jADU

Vol 8 No 1 2025
28-41

Journal of Architectural Design and Urbanism
https://ejournal2.undip.ac.id/index.php/jadu
E-ISSN: 2620-9810

Evaluating the Performance of Evacuation Routes in an Academic Facility Using Pathfinder Simulation and Regulatory

Aulia Herlina Putri*, Noor Cholis Idham, Rania Ababssi

Department of Architecture, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia 55584

Corresponding e-mail*: 22512046@students.uii.ac.id

Article info:
Received: 06-08-2025, Revised: 06-12-2025, Accepted: 08-12-2025

Abstract. Effective evacuation routes are crucial in educational buildings, particularly in earthquake-prone regions, to ensure the safety of occupants during emergencies. One of the most significant issues identified in such contexts is the potential for bottlenecks during evacuation. These bottlenecks often result from confusion caused by unclear signage, poor distribution of exits, and high occupant density during peak academic hours. This study evaluated the effectiveness of evacuation routes in the Faculty of Islamic Studies (FIAI) of the Universitas Islam Indonesia (UII), Sleman, through an evaluative approach that combines direct field observation and agent-based evacuation simulation using Pathfinder software. Observations were conducted to assess corridor widths, signage placement, and physical obstructions, while the simulation examined pedestrian movement, evacuation times, and congestion points under high-density scenarios. The evaluation was also benchmarked against the Indonesian National Standard (SNI 03-1746-2000) and NFPA 101: Life Safety Code for evacuation planning as part of the methodological framework. The findings indicate that only the building's structural components comply with the expected standards, while several supporting facilities—such as signage visibility, exit distribution, and circulation flow—require significant improvements. Enhancing these aspects is essential to improve overall evacuation performance and ensure safety in academic environments.

Keywords: evacuation routes, educational building safety, pathfinder simulation, universitas islam indonesia

1. Introduction

Emergencies pose a significant threat to building occupants and demand immediate response strategies to ensure safety. During emergencies, evacuations such as fires, earthquakes, or other unforeseen threats, time often forces building occupants to evacuate as quickly as possible for their safety. Evacuation effectiveness in vertical buildings is influenced by route capacity, staircase and corridor width, exit accessibility, and occupant behavior, as simulations by Saika et al. (2024) show that physical barriers and the overuse of a main staircase can significantly increase evacuation times beyond safety standards. In these critical situations, the existence of effective evacuation routes is essential to direct the flow of evacuation quickly, safely, and orderly. Without well-planned evacuation routes, the risk of mass panic, congestion at exit points, and loss of life can increase significantly. The effectiveness of evacuation routes is not only influenced by the completeness of evacuation facilities such as emergency stairs and exits, but also by the clarity of the wayfinding system, route accessibility, and the building's capacity to deal with mass panic (Anggoro & Darmawati, 2020).

The importance of effective evacuation routes is heightened in educational buildings, where high occupancy levels in lecture halls, classrooms, and communal spaces are common, especially during peak academic hours. In such environments, ensuring safe and efficient evacuation during emergencies becomes a complex challenge. According to Ding et al. (2024),

doi: 10.14710/jadu.v%vi%i.28897

the evacuation process is made more difficult by the complexity of human behavior in emergencies, particularly in high-density settings where erratic crowd dynamics can cause panic. This severe, anxiety-inducing state arises during emergencies and causes people to swarm together in a desperate attempt to find safety, potentially resulting in fatalities. In such situations, occupants may become disoriented and unaware of their surroundings, including the actions of others and the seriousness of the threat. This ambiguity leads to hesitation and confusion, which in turn can cause severe traffic congestion near exits. Addressing this, Sujatmiko (2016) also highlights a regulatory gap in Indonesia's current evacuation standards—namely SNI 03-1746-2000 and Ministerial Regulation PU No. 26/PRT/M/2008, which have yet to fully adopt the technical definitions provided by NFPA 101. In particular, inconsistencies in defining core concepts such as the "means of egress" (which includes the exit access, the exit itself, and the exit discharge) have led to varied interpretations in implementation, potentially undermining the consistency and effectiveness of evacuation route planning in real-world applications.

To better understand and evaluate these conditions, this study defines the effectiveness of evacuation routes based on three primary factors: corridor widths, signage placement, and physical obstructions. These elements play a central role in either facilitating smooth evacuations or, conversely, contributing to delays and safety risks. When corridor widths are insufficient, signage is unclear or poorly positioned, and obstructions block circulation paths, the evacuation process is significantly compromised, especially in emergency scenarios where every second counts.

Figure 1.1. Faculty of Islamic Studies, Universitas Islam Indonesia (Author, 2025)

The Faculty of Islamic Studies (FIAI) Building of Universitas Islam Indonesia, located in an active seismic area, analyzes building preparedness for emergencies, especially the evacuation system, important. Although various studies have been conducted to evaluate evacuation routes in public buildings such as hospitals and office buildings, research that specifically evaluates the effectiveness of evacuation routes in higher education buildings, especially in earthquake-prone areas such as Sleman, is still very limited. Most previous studies have only focused on the availability of physical facilities such as emergency stairs and exits, without examining occupant behavior factors, the effectiveness of the direction system, and emergency response in academic environments that have different activity densities and characteristics. In the context of the Faculty of Islamic Studies (FIAI) of Universitas Islam Indonesia, which accommodates academic activities with high mobility every day, a comprehensive evaluation based on national and international standards is needed to ensure evacuation readiness in emergency conditions.

