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Structural Analysis of the *Uma Lulik Kapitan Afaia* in Baricafa Village, Timor-Leste, Using the Load and Resistance Factor Design (LRFD) Method

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Abstract *Uma Lulik* in Baricafa Village, Timor-Leste, is a traditional building that represents the local community culture. This building has a wooden structure consisting of three main components: head, body, and legs/feet, showing adaptability to environmental changes. The purpose of this study is to examine the structural behavior of wooden buildings against axial force loading, internal force, and shear force. This research uses a quantitative approach with finite element modeling through SAP2000 V22 software to analyze the behavior of structures against axial forces, bending forces, and shear forces in accordance with *SNI* 7973-2019 standards. This research was conducted by taking direct measurements of the structural elements of *Uma Lulik Kapitan Afaia* and calculating the structural capacity. The analysis results show that the wooden structure of *Uma Lulik Kapitan Afaia* meets the structural design requirements. Although there are certain elements that experience maximum deformation, such as the second-floor cantilever beam (*Opui'i*), the overall structure remains stable due to the interconnectedness of the elements. The columns showed good capacity in resisting axial and shear loads, thus maintaining the stability of the structure despite facing combined vertical and horizontal loads.

Keywords *Uma Lulik*, Axial Force, Bending Moment, Shear Force, Baricafa, Timor-Leste

1. Introduction

Traditional architecture represents a profound manifestation of the relationship between humans, culture, and the environment. In the Lautem District, located at the easternmost tip of Timor-Leste, this architectural expression materializes in the form of the *Uma Lulik*.

Uma Lulik culture has been passed down from generation to generation. *Uma Lulik* are not buildings used as households for residency, but rather they are ritual buildings used on special occasions for gatherings and other ceremonies [1].

Lautem District shows a deep connection between the homeland and the country's cultural identity. According to Adriana [2], *Uma Lulik* is a place of worship and a meeting between the living and the dead and besides being a meeting place, at the time of the corn or rice harvest, there is a ritual when entering the house. The community builds or renovates an *Uma Lulik* building for 10 years to 20 years, depending on the *lian nain* (traditional leader) and structural problems that may affect *Uma Lulik* [3].

More than just a dwelling, the *Uma Lulik* serves as the spiritual and social axis of the Fataluku ethnic community [4]. It functions as a sacred animistic totem, acting as a medium through which the living communicate with ancestral spirits, store sacred heirlooms, and conduct customary rituals essential to the continuity of their cultural heritage [4]. Consequently, the physical integrity

of the *Uma Lulik* is directly linked to the community's social cohesion and cultural identity.

Architecturally, Lautem's traditional houses exhibit a highly distinctive and dramatic silhouette, most notably featuring a steeply pitched, four-sided roof that often rises to 12 meters above ground level [5]. Among leadership dwellings, this prominent roof is adorned with symbolic ornaments such as gamuti cones, carved beams, and strands of seashells, signifying status and authority [5]. The entire superstructure is elevated approximately three meters above ground level, a common feature in tropical architecture intended to protect against moisture and animals, while also enhancing natural ventilation [6].

From a structural engineering perspective, the most striking feature of the *Uma Lulik* is its seemingly minimalistic support system: the entire mass of the building is carried by just four main wooden columns [5]. These four pillars serve as the primary load paths for transferring both gravitational and lateral forces to the foundation. The external walls are typically non-load-bearing, composed of intricately carved wooden panels that serve both decorative and protective functions. All construction materials are locally sourced: timber for the main frame and columns, and bamboo and thatch collected from nearby forests for the roof and cladding, indicating that the upper structure is deliberately designed to be lighter than the main framework [7].

The modern historical context adds urgency to the study of these structures. During the Indonesian occupation, many *Uma Lulik* were deliberately destroyed as part of a strategy to undermine local spiritual and social systems [7]. Since independence, a significant cultural resurgence has emerged, with the reconstruction of *Uma Lulik* becoming a powerful symbol of identity recovery and communal resilience [7]. Understanding the structural performance of these buildings is therefore critical.

The *Uma Lulik* serves not only as a domestic space but also holds profound spiritual and communal values [8]. G. Suzi Maria [9] stated that it's a building built based on the cultural heritage and traditions of the local community. *Uma Lulik* is a symbolic representation of a hereditary group, the relationship of a group of extended families separated by family and clan or characterized by a clan [3] [9]. It serves not only as a place of residence but also as a repository for ancestral heirlooms and a medium of communication with the ancestors, referred to in the Tetum language as Bei'ala (Ancestors). Moreover, it embodies the values of life and local wisdom that have been transmitted across generations [10].

The construction of the *Uma Lulik* typically requires a considerable duration, often spanning six to eight months, as it comprises several culturally significant components and houses sacred objects, with a distinctively elevated roof that rises disproportionately relative to its base. Ashadi [11] also explains that it's a different perspective; we see that the horns of the dove and buffalo are clearly displayed on the roof, but the stars that symbolize the core values are often not clearly visible.

Traditional architecture emerges as a manifestation of human adaptation to the surrounding environment, resulting in diverse regional variations shaped by local natural conditions, availability of materials, climate, and vegetation.

The process of traditional house construction encompasses several stages, including site selection, choice of building materials, adherence to customary norms, and consideration of environmental factors. These stages are often guided by construction techniques transmitted across generations through oral traditions such as legends, rhymes, narratives, or through hands-on apprenticeship [11] [12].

Built with traditional timber construction techniques and local mechanical joints such as wooden pegs and lashings, these buildings have endured for decades without formal structural calculations. However, there remains a lack of scientific studies assessing the structural strength of such traditional buildings, particularly using internationally recognized frameworks such as Load and Resistance Factor Design (LRFD).

LRFD is a probabilistic structural design approach that incorporates reliability factors for both load and material resistance. While widely applied to concrete and steel structures [13], its application to traditional timber structures with non-standard local configurations remains underexplored in the literature. This highlights a critical gap in civil engineering research concerning the preservation and sustainability of indigenous structures.

This study occupies a strategic position within the academic discourse, as it explores a research locus that has been largely overlooked in previous investigations concerning traditional houses. To date, no specific studies have been identified that examine the structural aspects of the *Uma Lulik*, particularly the *Uma Lulik Kapitan Afaia* located in Baricafa Village, Timor-Leste. Therefore, this research is expected to make a significant contribution by addressing a gap in the existing literature on the structural analysis of traditional timber architecture.

