(2026), 4 (2): 177-199 **Scientica** 3021-8209

Jurnal Ilmiah Sain dan Teknologi

SPATIAL PROGRAMMING OF SMART BUILDING-BASED DISASTER EDUCATION AND LOGISTIC CENTER

Diana Helen Panggabean [1], Yulesta Putra [2]

[1]*Student of Department of Architecture, Faculty of Engineering, Universitas Sumatera Utara, 20156, Indonesia*

[2]*Lecturer of Department of Architecture, Faculty of Engineering, Universitas Sumatera Utara, 20156, Indonesia*

*Corresponding Author: diana.helen8008@gmail.com

Abstract

Indonesia is a region with a high level of disaster risk due to its geological and geographical conditions, particularly on Sumatra Island, which lies along active tectonic corridors and plate convergence zones. This high disaster potential requires risk management approaches that go beyond emergency response and place stronger emphasis on disaster education and logistical systems. This research aims to formulate a spatial program as the basis for designing a Disaster Education and Logistics Center based on Smart Building Architecture. The research method involves an analysis of user characteristics, disaster-related activity flows, and spatial and functional requirements. The results of this study are presented in the form of a structured spatial program organized into four main zones, namely public, education, logistics, and management, which are designed to support preparedness, operational efficiency, and adaptive coordination of regional disaster management.

Article History

Submitted: 12 April 2026
Accepted: 15 April 2026
Published: 16 April 2026

Key Words

education center, logistic center, natural disaster, spatial programming, smart building architecture

1. Introduction

Indonesia ranks second out of 193 countries as the nation with the highest disaster risk worldwide based on the World Risk Report 2024, with a disaster risk index of 41.13 [1,2]. During the period 2015–2021, the frequency of disaster events showed an increasing trend from year to year before declining in 2022. However, in 2023 the number of events increased again and then decreased in 2024, as shown in Figure 1. According to records from the Disaster Data, Information, and Communication Center of the National Disaster Management Agency (BNPB), a total of 3,472 disasters occurred across various regions of Indonesia throughout 2024. These events resulted in significant humanitarian impacts, including 540 fatalities, 63 people reported missing, 11,531 injured individuals, and 8,136,271 people affected and displaced. In addition to human casualties, disasters in 2024 also caused physical damage to buildings and infrastructure, including 80,304 housing units, 612 educational facilities, 415 religious facilities, 82 health facilities, 89 office buildings, and 445 bridges [3].

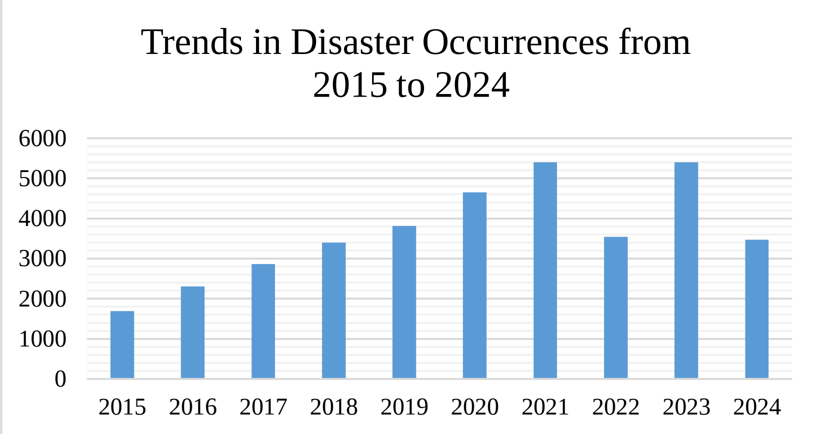

Figure 1 Trends in Disaster Occurrences from 2015 to 2024

Sumatra Island and its surrounding regions constitute one of the areas in Indonesia with a high level of vulnerability to natural disasters. This condition is influenced by the regional tectonic and geological setting, particularly the presence of subduction zones and active fault systems. Geologically, Sumatra Island is traversed by a major active onshore fault system known as the Great Sumatran Fault, which extends from the northern to the southern parts of the island. In addition, the Sumatra Trench is associated with the Sumatra forearc system, manifested in the Mentawai Fault, which serves as one of the primary sources of seismic activity in the Sumatra region [4].

Based on provincial disaster occurrence trends, North Sumatra and South Sumatra are included among the two of the five provinces with the highest number of disaster events, with forest and land fires being the most frequent hazards. North Sumatra experienced 170 events, accounting for 49% of the total disaster occurrences, while South Sumatra recorded 192 events, representing 71% of the total disaster occurrences [3]. Furthermore, based on the 2024 Indonesian Disaster Risk Index presented in Table 1, two out of ten provinces located on Sumatra Island and its surrounding areas fall into the high disaster risk category, namely Aceh with a score of 144.29 and Bengkulu with a score of 144.08. Meanwhile, the remaining eight provinces are classified as having a moderate disaster risk level [1]. This indicates that all provinces on Sumatra Island are vulnerable to natural disasters. Moreover, according to the disaster risk index by regency or city, seven regencies or cities from provinces on Sumatra Island are ranked among the top ten areas with the highest scores, namely Mandailing Natal Regency, North Nias Regency, Nias Regency, West Nias Regency, Agam Regency, Gunungsitoli City, and Aceh Besar Regency [1].

