMI Rectorate Building using Autodesk Revit 2025. The modeling process began with reconstructing the building geometry based on available two-dimensional architectural drawings and technical documentation. Building components were represented within the digital environment according to their geometric characteristics and spatial positions. The results of the field-based damage assessment were subsequently incorporated into the model by associating identified building elements with their corresponding damage information. The integrated information included damage locations, defect characteristics, measured dimensions, severity classifications, and recommended repair interventions. This approach enabled the visualization of component-level deterioration within the building's spatial configuration and supported the organization of inspection-derived information (Artus et al., 2022). The model was also used to organize quantity information relevant to the estimation of repair requirements. Measured damage quantities provided the basis for determining the volume of repair work associated with the identified defects. Preliminary repair costs were estimated by applying relevant unit prices to the corresponding repair quantities, consistent with quantity-based cost estimation principles (Jalaei et al., n.d.). The general calculation is expressed in Equation (2):

$$C_{\text{total}} = \sum_{i=1}^n (Q_i \times P_i) \dots\dots\dots (2)$$

where C_{total} represents the total estimated repair cost (IDR), Q_i denotes the quantity of the i -th repair activity, P_i represents its corresponding unit price (IDR per unit), and n indicates the total number of repair activities.

The estimated repair costs were associated with the relevant damage information to support the identification of maintenance requirements and preliminary budgeting. The resulting 3D model provided a spatially organized representation of building conditions by connecting geometric information with field-derived damage assessments and repair-related data. Importantly, damage percentages and severity classifications were determined through field-based calculations before being incorporated into the digital model, rather than being automatically generated by Autodesk Revit. The integrated model was intended to facilitate the identification of damaged components, interpretation of deterioration patterns, and retrieval of information relevant to maintenance planning. The overall methodological workflow is presented in Figure 1.

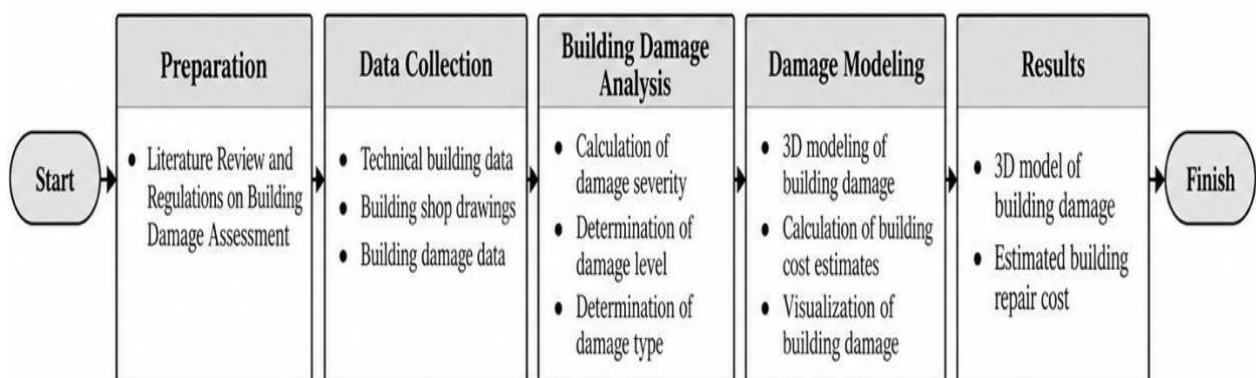


Figure 1. Research workflow for building damage assessment, 3D modeling, and repair cost estimation.

RESULTS AND DISCUSSION

Results

General Description of the Research Object

The subject of this study is the assessment of damage to the components of the UMMI Rectorate building. This building was selected based on its age, allowing it to represent a range of damage conditions accumulated over a long service life. Inspections were conducted on all building components, covering structural, architectural, utility, and finishing elements. The resulting data served as the basis for assessing damage severity, determining remediation methods, calculating cost requirements, and creating a 3D model of the damage. Details regarding the building under study are as follows:

The Universitas Muhammadiyah Sukabumi (UMMI) Rectorate building is a two-story structure serving as a facility for university administration and educational activities. Constructed in 1925, the building has a floor area of 1,480 m² and is owned and managed by Universitas Muhammadiyah Sukabumi. The UMMI Rectorate building was selected as a case study for damage assessment due to its advanced age. This factor creates a potential for performance degradation and damage across various building components—including structural, architectural, and utility systems.