Construction of the *Uma Lulik Kapitan Afaia*: the column elements are placed on split stones, locally known as *wualepe*, which are embedded into the ground. These stones measure approximately $65 \times 65 \times 0.75$ cm and are surrounded by compacted soil. The placement of the columns on the stones serves to mitigate the effects of soil volume changes due to expansion and contraction, soil moisture, and biological degradation by wood-damaging organisms. Furthermore, the split stones function as base isolators, enhancing the structure's resistance to vibrational energy generated by seismic activity and wind loads.

This study aims to analyze the structural strength of the *Uma Lulik Kapitan Afaia* by examining the behavior of its timber construction under axial forces, bending moments, and shear stresses, using the Load and Resistance Factor Design (LRFD) method.

The analysis focuses on key structural elements such as beams and columns. Local material properties and realistic load conditions, including dead loads, live loads, wind, and seismic loads are incorporated. The primary contribution of this research lies in integrating a modern structural design methodology (LRFD) with traditional construction wisdom that has, until now, remained largely unquantified in technical terms.

1.1. Structure and Construction System

Beyond the use of local terminology, cultural influences are also evident in the structural and construction systems of traditional houses. One of the key findings during field observation pertains to the column system of the *Uma Lulik*, in which the primary posts are embedded directly into the ground at depths ranging from approximately 0.60 to 1.00 meters. These posts are assembled using wooden pegs or pins known locally as *itun*, which serve to connect individual column elements. The substantial weight of the posts, combined with the overall mass of the structure, enables the building to remain stable atop a foundation of fractured stone (*wualepe*).

The main structural system of the *Uma Lulik* is supported by two principal beams referred to as *patan*, joined together using wooden pegs *(lutu-lutu*). Above these beams, six transverse floor joists known as hara'a are installed to form a rigid and stable floor frame. This floor structure supports a square plan framework called *ta'ala*, which is braced by peripheral wall posts *hirilepe, hirilarin, and hirimata*. These wall posts penetrate through both the *ta'ala, taileu'u and hara'a* components and concurrently support the twin *patan* beams secured by *lutu-lutu*, resulting in a continuous and robust box-like structural configuration.

The structural systems of modern and traditional buildings can be considered very similar, as they are both states of a system of stacking and bonding between their elements in assembling a single building [3]. Traditional house structural design, in this case, was that the response force experienced by one part of the structure (swaying on the main pillar/beam) becomes the force acting on the structural part through the response force, thus, creating a balance of action and reaction [14]. The high-rise building structural systems are categorized into systems that are used to resist gravity and lateral forces. According to Fajar A. [15], building structure refers to the arrangement of load-bearing building components of the main structure or construction, regardless of the aesthetics of the building. The structural system of a traditional house includes beam-column ties designed to resist lateral forces and ensure the stability of the building [16] [17]. This shows that *Uma Lulik* is a very flexible building in responding to the forces acting on its building, both those caused by its own loading and loads from outside the building [12].

Traditional buildings are culturally distinctive buildings that are the result of trial and error and have become one of the important identities of building traditional houses, consisting of three (3) parts such as the upper structure (head), the middle structure (body) and the lower structure (foot) (Figure 1) [18] [19].

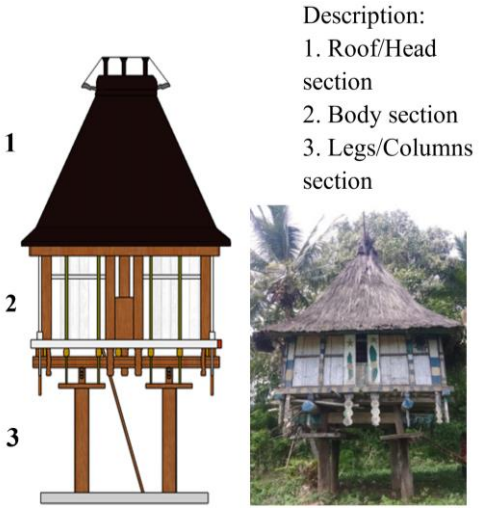


Figure 1. The building structure of *Uma Lulik*

1. The upper structure (head)

The head structure is very important in a building to protect the inside of the building from the weather. The roof not only protects the space from rain and heat, but also functions as a complement to the facade of the house. The building plan model is simple and symmetrical, with the roof using light materials and walls inside being regular and symmetrical.

2. The middle structure (body)

The middle structure is a structural element that functions to transmit the load to the column. This element is part of the core structure of the building along with the columns and foundation. Beams function to tie between columns together so that they can withstand horizontal forces.

3. The lower structure (leg)

The main function of the substructure is to transfer the load from the superstructure to the ground. It is necessary to ensure that all structural components such as foundations, columns and beams are well connected.

2. Materials and Methods

There are several reasons why Baricafa Village was chosen as the research locus. The structure and construction system of *Uma Lulik* looks simple, like most traditional buildings consisting of head, body and foot structures, but is able to survive and adapt to various changes in environmental conditions [12].

The selection of Baricafa Village as the research site for analyzing the structure of *Uma Lulik Kapitan Afaia* is based on several critical considerations that underscore the

urgency and relevance of this study. First, Baricafa Village represents one of the regions in Timor-Leste that has steadfastly preserved its ancestral traditions and cultural heritage. Local customs and value systems continue to be practiced consistently and are deeply integrated into various aspects of community life, including the form and function of traditional buildings. This makes Baricafa an authentic and appropriate locus for research on traditional architecture grounded in cultural values.

Specifically, *Uma Lulik Kapitan Afaia* holds a central role not only as a physical structure but also as a symbol of tribal identity, a spiritual space, and a hub for customary activities. The building reflects an intrinsic relationship between architectural form, structural integrity, and sociocultural function. Therefore, a technical analysis of its structural capacity is essential, given its vital role and potential for preservation as an element of intangible cultural heritage.

From a civil engineering perspective, this study adopts a quantitative approach using the Load and Resistance Factor Design (LRFD) method. LRFD was selected for its rational and safety-oriented framework in assessing structural strength by combining factored loads and resistance factors [20]. The application of this method enables a rigorous evaluation of structural components such as timber columns and, beam elements that have traditionally been constructed based on empirical knowledge and indigenous practices.

Thus, this research aims not only to assess the structural capacity of *Uma Lulik Kapitan Afaia* under actual service loads but also to contribute to the documentation and reinterpretation of traditional construction reliability through modern engineering principles. The findings are expected to serve as both a scientific reference and a practical foundation for the conservation and adaptation of traditional buildings, supporting the development of safe, functional, and sustainable structural designs.

