

## Seismic Resilience of The Amma Toa Kajang Traditional House: An Evaluation of Its Structure and Construction Based on Earthquake-Resistant Building Principles

\*Armin Aryadi<sup>1</sup>

<sup>1</sup>Civil Engineering, FST, Nineteen November University of Kolaka, Kolaka, Indonesia

Email: [civilarchitects.aryasi@gmail.com](mailto:civilarchitects.aryasi@gmail.com); [armin\\_civil@usn.ac.id](mailto:armin_civil@usn.ac.id)

\*Penulis korespondensi, Masuk: 16 Jan. 2026, Direvisi: 17 Feb. 2026, Diterima: 15 Mar. 2026

**ABSTRAK:** Hunian yang telah teruji interaksinya dengan lingkungan alam dalam jangka waktu lama adalah rumah tradisional. Rumah tradisional Kajang Ammatoa berbentuk sama dengan rumah panggung dan menunjukkan kesamaan (homogenitas) baik dalam bentuk (sederhana, tanpa ornamen dan berukuran agak kecil), konstruksi, tata ruang dan penggunaan material, sehingga tidak terlihat tanda-tanda stratifikasi sosial. Tujuan penelitian ini adalah untuk mengidentifikasi penerapan prinsip bangunan tahan gempa dalam pembangunan rumah bagi masyarakat Ammatoa Kajang di Kabupaten Bulukumba dari segi bentuk dan struktur bangunan. Metode penelitian yang digunakan adalah teknik analisis deskriptif, fenomenologis, dan eksploratif yang mengandalkan kemampuan untuk menafsirkan, membandingkan, dan menginterpretasikan data primer dan sekunder. Analisis mengacu pada dasar teoritis dan berangkat dari kerangka teoritis. Hal ini dimaksudkan untuk mengungkap fakta tentang penerapan prinsip bangunan tahan gempa pada hunian Kajang di daerah Ammatoa, Kabupaten Bulukumba. Hasil penelitian menunjukkan bahwa Rumah Kajang memiliki bentuk (1) rencana yang sederhana dan simetris, yaitu bentuk persegi panjang, dengan proporsi yang hampir sesuai dengan rumus "rasio emas", (2) menggunakan bahan lokal, yaitu kayu ringan, (3) sistem konstruksi, yaitu sambungan kolom-balok (mortise-tenon) dengan penguatan tiang, telah terbukti efektif dalam menanggapi beban gempa, dan secara keseluruhan struktur dan konstruksi Rumah Komunitas Ammatoa Kajang memenuhi semua prinsip rumah tahan gempa. Temuan penelitian ini diharapkan menjadi rujukan bagi pengembangan pedoman desain dan konservasi rumah vernakular berbasis material lokal yang adaptif terhadap gempa serta memperkuat strategi mitigasi bencana pada perumahan tradisional di masa depan.

**Kata kunci:** Rumah Kajang, Tahan Gempa, Konstruksi Vernakular, Material Lokal, Struktur Kayu

**ABSTRACT:** A traditional house is one that has been tested over a long period of time for its interaction with the natural surroundings. The Ammatoa Kajang traditional house is in the form of a stilt house and shows a high degree of similarity (homogeneity) in shape (simple, without ornaments and rather small in size), construction, spatial arrangement, and use of materials, so that there are no visible signs of social stratification. The aim of this research is to identify the application of earthquake-resistant building principles in the construction of houses for the Ammatoa Kajang community in Bulukumba Regency, with respect to building shape and structure. The research method used is descriptive, phenomenological, and exploratory, relying on the ability to interpret, compare, and analyze primary and secondary data. Analysis refers to a theoretical basis and is grounded in a theoretical framework. This is intended to reveal facts about the application of earthquake-resistant building principles to Kajang residences in the Ammatoa area, Bulukumba Regency. The results of the research show that the Kajang House has the shape of (1) a simple and symmetrical plan, namely a rectangular shape, with proportions that almost match the formula "The golden section", (2) using local materials, namely light wood, (3) construction system, namely Column-beam connections (mortise-tenon) with post reinforcement have proven effective in responding to earthquake loads, and overall the structure and construction of the Ammatoa Kajang Community House meets all the principles of earthquake-resistant houses. The findings of this study are expected to serve as a reference for the development of design and conservation guidelines for vernacular houses based on local earthquake-resistant materials, as well as for strengthening disaster mitigation strategies in traditional housing in the future.

**Keywords:** Kajang House, Earthquake Resistant, Vernacular Construction, Local Materials, Wooden Structure

## 1. INTRODUCTION

One of the nations with regions susceptible to volcanic and tectonic earthquakes is Indonesia. This is because Indonesia is sandwiched between four young, actively moving tectonic plates: the Eurasian, Australian, Philippine, and Carolina plates. Indonesia is very accustomed to earthquakes that have a Richter scale magnitude greater than 5.

According to historical accounts, a large number of victims, from those who lost their lives to those who suffered damage to their property, were dispersed as a result of the earthquake. For instance, the 2021 catastrophe, when West Sulawesi was jolted by a magnitude 6.2 earthquake, is still fresh in our memories. The earthquake's effects were clearly visible in the already constructed building. In fact, the damage caused so much destruction that many souls were buried in building supplies for their homes.

The region of Bulukumba Regency is vulnerable to earthquakes and tsunamis. The Bone Bay seabed expansion zone, which could trigger tsunamis, lies to the east of Bulukumba. A fault called Walenae lies on the mainland of Bulukumba Regency and has the potential to cause earthquakes that could displace land. Conditions that are prone to earthquakes seriously harm buildings, especially homes. Homes must be built to withstand earthquake shocks as a result. In addition to being lightweight, wood is an alternative material because it is readily accessible and easy to work with. Before science on the development of steel and concrete construction technology, wood was used as a building material. However, wood remains in demand today for construction projects due to its many benefits, such as high specific strength, light weight, ease of procurement, and, in some locations, its relatively low cost and ease of use [1].

Traditional people's empirical experience, intuitive knowledge, and attempts to transmit knowledge from generation to generation are what determine the stability of traditional architectures, which frequently rely on simple structures [2,3,4,5]. Building anatomy, or the sub-structure and upper structure, is closely related to structure. In contrast, construction is closely related to the procedures, strategies, and tools used to bind, lift, connect, etc [6].

Facts on the ground show that the structure of a house on stilts is earthquake-resistant because it does not directly absorb earthquake energy. Strengthened by the findings of Dogangun (2005) and Misam (2010), vernacular houses in Turkey have been shown to be reliable in responding to earthquake loads

compared to modern buildings [7,8]. Building structures made of wood and wood frame construction have a very good response to earthquakes in various parts of the world, for example, in Turkey [9,10,11,12], the Himalayan region in India [13], Nepal [14], Kaikoura in New Zealand [15], Japan [16], and Korea [17].

The Kajang tribe, also known as the Amma Toa, has lived in harmony with the surrounding natural environment for hundreds of years and has maintained a traditional way of life (see Figure 1). The Amma Toa Ammatoan community's homes' structure and form are significantly influenced by the consistency of these traditional values [18,19]. The homes of the Amma Toa Kajang people are stilted houses, just like other traditional structures in South Sulawesi. The use of natural materials, small room sizes, relative homogeneity, lack of ornamentation, and other indications of social stratification are, however, their defining traits [20].



Figure 1. Several homes from the *Amma Toa* Kajang neighborhood are displayed.

Source: Author documentation

The problem formulation to be studied is how to identify the application of earthquake-resistant building principles in the construction of Kajang

residential houses in Bulukumba Regency, with respect to the building's shape and structure.

**2. MATERIALS AND METHODS**

**2.1 The fundamentals of earthquake-resistant construction**

According to Sarwidi (2004) in CEEDS UII [21], the following earthquake-resistant principles must be followed when building simple residential homes: 1) The building is unaffected by light earthquakes; 2) In the event of a moderate earthquake, technical structures may sustain non-structural element damage but not structural damage, whereas simple structures may sustain wall damage; 3) Technical buildings may sustain damage to non-technical components and structures in the event of a strong earthquake. While simple buildings may experience wall damage and practical reinforcement, fixed structures may not collapse. There is still time to fix the harm.

Buildings that are ductile (tough, tough) are resistant to powerful earthquakes. Buildings that can change shape while still supporting a load are said to be ductile.

