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APPLICATION OF MODULAR ARCHITECTURE IN THE DESIGN OF COMMUNITY EVACUATION CENTER

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Abstract

Indonesia faces a high risk of natural disasters such as earthquakes, floods, and landslides due to its position on the Pacific Ring of Fire. With the frequency of disasters reaching more than 4,500 events per year, adequate evacuation facilities are needed to meet the needs of refugees. However, existing evacuation facilities are often temporary and less than optimal in meeting basic needs. This research proposes the development of a modular architecture-based evacuation center using the prefabrication method, which offers design flexibility, efficiency in construction time, and adaptability to the number of evacuees. Through a qualitative descriptive method, the researcher analyzes space requirements, minimum standards of evacuation facilities, and relevant modular construction typologies. Data was collected through literature study, case analysis, and design simulation to determine the best implementation approach. This approach considers technical, functional, and comfort aspects for refugees, volunteers, and the general public

Keywords: *Natural, Center Disaster Community, Evacuation Modular Architecture.*

INTRODUCTION

Natural disasters are events caused by geological, meteorological, and human environmental factors, which can threaten people's lives and cause losses, such as casualties, environmental damage, and economic and psychological impacts. Various types of disasters, such as floods, landslides, extreme weather, earthquakes, volcanic eruptions, and forest fires, often occur in Indonesia. As a country located on the Pacific Ring of Fire with high tectonic and volcanic activity, Indonesia has a significant level of vulnerability to geological, climatological, and socio-demographic disasters.

Indonesia's presence at the confluence of the world's three major tectonic plates, namely the Eurasian, Indo-Australian, and Pacific Plates, causes a high risk of geological disasters such as volcanic eruptions, earthquakes, and tsunamis. As a tropical country, Indonesia also faces climatological threats in the form of floods, landslides, and disease outbreaks triggered by climate change and extreme weather. These conditions have a broad impact on the social, economic, and environmental life of the community.

Province	Year						Total	Progression			
	2019	2020	2021	2022	2023	2024 (26 Sept 2024)		2019–2020	2020–2021	2021–2022	2022–2023
Aceh	180	364	279	222	236	74	1355	102.2%	-23.4%	-20.4%	6.3%
North Sumatra	71	150	173	107	217	89	807	111.3%	15.3%	-38.2%	102.8%
West Sumatra	103	241	212	78	136	52	822	134.0%	-12.0%	-63.2%	74.4%
Riau	58	55	148	96	260	46	663	-5.2%	169.1%	-35.1%	170.8%
Riau Islands	21	64	107	11	105	34	342	204.8%	67.2%	-89.7%	854.5%
Jambi	28	104	99	9	93	19	352	271.4%	-4.8%	-90.9%	933.3%
Bengkulu	26	37	45	45	38	10	201	42.3%	21.6%	0.0%	-15.6%
South Sumatra	95	90	92	103	85	57	522	-5.3%	2.2%	12.0%	-17.5%
Bangka Belitung	22	26	40	47	125	19	279	18.2%	53.8%	17.5%	166.0%
Lampung	50	43	76	71	74	43	357	-14.0%	76.7%	-6.6%	4.2%
West Kalimantan	43	82	69	57	116	39	406	90.7%	-15.9%	-17.4%	103.5%
Central Kalimantan	76	89	94	77	202	37	575	17.1%	5.6%	-18.1%	162.3%
East Kalimantan	55	115	119	46	252	16	603	109.1%	3.5%	-61.3%	447.8%
North Kalimantan	21	76	60	22	75	8	262	261.9%	-21.1%	-63.3%	240.9%
South Kalimantan	154	193	272	107	539	20	1285	25.3%	40.9%	-60.7%	403.7%
Banten	64	96	113	80	62	25	440	50.0%	17.7%	-29.2%	-22.5%
Jakarta	6	22	29	17	17	11	102	266.7%	31.8%	-41.4%	0.0%
West Java	706	942	1358	824	844	157	4831	33.4%	44.2%	-39.3%	2.4%
Central Java	924	1021	622	488	629	147	3831	10.5%	-39.1%	-21.5%	28.9%
Yogyakarta	29	36	26	29	176	8	304	24.1%	-27.8%	11.5%	506.9%
East Java	622	251	366	400	134	166	1939	-59.6%	45.8%	9.3%	-66.5%
Bali	56	93	94	35	67	13	358	66.1%	1.1%	-62.8%	91.4%
West Nusa Tenggara	56	89	112	47	156	30	490	58.9%	25.8%	-58.0%	231.9%
East Nusa Tenggara	38	17	116	45	113	16	345	-55.3%	582.4%	-61.2%	151.1%
Maluku	35	27	67	33	49	22	233	-22.9%	148.1%	-50.7%	48.5%
North Maluku	18	19	37	45	43	26	188	5.6%	94.7%	21.6%	-4.4%
South Sulawesi	165	163	185	145	267	81	1006	-1.2%	13.5%	-21.6%	84.1%
Southeast Sulawesi	22	16	73	26	12	20	169	-27.3%	356.3%	-64.4%	-53.8%
Central Sulawesi	23	54	149	99	105	70	500	134.8%	175.9%	-33.6%	6.1%
West Sulawei	11	11	45	35	60	11	173	0.0%	309.1%	-22.2%	71.4%
Gorontalo	6	25	39	33	53	32	188	316.7%	56.0%	-15.4%	60.6%
North Sulawesi	18	20	48	38	32	16	172	11.1%	140.0%	-20.8%	-15.8%
West Papua	11	9	8	21	14	16	79	-18.2%	-11.1%	162.5%	-33.3%
Papua	16	9	30	8	16	17	96	-43.8%	233.3%	-73.3%	100.0%
Total	**3829**	**4649**	**5402**	**3546**	**5402**	**1447**	**24275**	**21.4%**	**16.2%**	**-34.4%**	**52.3%**