2.1. Argumentation and Research Method

Uma Lulik Kapitan Afaia, located in Baricafa Village, Timor-Leste, is a traditional building that reflects the rich cultural heritage of the local community. The structure was reconstructed in 2007 following its complete destruction during the Indonesian occupation of Timor-Leste. Despite the reconstruction, the authenticity of its architectural form, construction materials, and building techniques has been meticulously preserved. The construction process was carried out through a series of ritual ceremonies and excluded the use of modern materials; all stages of construction were performed manually using timber and traditional measuring tools. The building primarily employs local materials with a knock-down (demountable) structural system, and the ground floor is built directly on compacted earth fill. The building has a square floor plan, a steep pyramidal roof, and is supported by four main columns that carry vertical axial loads.

The primary objective is to analyze the mechanical behavior of timber structural elements under various loading conditions. This research is particularly significant, as *Uma Lulik* serves not only as a physical structure but also as a cultural and spiritual symbol for the local community. In the context of sustainable cultural heritage preservation, a comprehensive understanding of the structural performance and durability of traditional buildings is crucial, especially in addressing environmental challenges and natural hazards.

The study adopts a quantitative research methodology through numerical modeling using SAP2000, a finite element software widely applied in structural analysis. The three-dimensional modeling accurately represents the overall structural system, allowing for the calculation and evaluation of internal forces within each structural member, specifically axial forces, bending moments, and shear forces. Structural performance assessment is conducted in accordance with the Indonesian National Standard SNI 7973:2013, which provides technical guidelines for the design and evaluation of timber structures [21]. This standard establishes key parameters for determining the strength, stability, and serviceability of timber elements under various loading scenarios.

Primary data were collected through direct field observation, including the geometric measurement of structural dimensions, identification of timber materials, and documentation of traditional joinery techniques. Data collection was carried out systematically with high precision to ensure the validity and reliability of the structural model. The analysis incorporates realistic and contextually appropriate loading conditions, including dead loads, live loads, and lateral forces such as wind and seismic loads, based on regional parameters specific to Timor-Leste.

The analytical process involved multiple stages: the development of a detailed geometric model in SAP2000; assignment of material properties based on locally sourced timber and supporting literature; application of load combinations following the Load and Resistance Factor Design (LRFD) method; and stress analysis of each structural member. The output includes the distribution of axial, bending, and shear stresses, along with an evaluation of each element's capacity under the applied loads.

The findings of this study contribute to the body of knowledge in two key domains. Technically, the results demonstrate that traditional timber structural components, when designed based on empirical and indigenous knowledge, exhibit substantial structural resilience. Socio-culturally, the study reinforces the importance of integrating traditional architectural practices with modern engineering approaches to ensure the long-term sustainability of heritage buildings. Consequently, this research serves as a valuable reference for the conservation of vernacular architecture in Southeast Asia and supports the development of scientifically informed technical guidelines for the preservation of indigenous structures.

2.2. Process

The research methodology commenced with the identification and determination of the study object, namely a traditional *Uma Lulik Kapitan Afaia* building. The selection of the study object was based on considerations of cultural value, architectural uniqueness, and the physical condition of the building. The feasibility of the object was validated through literature review and preliminary field observations to ensure the relevance of the building's structural characteristics.

Primary data collection was conducted through direct field measurements to obtain geometric data of the structure, including the main dimensions and configuration of structural elements. Visual documentation was carried out in the form of photography and technical sketches. Additional observations focused on material types, traditional jointing systems (such as wooden pegs and local bindings), as well as indications of damage or deformation, Qualitative information regarding the philosophy and local construction techniques was obtained through interviews with customary leaders and traditional craftsmen.

The collected data were utilized to develop a three-dimensional structural model using SAP2000 software. The model incorporated key elements such as beams, columns, trusses, and joints, with wood material properties input based on relevant mechanical data to accurately represent the actual condition of the building.

Structural analysis was performed using the Load and Resistance Factor Design (LRFD) approach, which probabilistically considers load factors and resistance factors. Simulations conducted in SAP2000 generated outputs including stress distribution (bending, shear, and axial), deformation, maximum deflection, and utilization ratios, which were employed to assess the efficiency and safety levels of the structural elements under working loads.

3. Results and Discussion

Uma Lulik Kapitan Afaia in Baricafa Village, Timor-Leste, has a very unique culture. This building was reconstructed in 2007 after being destroyed during the Indonesian occupation of Timor-Leste. Even though it has been reconstructed, *Uma Lulik* still preserves the authenticity of its shape, materials, and construction process. The process of building *Uma Lulik* was done with ritual ceremonies and without the use of modern materials. Instead, measurements are taken traditionally using rope and wood during the entire construction process, from start to finish. The structure of *Uma Lulik* is dominated by local materials with an interlocking system, and the ground floor is leveled using urug soil. The main structure of the building consists of four columns that support the axial (vertical) load.

The building plan is box-shaped, with a high pyramid-shaped roof model, reflecting the characteristics of local culture. *Uma Lulik's* structure, which uses local materials and traditional construction methods, has a limited ability to withstand loads, especially when facing additional stresses such as earthquakes or strong winds. Therefore, an analysis is needed to determine the capacity of the material to carry loads, including axial, flexural, and shear loads. This research focuses on the analysis of the upper structure, specifically the beams, columns and roof trusses of *Uma Lulik Kapitan Afaia* in Baricafa Village, Timor-Leste. Analysis is carried out for loads acting on the *Uma Lulik* structure using the SAP 2000 program and the LRFD method.

The construction of the *Uma Lulik* is deeply embedded in ritual practices and adheres to traditional methods, avoiding the use of modern materials. Instead, the building process relies entirely on manual craftsmanship, utilizing wood as the primary measuring tool from inception to completion. The structural composition of the *Uma Lulik* predominantly incorporates locally sourced materials and follows a disassemblable system, with the ground floor being leveled using compacted soil (urug soil). The main structural framework consists of four vertical columns designed to bear axial loads, supporting a box-shaped plan and a high pyramidal roof. The *Uma Lulik* is built with a frame of teak wood, red wood, ai bubur and the roof cover uses *Tali-metan* (palm fiber).

The building construction of *Uma Lulik* in Timor-Leste, the building is conceptualized as a representation of the human body, and its construction is therefore divided into three main sections: the head, the body, and the legs, as illustrated in Figure 2.

