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The Design of Earthquake Evacuation Spaces Based on Local Wisdom: A Case Study of Traditional Houses in South Sulawesi

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Abstract: Indonesia is situated on the Ring of Fire, which causes a lot of earthquakes. On the 28 September 2018, there was an earthquake in Palu, Sulawesi Island, Indonesia, which was one of the strongest shakings since 1980. Surprisingly, most traditional houses in Sulawesi survived. There has been some research on adapting traditional house structures to modern residential buildings. The limited availability of wood and complicated construction make adapting wood structures to current conditions challenging. The purpose of this study is to analyze space organization in ten traditional South Sulawesi house designs. A possible evacuation route can be found through the analysis as the first space for expeditiously escaping from an earthquake. In addition, modernizing the layout of a traditional South Sulawesi house and introducing it to local people was easy since they were familiar with the design. A deep analysis of spatial organization and its interrelations can help develop realistic designs, plans, and knowledge, thus improving the quality of residential projects. A descriptive qualitative method was used as a research method. Data were collected from field observations, brief interviews, and literature reviews. In order to analyz thee data, ORA-LITE was used to redraw the data and create the charts. It was found that different cultures have different evacuation spaces, in this case the Bugis tribe and the Toraja tribe. A corridor and kitchen were the most strategically located areas that could possibly be used for evacuation. Considering the differences in culture among tribes, designing evacuation spaces based on local culture was important. A recommendation based on this finding can also be made to the government of South Sulawesi in the design of residential houses.

Keywords: earthquake; mitigation space; local wisdom; South Sulawesi traditional house; evacuation area; residential building

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1. Introduction

Indonesia has made global headlines over the past 20 years due to devastating natural disasters that have caused the deaths of hundreds of thousands of people and damaged the country's infrastructure [1]. Indonesia is situated in the Ring of Fire, which results in frequent earthquakes [2]. There are several tectonic plates colliding under Indonesia's arc in the Pacific Ocean's Ring of Fire. An earthquake that was one of the strongest since 1980 struck Palu, Sulawesi Island, Indonesia on 28 September 2018 [3]. The 7.5-magnitude earthquake that struck Central Sulawesi and the 1.5 m tsunami waves that struck Palu and Donggala caused widespread destruction. According to Indonesian authorities, there were 2.4 million people affected by the disaster. It was surprising to find that most traditional houses in Sulawesi survived this disaster [4,5].

The traditional house in Indonesia was adapted from the environment, which reflected in the daily lives of the people and represented their culture [6]. Having a wide variety of geographic conditions, cultures, and social backgrounds produces a wide variety of

architecture in Indonesia. The majority of references regarding earthquake adaptation to traditional houses focus on the structure of the houses. A V-shaped structure in the Sulawesi traditional house system responds structurally to the lateral loads produced by earthquakes [7]. Due to their current condition, it is not possible to use these structures. There were several problems with finding the wood, including its high cost. In addition, the huge shape of the house makes it difficult to use in the current situation, where there is limited land available. A lot of elements from traditional houses could be developed as a mitigation for earthquakes instead of their structure.

Obtaining an evacuation route is one of the most important factors in escaping from an earthquake as soon as possible. Moreover, this route can be designed based on an understanding of the behavior of the occupants. It is possible to understand the behavior of the house from the layout of the house. Adapting a traditional South Sulawesi house layout to a modern home was simple and straightforward.

Sulawesi Island's traditional houses were unique. Contrary to traditional houses on Java Island, which almost all have similar shapes [8], Sulawesi traditional houses have different shapes. Despite the fact that both islands (Java and Sulawesi) have multiple tribes living on them, each tribe in Sulawesi has its own belief system and culture, which is reflected in their houses. As an example, South Sulawesi had four large tribes: Bugis, Makassar, Toraja, and Mandars. Even though they were located in the same province, the cultural background, concept, philosophy, and detailed architectural form of their houses were completely different. However, due to the similarity of geographical background, there are several similarities in the shapes of traditional houses between Makassar and Bugis, as well as between Toraja and Mandar. In this study, Bugis and Makassar traditional houses are categorized as the same, commonly referred to as Bugis–Makassar houses. Furthermore, this research only discusses the Bugis–Makassar house and the Toraja house.

The objective of this study is to investigate how traditional architecture in South Sulawesi responds to its natural conditions, in this case, an earthquake, when it comes to the design of building layouts. A possible evacuation route can be found through the analysis as the first space for escaping from an earthquake as soon as possible. In addition, modernizing the layout of a traditional South Sulawesi house and introducing it to local people was easy since they were familiar with the design. A qualitative research methodology was used to achieve the objectives. A deep analysis of spatial organization and its interrelations can help develop realistic designs, plans, and knowledge, thus improving the quality of residential projects. Additionally, field observations, interviews, and literature reviews were used to enrich the data and analysis. In the field observations, visual condition data regarding traditional architectural conditions were collected using a camera. In order to determine the conclusion from the field research, the data obtained in the field is compared with the literature.

2. Methodology

The method used in this study was descriptive qualitative. In order to develop a reliable and effective observation instrument, a literature review and field observations were conducted. Researchers collect data about the traditional houses of the Bugis–Makassar and Toraja tribes.

2.1. Data Collection

South Sulawesi Province is the location of the research. This study explored six traditional houses located in Fort Somba Opu Makassar museum as a representative example of the traditional house among the common populace, adopting the architectural style of six sultan traditional houses and four traditional houses of Toraja located in Toraja (Figure 1), including their associated culture, tradition, and nature norms. On-site observations were complemented by interviews with village participants to gain a deeper understanding of the data. The researcher observes and interacts with informants in

the community to collect data about the traditional houses regarding their function, space, form, and meaning, as well as analyze the phenomena that occur.