Figure 1. Table of Number of Indonesia's Natural Disasters in 2019-2024

Data from the National Agency for Disaster Management (BNPB) indicates that Indonesia experiences over 1,000 disaster events annually across all 34 provinces. During the 2019-2024 period, the average number of natural disasters reached 4,562 per year, with the highest peak recorded in 2023. A significant increase was observed during the 2022-2023 period, indicating a rise in the frequency of natural disasters that necessitates more integrated mitigation.

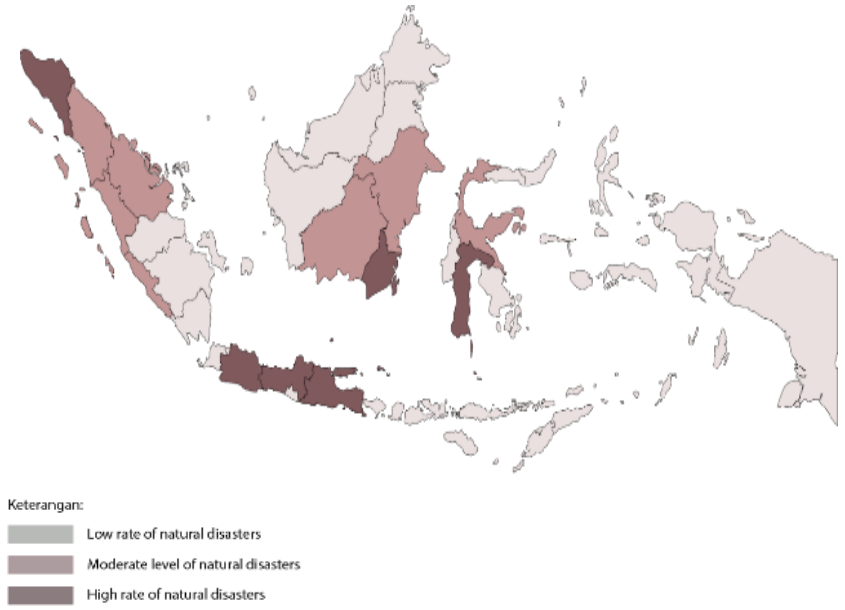

Figure 2. Level of Natural Disaster in Indonesia

The increasing frequency of disasters in Indonesia has serious impacts, especially in areas that are disaster-prone, with consequences in the form of casualties, infrastructure damage, and loss of life. This calls for adequate facilities to accommodate displaced communities, support their basic needs, and facilitate the recovery process until they can return to normal life after the disaster

Based on research conducted by Haris Mulyono, Naniek Utami Handayani, and Hery Suliantoro(2018), in the case of the flood disaster in Jakarta regarding factor analysis of meeting the needs of evacuees, evacuation During the Emergency Period, it was found that the assessment of facilities and services from disaster victims showed a low level of satisfaction. This indicates a critical gap in the effectiveness of the response mechanisms in place. Addressing these deficiencies is essential for improving future disaster management strategies and ensuring that displaced communities receive adequate support during such crises. The evacuees assessed that the service aspects during the evacuation period still require significant improvement to meet an adequate standard. Therefore, enhancing the quality of evacuation services and facilities is an urgent matter that needs to be addressed.
Facilities designed to replace the shelter function for displaced people must not only be able to fulfill their basic needs but must also provide an adequate level of comfort. Therefore, the existence of decent, efficient, and standardized temporary shelters is an important element in supporting the recovery process of victims of natural disasters from emergency conditions. Other than that, such facilities should be designed to be quickly established to provide a responsive and effective response to the needs of the victims. One solution that can be applied to achieve these goals is to utilize the prefabrication method or modular architecture concept.