Table 1 Provincial Disaster Risk Index for 2024

No.	Regency	IRBI 2024	Kelas
1.	Aceh	144,29	High
2.	Bengkulu	144,08	High
3.	Kepulauan Bangka Belitung	143,42	Moderate
4.	Sumatera Barat	142,55	Moderate
5.	Sumatera Utara	139,84	Moderate
6.	Jambi	138,02	Moderate
7.	Riau	137,69	Moderate
8.	Sumatera Selatan	131,05	Moderate
9.	Lampung	130,10	Moderate
10.	Kepulauan Riau	109,24	Moderate

The high level of risk and intensity of disaster events on Sumatra Island underline the urgency of increasing awareness of disaster potential and implementing comprehensive disaster risk management, including through education-based strategies [5,6]. Education plays a strategic role as a means to introduce types of disasters and their associated risks to learners from an early stage. Disaster risk education, or disaster education, is a process of building awareness that includes strengthening knowledge, understanding, and concrete actions that support preparedness, prevention efforts, and post-disaster recovery processes [6]. However, field conditions indicate that over the past decade, disaster events have continued to cause significant impacts on the education sector. During the period 2016–2019, natural disasters were recorded to have affected approximately 568,000 students across 5,680 educational institutions [7]. This situation is exacerbated by the low level of knowledge and awareness among students and educators regarding emergency response procedures, even though educational institutions ideally function as centers for information dissemination and learning related to disaster prevention and mitigation [8]. Such knowledge and awareness are further expected to extend to the wider community, including parents and surrounding communities, so that all segments of society develop sensitivity to disaster issues and are encouraged to actively participate in disaster risk reduction efforts [9].

The challenges of disaster management are not limited to the education sector but also arise across various other sectors. The Deputy for Emergency Management of the National Disaster Management Agency (BNPB), Major General TNI Lukmansyah, M.Tr., stated that resource availability is a crucial aspect of emergency disaster response, including personnel, logistical assistance, equipment, and budgetary support. It was further emphasized that the capacity and capability of trained human resources still need to be continuously improved. In addition to human resource issues, the distribution of logistics and equipment necessary for evacuation and for meeting the basic needs of victims and displaced populations remains uneven across regions. This is reinforced by a statement from the Director of Logistics and Equipment Management at BNPB, Nadhirah Sera Nur, who emphasized that budget limitations and weak inter-agency coordination constitute major challenges in disaster logistics management, particularly in the procurement of necessities during the emergency phase, even though disaster logistics operations are part of the minimum service standards for disaster management [10].

In line with this perspective, the Coordinating Minister for Human Development and Cultural Affairs (Menko PMK), Prof. Dr. Pratikno, M.Soc.Sc., highlighted the importance of strengthening the capacity of local governments in facing disaster situations. In his directive, the Minister outlined five main points related to disaster prevention and mitigation, three of which include the development of anticipatory infrastructure through the provision of shelters and evacuation routes, the establishment of resilient disaster response units supported by early warning systems and emergency communication, and the strengthening of community awareness regarding disaster risks. The Coordinating Ministry for Human Development and Cultural Affairs also considers community-based disaster education, such as waste-free movements, the development of disaster-resilient villages, and the implementation of community-based disaster risk management, as highly important measures [10]. Within this framework, architecture can serve as a strategic medium to integrate disaster mitigation needs into spatial organization, activity patterns, and well-planned building systems. The formulation of spatial programming becomes a critical stage, given the diversity of user needs, ranging from disaster management professionals, volunteers, and educators to the general public, with activities that include education, simulation, and logistics management. A smart building architecture approach enables the integration of interactive learning technologies, sensor-based simulation systems, and real-time monitored logistics management, allowing buildings to function not only as physical facilities but also as adaptive systems that support disaster preparedness. Therefore, this research focuses on the development of spatial programming as the foundation for designing a smart building-based Disaster Education and Logistics Center, which is expected to enhance preparedness, operational efficiency, and disaster coordination at the regional level of Sumatra Island.

2. Literature

2.1 Natural disaster

Based on Law Number 24 of 2007 on Disaster Management, a disaster is defined as an event or a series of events that pose threats and disruptions to the continuity of community life and livelihoods. Such events may be triggered by natural factors, non-natural factors, or factors originating from human activities, thereby potentially causing loss of life, environmental damage, material losses, and psychological impacts. Within this definitional framework, natural disasters refer to disasters originating from natural processes, including earthquakes, tsunamis, volcanic eruptions, floods, droughts, cyclones, and landslides [11].

2.2 Natural disaster education

BNPB Regulation Number 1 of 2020 on the Accreditation of Education and Technical Training for Disaster Management defines the Disaster Management Education and Training Center (Pusdiklat PB) as a working unit responsible for coordinating and implementing capacity development activities for human resources in the field of disaster management. One of the key activities conducted is Technical Education and Training for Disaster Management (Diklat Teknis PB), which aims to enhance the mastery of knowledge and technical skills related to disaster management.

Within the framework of Diklat Teknis PB, emergency disaster response is understood as a series of actions carried out quickly and appropriately at the time of a disaster to address the negative impacts that arise. These actions include rescue and evacuation of victims, fulfillment of basic needs, protection of affected groups, management of displaced populations, and restoration of affected infrastructure and facilities. Furthermore, based on BNPB Head Regulations and emergency response documents of the Government of Aceh, the Disaster Emergency Response Command Post functions as the operational control center for emergency response implementation, serving to coordinate, control, monitor, and evaluate all disaster response activities in an integrated manner.

2.3 Natural disaster logistics

Logistics are defined as all tangible goods used to meet basic human needs and are consumable in nature, including food, clothing, and shelter along with their derivatives. In the context of disaster management, logistics categories include various types of consumable goods, such as staple food items, medicines, clothing and related equipment, clean water, sleeping bags, baby supplies, and household equipment for affected families [12].

An emergency warehouse is a facility that functions as a location for the receipt, storage, and direct distribution of logistical assistance at disaster sites. Such facilities may involve the use of existing buildings, the establishment of emergency tents, or the construction of new buildings with simple or semi-permanent structures [12]. Referring to Article 23 paragraph (1) of Government Regulation of the Republic of Indonesia Number 21 of 2008 on the Implementation of Disaster Management, the management of logistical assistance is carried out during the emergency phase, beginning from the emergency preparedness status, continuing through the emergency response phase, and extending to the emergency transition phase toward recovery [13].