Figure 1. The research is performed in six traditional historic houses of Fort Somba Opu Museum, representing the traditional houses of six different sultanates in South Sulawesi and four traditional houses of Toraja. In total, there are ten traditional houses: (**A**) Lapinceng, Barru; (**B**) Bola Soba, Bone; (**C**) Sao Mario Soppeng, (**D**) Balla Lompoa, Makassar; (**E**) Balla Lompoa, Gowa; (**F**) Balla Lompoa, Takalar; (**G**) Tongkonan Borong, Toraja; (**H**) Tongkonan Tombang, Toraja; (**I**) Tongkonan Londa, Toraja; (**J**) Tongkonan Barana, Toraja.

2.2. Data Analysis

The process of qualitative data analysis requires the work of organizing data, dividing it into manageable units, synthesizing it, finding patterns, and analyzing it qualitatively. The data collected were compared to identify the differences and similarities between traditional houses and their designs to cope with earthquakes. Furthermore, this approach was commonly used for examining the domestic spatial arrangement of houses [9,10]. A closer look at spatial arrangements, social events, and their interrelationships could improve the quality of residential construction by enabling realistic conceptions, plans, and knowledge [11].

Redrawn data and analysis were carried out using ORA-LITE software (v.3.0.9.9.116) [12]. This tool, developed by Carnegie Mellon's CASOS, is used to analyze and assess dynamic meta-networks. Through this method, local patterns have been examined over time and space to determine how networks change. The architectural plans were translated into adjacency matrixes. Domestic spaces are represented as nodes, as shown by their connections in each adjacency matrix. Passageways of all types are referred to as connectors. These data were processed by ORA to characterize and visualize spatial networks. The following four centralities measurements [13] were used to characterize social networks:

1. The total degree of centrality reflects the "direct influence" or "control" space;
2. The closeness centrality of a node is calculated by summing up the distance of the node to all other nodes;
3. The betweenness centrality of a given node measures its ability to act as a bridge in a network;
4. Exclusivity refers to the level of exclusive access a specific node has to other nodes.

3. Case Study

The information on traditional houses in Sulawesi, Indonesia, is limited. In addition, this manuscript focuses on South Sulawesi (Figure 1), as well as the three largest tribes of Sulawesi, Bugis–Makassar, and Toraja. There are several houses that are used for research, such as (A) Lapinceng, Barru; (B) Bola Soba, Bone; (C) Sao Mario Soppeng, (D) Balla Lompoa, Makassar; (E) Balla Lompoa, Gowa; (F) Balla Lompoa, Takalar; (G) Tongkonan Borong, Toraja; (H) Tongkonan Tombang, Toraja; (I) Tongkonan Londa, Toraja; (J) Tongkonan Barana, Toraja. It is possible to gain a deeper understanding of Sulawesi culture by looking at these houses.

South Sulawesi's roof shapes can clearly show the difference between houses, as shown in Table 1. There were two different tribes in South Sulawesi, first from the Bugis–Makassar tribe, e.g., (A) Lapinceng, Barru; (B) Bola Soba, Bone; (C) Sao Mario Soppeng, (D) Balla Lompoa, Makassar; (E) Balla Lompoa, Gowa; (F) Balla Lompoa, Takalar. Listed in (G) Tongkonan Borong, Toraja; (H) Tongkonan Tombang, Toraja; (I) Tongkonan Londa, Toraja; and (J) Tongkonan Barana, Toraja, are some of the second-type houses of the Toraja tribe. There is an open-plan layout throughout the houses.

Table 1. The shape and detail of a Bugis and Toraja traditional house in South Sulawesi.

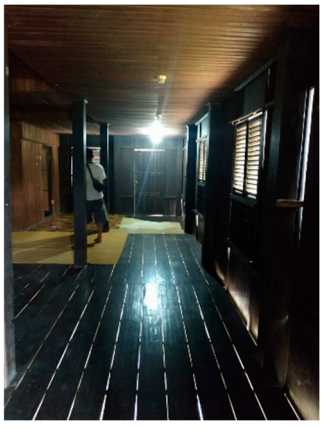
House Name	House Detail		
(A) Lapinceng, Barru			
(B) Bola Soba, Bone			

Table 1. *Cont.*

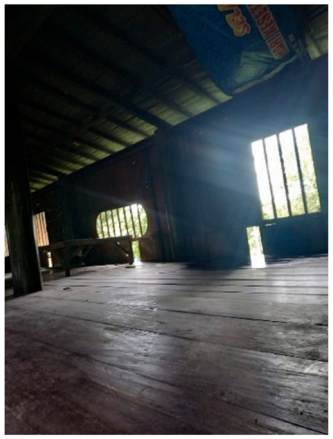
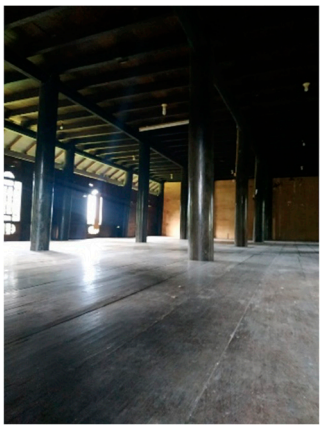
House Name	House Detail		
(C) Sao Mario Soppeng			
(D) Balla Lompoa, Makassar			
(E) Balla Lompoa, Gowa			

