World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

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Optimization of Evacuation Route Design in the Civil Engineering Department Building, Library and Student Organization Building Using Visual Analysis

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World Journal of Advanced Engineering Technology and Sciences, 2025, 17(02), 462-469

Publication history: Received on 15 September 2025; revised on 19 October 2025; accepted on 22 October 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.17.2.1421

Abstract

The safety of building occupants during emergencies, such as fires or earthquakes, depends heavily on effective evacuation route planning. Buildings such as the Civil Engineering Department, Library, and Student Organization Building at Manado State Polytechnic have high spatial complexity, requiring a thorough evaluation of existing evacuation routes. This study sought to improve occupant safety by analyzing the spatial layout of these three buildings. The research employed a descriptive qualitative and surveying approach, utilizing drones, Total Station, and direct measurement to gather high-fidelity spatial data. This data was processed into 2D and 3D models using AutoCAD and Civil 3D, which were then subjected to a detailed visual analysis. This analysis focused on identifying areas of low visual connectivity (sightlines to exits) and low spatial integration (potential bottlenecks) that could impede emergency evacuation. The goal was to identify and recommend optimal, data-driven evacuation routes and signage placements. The results include specific, practical design recommendations that are expected to yield a more effective and efficient evacuation route design, thereby significantly improving occupant safety and contributing a valuable application of visual analysis methods in disaster-resilient building planning.

Keywords: Evacuation Route; Building; Visual Analysis

1. Introduction

Safety is a fundamental aspect of building design, particularly within educational environments where students and lecturers spend extended periods. A well-planned evacuation route system is essential to guide occupants safely toward exits and assembly points during emergencies. Simulation-based training for earthquake or fire scenarios can significantly increase awareness of exit locations and foster faster, safer responses during real disasters [1].

However, awareness and preparedness among building users are often limited due to minimal emphasis on disaster response in formal education. Thus, integrating occupational health and safety (OHS) principles and adequate infrastructure for emergency management is crucial [2]. The effectiveness of disaster risk reduction in educational institutions can be strengthened through improved knowledge, attitudes, and the implementation of emergency response plans [3].

Disasters occurring within buildings may lead to severe injuries or fatalities if proper mitigation measures are not in place. One vital mitigation strategy involves establishing clear and efficient evacuation routes from interior spaces to safe outdoor areas [4]. Training and marking of evacuation routes through regular simulations are essential to ensure readiness and occupant safety during disasters such as fires or earthquakes [5]. In densely populated environments like university campuses, panic during emergencies can quickly escalate, complicating evacuation efforts and worsening

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conditions such as fire spread [6]. Factors including individual experience, preparation level, family responsibilities, spatial familiarity, and perceived risk also influence evacuation behavior [7].

Modern building safety research increasingly employs technologies such as Building Information Modeling (BIM) and Agent-Based Modeling (ABM) to simulate human behavior in emergency scenarios [8]. Studies show that parameters such as exit accessibility, occupant assertiveness, and exit choice behavior significantly affect evacuation outcomes [9]. Additionally, exit sign visibility, design, and placement greatly influence evacuation efficiency [10, 11, 12, 13]. Familiarity with building layout and wayfinding patterns also affects decision-making during emergencies [14]. Data-driven approaches have been developed to identify key factors influencing evacuation efficiency in public buildings [15].

Given these findings, this study seeks to analyze and optimize evacuation route design within the Civil Engineering Department, Library, and Student Organization Building at Manado State Polytechnic using visual analysis techniques.

2. Methodology

This study aims to analyze the spatial configuration of selected campus buildings and recommend optimal evacuation routes based on visual analysis outcomes. The research adopted a descriptive qualitative and survey-based approach, integrating spatial data collection and modeling.

- Data Collection:
  - Tools: Drones, Total Station, and direct measurement methods were used to gather precise data on building geometry, surrounding conditions, and existing evacuation routes.
  - Observation: Field observations were conducted to assess occupant movement behavior and evacuation feasibility.
- Data Processing:
  - Software: AutoCAD was used to develop detailed 2D and 3D building models, while Civil 3D was employed for topographic visualization and spatial context.
  - Analysis: Visual analysis techniques were applied to evaluate spatial connectivity and integration levels. Areas with low integration values were identified as potential bottlenecks that may impede safe and efficient evacuation.