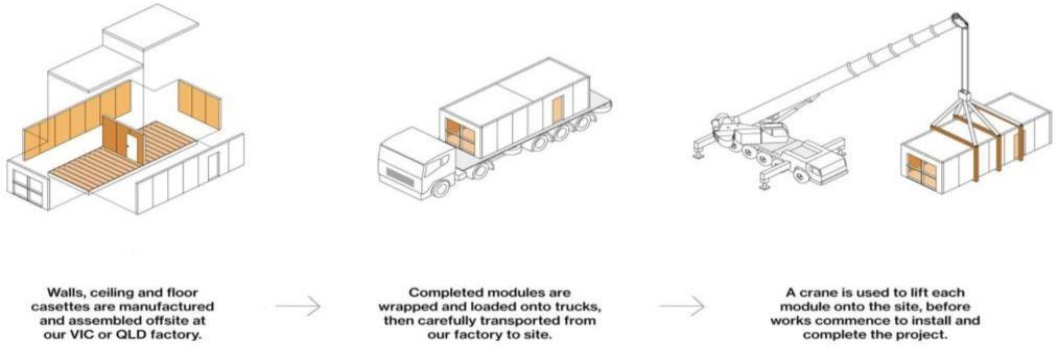

Figure 3. Systematic Modular Construction
Source: https://modscape.com.au/

Modular architecture is a method in building design and construction that utilizes units of modules that are manufactured separately and then assembled at the building site. According to Le Corbusier's theory (Mameli, 2016), modular refers to a size that corresponds to the human scale, both horizontally and vertically, including the dimensions of the space and the height of the room adapted to the scale of the human body and its movement space needs. One of the main advantages of modular architecture is its flexibility in building design and adaptation. With modules that can be easily installed and removed, modular buildings can be adapted to changing needs over time.

The utilization of prefabricated methods or modular architecture can simplify the construction process of evacuation facilities while providing flexibility in the development of evacuation shelters according to pre-produced modules. In addition, the use of modular systems in evacuation facilities addresses the issue of inadequate standard evacuation options by offering modules specifically designed to meet the needs and functions of each room, thereby enhancing the effectiveness of evacuation facilities.

METHODS

The research method used in this research is a descriptive method with a qualitative approach, which plays a crucial role in analyzing phenomena in depth by collecting and presenting data in descriptive form through narratives or illustrations. This approach does not depend on statistical analysis or quantification of data but instead emphasizes qualitative interpretation to gain a deeper understanding of the context and significance of the data obtained. With a systematic and purposeful framework, this method facilitates theory testing, hypothesis formulation, and informed decision-making based on research findings in a scientific and cohesive manner.

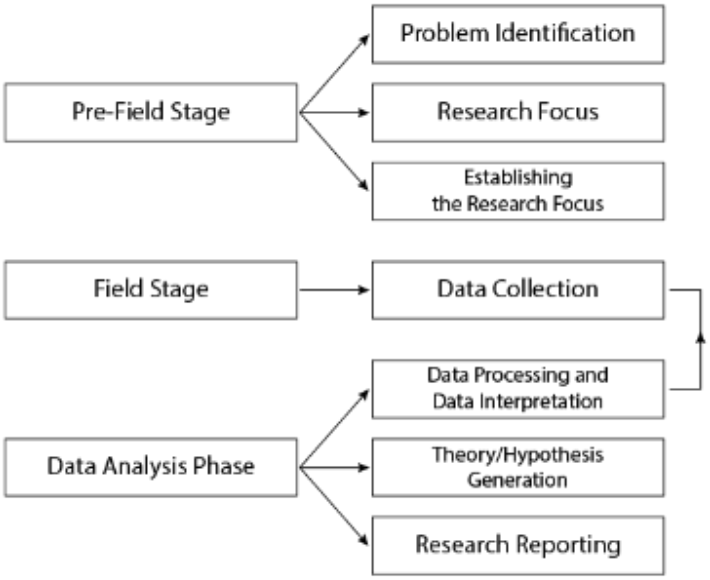

Figure 4. Qualitative Research Procedure

Qualitative research is a type of research that aims to holistically understand phenomena related to various perceptions, motivations, actions, and other factors. It achieves this by providing descriptions that are expressed in words and language, situated within a specific natural context, and by employing various scientific methods (Moleong, 2011). According to Moleong, the stages in qualitative research are broadly carried out through three stages: the pre-field stage, the fieldwork stage, and the data analysis stage.

1. **Pre-field Stage**
   The pre-field stage is the initial research, which includes determining the problem and the focus of the research, as well as identifying the core of the problem. This stage also encompasses research preparations, such as selecting a research field, obtaining necessary licenses, and preparing data and information, among other tasks.
2. **Field Work Stage**
   At this stage, researchers conduct their studies at a predetermined location, collecting data that aligns with the focus of the problem and the research objectives through methods such as observation, interviews, and documentation studies.
3. **Data Analysis Phase**
   After all the necessary data was collected, the researchers proceeded to analyze the data through several stages. The first stage involves testing the credibility of

the data, which includes assessing the number of natural disasters in Indonesia, evaluating the quality of evacuation services provided to affected victims, and analyzing other supporting data. Furthermore, the verified data was analyzed in depth in accordance with the research focus. This analysis resulted in a hypothesis regarding the need for evacuation facilities that are not only capable of accommodating evacuees but also providing comfort as a temporary residence. The final stage of this research is the presentation of the results in a descriptive format that systematically and comprehensively outlines the findings.