Furthermore, as the building remains in use for administrative and educational functions, it is essential to ensure it stays safe, comfortable, and fully functional. Damage assessment is necessary to identify the types and severity of damage, understand the building's current condition, and determine the requirements for maintenance or repair actions. The details are presented in the table below :

Table 1. Technical Data of the UMMI Rectorate and Auditorium Building

Building	UMMI Rectorate and Auditorium Building
Building Area	1.480 m ²
Number of Floors	2 Floors
Floor Area	1st Floor = 1,200 m ² 2nd Floor = 280 m ²
Room Functions	1st Floor : Rector's Office and Department Offices 2nd Floor : Auditorium
Substructure	Foundation : Stone masonry (continuous foundation) Sloof: Concrete structure
Superstructure	Columns: Concrete structure Beams: Concrete structure Roof Structure: Timber structure
Exterior Walls	Red brick masonry
Interior Walls	Red brick masonry
Doors & Windows	Glass doors with timber frames; sliding and fixed glass windows with timber frames
Flooring	40 cm × 40 cm ceramic tiles
Ceiling	Gypsum board ceiling and gypsum cornice with timber framing
Roof	Clay tile roofing

Damage Analysis and Handling

The initial survey stage involves compiling building technical data. Original volume and specification data are then coded for all building components. Coding generally uses 1–3 initial letters, followed by floor number and component sequence—e.g., Foundation 1st Floor No. 5 = PND1-5, Column 2nd Floor No. 10 = K2-10. The volume inventory and coding phase is time-consuming and requires precision, as every component must be assigned a code and the data must be synchronized between the tables and the floor plans. However, this step is performed only once—during the initial

data entry—and the resulting data is used throughout the building's lifecycle, barring any subsequent changes. The following table outlines the component coding for the UMMI Rectorate building:

Table 2. Example of Component Coding for the UMMI Rectorate Building

No	Komponen	Sub Komponen	Jenis Struktur	Lantai 1						Volume Total	Lantai 2							
				Jumlah	Kode	Dimensi					Jumlah	Kode	Dimensi					
						P	L	T	Volume				P	L	T	Volume		
1	Pondasi	Pondasi	Footplate	24	FD-1/FD-24	1,5	1,5	0,4	0,9	m3	21,60							
				24							21,60							
2	Struktur	Kolom	Beton Bertulang	58	K1-1/K1-58	0,15	0,3	3,5	0,158	m3	9,14							
18				K1-59/K1-76	0,3	0,35	3,5	0,368	m3	6,62	8	K2-1/K2-8	0,3	0,35	3,5	0,368	m3	
20				K1-77/K1-96	0,3	0,55	3,5	0,578	m3	11,55	16	K2-9/K2-24	0,3	0,55	3,5	0,578	m3	
96									27,30	24								
		Balok	Beton Bertulang									10	B2-1/B2-10	0,3	0,4	3	0,360	m3
										20	B2-11/B2-30	0,3	0,4	4	0,480	m3		
										7	B2-31/B2-37	0,3	0,4	6	0,720	m3		
										1	B2-38	0,3	0,4	2	0,240	m3		
												38						
		Plesteran	Plesteran, Acian	58	K1-1/K1-58	0,15	0,3	3,5	3,150	m2	182,70	8	K2-1/K2-8	0,3	0,35	3,5	4,550	m2
18				K1-59/K1-76	0,3	0,35	3,5	4,550	m2	81,90	16	K2-9/K2-24	0,3	0,55	3,5	5,950	m2	
20				K1-77/K1-96	0,3	0,55	3,5	5,950	m2	119,00	10	B2-1/B2-10	0,3	0,4	3	4,200	m2	
										20	B2-11/B2-30	0,3	0,4	4	4,400	m2		
										7	B2-31/B2-37	0,3	0,4	6	6,600	m2		
										1	B2-38	0,3	0,4	2	2,200	m2		
					96						383,60	62						
3		Atap	Penutup Atap	Genting	1	PA1-1				luas total	334,3268	m2	334,33					
					1	PA1-2				luas total	1084,3527	m2	1084,35					
					1	PA1-3				luas total	887,6468	m2	887,65					
					1	PA1-4				luas total	888,6038	m2	888,60					
					1	PA1-5				luas total	1794,4546	m2	1794,45					
				1	PA1-6				luas total	1756,3873	m2	1756,39						
				1	PA1-7				luas total	1188,1944	m2	1188,19						
				1	PA1-8				luas total	1156,1548	m2	1156,15						
				1	PA1-9				luas total	2625,3594	m2	2625,36						
				9							11715,48							
		Rangka Atap	Kayu	1	PA1-1				volume total	4,6805752	m3	4,68						
				1	PA1-2				volume total	15,1809378	m3	15,18						
				1	PA1-3				volume total	12,4270552	m3	12,43						
				1	PA1-4				volume total	12,4404532	m3	12,44						
				1	PA1-5				volume total	25,1223644	m3	25,12						
				1	PA1-6				volume total	24,5894222	m3	24,59						
				1	PA1-7				volume total	16,6347216	m3	16,63						
				1	PA1-8				volume total	16,1861672	m3	16,19						
				1	PA1-9				volume total	36,7550316	m3	36,76						
				9							164,02							

Regarding the coding, volume, and quantity of components for the UMMI rectorate building, there are 7 main components comprising 11 sub-components, with the following quantities: 24 foundations, 120 columns, 38 beams, 3,214.52 m² of roofing, 1,514.46 m² of ceiling, 2,203.81 m² of walls, 42 doors, and 1,403.16 m² of flooring. Subsequently, coding was applied to the floor plans for each building component; the following are examples of such coding on the building plans :

