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Disaster Vulnerability Assessment of Low-Cost Houses in Java Island

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ABSTRACT

Among all of the Indonesian islands, Java poses the highest risk for all types of disasters, making it a significant threat to low-cost houses due to its high population vulnerability. The objective is to enhance comprehension of it by conducting a building typology analysis concerning various natural hazards/ risks. The methodology consists of 10 sample houses field observation, AutoCAD drawing, literature analysis, and built environment expert interviews. The results developed four categories of houses emphasising brick or timber walls with a combination of clay tile or zinc roofs. Related to disaster vulnerability, an improper building structure is the main problem. Smooth roof material is significant in a volcano eruption, a complete interconnection of structure is a must for the tornado, light materials are preferable in an earthquake zone, natural material is not recommended for high risk of forest fire and elevating floor is mandatory in flooding. Focus on designing the four categories' houses and quality control of the construction process are two strategies recommended. Also, a minimum of two types of disasters in the area should be considered in the design. Resilient low-cost houses will have an impact on reducing casualties, environmental damage, and economic losses. Covering more samples and areas in Java in future studies will provide a comprehensive understanding of low-cost houses.

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Highlights:	Contribution to the field statement:
- There are 4 types of low-cost houses on Java Island emphasized in the wall and roof materials; - Focus on upgrading the design and quality of 4 types of low-cost houses is more efficient as it covers the majority of low-cost houses in Java Island; - Emphasizes the construction phases are significantly needed, such as the quality of the builder's skills and monitoring intervention, especially for self-built houses; - A minimum of two types of disasters in the area should be considered in the design due to the multiple types of disasters that could exist in every area; - Every type of low-cost house has different vulnerability aspects towards different types of disasters.	Before providing an instant design solution or any policy towards low-cost houses' vulnerability problems, this study argues that understanding their houses and risk will arguably provide a better picture and insight into a sustainable mitigation solution. Therefore, it will have an impact on reducing casualties, environmental damage, and economic losses.

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1. Introduction

Indonesia is a country that has many high-risk areas with various natural disasters, including floods, landslides, extreme weather, volcanic eruptions, fire, earthquakes and tsunamis. According to The World Risk Index for 2021, Indonesia is ranked 38th of the 181 most disaster-prone countries (Garschagen, Doshi, Reith, & Hagenlocher, 2021). The National Agency for Disaster Management (BNPB-Badan Nasional Penanggulangan Bencana) noted that the intensity of natural disasters in Indonesia has increased significantly in recent years. Based on the BNPB report, in 2020 there were 4,649 incidents of disasters and in 2021 recorded 5,402 disasters or experienced 16.2% increase. From the Indonesia disaster-prone index map in 2022 published by the BNPB (Figure 1), it shows that almost all regions in Indonesia are dominated by high disaster-prone levels. Among all five big islands, the BNPB stated that Java Island is the area in Indonesia that is most prone to disasters. According to the Central Bureau of Statistics (BPS) of Indonesia, the potential for the exposed population is also high because almost 58 percent of Indonesia's population is on Java Island (N.C. Idham, 2019). Based on several reports, housing was the most severely impacted sector after the disasters (Hai & Hoang, 2023; Pribadi, Kusumastuti, Sagala, & Wimbardana, 2014). In 2022 alone there were 95403 houses damaged by disasters and 21% of them were seriously damaged in Indonesia. According to the same report, flood is the most common type of natural disaster followed by extreme weather while the earthquake that claimed the most victims occurred 28 times last year.

Figure 1. Indonesia disaster infographics in 2022 (Source: modification from BNPB).

The majority of these houses are from middle to lower-class groups, it is the largest population in Indonesia. Based on data from the World Bank in 2019, the majority of Indonesia's population is middle to lower divided by middle class (44.5%) and poor (11%). Due to growing demands for more inexpensive basic housing in Indonesia, vulnerable houses continue to develop among low-income and low-to-medium-income communities (Saputra et al., 2017). Lots of previous research emphasized that these groups are the most vulnerable and impacted during a disaster (Yaseen, Saqib, Visetnoi, McCauley, & Iqbal, 2023). Studies show that low-cost houses are more vulnerable to the risk of disaster for several reasons (Charlesworth & Fien, 2022; Ma & Smith, 2020; Pujianto, Prayuda, & Monika, 2019): poorly constructed houses as often built based upon experiences of local masons without technical designs and construction supervision (Tipple, 2005), and mostly located in higher-risk places due to high land prices or even worst (Ma & Smith, 2020), living in informal settlements.

