Directing Housing Developments for Achieving Earthquake Disasters Safety in Indonesia

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Abstract. The high number of fatalities and damage to buildings in the areas most affected by the earthquake should affect how to build houses. Especially in the case of self-housing, the community's trauma will immediately encourage them to increase the safety of their buildings. However, early studies do not confirm so. Although it looks pretty built concerning the earthquake, the number of self-help houses found in post-disaster construction shows that concern for structural safety is still below expectations. This paper examines how safety precautions affect the way people build their homes. We discussed current housing developments geared towards earthquake vulnerability in Indonesia and found that housing security, in general, is still far from expectations. Learning from many post-disaster cases informs us that we must take radical and massive action regarding housing schemes and building structures to reduce the toll caused by destructed weak houses under every hit of an earthquake.

1. Introduction

Human civilisation continuously learns by the process they experience to live for more safety and convenience than ever. The existing natural and social context always teaches how to deal with a given occurrence to face a better future. In the case of earthquakes, some civilisations already learn much to deal with. Yet others need more to understand or re-understand. Earthquake, however, has its own culture. The earthquake catastrophic should be powerfully written in mind such fairy tales so the people will not forget and learn from them [1].

In many cases, however, the existing social considerations tend to affect the societies rather than earthquake safety itself [2]. The danger of earthquakes is thus easily forgotten. Housing in this regard has very significant for examination since its close connectivity to the people, especially in the most vulnerable zones such as most of areas in Indonesia except Kalimantan.

Lightweight structures are the common answer to be less affected by earthquake shakes. In the traditional method, wooden houses were expected to be utilised rather than stone and other earthy materials [3]. For thousands of years, people in Japan, the Philippines, Indonesia, and other tropical-ringed fires have been blessed with an abundant source of woods to accommodate their shelters' need for safety [4]. Timber buildings, in general, will quickly face the earthquake [5]. However, it is also subject to changes in the code to increase safety [6]. Traditionally, people build buildings all entirely timber in the antiquity of Indonesia. Unfortunately, the further application affected by some reasons has made the wooden houses become out of favour. Steel and other metallic components are also known for better performance, especially for contemporary structures. The scarcity of hardwoods for further structural application and the industrial revolution have made metallic materials used as a preferred
substitution. Thus, we can build higher and bigger though located in the ring of fire for earthquake threats.

Earlier brick walls and later reinforced concrete (RC) became famous for constructing houses without exception in Indonesia. Although bricks were only utilised for non-domestic structures in the previous culture, they became essential for practicality, endurance, and social preference. The Dutch reintroduced bricks as the primary building materials imported directly for their colonial infra-structures, including residential. The natives then adopted brick and replaced the wooden structure gradually for most in vernacular or self-help houses and left timber structure only for the purpose of antiquity. Western architecture is then seen as no longer alien [7]. The brick construction became widely popular, particularly for middle-upper economic families. RC follows the brick wall as complimentary when frame confinement is needed to stiffen the buildings from shear loads. Nevertheless, in post-disaster construction, application appropriateness became the most prominent problem [8].

User awareness and preferences, however, in the end, will decide the application in the field. In the case of Yogyakarta 2006, Padang 2009, Lombok Island 2018, or Palu Central Sulawesi 2018, housing reconstruction had been taken by many actors for helping the people rebuild the collapsed houses. Some donors have included the participation and expectation of the people, but others exclude them because of some reasons. Driven by the large number of houses needed within a limited time, the project's outcome widely varies [9]. Furthermore, in the post-disaster period, the self-development of housing also resulting in a large amount of diversity of housing qualities. Limited supervision, especially in rural areas in Indonesia, causes uncertainty. The safety awareness was found relatively different among the users based on their resources, knowledge and understanding. Thus the discussion on building safety related to the housing development is favourable.

![Figure 1. RC roof frame applications; done directly from the wooden truss technique in post-disaster housing in Yogyakarta](image)

Figure 1. RC roof frame applications; done directly from the wooden truss technique in post-disaster housing in Yogyakarta

The method used in this paper to deeper understands the safety development is by examining the housing schemes related to their structural qualities focusing on earthquake’s vulnerabilities. The typical building failures, particularly houses, reconstruction, and post-disaster development, are discussed, resulting in housing suggestions. Some cases taken from the fields are utilised to clarify the general direction of building safety related to the earthquake. Though the investigation is in general, the result may be helpful to a deeper understanding of housing safety in Indonesia.

2. Discussions

2.1. Housing and vernacular architecture in Indonesia

Massive housing supported mainly by the government is uncommon yet in Indonesia. Instead, self-supporting housing flavours both in city and rural areas. Approximately one-third of the urban population in developing countries live is in informal settlements [10]. Apartment tower seems to have started to be an alternative in big cities like Jakarta and Surabaya but limited only for the middle-upper
class [11]. Due to global capitalism and neoliberalism, private commercial companies build most of these apartments in sound quality [12].