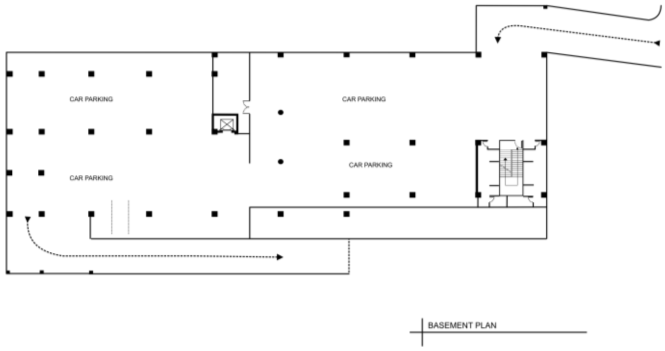


Figure 1.2. Basement Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

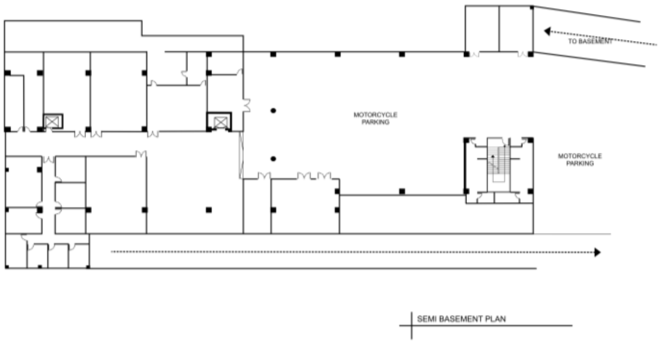


Figure 1.3. Semi Basement Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

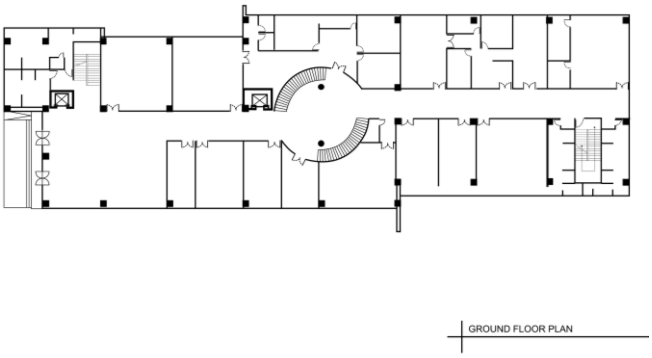


Figure 1.4. Ground Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

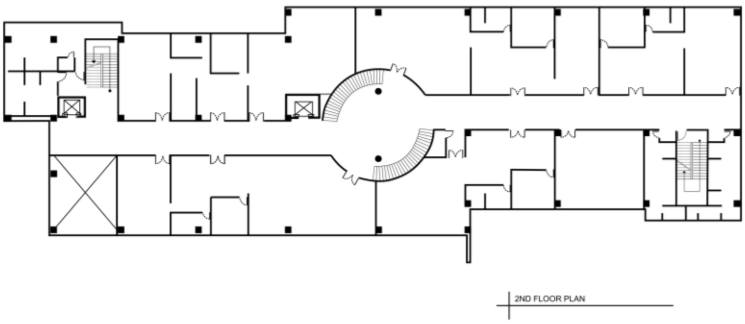


Figure 1.5. 2nd Storey Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

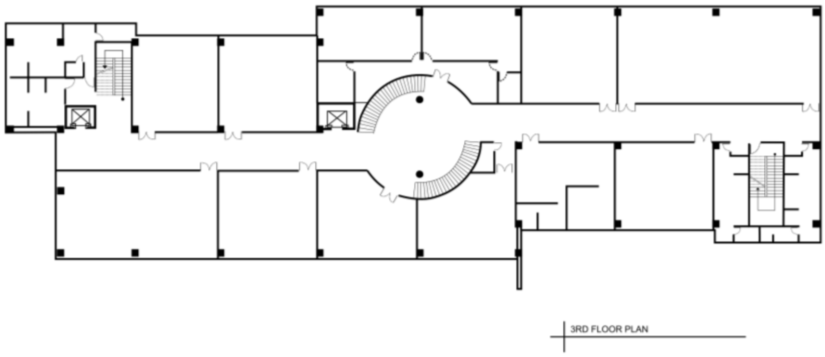


Figure 1.6. 3rd Storey Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

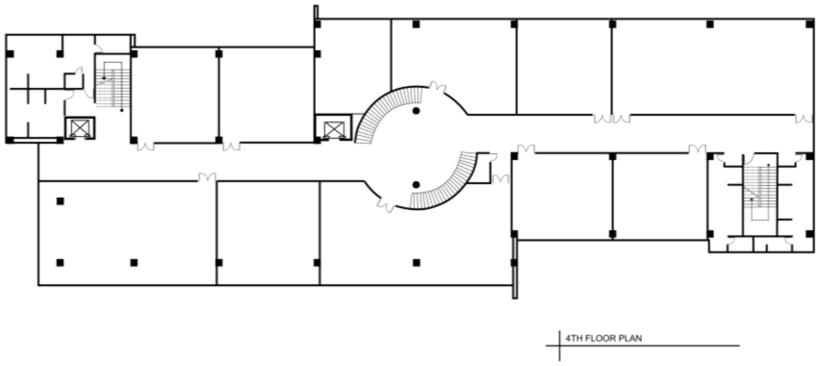


Figure 1.7. 4th Storey Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

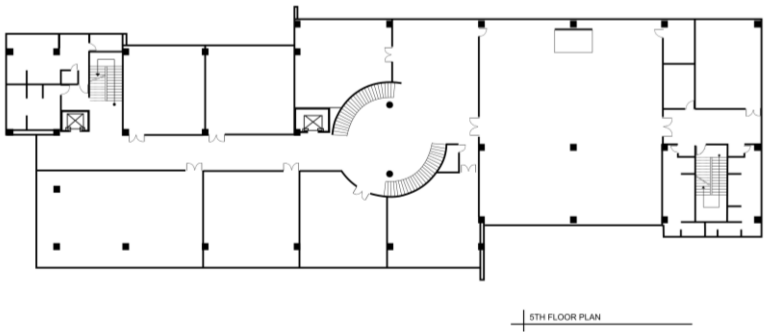


Figure 1.8. 5th Storey Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

This study will analyze the effectiveness of evacuation routes in the FIAI UII building in accordance with disaster evacuation planning standards, including SNI 03-1746-2000, which pertains to Procedures for Evacuation Route Planning in Building Planning, as well as international guidelines such as NFPA 101: Life Safety Code. The adoption of these standards ensures that evacuation systems are designed systematically to minimize casualties and confusion during emergencies, ensuring a higher level of resilience for educational facilities.

1. How effective is the current evacuation route design at FIAI UII, specifically the wayfinding system, route accessibility, and the distribution of exits and staircases, in supporting safe and efficient evacuation performance when tested using Pathfinder simulation under high-occupancy scenarios?

2. How well do the evacuation routes in the FIAI UII building comply with safety criteria outlined in SNI 03-1746-2000 and NFPA 101 standards based on the physical elements such as corridor width, staircase dimensions, exit availability, and signage placement?

To answer these questions, this study is conducted on-site at the Faculty of Islamic Studies, Universitas Islam Indonesia, by assessing the quality of evacuation elements through observation and simulation. The analysis combines the use of a checklist-based observation method to evaluate the compliance of the evacuation route with SNI 03-1746-2000 and NFPA 101 standards, followed by a simulation using Pathfinder software. Therefore, an evacuation simulation reflecting pedestrian movement and congestion patterns was carried out in this study using Pathfinder to evaluate the actual performance of the evacuation system and identify any critical bottlenecks that may occur during emergency scenarios.

2. Methods

Following this, an evacuation simulation using Pathfinder software was conducted. This agent-based simulation modeled occupant movement based on actual building layout and estimated occupant load, assessing evacuation time, congestion points, and exit route effectiveness. Simulation results were then analyzed against relevant regulatory standards, including BNPB guidelines, to identify gaps and recommend improvements.