Table 1. *Cont.*

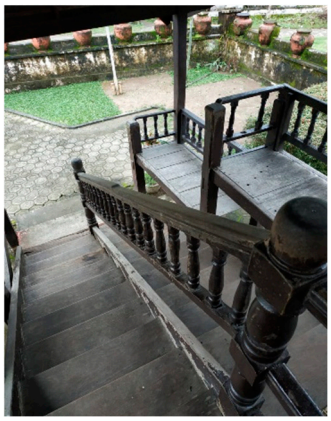
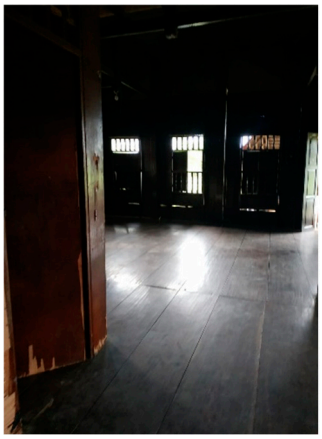
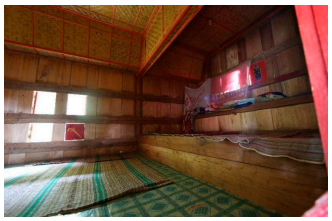
House Name	House Detail		
(F) Balla Lompoa, Takalar			
(G) Tongkonan Borong, Toraja			
(H) Tongkonan Tombang, Toraja			

Table 1. *Cont.*

House Name	House Detail		
(I) Tongkonan Londa, Toraja			
(J) Tongkonan Barana, Toraja [14]			

3.1. The Toraja Tribe's Tongkonan House

Traditional Tongkonan houses belong to the Toraja people, and they serve as a place of residence, traditional power, and the development of their social and cultural life. The roof represents the core identity of Torajan society through its resemblance to ships, therefore connoting the ancestors [15]. Rumah Tongkonan's roofs are larger than its bodies and foundations, highlighting its protective function.

A Tongkonan house always consists of an elevated pit and rooms above it, which vary in height and depth under the pit. Though Tongkonan architecture has the same overall shape, some differences exist in sizes, shapes, materials, construction, decoration, and other details [16]. In traditional Toraja houses, the layout or plan is determined by *Aluk Todolo* cosmology, primarily by the direction of sunrise and sunset. Tongkonan houses have rectangular shapes with long sides oriented toward sunrise and sunset. The sunrise is considered a symbol of life and birth [16]. Due to this, the stairs and kitchen inside have been placed in this (east) direction.

The Toraja tribes used to build their villages on flat, high fields far apart from each other in the past. A settlement must be located near a workplace (rice fields or gardens), a water source, and bamboo groves [16]. Traditionally, Tongkonan houses are not built all at once but in stages, one after the other, which takes a long time. Every number represents the socioeconomic status of the owner's family. A newer house is built towards the sunrise, and the oldest is built towards the sunset [16].

A Tongkonan house always resembles a pit; it just varies in height and depth. An earthquake-resistant stilt house has a frame structure that forms a complete unit [16]. Building horizontal and vertical elements from wood is a common characteristic of traditional architecture, symbolizing the relationship between man and nature. *Silongko* (connected) and *siamma* (meal) are connected by grooves, pins, and rattan ropes. The pillars of a building are built on mountain stone foundations (Figure 2).

Figure 2. Mountain stone foundations support the pillars of Tongkonan houses.

3.2. The Bugis–Makassar Tribe's Traditional House

On the other side is the Bugis–Makassar Tribe, which is built according to a "cosmic balance" philosophy [17]. According to Buginese belief, the universe is rectangular (*Sulapa Eppa*). As the Bugis–Makassar houses were philosophically inspired by the cosmic structure, they represented four elements: land, water, fire, and wind, and the *Sulapa Eppa* philosophy was reflected in the site and shape of the houses [17,18]. For a balanced life, the Bugis–Makassar tribe believes that a harmonious relationship between humans and the environment is crucial. This includes earthquake-resistant designs. Bugis–Makassar houses had a spatial pattern, both vertically and horizontally, that reflected the anatomy of the human body. As a result, the body (wall/ale-bola), head (roof attic/*rakkeang*), and foot (foundation/*awa-bola*) are sized in balance [19,20], while horizontally it is positioned as a lying position: the public area serves as the guest room (*lontang ri saliweng*), the private area serves as the family room and bedroom (*lontang ri tengnga*), and the semi-private area serves as the kitchen (*lontang ri laleng*) [19]. Three *longtangs* are connected by circulation spaces (*tamping*), which usually have lower floor levels [21]. *Tamping* patterns provide an evacuation route in Bugis–Makassar houses in case of natural disasters like earthquakes (Figure 3). Bugis–Makassar tribe associates all of its components with the human body, reflecting the beliefs of society and creating a complete stilt house. For the Bugis–Makassar, building a house on stilts has become a generational tradition.

Figure 3. "*Tamping*" circulation spaces in Bugis–Makassar traditional houses to act as evacuation routes during natural disasters, including earthquakes. A view from inside the house (**a**) and a view from outside the house (**b**).

In the Bugis–Makassar Tribe, these houses have a variety of meanings and values incorporated into and embodied as views of daily life that are inseparable from local wisdom. The choices of orientation, where to put the main door, the spatial planning, and the structure of the building are all part of local wisdom [19]. This means that the arrangement should resemble the parts of the human body as well as ensure harmony between other natural elements.

The house is rectangular with two entrances, a porch in front and behind, which is larger on the front [19]. Windows and doors are placed according to the placement column, or in the middle of the *lontang* [22]. The main room does not have a partition, except for a separate room for residents. A rear entry leads to the kitchen, which is the first space encountered upon entering.

Typically, Bugis–Makassar houses have a steeply inclined, long-ridged roof with a simple double-pitched roof [23]. There are two parts to the roof; the main roof has a steeper slope, whereas the secondary roof is almost flat [20]. An air circulation system and a light distribution system are provided by casements between the main roof and the secondary roof.

In the lower structure of the Bugis–Makassar traditional house, columns measure 10 m × 19 m with 20 pillars of different sizes due to the production of beams (*tomakbau'*) [22]. The earthquake load that hits the structure causes the structure to move as a whole, in line with the direction of the horizontal earthquake load, both in the vertical and horizontal directions [24].