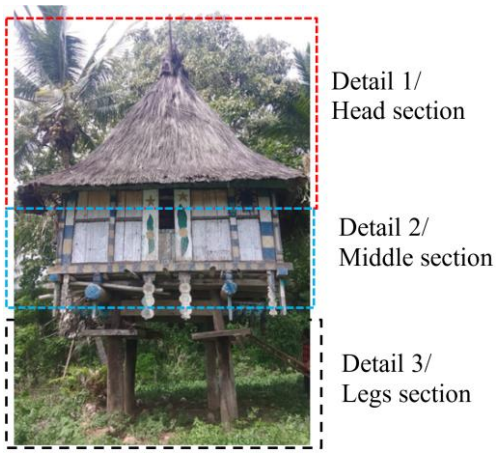


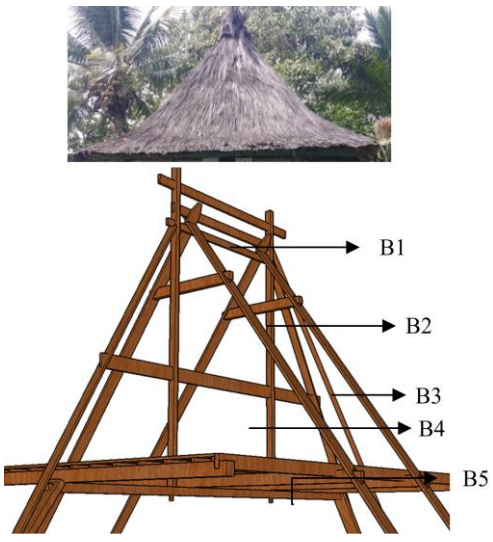
Figure 2. *Uma Lulik* building details

The Head Section (Detail 1) constitutes the roof or uppermost part of the structure, symbolizing the upper world and representing the spiritual connection with ancestors and the metaphysical realm. Structurally, it consists of roof frameworks such as trusses, rafters, and ridge beams that serve to protect the building from heat, rain, and wind. In certain *Uma Lulik*, this section is further adorned with traditional symbols or ornaments imbued with sacred meaning.

The Middle Section (Detail 2) corresponds to the walls and main interior space, which are regarded as the body of the building. Functionally, it serves as the dwelling area, the center of social interaction, and the locus of customary practices. From a structural perspective, this section transfers loads from the roof to the supporting columns. Symbolically, it represents the human world as the domain of daily life.

The Legs Section (Detail 3) comprises the foundation and supporting columns that bear the entire superstructure. The foundation, typically constructed from river stone, functions to prevent rainwater from seeping into the lower floor area (*omawasi*). In traditional symbolism, this section is associated with the underworld, representing the earth, water, and the guardian spirits that safeguard the dwelling.

The roof structure, illustrated in Figure 2 (Detail 1) and elaborated in greater detail in Figure 3, constitutes a primary construction element resting on the dwelling zone and functions as the main covering of the building. This system comprises the principal roof post (B2), the roof framing elements including the opuii beam (B5), the kii tekihi truss (B4), the kilarin truss (B3), and the main ridge beam *pu'u* (B1), as well as the roofing material. Collectively, these components form a steep pyramidal-shaped hip roof configuration. Additional structural elements include rafters (hisa larin), which are inclined beams supported by the main ridge pu'u (B1) and the upper tie beam, along with battens (hisa or pora) that serve as the supporting base for the roof covering. Traditionally, the roof of the *Uma Lulik* continues to employ natural materials, predominantly tali-metan, selected for their cultural significance and durability in response to local environmental conditions.



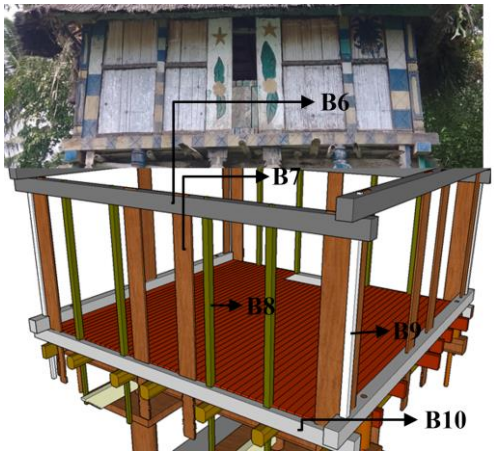
Description: *Pu'u* (Beam/B1), *Kuda-kuda ki'ia* (Post /B2), *kuda-kuda Kilarin* (Beam/B3), *Kuda-kuda kitekihi* (Beam/B4) and *Balok Opui*'i (Beam/B5)

Figure 3. Roof/Head structure details (Details 1)

The Body/ middle structural system (Detail 2) employs a table-like or box-shaped configuration, positioned on top of the columns and functioning as the main support for the roof structure. This system consists of two primary components: the horizontal floor structure and the vertical wall structure.

The horizontal component comprises the floor frame and its covering. The floor frame is constructed from timber beams locally known as *Patan* (B11) and *Hara'a* /B12 (Figure 5).

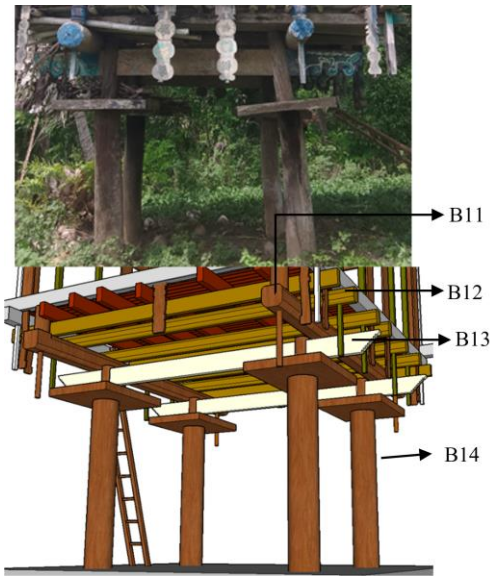
The vertical component consists of the wall frame *Hirilepe* (B7), *Hirimata* (B8), and *Hirilarin* (B9) and infill elements. The primary wall frame is composed of four hardwood beams referred to as *Hirilarin* (B9), which are rigidly connected at the bottom (*Ta'ala*, B10) and the top (*Taile'u*, B6) through supporting beams, thereby forming a stiff box structure (Figure 4). Additional vertical secondary beams are placed at the center of the wall plane to enhance stability. Both wall and floor coverings are made of split bamboo, locally termed *lesere*.