There are not many studies focused on low-cost house design and the Indonesian government has not published the typical and quantifiable vulnerability of homes (Saputra et al., 2017). Therefore, this study comes out with the research question "What is the typical design for low-cost houses on Java Island and how it is vulnerable to different types of disasters that exist". The objective of this study is to understand low-cost house designs on Java Island and analyse their vulnerability to various natural risks that exist on the island. The common approach of applying one-size-fits-all solutions for geographically and culturally different regions in some housing projects recently may create more severity of post-disaster situations (Johnston, Taylor, & Ryan, 2022). Before jumping directly into providing an instant design solution or any policy towards low-cost houses' vulnerability problems, this study argues that understanding their houses and risk will arguably provide a better picture and insight into finding a sustainable mitigation solution. Past experiences have highlighted the need for more context-specific approaches, that do not focus only on effective and efficient built products but that directly contribute to a sustainable and long-term vulnerability reduction and poverty reduction (Molesa, Caimi, Islam, Hossain, & Podder, 2014).

1. Material and Methods

This research has two objectives. One is to have a better understanding of the low-cost houses in Java Island. To meet this objective, it used a building typology approach through document analysis and observation on the field. The fieldwork was conducted on Java Island specifically in Semarang province in 2022 with a total of 10 houses as the object samples. It followed with AutoCAD drawing to conduct document analysis together with the documentation pictures. Typological studies usually identify and study architectural styles and history based on the structure, material, decorations, form, and contexts of the buildings (Sun, Fan, Duarte, & Ratti, 2022). The typology here is divided by roof, wall, and floor plan where previous study emphasizes the important roles of these aspects in low-cost houses (Agayi & Karakayacı, 2020). The second objective is to analyse the low-cost houses' vulnerability to different types of disasters that occurred on Java Island. This was fulfilled by literature analysis and expert interviews in the field of built environment (architect, architecture lecturer, and civil engineering lecturer). All of these approaches are categorized as qualitative research methods, which according to (Jamshed, 2014) comprise observation, mapping, documentation, and referring to published documents. A similar study evaluating the strengths and weaknesses of low-cost houses in Iran was conducted through a literature review, observation, and physical analysis (Ghasemi & Özay, 2018).

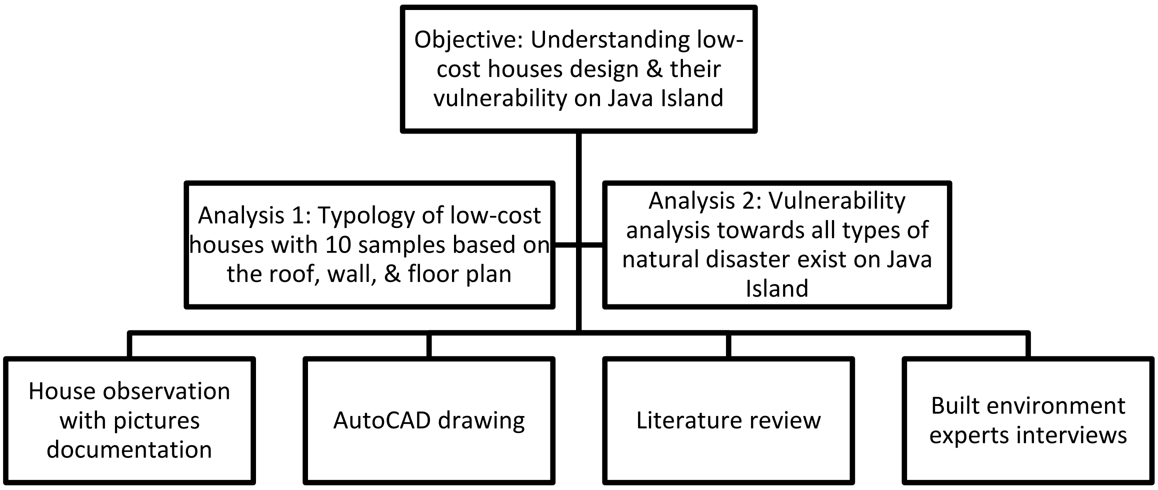


Figure 2. The research methodology.

The challenge found in the field during observation is the difficulty in classifying RTLH and low-cost houses due to the resemblance among them. Below is the table containing indicators that differentiate between those two. These indicators cannot be seen as individual certainty but rather comprehensive where more than one indicator is needed to determine the grouping. For example, the size of the floor area for low-cost housing has several dissents. The Indonesian government stated that it should not exceed 70m^2 while according to Prayitno, Kindangen, and Rengkung (2019) is around 22-36m^2. Based on one of the developer websites (RayWhite) that often built low-cost houses in Indonesia, generally, developers distinguish it into 6 types: 21, 36, 45, 54, 60, and 70. Therefore, it is safe to consider low-cost houses with a floor area of 70m^2 and below. Another important indicator is the existence of a bathroom or toilet. According to BPS data, just two out of every ten Indonesians live in areas with adequate sanitation services, including in urban and rural areas. Hence, floor area and the existence of a bathroom/toilet are the two most significant indicators that differentiate a low-cost house with RTLH. With these indicators, the houses are selected in the field observation.