4. Results and Discussion

The 10 floor plans of the Bugis–Makassar Tribe, along with the Toraja Tribe, are analyzed and summarized in Tables 2 and 3, respectively. This study attempts to reconstruct the Bugis and Toraja cultures using diverse sources. The network measurements were used to discover how individual spaces functioned in the domestic spatial organization within groups and between groups. A Newman grouping was employed for the purpose of identifying subgroups [13].

Table 2. Traditional houses from the Bugis–Makassar Tribe are located in South Sulawesi with a unique layout and occupant circulation.

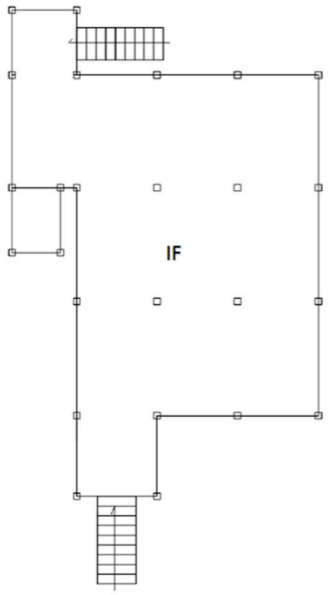
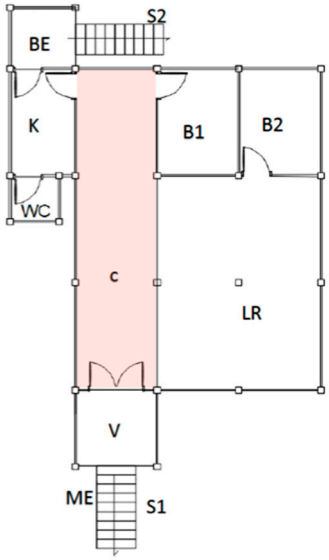
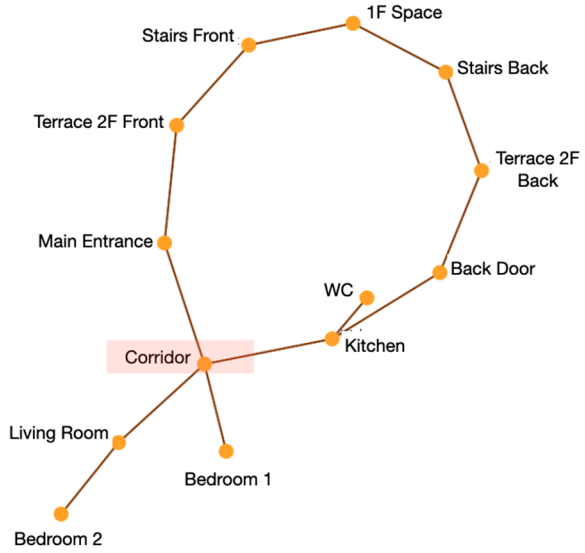
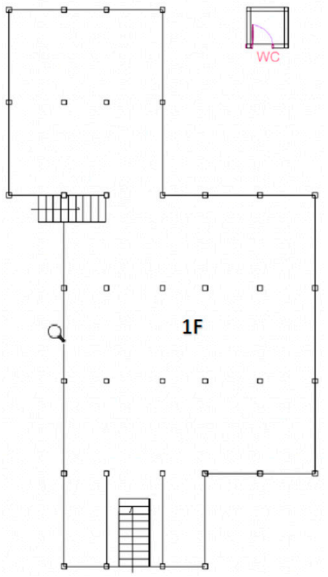
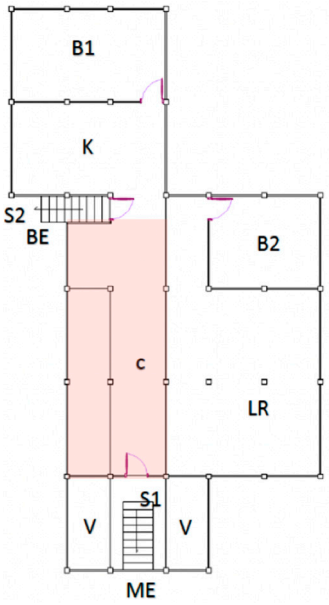
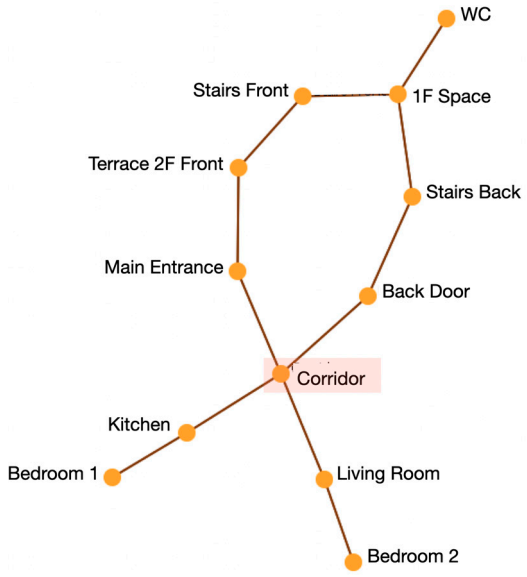
Drawing		House Circulation
Three Lontangs		
(A) Lapinceng, Barru		
1st Floor  	2nd Floor  	Corridor 
ME: Main Entrance S1: Stairs 1 V: Verandah C: Corridor	LR: Living Room B1: Bedroom 1 B2: Bedroom 2 WC: Bathroom	K: Kitchen BE: Back Entrance S2: Stairs 2
(C) Sao Mario Soppeng		
1st Floor  	2nd Floor  	Corridor 
ME: Main Entrance S1: Stairs 1 V: Verandah C: Corridor	LR: Living Room B1: Bedroom 1 B2: Bedroom 2 BE: Back Entrance	S2: Stairs 2 K: Kitchen WC: Bathroom