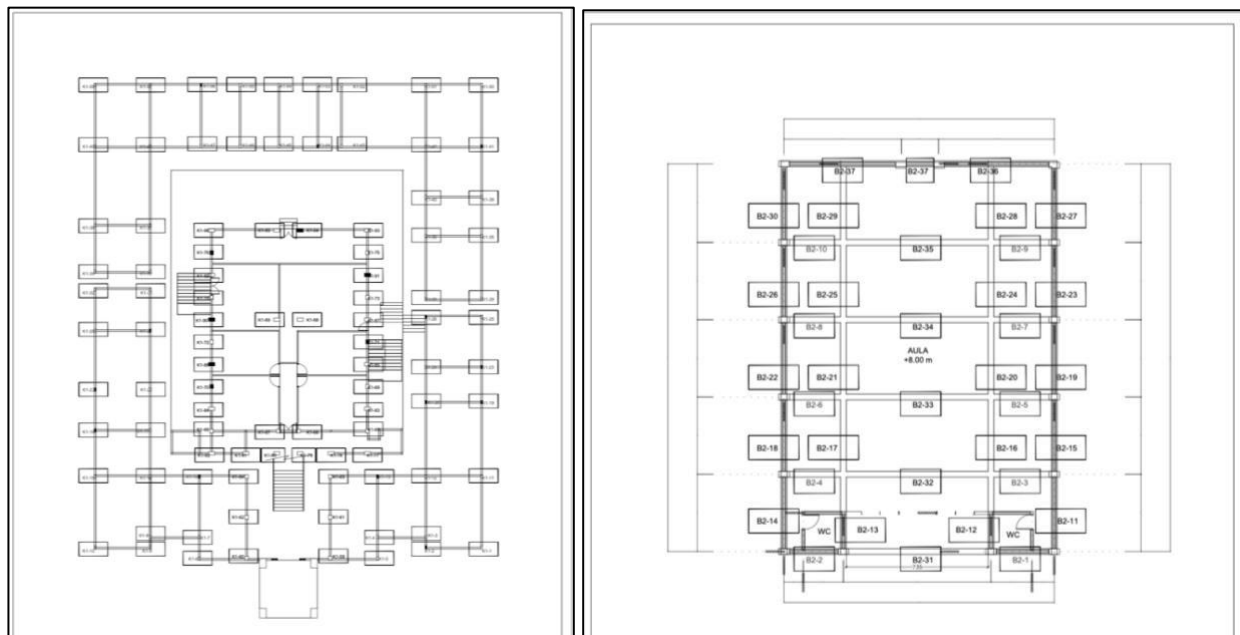


Figure 2. Example of coding of 1st floor columns and 2nd floor beams of the UMMI Rectorate Building

The purpose of creating a coding plan is to make it easier for surveyors to carry out surveys in the field, so that building components will not be confused when carrying out inventory and inputting damage data.

Analysis of Damage Levels in UMMI Buildings

Data regarding damage to the UMMI Rectorate building was obtained through field surveys, covering building components and sub-components, types of damage, and photographic documentation of the damage for all components. Inspections of the building revealed that all identified damage was confined to architectural components; no damage was found in the structural components. A total of 108 damage items were recorded for the UMMI Rectorate building.

The fact that all findings were limited to architectural components indicates that the damage visible during inspection did not signify underlying structural issues. Architectural components—such as walls, plasterwork, finishes, ceilings, flooring, doors, windows, and other non-structural elements—are more susceptible to damage caused by building usage, moisture, material aging, and environmental conditions. However, if architectural damage is left unaddressed for an extended period, it will inevitably impact the building's functionality and operations. A summary of the damage by building component, based on the survey of the UMMI Rectorate building, is presented below :

Table 3. Examples of damage identified during the survey of the UMMI Rectorate Building

No	Komponen	Sub Komponen	Jenis Kerusakan	Kode	Volume (m, m2, m3)	Dimensi Kerusakan (m)			Volume Kerusakan (m, m2, m3)		Bobot (%)	Kategori Kerusakan	Dokumentasi
						P	L	T					
1	Pondasi	Pondasi	Tidak Rusak		21,60 m3	0	0	0	0,00 m3		0,00%	Tidak Rusak	
2	Struktur	Kolom	Tidak Rusak		39,48 m3	0	0	0	0,00 m3		0,00%	Tidak Rusak	
		Balok	Tidak Rusak		18,48 m3	0	0	0	0,00 m3		0,00%	Tidak Rusak	
		Plesteran Struktur	Retak	K1-2	3,150 m2	0,53		0,003	0,002 m2		0,05%	Rusak Ringan	
			Retak	K1-13	3,150 m2	0,6		0,010	0,006 m2		0,19%	Rusak Ringan	
			Retak	K1-14	3,150 m2	1,9		0,002	0,004 m2		0,12%	Rusak Ringan	

Subsequently, a summary of the detailed damage data was compiled to assess the building's overall condition—specifically, whether the damage level was minor, moderate, or severe. The findings regarding damage to the UMMI Rectorate Building are presented below:

