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Analysis of Evacuation Route and Fire Safety in Library Case Study: Main Library of University Islam Indonesia

Fira Rahmawati*, Noor Cholis Idham, Rania Ababssi
Department of Architecture, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia
*Corresponding author: 22512149@students.uii.ac.id.

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Abstract
Fire safety is a major concern in public buildings, especially in educational institutions with high user density and complex layouts. The Main Library of Universitas Islam Indonesia (UII) must be prepared to handle emergencies through well-planned evacuation routes. This study analyzes the existing evacuation system and fire safety conditions in the library. Using Pathfinder simulation software, the research models pedestrian behavior during evacuation to assess time efficiency, congestion points, and overall route effectiveness. Key factors include exit accessibility, user familiarity, crowd density, and pathway dimensions. The simulation reveals issues such as limited stairwell capacity, poor signage visibility, and inadequate alternative routes.This study recommends improving exit width, repositioning emergency signs, and conducting regular evacuation drills. These interventions aim to enhance evacuation safety and align with national fire safety standards, contributing to a safer and more resilient academic environment.

Keywords: *evacuation route; fire safety; Library UII*

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1. INTRODUCTION

Emergency situations such as fires, earthquakes, or other unforeseen incidents can occur at any time, posing serious risks to building occupants. Emergencies are generally defined as events with high stakes and urgency, often characterized by uncertainty and requiring immediate action to prevent loss of life or property (Howitt et al., 2017). In library environments where user density, limited visibility, and complex spatial arrangements are common, emergency preparedness becomes especially critical. When emergencies strike in a library, the consequences can be severe,ranging from injury or loss of life to damage of valuable academic resources and disruption of essential educational activities.

Fire safety is one of the most essential components in emergency planning, particularly in public institutions like libraries. It encompasses a range of measures, including fire detection systems, suppression equipment, clear evacuation routes, and user preparedness through drills and training. Libraries face unique challenges due to the combustible nature of books and materials, as well as the presence of electrical equipment, which can increase fire risk (Higgins, 2018). Effective fire safety also requires regular risk assessments, updated emergency plans, and the active participation of

both staff and users in safety programs (NFPA,2018).

In a library, where users may be unfamiliar with exit paths and emergency protocols, fire safety becomes even more crucial. The absence of proper fire safety measures can endanger lives, hinder evacuation, and escalate the overall impact of the emergency on occupants and infrastructure (Purwanto, 2020).

1.1 Fire Safety Challenges in Libraries

Libraries present unique challenges for fire safety management due to their typical characteristics: high occupancy, complex spatial layouts, and the presence of highly combustible materials such as paper, wood, and textiles. These factors increase the risk of rapid fire spread and complicate evacuation efforts (Smoke Guard, 2018). Furthermore, libraries often house irreplaceable collections of historical and academic value, making fire protection not only a matter of occupant safety but also preservation of cultural heritage (British Library case, Wagner Group, 2025). The presence of tightly packed shelving and confined spaces can create obstacles that impede evacuation and hinder firefighting operations (UNESCO, 2002).

Effective fire safety in libraries requires a multi-layered approach, combining early fire detection, suppression systems, and well-planned evacuation routes. Early detection systems-such as smoke and heat detectors linked to central alarm stations-are critical for prompt response, as the first few minutes of a fire are decisive in controlling damage and ensuring occupant safety (CORE, 2005). However, failures in detection systems due to poor installation or maintenance have been documented, emphasizing the need for rigorous upkeep and system testing (CORE, 2005)

1.2 Regulatory Framework for Library Fire Safety in Indonesia

Fire safety in libraries is a global concern, as evidenced by international standards and case studies. The National Fire Protection Association (NFPA) 101: Life Safety Code provides comprehensive guidelines for fire protection, egress, and emergency planning in public buildings, including libraries (NFPA, 2018). Research indicates that libraries are particularly vulnerable to fire hazards due to the presence of flammable materials, high occupancy rates, and often complex internal layouts (Parker, 2015). Effective fire safety management in libraries requires not only the installation of appropriate equipment but also regular staff training, clear communication of evacuation procedures, and routine safety drills (Rahman et al., 2021).