RESULT AND DISCUSSION

A. Community Evacuation Center

Evacuation is the evacuation or relocation of people from an area of potential danger, e.g., war, flood, or volcanic eruption, to a safe area. According to the Mozambique Community Center Guideline Text, center evacuation falls under the category of temporary shelter, which is a safe place to accommodate several groups of people for a temporary period of time. Center of evacuation is a form of disaster management that provides temporary shelter for evacuees during a disaster for a certain period of time until the evacuees can return to their homes.

The Community Evacuation Center is a location for evacuees to stay temporarily until conditions return to normal or they can return to their respective homes. The site must be able to support the lives of evacuees from their arrival to their departure from the evacuation site. The following are the main factors that influence the design of evacuation centers.

A. Accessibility

Road access to the evacuation site must be adequate, both for vehicles and pedestrians. Roads that are wide and in good condition will facilitate the evacuation and aid distribution process.

B. Location

The site selection for designing the evacuation center should be in an area that is safe, away from the center of the disaster and areas that are disaster-prone.

C. Capacity and

The evacuation center should be able to accommodate the expected number of evacuees by considering the land area and be able to facilitate the primary needs of evacuees.

D. Regulation and Policy

Government regulations regarding building and infrastructure standards for evacuation centers must be adhered to. This includes capacity requirements, sanitation facilities, and road accessibility.

Community evacuation centers, which serve as temporary shelters for disaster evacuees, are divided into two categories based on the stage of disaster mitigation. Temporary Evacuation Site (TES) and Final Evacuation Site (FEA) are two important concepts in disaster management, especially in the context of mitigation that has the potential to affect community occupancy, such as in the case of earthquakes, volcanic eruptions, tsunamis, and other disasters.

A. Site Evacuations

A Temporary Evacuation Site (TES) is a location used to temporarily house evacuees during a disaster. TES serves as a gathering point for disaster-affected communities before they are moved to a safer location.

B. Final Evacuation Site

A Final Evacuation Area (FEA) is a location designated as the final destination for evacuees after an emergency situation has ended. TEAs serve as temporary shelters that are more permanent than TES.

Community evacuation centers, designed as temporary living facilities for disaster victims, can be developed by considering the various user groups and their activity needs. In general, user groups and activity needs in Centers Community Evacuation can be classified into three main categories.

A. Refugee

Evacuees are individuals or groups who leave an area to avoid a particular disaster or type of disaster. The duration of a refugee's stay at an evacuation site is unpredictable; however, it can be categorized based on the severity of the impact experienced. This categorization considers both material loss and the physical condition (health) of the individuals affected by the disaster.

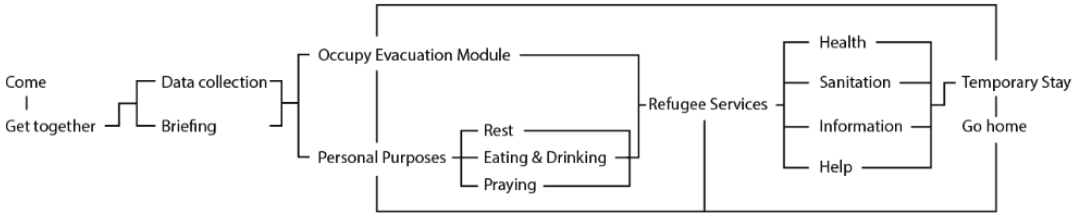

Figure 5. Schematic of Refugee Activities

Refugee group activities encompass two primary categories: personal activities and service activities. Personal activities involve addressing basic individual needs, such as shelter and personal hygiene, along with various other activities. In contrast, service activities for refugees encompass a range of areas, including health services, sanitation, information dissemination, and additional support needs. Based on the analysis of evacuee evacuation activity schemes, regulations, and various case studies, the estimated space requirements for the Center Community are as follows:

1. Module
2. Search & Evacuation
3. Services
4. Restoring Family Link (RFL)
5. Psychosocial Support Program (PSP)
6. Public Kitchen
7. Place of Worship
8. Class
9. Mini Library
10. Playground
11. Public Restroom
12. Latrine
13. Clinic
14. Pharmacy

B. Volunteer

Disaster volunteers are individuals or groups who are voluntarily involved in disaster management, both in the stages before, during, and after a disaster. Volunteers can consist of trained workers or members of BPBD, as well as the general public who voluntarily participate in handling disaster situations.

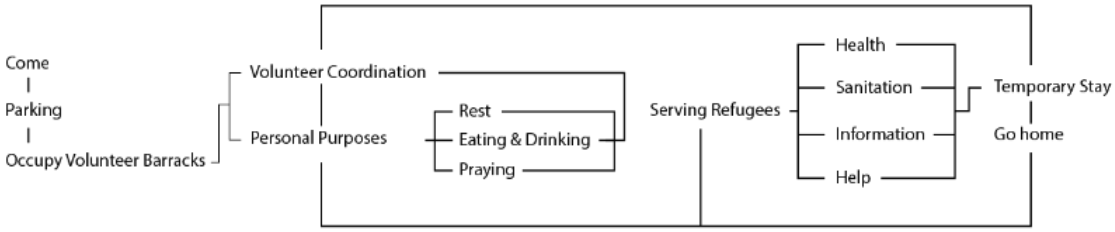

Figure 6. Schematic of Volunteer Activities

Volunteer groups have the responsibility to provide evacuation services for evacuees, which include health services, information, sanitation, as well as other forms of assistance. However, on the other hand, volunteer groups also need a private space that is separate from the area designated for evacuees to support their personal activities. Based on the analysis of the estimated activities of the volunteer group, the following space requirements are obtained:

1. Male Volunteer Barracks
2. Women's Volunteer Barracks
3. Kitchen
4. Dining Area
5. Place of Worship
6. PR & Communications
7. Relief & Distribution
8. Condition Assessment
9. Water Sanitation
10. Logistics
11. RESTROOMS
12. Bus Parking
13. Truck Parking
14. Parking Volunteer (Motorcycle & Car)

C. General Public

The general public included as users of the Community Evacuation Center can be visitors who want to provide assistance or check on the condition of evacuees, as well as families of victims who come to search and confirm the condition of their family members.

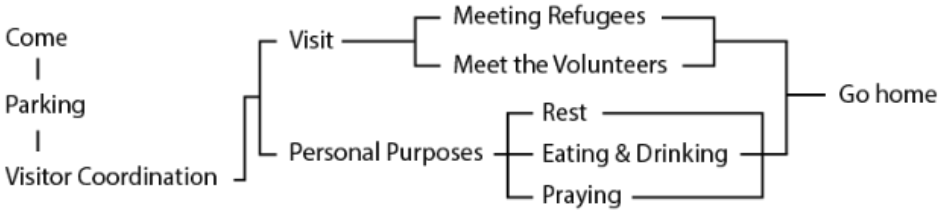

Figure 7. Visitor Activity Scheme

The activities of the general public in the evacuation center mainly focus on visiting both the volunteer groups and the evacuees. In addition to visiting relatives in the evacuation center, visitors also have various personal needs, such as resting with evacuees or volunteers, performing worship, meeting sanitation needs, and so on. Based on the analysis of the estimated activities of the general public or visitors, the following space requirements are obtained:

1. Area
2. Place of Worship
3. Restrooms
4. Motorcycle Parking Visitor
5. Car Parking Visitor

Temporary shelter assistance is typically provided in the form of tents, barracks, or public and social facility buildings, such as places of worship, sports halls,

village halls, and similar structures, which can be utilized as temporary housing. The minimum requirements of a building that is suitable for evacuation are as follows (National Disaster Management Authority/BNPB, 2008):

a. Measures 3 (three) meters square per person.
b. Has health and safety requirements.
c. Have accessibility to public facilities.
d. Guarantee privacy between genders and different age groups.
e. A 100-liter bin for a family of 10, or an equivalent item.
f. One family latrine is used for a maximum of 20 people.
g. One place used for washing clothes and household appliances, most at for 100 people.
h. Water supply should be sufficient to provide at least 15 liters per person per day.

B. Modular Architecture

Evacuation The approach Modular architecture is a method in building design and construction that utilizes units of modules that are manufactured separately and then assembled at the construction site. According to Le Corbusier's theory (Mameli, 2016), modular refers to the size corresponding to the human scale, both horizontally and vertically, including the dimensions of the space and height of the room adapted to the scale of the human body and its movement space needs. One of the main advantages of modular architecture is its flexibility in building design and adaptation. Modular buildings can be adapted to changing needs with modules that can be easily installed and removed.

The principles of Architecture

A. Modules

Modular architecture utilizes modules manufactured in a factory, with approximately 60%-90% of the construction process completed before the modules are transported to the project site. This approach allows for faster and more efficient completion of the structure.

B. Grid-Based Design

Modular building structures are generally designed using a regular grid system. This system makes it easier to organize spaces and allows for future modifications. Grid-based design also creates uniformity and consistency in module size and shape.

C. Structure

Modular buildings can consist of multiple levels or units arranged vertically or horizontally. This results in multifunctional spaces that can be customized according to user needs.

D. Flexibility and Adaptability

Modular buildings are designed to be disassembled and moved easily, thus providing flexibility in the use of space. This allows the building to be adapted to the dynamic needs of the users.

E. Waste Reduction

The modular construction approach contributes to waste reduction, as most components are efficiently produced in the factory. Thus, material waste during the construction process can be minimized.

F. Standardization and Consistency

Using standardized modules in modular building design ensures consistency in material, quality, and specifications, thus meeting established safety and quality standards.

G. Affordability

Modular construction is often more economical than traditional construction methods. Efficiencies in the production process and reduced lead times make it an attractive option, especially for projects with limited budgets.

1. Construction Typology

Modular architecture is a building design method that utilizes prefabricated components manufactured off-site and assembled on-site. This prefabricated component design system can be applied with various approaches, either by fabricating all building components off-site and then assembling on-site, or by only producing some off-site components. In contrast, the main building structure is designed and constructed in situ. The following are some types of design systems in modular architecture.