Logistics assistance management under emergency conditions is an integrated activity that covers various stages, ranging from sourcing assistance, logistics procurement, quality control, packaging, delivery and transportation, warehouse storage, to inventory management. The distribution of logistical assistance must adhere to the principles of timeliness, appropriate location, target accuracy, quality, and quantity in accordance with on-site needs. Therefore, logistics management during disaster emergencies is required to be conducted effectively and efficiently, making the preparation of logistics management guidelines a crucial aspect in supporting disaster management service standard [13].

2.4 Smart building architecture

According to The Intelligent Building Institution Washington (1998), a smart building is a building that integrates various systems in a coordinated manner to manage building resources through centralized control mechanisms. This system integration aims to optimize technical performance and investment value, while reducing operational costs and enhancing building flexibility in the long term [14].

The emergence of the smart building concept is closely related to increasing societal welfare and changes in modern lifestyles that demand higher service quality and improved management of the built environment. This condition has direct implications for the level of comfort and service quality experienced by building users, which subsequently affects productivity, motivation, and satisfaction for both users and building owners [14].

In the context of smart building planning, the Intelligent Building concept formulates a set of fundamental design principles known as Quality Environmental Modules (QEM). These principles include environmental friendliness, health, energy efficiency, spatial flexibility, operational cost effectiveness, user comfort, construction process efficiency, safety and security, cultural sensitivity, application of high technology, quality of structural and construction processes, as well as compliance with health and sanitation standards. These modules serve as the conceptual foundation for the development of sustainable and adaptive smart building design [15].

2.5 Case study

A review of comparable buildings is required to formulate the spatial program for the Disaster Education and Logistics Center. The case studies presented in Table 2 highlight several international disaster education centers that share similar functions, namely as facilities for learning, simulation, and enhancing community preparedness for disasters. The analysis focuses on identifying the types of spaces and the main activities accommodated, without addressing the form or aesthetic aspects of the buildings.

Table 2 Case Study

Case Study	Space	Function
Honjo Life Safety Learning Center / Honjo Disaster Prevention Center	Disaster Education Theater	A room that functions as a screening area for educational videos explaining types of disaster risks and basic safety procedures prior to the simulation activities.
	Earthquake Experience Corner	This room is used to simulate earthquake shaking with the aim of training basic Drop–Cover–Hold On responses.
	Smoke Room / Smoke Maze	This room is equipped with an artificial smoke system to train evacuation procedures under fire conditions with limited visibility.
	Flood Simulation Area	A room designed to simulate water pressure and urban flood conditions in order to enhance understanding of flood risks.
	Rainstorm / Typhoon Simulation Room	This room is used to simulate heavy rainfall, strong winds, and storms to introduce extreme weather conditions.

	Fire Extinguisher Practice Area	This room functions as a training area for the use of portable fire extinguishers through visual-based simulation.
	First Aid / AED Training Zone	This room is used for first aid training and the use of automated external defibrillators (AED) in emergency situations.
	Exhibition Area / Life Safety Gallery	This room functions as an exhibition space presenting information on disaster mitigation and community preparedness.
	Interactive Learning Zone	This room is used for interactive learning through quizzes, educational games, and digital media.
Yokohama Disaster Risk Reduction Learning Center	Disaster Theater	This room serves as a visual educational medium displaying documentation of major earthquakes in Yokohama and their potential impacts on the city.
	Eartquake Simulator	This room is used for earthquake simulations with varying intensity levels, including scenarios based on historical major earthquakes.
	Fire Simulator	This room functions to train the use of fire extinguishing equipment and evacuation procedures under fire and smoke conditions.
	Disaster Mitigation Training Room	This room is arranged to resemble a residential environment and is used for random disaster simulations to train spontaneous responses and evacuation routes.
	Disaster Prevention Library	This room functions as a disaster information center, including reading materials, educational media, and emergency procedure training.
	Mansion Disaster Preparedness Room	This room is used to simulate disaster preparedness in vertical residential environments, including the use of emergency staircases and earthquake-resistant devices.
	VR Experiences, Video, and CG	This room utilizes virtual reality technology and digital media to simulate various disaster scenarios.
921 Earthquake Museum of Taiwan	Chelungpu Fault Gallery	This room functions to display active fault lines and ground deformation resulting from earthquakes in a tangible manner.
	Earthquake Engineering Room	This room is used to demonstrate building damage and the principles of earthquake-resistant structural engineering.
	Image Gallery	This room functions as visual documentation of post-disaster conditions, including evacuation processes, relief efforts, and reconstruction.
	Disaster Prevention Room	This room is used for public education regarding types of disasters and preparedness measures.

	Reconstruction Records Room	
	Outdoor Preserved Site / Outdoor Area	Documentation presenting reconstruction processes, historical events, and how communities and governments responded.
	Outdoor preserved site	This area functions as an outdoor educational space that preserves damaged buildings and infrastructure as direct learning media.

The case studies presented in Table 1 indicate that disaster education centers generally include spaces dedicated to theoretical education, experiential-based simulations, and technology-supported supporting facilities. The spatial patterns identified emphasize the importance of interactive learning, realistic simulations, and well-structured activity flows. These findings serve as the basis for formulating the spatial program of the proposed Disaster Education and Logistics Center, with adjustments to the disaster risk context, user needs, and the smart building architecture approach.

3. Method

This research adopts a descriptive qualitative approach that focuses on analyzing functional requirements, user characteristics, and activity patterns to formulate the spatial program of a disaster education and logistics center. This approach is selected because spatial programming design does not require experimental measurement, but rather a comprehensive understanding of activity characteristics and applicable spatial standards. Data are collected through a literature review of guidelines for education and training facilities, disaster logistics warehouses, and case studies of comparable buildings.