Description: Beam (*Taile'u*)(B6), Post (*Hirilepe*)(B7), Post *(Hirimata)* (B8), post (*Hirilarin)*(B9) and Beam (*Ta'ala)* (B10)

Figure 4. Body/ middle structure details (Details 2)

In Detail 3, a stone foundation (pondasi batu kali) is employed as a protective layer to prevent water infiltration into the ground floor area (oma vasi), particularly during the rainy season. The Tutuia (B14) element adopts a three-dimensional portal system, which functions to transfer structural loads from the roof to the ground through the main column (B14). This column is constructed from locally sourced round timber with a height of 2500 mm. The primary material used is Ai-Bubur wood, with a diameter of 400 mm, serving as the principal vertical support of the structure. The column is joined and interconnected with Itun (B13) beams, thereby forming a rigid and stable structural system. The upper part of the column, known as hele, serves both as a barrier to prevent rodents (e.g., rats) from climbing into the building and as a storage area for valuable items. The Itun, made of teakwood planks, connects the columns to enhance structural rigidity while simultaneously channeling loads from the upper sections of the building down to the stone foundation and into the ground (Figure 5).



Description: Beam (*Patan*)(B11), Beam (*Hara'a*)(B12), Beam *(Itun)* (B13) and Column B14

Figure 5. Leg/Column structure details (Details 3)

The structural system of the *Uma Lulik* buildings located in Baricafa Village (Figure 6) was analyzed with a focus on the design of the primary structural elements namely, beams and columns to ensure compliance with safety and strength criteria in accordance with civil engineering standards. The design methodology employed in this study follows the Load and Resistance Factor Design (LRFD) approach, which integrates load factors and resistance factors to determine the design strength of structural elements.

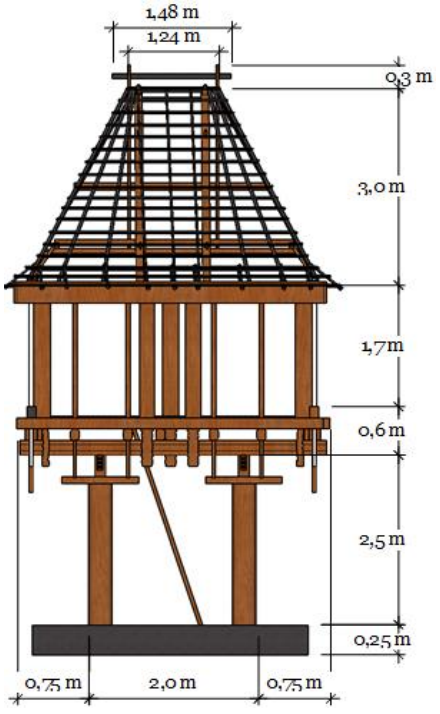


Figure 6. *Uma Lulik* Building structure

The analysis parameters include design bending moments, shear forces, axial forces, which were obtained through numerical modeling and simulation using SAP2000 version 14. The loading scenarios comprise combinations of dead loads, live loads, and seismic loads, with the most critical combinations used as the basis for structural evaluation. The maximum values derived from these load combinations were applied to the beam and column elements to assess their structural adequacy and overall stability (Tabel 1).

This section specifically examines the structural loads of *Uma Lulik* buildings as part of a comparative study to evaluate the structural efficiency and performance of each configuration. The objective of this analysis is to assess the extent to which the existing traditional designs can accommodate extreme load conditions in accordance with modern engineering codes and standards.

For instance, the load analysis results for the *Uma Lulik Kapitan Afaia* structure reveal varying magnitudes of bending moments, shear forces, and axial forces acting on each structural element. These values are categorized based on the type of element (beam or column) and its specific position within the structural system. Each element exhibits distinct loading characteristics depending on its function and spatial role within the overall structural configuration.

To facilitate further interpretation and evaluation, the loading results are presented in detailed tabular format, highlighting the magnitude of internal forces acting on each structural member. These tables serve as the basis for determining appropriate cross-sectional dimensions, material specifications, and connection types, and are crucial for verifying whether the structure meets the required strength and stability criteria as prescribed by the LRFD-based design methodology.

Table 1. Forces on *Uma Lulik* structure (axial, internal force, and shear force)

N0	Beam code	Axial force (kN)	Shear force (kN)	Bending moment (kNm)	length (mm)
1	**B1**	-	0,641	0,1048	1223
2	B2	4,822	0,617	-	2820
3	B3	-	0,166	0,4528	3300
4	B4	-	0,667	0,7042	3300
5	B5	-	9,172	2,9139	2700
6	B6	-	4,167	4,4104	3600
7	B7	0,389	0,0001281	-	2300
8	B8	1,9366	3,264	-	2300
9	B9	13,315	6,958	-	2300
10	B10	-	13,54	3,512	3600
11	**B11**	-	**102,35**	**70,712**	**3600**
12	B12	-	8,965	14,298	3600
13	B13	-	37,167	50,581	3500

3.1. Analysis of Flexural Strength, Shear and Deflection of Beam B11 (*Patan)*

3.1.1. Analysis of Flexural Strength

Flexural strength is the ability of a material or structure to resist forces that can cause deformation or change in shape.

The dimensions of the bending bar are made of 120 x170 mm timber beam with grade III timber quality code E-13 and the beam is given a compressive load of 70.7123 kNm.

The elastic modulus of the corrected stability beam can be calculated as follows:

Format conversion factor (K_F) = 1
Flexural resistance factor (ϕc) = 0.9
Size factor (for maximally sorted wood) (C_F) = 1,0
Wet service factor (for *F*b in dry condition) (CM) = 0,8
Puncture factor (Ci) = 1.0
Temperature factor (Dry condition <380C) (C_t) = 1
Bending stiffness factor can be taken > 1.0 (C_T) = 1
Without calculating the parameter λ, it is calculated

$$E'_{mim} = \phi_c x C_m x C_i x C_t x C_T x K_f x E_{mim}$$

$$E'_{mim} = 0{,}9x0{,}8x1{,}0x1{,}0x1{,}0x6500$$

$$E'_{mim} = 4680MPa$$

Beam critical buckling design value

$$F_{eb} = \frac{1{,}5xE'_{mim}}{Rb^2} = \frac{1{,}5x\,4680}{4{,}2029^2} = 23{,}9741\text{MPa}$$

$$\text{ab} = \frac{\text{Feb}}{\text{Fc'}} = \frac{3{,}9741}{14{,}199856} = 27{,}9869$$

Stability factor of beam

$$C_L = \frac{1+\text{ab}}{1{,}9} - \sqrt{\left[\frac{1+\text{ab}}{1{,}9}\right]^2 - \frac{\text{ab}}{0{,}95}}$$

$$C_L = \frac{1+27{,}9869}{1{,}9} - \sqrt{\left[\frac{1+27{,}9869}{1{,}9}\right]^2 - \frac{27{,}9869}{0{,}95}}$$

$$C_L = 0{,}998\,\text{MPa}$$

Rebound influence factor, where the beam is used edgewise (Flexure about the strong axis), C_{fu} = 1,0.

