Flexible housing implementation in dome-shape post-disaster relief house: Is it possible?

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Abstract. One of the major disasters in Indonesia within the last two decades was the 2006 earthquake in Yogyakarta. The earthquake prompted the government to assist the victims by rebuilding their houses through the post-disaster housing programs. Usually, when designing post-disaster relief houses, aspects such as mass-production speed, building strength, and other functional aspects became the main priority. Consequently, local culture, each occupant's uniqueness, and particular needs are often forgotten to be accommodated in the house. These issues can be solved by applying the flexible housing concept where a house can change according to its users' needs and adjustments to specific patterns as demographics, economy, and the environment. However, previous precedents of houses built with this concept tend to use a frame structure system that is more flexible to modify within the long term. Thus, this research raises a case study of post-disaster relief houses in Yogyakarta built after the 2006 earthquake, which uses a dome structure. Interviews and on-site observation were applied to investigate whether flexible housing applications can be implemented in the house. Overall, this dome-shaped post-disaster house is still far from being categorized as flexible housing.

1. Introduction
According to the Indonesian National Disaster Management Agency (BNPB-RI), Indonesia is located above a magma line with around 127 active volcanoes, with 5 million people living in the vicinity [1]. Indonesia also has very high seismic activity, as evidenced by the 8,000 earthquake events from 1900 - 2009 with a magnitude of M> 5.0 [1]. These data show that the potential for casualties and damage due to natural disasters is very high in Indonesia, primarily if not handled remarkably. Furthermore, damage to residents' houses is a particular concern because many people have lost their homes due to natural disasters. In order to overcome this, the Indonesian government implemented a post-disaster housing assistance program. However, in many cases, post-disaster relief houses are often designed based on universal prototypes without paying attention to local climate aspects. When designing post-disaster relief houses, the aspects prioritized are the speed of mass production and the holistic aspect of reconstruction. As a consequence, each occupant's uniqueness and particular needs are often forgotten [2]. In the future, this could make it difficult for the occupants to modify or adjust the physical house to their needs.

In addition, the ability of the house to respond to environmental and climatic aspects is also not considered. According to Till & Schneider, these issues could be overcome by applying the flexible housing concept, which is a house that can change according to the needs of its users and adjust to specific patterns such as demographics, economy, and the environment [3]. However, previous
precedents of houses built with this concept tend to use a frame structure system that is flexible to be modified in the long term. Indirectly, a new question arises whether the flexible housing concept will be compatible with a building that uses other types of structure, such as a dome. This research investigates whether or not flexible housing applications can be implemented in a house that uses a dome structure. Dome-shaped post-disaster relief houses in Yogyakarta built after the 2006 earthquake, was chosen as a case study.

1.1. Theoretical review

1.1.1. Post-disaster relief house. The post-disaster relief houses are referred to as Residential Houses based on the 2013 Head of BNPB's Regulation on Technical Guidelines for Post-disaster Rehabilitation and Reconstruction for the Residential Sector [4]. Permanent Residential Houses are houses built by Community Groups financed through a grant-patterned social assistance fund. Permanent housing is also a place to live for victims of post-residency disasters from permanent, temporary housing. Viewed from the cycle of disaster management according to Government Regulation of the Republic of Indonesia No. 21 of 2008, this post-disaster relief house is built in the last stages, there are rehabilitation and reconstruction [5].

Considering that one of the basic needs that must be met after the disaster subsides is the need to leave, the Indonesian government has built several relief houses that generally use one type of design for all disasters. One of the last examples of home design is the Simple Healthy Instant Home (RISHA), which again emphasizes post-disaster relief houses that emphasize production speed and structural strength with a modular knock-down concept [6]. Indirectly, post-disaster relief houses in Indonesia are still in line with Wageman's statement, which has not considered occupant's uniqueness and particular needs [2].

1.1.2. Monolithic domes. The monolithic dome is a dome-shaped structure that is formed into a homogeneous part of the structure. The monolithic dome is constructed using a method that requires polyurethane foam insulation, air-filled air form, and reinforced concrete [7]. This monolithic dome structure claimed to be resistant to tornadoes, storms, and earthquakes—so it can minimize damage should a disaster happen again. In terms of energy consumption, durability, disaster resilience, and maintenance, monolithic domes should work well in any climate, even very hot or cold climates [7]. Moreover, it can also be built in any location: mountains, coast, even underground or underwater. The monolithic dome structure is claimed to be more cost-effective, durable, and easy to maintain than other types of structure; buildings using monolithic dome structure claims to use only 50% less energy than a conventionally constructed building of the same size [7]. However, this structure's disadvantage is that the loads must be evenly transferred along its surface; thus, making changes could reduce the load distribution on the surface and decrease its structural integrity. Therefore, this type of structure is more complicated to change compared to the frame structure.