Table 1. Differentiate between RTLH and Low-cost House.

RTLH Definition & Indicators	***Low-Cost House Definition & Indicators:***
Definition: is a residential house that does not meet health, safety, and social requirements. Indicators: ● Walls and/or roofs are in very poor condition that might harm occupants; ● House materials are easily damaged/ rotten; ● No material for the floors directly in touch with the earth or bamboo/timber or cement. Some use ceramics but already damaged; ● No toilet or place for bathing or washing; and/or ● The Size of the house is less than 7.2m^2/ person Source: Regulation of the Minister of Social Affairs of the Republic of Indonesia Number 20 of 2017.	Definition: houses built on land with a plot area between 54m^2 and 200m^2 and the building cost per m^2 does not exceed the highest unit price per m^2 for the construction of class C government official housing that applies with a floor area of 36 to 70 m^2 and at least has a bathroom or toilet (Decree of the state minister for Public Housing No.04/KPTS/BKP4N/1995). Indicators: ● The floor area of the building is not more than 70 m^2; ● Consists of one floor with a land area of 54-200 m^2 (Joint Decree between the Minister of Home Affairs, the Minister of Public Works, and the state minister for Public Housing, Number 648-381 of 1992, 739/KPTS/1992 and 09/KPTS/1992); ● The space requirement per person is 9m^2 with an average ceiling height calculation of 2.80m; ● The activity room gets plenty of light; ● Ventilation holes of at least 5% of the floor area of the room; ● Room air temperature and humidity are by normal human body temperature; ● Using a direct, indirect and local foundation system made of stone masonry or concrete without reinforcement and the indirect foundation system is ironwood or wood; ● Walls can be made of concrete, boards, half concrete and half boards or other materials such as bamboo which have strong and durable qualities; ● Wall frames for brick houses are made of reinforced concrete structures. For half-walled houses, use half of the reinforced concrete frame and half of the wood frame. For wooden houses that are not staged, the wall framework uses wood. For sloof use reinforced concrete. Meanwhile, wooden houses on stilts use wood entirely, both for the building frame and for the walls and foundation; ● At a minimum use a gable roof with wooden frame trusses with strong and durable class II measuring 5/10 or those that are widely circulated in the market with equivalent sizes; Source: Decree of the Minister of Settlement and Regional Infrastructure No: 403/ KPTS/ M/ 2002

3. Results: House Typology in Java Island

In this study, the focus is the typology of low-cost houses in Java Island. Therefore, any characteristic that is not intended for low-cost houses is excluded.

3.1 Low-Cost Houses in the Modern Era

Officially, the dwellings of the lower middle class in Indonesia can be identified with two types of houses: Uninhabitable Houses (RTLH - Rumah Tidak Layak Fungsi) and Simple Houses (RS - Rumah Sederhana) or Healthy Simple Houses (Rs Sehat). Uninhabitable houses do not meet the minimum requirements for building safety and occupant health (Regulation of the Minister of PUPR of the Republic of Indonesia, 2018). Meanwhile, a simple house is suitable for living and affordable for people with low and moderate incomes (Prastiwi, Saraswati, & Witasari, 2019). Since RTLH does not meet building safety requirements and priority to increase the house quality to at least a simple house condition (Larasati, Yuniningsih, Widowati, & Sagala, 2021), therefore, this type of house's main risk is poverty rather than natural disaster. In this case, RTLH is excluded from this study and focuses on simple houses - where intervention is needed to be resilient.

Another type is vernacular housing. The traditional dwellings have developed to respond to natural environmental conditions, particularly Indonesia's warm and wet tropical climate (N.C. Idham, 2019). In the wealth of archipelago architecture, there have been many studies that prove that vernacular buildings are resistant to several natural disasters such as earthquakes (Putra, 2020) and floods (Nyssa, Susanto, & Panjaitan, 2022). This study also eliminates vernacular housing because they are better at responding to natural disasters, yet this type of house constructed traditionally is rarely built because of the level of difficulty of construction as well as natural materials that are hard to come by. The government offers affordable apartments to the lower middle class, but this still appears to be unsuccessful (Rosadi, Meizy, & Suryanto, 2010). This type of residential with the form of high-rise buildings is also excluded in this study because it needs specific analysis and is not a majority case in Indonesia.