In Indonesia, fire safety and evacuation planning in public buildings, including libraries, are regulated under national standards and laws. The Law No. 43 of 2007 on Libraries mandates that libraries provide safe and secure environments for users and staff, including compliance with fire safety regulations (Undang-Undang No. 43 Tahun 2007). The Indonesian National Standard (SNI) 03-1736-2000 specifically addresses building evacuation procedures, setting minimum requirements for exit routes, signage, and emergency preparedness (BSN, 2000). Additionally, the SNI 7330:2009 on library buildings provides guidelines for architectural design that incorporate fire safety features such as fire-resistant materials, adequate ventilation, and unobstructed evacuation paths (BSN, 2009).

The following paragraph will provide a clear comparison between Indonesian fire safety standards (SNI and Permen PU 26/2008) and the NFPA 101 Life Safety Code from the United States. Indonesian standards focus on regulations for building evacuation, fire protection systems, and specified rules for exits, materials, and active safety systems, with some aspects still developing toward performance-based approaches. NFPA 101 offers broader and more detailed requirements for all elements of life safety, integrating both prescriptive and flexible performance-based design options, and emphasizes comprehensive protection for occupants in various building types. This comparison highlights differences in detail, scope, and design flexibility between the two standards.

In terms of scope, Indonesian standards Focuses on Building evacuation (SNI Sarana Jalan Keluar) and fire protection systems in buildings, aligned with performance-based concepts adapted from Australian and New Zealand codes (SNI 03-1736-2000, Permen PU

26/2008). On the other hand, Comprehensive life safety code covering building design, construction, operation, and maintenance for fire protection and occupant safety. The legal regulatory basis for fire safety standards in Indonesia is based on National Law No. 28/2002 on Building, Law No. 43/2007 on Libraries, SNI standards, and Ministerial Regulations (Permen PU 26/2008). Meanwhile, NFPA 101 operate as a voluntary consensus standard widely adopted in the US and internationally, updated regularly by the National Fire Protection Association. Regarding evacuation requirements, Indonesia has established specific rules for exit widths, number of exits, signage, and emergency lighting; based on "Mean of Egress" chapter from NFPA 101 (1997 edition) but less detailed for building classes. On the other hand, NFPA 101 offers detailed requirements for evacuation components, occupant load calculations, travel distances, and emergency lighting, with performance-based options. For fire resistance and materials, Indonesian standards specifies Fire Resistance Rate (FRR) testing per SNI 1741:2008, referencing ISO 834-1:1999 and JIS A 1304-1994; mandates testing of building components. Similarly, NFPA 101 establishes fire resistance ratings for structural elements, fire barriers, and assemblies, with extensive testing standards and classifications. In the field of active fire protection systems, Indonesia regulations require installation of fire detection, alarm, sprinkler, and smoke control systems per SNI 03-3989-2000 and related standards; aligned with performance-based design. NFPA 101 also requires automatic detection, alarm, suppression, and smoke control systems; detailed design and maintenance requirements. The performance-based approach in Indonesian standards concepts adapted from Australian/New Zealand codes and partially from NFPA; still evolving with need for more prescriptive guidance. On the other hand, NFPA 101 fully integrates performance-based design options alongside prescriptive requirements, allowing flexible compliance paths. In terms of building classification, buildings are classified based on function, complexity, fire risk, and ownership; fire safety requirements vary accordingly. NFPA 101 classifies buildings uses based on type and hazard level; requirements tailored to occupancy and use.

These regulations align with international standards like the NFPA 101: Life Safety Code, which prescribes comprehensive fire protection and life safety requirements for public buildings, including libraries (NFPA, 2018). The NFPA code emphasizes the importance of occupant load calculations, fire detection and suppression systems, and clearly marked, accessible evacuation routes (NFPA, 2018).

1.3 Evacuation Behavior

Human behavior during emergencies plays a crucial role in evacuation effectiveness. Studies by Gwynne et al. (1999) highlight that factors such as occupants' familiarity with the building layout, movement speed, decision-making under stress, and crowd density significantly influence evacuation outcomes. In university libraries, these factors are amplified due to diverse user groups, including students, faculty, and visitors, who may be unfamiliar with emergency procedures (Gwynne et al., 1999).