Furthermore, apartment in such a city as Jakarta has also become an investment object locally and overseas, making the price rises irrepressible and speculative [13]. The government also provides flats or “Rumah Susun” as a cost-effective apartment for the lower-middle-class, but it seems not successful yet [14]. Numerous flats still have empty rooms either not occupied yet or left by the users because of one and other reasons. Millions of them seem to prefer to stay in the city's kampong or self-help residential quarter, which some appear in the form of a slum.

In grounded houses both in the city and in the countryside, self-help housing is the problem most associated with almost all safety means. Landed houses take up most of the city's perimeter land developed either by real estate companies or the communities themselves. Meanwhile, people build homes in rural areas, especially with self-help housing, both in modern and conventional/traditional types. In addition to using the work of architects or engineers, houses built by themselves in cities or villages are called vernacular architecture. Still, the majority, these vernacular houses characterise the quality of structure and construction, which means that there is no certainty of safety guarantees according to contemporary standards, especially from the threat of earthquakes. For that, we need to discuss starting from the housing scheme to its vulnerability. Thus, better housing can be suggested.

2.2. Indonesian traditional architecture and tectonic
Traditional architecture in Indonesia is very diverse in forms and structures built with wood materials that are plentiful in nature. Their structural principles range from simple pillars and beams to enormous and complex shapes. Buildings stand to vary from piles on the ground to floating structures in the water. Most of them have proven their ability to deal with natural risks, including earthquakes [15]. However, the traditional house is no longer the main house used by ordinary people. Only a small number of people of some ethnic group in Indonesia still maintain the form of their traditional homes. The rest occupy the latest build of vernacular houses.

Brick walls were never applied to the 300 and more ethnic houses, although historically, they were used for non-domestic buildings. On the other hand, various kinds of wooden materials, from hardwood to bamboo and grass or event leaves, are familiar to the public. Abundant wood resources in the tropical character of warm-humid air and high rainfall have encouraged environmental synchronisation. Ventilation is an essential factor for tropical homes instead of insulation for other climates. Perforated walls and roofs are always expected to get rid of damp air and invite fresh air. Even without windows, the building still circulates air for circulation. The buoyancy effect pushes hot air into higher spaces under the roof [16]. For this reason, roofs, exceptionally high and sloping ones, serve as chimneys to dismiss hot air.

When the Dutch came, they began to use massive brick walls with some synchronisation, such as using lots of large perforated windows or jalousie as window coverings which were rarely applied in their home country. Dutch East Indies or Indische architecture is a term used for a combination of Dutch and traditional architecture [17]. Even though they built an extensive wall system, they were immediately aware of the earthquake threat and took appropriate precautions with thick brick walls. Many old colonial buildings have survived, relying solely on large brick walls to withstand shear loads.

2.3. The failure of the houses in earthquakes
Historically, besides tsunamis, earthquakes in the modern era have a higher frequency of occurrence with significant loss of life and damage to buildings. Although the magnitude was not too high, the 2006 Yogyakarta earthquake was the most powerful, 5.9 (BMKG) or 6.1 (USGS). More than 400,000 houses were damaged, and more than 6,000 people died mainly due to the structural failure of the houses. The 2005 Nias and Padang 2009 earthquakes were also earthquakes with a higher magnitude, increasing fatalities (Table 1). The figure shows us that the earthquake directly destroyed housing and caused building failure. In the case of the 2006 Java or Yogyakarta earthquake, the population of high-density buildings with low-quality structures became one of the leading causes of these deaths.
Table 1. List of significant earthquakes without tsunami and loss of life in Indonesia (sources mainly based on BMKG)

| Date             | Magnitude | MMI | Location       | Loss of life |
|------------------|-----------|-----|----------------|--------------|
| 1976, June 26    | 7.1 Mw    | X   | Papua          | 422          |
| 1976, July 14    | 6.5 Mw    | IX  | Bali           | 573          |
| 1995, October 7  | 7.0 Mw    | VIII | Kerinci, Sumatera | 84          |
| 2000, May 4      | 6.5 Mw    | VII | Kepulauan Banggai | 54          |
| 2000, June 4     | 7.3 Mw    | VI  | Bengkulu, Sumatera | 100         |
| 2004, November 12| 7.3 Mw    | VIII | Alor, NTT     | 34           |
| 2005, March 28   | 8.6 Mw    | VI  | Nias, Sumatera | 1.300       |
| 2006, May 27     | 5.9 Mw    | IX  | Yogyakarta, Java | 6.234       |
| 2009, September 30| 7.6 Mw     | VII | Padang, Sumatera | 1.115       |
| 2010, October 25 | 7.7 Mw    | VII | Sumatra Barat | 408         |
| 2016, December 7 | 6.5 Mw    | IX  | Pidie Jaya, Sumatera | 104         |
| 2018, August 5   | 7.0 Mw    | VII | Lombok         | 390         |
| 2021, January 15 | 6.2 Mw    | VII | Sulawesi Barat | 105         |