Figure 3. Types of houses excluded in this study: vernacular houses in Java (left); flats (middle); and Uninhabitable Houses/RTLH (right).

This simple house group mostly is self-built because cannot afford to use an architect or civil engineer. But there is also a simple house built by private developers or the government which are usually subsidized housing. The figure above shows a simple house (a) built by the community and a simple house (b) built by the developer/government. The majority of this housing, which is made up of landed homes, is located on perimeter land that has been either developed by real estate firms or the communities themselves. Therefore, this study argues it is not suitable to use the term self-housing and prefers the term low-cost or simple house. Since the same main characteristic between those two types of houses (built by the community and developer/government) is the low budget to build. This type of house is usually one-story and made of reinforced concrete which also identifies as the era of modernity in Indonesia after the independence in 1945 (Wihardyanto & Ikaputra, 2019).

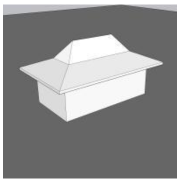
Figure 4. Low-cost houses are self-built by the community (left) and built by a developer (right).

3.2 Typology of Low-Cost House in Java Island Based on the Roof Material

For low-cost houses on Java Island, mostly very simple forms of roofs. Even in vernacular architecture, the difference between villagers and noblemen is the roof. The more complicated the roof shows higher social status and economic class. The next table shows the roof typology for low-cost houses on Java Island.

Table 2. Typology of Low-Cost House Roof Designs in Java.

<table>
<tr><th>Roof Design</th><th>Illustration</th><th>Description</th><th colspan="2">Roof Material</th></tr>
<tr><td>Panggang-Pe</td><td></td><td>The shape is the simplest form of a house, consisting of a roof with four or more pillars where the tops are used for drying items such as tea leaves, cassava, corn etc. The shape of the roof of the house consists of one side of the sloping roof with a very simple shape.</td><td>
Clay Tile</td><td>Most low-cost houses in Java use this material for the roof.</td></tr>
<tr><td>Kampung or Pelana</td><td></td><td>It is an architectural variant that is one level more perfect than Panggang-Pe, with a rectangular plan with four pillars, and two sloped roof areas that meet on the upper side and are closed with a conch lid. This form of house was very commonly used by villagers.</td><td rowspan="2">
Zinc

Metal</td><td rowspan="2">Usually used by developers for subsidized housing. This is the second material used after clay tile due to its affordable price and ease of use.</td></tr>
<tr><td>Limasan (traditional version)</td><td></td><td>The pyramid-shaped house has a rectangular plan, with four roof areas. During its development, the shape of the pyramid was given additions. This variety is widely used both for villagers and noblemen. This is almost close to the “Joglo” roof, which is more complicated and usually owned by the middle-upper class.</td></tr>
</table>

Roof Design	Illustration	Description	Roof Material	
Limasan (modern version)		Used by people with middle to lower economic levels. The shape of the building is very simple which is typical of the Javanese house	 Asbestos	According to The World Health Organisation (WHO), about 10 percent of Indonesian homes have roofs made from white asbestos.
Combined 2 or more of *Lima San* shape		Many people use it at a middle economic level. The shape of the building began to lead to a modern form		

3.3 Typology of Low-Cost House in Java Island Based on Wall Material

The Indonesian government distributed prototypes of Rs Sehat (Healthy House) into four types: walled houses; ½ wall houses; wooden houses without stilts; and wooden houses on stilts. This shows that the wall is the main aspect to distinguish the type of houses. Referring to this division, Java Island in the majority is categorized as wall houses. According to Saputra et al. (2017), overall houses in Java Island can be categorized into 5 types: mud bricks - unreinforced bricks with mud mortars; bricks - unreinforced bricks with cement mortars; reinforced bricks; reinforced concrete; and others. The majority (84.8%) of houses use mud bricks, bricks, and reinforced bricks.

Table 3. Typology of Low-Cost House Walls in Java.

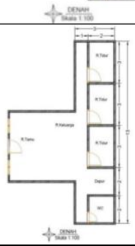
Wall	Illustration	Description
Brick wall		The easy-to-obtain clay raw material and the simple manufacturing process make it relatively inexpensive. The usual size on the market is 25 x 12 x 5 cm or less. Walls of brick masonry are generally made with a thickness of ½ stone and a minimum distance of 3 m is given a practical column as a binder and load distribution. Brick walls are usually worn as a non-structural construction that is not load-bearing.
Brick and cement walls		This type of house uses brick with cement plaster which is found in traditional houses of nobles and modern houses. Financial constraints as the main reason, but most brick wall houses will plaster as the finishing at the end.
Adobe wall		Same as brick, this type of house uses adobe brick instead of brick. Also, it was found with or without cement plaster.
Wood Plank Wall		Wooden plank walls are used in wood frame construction buildings. Board construction is nailed/screwed to horizontal and vertical wooden frames with a distance of about 1 meter. Yet more attention towards the quality of wood due to the possibility of expansion and shrinkage.