Simulation tools have become essential in analyzing and improving evacuation strategies. Pathfinder, an agent-based pedestrian simulation software, models individual movement and interactions during evacuations, accounting for physical obstacles, route choices, and behavioral variables (Kuligowski et al., 2010). By simulating different scenarios, architects and safety planners can identify bottlenecks, test the impact of blocked exits, and optimize evacuation routes before actual emergencies occur (Kuligowski et al., 2010).

Several case studies demonstrate the value of such simulations in library settings. For example, the British Library employs advanced fire detection and oxygen reduction systems to prevent fire spread, complemented by detailed evacuation planning informed by simulation and risk analysis (Wagner Group, 2025). Similarly, fire safety protocols in academic libraries such as Dublin City University's Cregan and O'Reilly Libraries emphasize clear evacuation procedures, staff training, and the role of fire wardens to ensure orderly evacuation (DCU Library, 2024).

1.4 Fire Protection Measures and Evacuation Procedures

Effective fire protection in libraries includes a combination of active and passive measures. Active systems involve automatic fire detection, sprinklers, and smoke curtains that compartmentalize fire and smoke to limit damage and facilitate safe evacuation (Smoke Guard, 2018). Passive measures include fire-resistant building materials, fire doors, and clear signage to guide occupants to exits (CORE, 2005).

Evacuation procedures must be well-documented, regularly practiced, and communicated clearly to all users. Guidelines from various libraries stress the importance of immediate response to alarms, avoiding the use of lifts, assisting disabled persons, and never re-entering the building until declared safe (DCU Library, 2024). These procedures are critical in minimizing panic and ensuring a safe, orderly evacuation.

To assess the effectiveness of evacuation routes at the Main Library of Universitas Islam Indonesia (UII), this study utilizes the simulation tool Pathfinder, which models pedestrian movement during evacuation by accounting for walking speed, route choices, and physical obstacles, allowing for a realistic analysis of egress efficiency. Given UII Library's high user density and complex architectural layout, it is crucial to evaluate its emergency preparedness to ensure occupant safety and protection of valuable academic resources. This study refers to standards such as NFPA 101: Life Safety Code and Indonesia's SNI 03-1736-2000 to guide the evaluation of fire hazard vulnerability and evacuation procedures.

The research focuses on key questions: what is the optimal evacuation time under various emergency scenarios? How do factors such as occupant density and exit accessibility influence evacuation efficiency? And what improvements can be made to evacuation routes and fire safety measures to ensure compliance with both national and international regulations? Although fire safety guidelines and evacuation standards are well-established, existing studies tend to address them in a general building context and rarely provide a performance-based analysis tailored to library facilities. Moreover, previous research often evaluates evacuation routes only from a regulatory standpoint, without incorporating dynamic variables such as fluctuating occupancy patterns, multiple emergency scenarios, and real-time route accessibility. This creates a research gap between prescriptive standards and actual evacuation performance in library environments. Addressing this gap, the present study aims to generate evidence-based recommendations to enhance fire safety strategies and optimize evacuation route planning for future library facilities.

2. METHODS

This study employs a quantitative research method to analyze the evacuation routes and fire safety conditions in the Main Library of Universitas Islam Indonesia (UII). Quantitative methods are appropriate for this research as they allow for objective measurement and statistical analysis of evacuation performance, providing replicable and data-driven insights (Creswell, 2014). Field data, including measurements of corridor widths, exit locations, and potential obstacles, were digitized into a floor plan model to simulate realistic emergency conditions. Within this framework, the study addresses two main research questions: (1) How effective are the current evacuation routes in the Main Library of UII in ensuring safe and timely egress during emergency situations? and (2) What improvements can be made to the existing fire safety infrastructure and evacuation planning based on simulation results using Pathfinder software? Specifically, this study utilizes Pathfinder, a dynamic agent-based pedestrian simulation software developed by Thunderhead Engineering, which is widely recognized for modeling human behavior during emergency evacuations (Kuligowski et al., 2010).