**2.2 The main principle of earthquake-resistant construction**

Based on Public Works Department guidelines SNI 03-1726-2002, Procedures for Planning Earthquake Resistance for Buildings and RSNI T-02-2003, Procedures for Planning for Indonesian Timber Construction, the main principles in earthquake-resistant construction include: 1) A simple and symmetrical plan investigations into earthquake damage highlighted the value of straightforward building designs and symmetrical horizontal force-resisting structural components; 2) Building supplies ought to be as lightweight as possible; 3) A sufficient construction system. A sufficient load-bearing construction system is required. A building must be able to transmit the inertial forces of an earthquake from each structural component to the main structure, where horizontal forces are then transferred to the foundation and the ground, in order to withstand earthquakes.

**2.3 Research Methodology**

This research was conducted in Kajang Village, Kajang District, Bulukumba Regency, in Kajang Village (Kajang Dalam), a traditional area often referred to as the "Tana Toa" or "kamase-masea" area, as shown in Figure 3, the study location map. In the research location, there is a monogen community

better known as the Ammatoa leadership. The population in this study is all Kajang traditional houses, especially in the Ammatoa Kajang area. Representative sampling depends on the population conditions. If the research population is homogeneous, then it is sufficient to take 5% of the sample. The number of house samples studied is 7, namely 3 in Benteng hamlet and 4 in Sobbu hamlet, as shown in Figure 4. In this study, there are 2 (two) variables used as research variables, namely: 1. Causal Variables, namely cultural aspects that are considered as guidelines and characteristics of canopy shape, shape patterns, spatial patterns, spatial division patterns (horizontal/vertical), 2. Consequence Variables, namely, structural aspects of canopy shape, are examined in the context of earthquake-resistant buildings. For data analysis, descriptive, phenomenological, and exploratory techniques were used, which rely on the ability to interpret, compare, and analyze primary and secondary data, as well as literature reviews related to the simulation of the resilience of canopied houses using numerical methods. The flowchart for this research is shown in Figure 2.

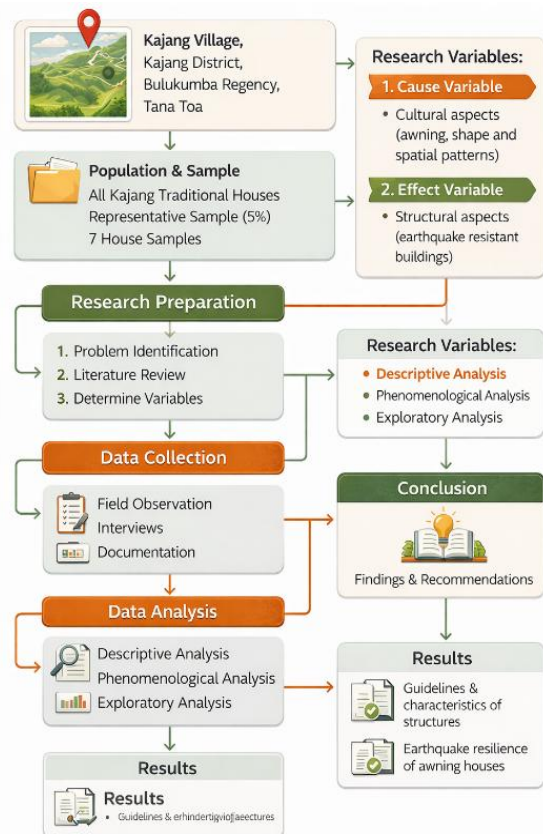


Figure 2. Flowchart of the study

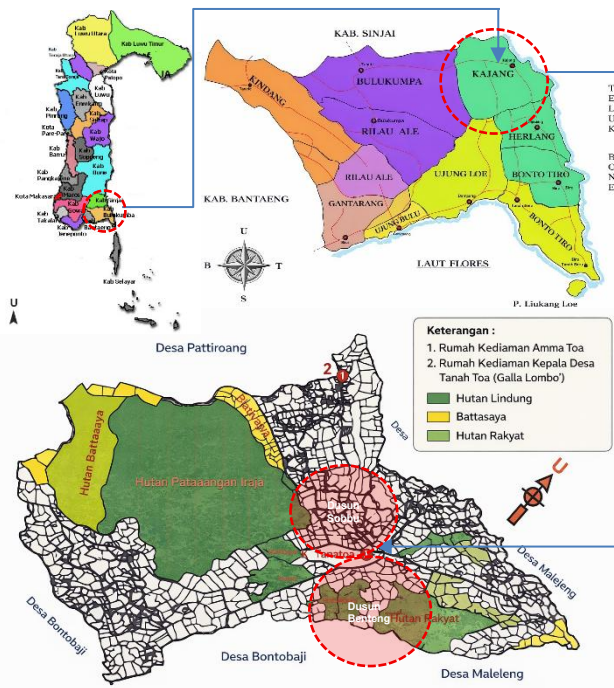
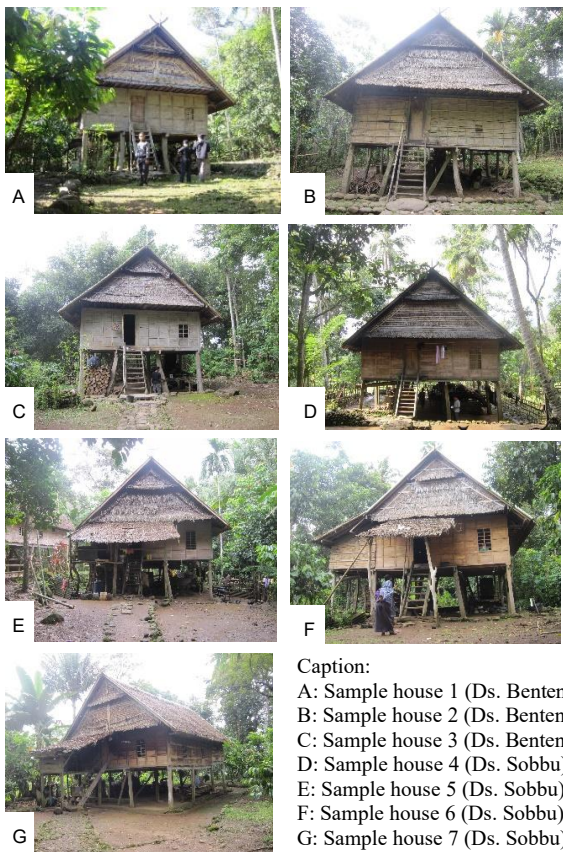


Figure 3. Study location map



Caption:  
 A: Sample house 1 (Ds. Benteng)  
 B: Sample house 2 (Ds. Benteng)  
 C: Sample house 3 (Ds. Benteng)  
 D: Sample house 4 (Ds. Sobbu)  
 E: Sample house 5 (Ds. Sobbu)  
 F: Sample house 6 (Ds. Sobbu)  
 G: Sample house 7 (Ds. Sobbu)

Figure 4. Documentation of object study of 7 houses.  
 Source: Author Documentation

## 1. RESULTS AND DISCUSSION

### 3.1. The Amma Toa Kajang Community House's general description.

Similar to other traditional South Sulawesi homes, the *Amma Toa* Kajang community house is built on stilts. The *Amma Toa* Kajang community differs in that it exhibits homogeneity (similarity) in form (simple, without ornamentation, and of rather small dimensions), construction, spatial statement, and material use, so that there are no obvious signs of social stratification [22].