The analytical process in this study is carried out through several main stages, as illustrated in Figure 2. The first stage is user analysis, which aims to identify the primary user profiles of the building, including disaster management professionals, volunteers, school students, university students, and the general public. The second stage involves activity analysis, which maps various activities carried out within each function, such as storage and distribution of relief logistics, evacuation training, learning activities, and disaster simulations. The third stage is space requirement analysis, which translates user activities into spatial requirements, including inter-space relationships, capacity, and area standards.

The analysis of space requirements is not solely based on user activities, but also considers types of disasters and relevant forms of disaster education, the smart building architecture approach, and the application of evacuation technologies. The outcomes of these stages are a set of spaces formulated as a spatial program and grouped according to functional zones. The subsequent stage is inter-space relationship analysis, determined by considerations of building zoning, coordination needs between functions, and user activity flows. The final stage is spatial placement analysis to determine the position and distribution of spatial zones within the building. Overall, these analytical stages result in a schematic plan as an initial representation of the building’s spatial layout.

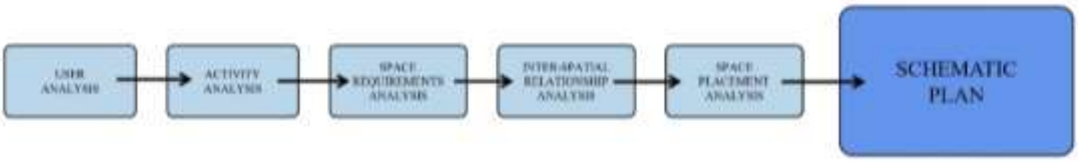

Figure 2 Design Thinking Process

4. Result and Discussion

4.1. Building main function

The Disaster Education and Logistics Center is designed as an integrated facility that combines educational and technical training functions with the provision of disaster logistics support. The first function focuses on disaster management education through the implementation of technical training, disaster simulations for professional personnel, and disaster preparedness education programs for school and university students. This educational function aims to enhance understanding, technical skills, and community readiness in facing emergency situations in a structured and sustainable manner. The second function serves as a center for the provision and distribution of logistical resources required during emergency response conditions, including the storage, management, and distribution of aid to disaster-affected communities. In carrying out these two functions, the building primarily serves user groups consisting of facility management or administrators, operational or service personnel, and partner institutions involved in both educational activities and disaster logistics operations. Table 3 describes the main activities that are the focus of each building function.

Table 3 Building Main Function

Building Function	Building Function	Main Activity
Education	Professional Education Program	Emergency response training and simulation Digital disaster simulation (VR/AR) Disaster response personnel certification program
	Student Education Program	Receiving education on disaster preparedness Conducting light simulations of natural disasters
Logistic	Logistic Function	Storage and management of aid stocks Packaging and distribution of logistics Coordination of inter-agency distribution Collection and verification of community aid Maintenance of emergency aid equipment and facilities Smart logistics storage (smart warehouse)

4.2. User Analysis

Based on the Comprehensive School Safety Framework (2017), disaster management within the school environment constitutes one of the three main pillars in achieving comprehensive school safety. The United Nations Office for Disaster Risk Reduction (UNDRR) emphasizes that schools serve as the most effective entry point for building a culture of disaster awareness, as students act as multipliers who are able to disseminate the disaster-related knowledge they acquire to their parents and family environments. Therefore, the implementation of formal disaster education in schools has a significant influence on increasing community preparedness at a broader level [16].

In line with this, the 2025 National Coordination Meeting on Disaster Management (Rakornas PB) also emphasized the importance of delivering disaster education to the community, particularly in the context of disaster risk management and the development of communities that possess awareness and capacity to face potential disasters [10]. This indicates that disaster education should not only be directed at students, but also needs to reach the general public as part of a sustainable preparedness system.

On the other hand, the effectiveness of disaster management efforts is highly dependent on the availability of adequate resources. The Deputy for Emergency Management of the National Disaster Management Agency (BNPB), Major General TNI Lukmansyah, M.Tr.(Han), stated that the main challenge faced by many regions in emergency disaster response is limited resources, including personnel, material assistance, equipment, and budgetary support. In addition, the capacity and capability of trained human resources still need to be continuously enhanced in order to respond optimally to emergency situations. Therefore, disaster management professionals who operate during disaster events constitute one of the primary user groups that require facility support tailored to their operational needs [10].

In addition to human resources, logistics and equipment are also critical factors in the success of emergency response. Limitations in logistics and supporting facilities directly affect evacuation processes and the fulfillment of basic needs for victims and displaced populations. The Deputy for Emergency Management of BNPB emphasized that disaster logistics operations are part of the minimum service standards for disaster management, and therefore must be planned and managed in an integrated and effective manner [10]. Accordingly, in addition to supporting educational and coordination activities, disaster-related facilities also need to accommodate the requirements for optimal logistics and equipment management.

Table 4 describes the classification of building users as the basis for determining spatial requirements and functional zoning. Users are divided into four main groups, namely visitors as the primary building users involved in disaster education, training, and simulation activities; managers and staff as administrators responsible for operational functions, facility management, and control of building activities; and stakeholders as external parties who play strategic roles in cooperation, policy support, and the strengthening of the Disaster Education and Logistics Center's functions.

Table 4 User

User	User Detail
Visitor	Profeasional worker (BNPB, BPBD, TNI/Polri, BASARNAS, firefighter, dan PMI personnel) NGO volunteer Student College student Public
Manager	Chief Manager Education Division Manager Professional Education Program Manager Student Education Program Manager Logistics Division Manager
Staff	Administration and public relations Technicians and MEP Cleaning and security Operational personnel Logistic Staff Service Staff Utilities Staff
Stakeholder	BNBP BPBD

	BASARNAS Education Office Social Services Office Indonesian National Armed Forces/Indonesian National Police Humanitarian NGO Volunteers Fire Department

4.3. Activity analysis

As part of the spatial programming method, an analysis of activities and space requirements is conducted to link building functions with user activities. The analysis presented in Table 5 includes the identification of activity actors, types of activities categorized into primary and supporting activities, as well as the corresponding space requirements. The results of this analysis are presented in tabular form to facilitate a clear understanding of the relationships between activities and the planned spaces.