Wall	Illustration	Description
Bamboo Wall		The wall material used is non-permanent. The advantage of using bamboo as a frame material for house walls is that bamboo is known as a renewable building material, hence there is no need for skilled labour and it is enough to use simple tools that are easily found.

3.4 Typology of Floor Plan for Low-Cost House on Java Island

The following table shows the typology of low-cost houses on Java Island based on their floor plans. The coverage floor area for this type of house is in the range of 36-70m^2, so there is not much alternative. The floor plan on this table is originally from Javanese vernacular architecture that still could be found in modern low-cost houses.

Table 4. Typology of Low-Cost House Floor Plans in Java.

Floor Plan	Illustration	Description
I Type		Rectangle plan shape. It has a basic rectangular shape, with variations on terraces and an annexe behind the main building. The main entrance is generally located in the middle of the wall on the side facing the street. Buildings that have a floor plan like this are generally single houses in the local community.
L Type		The shape of the floor plan of the letter L. It has the basic shape of the letter L with variations on the processing of the terrace and the position of the entrance to the house. A Formation like this has a general function as a private residence (single house) in the local community.
T Type		The shape of the floor plan of the letter T. Has the basic form of a combination of two rectangular shapes that form the letter T with variations in the position of the entrance.
Ordinary People's House Plan		The floor plans of ordinary people's houses also follow the provisions of traditional houses but do not separate one component from the other components, this is because the land for ordinary people's houses is not as large as that of a nobleman's house.

4. Discussion: House Vulnerability to Disasters on Java Island

The objectives of this study are to understand low-cost house designs on Java Island and analyze their vulnerability to various natural risks that exist on the island. For the first objective, based on the typologies analysis earlier, this study divided low-cost houses on the Java Islands into 4 groups:

1. House with brick/ adobe/ cement wall and clay tile roof;
2. House with brick/ adobe/ cement wall and zinc/ metal tile/ asbestos roof;
3. House with wood/ bamboo wall and clay tile roof;
4. House with wood/ bamboo wall and zinc/ metal tile/ asbestos roof.

The main reason to divide between materials of wall and roof is because on the field mostly low-cost houses in Java Island fall into those four groups. It is understood that the building structure is also closely related to the house's vulnerability (Noor Cholis Idham, 2020). This study found that building structures can be identified based on the walls and roof materials.

All of those four types of houses could be self-built or built by developers or appropriate design/engineered or inappropriate design/non-engineered. Saputra et al. (2017) found that 93.5% of houses in Yogyakarta province (in Java) were non-engineered houses and very vulnerable to earthquakes. However non-engineered houses in his study included brick walls categorized as un-reinforced bricks with mud mortal, un-reinforced bricks with cement mortal, and reinforced brick. Meanwhile, this study argues that those three types of houses could be appropriate if the building structure is properly designed and constructed.

Where definitely, inappropriate design/non-engineered in disaster-prone areas is considered one of the key causes of a vulnerability house and needs to be addressed (Charlesworth & Fien, 2022). Self-made construction and the lack of experience make slum houses vulnerable to environmental hazards and seismic activity (Ebrahimi, Devillers, & Garcia-Diaz, 2022). The number of self-help houses found in post-disaster construction shows that concern for structural safety is still below expectations (Dartanto, 2022; N. C. Idham, 2021). Among them, the self-help housing type is the problem most associated with almost all safety means (Pribadi et al., 2014). Meanwhile, low-cost houses built by developers are more guaranteed because it is required by Indonesian law and because of the involvement of architects and civil engineering experts in the process (theoretically). However, because of the risks of various natural disasters, this type of house remains vulnerable in certain cases.

After acknowledging the types of low-cost houses in Java Island, this study was able to analyse their vulnerability to disaster, especially after categorizing them into four groups. Based on data from the BNPB in the last few years (2020, 2021, 2022), the natural disasters that have plagued Java are tsunamis, earthquakes, floods, tornadoes, droughts, landslides, volcanic eruptions, and forest fires. All type of natural disasters is included in the following analysis except drought which does not have any direct impact on the house damage. The analysis of each disaster threat was built from the interviews with built environment experts (architecture and civil engineering lecturers and practitioners).

Table 5. House Vulnerability Analysis.