The corrected bending strength.

$$M' = C_L x C_{fu} x Fc' x S_x$$

$$M' = 0{,}998x1{,}0x14{,}199x578$$

$$M' = 8190{,}6079m$$

$$= 81{,}906079kNm$$

Checked Mu<M′=70.7123<81.906079...Sufficient

The factored flexural load acting on the beam (Mu) does not exceed the nominal flexural strength (M') that is, Mu<M′, it can be concluded that the beam possesses sufficient flexural capacity to safely resist the applied loads in accordance with structural design requirements.

In the design of the traditional *Uma Lulik* house, flexural strength is a critical consideration, as the structure primarily utilizes wood and other natural materials with distinct mechanical properties. Consequently, an analysis was conducted to evaluate the strength of the materials used in the construction of *Uma Lulik* Kapitan Afaia in Baricafa Village, Timor-Leste. The findings, including the calculated flexural strength for each beam, are presented in the table below.

Table 2. Recapitulation of bar forces (Flexural)

NO	Code	Dimension (mm)	Mu (KNm)	LRFD M' (kNm)	Descriptions (Mu<M')
1	B1	40x120	0,105	0,159	sufficient
2	B3	60x100	0,453	17,202	sufficient
3	B4	30x130	0,704	9,414	sufficient
4	B5	70 x 60	2,914	0,690	insufficient
5	B6	150x120	4,410	321,022	sufficient
6	B10	150x120	3,512	63,630	sufficient
7	**B11**	**120x170**	**70,712**	**81,834**	**sufficient**
8	B12	120x100	14,298	81,834	sufficient
9	B13	70x280	50,581	125,419	sufficient

Based on the analysis results presented in Table 2, the evaluation of allowable stresses in the beam frame elements indicates that the bending stresses generated within the *Uma Lulik* structure remain within the permissible limits and, in general, are adequate to resist the bending loads resulting from the applied load combinations. However, for the second-floor cantilever beam (*Opui'i*), identified as beam B5 with a cross-sectional dimension of 70 × 60 mm, the bending capacity is found to be insufficient to independently withstand the maximum bending moment.

Despite experiencing a critical loading condition, beam B5 remains capable of sustaining internal forces due to its structural integration with the roof framing system. This interconnection provides additional support in distributing loads and enhances the overall stability of the element. Although beam B5 undergoes maximum deformation under such conditions, structural failure does not occur. This is attributed to its function as an integral part of the roof structural system, whereby load transfer and interaction between elements enable efficient force distribution and prevent localized failure (Figure 7).

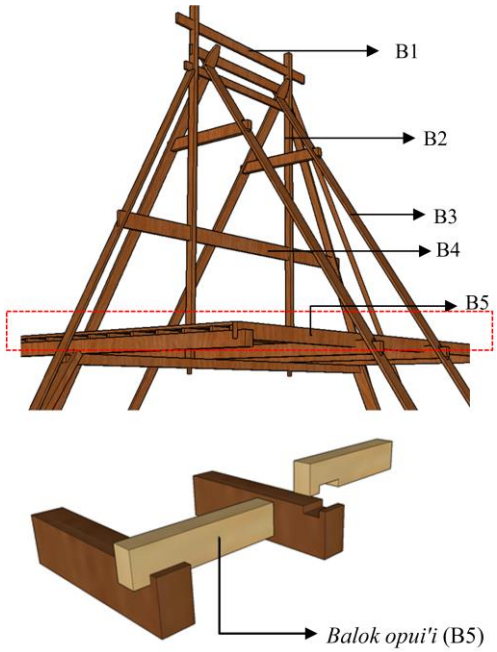


Figure 7. Roof truss structure and *opui'i* beam detail

3.1.2. Strength against Shear for Beam

Shear strength is a mechanical parameter that describes the ability of a material or structural element to resist shear forces, which are internal forces acting parallel to the cross-sectional surface and tending to cause relative displacement between interconnected structural components. This parameter is crucial in structural engineering and materials science because it directly affects the stability and structural integrity when the structure is subjected to transverse loading.

In the context of designing traditional wooden structures including traditional houses such as *Uma Lulik*, the Load and Resistance Factor Design (LRFD) approach is applied to accommodate uncertainties in loads and material strength through the use of safety factors. The fundamental principle in shear strength analysis is to ensure that the factored shear force, denoted as Vu, does not exceed the adjusted nominal shear strength, denoted as V′. This relationship is expressed by the inequality Vu ≤V′, which forms the basis for ensuring that structural elements do not fail due to shear forces.

The application of this principle is particularly important in the conservation and redesign of traditional timber structures, especially considering the anisotropic characteristics of wood material and the variability of its mechanical properties. Evaluation of shear strength is necessary to guarantee that the structure can function safely and reliably throughout its service life.

For shear strength calculation with LRFD:

Format conversion factor (K_F) = 2,88

Flexural resistance factor (ϕV) = 0.75

Wet service-factor (for *F*V in dry condition) (CM) = 0,97

Puncture factor (Ci) = 0,8

Temperature actor (Dry condition <380C) (C_t) = 0,7

Bending stiffness factor can be taken > 1.0 (C_T) = 1

Corrected shear of beam:

$$F'v = \lambda x \phi_v x C_m x C_i x C_t x K_f x F_v$$

$$F'v = 0{,}8 \text{ x } 0{,}75 \text{ x } 0{,}97 \text{ x } 0{,}8 \text{ x } 0{,}7 \text{ x } 2{,}88 \text{ x } 1{,}419$$

$$F'v = 1{,}3328 MPa$$

Shear strength of beam

$$Vu' = F'_v \, x \frac{2}{3} xbxd = 1{,}3328 x \frac{2}{3} x120x170$$

$$Vu' = 181270{,}1725 MPa.mm$$

$$Vu' = 181{,}270 kN$$

The shear force applied to the beam as a result of the acting load is determined to be Vu' = 181,2701kN, then it is **checked Vu < Vu' =102,35 kN <181,2701kN … Sufficient.**

Based on the calculations presented in Table 3, the allowable stress values in the beam frames indicate that, overall, the *Uma Lulik* structure possesses adequate capacity to resist shear forces resulting from the combination of applied loads. This finding suggests that the structural design, timber material selection, and dimensional configuration of the beam elements comply with established structural strength and safety standards.