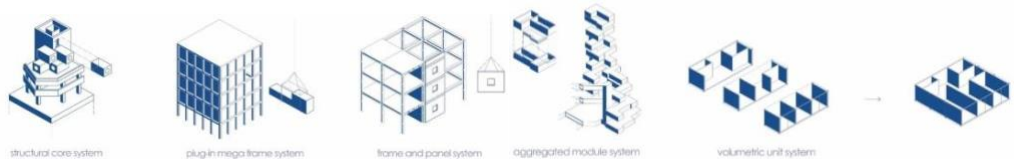

Figure 8. Construction Typology of Modular Architecture
Source: Mitsimponas, D., & Symeonidou, I., 2024

a. Structural Core System

The system relies on prefabricated modules installed around a reinforced concrete central core. This, which is constructed in situ, serves as the center of the structure and contains essential elements such as elevators, stairs, and other supporting functions.

b. Mega Frame Plug-In System

In this system, prefabricated modules are inserted into three-dimensional structural grid cells. This grid structure is the main framework supporting the designed modules for precision installation.

c. Frame Panel and System

This system utilizes prefabricated structural members in the form of two-dimensional frames. The frames are then attached to the main structural frame designed to support the overall building load.

d. Aggregated Module System

The aggregate module system consists of prefabricated modules that can be self-supporting. These modules can be stacked to form self-contained spaces. Although the design is flexible, in application to buildings, certain functions, such as circulation or utilities, must be organized in a central core.

e. Volumetric Unit System

This system is designed with volumetric modules that can be independent spaces or part of a space. The modules are produced as prefabricated units that are ready for installation, allowing for high efficiency in the construction process.

C. Application of Modular in the Center System Community Evacuation

1. Space Standard

The space requirements of a community evacuation center are determined based on the user analysis and activities in it. Based on this analysis, the users of the evacuation center are divided into three main groups. First, volunteers are individuals or groups tasked with serving the evacuees until the evacuation period ends. Second, evacuees, who consist of people affected by natural disasters, need temporary shelter until they can return to their homes. Third, the general public, individuals or groups visiting the evacuation center for a specific purpose, such as visiting volunteers or evacuees. From the identification of these three user groups, the space requirements of the community evacuation center are formulated by considering the activities and functions of each group.

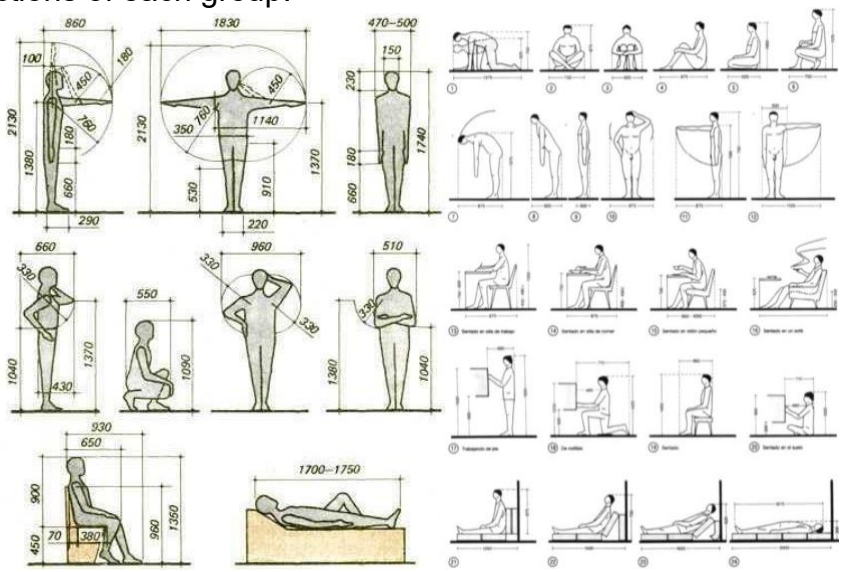

Figure 9. Human Ergonomic Dimension Standards
Source: Souza, E., 2020

Although until now, space standards for community evacuation centers do not have a concrete reference, and only some aspects have been standardized, space size planning in evacuation centers is designed concerning anthropometric and ergonomic principles. This approach aims to ensure that each space provided is comfortable and convenient for all users, including volunteers, evacuees, and the general public. These principles are considered essential to support the function of the evacuation center as a safe, comfortable, and functional place for all who use it. Based on the calculation, the space required for the community evacuation center is presented in the following table:

Table 1. Space Center Requirement Analysis Table of Community Evacuation

User	Space Requirement Analysis of Community Evacuation Center							
	Room Type	Room Name	Space Properties	Activities	Capacity (people)	Standard (m2/person)	Room Area (m2)	Source
Refugees	residence	Evacuation Module	Privat	Evacuate	4-7 (1 KK)	3	12	SPH
	facilities and infrastructure	Search and Evacuation	Semi-Public	Search and Evacuation Activity Control	10	3,6	36	AP
		Communication Services	Semi-Public	Serving Communication	5	3,6	18	AP
		Restoring Family Link	Semi-Public	Restoring Family Relationships	5	3,6	18	AP
		Psychosocial Support Program	Semi-Public	Psychological Treatment	5	3,6	18	AP
		Public Kitchen	Public	Eating and Drinking	70	1,95	136,5	SK
		worship place	Public	Worship	50	1,44	72	AP
	education	Classroom	Semi-Privat	Learning	10	3,6	36	SK
		Mini Library	Semi-Privat	Learning	20	2	40	AP
		Playground	Public	Playing	20	2	40	AP
	sanitation	Public Toilet	Semi-Privat	Sanitation	1 (1 Unit = 20 people)	1,8	1,8	SPH
		Latrines	Semi-Privat	Sanitation	10 (1 Unit = 100 people)	1,8	18	AP
	health	Clinic	Semi-Public	Health Check	10	9,6	96	SK
		Pharmacy	Semi-Public	Drug Distribution	1	26	26	SK
Volunteers	residence	Male Volunteer Barracks	Privat	Rest and Temporary Stay	4	3	12	SPH
		Female Volunteer Barracks	Privat	Rest and Temporary Stay	4	3	12	SPH
	facilities and infrastructure	Kitchen	Semi-Privat	Eating and Drinking	5	1,7	8,5	AP
		Dining Area	Semi-Privat	Eating and Drinking	35	1,95	68,25	SK
		Worship Place	Semi-Privat	Worship	20	1,44	28,8	AP
	coordination	Public Relations and Communication	Semi-Public	Communication Activity Control	5	3	15	AP
		Relief and Distribution	Semi-Public	Distribution Activity Control	5	2,75	13,75	AP
		Assessment	Semi-Public	Refugee Assessment Activity Control	5	3	15	AP
		Water Sanitation	Semi-Public	Water Sanitation Control and Distribution	5	2,75	13,75	AP
		Logistic	Privat	Goods Control	4	2,75	11	NAD
	sanitation	Bathroom	Privat	Sanitation	4	2,47	9,88	NAD
Public	facilities and infrastructure	Visitor Area	Public	Visiting	30	0,95	28,5	AP
		Worship Place	Public	Worship	20	1,44	28,8	AP
	sanitation	Bathroom	Semi-Privat	Sanitation	4	2,47	9,88	NAD
	parking area	Truck Parking	Public	Parking	8	42,5	340	NAD
		Bus Parking	Public	Parking	4	40,8	163,2	NAD
		Motorcycle Parking	Public	Parking	40	1,69	67,6	NAD
		Car Parking	Public	Parking	54	7,7	415,8	NAD

2. Design Concept

a. Space Module

The space modules of the community evacuation center are designed using a prefabricated or modular method. Architectural approach: Each space module is individually designed and tailored to the standard space requirements that have been previously analyzed. One of the main space requirements that are modularly designed is the temporary shelter space for evacuees. This design is in line with the main objective of the modular architecture approach, which is to create a living space that is efficient, flexible, and able to grow according to the needs of the refugee capacity. With this method, evacuation centers can provide adequate shelter in a short period of time while allowing for adjustments to the scale of the space as the number of evacuees to be accommodated changes.

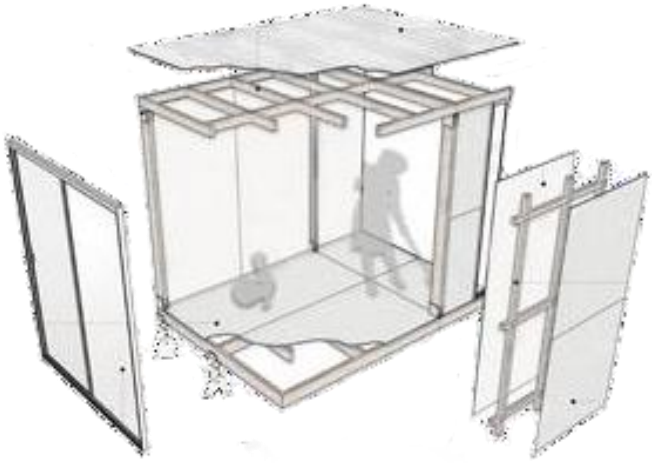

Figure 10. Application of the Modular to the Room Module Architecture Concept Refuge

The space module pictured above is a refugee module that serves as a temporary housing unit for disaster-affected families. Each evacuation module unit has an area of 12 m² and is designed to accommodate one family with a maximum capacity of up to seven people per module. The module is prefabricated in the form of individual panels that are made separately before being shipped to the construction site. The module

construction process is carried out on-site by assembling the panels according to the construction typology used, which is a frame and panel system.

b. Construction Typology & Materials

The concept of a modular community evacuation center is designed as a final evacuation site for evacuees, accommodating them from temporary sites to more adequate facilities to meet their needs. These evacuation centers can be constructed semi-permanently, i.e., buildings that can be erected and dismantled again as needed, or permanent buildings with a specific duration of use. In the context of modular architecture, various construction typologies can be applied to erect modular structures, where each evacuation center has its own advantages and disadvantages in the application of the evacuation module.