Direct observation was conducted using a checklist instrument to examine key aspects of the evacuation route: corridor widths, signage placement and clarity, emergency stair locations, and physical obstructions. These observations were evaluated for alignment with SNI 03-1746-2000 and NFPA 101: Life Safety Code.

2.1. Agent-Based Modeling Using Pathfinder

To evaluate the real-time effectiveness of evacuation routes at the Faculty of Islamic Studies (FIAI), Universitas Islam Indonesia (UII), this study employed Pathfinder, an agent-based simulation software developed by Thunderhead Engineering. Pathfinder allows researchers to create a detailed digital model of the building and simulate emergency scenarios by representing each occupant as an intelligent agent capable of responding to spatial conditions, environmental barriers, and evacuation signage (Ahn et al., 2022).

The simulation process began with inputting the building's floor plan, identifying key architectural elements such as stairs, exits, corridors, and rooms. Then, occupant profiles were configured based on estimated usage patterns, including a total of 190 individuals spread across multiple floors, each with varying walking speeds and behaviors. The main evacuation routes consisted of two vertical emergency staircases located on the left and right sides of the building.

Unlike traditional static assessments, Pathfinder provides dynamic outputs, including total evacuation time, occupant density, identification of bottlenecks, and individual path choices. According to Liu et al. (2023), Pathfinder's strength lies in its ability to simulate a variety of behaviors, including hesitation, flow disruption, and congestion-related delays, making it ideal for assessing safety infrastructure in complex buildings such as hospitals, transit hubs, and academic institutions.

In this study, Pathfinder was used not only to visualize evacuation flows but also to quantify how design factors—such as corridor width, stair accessibility, signage placement, and exit distribution—impact the evacuation process. This insight is crucial to determining whether the current evacuation system supports safe and efficient exit strategies during an emergency, and where improvements are needed.

2.2. Fire Evacuation

This study incorporates a specific fire evacuation scenario to reflect a realistic emergency in a multi-story academic building. Fire emergencies present unique challenges due to smoke spread, reduced visibility, potential heat hazards, and functional limitations of some circulation elements. These factors significantly impact occupant movement patterns and the effectiveness of available evacuation routes. (Gao et al., 2023)

The scenario will assume that the fire originates in a second-floor corridor, a location with high circulation activity and direct connections to several classrooms. This point of fire was chosen to represent a high-risk zone where smoke can spread rapidly to the surrounding area. Smoke propagation is assumed to follow the principle of vertical movement in an open atrium space; therefore, the central spiral staircase, which lacks a fire-resistant enclosure, is excluded as an evacuation route. This condition limits occupants to only two fire-resistant staircases located at the east and west ends of the building (Staircase 1 and Staircase 3), as in Figure 2.2.1.

