Bamboo-based temporary house for post disaster relief: A conceptual design and prototype built after Lombok Earthquake 2018

J Fajrin, IW Sugiartha, M Eniarti and Pathurahman
Department of Civil Engineering, Faculty of Engineering, Mataram University, Indonesia

Abstract. This paper presents an alternative design of a temporary house made of bamboo and its manufacturing process to become a prototype that can be seen by the public. It was expected that by seeing this prototype, the people who lives around disaster affected areas can build their own temporary houses or the government can build it for them. The process was initiated by reviewing the existing designs published previously which were then examined from the perspective and experience of the authors. The next step was defining some basic design criteria by combining findings from literature, author experiences, local conditions and the availability of resources. The proposed conceptual design was then developed based on the design criteria of a temporary house. At the last stage, a prototype of temporary house was constructed as a showcase. This article summarized all these processes which indicated that, to such extent within the boundary condition of the study, bamboo can be practically applied for building a temporary house following earthquake disaster, with a special reference to Lombok Earthquake in 2018.

1. Introduction
A series of strong earthquakes hit Lombok Island in August 2018 devastated lives of many local peoples. Thousands of houses which is approximately 149,706 houses were heavily damaged [1]. As a quick and immediate response to the earthquake disaster, thousands of emergency and temporary shelters were built by government and agencies. Unlike providing food and clothing that can be done quickly and immediately, providing accommodation for victims of natural disasters such as earthquakes requires a long and complicated processes and may face a lot of challenges prior to start the reconstruction works. Sultani et al. [2] quoted that in The United States, providing post disaster accommodation consists of the following phases; emergency and temporary sheltering, temporary housing and permanent housing. Emergency and temporary sheltering may last for several days up to weeks or months [3]. Furthermore, it was stated in Reference [3] that temporary housing usually designed for a longer period after the disaster and in some circumstances it can be a long term settlements. Reconstruction of houses for victims of natural disasters always have great challenges in the realization process which includes; program management, community participation, coordination, administration, quality assurance and technical design [1]. Similarly, Okazaki et al. [4] stated that technical design and its procedures played important role in meeting the needs of community. Although it was considered to have an important role, many of disaster relief shelter were improperly designed [5], so that the provision and performance failed to meet the required standards.
In relation to technical design, another aspect which is also quite crucial in the process of rehabilitation and reconstruction of people's houses is the availability of material. In the development of technical design, it should also take into account the availability of material on site. Another aspect that also pretty important to be considered is the opportunity of using alternative materials for the replacement of the conventional ones. A comprehensive evaluation on the reconstruction process after the Lombok earthquake as reported in Reference [1] indicated that many residents interested in using timber for re-building their houses. However, as the demand was very high in a relatively short period, eventually it was difficult to obtain these materials.

This article presents an alternative temporary house made of bamboo, as a substitute material for timber, which meets technical requirements. Bamboo has been long recognised as a viable sheltering material, especially for people who live in rural areas. Bamboo is regarded as a favourable material for housing and also for structural component due to its low weight to strength ratio, ductility, low cost, simple processing and faster production [6].

Many studies have been reported in the application of bamboo as a building or housing materials. Das and Mukhopadhyay [7] reported their work on developing multi-hazard resilient housing using bamboo-based system. Vengala et al. [8] examined the seismic performance of bamboo housing. While Lugt et al. [9] assessed the environmental, economic and practical aspect of bamboo as building material. In Addition, Baghel and Thakkar [10] analysed the viability of bamboo as a resilient material for mas housing and concluded that bamboo is a green, safe, climate responsive, affordable and socially acceptable. Further they said that bamboo could make architectural design fairly functional. In addition, as an immediate response to Lombok Earthquake disaster, Fajrin et al. [11] developed emergency shelter using bamboo and plywood material.

2. Method
The research methodology applied for this work was a mixed model that combining field observation, desk evaluation and applied research approach. The research work includes reviewing existing design published elsewhere, developing design criteria and arrangement of technical design that ended up with the construction of a prototype. During the development of design criteria and technical design, it was considered adopting a unique design that match with the local circumstances and needs. Design criteria mainly developed as per the work reported by Sener and Altun [12].

3. Results and Discussions
3.1. Design concepts
In this initial step, a design objective was clearly defined prior to specifying the design criteria. The design objective was developing a house unit made of locally available material, structurally acceptable, temporary and multiple use with a minimum negative impact on environment. Few basic design criteria were applied throughout the development of the technical design. First, material should be locally available, structurally acceptable, ease of processing and handling. Second, the cost relates to material and manufacturing should be effective and kept as minimum as possible. Third, in term of physical performance; the indoor climate should be comfort and healthy environment. Four, in relate to special organisation, the design has to provide privacy and flexibility. Five, it also has to meet aesthetic requirements and provides optimum security.