Pathfinder simulates pedestrian movement by incorporating variables such as walking speed, reaction time, population density, door widths, and interior spatial configurations. These parameters are critical in reflecting realistic evacuation scenarios and assessing the efficiency of egress routes (Gwynne et al., 1999). The study began with detailed field

observations and measurements of the Main Library's physical layout, including floor plans, exit locations, corridor widths, and potential obstacles. These data were digitized into a precise floor plan model to serve as the simulation environment in Pathfinder.

To ensure the simulation aligns with relevant safety standards, this research references the Indonesian National Standard SNI 03-1736-2000, which provides guidelines for building evacuation procedures, and the NFPA 101: Life Safety Code (2018), which sets international benchmarks for fire protection and occupant safety in public buildings. These standards guided the selection of input parameters and the evaluation criteria for evacuation performance.

Multiple evacuation scenarios were simulated to reflect varying conditions, such as different crowd densities, blocked exits, and delayed reaction times. The simulation outputs include total evacuation time, identification of congestion points, and overall escape route efficiency. These quantitative metrics enable a comprehensive evaluation of the existing evacuation routes and highlight potential vulnerabilities or bottlenecks.

Figure 1. Example of the 3D Results View on Pathfinder that Showing Occupants

The Figure 1 illustrates an example of the 3D results view generated using Pathfinder, which visually represents the distribution and movement of building occupants during an evacuation scenario. Through this simulation interface, individual occupants are modeled within a multi-level facility, allowing researchers to observe their evacuation progress in real time. The visualization effectively demonstrates how people navigate exits and evacuation routes, and provides valuable insight into occupant flow, bottlenecks, and densities at different stages. Such 3D modeling results are essential for evaluating actual evacuation performance and for refining fire safety strategies and building design based on realistic occupant behaviors.

3. RESULT AND DISCUSSION

3.1 Main Library of UII

The Main Library of Universitas Islam Indonesia (UII), known as the Mohammad Hatta Central Library, spans approximately 9,000 square meters over five floors and serves as a central academic hub with over 71,000 volumes, reading areas, administrative offices, and multimedia spaces. Its complex layout, shaped by functional requirements and the preservation of an ancient archaeological site within its structure, creates challenging spatial dynamics that impact occupant flow and emergency evacuation. The varied room types, multiple access points, and high user density demand careful analysis of evacuation efficiency to ensure safety and effective emergency management in this critical academic facility.

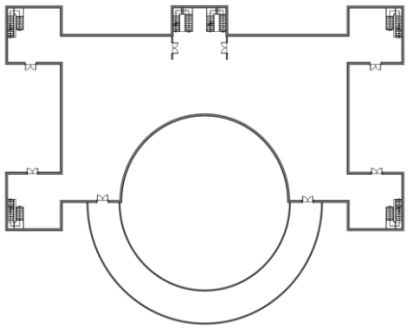

Figure 2. Building Plan with Staircase Location at Lower Ground Library of UII

The Main Library of Universitas Islam Indonesia (UII) is organized over five floors (Figure 2), each dedicated to specific academic and administrative functions. The Lower Ground floor focuses on digital resources, offering e- library access and specialized collections in social sciences, computer science, and related fields. The Upper Ground and First Floors primarily house general, reference, and reserved collections organized by the Dewey Decimal Classification, covering a wide range of disciplines from political science to engineering and the arts.

The Second Floor serves as the administrative center, containing meeting rooms, the

Director's Office, language labs, and various administrative departments responsible for procurement, finance, and general operations. This floor supports the management and coordination of library services while facilitating staff functions.

The Basement integrates historical and technical spaces, including access to the Kimpulan Temple museum and management rooms, technical service offices, canteen, and digital archiving. Throughout all levels, the library provides study areas, computer access, Wi-Fi, prayer rooms, and other amenities to support the academic community.

3.2 Emergency Stairs

The emergency staircases in the Main Library of Universitas Islam Indonesia meet the dimensional requirements specified in SNI 03-1736-2000, with a standard width of 30 cm, tread length of 1 meter, and riser height of 15 to 18 cm, as well as non-slip surfaces, in Figure 3. Additionally, evacuation route signs and directional stickers (up and down) are installed on each staircase, supporting clear wayfinding during evacuations (Figure 3). This complies with both SNI and NFPA 101 requirements for means of egress, which mandate sufficient dimensions and accessibility to facilitate safe and efficient evacuation (BSN, 2000; NFPA, 2018).