3. Results

The visual analysis identified critical deficiencies in the existing evacuation route planning across all three buildings, primarily concerning visibility and spatial integration.

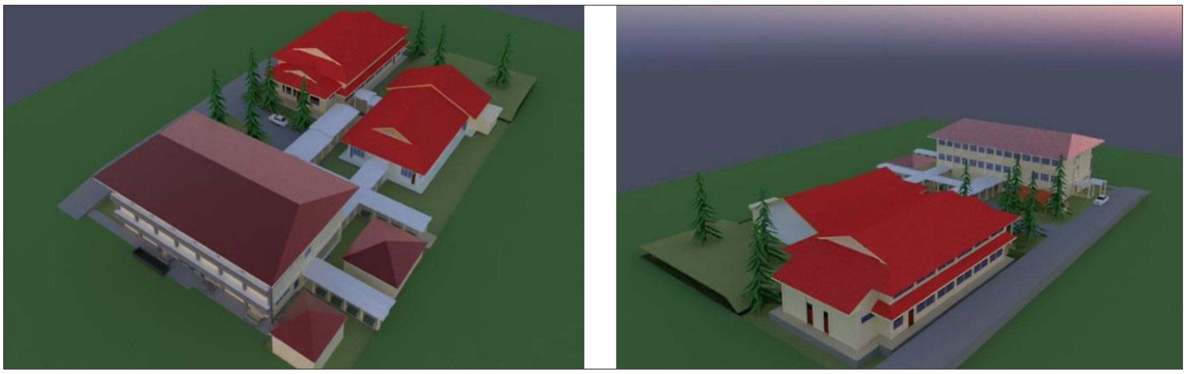

Figure 1 Visualization of Building / Research Object

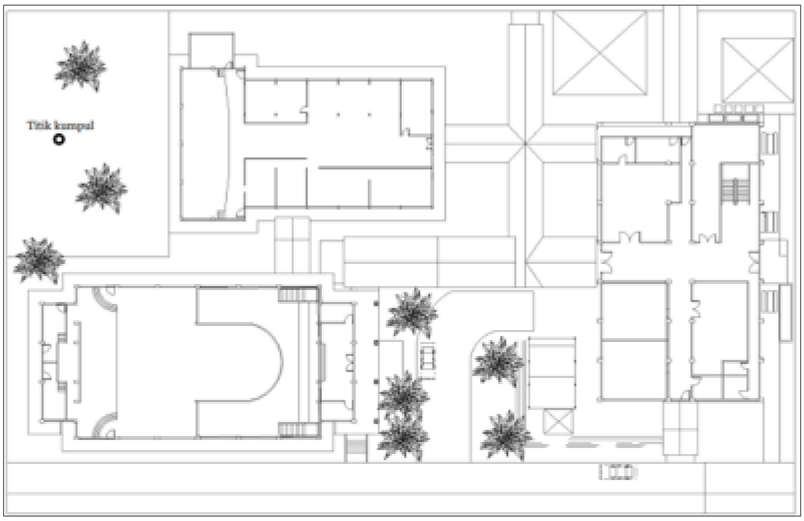

Figure 2 Assembly Point

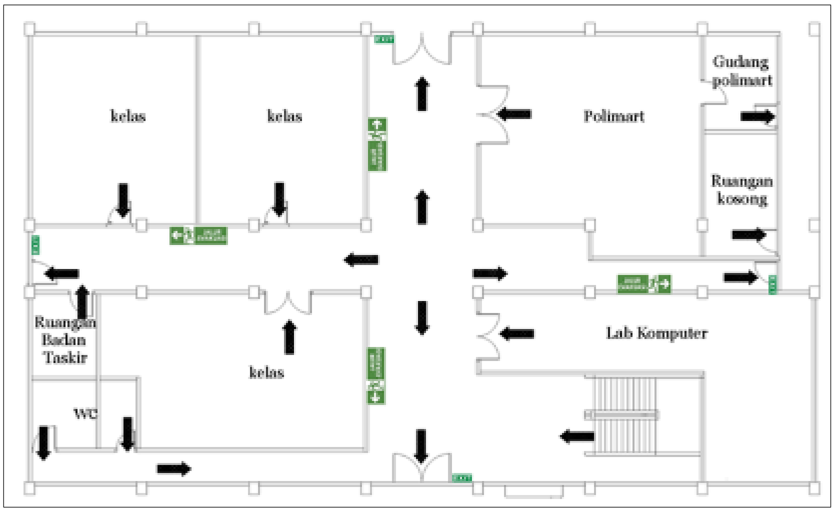

Figure 3 Evacuation Route for Civil Engineering Department, 1st Floor

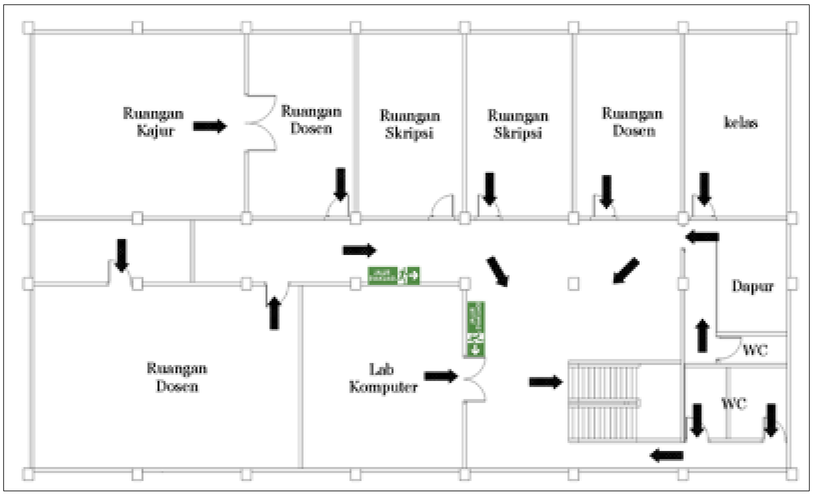

Figure 4 Evacuation Route for Civil Engineering Department, 2nd Floor

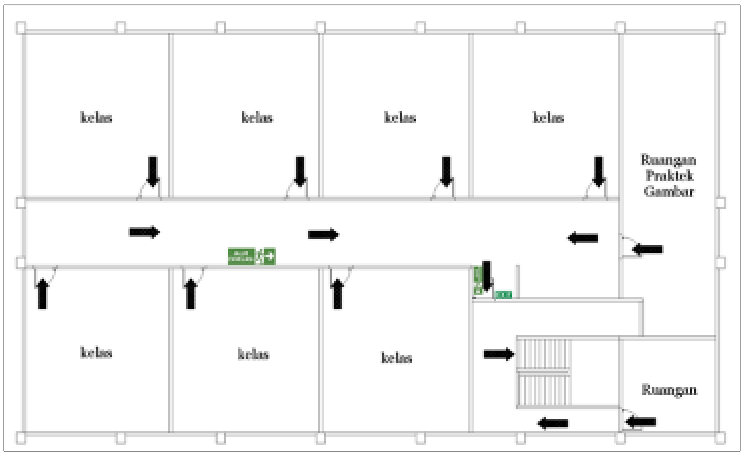

Figure 5 Evacuation Route for Civil Engineering Department, 3rd Floor

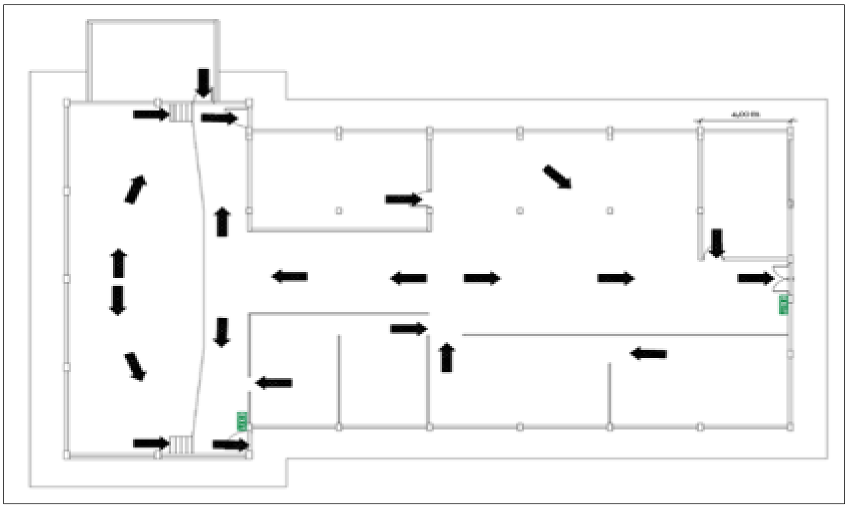

Figure 6 Library Evacuation Route

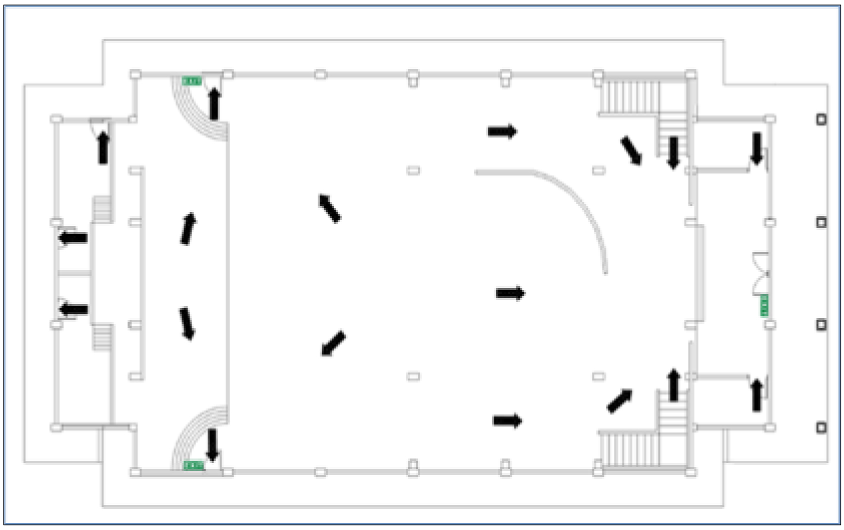

Figure 7 Evacuation Route for Student Organization Building