All criteria were discussed thoroughly from different point of views. The team realised that it was impossible to satisfy all criteria at the same level, especially when time and money were a significant constraint. Having considered all the pre-established design criteria, it was decided that the temporary house unit has to meet the following criteria; 1) The unit is made of bamboo, as the replacement of timber, 2) The unit shall be constructed as a fabricated component, 3) The pre-fabrication component uses simple but sound connection system and 4) the unit shall provide optimum space and can be constructed and replicated easily.
3.2. Technical design
This proposed design unit was developed based on a modular panel concept where each part of the building was made separately and then combined together into one unit on location. This concept allows building to be mass produced in workshop and then transported in separate panels and assembled on site. The main structure used bamboo-based system with a unique joint system for connecting different parts of housing components. The main bamboo frame was also diagonally strengthened to provide maximum support under earthquake event. In term of spatial organisation, the concept adopted a simple house type 45 which consisting of two bedrooms, family room, kitchen and bathroom. The plan of the temporary house is shown in Figure 1, while front and rear view are presented in Figure 2.

![Figure 1. Plan of the temporary house](image)

![Figure 2. Front and rear view of the temporary house](image)

3.3. Manufacturing process and prototype
The manufacturing process of this temporary house are presented in Figure 3. The construction process started with preparing the base of the temporary house. The base was made of brick laying with a deep of approximately 20 cm around the edge of the base, which was firmly filled with soil. The surface of the base which later used as the floor was prepared with mortar (a mixture of cement and sand in a ratio of 1: 8). The main frame structure was designed as a single unit, where the bamboo pole and bamboo truss integrated in a single frame. For a unit house, it consists of 3 main frames. All
the three main frames then installed on the floor by tighten up bolted connector that already pre-installed on the floor. Unlike a conventional system that joining bamboo component by tiding up with palm fibre (ijuk), this proposed design introduced the use of plywood board with a thickness of 8 mm as a connection plate (for a replacement of steel plate in steel structure) and then bolted together. The connection arrangement and detail are depicted in Figure 4.

Figure 3. Construction process of the temporary house

Having installed all the main frames on their designed positions, the next process was installing roof cover which is using metal roof with a commercial name of Spandex, instead of conventional material made of reeds. The next following process was placing wall’s cover that prepared using bamboo woven in the form of pre-fabricated wall panels. After all the housing parts installed in position, the final step was installing windows and doors shutter.

Figure 4. Detail of the temporary house
A post disaster temporary house unit was successfully constructed with the help of civil engineering students that works together in a community group that called as “JTS Shelter for Lombok”. It was a distinctive effort among many designs of temporary housing proposed by many agencies after Lombok earthquake disaster in 2018. The unique prototype built and showed in the corner yard of the Department of Civil Engineering, Mataram University, is shown in Figure 5.

![Figure 5. The prototype of the temporary house](image)

4. Conclusions
A series of works which included reviewing all published design concepts, developing design criteria and technical design, drawing detailing works and construction of a house prototype, had successfully carried out in dealing with the development of temporary house based on bamboo-system. A post disaster temporary bamboo house prototype was built and located at the back corner yard of The Department of Civil Engineering, Mataram University campus. It was a unique attempt to help local affected people to re-build their houses after the Lombok earthquake in 2018.

References
[1] Pribadi K S, Pradoto R G, Hanafi E A, and Rasmawan I M A B 2020 Lombok earthquake, one year later: housing sector recovery. *E3S Web of Conference* 156.
[2] Soltani A, Ardalan A, Darvishi B A, Haghdoost A, and Hosseinzadeh-Altar M J 2015 Criteria for site selection of temporary shelters after earthquakes: a Delphi apnel. *PLOS Current Disasters*. Edisi 1.
[3] Quarantelli E L 1995 patterns of shelters and housing in US disaster. *Disaster prevention and management*. 4 No 3, pp 45-53.
[4] Okazaki K, Narafu T, Kusumastuti D, and Pribadi K S 2008 Reconstruction practice in Aceh after 2004 tsunami disaster, in *Proceeding of 14th World conference on earthquake engineering*, Beijing.
[5] Bashawri A, Garrity S and Moodley K 2014 An overview of the design of disaster relief shelter, *Procedia Economics and Finance*, 18, pp 924-931.
[6] Mukhopadhyay P 2008 Role of bamboo in seismic architecture, *Material Matters*, 1 (a and b), pp 102-106.
[7] Das S and Mukhopadhyay P 2017 Multi-hazard disaster resilient housing with bamboo-based system, *Procedia Engineering*, 212, pp 937-946.
[8] Vengala J, Mohanty B N and Raghinath 2015 Seismic performance of bamboo housing—an overview, semantic scholar.org.
[9] Lugt P, Dobbelsteen A A J F and Janssen J J A 2006 An environmental, economic and practical assessment of bamboo as a building material for supporting structures, Construction and Building Materials, 20/1, pp. 648-656.

[10] Baghel A and Thakkar A 2017 Bamboo: A resilient material for mass housing in earthquake prone zones of Gujarat, Proceeding of Sustainable built environment.

[11] Fajrin J, Muchlis M and Tandean Y R 2020 Development of temporary shelter designs for Lombok earthquake victims, Journal of Multidisciplinary Community Service, 4/1, pp. 26-32. (In Bahasa)

[12] Sener S M and Altun M C 2009 Design of post disaster temporary shelter unit, Journal ITU A/Z, 6/2, pp. 58-72.

Acknowledgments
Authors wishing to acknowledge assistance from the group member of Shelter for Lombok and Mr. Yogi Rosita Tandean who worked in this project for his PKL (field work project) at the Department of Civil Engineering, Faculty of Engineering, Mataram University.