It is divided into three levels based on the cosmological concept. The upper part is known as *Para* ; it is a place that is sacred and is typically used to store food ingredients; the middle part is known as *Kale Balla* ; it serves as a place for people to settle or live; the lower part is known as *Siring* ; it serves as a place to weave cloth or a place for the *Amma Toa* people to make their traditional black sarongs (*topeh le'leng*). The head, body, and legs of a human being make up their physical form, which is represented by this concept. (Figure 5) depicts the *Amma Toa* Kajang community house after it has been rebuilt

The vertical division of the *Amma Toa* Kajang community house into three levels, namely *Para* (top), *Kale Balla* (middle), and *Siring* (bottom), not only reflects the cosmological concept that interprets the house as a microcosm of the human body, but is also structurally aligned with the principles of earthquake-resistant buildings. The spatial configuration that separates the residential function (*Kale Balla*) from the heavy storage area at the top (*Para*) and the light activity area below (*Siring*) creates an ideal mass distribution. In earthquake engineering, an even distribution of mass and a low mass concentration at the base of the structure are crucial for reducing the inertial forces acting on the building during shaking. A study by Hariyanto et al. (2022) on vernacular stilt houses in Bima, Sumbawa, confirmed that the stilt structure, with columns, diagonal braces, and wooden dowels, was effective in reducing deformation under earthquake loads [23]. Furthermore, a full-scale experimental study on Bugis-Makassar stilt houses by Sari et al. (2024) showed that the wooden stilt house structure exhibits elastic behavior with high performance under cyclic lateral loads; earthquake energy is stored and released cyclically, minimizing damage to structural elements [24]. This principle is precisely reflected in the Kajang house, where the open *Siring* section and lightweight *Kale Balla* allow the structure to sway

and absorb earthquake energy without significant damage.

The existence of this three-part cosmology also indicates a Local Seismic Culture (LSC) passed down through generations. The *Ammatoa* people, through local wisdom derived from *Pasang ri Kajang*, have implicitly applied modern earthquake engineering principles in their architecture. Ortega et al. (2018), in their comprehensive study of traditional earthquake-resistant building techniques, asserted that the effectiveness of vernacular structural systems in responding to earthquakes is clear evidence of the existence of LSC, accumulated from centuries of empirical experience of earthquake-affected communities [25]. These findings are reinforced by Wasilah (2019), who specifically examined the structural effectiveness of bent columns in *Ammatoa* vernacular houses and demonstrated that this structural system performs well under earthquake loading [26]. In fact, Zuber's (2022) study of stilt houses in the earthquake-prone Palu area identified socio-cultural factors as a key driver of architectural adaptation, demonstrating that cultural values, such as cosmology, are inseparable from the structural resilience of buildings [27]. Thus, the three-story division of the *Kajang* house is concrete evidence that cosmology, spatial function, and earthquake-resilience principles are harmoniously integrated into sustainable vernacular architecture.

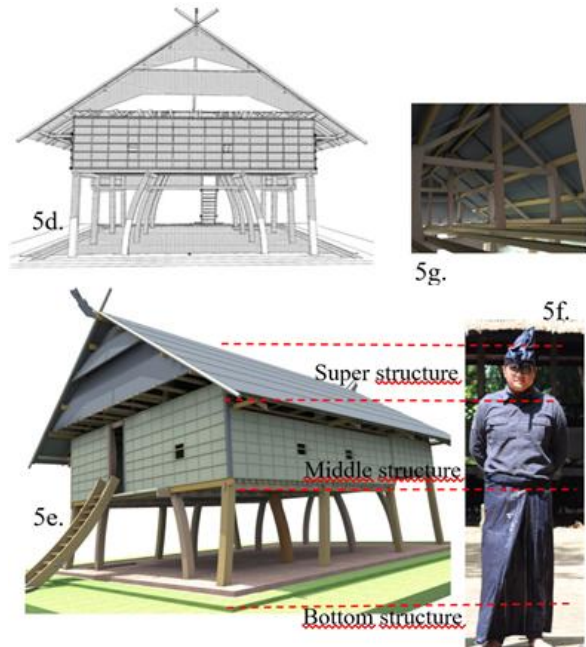
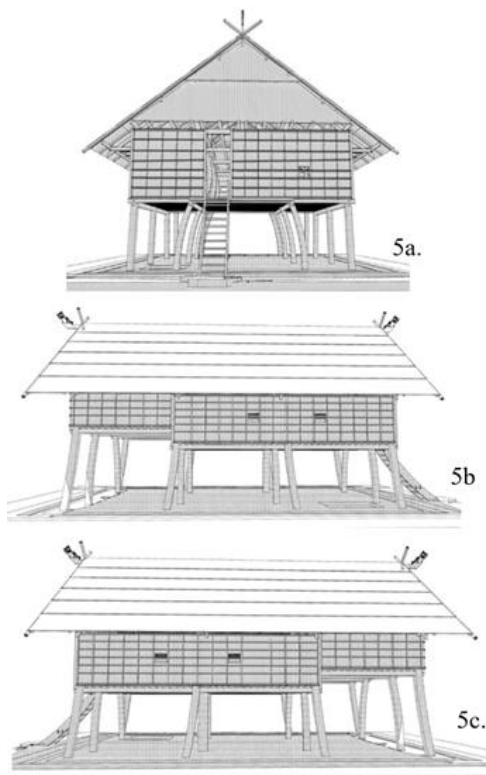


Figure 5. *Amma Toa Kajang* community house reconstruction. Views from the front, left, right, and back are shown in (Fig. 5a–5d). Front View Perspective (5e), 5f. The Human Physical Form of *Kajang*, 5g. View the details of *Para*  
 Source: Results of analysis (in Archicad)

### 3.2. The house's facade and floor plan's shapes

In general, the shape of the *Kajang* house plan (shown in Figure 6) is rectangular in shape, with interesting proportions that almost match the formula "The golden section," where the size of the plan is approximately 7 m x 10 m (width of the house = 7 m and length of the house = 10 m). Although the figures obtained from field measurements vary, the dimensions of the various elements of the *Kajang* house always suggest odd numbers. And instead, he avoids even numbers.

The basic plan of a house is rectangular, with four sides, symbolic of the four elements of life it possesses. The house is always analogous and perceived as something that lives and "has a spirit." Fire, wind, water, and earth are the four basic elements. When it was first conceived, Bugis/Makassar was known as a "*sulapa eppa*" or rhombus. The four compass directions are frequently represented by the rectangular pattern (rhombus). *Siring's* ground floor plan and *Kale Balla's* first floor plan.

A good floor plan for buildings and houses in earthquake areas is a simple shape, symmetrical about both building axes, and not too long, according to the book "Technical Guidelines: Earthquake Resistant Houses and Buildings, Ministry of Public Works, 2006". To prepare for earthquake damage, the

placement of the insulating walls and door/window openings should also be as symmetrical with respect to the building plan's axes as possible. As can be seen from the explanation above, the Kajang house's straightforward design, with a symmetrical rectangular shape and symmetrical window openings, can withstand earthquake forces more effectively because it has no torsional effects and the strength is distributed more evenly.

The findings regarding the symmetrical rectangular shape of the Kajang house plan, with proportions approaching the golden ratio (7 m x 10 m), and the use of odd numbers in the dimensions of building elements indicate a deep integration between cosmological values and structural engineering principles. The philosophy of this rectangular shape refers to the concept of *sulapa eppa*, which is widely known in Bugis-Makassar culture, symbolizing the four elements that form the universe: fire, wind, water, and earth, while also representing the four cardinal directions. Syarif et al. (2018), in their publication in SHS Web of Conferences, emphasized that *sulapa eppa* is a fundamental philosophy that underlies the formation of traditional Bugis architecture, both physically (shape, size, proportion, and building elements) and non-physically (spiritual values) [28]. This concept is also reflected in various other cultural elements, such as the lontara script "sa" and the construction of *walasuji* in traditional ceremonies. Thus, the rectangular floor plan of the Kajang house is not a mere structural coincidence, but rather a physical manifestation of the *Ammatoa* people's view of life, which views the house as a living entity balanced by natural elements.