Figure 3. Staircase with Sticker at Lower Ground Library of UII

However, while the physical dimensions and signage meet regulatory standards, the simulation and real-world observations suggest potential behavioral bottlenecks during peak occupancy periods. Narrow stair widths (30 cm per step as reported) may restrict flow when user density is high, especially during panic or reduced visibility conditions. NFPA 101 emphasizes not only stair dimensions but also the necessity for unobstructed and adequately sized staircases to handle occupant loads safely (NFPA, 2018). Enhancements such as additional signage, lighting improvements, and drills may be needed to optimize egress efficiency.

3.3 Fire Alarms, Smoke Detectors, and Fire Extinguishers

Each floor is equipped with a fire alarm system near the lobby and fire extinguishers placed near emergency stairs (Figure 4), which aligns with SNI 03-1736-2000 requirements regarding fire detection and initial fire suppression tools (BSN, 2000). The presence of 20 smoke detectors per floor indicates a substantial investment in early fire detection (Figure 5). Nonetheless, these smoke detectors appear outdated and require urgent inspection or replacement to ensure functionality. NFPA 101 stresses the importance of reliable and well-maintained fire detection systems as a cornerstone of occupant safety, enabling quick alarm activation and response (NFPA, 2018). Failure to maintain detection systems can delay occupant alert and increase risk, undermining the effectiveness of evacuation plans.

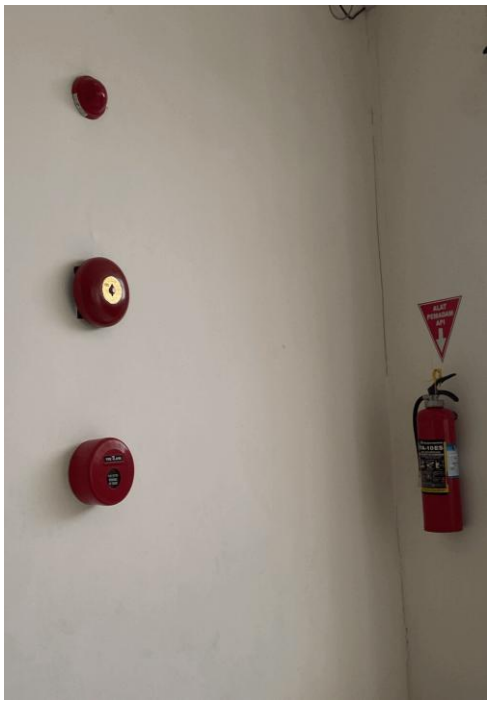

Figure 4. Fire Alarm and Fire Extinguishers in Library of UII

Figure 5. Smoke Detector in Library of UII

Similarly, the placement of fire extinguishers near emergency exits aligns with standards, but their readiness depends on regular maintenance and accessibility, which should be formally documented.

3.4 Sprinkler System Deficiency

The absence of sprinkler systems in non-book storage areas, such as hallways and the second floor, highlights a significant gap in fire suppression coverage. According to NFPA 101 and best practices for libraries, sprinkler systems are recommended or mandatory in areas with high fire load and general circulation spaces to control fire spread (NFPA, 2018).

SNI standards also advocate for active fire protection devices across critical and vulnerable building zones (BSN, 2000). The lack of sprinklers in these areas reduces overall fire resilience, increasing potential damage and occupant risk in case of fire outside book stacks. Installing automatic sprinklers, especially in high-risk areas and common spaces, would substantially improve fire suppression capabilities.

3.5 Fire Hydrant Locations and Accessibility

Outdoor hydrants are installed at two primary locations which are north and east (Figure 6), but internal hydrants are positioned far from high visitor traffic areas, which could delay firefighting response during a fire event. Both SNI 03-1736-2000 and NFPA standards require strategic placement of hydrants to enable rapid access to all areas of the building (BSN, 2000; NFPA, 2018).

Figure 6. Hydrant in East Library of UII

The current hydrant placement may pose challenges in firefighting operations, especially in dense visitor zones where fire spread is most probable (Figure 6). Regular evaluation of hydrant locations and possible installation of additional hydrants or hose stations inside visitor-dense zones are recommended to improve readiness.