In the case of vernacular houses, the weak brick construction built by the community was one of the leading causes of earthquake failure in Yogyakarta. Thin brick wall structures constructed with soft mortar without confining reinforced concrete are the most common causes [18]. Instead of using Portland cement (PC), people used to be more familiar with red cement soil made from red bricks and limestone powder. The bricks are weakly bonded to the bearing wall system without any reinforcement. This 'tradition' was common until the 90s before PCs became practical for household buildings.

Achieving the structural system as a single unit is critical to structural integrity under earthquakes. The problem with most brick wall applications in Indonesia is that this material is seen only as a dividing element or bearing wall without considering the shear load. Some are even combined with weakly assembled wooden frames with massive walls. For house construction, the community primarily builds one and a half layers of brick walls, known as the three-quarter wall type, with a thickness of about 22 centimetres. The walls are much thinner than the construction of Dutch Colonial buildings in Indonesia. For further developments, confinement by providing practical columns and beams with reinforced concrete then became the custom. However, the level of integrity is by no means achieved automatically because of the lack of completeness, quality of material, and quantity of these elements. Several studies confirm the problem in post-event mitigation [18], [19].

In other cases, incomplete application of structural members is also a significant problem in new buildings. Although the RC frame has also been involved in several houses, incompletely completed elements are still found and are strongly suspected to be the main factor [20]. Due to the scarcity of wood, direct replacement of wooden roof trusses with RC has become common. 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. Incompletely reinforced concrete confinement members such as missing columns or beams are also familiar. Some traditional wooden houses have also collapsed due to age and poor maintenance.

Houses collapsed in other massive non-tsunami earthquakes, such as the Padang (2009) and Lombok 2018 earthquakes were massive. Out from the tsunami range, the Palu earthquake (2018) also showed similar collapses in residential areas. Most collapsed houses were mostly built by weak structures and improper structural elements (see figure 2). Again, semi-massive houses built with brick walls with or without reinforced concrete confinement do not have sufficient strength to withstand shocks. Some of the failures also involved many lightweight truss roofs with extra light zinc-alum profiles named "Baja
"Ringan." Applying a lighter profile with heavier roof tiles is suspected to be a significant problem in a later incident. Instead of providing security, the popularity of lightweight metal roof structures without sufficient proper installation is life-threatening.

![Figure 2. Palu collapsed house with incomplete RC frame, and Lombok destructed house without RC confine](image)

Further field studies in Yogyakarta and other earthquake-affected areas show that the safety principle of using safe structures is unfortunately low. Indonesia's ring of fire and the pacific ring of fire are where 90% of earthquakes occur [1]. So why is this earthquake disaster happening so regularly? The lack of wood materials makes people switch to RC frames or lightweight metal frames, which are much practical and cheaper.

RC frames became popular in Yogyakarta, especially for vernacular houses after the 2006 earthquake. The frame can improve the house's structural integrity compared to the only bearing brick wall, which collapsed due to the earthquake [21]. However, incomplete confinement members are also most of the problems caused by a common misunderstanding of structural integrity. People generally feel happy with reinforced concrete columns and beams in their homes without considering the interconnection of elements. Everywhere often found houses that only use columns without being connected to beams (figure 3). Or, when using both, the connection, especially the reinforced steel bar, cannot be ensured.

The tendency to misuse the extra light frame combined with heavier roof tiles is high because of economic reasons and comfort expectations. Unfortunately, it does not match with the heavy ceramic or terracotta roof tiles. The massive roof tiles are needed to anticipate heat penetration into the interior space by avoiding excessive heat transfer from the metal roof. Although appropriate calculation can be achieved by using extra elements on the roof truss installation, budgetary constraints and construction techniques are the biggest problems for the safety application in the field. Weak supervision from the authorities for the self-supporting housing has made the application of RC frame and light metal frame cannot completely replace wood or address security issues.
Figure 3. Recent earthquake vulnerabilities for self-housing; traditional building with brick wall and column (above), vernacular houses with incomplete RC frame and the lightweight frame with heavy roof tiles (below)

2.4. The future of Indonesian housing

Indonesia constantly needs at least 400,000 new homes every year and a housing backlog of 13.5 million units by 2014 [22]. Since being first elected in 2014, President Joko Widodo has declared launching a program of one million houses per year in 2015. The realisation of the program was stacked at the beginning, caused by the land availability and financing constraints [23]. However, by 2019, the Public Works and Housing Ministry declared already developed nearly the target by 4.7 million [22], [24]. By 2020 alone, 965.217 new houses were also constructed [25]. Financing entirely by the government seems still complicated to achieve for an uncertain time. The private sector on real estate companies is also part of the program. They are expected not to develop only for middle-high consumers, but their contribution was minimal under 20% [11], [14], [22].