Table 3. Recapitulation of Shear Forces

NO	Code	Dimension (mm)	Mu (KNm)	LRFD M' (kNm)	Descriptions (Mu<M')
1	B1	40x120	0,6410	0,903	sufficient
2	B3	60x100	0,1660	4,397	sufficient
3	B4	30x130	0,6670	11,612	sufficient
4	B5	70 x 60	9,1720	2,710	Not sufficient
5	B6	150x120	4,1670	77,414	sufficient
6	B10	150x120	13,5400	77,414	sufficient
7	**B11**	**120x170**	**102,3500**	**186,876**	**sufficient**
8	B12	120x100	8,9650	11,612	sufficient
9	B13	70x280	37,1670	50,577	sufficient

However, the cantilever beam on the second floor, referred to as *Opui'i* B5 (Figure 7), with cross-sectional dimensions of 70 ×60 mm, demonstrates insufficient shear resistance capacity. This condition indicates that the beam is subjected to shear stresses approaching or exceeding the allowable limits defined by the design calculations.

Nevertheless, the beam remains structurally viable, as it does not exhibit significant structural failure or cracking that could compromise the overall stability of the system, despite experiencing maximum deformation (deflection or distortion). One of the contributing factors to this structural

adequacy is the beam's connection to the roof truss system (as illustrated in Figure 7), which functions as an auxiliary support mechanism and facilitates load redistribution, thereby enhancing the beam's capacity to withstand internal forces.

In other words, although the *Opui'i* beam (Figure 7) undergoes relatively significant deformation, its integration with other structural elements, particularly its connection to the roof truss, plays a critical role in maintaining overall stability and preventing structural failure. This finding highlights the coherence and synergistic performance of the traditional timber structural system of *Uma Lulik*, which effectively compensates for the limitations of individual components through the contribution of interconnected elements.

3.2. Analysis of Compressive Strength and Shear on Column Structure

The strength against compressive and shear forces is a critical aspect in structural design, particularly for column elements that function to resist both vertical and horizontal loads. In traditional structures such as the *Uma Lulik*, columns must be capable of withstanding the combined effects of compressive loads from the roof and floor systems, as well as shear forces resulting from external actions such as wind and seismic events. Given the anisotropic nature of timber and its sensitivity to environmental conditions, evaluating the interaction between these forces is essential to ensure the stability and durability of the structure. A performance-based design approach, complemented by the application of modern structural engineering methods such as the Load and Resistance Factor Design (LRFD), can significantly enhance the reliability of the structural design and contribute to the preservation of traditional buildings from a structural standpoint.

3.2.1. Compression against Strength

Compression structural components play a critical role within building structural systems, particularly in the efficient transfer of axial compressive forces. A key element within this system is the batab press, which serves as the primary medium for transmitting compressive loads. In truss configurations, compressive members are also present, predominantly in the form of columns responsible for channeling vertical loads from upper elements, such as roofs or upper floors, down to the lower floors or foundation.

Columns function as primary structural elements that provide vertical stability and overall structural integrity. The mechanical behavior of columns is highly dependent on the properties of the constituent materials, including traditional timber utilized as a principal structural element. In this context, timber mechanically graded according to the E20 classification standard exhibits specific technical characteristics such as modulus of elasticity, compressive strength parallel to the grain, and bending strength that form the basis for analyzing and designing compressive members following Load and Resistance Factor Design (LRFD) or comparable design methodologies.

The selection of E20 grade timber as a structural material reflects a technical consideration of its strength and reliability in resisting compressive loads, as well as its suitability within both traditional and modern construction systems. Consequently, precise material characterization and a thorough understanding of the compressive element behavior are essential to ensure the overall performance and safety of the structural system.

Modulus of elasticity E_{min} = 14131,25 MPa.

Compressive design value F_c = 10,44 MPa

$$L_{e1} = kexl_1 = 1x2500 = 2500$$

$$L_{e2} = kexl_2 = 1x1250 = 1250$$

Determine the Slenderness Ratio Le/d

$$\frac{L_{e1}}{d_1} = \frac{2500}{400} = 6{,}25\,\text{mm}$$

Slenderness Ratio Control Le/d < 50 then 6.25 <50.....Ok

Determine the Correction Factor

Format conversion factor (K_F)	= 2,4
Flexural resistance factor ($\phi\, c$)	= 0.9
Size factor (for maximally sorted wood) (C_F)	= 1,0
Wet service factor (for *F*b in dry condition) (CM)	= 0,8
Puncture factor (Ci)	=1.0
Temperature factor (Dry condition <380C) (C_t)	= 1
Bending stiffness factor can be taken > 1.0 (C_T)	= 1

Calculating compressive strength Fc'

$$Fc = 0{,}8xF_c tabel = 0{,}8x17{,}4 = 13{,}92\,\text{MPa}$$

$$Fc = 0{,}75xF_c = 0{,}75x13{,}92 = 10{,}44\,\text{MPa}$$

$$Fc' = F_c xC_m xC_t xC_f xC_i = 10{,}44x0{,}8x1{,}0x1{,}0x0{,}8$$

$$Fc' = 6{,}6816\,\text{MPa}$$

Assess the slenderness of the column by determining the cross-sectional area and the corresponding equivalent cross-section.

$$A = \frac{1}{4}\pi xd^2 = \frac{1}{4}\pi x400^2 = 125663{,}7061\,\text{mm}^2$$

For circular cross-sections, the calculation uses an equivalent square cross-section with the same area. So the side of the square is obtained.

$$D = \sqrt{A} = \sqrt{125663{,}7061} = 354{,}490770mm$$

The slenderness ratio Le/D

$$\frac{K_e xL}{D} = \frac{1x2500}{354{,}490770} = 7{,}0524mm$$

Slenderness Ratio Control Le/D < 50 then 7.052<50...Ok!