Type of Low-Cost Houses		Vulnerability	Disaster Threats
Brick/adobe/cement wall & Clay tile roof	  	• When the Dutch colonial came, they started using brick walls (N.C. Idham, 2019). They were immediately aware of the danger of earthquakes and took necessary precautions by creating thick brick walls. That is why, many old colonial buildings remain well (Vogelsang, 2020). • The problem with most Indonesian brick wall applications is that this material is only considered a load-bearing wall without	**Earthquake:** Brick/cement wall & clay roof: • This house is vulnerable to moderate-intensity earthquakes; • The masonry wall will result in some failure namely: diagonal and horizontal cracks will reduce the wall stiffness, opening cracks at the corner of the wall, crushing bricks; • At high-intensity earthquakes, bricks may fall or dislodge; • The clay tile roof is heavy, increasing the lateral force and making the roof highly vulnerable to collapse during the earthquake. Brick/adobe/ cement wall & zinc/metal roof:

Type of Low-Cost Houses	Vulnerability	Disaster Threats
	considering the shear load (N. C. Idham, 2021). • It is common to find houses using columns without connecting beams. Or if they use it but with a poor connection, especially with reinforcing steel bars (Noor Cholis Idham, 2020). This structural failure was responsible for most of the deaths and injuries.	• The weight of the zinc/metal roof added to the whole structure made the house less vulnerable to earthquakes; • A lighter material used for roofs will minimize the injured people and casualties that happen during earthquakes. Wood bamboo wall & clay tile roof: • Material from wood and bamboo is light and tends to endure when subjected to earthquakes and have minor damage at moderate earthquakes; • If the bamboo wall falls during the earthquake, it is not likely to cause casualties; • Clay tile roof which was heavy, increased the lateral force and made the roof highly vulnerable to collapse during the earthquake. Wood/bamboo wall & Zinc/metal tile/asbestos roof: • This type of house is lighter structure and has high performance against earthquake load with just minor damage; • A lighter structure will minimize the injured people and casualties happened during earthquake. **Landslide:** Brick/cement wall &clay roof: • Brick/cement wall and clay roof will have light or moderate damage when subjected to landslide because the material is strong enough to resist the soil from the landslide; Brick/adobe/ cement wall & zinc/metal roof: • Usually, brick/cement wall and zinc/metal roof house is strong enough to resist light and moderate landslide. Wood bamboo wall & clay tile roof: • The landslide can damage the house. •
Wood/bamboo wall & clay tile roof   	• Lightweight wooden construction will create a flexible or minimal movement of the building after an impact because the system will easily return to its original position against heavy materials (N.C. Idham, 2019) during an earthquake. • Some traditional wooden houses have also collapsed due to age and poor maintenance (N.C. Idham, 2019). Poor quality materials make it more vulnerable to climate hazards. • The majority of Indonesian traditional architecture is built with natural (timber) materials that create many designs and structural principles that range from simple columns/ beams to massive and complex shapes. And many of them have proven to be able to survive various disasters (Rini & Idham, 2021).	

<table>
<tr><th colspan="2">Type of Low-Cost Houses</th><th>Vulnerability</th><th>Disaster Threats</th></tr>
<tr><td></td><td></td><td>
• According to Pujianto et al. (2019), the common cause of Joglo (a traditional house in Java that use timber for wall and clay tile for a roof) structure: damage are
1. The lack of column foundation impacted a connection failure between columns and foundation;
2. The damage of both column and beam after receiving the lateral force of the earthquake;
3. Failure on the roof structure due to the deformation, unstable, or collapse of the outer structure.
</td><td rowspan="2">
Tsunami:
Brick/cement wall & clay roof:
• Tsunami will cause severe damage especially to brick wall and clay roof.
Brick/adobe/ cement wall & zinc/metal roof:
• The masonry walls would first fail under the tsunami wave force which in turn would result in the failure of the roof.
Wood bamboo wall & clay tile roof:
• a house with bamboo walls will be more resistant to tsunamis because water will flow between the walls.
Wood/bamboo wall & Zinc/metal tile/asbestos roof:
• Bamboo walls will be more resistant to tsunamis because water will flow between the walls.
Flood:
Brick/cement wall & clay roof
• Brick/cement wall and clay roof has less chance of collapsing or being structurally damage.
Brick/adobe/ cement wall & zinc/metal roof.
• Brick/cement wall and zinc metal roof has less chance to collapse or structurally damaged to flood.
Wood bamboo wall & clay tile roof:
• Wood bamboo wall and clay tile roof are less vulnerable to flood and will not cause major damage to the house structure.
Wood/bamboo wall & Zinc/metal tile/asbestos roof
• Wood/bamboo wall is less vulnerable to flood but flood will cause damage to asbestos roof.
Tornadoes:
Brick/cement wall & clay roof
• Brick/cement walls and clay roofs are less vulnerable to tornadoes because brick and clay are heavy materials.
</td></tr>
<tr><td>Brick/adobe/cement wall & Zinc/metal tile/asbestos roof</td><td>