Table 5 Activity Analysis and Space Requirement

Specification of Actors	Activity		Space Requirement
Professional Worker	Main Activity	Activities coming and going from the building	Public Parking Area
			Drop off dan Pick up
			Entrance
			Lobby
		Conducting initial introductions, registration, and obtaining preliminary information	Reception
			Information Center
		Conducting a briefing before conducting simulation activities	Briefing Room for professional
		Conducting technical training and emergency response simulations	Simulation and Training Room for Professional
		Obtaining simulations of natural disasters	Natural Disaster Education Room
		Conducting digital disaster simulations (VR/AR)	VR/AR Simulation Room for Professional
		Obtaining a disaster training certificate program	Examination Room for professional
		Gaining insights about disasters through books	Library
	Supporting Activity	Receiving medical assistance in case of accidents/injuries during training	Clinic Corner for professional
		Storing participants' bags, shoes, or equipment before the simulation	Locker Area for Professional
		Consumption activities, worship, and use of public sanitation facilities.	Rest Area
	Main Activity	Activities coming and going from the building	Public Parking Area
			Drop off dan Pick up

Student and General Public			Entrance
			Lobby
		Conducting initial introductions, registration, and obtaining preliminary information	Reception
			Information Center
		Learning the basics about types of disasters, causes, impacts, and self-rescue measures.	Natural Disaster Education Class for Students
		Receiving briefings and information about disaster learning before the simulation	Student Longue
		Providing direct experience in dealing with minor emergencies such as earthquakes or fires.	Simulation Room for Student
		Virtual reality (VR/AR) experiences simulating disaster conditions (earthquakes, floods, fires, etc.) to enhance awareness and reflexes.	VR/AR Simulation Room for Student
		Providing education or learning about earthquakes through visual media	Gallery/Exhibiton Hall
			Interactive Display Room
		Watching documentary films or stories of disaster survivors	Mini Theater
		Gaining insights about disasters through books	Library
		Conducting light practices such as making simple evacuation tools.	Workshop Room
		Issuing participation certificates to motivate students to understand disaster preparedness.	Certification & Admin Room
	Supporting Activity	Conducting discussions or sharing sessions.	Discussion Longue
		Purchasing or obtaining merchandise related to disaster management, such as books, stationery, and so on.	Souvenir shop
		Providing minor medical treatment for minor injuries.	Clinic Corner
		Storing participants' bags, shoes, or equipment during simulations.	Locker Area for Student
		Supporting Student Comfort	Rest Area
Chieff Manager	Main Activity	Activities coming and going from the building	Special Parking Area for Managers and Staff
			Drop off
			Entrance
			Lobby
		Evaluate the work results of each division and ensure efficiency	Inter-Division Meeting Room

		Coordinate with partner institutions such as BNPB, PMI, universities, or international institutions	Meeting Room with Stakeholders
		Compile performance reports, financial reports, and evaluations of the effectiveness of activities.	Archieve Room
		Become the command center in emergency situations or major disasters	Manager's Office
			Command Center
		Communicate with the media and the public during emergency situations (situations that require orders from the local government)	Command Center
	Supporting Activity	Secretary: Managing schedules, correspondence, meeting archives, and reports	Manager's Secretariat Office
		Finance and administration team: Managing budgets, operational logistics, and facility maintenance needs.	Administration and Finance Office
		Public Relations Team: Managing media publications, event promotions, and inter-institutional relations.	Public Relations Office
		IT Team: Managing participant digital data, VR/AR systems, and event archives.	Server Room / IT Staff Office
		Monitoring and Evaluation Team: Evaluating the effectiveness of educational programs and logistics	Small Meeting Room / Evaluation Room
		Supporting the comfort of staff and key managers.	Rest Area
Manager and Staff of the Professional Workforce Education Program	Main Activity	Activities coming and going from the building	Special Parking Area for Managers and Staff
			Drop off and Pick up
			Entrance
			Lobby
		Arrange training participant schedules, manage participant data, training schedules	Professional Division Manager's Office
			Professional Training Administration Office
			Coordinator Room
		Register training participants	Lobby/Resepsionis
		Set up digital disaster scenarios	Control Room VR/AR

			Server Room / Data Storage
		Maintain VR devices, sensors, and motion tracking systems.	Maintenance & Calibratioon Room
		Managing participant data, accreditation, and certificate issuance.	Certification Room
		Checking, maintaining, and storing training equipment.	Storage and Equipment Bay
			Drying and Cleaning Room
		Operating virtual or other technologies to support student education.	Professional Education IT Room
		Staff Comfort Support	Rest Area
Manager and Staff of Student Education Program	Supporting Activity	Activities coming and going from the building	Special Parking Area for Managers and Staff
			Drop off dan Pick up
			Entrance
			Lobby
		Arrange training participant schedules and manage visitor data	Student Division Manager's Office
			Student Training Administration Office
			Coordinator Room
		Register training participants	Lobby
			Resepsionis
		Organize curriculum or learning materials	Lecturer/Teacher Room
		Maintain training and simulation equipment	Maintenance & Calibratioon Room
		Manage certificate issuance.	Certification Office for Student
		Check, maintain, and store training equipment	Storage and Equipment Bay
		Operate virtual or other technology to support student education	Student Education IT Room
		Staff Comfort Support	Rest Area
Logistics Manager and Staff	Main Activity	Logistics vehicle arrivals and departures	Special Parking Area for Logistics Vehicles
		Building arrivals and departures	Special Parking Area for Managers and Staff
			Drop off
			Entrance
			Lobby