1.1.3. Flexible housing and its relation to sustainable housing. According to Till & Schneider, flexible housing can adjust to changing needs and patterns, both social and technological. These changing needs may be personal (say an expanding family), practical (i.e., the onset of old age), or technological (i.e., the updating of old services) [3]. The flexible housing application is divided into three: building indetermination, circulation, and moveable elements. Building indetermination is a different use of space functions but is still connected to the same structural system. The circulation can be used as an opportunity for the house by providing more space, especially for storage. Furthermore, flexibility is often associated with architectural elements that can move. With moveable elements, space can be easily divided, separated, combined, and integrated according to its inhabitants' needs [3]. However, the three applications are further detailed into application subtypes (figure 1).
This flexibility also closely relates to construction techniques. Technically, successful flexible housing also relies on robust and straightforward construction techniques so that this construction is possible to intervene in the future. Thus, the house can change quickly according to the needs of its users. According to UN-Habitat, housing is necessary social conditions that determine people and places' quality of life and welfare [8]. Factors such as home location, the wellness of its design and construction, and its contextuality to the condition of the surrounding—environmental, social, cultural, and economic fabric of the communities—could influence people's daily lives. Given the long life of dwellings as physical structures, these factors may affect both the present and future generations. Therefore, housing is considered central to sustainable development. According to Edwards & Turrent, sustainable housing is a home that must ensure a better quality of life for its users, not only when the house is built, but for future generations [9]. Flexible housing indirectly also accommodates some factors of sustainable housing because it should adapt to changes that will occur in the future. Therefore, flexible housing can be said to be in line with the needs of sustainable housing.

2. Method
The observation objects were dome houses located in Sengir village, Sleman Yogyakarta. These houses were built in 2006 after the Yogyakarta earthquake and completed in 2007, where the disaster victims immediately occupied these houses. These dome houses were made into a complex, consisting of six blocks or lots. Each lot consists of twelve houses with different land areas. The domes in one lot had different orientations and were placed alternately, causing the land conditions owned by each occupant to be varied.

This research uses qualitative research methods with data collection through observation and interview methods. The use of two different data collection methods is believed to be complementary, resulting in a better and more comprehensive understanding and reducing bias [10]. This method is also considered more flexible to have adjustments if the researchers discovered new information or contexts during the research process.

Observations were conducted at three dome houses (figure 2). These houses were chosen to represent the majority, in which the owner had added space to their house. These houses also had spaces that were

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**Figure 1.** The applications of flexible housing.
added in various directions based on the land conditions. The observations aimed to determine how the houses were developed, both in terms of space use and construction techniques. The observations also detected whether or not the dome houses were in line with the flexible housing principle to support sustainable housing. The researchers also interviewed each homeowner with open-ended questions regarding their daily activities with their family and what aspects made them add additional space.

3. Results and discussion
The dome house is a post-disaster relief house intended for Sengir Village residents affected by the 2006 Yogyakarta earthquake. This relief house was built into a village complex consisting of six housing blocks. One block consists of twelve houses with one communal bathroom shared and located in the block center (the black colored dot in figure 3).

In one housing block, the dome houses were arranged alternately so that their positions varied. The orientation of the houses was also diversified. However, each house has the same land title: rectangular with an area of approximately 8x15 m². The different positions and orientations allowed the dome houses to have several possibilities for adding other rooms. There are seven possibilities for additional space in the dome house based on its position and availability (see figure 3). This study took three examples of dome houses in which the owner had added space by extending to the back, the left and/or right sides. The addition of space to these three samples used a structure with a frame system attached to the house's dome structure. Although it looks connected, the additional new structure did not interfere with the existing dome structure.
Overall, these dome houses had a relatively simple structure. Monolithic Ecoshell divided the building components into three: the foundation and floor plates, shell construction, and interior [11]. The foundation in this house has a full circle shape that adapts to the house plan. This foundation's depths are built about 40 cm, whereas the slab's diameters 7m [11]. After the foundation and slab were finished, the next step would be to make a semi-circular mould with a monolithic dome-type using a tool called an 'air form' filled with air to form a perfect dome. (figure 4).