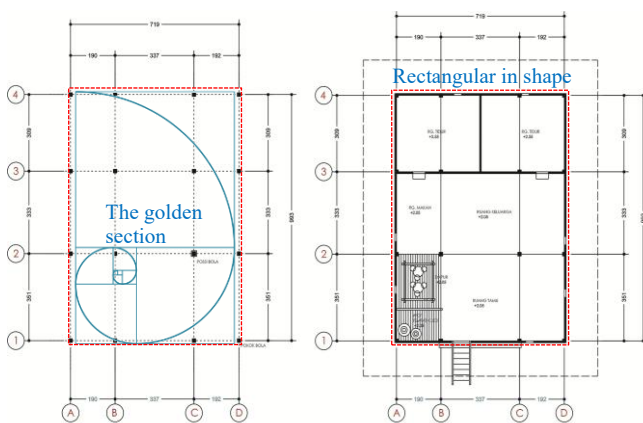


Figure 6. *Siring's* ground floor plan (3a) and *Kale Balla's* first floor plan (3b)

Source: Results of analysis (in Autocad)

From an earthquake engineering perspective, the simple, symmetrical, and compact floor plan found in Kajang houses is an ideal configuration for reducing

torsional effects during earthquakes. A study by Gálvez-Cortés et al. (2020) in *Ingeniería Sísmica* on estimating the effects of accidental torsion in multi-story buildings demonstrated that floor plan asymmetry can lead to eccentricities between the center of mass and the center of stiffness, which can trigger excessive torsional stresses and potentially lead to structural collapse [29]. Recent research by civil engineers in China (2024) on multi-story buildings with irregular floor plans also confirmed that the more asymmetrical a floor plan (the greater the length-to-width ratio of the building's wings), the greater the resulting torsional effects, making symmetrical design key to controlling a structure's response to earthquakes [30]. This finding is reinforced by a study by Hariyanto et al. (2022) on vernacular stilt houses in Bima, located in an earthquake-prone area; they found that the stilt structure with a symmetrical configuration and the use of diagonal elements (braces) proved effective in reducing deformation due to earthquake loads, which is part of the local seismic culture of the local community [23]. The presence of symmetrical window openings in Kajang houses further enhances earthquake resistance by distributing wall strength evenly and avoiding stress concentrations at specific points. Thus, Kajang houses prove that local wisdom rooted in the *sulapa eppa* cosmology is intrinsically aligned with modern earthquake engineering principles regarding ideal floor plan configurations.

### 3.3. Pole Formation Module / Grid (*Benteng*)

Based on the 7 (seven) house samples that comprise the study's main sample set, the pillar formation (fortress) in the Kajang house exhibits a variety of modules/grids. Because the bottom of the pole is always bent and, when measured, is not aligned with the hole in the peg above it, the distance between one pole and another can vary greatly. The 16 pile formations are always structurally visible and can support wind loads, dead loads, or walking loads on the house, even though the modules/grids are not uniform. The Kajang house's structural section is shown in Figure 7 below; note that the pillars are always bent outward, making the displayed modules non-uniform. This is where the use of materials (poles) reflects local wisdom values. In Uragi's story, the length of the materials (poles or pegs) used to build the house significantly affects the distance (the measurement between the pillars). Additionally, unlike most modern builders, the measurement pattern used to determine the pile module does not use metric (meters) measurements.

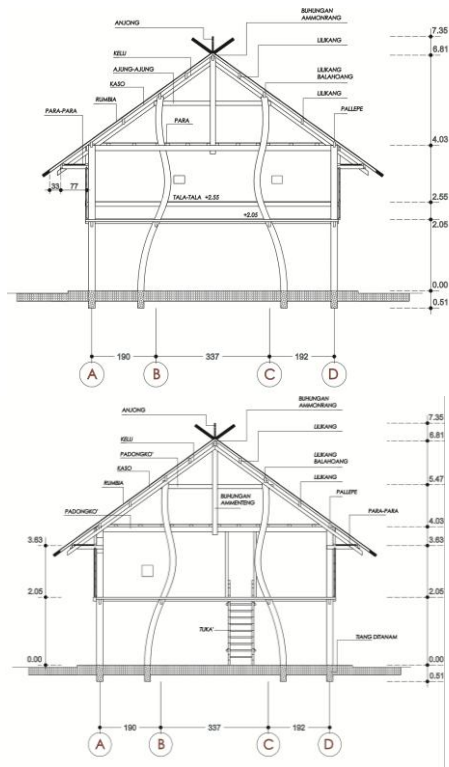


Figure 7. View of a section of the Kajang house  
 Source: Results of analysis (in Autocad)

A structural cross-section of a Kajang house reveals a unique column configuration in which the main pillars (*burhang*) are always bent outward, creating a non-uniform column module. This phenomenon, which may appear irregular from a modern engineering perspective, is actually a sophisticated structural strategy born from the *Ammatoa* people's empirical understanding of earthquake behavior. Sari et al. (2024) in their experimental study on Bugis-Makassar stilt houses demonstrated that wooden structures with flexible column configurations exhibit elastic behavior and store earthquake energy through cyclic deformation mechanisms [24]. The slight outward bending of the columns creates a natural inclination angle that increases the building's lateral stability, like the principle of battered piles or inclined piles in modern foundation engineering. A study by Wasilah (2019) that specifically examined the structural effectiveness of bent piles in *Ammatoa* vernacular houses confirmed that this system performs well under earthquake loads, as it can redistribute lateral forces to the ground through controlled buckling mechanisms [26]. This configuration allows the structure to sway uniformly without experiencing excessive stress concentration at the joints, which is a basic principle of earthquake-resistant ductile building design.

The modularity of the pillars in Kajang houses cannot be understood without reference to the local knowledge system that governs the selection and placement of wood materials. In the oral narratives of the *Ammatoa* people, known as *Uragi* stories, the length of the material (poles or pegs) used significantly impacts the spacing between pillars. This suggests that the *Ammatoa* people do not impose rigid modular standards on natural materials, but rather allow the wood's natural characteristics (such as trunk length, grain straightness, and diameter) to determine the building's structural configuration. This approach reflects a profound ecological wisdom in which humans adapt to the material's properties, not the other way around. A study by Hariyanto et al. (2022) on vernacular stilt houses in Bima, Sumbawa, found that the use of local wood materials with variable dimensions contributes to the structure's overall flexibility, a key factor in dampening earthquake energy [23]. Furthermore, Aktaş's (2017) study of traditional *Hımsı* wooden structures in Turkey confirmed that a timber frame system with varying element dimensions naturally creates structural redundancy, so that if one element fails, others can take over the load [31]. Thus, the non-metric measurement system in Kajang houses is clear evidence of a local seismic culture that prioritizes structural resilience through harmony with nature.

The structural cross-section in Figure 7 also clearly shows the vertical division of the Kajang house into three levels with varying floor heights: the *Siring* (base) at an elevation of  $\pm 0.00$ , the *Kale Balla* (residential floor) at an elevation of  $+2.05$ , and the *Para* (attic) at elevations of  $+2.55$  to  $+7.35$ . This variation in elevation not only separates the spaces according to cosmology but also creates an optimal distribution of mass and stiffness for earthquake resistance. The lower level (*Siring*) with tall, flexible columns serves as a natural base isolation system, allowing the building to move relative to the ground during an earthquake. Ortega et al. (2018), in their comprehensive study of traditional earthquake-resistant building techniques, asserted that many vernacular architectures in earthquake-prone areas intuitively develop flexible ground floor systems to isolate the superstructure from ground vibrations [25]. The central section (*Kale Balla*) with floor beams (*padongkok* and *pal lipe*) and wooden walls function as a rigid diaphragm that distributes the load evenly to the columns. Meanwhile, the upper section (*Para*), with a lightweight roof truss, ensures that the building's center of mass remains low, reducing overturning moment during shaking. Zuber's (2022) research on stilt houses in Palu found that the three-

story vertical configuration of vernacular architecture significantly contributes to seismic resilience by creating a gradual stiffness profile from bottom to top [27]. Even a recent study by Haji Sadeghi et al. (2025) on the conservation of adobe architecture in earthquake-prone areas emphasizes the importance of understanding traditional structural configurations to develop sustainable disaster mitigation strategies. [32]

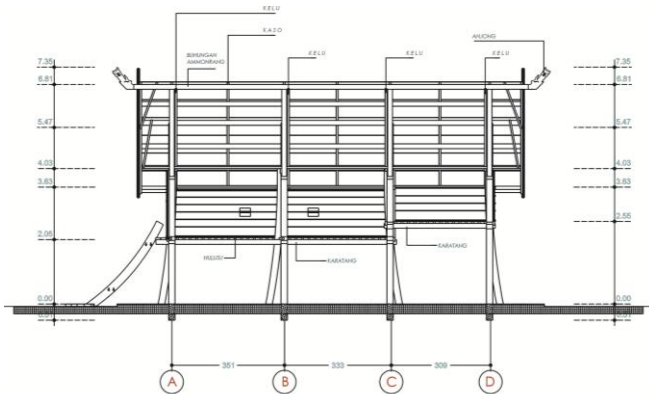


Figure 8. The image display extends to the back  
Source: Results of analysis (in Autocad)

The most intriguing fact is that the number of building components is always rated with an “odd” number across all units of measurement, indicating that whatever size is intended, it is always in an odd-numbered position. For instance, there are always odd numbers of steps in the Kajang house (5, 7, 9, and 11).