Table 4. Summary of damage to the UMMI Rectorate Building

NO.	URAIAN PEKERJAAN				TERHADAP SELURUH BANGUNAN	BOBOT MAKSIMUM	BOBOT (%)	NILAI (%)
1.	PONDASI	PONDASI			10,00%	15,00%	0,00%	0,00%
2.	STRUKTUR	KOLOM, BALOK & RING BALK			27,00%	30,00%	0,00%	0,00%
		PLESTERAN			2,00%	100,00%	0,58%	0,01%
3.	ATAP	RANGKA ATAP			8,00%	30,00%	0,00%	0,00%
		PENUTUP ATAP			2,00%	75,00%	27,59%	0,55%
4.	LANGIT-LANGIT	RANGKA LANGIT-LANGIT			3,50%	100,00%	0,00%	0,00%
		PENUTUP LANGIT-LANGIT			4,50%	100,00%	27,85%	1,25%
5.	DINDING	BATU BATA/ PARTISI			4,50%	50,00%	0,00%	0,00%
		PLESTERAN			1,75%	100,00%	0,24%	0,00%
		KACA			1,25%	100,00%	34,40%	0,43%
		PINTU			1,00%	100,00%	0,00%	0,00%
		KOSEN			1,50%	100,00%	63,66%	0,95%
6.	LANTAI	PENUTUP LANTAI			10,00%	100,00%	42,80%	4,28%
7.	UTILITAS	INSTALASI LISTRIK			5,00%	100,00%	0,00%	0,00%
		INSTALASI AIR			1,50%	100,00%	0,00%	0,00%
		DRAINASE LIMBAH			1,50%	100,00%	0,00%	0,00%
8.	FINISHING	FINISHING STRUKTUR (CAT)			1,00%	100,00%	0,00%	0,00%
		FINISHING LANGIT-LANGIT (CAT)			4,00%	100,00%	0,00%	0,00%
		FINISHING DINDING			6,00%	100,00%	43,80%	2,63%
		FINISHING PINTU/ KOSEN (CAT)			4,00%	100,00%	22,50%	0,90%
JUMLAH NILAI TINGKAT KERUSAKAN					100,00%			11,01%
Jenis Kerusakan = KERUSAKAN RINGAN							RINGAN	< 30%
							SEDANG	> 30% - 45%
							BERAT	> 45% - 65%
							KHUSUS	> 65 %

The building damage level for the UMMI Rectorate Building was calculated at 11.01%. This figure falls below the 30% threshold, classifying the building under the "minor damage" category. In terms of the overall building, the most significant damage—based on weighted values—was found in wall finishes (contributing 2.63% to the total damage score, with a component damage weight of 43.80%), followed by floor coverings (contributing 4.28%, with a component damage weight of 42.80%). Survey results indicate that the damage to the UMMI Rectorate Building stands at 11.01%, placing it in the minor damage category. Identified components include ceiling coverings, floor coverings, wall finishes, column plastering, glass, door/frame finishes, brickwork or partitions, beams, roof coverings, and frames. Inventory data shows 108 inspection points based on damage codes.

The types of damage found were diverse, indicating that the building's deterioration involved not only severe physical damage but also issues affecting surface conditions and component functionality. The most frequently observed defects included detached ceiling panels, column cracks, discoloration of door/frame finishes, broken or fractured floor coverings, wall finish discoloration, scratches or mold on glass, condensation on glass, and cracks in brickwork or partitions. Damage to ceiling coverings was particularly prevalent, with 26 recorded instances of detached panels. Additionally, 19 instances of cracking in column plastering were identified. Although most damage was classified as minor, the presence of cracks in columns warrants attention during further inspections, as columns are integral to the building's structural system.

Classification results show 77 records of minor damage, 19 records of moderate damage, and 12 records of severe damage. The data indicates that minor damage is the most prevalent condition, accounting for approximately 71.30% of the total inventory findings. This suggests that the majority of the damage identified during the inspection remains at a level that can be addressed through maintenance or localized repairs. However, the presence of 19 instances of moderate damage and 12 instances of severe damage demonstrates that the inspection revealed more than just minor issues. Moderate and severe damage require greater attention, as they generally entail repair work involving larger volumes, different methods, or higher costs.

3D Modeling of the UMMI Rectorate Building

The first stage in integrating the application for assessing and addressing building damage involves creating a 3D model of the structure. This modeling process entails generating a digital representation of the building based on its condition and technical data derived from working drawings, field measurements, and as-built documentation.