3.6 Fire Hydrant Locations and Accessibility

The library's two assembly points, located at the east front entrance and the south side of the building (Figure 7), comply with SNI and NFPA guidance to provide clearly designated, safe outdoor locations within a reasonable evacuation distance (BSN, 2000; NFPA, 2018). Their visibility and accessibility were confirmed through field observations.

Figure 7. Assembly Point at Library of UII

However, user awareness of these locations, especially among new users, remains limited. Both standards emphasize not only structural provision but also the need for regular drills and signage to ensure occupants can quickly and confidently reach assembly points in emergencies (Rahman et al., 2021). Increasing signage presence and conducting orientation sessions are potential improvements.

3.7 Ventilation and Smoke Control

A major concern identified is the lack of natural ventilation—most windows are fixed and cannot be opened—paired with low ceiling heights that facilitate rapid accumulation of smoke inside the building during a fire. This condition increases the risk of smoke inhalation, which is a primary cause of fatalities in fires (NFPA, 2018).

Although NFPA 101 sets out requirements for smoke control and ventilation systems to maintain tenable conditions during egress, the current library design relies heavily on sealed environments without active smoke extraction or pressurization systems (BSN, 2000). The absence of such mechanisms undermines occupant safety, suggesting a need for mechanical smoke control systems or retrofit ventilation solutions to facilitate smoke clearance and support safe evacuation.

3.8 Fire Emergency Exit Access and Door Usage

The dual use of entrance and exit doors as emergency exits without dedicated emergency exit doors represents a critical safety and regulatory concern. Both SNI 03-1736-2000 and NFPA 101 prescribe that emergency exits must be clearly designated, separate where possible, and designed for quick, unobstructed egress (BSN, 2000; NFPA, 2018).

Using the main entrance doors for emergency evacuation (Figure 8) can lead to congestion, confusion, and delayed evacuation times, particularly if the volume of occupants is high. Furthermore, emergency exits should have features such as panic hardware and illuminated signage to ensure rapid recognition and use. The lack of dedicated emergency exits calls for urgent reconsideration of door configurations or additional exit installations to meet safety codes fully.

Figure 8. Main Entrance Door at Library of UII

3.9 Pathfinder Simulation

The Pathfinder simulation (Figure 9) for the Main Library of Universitas Islam Indonesia (UII) was conducted under normal conditions, modeling an evacuation scenario involving 270 occupants. The first image (Figure 9) presents a 3D heatmap overlay of the library floor plans, illustrating occupant distribution during evacuation. The color scale on the right indicates "Social Linkage (occupants per square meter)" with blue representing low density and red representing high density. At the simulation time shown, all 270 occupants are still evacuating, with none having exited yet. Areas marked in yellow, green, and red correspond to higher occupant densities, while blue areas indicate lower or empty spaces. The highest concentrations of occupants appear near the main circulation routes, staircases, and likely close to exits, as shown by the red and yellow clusters.