</td><td>
• This is the most common type built by contractors for low-cost housing projects in Indonesia.
• The popular way of using zinc or metal tile roof, and roof trusses do not use wood anymore but light steel instead. Yet, the problem is the installation method mostly uses the same way as with wood. Also, the tendency of using heavier roof tiles is high because of economic reasons and comfort expectations however not suitable.
• Improper structural systems from truss-like reinforced concrete frame construction are easy to find, such as pointed on top of bearing walls without a proper column system below
</td></tr>
</table>

Type of Low-Cost Houses		**Vulnerability**	**Disaster Threats**
		(Noor Cholis Idham, 2020).	Brick/adobe/ cement wall & zinc/metal roof. • Zinc/metal roof will be flown by tornadoes as it is a light material;
Wood/bamboo wall & Zinc/metal tile/asbestos roof	 	• Lightweight structures are the common answer to be less affected by earthquake shakes. Houses built with lightweight materials such as wood may be able to resist strong ground shaking and would also be less deadly if they collapse (Tipple, 2005). • Similar to the previous explanation, the majority of failures with zinc roofs are mostly due to extra light zinc-alum profiles while applying heavy roof tiles (N. C. Idham, 2021). • Another problem with zinc or metal roof tiles is causing heat in the interior space. This can be anticipated with an appropriate calculation by using extra elements installation but of course, will increase the construction budget and also require specific construction techniques that might not be available (N. C. Idham, 2021)	• The more the angle of the metal roof the more vulnerable to tornadoes; • The connection of the roof frame must also follow the specification of the area of the houses. Wood bamboo wall & clay tile roof: • Wood bamboo walls and clay tile roofs are not prone to tornadoes because clay is heavier and will not easily be flown. Wood/bamboo wall & Zinc/metal tile/asbestos roof • Wood bamboo walls and metal/zinc roofs are more vulnerable to tornadoes as those materials are light. **Volcanic Eruptions:** Brick/cement wall & clay roof • Brick /cement walls and clay roofs tend to be less vulnerable to volcanic eruptions. Those materials can resist heat. Brick/adobe/ cement wall & zinc/metal roof. • One of the important components in volcanoes risk-prone house is designing a roof to withstand a volcanic eruption by creating it smooth, slick surface so that the ash can slide off without collecting on the surface. Wood/ bamboo wall & clay tile roof • The same analysis with brick/cement wall & clay roof, but the concern is with the timber material for wall that is easily burn. Wood/bamboo wall & Zinc/metal tile/asbestos roof • The same analysis with brick/adobe/ cement wall & zinc/metal roof but the bigger risk for the wall material to be burn because made of timber. • Another architectural feature is to have a reinforced structure with

Type of Low-Cost Houses		Vulnerability	Disaster Threats
			titanium. Titanium is durable and robust material often used for lateral support in buildings that may experience a volcanic eruption. **Forest fires:** Brick/cement wall & clay roof • Brick /cement walls and clay roofs are less vulnerable to fire. Brick and cement materials resist more fire. Brick/adobe/ cement wall & zinc/metal roof. • Brick /cement walls with zinc/ metal are also less vulnerable to fire. They are not easily burn. Wood bamboo wall & clay tile roof: • Wood/ bamboo material is easy to burn but clay roof is less vulnerable to fire. Wood/bamboo wall & Zinc/metal tile/asbestos roof • Wood/bamboo wall will be burnt easily, while metal/zinc roof is less vulnerable to fire but it transfers heat easily.

From the vulnerability analysis above, there are several key points: first of all, the main problem for all types of houses is unproper building structure. Brick wall, mostly built with in-complete reinforced steel bars. While for timber wall which it is supposed to be safety yet still found building failure cases after a disaster. The reasons are poor timber quality and failure connection between columns and foundation or upper beam. For roofs, the trend is using lightweight frames from wood to metal (mainly steel) roof construction. Inappropriate structure is commonly found especially metal/steel frame that are constructed as same as wood. It is obvious in the field, that zinc/metal roof material starting to dominate low-cost houses but in Java Island, clay tile roof is still easily found since produced locally by the home-industry at affordable price.