In this study, the 3D model serves as a visual foundation for displaying and navigating information regarding building damage. The model is not used to calculate the severity of the damage; rather, it acts as a medium to link inspection results—obtained through surveys—with specific building elements within the 3D model. Consequently, once the damage data has been integrated, users can select or navigate to specific elements in the 3D model to view details such as the type, location, volume or dimensions, percentage, and severity of the damage, as well as recommended remediation measures. The initial 3D model of the UMMI Rectorate Building is shown below:

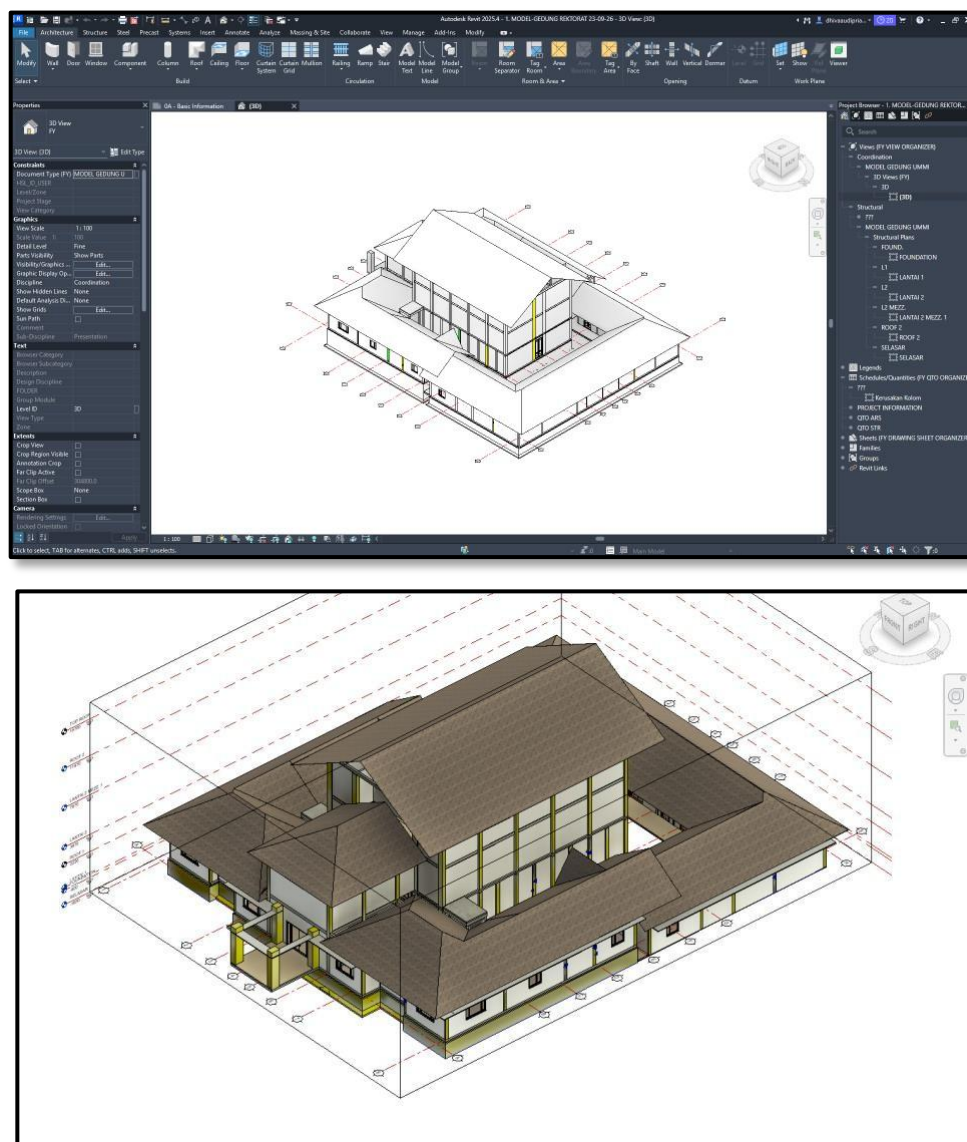


Figure 3. Initial 3D Model – UMMI Rectorate Building

3D Modeling of Damage to the UMMI Rectorate Building

3D modeling of damage to the Rectorate Building of the Muhammadiyah University of Sukabumi (UMMI) was carried out as part of the integration of the results of inspections of building

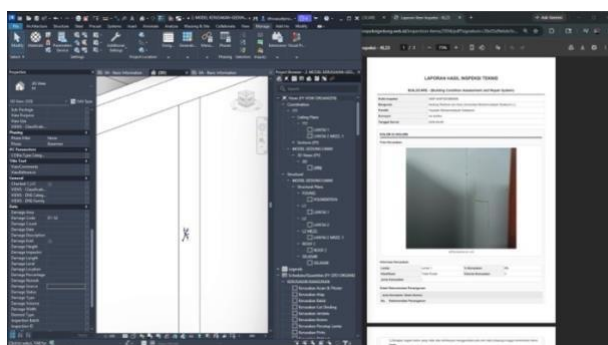
damage with 3D modeling. This modeling aims to provide a spatial representation of damaged building elements so that inspection results are not only presented in table or report form, but can also be traced directly based on location and building elements in a three-dimensional model.

In the 3D model, each building element identified as experiencing damage has attribute information that is connected to the inspection results according to the survey results. This information includes the identity or code of the element, location of the element, type of damage, volume or dimensions of damage, level of damage, recommendations for handling, and estimated handling costs. Thus, the 3D model not only functions as a geometric representation of the building, but also becomes a medium for connecting the physical condition of elements with information on assessment results and handling needs.