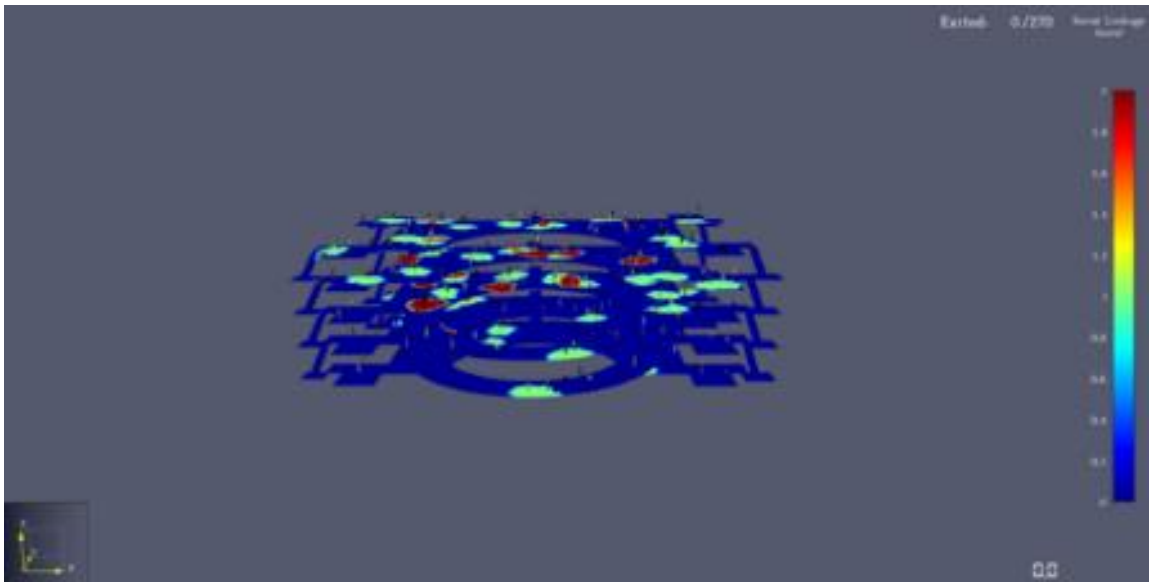

Figure 9. Pathfinder Showing the Social Linkage of Library UII

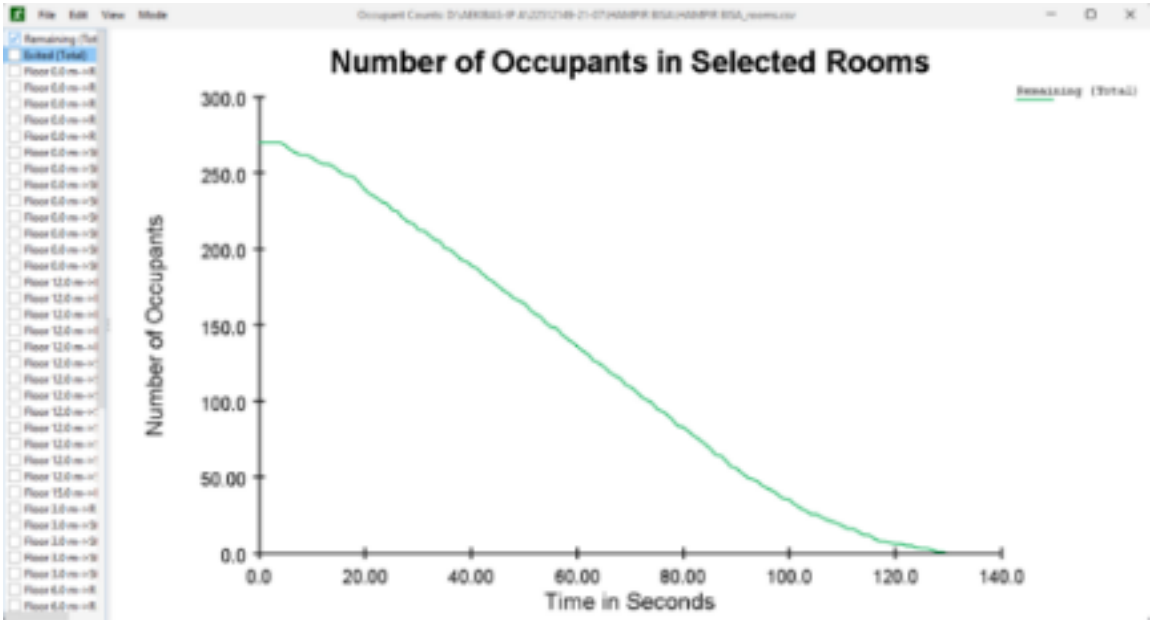

Figure 10. Pathfinder Showing the Number of Occupant of Library UII

These hotspots suggest potential bottlenecks at locations where narrow corridors or doorways channel large numbers of people, consistent with red areas on the heatmap. Central library zones and major intersections also display significant crowding, highlighting critical pinch points in evacuation flow. Conversely, side zones and peripheral rooms exhibit lower occupant densities (blue overlay), indicating faster clearance in these areas. Overall, the evacuation movement is directed towards the exits but experiences substantial congestion at key nodes such as stair entrances, doorways, and hallway curves. These observations align with previous field findings that identified possible evacuation slowdowns in major circulation areas and underline the need to reassess corridor widths, exit capacities, signage effectiveness, and occupant guidance strategies to improve flow and safety during emergencies.