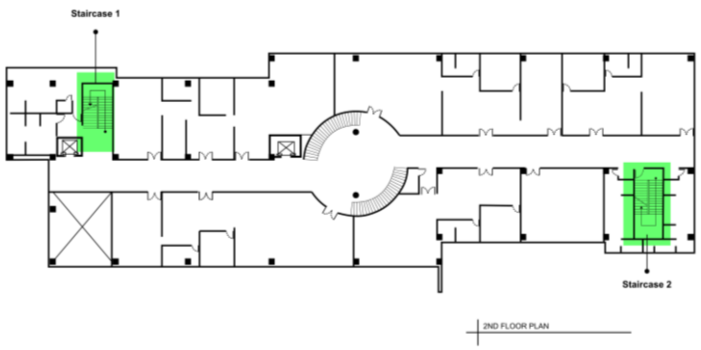


Figure 2.2.1. Staircase on the Second Floor of the Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

To model fire-related evacuation behavior, this simulation incorporates several key assumptions:

1. Reduced Usefulness of Vertical Circulation
   Only staircases protected by fire-resistant construction are available for evacuation. The central staircase was eliminated due to its open configuration, which encouraged upward smoke spread and endangered life safety.
2. Increased Evacuation Density and Flow Pressure
   The concentration of 190 occupants in two staircases significantly increased crowding at landings and assembly points. The Pathfinder agent-based behavioral model considered slower movement speeds under high-density conditions to simulate realistic crowd dynamics during a fire emergency.
3. Influence of Visibility and Directional Signage
   Because smoke was assumed to reduce visibility along the corridor, the simulation prioritized the role of directional signage. Officers primarily relied on clearly marked exits and the shortest protected paths to Stairs 1 and 3.
4. Horizontal-to-Vertical Transition Delay
   Additional time was modeled when large groups transitioned from the corridor to the stairwell entrance, reflecting typical delays caused by queues, hesitation, and reduced visibility during fire conditions.
5. Continuous Movement to a Safe Disposal Area

Occupants descended the protected staircase and proceeded directly to the designated assembly point outside the building, ensuring that the complete evacuation sequence—from the room to the safe exterior area—was represented.

This fire-specific scenario provides a more rigorous evaluation of a building's evacuation system by testing its performance under conditions where circulation options are limited, and movement behavior becomes more restricted. Simulation results demonstrate congestion, evacuation times, and route efficiency under fire-related stress, providing insight into the overall level of preparedness of the building's emergency exits.

2.3. SNI 03-1746-2000: Indonesian National Standard for Evacuation

To evaluate the conformity of the evacuation infrastructure with national standards, this study applies SNI 03-1746-2000, which provides comprehensive technical guidelines for the planning and design of fire evacuation routes in buildings across Indonesia. This standard regulates critical aspects such as the number, width, layout, and structural integrity of escape routes and emergency stairs, as well as requirements for obstruction-free access and signage clarity (Badan Standardisasi Nasional, 2000).

SNI 03-1746-2000 outlines minimum dimensions—such as a minimum corridor width of 1.2 meters and stair widths adjusted for occupant load—and ensures that route accessibility meets safety thresholds during emergencies. In the context of educational buildings like FIAI UII, which regularly accommodate high-density occupancy in lecture halls and classrooms, adherence to this standard is essential to support fast and safe evacuations.

In this study, a field observation checklist based on SNI criteria was developed to systematically examine physical elements such as corridor width, stair dimensions, door accessibility, signage presence, and the number and placement of exits. Each item is marked for compliance or deficiency to determine whether the evacuation system meets the required national safety baseline.

2.4. NFPA 101: Life Safety Code

NFPA 101, published by the National Fire Protection Association (NFPA), is an internationally recognized code that offers prescriptive and performance-based criteria to ensure occupant safety during building emergencies. While this standard emphasizes human behavior, decision-making, and accessibility during evacuation, this study primarily used NFPA 101 to assess the physical performance of evacuation infrastructure compared to global best practices (*NFPA 101 Life Safety Code, 2000*, n.d.).

The evaluation process for NFPA 101 follows the same approach as the SNI 03-1746-2000 assessment method, ensuring consistency in data collection and analysis.

Step 1: Evaluating Behavioral Support Through Design

While this study does not simulate occupant behavior directly, it assesses whether the building's layout facilitates safe and intuitive responses during emergencies. Using the same structured checklist format applied in the SNI assessment, this step examines exit visibility, signage clarity, and the flow of movement throughout the evacuation route. This allows identification of any design-related issues that may lead to hesitation, congestion, or panic in real-world emergencies.

Step 2: Reviewing Physical Compliance with NFPA Standards

Similar to the SNI method, field observations were conducted to inspect key physical elements—such as corridor width, stair dimensions, signage placement, door swing direction, and exit accessibility. These components were compared against NFPA 101 criteria to evaluate which aspects meet or fall short of the international standards. The goal is to highlight any necessary improvements in evacuation design to enhance occupant safety.