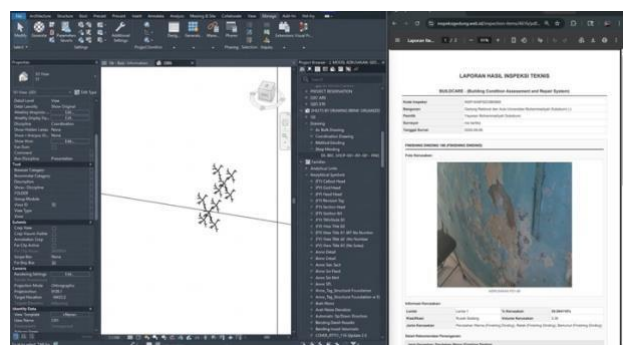
The modeling results show that every element that has damage findings can be traced through the element identity in the 3D model. When an element is selected, information regarding the type of damage and estimated handling costs can be known based on inspection results data. This integration provides a relationship between three main components, namely the physical elements of the building, damage information, and handling needs. In this way, users not only know that an element is damaged, but can also find out the form of damage that occurred and the estimated costs required to handle it.

There is the UMMI Rectorate Building which has a relatively large number of damage findings, namely 108 architectural damage findings. 3D modeling provides benefits in the process of tracing the location of damage. Damage data previously presented in list form can be linked to the position of elements in the model so that the process of identifying and searching for elements becomes easier. This also supports the maintenance process because damage information can be used as a basis for determining elements that need attention and treatment. From a cost management perspective, including estimated handling costs in the information for each element provides added value to the 3D model. This information allows the results of inspections of building conditions to be linked to treatment needs in a more measurable manner. In this way, the 3D model can support the process of prioritizing treatment and maintenance planning based on element conditions and estimating cost requirements, without using the 3D model as the main tool for calculating the level of damage.

The results of the damage assessment obtained from the survey results are displayed on the 3D model and can be seen in the image below:



(a) Minor Damage



(b) Moderate Damage



Figure 5. Damage and Handling Data Details + Repair Cost Estimates

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cost amounts to approximately IDR 149,175,912. The results indicate that minor damage accounts for the highest number of damage points and the largest accumulated cost; a high volume of minor damage can result in a higher cumulative cost than a smaller number of severe damage instances. Raw observational data regarding damage can be categorized by severity, serving as a basis for prioritizing remediation efforts. These findings demonstrate the advantages of the developed 3D modelling approach, as the severity level alone is not the sole determinant of cost; instead, the system links inspection results with damage dimensions or volumes and unit remediation costs.

Discussion

The findings of this study demonstrate that systematic building damage assessment provides essential information for understanding deterioration patterns and establishing maintenance requirements in aging institutional facilities. The UMMI Rectorate Building, constructed in 1925, exhibited an overall weighted damage level of 11.01%, placing it within the minor damage category according to the classification criteria adopted in this study. Although the overall condition was classified as minor, the identification of 108 damage findings indicates that deterioration was distributed across multiple architectural components, requiring differentiated maintenance interventions. This finding is consistent with Wardach et al. (2023) and Pereira and Silva (2024), whose research emphasizes the importance of component-level condition assessment in developing systematic building maintenance strategies. The predominance of architectural deterioration also supports the relevance of routine inspections for identifying defects that may affect building functionality and serviceability without necessarily indicating structural failure (Prusov et al., 2024; Rapiński et al., 2025). However, the absence of visible structural damage during inspection should not be interpreted as definitive evidence of structural integrity, particularly because 19 instances of cracking in column plastering were documented. Such observations highlight the importance of distinguishing between surface deterioration and potential underlying structural deficiencies, which may require additional diagnostic investigations beyond visual inspection. Furthermore, the distribution of damage across ceiling coverings, wall finishes, flooring, and other architectural elements suggests that maintenance planning should consider both the extent of deterioration and the functional significance of affected components. Compared with studies emphasizing automated damage identification following natural disasters, this investigation focuses on documenting deterioration accumulated during normal building operation rather than evaluating sudden structural damage caused by extreme events (Zhang & Pan, 2022; Hong et al., 2024). Accordingly, the findings reinforce the importance of systematic field-based assessment as a foundation for maintenance planning, particularly in existing buildings where deterioration develops progressively and requires periodic monitoring.