		Main route for heavy goods to enter and exit without disturbing visitors.	Loading Dock
			Unloading Dock
		Collection and Verification of Community Aid	Receiving Area
			Verification & Sorting Area
		Storage and Management of Aid Stock	Dry Storage
			Food Storage
			Medical Supplies Storage
			Waste Storage
		Packaging and Distribution of Logistics	Packing Zone
			Distribution Preparation Area
		Smart Logistics Storage (Smart Warehouse)	Smart Storage Zone
			Control Room
	Supporting Activity	Handling correspondence, documentation, and activity archives.	General logistics administration room
		Welcoming official guests, partner institutions, or activity speakers.	Logistics reception room
			Coordination Office / Command Center
		Conducting routine checks on technical facilities and building cleanliness.	Maintenance room
			Equipment warehouse
		Supporting Staff Comfort	Rest Area
Utilities Staff	Main Activity	Supporting building utilities	Fire Control System Room
			CCTV Room
			Panel Room
			Generator Room
			AHU Room
			GWT Room
			Pump Room
			Chiller Room
			Water Disposal Area Temporary
Cleaning Staff	Main Activity	Maintaining Room Cleanliness	Janitor
Security Guard	Main Activity	Maintaining Building Security	Guard Post
All Staff	Supporting Activity	Supporting Staff Comfort	Rest Area

4.4. Space requirement analysis

The analysis of space requirements is not solely based on user activities, but also takes into account relevant disaster types and forms of disaster education, the smart building architecture approach, and the application of evacuation technologies. The results of this space requirement analysis produce a more detailed spatial program that comprehensively accommodates user space needs.

4.4.1. Space requirements based on disaster types

Each type of disaster has distinct risk characteristics, event dynamics, and safety levels, meaning that not all disasters can be physically simulated within the learning process. Therefore, the formulation of space requirements in this research is differentiated according to disaster types and the most appropriate educational approaches. Disasters with characteristics that allow for safe simulation, such as floods, storm rainfall or strong winds, and earthquakes, are accommodated through experiential-based training and simulation spaces. Meanwhile, disasters with high risk levels or long event durations, such as landslides, volcanic eruptions, droughts, and coastal abrasion, are addressed through theoretical and visual learning in media-based interactive education spaces. Table 6 presents a mapping of disaster types, learning activities, and space requirements specifically designed to support the effectiveness of disaster education.

Table 6 Application of Educational Technology

Actor	Natural Disaster	Activity	Space Requirements	Detail Space
Professional Worker, Student, and Public	Flood, Flash Flood, dan Tsunami	Training and simulation	Simulation and Training Room	High water training room
	Flood and Flash Flood	Training and simulation	Simulation and Training Room	Flood Door Pressure Simulator
	Extreme Weather (Strong Winds & Heavy Rain)	Training and simulation	Simulation and Training Room	Rainstorm Simulation Room
	Fires	Training and simulation	Simulation and Training Room	Smoke Maze
		Training and simulation	Simulation and Training Room	Fire Extinguisher Practice Area
	Earthquakes	Training and simulation	Simulation and Training Room	Earthquake Simulator (Drop-Cover-Hold-On)
	-	Training and simulation	Simulation and Training Room	First Aid Simulation
	Landslides, volcanic eruptions, droughts, tornadoes, tidal waves, and abrasion.	Theoretical learning about natural disasters	Natural Disaster Education Room	Classroom
				VR/AR Simulation Room
				Disaster Education Center
				Interactive Learning Zone
				Hybrid Learning / Distance Learning Room

4.4.2. Space Requirements Based on the Smart Building Architecture Approach

Based on the smart building architecture approach, several additional spaces are required to support the integration of technological systems, simulation management, and adaptive, data-driven learning processes. These spaces function not only as support for educational and training activities, but also play a role in building system management, learning content development, and evaluation of simulation outcomes. Table 7 presents the proposed additional spaces required as an implication of implementing the smart building architecture approach in the Disaster Education and Logistics Center.

Table 7 Application of Smart Building Architecture

Smart Building Features	Space Requirements	Function
Simulation scenario control	Disaster Simulation Control Room	• Controlling disaster simulation scenarios, sensors, and digital systems • Disaster simulation processing & scenario visualization
Data management	Building Management System (BMS) Room	Monitoring building performance, energy, and safety systems
Learning development	Digital Learning Content Room	Production of VR/AR content, educational videos, and interactive modules
Training evaluation	Evaluation & Debriefing Room	Analysis of simulation results and post-training discussions
Information management	Disaster Data & Information Center	Storage and processing of disaster data for education
Monitoring data bencana real-time	Smart Disaster Dashboard	Data analysis center, simulation coordination, and decision making
Sensor & Data Gathering	Building Data & Server Room	Collection of earthquake, flood, weather, and air quality data
Smart Evacuation System	Evacuation Control Room	Adaptive evacuation routes & early warning systems
Smart Energy System	Energy Monitoring Room	Monitoring of solar panels, batteries, and energy consumption
Smart Water System	Smart Water Management Room	Control of water distribution and quality

4.4.3. Space requirements based on evacuation technologies

The implementation of evacuation technologies in this building functions not only as a safety system but also shapes specific spatial requirements. Each evacuation technology has distinct operational characteristics, and therefore requires appropriate spatial support to function optimally under emergency conditions. Accordingly, the space requirements presented in Table 8 are developed based on the types of evacuation systems applied, such as alternative evacuation routes, vertical evacuation systems, smoke-free ventilation, and temporary refuge spaces. This approach ensures that evacuation systems are not treated as add-on elements, but are integrated from the early stages of spatial planning.