The second image (Figure 10) presents an occupant evacuation curve, which plots the number of occupants remaining in selected rooms (y-axis) against time in seconds (x-axis). The initial occupant count is approximately 270 individuals. The curve demonstrates a steady and continuous decline, reaching nearly zero occupants by around 130 to 140 seconds. This indicates that evacuation begins promptly without significant delays or initial plateaus. The smoothness of the curve, lacking flat sections or abrupt drops, suggests a consistent flow of evacuees without considerable stoppages or gaps.

Under these simulated conditions, all occupants are able to exit or reach safe zones in just over two minutes, reflecting reasonably fast evacuation performance. The absence of sharp drops or prolonged hold-ups implies no severe trapping of large groups, although minor bottlenecks likely caused slight deceleration, corresponding to high-density hotspots observed in the heatmap. It is important to note that real emergency scenarios involving smoke, panic, or blocked exits might increase evacuation time, so this simulation likely represents best-case or standard conditions.

Overall, the simulation highlights that the building's main circulation paths and exit routes can facilitate complete evacuation within a short and predictable timeframe. However, identified congestion points, especially near staircases, main corridors, and exits (consistent with red and yellow clusters in the heatmap), could pose critical challenges under emergency stress if conditions worsen due to obstruction or reduced visibility.

4. CONCLUSION

The comprehensive analysis of fire safety and evacuation conditions in the Main Library of Universitas Islam Indonesia (UII) shows that while the facility meets many fundamental requirements outlined by SNI 03-1736-2000 and NFPA 101 (2018), critical improvements are necessary to enhance occupant safety during fire emergencies. Emergency staircases comply with dimensional standards and have appropriate signage, and fire alarms and extinguishers are installed on every floor to support early detection and initial fire response. However, the smoke detectors are outdated and require urgent inspection or replacement to ensure functionality, and the absence of sprinkler systems in key zones such as hallways and certain floors limits active fire suppression capacity. Moreover, the placement of fire hydrants is inadequate, with internal hydrants located far from busy visitor areas, potentially hindering firefighting efforts.

Another concern is the lack of natural ventilation and the prevalence of fixed glass windows, causing smoke to accumulate easily and jeopardizing safe egress. The emergency exit system also has shortcomings, as entrance and exit doors serve dual functions, which may cause congestion and confusion during evacuations. Pathfinder simulation results support these findings by showing that although evacuation of all occupants can be completed within approximately 140 seconds under ideal conditions, there are significant bottlenecks around staircases, corridors, and exit points that could delay evacuation in real emergencies, especially if compounded by smoke, obstructed routes, or panic.

To address these issues, it is recommended that UII undertake several key improvements. First, the fire detection system should be upgraded by maintaining or replacing smoke detectors to ensure reliable early warnings, and automatic sprinkler systems should be installed in vulnerable areas to strengthen fire suppression capabilities. Second, the accessibility and distribution of fire hydrants should be improved by adding additional hydrants or hose connections closer to high-density visitor zones. Third, the building should be retrofitted with mechanical smoke extraction or pressurization systems to enhance ventilation and prevent smoke trapping, especially given the fixed-window design. Fourth, dedicated emergency exits distinct from main entrances should be created, equipped with panic hardware and clear signage to minimize congestion and facilitate rapid egress. Fifth, widening and optimizing circulation paths such as corridors and stairways identified as bottlenecks in simulations will improve evacuation flow.

In addition, regular fire safety drills and training for staff and users must be implemented to

increase familiarity with evacuation routes, assembly points, and emergency protocols. Finally, enhanced signage and orientation programs should ensure that all occupants, including new users, are well informed about assembly points and safety procedures. By combining these infrastructural and operational measures, the Main Library of UII can significantly improve its fire safety posture and emergency preparedness, thereby better safeguarding occupants and valuable resources in line with both national and international standards.

AUTHOR CONTRIBUTIONS

Fira Rahmawati contributed to the research's topic, research concepts, preparation, methodologies, investigations, data analysis, simulation, articles drafting, and revisions

Rania Ababssi contributed to manage preparation, methodology, and supervision.

Noor Cholis Idham contributed to methodology, supervision, reviewer, and validation.

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