The distribution of damage severity provides further insights into the relationship between building condition, deterioration characteristics, and maintenance priorities. Among the 108 recorded findings, 77 were classified as minor, 19 as moderate, and 12 as severe, representing approximately 71.30%, 17.59%, and 11.11% of the total observations, respectively. The predominance of minor defects indicates that localized deterioration constituted the most frequently observed condition, although the presence of moderate and severe findings demonstrates that maintenance requirements cannot be determined solely from the overall building damage percentage. This result aligns with the maintenance-oriented perspectives discussed by Villa et al. (2022) which emphasize the importance of structured condition information for developing appropriate maintenance strategies. The identification of 26 instances of detached ceiling panels and 19 instances of cracking in column plastering further illustrates how recurring defect types can inform the selection of inspection priorities and repair interventions. Nevertheless, the frequency of damage findings should be interpreted alongside affected dimensions, component functions, and

potential safety implications because a greater number of defects does not necessarily correspond to greater physical deterioration or repair complexity. The reported component-level results also indicate that wall finishes and floor coverings contributed substantially to the overall damage assessment, highlighting the relevance of architectural elements in maintenance planning for operational buildings. From a methodological perspective, the combination of component-level damage percentages and severity classifications provides a more detailed description of building conditions than a single aggregated damage indicator. This interpretation is compatible with recent research on preventive maintenance planning, which highlights the importance of component-specific deterioration information for determining intervention requirements and allocating maintenance resources (Li et al., 2026; Nageeb et al., 2026). Therefore, maintenance decisions for the UMMI Rectorate Building should consider the distribution, severity, physical extent, and operational consequences of individual defects rather than relying exclusively on the overall minor-damage classification.

The integration of inspection-derived damage information into a three-dimensional model represents a significant practical outcome of this study, particularly in improving the spatial organization and accessibility of building condition records. By developing a digital representation of the UMMI Rectorate Building using Autodesk Revit 2025, the study established a connection between geometric building elements and their corresponding inspection findings. The resulting model incorporates component identification codes, damage locations, defect characteristics, affected dimensions, severity classifications, and recommended repair interventions, allowing users to retrieve condition information through identifiable building elements. This approach is consistent with the information management principles of Building Information Modeling described by Azhar (2011), particularly the association of geometric representations with structured technical information throughout the building lifecycle. Similarly, emphasized the relevance of three-dimensional visualization for improving the representation and accessibility of information required for building management and maintenance. Compared with the BIM-WebGL visualization approach investigated by Liu et al. (2021) for airport pavement condition representation, the present study applies spatially referenced damage information to architectural components within an existing institutional building. The findings also complement the scan-to-BIM approach examined although the present model was developed from existing drawings and field inspection records rather than being described as a scan-based geometric reconstruction. Importantly, the developed model functions as an information visualization and retrieval environment rather than an automated damage detection or severity calculation system, distinguishing its methodological purpose from deep learning-based damage assessment frameworks (Zhang & Pan, 2022; Hong et al., 2024). The ability to associate 108 inspection findings with corresponding building elements demonstrates the feasibility of organizing extensive damage records within a component-based digital representation, although improvements in retrieval efficiency were not quantitatively evaluated. Consequently, the principal contribution of the 3D modeling approach lies in establishing a spatially traceable connection between physical building components, inspection-derived deterioration information, and maintenance requirements.

The integration of repair cost information with component-level damage records further extends the practical relevance of the developed 3D model for maintenance planning and preliminary budgeting. The total estimated remediation cost of IDR 149,175,912 indicates that addressing the identified deterioration requires a measurable financial commitment despite the building's overall classification as experiencing minor damage. Notably, minor damage accounted for both the largest number of inspection findings and the highest accumulated repair cost, demonstrating that the frequency and cumulative extent of localized deterioration can substantially influence total maintenance expenditure. This finding highlights the distinction between damage severity and

financial consequences because repair costs depend not only on classification levels but also on affected quantities, required interventions, and applicable unit prices. Similar considerations are reflected in BIM-based rehabilitation quantity take-off research, where geometric and component information is connected with construction quantities to support project estimation. Furthermore, investigated BIM-based seismic damage and repair cost estimation, providing a related application context in which damage information is connected with anticipated financial requirements. Unlike seismic damage estimation approaches, the present study derives repair quantities and cost information from direct field observations of an existing operational building, with the 3D model serving primarily as an integrated information interface. The incorporation of estimated repair costs into component-specific records provides facility managers with a basis for examining the financial implications of identified defects and considering alternative maintenance priorities. This approach is also relevant to sustainability-oriented maintenance frameworks that emphasize systematic resource allocation and informed intervention planning (Villa et al., 2022). Nevertheless, the estimated cost should be interpreted as a preliminary budgeting indicator rather than evidence of realized financial savings, since the study did not compare actual maintenance expenditures or evaluate the economic performance of alternative intervention strategies.