Therefore, self-help housing is still the majority for housing schemes, either by banking loans or self-financing. For the majority, finishing a house in just a single process is still a rarity. On the other hand, growing homes due to lack of funds are more common. Thus construction quality is generally less than would be expected for structural integrity. On the other hand, finding vacant land in the city is certainly not easy. Shifting a landed house to vertical housing is logical to reduce urban land cover and increase land capacity. Engineered buildings, especially tower housing, could be a best-case scenario for future housing in cities as they offer scientific assurance of building safety. Insufficient land in urban areas and environmental sustainability issues have triggered the popularity of high-rise housing. The down-to-earth housing tradition seems no longer an option in cities or even rural areas in many countries.

However, in Indonesia, the public has not yet widely accepted vertical housing or favoured by the authorities despite its high population. Therefore, efforts to promote multi-storey mass housing are more than necessary. The previous failed vertical housing efforts, especially for the lower middle class, should not discourage the government to serve more appropriate housing system. More expansive city perimeter because of housing should be eliminated or reduced. Otherwise, cities will spread widely, and infrastructure systems will become inefficient or even fail. Thus, flooding, road congestion, lack of clean water, slums, and many other negative impacts are common results inside the cities.

Outside the big cities, engineered single housing, however, may still be a good option. Without clear policies on massive settlements, housing clusters provided by real estate developers or government agencies seem a reasonable compromise for their safety considerations. Otherwise, the self-providing engineered house should be accompanied by suitable technical supports from the government. Of course, this housing scheme is still less practical in Indonesia because of financial reasons for the majority of the population. A suitable single engineered landed house is still expensive and less considered for most people. For this reason, the percentage of single engineered houses is still low. Only with a better economic situation can the development of self-support engineered buildings be promoted.
On the contrary, vernacular housing, known as non-engineered buildings developed from tradition, turned into contemporary habits. The process of change is always ongoing to adapt newer materials and techniques. Thus, knowledge construction also changes dynamically. The vernacular housing in Indonesia is the majority; however, it is still far from government involvement in the planning, design, construction, and post-occupancy stages. People have their abilities and preferences to develop on their own.

Furthermore, the knowledge of people dealing with some new material is always lagging. Specific applications supposed to apply for new material are often misunderstood as is in the old way. Even after the post-disaster reconstruction of several earthquake cases, many of the properties of this new material are forgotten; for instant, applying an RC roof truss is only considered as using a wooden truss. Post-disaster supervision on housing development is still largely ignored by the authorities in almost cases. To have a better safe dwelling in the future, we must pay serious attention to this type of dwelling, including technical guidance and construction quality.

People are familiar with contemporary materials, such as bricks, reinforced concrete, lightweight metal frames, ceramic tiles, and the rudimentary things that drive future housing. As a technologically advanced product with better durability and affordable prices, there seems to be no reason not to apply these materials in a human and environmental context as long as life safety is concerned. Using brick walls with a reinforced concrete frame appropriate for firmness and stability under earthquakes is essential. While using a lightweight metal frame with a proper application is also a critical factor in achieving adequate protection.

On the other hand, the construction of traditional houses has proven to be the best way to deal with earthquakes; unfortunately, it seems 'out of date.' The scarcity of wood is one of the reasons for this type of structure; thus became to be expensive and difficult to achieve. The complete traditional wooden houses are now going to vanish. The traditional house became antique and exclusive which generally only for the purpose of collection of the rich. The traditional architecture seems to be coming to an end. Instead of only being seen as part of romanticism with strict rules, it should also be more pragmatic, including reintroducing it in new forms and techniques. Thus, traditional architecture needs to be developed based on current conditions, so new traditional architecture must emerge as part of the new culture.

3. Conclusion
Safety from earthquake disasters is achieved by almost all forms of traditional houses scattered throughout the archipelago. The shortage of wood materials, economic limitations, constraints in proper housing construction, and the use of new, cheaper materials have contributed to Indonesia's low security of housing development. For contemporary buildings, low-quality vernacular houses in urban and rural villages are typical housing progress. Until people accept engineered houses and apartments or flats, the supervisory housing programs for all areas seems the most reasonable for safe housing in Indonesia. Redeveloping building safety in Indonesia also requires revolutionary changes to vertical housing, especially in urban areas. Tower buildings as a product of engineering have more up-to-date calculations according to the current and predicted conditions to face nature. Besides improving the national economy, the biggest challenge of this idea lies in the technical or financial aspects and social understanding and the willingness of the government.

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