The longitudinal cross-section of a Kajang house (Figure 8) shows a configuration of pillars (fortresses) that are bent outward alternately, with a forward-and-backward pattern in the longitudinal plane. This configuration results in a non-uniform grid/module between the pillars, but actually creates a very effective lateral stabilization system. In structural mechanics, this variation in pile orientation functions like a battered pile system (tilted piles) that can withstand lateral loads from various directions. A study by Gani et al. (2023), who conducted shake table tests on a traditional timber frame system, demonstrated that structures with a visually non-rigid pile configuration actually exhibited better energy damping, with natural frequencies reduced by up to 30% and stiffness degradation controlled by up to 48% when loaded up to 0.45g ground acceleration [33]. These findings confirm that the modular irregularity of Kajang houses is not a weakness, but rather an adaptive strategy that allows the structure to deform elastically without experiencing brittle failure. Dawson and Gillow (1994), in their comprehensive study of traditional Indonesian

architecture, asserted that peg-and-wedge construction provides buildings with both the strength and flexibility necessary to withstand earthquakes [34]. This principle is exemplified by the bent-pillar system of Kajang houses, where flexible joints and varying pile orientations allow the building to move adaptively in response to earthquake or wind forces.

The fact that Kajang houses on piles were unheard of and toppled by strong winds during the observation period provides invaluable empirical evidence of the reliability of this structural system. Resistance to strong winds requires a structure's ability to withstand cyclic and sudden lateral loads, similar to those from earthquakes. Dutu and Yamazaki (2024), in their book *Seismic Resistance of Vernacular Timber Frames with Infills\**, explain that traditional timber frames in various parts of the world, from Minka Japan to Paianta Romania, have stood the test of time against earthquakes and typhoons through flexible joint mechanisms and even load distribution [35]. The Kajang house, with its bent pillars, creates structural redundancy by distributing lateral loads across various elements, so that no single point bears excessive weight. Researchers' studies of Bugis architecture have revealed that the house's frame, which adopts the human body as a structural analogy, is designed to support itself and ensure sufficient strength to withstand earthquakes, floods, and strong winds. Thus, the Kajang house has undergone generations of "natural testing," proving itself to be a resilient structural system against a wide spectrum of natural disasters.

The success of the Kajang house in withstanding earthquakes, winds, and floods without any recorded structural failures is a clear manifestation of what is known as Local Seismic Culture (LSC). Dragomir et al. (2018), in their study of traditional building concepts, asserted that in earthquake-prone areas, local communities develop empirical knowledge accumulated over generations on how to build resilient dwellings using local materials and techniques [36]. This knowledge, embodied in the Kajang house's choice of wood materials, bent-post configurations, and traditional connection systems, allows for the maintenance of acceptable vulnerability with minimal knowledge transfer within the local community. Gani et al. (2023), in their publication in *Innovative Infrastructure Solutions*, emphasize that traditional timber-frame structures developed in response to local seismic hazards demonstrate superior performance in earthquake tests, and understanding their working mechanisms can inspire more sustainable modern building solutions [33]. Case studies from countries such as

Japan, Romania, and Italy demonstrate that time-tested traditional technologies can provide valuable lessons for new construction using local materials. The fact that Kajang houses have never collapsed due to strong winds or earthquakes demonstrates that this local wisdom is worthy of study and even has the potential to be adapted in future disaster-resistant housing developments, in line with preventive conservation efforts for vernacular architecture in disaster-prone areas.

**3.4. Building Materials**

Traditional or vernacular structures often use natural building materials such as wood, bamboo, rattan, leaves, and other materials found in the local environment. Building materials sourced from the environment are carefully processed, such as drying and preserving, before being crafted into house components. Nature-made building materials fall under the category of renewable materials, which are those that can be obtained quickly and were created by nature.

above, which use "renewable and sustainable" materials, are extremely wise and highly valuable.



Figure 9. Types of materials commonly used in the Kajang house

Source: Author documentation

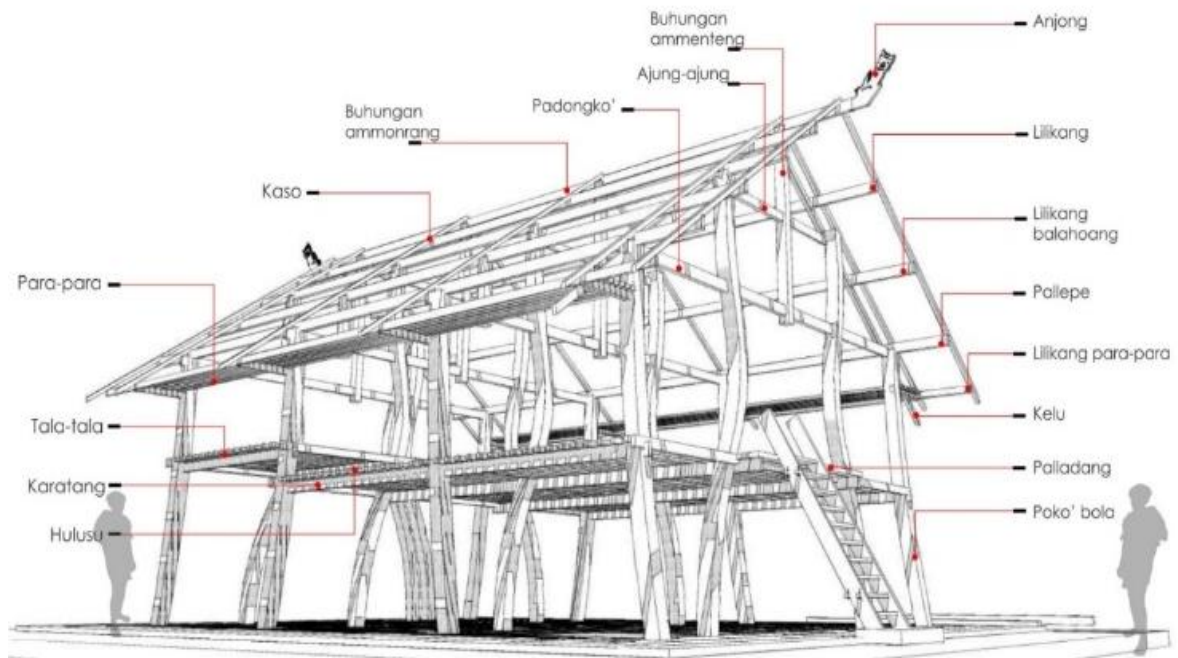


Figure 10. Structure and construction of the Kajang house depicted in perspective.

Source: Results of analysis (in Archicad)

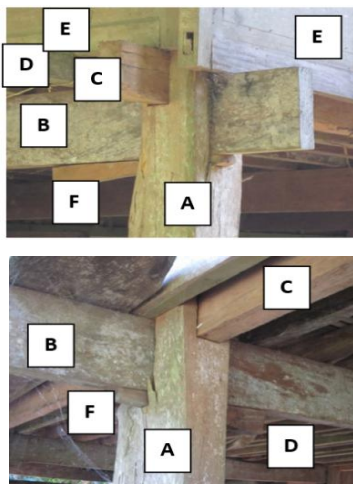
It is also categorized as a "sustainable" material, meaning that even if the material has aged or worn out, it is easy to replace it with another of a similar nature. The methods of development described

The houses in the Amma Toa Kajang neighborhood are uniform in their diversity and exhibit a distinct, one-of-a-kind vernacular character. For instance, walls made of Sandalwood,

Teak, Bitti, Campaga, Bajang, Kalapi, or Bamboo wood (parring), pillars (fortress) made of Bitti wood (*Na'na'sa*), pegs (*pannyo'loro*) made of Teak, Bitti, Bajang, Coconut wood, and the roof is made of Nipah leaves (see figure 9 above).

**3.5. Structure and Construction**

From a structural and construction perspective, the stilt houses (houses on pillars) in the *Amma Toa Kajang* neighborhood exhibit a simple yet useful and relevant structural model to the local natural environment, as shown in Figure 10. The structural and construction systems used include clamps, stud holes, notches, and pillars (*benteng* and *pannyo'loro*). This connection system allows structural elements to bond effectively, resulting in a stable, efficient construction that distributes the building's load effectively.