From a broader perspective, the integration of field-based damage assessment, 3D visualization, and repair cost estimation provides a practical framework for supporting more systematic maintenance management in aging institutional buildings. The study demonstrates that inspection records can be transformed from conventional tabulated documentation into spatially organized digital information without replacing the field-based procedures used to determine damage severity. This approach complements recent developments in predictive and optimization-based maintenance frameworks, which seek to improve infrastructure management through degradation modeling, digital information integration, and systematic intervention planning (Li et al., 2026; Nageeb et al., 2026). However, unlike predictive maintenance systems, the developed model does not estimate future deterioration, optimize intervention schedules, or automatically update building conditions through continuous monitoring. Its contribution is therefore more appropriately characterized as an inspection-informed digital documentation and decision-support approach that establishes a foundation for subsequent maintenance management applications. The potential sustainability benefits arise from improved access to component-level information, clearer identification of repair requirements, and opportunities to prioritize localized interventions rather than undertaking unnecessary large-scale replacement. Nevertheless, these benefits remain prospective because the study did not directly measure reductions in material consumption, maintenance-related emissions, operational disruptions, or lifecycle costs. The findings are also limited to a single institutional building, and the reliability of the digital representation depends on the accuracy of field measurements, available technical drawings, component coding, and consistency between inspection records and model attributes. Future research should therefore examine the applicability of the proposed approach across buildings with different characteristics while incorporating longitudinal condition monitoring, standardized data exchange, maintenance prioritization criteria, and quantitative assessments of environmental and economic performance. Overall, the study contributes to digital building maintenance research by demonstrating how field-derived damage classifications, spatially referenced component information, and preliminary repair costs can be integrated to support evidence-informed maintenance planning for existing institutional infrastructure.

Implications

This study provides theoretical and practical implications for integrating building damage assessment with 3D visualization to support sustainable maintenance planning. The findings demonstrate the potential of digital modeling to organize inspection results, damage classifications,

and repair information within a unified framework. The integration of component-level damage data into Autodesk Revit facilitates spatial identification and retrieval of building condition information. The identification of 108 damage findings and an overall damage level of 11.01% highlights the importance of systematic condition assessment. Furthermore, the estimated repair cost of IDR 149,175,912 provides a basis for preliminary maintenance budgeting. The predominance of minor damage indicates that maintenance priorities should consider defect frequency and repair requirements alongside damage severity. From a practical perspective, the developed model can assist facility managers in identifying deteriorated components and planning appropriate interventions. Its application may also improve coordination among building inspectors, engineers, and maintenance personnel. From a methodological perspective, the study demonstrates how field-based damage assessments can be connected with spatially referenced digital information. This integration could support more targeted repairs and potentially reduce unnecessary material consumption and maintenance expenditures. However, these potential efficiency and sustainability benefits require further empirical evaluation. Overall, the proposed approach offers a practical foundation for evidence-informed maintenance planning and the sustainable management of aging institutional buildings.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, the investigation focused on a single institutional building, limiting the generalizability of the results. Second, damage assessment relied on visual inspections without advanced structural or material testing. Third, the developed 3D model supported damage visualization and information management rather than automated damage detection. Fourth, model accuracy depended on existing technical drawings, field measurements, and component identification. Fifth, repair cost estimates were not validated against actual maintenance expenditures. Additionally, improvements in maintenance efficiency and environmental sustainability were not quantitatively evaluated. Future research should examine multiple buildings with different structural characteristics and deterioration conditions. Advanced diagnostic techniques and automated monitoring could improve damage identification and assessment accuracy. Integrating predictive maintenance and lifecycle cost analysis would strengthen long-term maintenance planning. Environmental impact assessments are also recommended to evaluate potential resource savings and sustainability benefits. Finally, comparative studies should assess the effectiveness of conventional and 3D-based approaches in improving maintenance efficiency and decision-making.

CONCLUSION

This study demonstrates the potential of integrating field-based building damage assessment with three-dimensional (3D) modeling to support systematic maintenance planning for the Universitas Muhammadiyah Sukabumi (UMMI) Rectorate Building. Field inspections identified 108 damage findings affecting architectural components, including ceiling finishes, column plastering, wall finishes, flooring, glazing, door and window frames, and masonry partitions, with no visible structural damage detected during the assessment. The overall weighted building damage level was 11.01%, indicating a minor damage classification, although the individual findings comprised 77 minor, 19 moderate, and 12 severe damage cases. These results highlight the importance of component-level assessment because an overall minor damage classification does not eliminate the need for targeted repairs and further investigation of potentially significant defects. The developed 3D model using Autodesk Revit 2025 successfully integrated inspection-derived information, including component identification, damage location, affected dimensions, severity classification,

repair recommendations, and estimated costs, into a spatially organized digital representation. This integration facilitated the identification and visualization of deteriorated components while providing structured information to support maintenance decision-making. The estimated total repair cost of IDR 149,175,912 further demonstrated the practical relevance of connecting damage assessment results with preliminary maintenance budgeting. The study contributes an applied digital information framework that links conventional building inspections with component-level visualization and repair planning without relying on automated damage detection or severity calculations. Overall, the proposed approach offers a practical foundation for evidence-informed maintenance prioritization and potentially more sustainable management of aging institutional buildings, although its effectiveness in improving maintenance efficiency and environmental performance requires further empirical validation.

AUTHOR CONTRIBUTIONS STATEMENT

Nia Kartika contributed conceptualization, methodology, investigation, data collection, data analysis, software development, validation, visualization, and writing original draft. Pratikso contributed supervision, conceptualization, methodology, validation, critical review, and writing review and editing. Henny Pratiwi Adi contributed supervision, methodology, validation, data analysis, critical review, and writing review and editing.

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