Table 2. *Cont.*

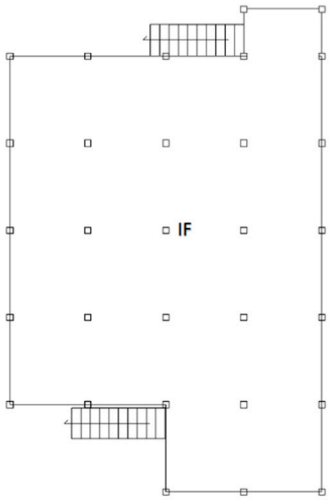
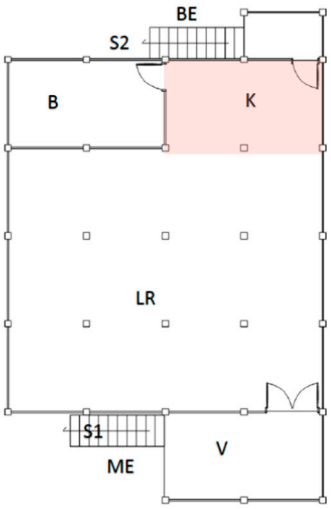
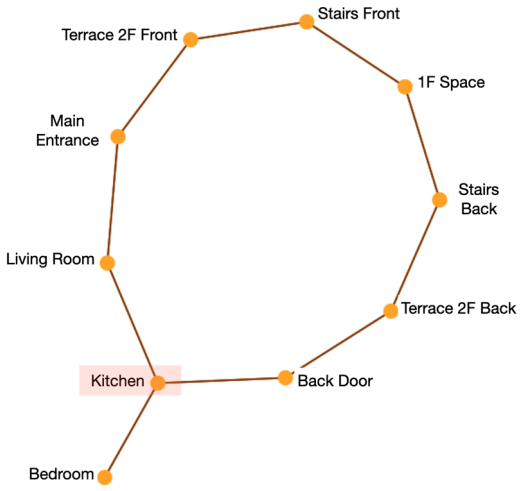
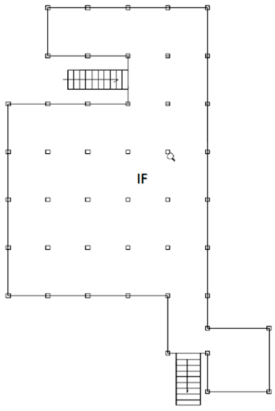
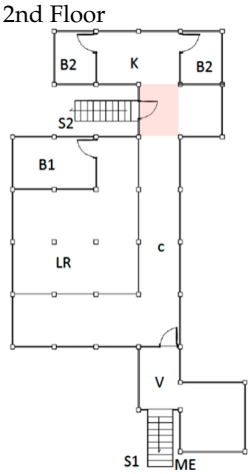
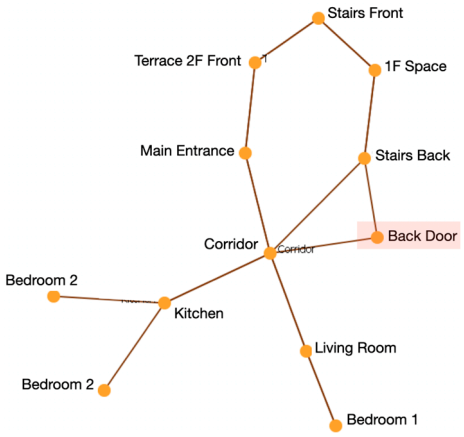
Drawing		House Circulation
Four Lontangs		
(B) Bola Soba, Bone		
1st Floor	2nd Floor	Kitchen
		
ME: Main Entrance S1: Stairs 1 V: Verandah	LR: Living Room B: Bedroom K: Kitchen	BE: Back Entrance S2: Stairs 2
(E) Balla Lompoa, Gowa		
1st Floor	2nd Floor	Back Door
		
ME: Main Entrance S1: Stairs 1 V: Verandah	C: Corridor LR: Living Room B1: Bedroom 1 B2: Bedroom 2	K: Kitchen S2: Stairs 2 BE: Back Entrance