The process of weaving steel reinforcement coincided with the installation of door and window frames. Once the mold had been filled with air to form a dome, the concrete was casted around the structural wall's surface to form the dome house, followed by making the interior elements. Non-structural walls in the house's interior were built using bricks that would divide the room on the first floor into four parts. For the second floor, wood was chosen as the floor material instead of concrete (see figure 3).

| Table 1. The demographics of Interviewer. |
|------------------------------------------|
| House | (Sample A) | (Sample B) | (Sample C) |
| People(s) | 3 Person | 4 Person | 4 Person |
| Work | Housewife, Farmer, Laborer | Housewife, Entrepreneur, Students | Housewife, Laborer, Students |
| Gender | 1 Female ; 2 Male | 1 Female; 3 Male | 1 Female, 3 Male |
| Additional Space | Shop | Bedroom, Living room, Kitchen, Bathroom | Kitchen, Drying Room, Multifunctional Room |
To understand the urgency of the application of the flexible housing, we must first identify the aspects that influence it. This analysis focuses on three aspects which have the most influence on flexible housing—demographic, economic, and environmental—as stated by Till & Schneider [3]. In addition, according to Edward & Turrent, these three aspects should also support sustainable housing which consists of environment, economic growth and social processes. Thus, they should bridge the concept of flexible housing and sustainable housing [9].

3.1. Demographic, economical and environmental aspects

In the original design, the dome house has two floors and consists of five rooms. The first floor consisted of a living room, two bedrooms, and a kitchen; the second floor consisted of a multifunctional room that could be used as a family room.

Demographically (Table 1), the house for sample A was occupied by three people—a married couple with one child—thus, not too much space was required and no addition was needed. In sample B, the house was occupied by four people and needed more space than provided by the dome house's default design. The occupants of house B also have cows as livestock. When first occupying the dome house, house B occupants only consisted of three people: two parents and one child. As of 2020, he has two children and needs more space in his house. Therefore, they added a bedroom and a living room and family room because of the need for demographic aspects.

As for sample C, the occupants are also four people. Like sample B, house C occupants also have other needs that the dome house cannot accommodate. The homeowner adds a drying area and storage for firewood and a kitchen, bathroom, and chicken coop area. When first occupying the dome house, house C occupants only consisted of three people with only one child. As of 2020, they have one more child at the age of five years old. Considering the children's age, the occupants have not yet added a bedroom because they are still small and can still accommodate the dome house. However, additional space may be needed in the future, once their children have grown. The occupants of house C have a chicken pet, thus requiring a particular additional room. Therefore, the finding shows that only two of the three observed houses added space because of the demographic aspect.

Viewed from the economic aspect, in sample A, Mrs. Widi was a housewife before the earthquake occurred. However, after the earthquake and an economic boost that had to be fulfilled, Mrs. Widi decided to start selling goods, encouraging the addition of space for a shop next to her house. As for sample B, Mr. Rajimin worked as an entrepreneur, his wife was a housewife, and his children were still in school. Thus, the addition of space was not encouraged by the economic aspect. For sample C, Mrs. Purwanti worked as a housewife and a tailor, her husband works as a construction worker, and her children are still in school. Due to her husband's job as a construction worker, sometimes he may need to store building materials: thus, additional storage space is required. This finding shows that only two of the three dome house samples had needed to add space for economic reasons.

From the environmental aspect, Yogyakarta is in the tropical humid climate category with an average rainfall of 2012 mm/year with 119 rainy days [12], an average temperature of 27.2 °C, and average humidity of 24.7% [13]. Based on this data, Yogyakarta's weather is quite hot during the day; thus, requiring a responsive building. However, this was not the case in the dome house. The dome-like shape trapped heat in the house because the ceiling is not high enough, and there was no extensive ventilation. Thus, the air could not circulate quite well, especially on the second floor. According to Mustaqim, walls are the building elements contributing the most to the heat gain in the dome houses [14]. This theory contradicts the previous theory, which stated that a monolithic dome should respond to any climate [7]. More so, because this structural wall was made of concrete that stores heat for a long time, the dome house's second floor was not comfortable to be used as a family room. This fact was also supported by the interview with Mr. Rajimin, which shows that their second floor was converted into a warehouse instead. These findings show that the dome house does not support flexible housing principles in the environmental aspect, indicated by the lack of response to the climate, which encouraged most residents to convert the room function (figure 5). It was also difficult for the residents to make any efforts to improve the quality of thermal comfort on the upper level due to the inflexibility of the structure.
In short, the data suggested that all three aspects (demographic, economic, and environmental) had required residents to make changes or adjustments to their homes. However, the urge to make changes caused by environmental factors could not be done because the structure of the existing dome house did not allow for adjustments, suggesting that the dome house's design had not fully considered user needs. These findings are unfortunate because post-disaster building should use structural systems and construction techniques, which would allow users to make necessary adjustments in the future [15].