3. Result and Discussion

The Faculty of Islamic Studies is located on the UII Main Campus on Jalan Kaliurang. The building has an area of 13,834.06 square meters and has 5 floors consisting of 15 classrooms and 4 large classrooms, 1 semi-basement floor and 1 basement, a computer lab, microteaching, a business incubator, and an auditorium with a capacity of 200 people. Each floor of the building is equipped with 4 stairs—one staircase near the exit, two stairs in the middle of the building with a spiral shape, and one emergency staircase at the back. The building is also equipped with an elevator on each floor and a ramp at the entrance, indicating that the building has met several important aspects to accommodate individuals with disabilities. This initial observation aligns with the study's purpose to evaluate the effectiveness of evacuation routes during emergencies, especially for residents with various needs.

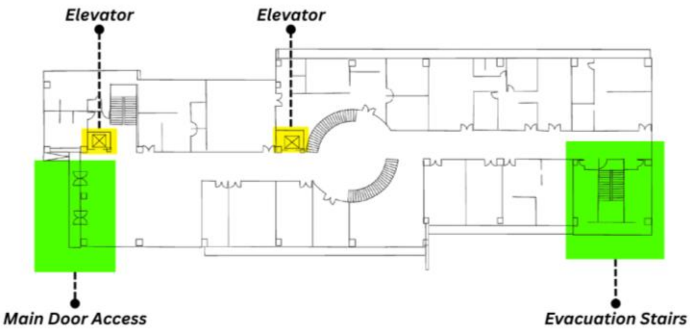


Figure 3.1. First Floor Plan of Faculty of Islamic Studies, Universitas Islam Indonesia (Universitas Islam Indonesia, Redrawed by Author, 2022)

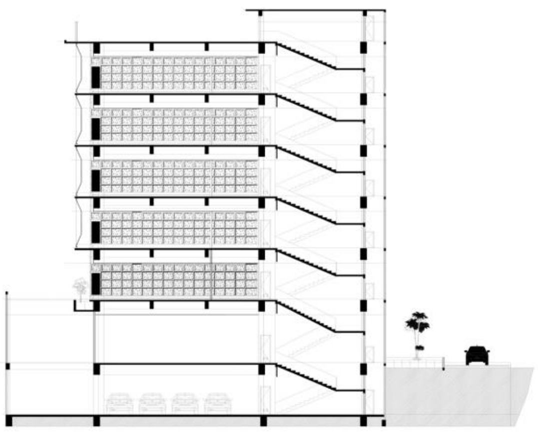


Figure 3.2. Evacuation Stairs From The Five Floors and also The Semi-Basement And Basement Floors (Universitas Islam Indonesia, Redrawed by Author, 2022)

3.1. Simulation Using Pathfinder

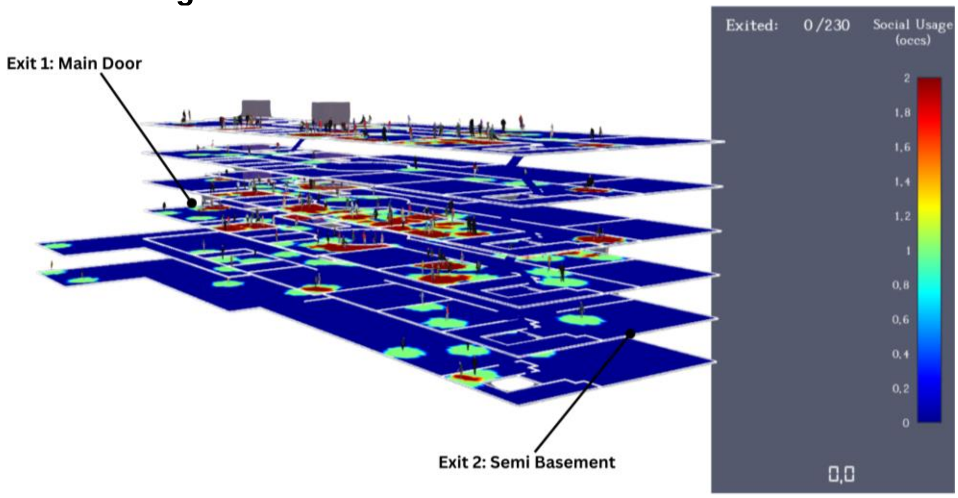


Figure 3.1.1 The Initial Part of The Simulation Results with Pathfinder (Author, 2025)