Table 2. *Cont.*

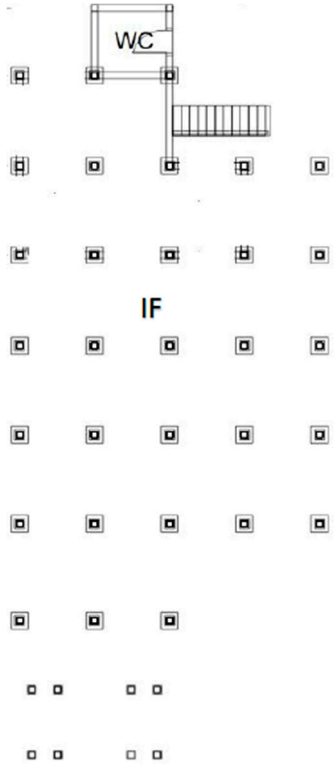
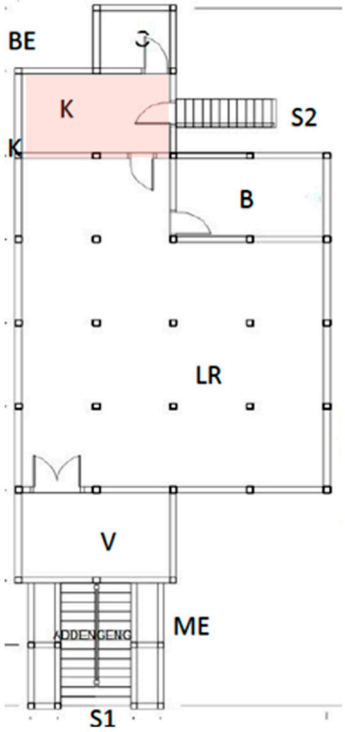
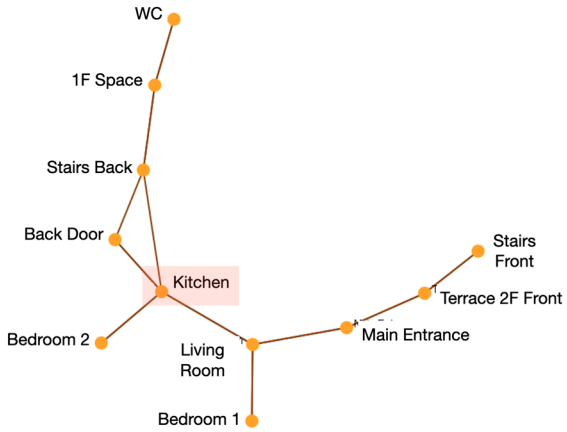
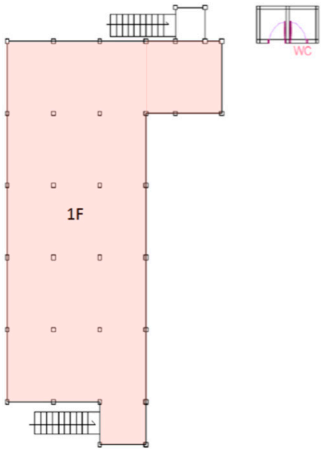
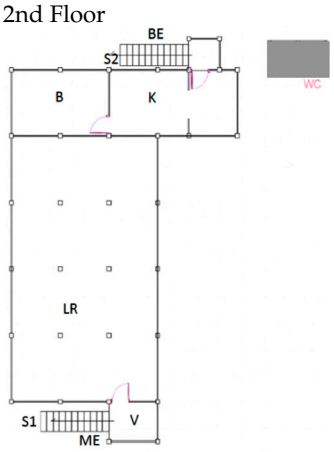
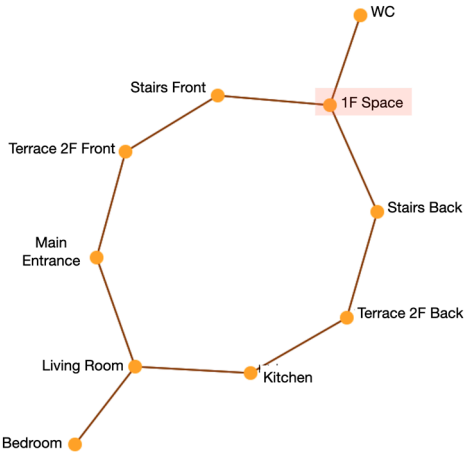
Drawing		House Circulation
(F) Balla Lompoa, Takalar		
1st Floor 	2nd Floor 	Kitchen 
ME: Main Entrance S1: Stairs 1 V: Verandah	LR: Living Room B: Bedroom K: Kitchen	S2: Stairs 2 BE: Back Entrance
Five Lontangs		
(D) Balla Lompoa, Makassar		
1st Floor 	2nd Floor 	1F Space 
ME: Main Entrance S1: Stairs 1 V: Verandah	LR: Living Room B: Bedroom	K: Kitchen BE: Back Entrance S2: Stairs 2

Table 3. Traditional South Sulawesi house layout and occupant circulation from the *Toraja* Tribe.