Caption:  
 A: Pole (*benteng*)  
 B: Peg (*pannyo'loro*)  
 C: Peg above (*karateng*)  
 D: Floor beams (*hulusu*)  
 E: Wall (*rinning*)  
 F: Tog (*pa'pasa*)

Figure 11. Detailed prototype of the Kajang house structure

Source: Author documentation

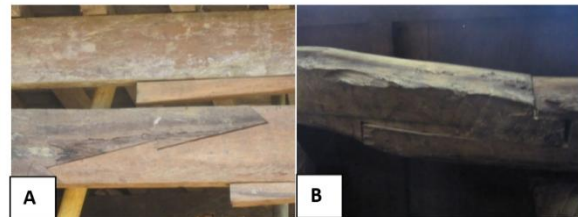
According to *Uragi's* account, the Kajang houses have never used a "stakeholder" system, which involves using nails to strengthen the bond between two pieces of wood; instead, this reinforcement is done using "*pa'pasa*" (tog) or "bonding," all of which demonstrate local knowledge. Additionally, there is zero innovation in the structural and construction systems used. Everything is "hand-made" and carried out manually with only improvised carpentry tools. A detailed prototype of the Kajang house's structure is shown in Figure 11. This Kajang home is disassembled or knocked down using a rigid joint system. A square hole is drilled into the column to receive the beam as purus, and a peg (joit of the fitting type) is added to strengthen the connection. Purus connections are of this kind. The purus (tenon) and

hole (mortise) joints with square shapes were better able to withstand external loads, according to research by A.N. Tankrut and N. Tamkrut (2005) [37].

**3.6. System of Connections**

If you look at the connection systems commonly used in traditional houses, you'll notice that they are always based on structural and construction factors. What matters is that the two materials being joined function properly, and that's how the connection system he recognized worked. Although he himself analyzed it simply, builders must be able to connect various components (posts, pegs, beams, etc.) and, of course, understand loading (tensile or compressive).

Naturally, these two material components are connected to achieve the material's modular purpose; the connection system is applied to conventional building structures while still adhering to construction standards, including strength standards. Nails, bolts, screws, and buckles are not recognized by the tools used to manually connect everything. Furthermore, these traditional connection techniques demonstrate an empirical understanding of the principles of force balance and load distribution, enabling each structural element to work together to maintain the building's stability and strength.



Caption :  
 A: Hooked oblique lip joint (adopted from outside)  
 B: Conventional pole connection

Figure 12. Types of connection systems found in the *Amma Toa* area

Source: Author documentation

While (Figure 12.B) remains conventional, the "hooked slanted lip" connection shown in (Figure 12.A) is a well-known type used extensively in the *Amma Toa* Kajang region. The joining technique he used had begun to adopt the connection system depicted in Figure 12. A) above, but it no longer fully maintained the connection system that he was familiar with. Tensile strength is used in the connection shown in Figure 12.

Wasilah's (2019) simulation of the Kajang house's construction demonstrates that it can withstand earthquakes and other natural disasters

[26]. (Fig.10) from this study's analysis of output values, which range from 9.3 to 10 KN-m, illustrates how the outcomes are explained. The building will withstand an earthquake without collapsing or sustaining significant damage, according to the US Geological Survey (USGS) Energy Resources Program's earthquake-magnitude estimate for the Bulukumba region (home of the *Amma Toa* tribe).

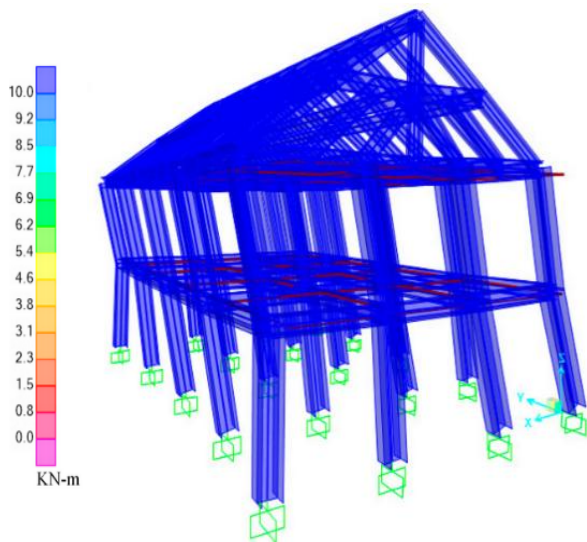


Figure 13. An illustration of the *Amma Toa* Kajang community house's connection system.

Source: Adapted from Wasilah (2019)

Figure 13 illustrates the Kajang house connection system, with a moment diagram showing the distribution of internal forces in the structural members. From the illustration, it can be seen that the bending moment is not concentrated exclusively at the connection point but is distributed along the structural element, indicating semi-rigid connection behavior. This characteristic is very different from the rigid connections in modern concrete structures, which tend to concentrate moments at the joint. In the traditional Kajang connection system that uses dowel-and-mortise-tenon technology, the connection is designed to allow limited rotation, which functions as a mechanism for damping earthquake energy. Research by Parisi et al. (2018) on traditional wooden frames in Italy proved that connections with semi-rigid behavior can significantly increase the deformation capacity of the structure without reducing its strength, with ductility factors reaching 3-4 times that of rigid connections [38]. A study by Gani et al. (2023) conducted shake table tests on traditional timber framing systems, confirming that structures with flexible connections exhibit superior energy damping, with a controlled reduction in natural frequency and gradual stiffness degradation

under ground acceleration up to 0.45g [33]. Thus, the moment distribution pattern in Figure 10 represents a sophisticated traditional engineering strategy in which connections act as structural fuses, intentionally designed to deform and absorb earthquake energy, protecting the primary elements from brittle failure.

The moment diagram in Figure 13 also shows how lateral loads are distributed throughout the connection network, creating what is known in modern earthquake engineering as structural redundancy. Redundancy means the availability of alternative paths for load transfer, so that if one connection fails, another connection can take over. The connection system of a Kajang house, comprising various types of burhangs (posts) in a staggered configuration, as described in the previous section, creates a mutually reinforcing structural network. A study by Dutu and Yamazaki (2024) in their book on the seismic resistance of traditional timber frames in Japan and Romania confirmed that the traditional post-joint system provides an effective energy dissipation mechanism through interfacial friction between the timber and the posts, as well as the posts' elastic deformation [35]. When an earthquake occurs, energy is absorbed through slip and bearing mechanisms in the joints, rather than through failure of the main elements. Branco et al. (2017) in their study of traditional timber joints in Europe found that the rotational capacity of mortise-tenon joints is largely determined by the ratio of post dimensions to holes, with a controlled gap allowing sufficient deformation without loss of strength [39]. In Kajang houses, knowledge of these proportions has likely been accumulated through empirical experience passed down through generations and is manifested in traditional measurements that use non-metric units based on anthropometry and material characteristics.

The moment distributions shown in Figure 13, although analytical and illustrative, represent the Ammatoan people's deep understanding of structural behavior that has only been scientifically explained in recent decades. The fact that Kajang houses have withstood earthquakes, strong winds, and floods without any recorded structural failures over generations is an undeniable empirical validation of the reliability of this connection system

Table 1. Building Data, Dimensions, and Materials of Ammatoa Kajang Vernacular Houses in Earthquake Resistance Evaluation

No.	Building Elements	Main Specifications	Implications for Earthquake Resilience
1.	Research Context	The research was conducted in the Ammatoa Kajang traditional area, in Benteng and Sobbu hamlets, Tanah Toa Village, Bulukumba Regency. The sample consisted of seven vernacular houses (Bola To Kajang) with relatively homogeneous shapes and construction.	Uniformity of shape and construction system allows for a more representative analysis of the structure's behavior with respect to earthquake resistance.
2.	Building Dimensions	The average size of the house: length $\pm 9.2$ m, width $\pm 6.8$ m, and height $\pm 7.5$ – $7.9$ m with a structural system of 16 main pillars.	The relatively balanced floor plan proportions result in a more even distribution of lateral forces during an earthquake.
3.	Main Structural System	The columns are made of bitti wood ( <i>Vitex cofassus</i> ) with a diameter of approximately 15–20 cm. The main posts are planted directly into the ground at a traditional depth.	The flexible pile foundation system allows the structure to adapt to ground movements caused by earthquakes.
4.	Beam System	Bitti wooden beams measuring approximately 60×150 mm and 60×120 mm. There are main tie beams connecting the rows of columns.	Beams function as binding elements that increase the stability and integrity of the structure.
5.	Wall	The walls use woven bamboo and do not function as structural elements.	The light weight of the material reduces the inertial load during an earthquake.
6.	Floor	The floors generally use bamboo and some use wooden planks in certain areas.	Lightweight floor materials contribute to reducing the total load of the structure.
7.	Roof	The roof shape is gabled with a slope of about 45° and a roof covering made of rumbia leaves.	Lightweight roof coverings reduce the gravitational loads and earthquake forces acting on the structure.
8.	Materials and Connections	The joints use natural materials like rattan and palm fiber without metal nails. Building materials come from wood, bamboo, and leaves.	Elastic natural materials increase the flexibility of structures in responding to earthquake vibrations.