Table 8 Application of Evacuation Technology

Evacuation Technology	Description	Space Requirments
Emergency Escape Chute	A tube or slide system that allows evacuees to descend quickly from upper floors to the outside of the building during emergency situations. This system can reduce the load on emergency staircases and accelerate the evacuation process.	Entrance chute or balcony chute, an upper-floor space with direct access to the evacuation chute. A lower-floor space where chute users land.
External Escape Staircase	An external open staircase that enables evacuation without passing through interior spaces that may be filled with smoke or obstructed by earthquake damage.	Exit routes on each floor. External staircase landing.
Control Devent Devices	A harness-based device that allows users to descend in a controlled manner from upper-floor windows or balconies to the ground safely. This evacuation technology is useful when stairs and elevators cannot be used.	Control Room
Smart Evacuation Signage	A dynamic evacuation signage system that can change directions or guide occupants to the optimal evacuation routes based on real-time conditions. This technology helps reduce panic and congestion during emergencies.	Main Corridor Emergency staircase.
Smoke Extraction System & Stair Pressurization	A specialized ventilation system that removes smoke from evacuation routes and keeps emergency staircases smoke-free, thereby enabling safe evacuation.	Main Corridor Emergency staircase
Refuge Balcony	A space or balcony designed as a temporary refuge area when evacuation is delayed, equipped with positive pressure or smoke control systems and emergency communication facilities.	Refuge Room

4.4.4. Spatial programming

Following the analysis of user activities, disaster types, the smart building architecture approach, and the application of evacuation technologies, a comprehensive building spatial program is formulated. The spatial program presented in Table 9 is the outcome of all preceding analytical stages and serves as the basis for designing the building's spatial layout. Each space within the program not only responds to functional requirements, but also takes into account aspects of education, safety, flexibility, and disaster preparedness.

Table 9 Spatial Programming

Entrance Zone	Education	Logistic Zone	Management Zone	Service Zone	Utilities Zone
Special Parking Area for Managers and Staff	Briefing Room for professional	Special Parking Area for Logistics Vehicles	Inter-Division Meeting Room	Visitor Restroom	Fire Control System Room
General Parking Area	High water training room for professional	Special Parking Area for Managers and Staff	Meeting Room with Stakeholders	Prayer Room	CCTV Room
Drop off dan Pick up	Flood Door Pressure Simulator for professional	Drop off	Archieve Room	Profession al Staff Changing Area	Panel Room
Entrance	Rainstorm Simulation Room for professional	Entrance	Manager's Office	Profession al Staff Rest Area	Generator Room
Lobby	Smoke Maze for professional	Lobby	Command Center	Profession al Staff Shower	AHU Room
Reception	Fire Extinguisher Practice Area for professional	Loading Dock	Manager’s Secretariat Office	Profession al Staff Restroom	GWT Room
Informatio n Center	Earthquake Simulator (Drop-Cover-Hold-On) for professional	Unloading Dock	Administration and Finance Office	Student Changing Area	Pump Room
	First Aid Simulation for professional	Receiving Area	Public Relations Office	Student Rest Area	Chiller Room
	Natural Disaster Classroom for professional	Verification & Sorting Area	Server Room / IT Staff Office	Main Manager Restroom	Water Disposal Area Temporary
	VR/AR Simulation Room for professional	Dry Storage	Small Meeting Room / Evaluation Room	Profession al Staff Education Program Manager Restroom	Janitor
	Disaster Education Center for professional	Food Storage	Professional Division Manager’s Office	Student Education Program Manager Restroom	Guard Post

	Interactive Learning Zone for professional	Medical Supplies Storage	Professional Training Administration Office	Logistics Division Manager Restroom	Energy Monitoring Room
	Hybrid Learning / Distance Learning Room for professional	Waste Storage	Coordinator Room	Staff Manager Restroom	Smart Water Management Room
	Examination Room for professional	Packing Zone	Control Room VR/AR	Staff Longue Manager Utama	Entrance chute or balcony chute
	Library	Distribution Preparation Area	Server Room / Data Storage	Staff Longue Divisi Edukasi	A lower-floor space where chute users land.
	Clinic Corner for professional	Smart Storage Zone	Maintenance & Calibrationoon Room	Staff Longue Divisi Logistik	Exit routes on each floor.
	Locker Area for Professional	Control Room	Certification Room	Toilet Staff	External staircase landing.
	Student Longue	General logistics administration room	Storage and Equipment Bay	Locker Staff	Emergency staircase.
	High water training room for student and public	Logistics reception room	Drying and Cleaning Room		
	Flood Door Pressure Simulator for student and public	Coordination Office / Command Center	Professional Education IT Room		
	Rainstorm Simulation Room for student and public	Maintenance room	Student Division Manager’s Office		
	Smoke Maze for student and public	Equipment warehouse	Student Training Administration Office		
	Fire Extinguisher Practice Area		Coordinator Room		

for student and public	
Earthquake Simulator (Drop-Cover-Hold-On) for student and public	Lecturer/Teacher Room
First Aid Simulation for student and public	Maintenance & Calibratioon Room
Natural Disaster Classroom for student and public	Certification Office for Student
VR/AR Simulation Room for student and public	Storage and Equipment Bay
Disaster Education Center for student and public	Student Education IT Room
Interactive Learning Zone for student and public	Disaster Simulation Control Room
Hybrid Learning / Distance Learning Room for student and public	Building Management System (BMS) Room
Gallery/Exhibition Hall	Digital Learning Content Room
Interactive Display Room	Evaluation & Debriefing Room
Mini Theater	Disaster Data & Information Center
Library	Smart Disaster Dashboard
Workshop Room	Building Data & Server Room

	Certification & Admin Room	Evacuation Control Room
	Discussion Longue	
	Souvenir shop	
	Clinic Corner	
	Locker Area for Student	

4.4.5. Inter-spatial relationship analysis

The inter-spatial relationship analysis is conducted to ensure that functional linkages among the main spaces within the building operate effectively and efficiently. These relationships are determined based on building functional zoning, user interactions, activity flows, and coordination requirements among educational, logistics, and management functions. Based on Figure 3, spaces requiring close adjacency, separation, or indirect relationships can be identified in order to support smooth activity flows and minimize potential functional conflicts, particularly under emergency conditions.