Secondly, the suitability of house materials varies depending on the type of natural disaster. For earthquakes, it is advisable to use lightweight materials for both walls and roofing. Reinforced structures are crucial for brick walls, which have often been identified as causes of casualties. A more suitable choice would be wooden walls with zinc roofing. Regarding tsunamis, generally, no house design is completely safe without robust columns and a two-story structure. In the case of both earthquakes and tsunamis, the main aim is to ensure the house remains intact for a sufficient duration, allowing residents to evacuate to safety. During floods, while all types of houses may be impacted, wooden structures are prone to rot, and concrete may suffer erosion unless properly protected. Asbestos also fares poorly in floods. A two-story design is preferable here as well. Contrary to earthquake scenarios, heavier materials such as brick walls and clay tile roofing offer better resistance against tornadoes, with the critical factor being a robust structural connection from the foundation to the roof. In volcanic eruptions and forest fires, wooden materials pose a high risk due to their flammability. For roof protection from volcanic ash, smooth metal materials like zinc are more effective than clay tiles.

However, the challenge is the diversity of types of disasters faced by each location makes the design complicated (Sastra & Idham, 2019). For example, the city of Semarang in Central Java is at high risk for floods and landslides. But the city of Jember in East Java is at high risk for flooding and tornadoes. The city of Cianjur, West Java, is prone to earthquakes and landslides. Meanwhile, Yogyakarta city has a high potential for natural disasters such as earthquakes, volcanic eruptions, and floods. This is only within the district/city scope, when examined in more detail, the differences and multiple of disaster risk become more diverse at the sub-district level.

To compare, the study of Islam and Hossain (2017) in Bangladesh with their multi-hazards risk, developed 35 (thirty-five) designs of disaster-resilient low-cost houses for eight different geographic regions of Bangladesh. In their study, they identify each region with one or a maximum of two types of disaster. Considering local practice, the availability of building materials, and the culture of the community are significantly important in reducing vulnerable housing. Yet, providing a new design is also challenging for the majority of people.

So, what about houses for Java Island? According to Charlesworth and Fien (2022), there are no universal, one-size-fits-all solutions for resilient design. For Java Island, based on the typology study, it is recommended to focus on upgrading the quality of the four types of houses rather than creating a new design house. Understanding the typology of residents living in disaster-prone areas is important as an input for policy-makers (Amin, Sukamdi, & Rijanta, 2018). Recommendation to upgrade the quality of house by considering at least two types of disaster high risk in the area. Through the vulnerability list from Table 5, design and construction aspects that should be considered for each disaster type are available.

As previous studies show this group of people usually do not have knowledge of construction works and know little to nothing about the maintenance of the house (Hai & Hoang, 2023). This study also emphasizes the construction phases such as the quality of the builder's skills and monitoring intervention, especially for self-built houses. Quality control or inspection should be instituted by local authorities and certification programs for masons/craftsmen are needed to ensure the quality of the construction (Hochrainer-Stigler, Linnerooth-Bayer, & Mochizuki, 2019). This study argued, that focusing on these strategies, it will help the majority of middle to lower-income communities in Java Island to be resilient under the threat of disaster. According to Tipple (2005), important issues in reducing the vulnerability of housing to disasters include improving the ability of dwellings to resist shocks. Because the island of Java is large with cultural diversity, a broader study covering unreached areas with a more representative number of house samples is needed in the future.

5. Conclusion

The aim of this research was to evaluate the design of low-cost housing on Java Island and to assess their susceptibility to the array of natural hazards prevalent in the region. Through a typological analysis, the study identified four principal categories of low-cost housing differentiated by wall and roof materials: (a) structures with brick, adobe, or cement walls topped with clay tiles; (b) those combining brick, adobe, or cement walls with roofs made of zinc, metal tiles, or asbestos; (c) buildings with wooden or bamboo walls and clay tile roofs; and (d) constructions of wood or bamboo with zinc, metal tile, or asbestos roofing.

The vulnerabilities of each house type to different natural disasters common in Java were examined in detail. It was found that brick walls could be earthquake-resistant if fully reinforced with concrete. Wooden and bamboo walls and roofs are preferred for their earthquake resilience, though they also require a robust structural design. For tornadoes, the strength of materials and the integrity of the structural connections are crucial. Conversely, natural materials typically fare worse in forest fires. During volcanic eruptions, the choice of a smoother roof material can significantly mitigate ash damage. In flood scenarios, houses on semi-stilts perform better, although this feature is uncommon in Java's low-cost housing, with exceptions like vernacular or RTLH (Rumah Tidak Layak Huni) houses.

The primary takeaway is that attention to the specific design requirements of these four types of houses, along with a focus on quality construction practices, is essential for creating resilient low-cost housing for Java's middle- and lower-income populations. Disaster preparedness strategies for low-income housing should incorporate these insights to minimize risks. Future research would benefit from a broader sampling of house types across Java Island to account for its vast geographical spread and cultural diversity.

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Conflicts of Interest

The Authors s declare that there is no conflict of interest.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author, Aulina Adamy.

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