The typology structural core system requires a core structure to support the space modules. However, this approach is less ideal for space modules that need to be erected within a short period of time. In addition, the need for a four-core structure makes the building more suitable for permanent rather than semi-permanent construction. Meanwhile, the aggregate module system has the disadvantage of managing circulation and utilities. It requires intensive organization of the building core, which is less suitable for evacuation buildings where efficient circulation is a key aspect. In addition, utilities that tend to be centralized and more suitable for volunteer areas are an obstacle in applying this system to evacuation centers.

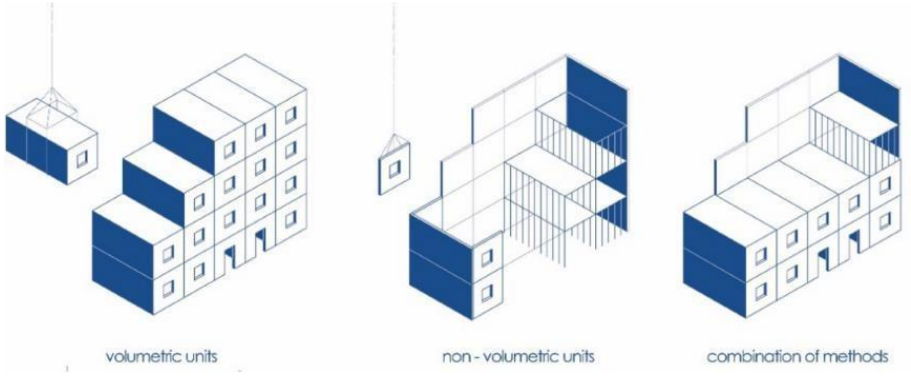

Figure 11. Construction Typology of Modular Architecture
Source: Mitsimponas, D., & Symeonidou, I., 2024

Of the various construction typologies in modular architecture, three systems are considered the most suitable to be applied to modular evacuation centers, namely the plug-in mega frame system, the frame and panel system, and the volumetric unit system. Among the three, the frame and panel system is one of the best options to be applied. This system allows for easier fabrication and transportation, as the building components are made in the form of individual panels. In addition, the use of structural frames provides more strength than the volumetric unit system, while the lightweight and modular nature of the panels eases the transportation process from the fabrication site to the construction site. Thus, the frame

and panel system is an ideal solution to support the design of an efficient and flexible modular evacuation center.

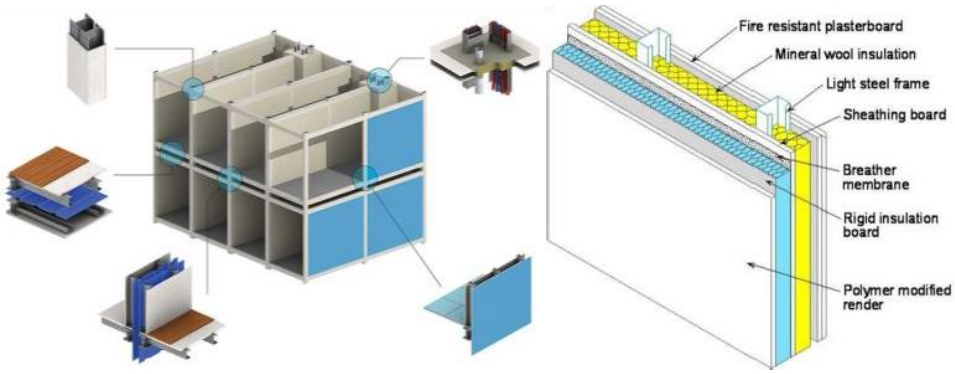

Figure 12. Frame and Panel Construction and Module Panel Materials
Source: https://www.promat.com/

The construction materials in the design of the modular evacuation center consist of two main components: materials for the frame and materials for the panels. The material used for the frame is steel, as steel has high efficiency in construction, both in terms of strength and ease of installation. Meanwhile, the material used for the wall panels is coated EPS panels, which are panels made of polystyrene composite cement with multiple structural and insulation layers. Coated EPS panels have a number of advantages, including ease of construction, optimal structural strength-to-load ratio, and good thermal insulation capabilities. The combination of these two materials provides an efficient, robust, and convenient construction solution for modular evacuation centers.

CONCLUSION

The increasing frequency of natural disasters in Indonesia demands efficient, flexible, and standardized community evacuation center facilities. This research shows that the application of the modular architecture concept with the prefabrication method can be an innovative solution to overcome various challenges in the design and construction of evacuation centers. This approach allows for efficient construction time and cost, design flexibility, and improved quality of evacuation facilities.

The evacuation center designed using the modular method was designed to meet the specific needs of three main user groups, namely evacuees, volunteers, and the general public. Construction typologies, such as frame and panel systems, were chosen as they are able to provide adequate structural strength as well as ease in fabrication and transportation. The combination of materials such as steel for the frame and coated EPS panels for the walls provides efficiency in strength, thermal insulation, and user comfort.

Through the implementation of the modular architecture concept, the evacuation center can be established quickly and effectively to provide proper temporary shelter while supporting the recovery process of disaster victims. This research is expected to contribute significantly to the development of evacuation facility standards in Indonesia and support a more integrated and responsive disaster mitigation strategy.

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