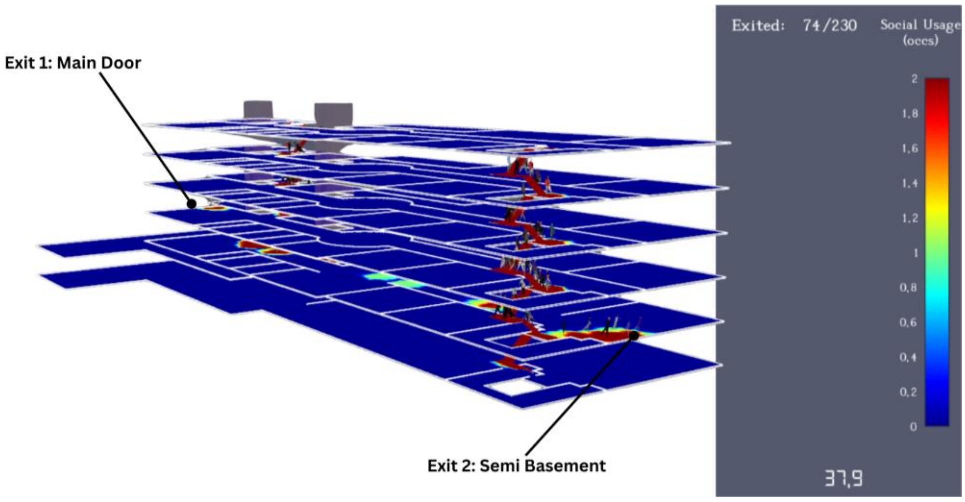


Figure 3.1.2 Middle Part of the Simulation Results with Pathfinder (Author, 2025)

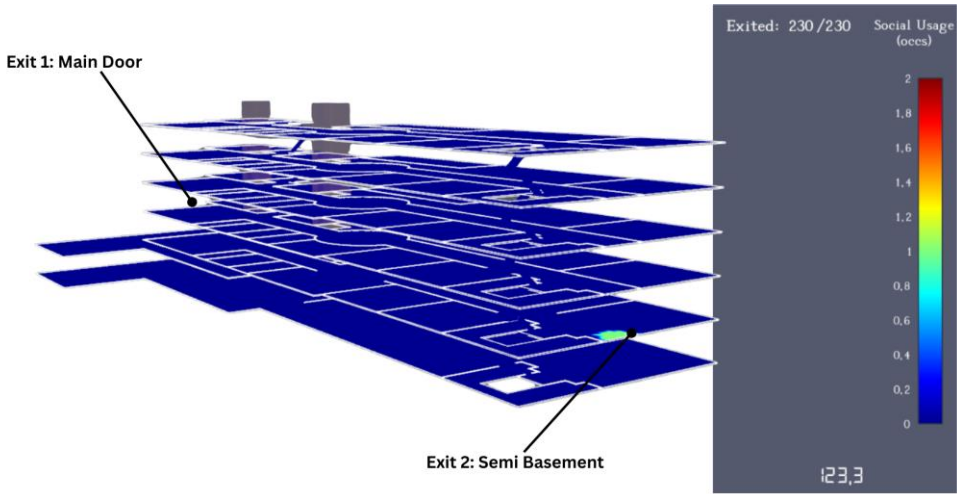


Figure 3.1.3 Final Results of the Simulation with Pathfinder (Author, 2025)

The evacuation simulations were conducted using a fire-specific scenario in which occupants were required to navigate through conditions realistically depicting smoke-filled corridors, limited visibility, and limited vertical circulation options. In this scenario, only two fire-protected stairways, Stairway 1 and Stairway 3, were available for safe vertical egress, as the central open atrium stairway was unavailable due to its vulnerability to smoke spread. A total of 230 occupants were modeled during the evacuation.

In the initial phase of the evacuation (Figure 3.1.1), all occupants remained inside the building (Exits: 0/230). Initial movement patterns showed the formation of a density cluster near the intersection of the corridors leading to Stairways 1 and 3. Density levels during this phase reached 2.0–2.75 persons/m², reflecting the natural buildup of crowd pressure as occupants converged toward the protected stairways in limited numbers. In the middle phase of the evacuation (Figure 3.1.2), movement became increasingly concentrated at the entry points of both stairways. The abandonment of the central stairway increased flow pressure, resulting in queues at the stairway thresholds and increased crowd density at the landings. Reduced visibility, modeled as a result of smoke development, further contributed to slower movement speeds, particularly during the horizontal-to-vertical transition. This situation highlights the critical impact of environmental factors on evacuation efficiency during a fire scenario.

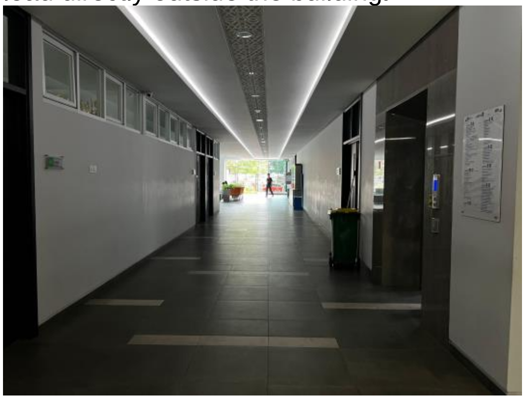
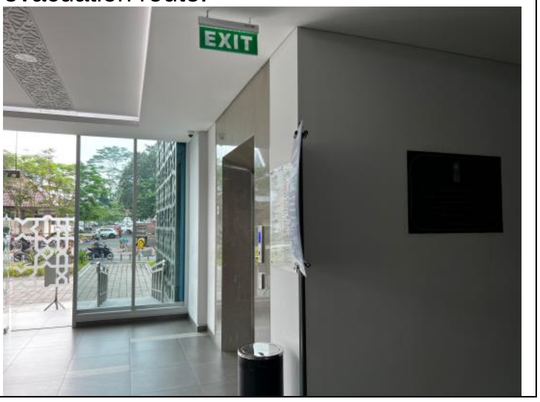
In the final phase (Figure 3.1.3), all 230 occupants successfully exited the building (Exits: 230/230). The total recorded evacuation time was 123 seconds, or 2 minutes and 3 seconds. These results demonstrate that, even under fire-related constraints, the building's protected stairwells provided adequate capacity for a controlled and safe evacuation. The balanced distribution of occupants between the two stairwell cores, despite temporary congestion, allowed the system to maintain overall flow continuity. In the final phase of the evacuation (Figure 3.1.3), all 230 occupants successfully exited the building (Exits: 230/230). The total recorded evacuation time was 123 seconds, or 2 minutes and 3 seconds. This duration indicates that the evacuation route, when limited to protected emergency stairwells, is capable of supporting a safe exit within the timeframe typically expected for a similarly sized academic facility during a fire emergency. The rapid completion time also reflects the effective distribution of occupants between the two available emergency stairwell cores, although increased reliance on these routes increases local congestion during peak movement periods.