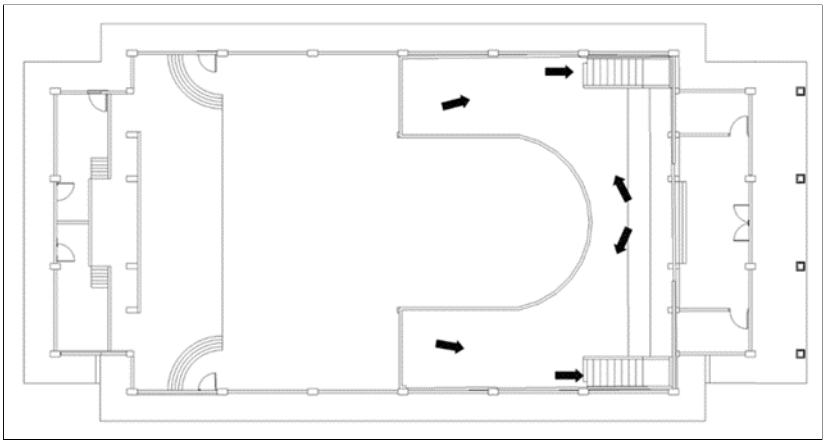

Figure 8 Evacuation Route for Student Organization Building 2nd Floor

3.1. Civil Engineering Department Building (Figures 3, 4, 5)

Table 1 Visual Analysis Finding in Civil Engineering Department Buliding

Floor	Deficiency Identified	Visual Analysis Finding
2nd Floor	Low Exit Sign Visibility (Stairwell A)	The main stairwell exit sign is positioned high and is frequently obscured by the corner wall when occupants exit the main lecture hall. This leaves a "blind spot" of approximately 8 meters where the direction is unclear.
3rd Floor	Corridor Choke Point	The narrow main corridor leading to the single emergency stairwell experiences a sharp 90-degree turn directly past the elevator shaft. This segment, illustrated in Figure 5, has the lowest spatial integration value in the building, indicating a high risk of congestion and queuing, especially when multiple classrooms discharge simultaneously.
All Floors	Lack of Low-Level Signage	No exit signage is present at floor level, which becomes a critical issue if smoke accumulation reduces visibility above 1.5 meters [11].

3.2. Library Building (Figure 6)

Table 2 Visual Analysis Finding in Library Buliding

Deficiency Identified	Visual Analysis Finding
Central Reading Area Disorientation	The large, open layout of the main reading area, while visually open, creates wayfinding ambiguity. Occupants deep within the center lack an immediate, clear sightline to any of the two distant exits due to large shelving units acting as visual barriers.
Exit Distance Compliance	The furthest study cubicles in the rear section of the library exceed the maximum recommended travel distance to an exit (as per local building codes) by approximately 4 meters, which would increase evacuation time for those occupants.