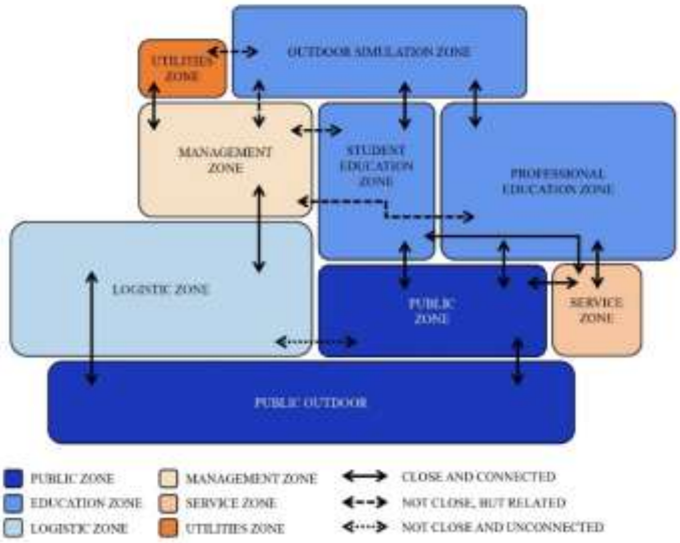

Figure 3 Inter-Spatial Relationship

4.4.6. Inter-spatial placement analysis

Based on the analyzed inter-spatial relationships, a spatial placement analysis is subsequently conducted to determine the position and zoning of spaces within the building. Spatial placement considers ease of access, functional hierarchy, and responsiveness to disaster conditions. Spaces with high public intensity are located in easily accessible areas, while operational spaces and smart building systems are placed in more controlled zones. The analysis presented in Table 10 aims to produce a spatial arrangement that is not only efficient under normal conditions, but also adaptive and safe during emergency situations.

Table 10 Zone Placement Analysis

Zone	Public, Logistics, Simulation Zone	Student Education	Professional Education	Management

Placement Analysis	The ground floor is the most accessible floor for visitors.	FEMA recommends that simulation rooms for students be located in areas with large capacity but still easy to evacuate (floors that are not too high).	Professional training involves more intense exercises, so it is conducted in a more isolated setting. FEMA emphasizes that professional training areas must be separated from students for safety and security reasons.	The management room must be protected, quiet, and far from public/logistics areas.
Space	Public Zone Entrance Lobby Reception Information Center Gallery / Exhibition Hall Interactive Display Room Souvenir Shop Musholla Visitor Toilet Logistic Zone Loading–Unloading Dock Receiving Area Verification & Sorting Area Main Logistics Warehouse Cold Storage Equipment Storage Service Zone Visitor Toilet Musholla Utilities Zone Guard Post Generator Room	Student Education Room Disaster Education Class for Students Indoor Simulation Hall for Students First Aid Simulation Room VR/AR Simulation Room for Students Student Lounge Discussion Lounge Mini Theater Workshop Room Additional gallery if needed Locker Area for Students Student Changing Area Student Toilets Student Rest Area	Professional Education Room Classroom for Professional Briefing Room for Professional Clinic Corner (Professional) Locker Area for Professional Professional Changing Room Professional Restroom Shower VR/AR Simulation Room for Professional Indoor Simulation Hall Control Room VR/AR Certification and Admin Office Storage and Equipment Bay	Management Zone Coordination Room / Command Center Meeting Room Meeting Room with Partners Division Manager Room (Professional, Student, Logistics) Administration & Finance Room Secretariat Room PR / Public Relations General Logistics Administration Room Inventory Control Office Control Room (IT/logistics) Server Room

	Pump Room AHU / Chiller Room GWT Room Panel Room Janitor Outdoor Education Zone Outdoor Simulation	Drying and Cleaning Room	Data Storage Room Maintenance & Calibration Room Staff Lounge Manager / Staff Toilet

Following the determination of general spatial zoning, the next stage involves a more detailed spatial placement analysis as presented in Table 11. This analysis seeks to elaborate the position of each space within the building based on activity characteristics, levels of accessibility, technical requirements, and functional relationships between spaces. A more detailed spatial placement is necessary to ensure smooth user circulation, operational efficiency, and integrated support for disaster education and logistics functions.

5. Conclusion

This study concludes that spatial programming is a fundamental stage in the design process of a Disaster Education and Logistics Center, particularly in high-risk disaster regions such as Sumatra Island. Through an analytical approach that includes the identification of user characteristics, mapping of disaster-related activity flows, and formulation of space requirements influenced by educational and logistical functions, this research produces a structured spatial program organized into education, logistics and management, public, service, and utility zones. The application of a smart building architecture approach plays a significant role in enhancing the effectiveness of disaster education, improving the efficiency of logistics management, and supporting adaptive operational coordination during emergency conditions. Therefore, the results of this study are expected to serve as a conceptual reference for the design of disaster-related facilities that are not only responsive to emergency response needs but also contribute sustainably to preparedness enhancement, risk mitigation, and regional disaster resilience capacity building.

6. Acknowledgment

The author expresses sincere gratitude to all parties who provided support, input, and references throughout the research process. Appreciation is also extended to the academic institution and supervising lecturers for their guidance and assistance during the completion of this study.

7. Conflict of Interest

The author declares that there is no conflict of interest, either financial or non-financial, that could have influenced the research process or the preparation of this article.

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