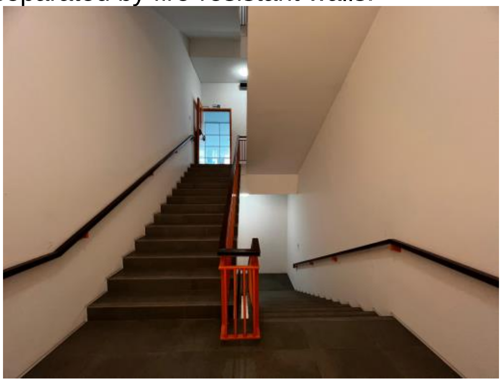
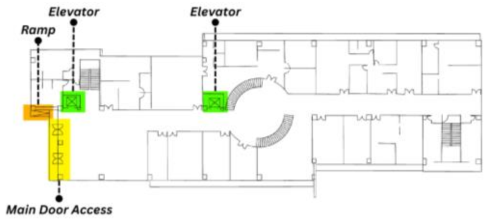
3.2. Evacuation Routes Following SNI 03-1746-2000 & NFPA 101 Standard

As an initial step in evaluating the effectiveness of the evacuation route in the Faculty of Islamic Studies (FIAI) Building, Universitas Islam Indonesia, a check was carried out on the conformity of the evacuation route elements with national and international standards. The standards used in this study are SNI 03-1746-2000 on Procedures for Evacuation Route Planning in Building Planning and NFPA 101: Life Safety Code issued by the National Fire Protection Association. Both standards provide comprehensive technical guidelines on providing safe, efficient, and barrier-free evacuation routes to ensure the safety of building occupants in emergency conditions. The following table shows the results of checking the physical aspects of the evacuation route based on the criteria of the two standards.

Table 3.1. Aspects required in a building's evacuation route based on the Criteria of SNI 03-1746-2000 & NFPA 101 (Author, 2025)

No.	Aspect Checked	Criteria of SNI 03-1746-2000 & NFPA 101	Yes	No	Information
1	Number of Evacuation Route	There are at least 2 separate evacuation routes on each floor/main area	✓		There are 3 stairs in the building. Stairs 1 and Stairs 3 are located at the ends of the building and can be counted as evacuation routes. However, stair 2 is located in the middle of the building. This stair is an open

					atrium stair without fire protection, and is usually not recommended for evacuation because it has the potential to spread smoke and fire. 
2	Evacuation Route Width	Minimum width according to standard (generally ≥ 80 cm, adjusted to occupancy capacity)	✓		The width of stairs 1 and stairs 3 is 2 meters, while stairs 2 which is located in the middle of the building has a width of 1.5 meters.
3	Obstacle-Free Evacuation Route	Evacuation routes are not obstructed by objects, decorations, or furniture	✓		There are no obstacles blocking the evacuation routes, all evacuation routes lead directly outside the building. 
4	Easy-to-Open Evacuation Doors	Doors can be opened without a special key, are easy to operate, and open towards evacuation	✓		There are only a few rooms that require access using a password, and the rest use manual keys. For rooms that require a password, it is easy to operate and will open automatically in case of an emergency.
5	Evacuation Route & Door Marking	There is a clear "EXIT"/"EXIT ROUTE" sign with min. 2.5 cm, contrasting background, easily visible	✓		There are clear "EXIT" signs in every evacuation route. 

6	Evacuation Route Lighting	Evacuation routes and doors have emergency lighting that functions when the power goes out	✓		The building have have emergency lighting that functions when the power goes out.
7	Evacuation Route Separation	Evacuation routes are separated by fire-resistant walls according to provisions (eg 60/60/60 or 120/120/120)	✓		Evacuation routes, such as corridors, stairwells, and lobbies leading to exits, are separated by fire-resistant walls. 
8	Accesibility for the Disabled Evacuation	Evacuation routes are accessible to occupants with mobility disabilities	✓		Outside of the building there is a ramp to make it easier for wheelchair users and there are also elevators on each floor. 
9	Exit Discharge	Exit directly to the public road or a safe area outside the building	✓		The exit lead directly to the safe area outside the building. 
10	Door Access Control System	If there is an access system, there is a manual and automatic release that opens during a power	✓		There are only a few rooms that require access using a password, and the rest use manual keys. For rooms that require a password, it is easy to operate and will open automatically in case of emergency.