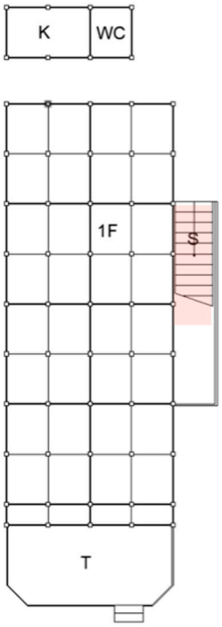
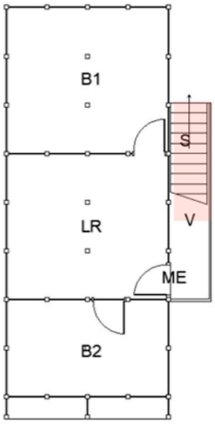
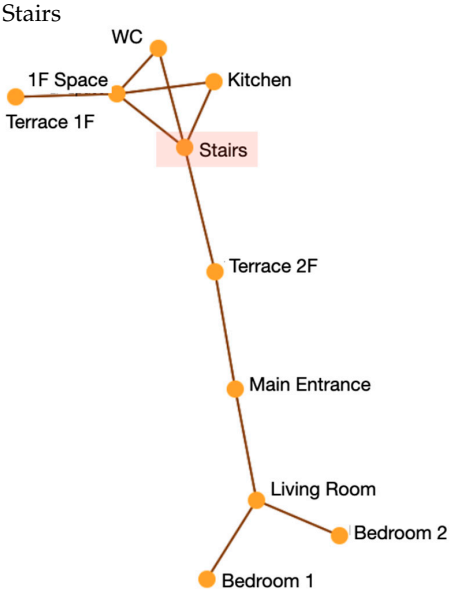
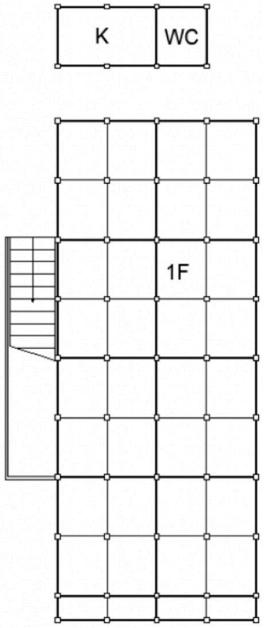
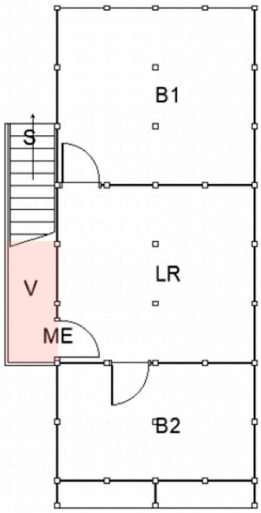
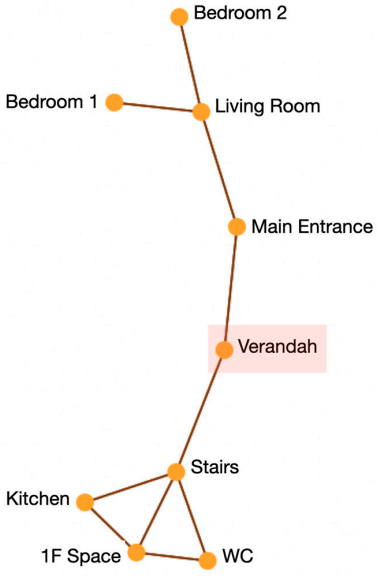
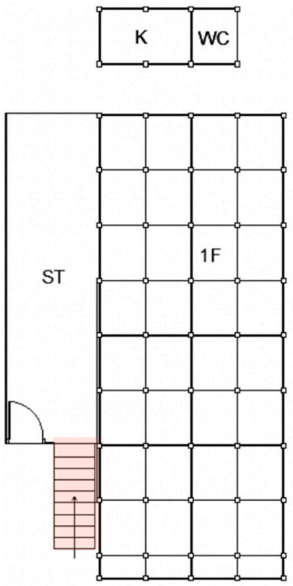
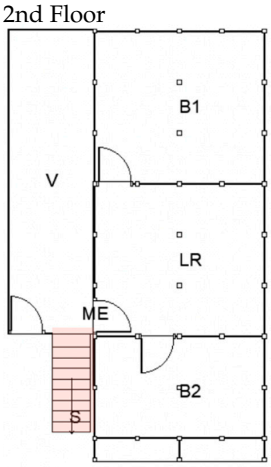
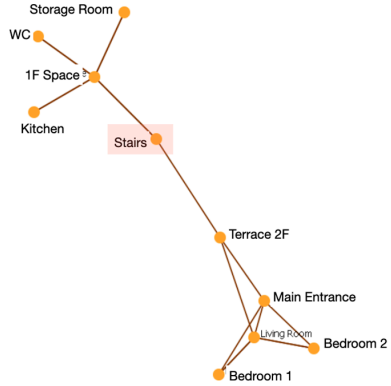
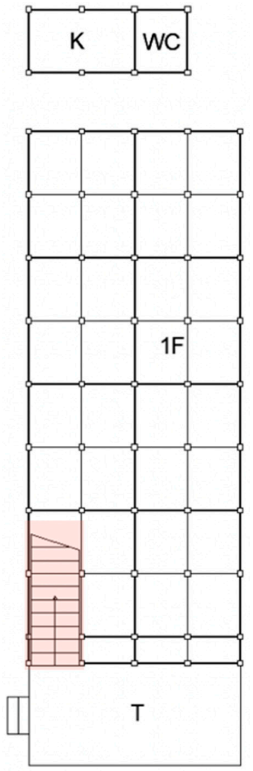
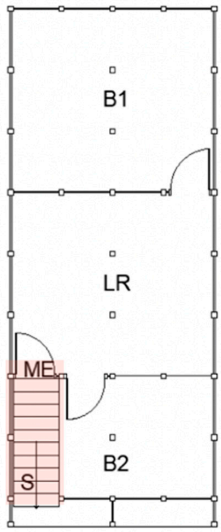
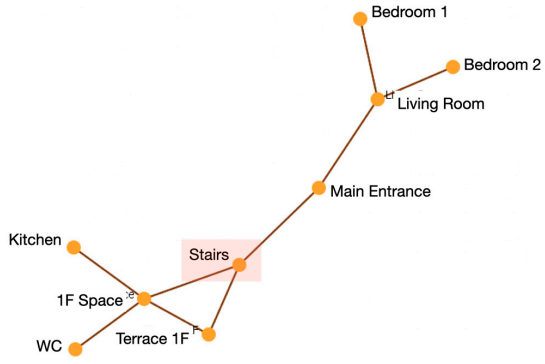
Drawing		House Circulation
(G) Rumah Tongkonan Borong		
1st Floor 	2nd Floor 	Stairs 
ME: Main Entrance S: Stairs V: Verandah	LR: Living Room B1: Bedroom 1 B2: Bedroom 2	K: Kitchen WC: Bathroom
(H) Rumah Tongkonan Tombang		
1st Floor 	2nd Floor 	Verandah (Terrace) 
ME: Main Entrance S: Stairs V: Verandah	LR: Living Room B1: Bedroom 1 B2: Bedroom 2	K: Kitchen WC: Bathroom

Table 3. *Cont.*

Drawing		House Circulation
(I) Rumah Tongkonan Londa		
1st Floor 	2nd Floor 	Stairs 
ME: Main Entrance S: Stairs V: Verandah	LR: Living Room B1: Bedroom 1 B2: Bedroom 2	K: Kitchen WC: Bathroom
(J) Rumah Tongkonan Barana		
1st Floor 	2nd Floor 	Stairs 
ME: Main Entrance S: Stairs LR: Living Room	B1: Bedroom 1 B2: Bedroom 2 K: Kitchen	WC: Bathroom T: Terrace