Source: Results of analysis, 2025

Research by Arief (2024) on traditional Indonesian timber connections reveals that the notch-and-pin connection technology found in various Indonesian vernacular architectures has a structural efficiency comparable to modern connections, with the added advantage of ease of assembly, maintenance, and disassembly [40]. A study by Indrabakit and Mulyadi (2021) in their literature review of earthquake-resistant vernacular houses in Indonesia emphasizes that traditional connection principles, such as those found in Kajang houses, can be adapted to develop more sustainable and contextually appropriate modern timber structural systems [41].

With advances in modeling and simulation technology, it is feasible to conduct further analysis of this connection system using the finite element method to precisely quantify its moment capacity, rotational stiffness, and cyclic behavior.

The results of this analysis can serve as the basis for developing earthquake-resistant timber connection design guidelines inspired by local wisdom, while still meeting modern safety standards.

This is in line with the recommendation of Haji Sadeghi et al. (2025) regarding the importance of preventive conservation of vernacular architecture through scientific understanding of its seismic behavior, so that traditional knowledge is not only preserved as cultural artifacts but also revived as relevant engineering solutions for the future [32].

Based on Table 1, here are the key points regarding the "Earthquake Resistance of Traditional *Amma Toa* Kajang Houses": 1) The "*Kamase-mase*" Philosophy and Lightweight Structures: The simplicity of life (*kamase-mase*) translates structurally into very lightweight buildings. All materials are derived from nature, and wood is used minimally. In earthquake physics, lightweight structures will experience much smaller inertial forces during an earthquake. This is a basic earthquake resistance principle that has been empirically applied by the *Amma Toa* people; 2) Flexible Connection System (Pin Joint): The absence of nails and the use of a system of ties and dowels creates a pin joint. This

connection can move and deform, serving as an energy-dissipation damper. Earthquake energy is absorbed by friction at the joints, rather than being transmitted to cause structural collapse; 3) Structural Innovation: "Bent Piles": This is the most significant finding. A special study has tested the effectiveness of these bent piles and found them to be structurally superior in resisting various environmental conditions, including earthquakes. Their non-straight shape makes them more flexible against lateral loads; 4) Adaptive Foundations: Pile foundations embedded in the ground (rather than stone or concrete foundations) allow the structure to "follow" the movement of the ground. This type of foundation prevents the soft story that often causes the collapse of modern, multi-story buildings during earthquakes.

This data demonstrates that the traditional *Amma Toa Kajang* house is not only a cultural heritage building, but also a vernacular earthquake-engineered structure that has stood the test of time for hundreds of years. Principles such as lightweight structures, flexible joints, and the use of elastic natural materials underpin its resilience.

## 2. CONCLUSIONS AND RECOMMENDATIONS

This research demonstrates that the traditional houses of the *Amma Toa Kajang* community possess structural characteristics that inherently support earthquake resilience. The study's key findings emphasize that the simple, symmetrical floor plan, the use of relatively lightweight natural materials, and the flexible construction system create a stable structural system that responds to lateral loads. These characteristics demonstrate that the basic principles of earthquake-resistant construction have been empirically implemented in the vernacular architecture of the Kajang community through a long process of adaptation to the natural environment. Thus, the *Amma Toa Kajang* stilt houses can be understood as a form of vernacular engineering that not only holds cultural value but is also relevant as a source of inspiration for developing contextual and sustainable earthquake-resistant building design concepts in Indonesia.

The contribution of this research lies in its effort to uncover the relationship between local wisdom, traditional construction systems, and the structural performance of buildings in response to earthquake hazards. These findings provide a conceptual basis for developing design guidelines that integrate vernacular architectural principles with modern structural engineering approaches, particularly for housing planning in earthquake-prone areas.

However, this study has several limitations. The analysis remains qualitative-descriptive and has not been supported by more in-depth experimental testing or numerical modeling, such as shake-table tests or finite element analyses. Furthermore, the number of house samples analyzed remains limited to a few units in the *Amma Toa Kajang* area, so it does not fully represent the variety of stilt house construction across the Bulukumba region. Therefore, further research using a quantitative approach and a broader sample is urgently needed to validate and strengthen the findings of this study.

## 3. ACKNOWLEDGEMENTS

The author expresses his deepest gratitude and appreciation to Mr. Syarif Beddu, architect and researcher of Kajang Vernacular Architecture, for his guidance, in-depth insights, and invaluable scientific discussions regarding the local wisdom and structural systems of the traditional houses of the *Amma Toa Kajang* community. His contributions have provided a crucial foundation for understanding the architectural values and vernacular construction explored in this research.

The author also expresses his gratitude to the Faculty of Science and Technology, Sembilanbelas November University, Kolaka, for the institutional support and facilities provided throughout the research process. He is especially grateful to the Civil Engineering Study Program, Sembilanbelas November University, Kolaka, for their academic guidance, technical input, and administrative assistance, which were invaluable in completing this research. Hopefully, this collaboration will continue and make a significant contribution to the development of science, particularly in structural engineering and the preservation of Indonesian vernacular architecture.