11	Emergency Lighting & Signage	Emergency Lighting & Signage Emergency signs and lights remain on during a power outage	✓		The Emergency Lighting & Signage Emergency signs and lights in the building remain on durineg a power outage.
12	Evacuation Route Does Not Pass Through Hazardous Areas	Evacuation routes do not pass through kitchens, warehouses, or high-risk areas	✓		The evacuation routes do not pass through kitchens, warehouses, or high-risk areas.
13	Testing & Maintenance	Evacuation routes and doors are tested and maintained regularly	✓		The evacuation route, such as stairs, is tested and maintained regularly, and it is also used for daily use. 
14	Refuge Area	There is a shelter area according to requirements if the building is high-rise		✕	There is no shelter area, only assembly points sign that located at the outside of the building. 
15	Use of Evacuation Route	Evacuation routes are not used for functions other than evacuation.		✕	Evacuation stairs are used as a daily route up and down floors.

4. Conclusion

This study evaluated the effectiveness, safety performance, and regulatory compliance of evacuation routes in the Faculty of Islamic Studies (FIAI), Universitas Islam Indonesia, by integrating field observations, national and international standards, and an agent-based simulation using Pathfinder. The results demonstrate that the existing evacuation system is capable of supporting safe egress under a fire-specific emergency scenario, with all 230 occupants successfully evacuating the building within 2 minutes and 3 seconds. This evacuation duration falls within a reasonable range for a multi-story academic facility, indicating that the protected staircases provide adequate capacity to accommodate high occupant loads during emergency conditions.

The simulation identified several critical movement characteristics influenced by fire-related constraints—including limited vertical circulation options, reduced visibility, and convergence of occupants at corridor–stair interfaces. While overall performance remained effective, localized congestion at stair entrances and elevated occupant density highlight the need for design improvements to optimize evacuation flow during peak movement intervals. Enhancing directional signage visibility, improving the configuration of corridor-to-stair transitions, and ensuring that protected staircases remain the primary evacuation routes are key opportunities for strengthening evacuation reliability.

From a regulatory standpoint, the building meets most SNI 03-1746-2000 and NFPA 101 requirements related to structural readiness, route width, lighting, and unobstructed circulation. However, certain non-structural aspects—such as the absence of a designated refuge area and the limited usability of the central atrium staircase—indicate areas where the evacuation system could be further aligned with best practice standards for life safety.

Overall, this study demonstrates that the FIAI building performs adequately under fire emergency conditions while also revealing specific aspects of the evacuation infrastructure that warrant enhancement. Strengthening these elements will not only improve safety outcomes but also increase building resilience and preparedness for future emergencies..

5. References

Ahn, C., Kim, H., Choi, I., & Rie, D. (2022). A Study on the Safety Evaluation of Escape Routes for Vulnerable Populations in Residential Facilities. *Sustainability 2022, Vol. 14, Page 5998*, *14*(10), 5998. https://doi.org/10.3390/SU14105998

Anggoro, A. R. W., & Darmawati, R. (2020). *Kajian Sirkulasi Evakuasi Terhadap Bencana Kebakaran (Studi Kasus Pasar Klewer Solo)*. https://dspace.uii.ac.id/handle/123456789/43455

Badan Standardisasi Nasional. (2000). *SNI 03-1746-2000 Tata Cara Perencanaan dan Pemasangan Sarana Jalan Keluar Untuk Penyelamatan Terhadap Bahaya Kebakaran Pada Bangunan*. https://www.scribd.com/document/615238315/PDF-Sni-03-1746-2000-Saran-Jalan-Keluar-Compress

Ding, Z., Xu, S., Xie, X., Zheng, K., Wang, D., Fan, J., Li, H., & Liao, L. (2024). A building information modeling-based fire emergency evacuation simulation system for large infrastructures. *Reliability Engineering & System Safety*, *244*, 109917. https://doi.org/10.1016/J.RESS.2023.109917

Gao, S., Chang, C., Liu, Q., Zhang, M., & Yu, F. (2023). Study on the optimization for emergency evacuation scheme under fire in university building complex. *Heliyon*, *9*(3), e14277. https://doi.org/10.1016/J.HELIYON.2023.E14277

Liu, J., Li, S., Liu, J., & Li, S. (2023). Pathfinder-Based Simulation and Optimization of Evacuation of Large Commercial Complexes. *Journal of Building Construction and Planning Research*, *11*(2), 27–35. https://doi.org/10.4236/JBCPR.2023.112002

NFPA 101 Life Safety Code, 2000. (n.d.). Retrieved June 16, 2025, from https://www.ojp.gov/ncjrs/virtual-library/abstracts/nfpa-101-life-safety-code-2000-edition

Saika, R. M., Idham, N. C., & Arkan, M. E. (2024). International Journal of Architecture and Urbanism Analysis of Evacuation Routes Effectiveness on Dormitory Building (Case Study: Rusunawa Putri UII, Yogyakarta). *International Journal of Architecture and Urbanism*, *08*(03), 400. https://doi.org/10.32734/ijau.v8i3.1781517815

Sujatmiko, W. (2016). Penerapan Standar Keselamatan Evakuasi Kebakaran Pada Bangunan Gedung Di Indonesia. *Jurnal Permukiman*, 116–127. https://jurnalpermukiman.pu.go.id/index.php/JP/article/view/46/pdf

Universitas Islam Indonesia. (2022). *Gambar Arsitektural Fakultas Ilmu Agama Islam Universitas Islam Indonesia*.