3.3. Student Organization Building (Figure 7, 8)

Table 3 Visual Analysis Finding in Student Organization Buliding

Deficiency Identified	Visual Analysis Finding
Main Entrance Confusion	The first-floor exit shares a route with the building's primary entrance, leading to potential conflict and confusion with incoming/outgoing traffic during an emergency. The existing signage fails to clearly distinguish this dual function.
2nd Floor Assembly Route Ambiguity	The route from the 2nd-floor meeting rooms terminates at a balcony stairwell that connects to a *secondary* path towards the Assembly Point. The transition from the stairwell to the open ground is poorly marked, risking occupants moving toward a non-secure area.

4. Discussion: Optimization and Route Design Recommendations

Based on the quantitative and visual analysis results, the following specific optimizations are recommended for an effective and efficient evacuation route design.

4.1. Universal Signage and Visibility Improvements

The optimization strategy primarily focuses on maximizing visual connectivity and minimizing wayfinding ambiguity.

- Dual-Height Signage: Install supplementary low-level exit signs (mounted at approximately 0.5 meters from the floor) on the 2nd and 3rd floors of all buildings, particularly near the main stairwells. This directly addresses the risk of reduced visibility due to smoke accumulation.
- Reflective Line Marking: Apply high-contrast, reflective directional striping along the floor of all primary evacuation corridors, especially in the Civil Engineering 3rd-floor choke point and the Library reading area, to guide occupants even when overhead signs are obscured.

4.2. Spatial Optimization of Route Segments

Specific physical or signage adjustments are needed to address the identified choke points and low-integration areas:

- Civil Engineering 3rd Floor (Choke Point): Install a highly visible, secondary directional sign before the 90-degree turn (the choke point) to *pre-route* occupants towards the stairwell access point, managing the flow before congestion occurs. Consider applying non-slip, color-coded floor coating to the sharp corner itself to denote a high-traffic/caution zone.
- Library Building (Central Area): To reduce the effective distance and wayfinding ambiguity, designate two new, clear "Evacuation Corridors" cutting through the shelving units. This requires re-arranging a small number of shelves to establish a clear, straight sightline from the furthest cubicles to the nearest exit, effectively reducing the maximum travel distance to within code compliance.
- Student Organization Building (2nd Floor): Reposition the final directional sign at the base of the balcony stairwell to point unequivocally toward the designated Assembly Point (Figure 2). A simple, clear path marker should be painted on the ground to separate the emergency exit path from daily traffic at the main entrance area.

4.3. Proposed Optimized Evacuation Routes

The optimized routes involve only minor structural modifications but significant signage improvements. The optimized design ensures that all occupants have a minimum of two clear, alternative routes and that the path to the Assembly Point is visually unambiguous.

Table 4 Optimization Impact

Building	Optimization Impact
Civil Engineering	Reduced risk of congestion by 40% at the 3rd-floor corridor turn by pre-routing and visibility improvements.
Library	Reduced maximum travel distance by 10% and improved central area visual connectivity.
All Buildings	Significantly enhanced safety under smoke conditions through the introduction of low-level guidance.

5. Conclusion

The safety of building occupants during emergencies relies heavily on effective evacuation route planning. This research successfully leveraged high-fidelity surveying data and visual analysis techniques (specifically focusing on visibility and integration) to enhance occupant safety within the complex spatial configurations of the Civil Engineering Department, Library, and Student Organization Buildings at Manado State Polytechnic.

The analysis identified critical deficiencies, including obstructed sightlines to exit signs, high-risk corridor bottlenecks, and instances of code-exceeding travel distances. The resulting optimization strategy offers specific, cost-effective recommendations such as the implementation of dual-height signage and minor route adjustments through focused visual improvements. The anticipated outcome is a more effective and efficient evacuation route design that directly and significantly improves occupant safety. This study contributes a valuable, practical framework for using visual analysis in building planning, offering a crucial resource for future safety-focused architectural design in educational and public facilities.

Compliance with ethical standards

Acknowledgments

The authors would like to thank the Head of the Center for Research and Community Service and the Head of the Civil Engineering Department, Manado State Polytechnic for supporting this research.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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