## REFERENCES

- [1] Aryadi A, Parung H, Irmawaty R, Amiruddin AA. Investigation of the mechanical behavior of full-scale experimental Bugis-Makassar timber house structures. *Civil Engineering Journal*. (2024) Jun;10(6):1765–87. doi: 10.28991/CEJ-2024-010-06-04.
- [2] Deddy M, Huzairin, Andini DN, Hartono R, Oktaviana A, Dahliani. Unwritten Rules and Oral Transmission in Architectural Proportion Systems: Case Study of Bubungan Tinggi House. *ASEAN J Sci Technol Dev*. (2025) ;42(3). doi: 10.61931/2224-9028.1647.
- [3] Sari DP, Sudirman M, Asmulyani A. The Design of Earthquake Evacuation Spaces Based on Local Wisdom: A Case Study of Traditional Houses in South Sulawesi. *Designs*. (2024) ;8(2):30. doi: 10.3390/designs8020030
- [4] Ramadhan F, Faisal G. Transfer Pengetahuan Arsitektur Tradisional Rumah Gadang dari Tukang Tuo ke Generasi Penerus. *Jurnal Arsitektur NALARs*. (2021);20(1):45-56.
- [5] Arni YF, Rahayu EA, Darsin C. The Integration of Local Stilt House Architecture in Natural Disaster Mitigation Education in South Sumatra, Indonesia. *Jamba J Disaster Risk Stud*. (2026) ;18(1):1-11. doi: 10.4102/jamba.v18i1.1987.
- [6] Sari R, Çalışkan EB. Building construction methods and systems: principles, requirements and application details. Cham: Springer; (2024). 402 p. (Springer Professional). doi: 10.1007/978-3-031-50043-5.
- [7] Koca G. Earthquakes, sustainable settlements and traditional construction techniques. *Journal of Design for Resilience in Architecture and Planning*. (2023) ;4(Special Issue 1):1-14. doi: 10.47818/DRArch.2023.v4si114.
- [8] Alsaj A. Housing reconstruction after natural disasters: a comparative review of modular box systems and traditional construction in post-earthquake Turkey (case study: Isias Hotel, Adiyaman) [master's thesis]. İstanbul: İstanbul Kültür Üniversitesi; (2025). 100 p.
- [9] Erarslan. Timber construction systems in anatolian vernacular architecture,” *Bull. Transilv. Univ. Brasov, Ser. II For. Wood Ind. Agric. Food Eng*. (2019).
- [10] Y. D. Aktaş. Seismic resistance of traditional timber-frame hımsı structures in Turkey: a brief overview, *Int. Wood Prod. J.*, vol. 8, pp. (2017) 21–28.
- [11] N. Ş. Guchan.. History and Characteristics of Construction Techniques Used in Traditional Timber Ottoman Houses, *Int. J. Archit. Herit.*, vol. 12, no. 1, pp. (2018) 1–20, Jan.
- [12] M. B. Bağbancı and O. K. Bağbancı. The Dynamic Properties of Historic Timber-Framed Masonry Structures in Bursa, Turkey,” *Shock Vib.*, vol. (2018).
- [13] B. Chand, H. B. Kaushik, and S. Das. Material Characterization of Traditional Assam-Type Wooden Houses in Northeastern India, *J. Mater. Civ. Eng.*, vol. 32, (2020) no. 12.
- [14] S. Paudel, N. Shima, and T. Fujii. Development of earthquake resilient housing in Nepal by development of earthquake introducing Japanese, *AIJ Journal of Technology and Design*, vol. 24, (2018) no. 57.
- [15] A. Buchanan and D. Moroder. Log house performance in the 2016 Kaikoura earthquake, *Bull. New Zeal. Soc. Earthq. Eng.*, vol. 50, (2017) no. 2.
- [16] T. Horie and S. Kaneko. Arrangement and terminology of the main structural members of the understructure in Japanese and British vernacular houses: Comparative studies in the terminology of traditional timber construction Part 2, *J. Archit. Plan. (Transactions AIJ)*, vol. 82, (2017) no. 740.
- [17] Y. M. Kim. Structural analysis and conceptual seismic design of large-span Korean traditional timber structure, *Civ. Eng. Archit.*, vol. 8, (2020) no. 2.
- [18] Abidah A, Yahya M, Rauf BA. The healthy homes of the Ammatoa Kajang indigenous people, Indonesia. *Conservation Science in Cultural Heritage*. (2022) ;21(1):67-82. doi: 10.48255/1973-9494.JCSCH.21.2021.01.
- [19] Yunistira, Asmunandar. Kosmologi arsitektur rumah adat Kajang di Desa Tanah Towa Kecamatan Kajang Kabupaten Bulukumba. *Jurnal Studi Budaya*. (2025) ;9(2):223-240. Tersedia pada: <https://ojs.unm.ac.id/JSB/article/view/73952>
- [20] W.Wasilah, A. Hildayanti. Filosofi penataan ruang spasial vertikal pada rumah tradisional Saoraja Lapinceng Kabupaten Barru [Philosophy of vertical spatial planning in Saoraja Lapinceng traditional houses, Barru Regency]. *J. RUAS (Rev. Urban. Archit. Stud.)* (2017) 14, 70–79.
- [21] Sarwidi, Satyarno I, Pribadi KS, Suhendro B, Purnomo H, Wibowo M, dkk. Barrataga (Bangunan Rumah Rakyat Tahan Gempa) dan Simutaga (Simulasi Tahan Gempa): koleksi masterpiece Museum Gempa. Yogyakarta: Universitas Islam Indonesia; (2019). 78 p. (Seri Pengurangan Risiko Bencana Gempa Bumi).
- [22] Wasilah, Hildayanti A. Manifesting locality and identity in traditional houses in response to environmental change. In: *Proceedings of the 3rd International Conference on Dwelling Form (IDWELL 2020)*; 2020 Oct 9; Makassar, Indonesia. Paris: Atlantis Press; (2020). p. 132-136. (Advances in Social Science, Education and Humanities Research; vol. 502). doi: 10.2991/assehr.k.201009.014.
- [23] Hariyanto, A. D., Triyadi, S., & Widyowijatnoko, A. A Simple Stilt Structure Technique for Earthquake Resistance of Wooden Vernacular Houses in Bima, Sumbawa Island, Indonesia. *International Journal on Advanced Science, Engineering and Information Technology*, (2022) 12(4), 1491-1497.

- [24] Sari, D. P., Sudirman, M., & Asmulyani, A. The Design of Earthquake Evacuation Spaces Based on Local Wisdom: A Case Study of Traditional Houses in South Sulawesi. *Designs*, (2024) 8(2), 30.
- [25] Ortega, J., Vasconcelos, G., Rodrigues, H., & Correia, M. Assessment of the efficiency of traditional earthquake resistant techniques for vernacular architecture. *Engineering Structures*, (2018) 173, 1-27.
- [26] Wasilah. The Structural Effectivity of Bent Piles in Ammatoan Vernacular Houses. *Buildings*, 09-00042-v2. (2019).
- [27] Zuber, A. Architectural adaptation of vernacular stilt houses in Palu city. *IOP Conference Series: Earth and Environmental Science*, (2022) 1075(1), 012032.
- [28] Syarif, S., Yudono, A., Harisah, A., & Sir, M. M. Sulapa Eppa As The Basic or Fundamental Philosophy of Traditional Architecture Buginese. *SHS Web of Conferences*, (2018) 41, 04005.
- [29] Gálvez-Cortés, G. S., De la Colina-Martínez, J., & Valdés-González, J. Estimation of the seismic accidental-torsion effects from the amplification of the response of a torsionally balanced model. *Ingeniería Sísmica*, (2020) 103, 56-76.
- [30] Chen, L., Wang, X., & Zhang, Y. Plane irregular multi-layer frame base isolation structure torsion effect and its control. *Journal of Vibration Engineering*, (2024) 37(12).
- [31] Aktaş, Y. D. Seismic resistance of traditional timber-frame houses structures in Turkey: a brief overview. *International Journal of Architectural Heritage*, (2017) 11(1), 21-28.
- [32] Haji Sadeghi, N., Azizi-Bondarabadi, H., & Correia, M. Preventive Conservation of Vernacular Adobe Architecture at Seismic Risk: The Case Study of a World Heritage Historical City. *Buildings*, (2025) 15(1), 134.
- [33] Gani, A., Banday, J. M., & Rai, D. C. Seismic evaluation of traditional timber framed masonry systems using shake table tests and finite element modelling. *Innovative Infrastructure Solutions*, (2023) 8, 231.
- [34] Oktawati AE. Sambungan konstruksi bola tungke' terhadap mitigasi bencana gempa bumi di Soppeng. *Jurnal Jendela Arsitektur*. (2024) ;6(2):65-74. doi: 10.37905/jjoa.v6i2.28390.
- [35] Dutu, A., & Yamazaki, Y. Seismic Resistance of Vernacular Timber Frames with Infills: Case Studies from Japan and Romania. *Taylor & Francis Group*, (2024).
- [36] Dragomir, C. S., Dobre, D., & Georgescu, E. S. The Evolution of Traditional Concepts for Masonry Dwellings in a Seismic Rural Area. *18th International Multidisciplinary Scientific GeoConference SGEM 2018*, 1.1, (2018) 1003-1010.
- [37] Hu W, Guan H. A finite element model of semi-rigid mortise-and-tenon joint considering glue line and friction coefficient. *J Wood Sci*. (2019) Dec;65(1):14. doi: 10.1186/s10086-019-1794-4.
- [38] Parisi, F., Ruggieri, S., & Augenti, N. Seismic response of traditional timber frames: Insights from pseudo-static tests on full-scale specimens. *Engineering Structures*, (2018) 167, 1-15
- [39] Branco, J. M., Piazza, M., & Cruz, P. J. S. Experimental evaluation of the cyclic behaviour of traditional timber connections. *Construction and Building Materials*, (2017) 151, 771-783.
- [40] Arief, A. Kajian Eksperimental Sambungan Kayu Tradisional Nusantara: Efisiensi Struktural dan Potensi Adaptasi. *Jurnal Rekayasa Sipil dan Lingkungan*, 8(1), (2024) 45-58.
- [41] Indrabakit, F., & Mulyadi, R. Studi Sistem Struktur Rumah Vernakular Tahan Gempa Di Indonesia, (2021)



© 2026 by the authors. Licensee LINEARS, Indonesia. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY NC ND) license (<https://creativecommons.org/licenses/by-nc-nd/4.0>).