3.2. Flexible Housing Application

Table 2. Applications of Flexible Housing in Dome-House of 2006 Yogyakarta Earthquake

| House                      | (Sample A) | (Sample B) | (Sample C) |
|----------------------------|------------|------------|------------|
| Raw Space                  | No         | No         | No         |
| Excess Space               | No         | No         | No         |
| Slack Space                | No         | No         | No         |
| Adding-On                  | Yes        | Yes        | Yes        |
| Expanding Within           | No         | No         | No         |
| Joining Together           | No         | No         | No         |
| Switching it               | No         | No         | No         |
| Dividing Up                | No         | No         | No         |
| Moving in                  | No         | No         | No         |
| Rooms Without Labels       | No         | No         | No         |
| Internal Circulation       | No         | No         | No         |
| External Circulation       | Yes        | Yes        | Yes        |
| Permeable Circulation      | No         | No         | No         |
| Moveable elements          | No         | No         | No         |

In all three samples, the residents had added new space: whether for a shop, bedroom, family room, bathroom, drying room, or multifunctional room. These additions were made using the adding-on application, where the structure of this additional space was independent and did not affect the building's
existing structure. In samples B and C, Mr. Rajimin and Mrs. Purwanti's house also added space by utilizing external circulation. In the case of Pak Rajimin's house, external circulation was used to store motor vehicles on the house; in contrast, Mrs. Purwanti's house used the external circulation to store firewood for cooking. These facts are also in line with Wagemann's theory, which stated that these houses' developments are undeniable and inevitable, mainly because each house occupants that are unique and have specific needs [2].

According to Till & Schneider, the most used flexible housing applications in dome houses are adding-on and external circulation [3] (Table 2). Given that the dome house's structure could not be modified, many of the residents did not make any changes to the dome house. Although the majority used the adding-on application, the addition was independent and did not interfere with the house's main structure. These houses were also supported by having extra land area, thus making it possible for external development or extensions to be made on each land.

Furthermore, this house could meet the applications of dividing up, switching it, joining together, and moving in, especially on the second level of a house that had no partition. However, the residents did not do this because of the unfavorable response to environmental aspects or climatic conditions. According to Mustaqim, a building's thermal comfort is a factor that has a significant impact on the user's comfort [14]. Relating to the building's physics, the dome house's semi-circular shape could cause heat to be trapped in the building; thus, the temperature on the second floor could get quite high during the day. Coupled with the absence of adequate ventilation—only a small vent is in the middle of the roof—the second floor of the dome house was thermally uncomfortable, so it was rarely used as a living room; instead, most of them use the second floor as a warehouse or storage area for their crops. The interview also suggested that the residents had been advised not to change the dome house since before its occupation. They are also reinforced by a culture of respect for gifts from others, so the dome house's structure still maintains its authenticity [16]. Most of the residents there did not interfere with the structure; only a few did-and were only limited to planting nails in the dome house structure.

4. Conclusion

The aspects that most influenced the application of flexible housing in the dome house were in the demographic and economic. The demographic aspect occurs naturally over time, specifically when new family members born or family members get older, in which house development became urgent. The economic aspect of the flexible housing principle is also present in this house; there have been many professions from previously being a farmer to a new job that encourages the need for space conversion or the addition of new spaces in the house. However, no environmental aspect encouraged flexible hosting in the dome house, considering that the house was not thermally comfortable but could not be adjusted due to the strict structural conditions. The flexible housing applications applied in the case study mostly used adding-on and external circulation because the dome structure was difficult to change. A flexible house can adapt well to its users' needs. This house can be said to be sustainable. Besides being responsive to its residents' needs, it also responds to other patterns such as demographic changes, economic changes, and environmental changes—such as being responsive to the climate where houses are built. However, in the case of the dome house, the environmental aspect was not responded well; thus, no applications could be applied, which resulted in this house being classified as less sustainable.

In short, the dome house only applied two principles of flexible housing entirely for external developments; thus, proving that this type of house can only implement flexible housing in a limited manner. Moreover, the existence of a good surrounding area played a considerable part in supporting the possibility of external development; thus, making it in line with sustainable housing. However, considering that the dome-shaped structure itself was not adjustable, the design of this house on its own was still far from being in line with the concept of flexible and sustainable housing.

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