4.1. The Traditional Houses of the Bugis Tribe

The following are examples of Bugis–Makassar traditional houses (Table 2): (A) Lapinceng, Barru; (B) Bola Soba, Bone; (C) Sao Mario Soppeng; (D) Balla Lompoa, Makassar; (E) Balla Lompoa, Gowa; and (F) Balla Lompoa, Takalar. These houses have a main living area located on the second floor, known traditionally as "Ale bola" [17,18]. The basic shape of the house is rectangular, and rectangular in the same horizontal line is also known as a "*lontang*" [19,23]. Space in the house was organized based on owner privacy, from public to semi-private to private. The Bugis–Makassar houses (Table 2) have more than one *lontang*. The three *lontangs* in traditional houses (Table 2): (A) Lapinceng, Barru, and (C) Sao Mario Soppeng consist of verandahs (lego-lego) in the front, main spaces (*ri tengnga*) in the middle, and kitchens (*ri laleng*) at the back. In the second space organization, there are four *lontang*, such as (B) Bola Soba, Bone, (E) Balla Lompoa, Gowa, and (F) Balla Lompoa, Takalar. The house's plan consists of a verandah (lego-lego) at the front, a main space (*ri tengnga*) in the middle, a kitchen (ri laleng), and a back terrace. The final space structure is divided into five *lontang* (D) Balla Lompoa, Makassar, composed of a front terrace, verandah (lego-lego) in front, central space (*ri tengnga*) in the middle, middle terrace, and kitchen (*ri laleng*) in the back. The more *lontang* a homeowner has in his or her house, the more prominent their status in society is [23].

A summary of the analysis results based on Newman partitions is shown in Table 2. Living rooms were the largest rooms in those houses. The areas of betweenness and closeness centrality in Bugis–Makassar tribe houses were as follows:

1. Corridors: (A) Lapinceng, Barru, and (E) Balla Lompoa, Gowa;
2. First floors: (B) Bola Soba, Bone;
3. Kitchens: (C) Sao Mario Soppeng; (F) Balla Lompoa, Takalar; and (D) Balla Lompoa, Makassar.

It was a link between the middle space (*ri tengnga*) and the back kitchen (*ri laleng*). According to the analysis, this connection space was ranked first in all houses. Mostly women and girls were used to staying in this area, as Bugis women should stay in semi-private or private areas. In the Bugis tribe, circular circulation dominates, but only Rumah Takalar (F) has linear circulation.

The lowest ranks were achieved by bedrooms and bathrooms, based on the analysis. There was the least access from the occupant in those spaces. The results of this analysis can be used to design earthquake house layouts. Generally, corridors and kitchens are the most frequented spaces, so they can be used as evacuation zones.

4.2. The Traditional Houses of the Toraja Tribe

Traditional Toraja houses are always rectangular in shape and symbolize the four corners of the wind with four specific rituals. Toraja's tribe's traditional houses (Table 3), shown as (G) Tongkonan Borong, Toraja; (H) Tongkonan Tombang, Toraja; (I) Tongkonan Londa, Toraja; and (J) Tongkonan Barana, Toraja. In the house, space size is directly proportional to its function and its diversity of uses. Floor plans varied between 3 m and 4 m in width, while the length was 1: 2 or 1: 2.5, so the total length was around 8 m to 10 m. Similar to Bugis' traditional houses, the second floor was the primary activity area.

On the second floor, there are three parts, the *tangdo* at the front, *sali* at the middle, and *sambung* at the back [25]. Aluk Todolo is a traditional name for this layout plan arranged according to the movement of the sun. A verandah and staircase were located in the west part of the house. On the front side (north) of the house is a bedroom (*tangdo*) for the kids. Toward the middle is the living room (sali). The main bedroom (*sambung*) for the parents is located on the backside (south).

Table 3 shows the results of the analysis by Newman partitions. The staircase and verandah near the staircase were the most important parts of Torajan houses. Betweenness centrality, closeness centrality, and total degree centrality of Torajan house are as follows:

1. The stairs lead to (G) Tongkonan Borong, Toraja; (I) Tongkonan Londa, Toraja; and (J) Tongkonan Barana, Toraja.
2. The verandah adjacent to (H) Tongkonan Tombang, Toraja.

The most frequently accessed areas of the house are located near the main entrance. This is different from Bugis tribes, who are predominantly present in connecting areas such as corridors and kitchens. A linear circulation is characteristic of this type of house.

5. Conclusions

The structure and construction methods of a traditional house are difficult to adapt to in a modern house. A lack of materials and techniques used in the construction of a house is one of the main reasons. Learning from local wisdom about earthquake mitigation is important, as it helps local people feel more comfortable since it is similar to their culture. Tradition also means that something has proved effective in resisting past seismic events in the region, as well as having the potential to resist seismic events in the future.

Researchers found that different cultures (Bugis–Makassar and Toraja) in South Sulawesi had different solutions to earthquake mitigation in residential buildings. These earthquake mitigation recommendations are based on a local culture that can be applied to new modern house designs:

1. The organization of the space can be adapted based on the culture of each tribe, even making it easier and faster for the occupant to adapt.
2. The Bugis tribe's best evacuation space is the corridor (*tamping*), while the Toraja tribe's best evacuation space is the veranda and staircase near the entrance. An evacuation route must be created through those places in the house plan.
3. To prepare for an earthquake, these emergency spaces need to have earthquake preparedness equipment, such as strong tables for covers as well as reducing hanging objects and dangers.

As a preliminary study, this research is not yet complete. Future designs and analyses of modern houses for South Sulawesi will be based on these findings. Preparation for earthquakes is crucial. Families in varying conditions and areas require policies and strategies that are tailored to their needs. A recommendation based on this finding can also be made to the government of South Sulawesi in the design of residential houses. The space needs to be prepared with a first emergency place in these cases, in order to reduce fatalities.

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