Calculating the corrected elastic modulus of stability

Format conversion factor (K_F) = 1,76

Flexural resistance factor (ϕc) = 0.85
Size factor (for maximally sorted wood) (C_F) = 1,0
Wet service factor (for *F*b in dry condition) (CM) =1,0
Puncture factor (Ci) = 0,95
Temperature factor (Dry condition <380C) (C_t) = 0,9
Bending stiffness factor can be taken > 1.0 (C_T) = 1
The corrected elastic modulus:

$$E' = \varphi_s x C_m x C_i x C_t x C_T x K_f x E_{\min}$$

$$E' = 0{,}85x1{,}0x0{,}95x1{,}0x1{,}75x10000$$

$$E'\min = 14131{,}25MPa$$

$$F_{cE} = \frac{0{,}822xE'_{\min}}{\left(\frac{Le}{D}\right)^2}$$

$$F_{cE} = \frac{0{,}822x14131{,}25}{(7{,}05424)^2} = 233{,}5491MPa$$

$$\alpha_c = \frac{F_{cE}}{Fc'} = \frac{233{,}5491}{6{,}6816} = 34{,}95407$$

The coefficient C = 0.85 is taken for circular section columns so that the column stability factor can be calculated.

$$C_p = \frac{1+\alpha_c}{2c} - \sqrt{\left(\frac{1+a_c}{2_C}\right)^2 - \frac{a_c}{c}}$$

$$C_p = \frac{1+34{,}9541}{2x0{,}85} - \sqrt{\left(\frac{1+34{,}9541}{2x0{,}85}\right)^2 - \frac{34{,}9541}{0{,}85}}$$

$$C_p = 0{,}9956$$

Compressive strength corrected

$$P' = C_p x Fc' x A$$

$$P' = 0{,}9956x6{,}6816x125663{,}7061$$

$$P' = 835940{,}2264MPa.mm^2$$

$$p' = 835{,}9402264kN.$$

Checked Pu < P' = 128.166 kN < 835.94 kN...Sufficient

The results of the calculation of the compressive and shear strength of each column and wall support can be seen in Table 4.

Table 4. Recapitulation of Compressive (Axial) Force

NO	Code	Dimension (mm)	Pu (KNm)	LRFD P' (kNm)	Descriptions (Pu<P')
1	B2	60x100	4,822	31,006	sufficient
2	B7	220 x 50	0,389	14,067	sufficient
3	B8	60x60	1,9366	8,554	sufficient
4	B9	70x70	13,315	15,079	sufficient
5	B14	⌀400	128,166	835,940	sufficient

The analysis presented in Table 4 demonstrates that the calculated allowable compressive stress in the column frame confirms the *Uma Lulik* structure's sufficient capacity to resist axial forces induced by combined loading conditions. The allowable compressive stress serves as a critical parameter in assessing the column's ability to withstand vertical loads. Since the computed allowable stress remains below the permissible limit, it can be inferred that the columns maintain their structural integrity without experiencing permanent deformation or damage. This finding underscores the effectiveness of the traditional *Uma Lulik* design in applying sound structural engineering principles to distribute and resist applied loads, thereby ensuring the safety and stability of the building under realistic loading scenarios. Moreover, these results reinforce the applicability and relevance of modern design methodologies, such as Load and Resistance Factor Design (LRFD), in evaluating the structural performance of traditional timber-based constructions.

3.2.2. Strength against Shear for Column

Shear strength is a mechanical parameter that describes the capacity of a material or structural element to resist shear forces internal forces acting parallel to the cross-sectional area, which tend to induce relative displacement between interconnected structural components. This parameter is critical in civil engineering and materials science, as it directly influences the stability and structural integrity of a system when subjected to transverse or lateral loading.

In the design of traditional wooden structures, including vernacular buildings such as the *Uma Lulik*, the Load and Resistance Factor Design (LRFD) method is employed to ensure structural safety and reliability. The LRFD approach integrates load factors and resistance factors to determine the structural capacity in a manner that is both conservative and efficient.

By applying the LRFD methodology, the shear strength of timber columns is assessed by considering various factors such as the mechanical properties of the wood, connection conditions, and the influence of both dynamic and static loads. This ensures that the columns are capable of withstanding shear forces throughout the building's service life without incurring excessive deformation or damage that could compromise occupant safety or the preservation of the cultural heritage structure.

Corrected shear of column:

$$F'v = F_v x C_T x C_i x C_b x K_f x \phi x \lambda$$

$$F'v = 6{,}6816x1x0{,}8x1x2{,}4x0{,}9x0{,}6$$

$$F'v = 7{,}6972MPa$$

$$V' = \frac{2}{3} x Fv' x A = \frac{2}{3} x 7{,}69x125663{,}7061$$

$$V' = 64{,}4235kN$$

Checked V < V'= 29,1840kN < 64,4235 kN....sufficient

Based on the calculation results, the maximum corrected shear force (*V'*) acting on the beam is determined to be 64.2435 kN. According to the design principles adopted in this study, particularly under the Load and Resistance Factor Design (LRFD) approach, the factored shear demand must not exceed the available (corrected) shear capacity to ensure structural safety and performance. Compliance with this criterion indicates that the beam is adequately designed to resist shear forces without experiencing structural failure.

The analytical results presented in Table 5 indicate that the shear stress experienced by the column elements of the traditional *Uma Lulik* structure remains below the maximum allowable shear stress as specified by current structural design standards. This condition reflects the adequacy of the columns' structural capacity in resisting shear forces induced by combined loading conditions, including lateral loads such as wind and seismic forces. The shear stress remaining within the permissible limits confirms that the lateral stability of the columns is maintained even under extreme loading scenarios. Therefore, it can be concluded that the column structural system of *Uma Lulik* satisfies the safety and performance criteria against shear forces, in accordance with the principles of Load and Resistance Factor Design (LRFD).

Table 5. Recapitulation of Shear Forces (Column)

NO	Code	Dimension (mm)	Vu (KNm)	LRFD V' (kNm)	Descriptions (Vu<V')
1	B2	60x100	0,617	20,670	sufficient
2	B7	220 x 50	0,000128	9,378	sufficient
3	B8	60x60	3,264	5,702	sufficient
4	B9	70x70	6,958	10,053	sufficient
5	B14	⌀400	29,184	64,423	sufficient

Structural engineering analysis of the primary elements of the traditional *Uma Lulik* building demonstrates that, in general, the timber structural system satisfactorily meets strength and stability criteria based on the Load and Resistance Factor Design (LRFD) approach. Evaluation of beam and column elements indicates that most bending, compressive, and shear stresses remain within the allowable limits prescribed by applicable technical standards.

However, the cantilever beam on the second-floor slab (O*pui'i*), specifically beam B5, exhibits limited bending and shear capacity insufficient to independently support the maximum applied loads. Nevertheless, this element maintains structural functionality due to its integration with the roof framing system. The connections between structural components, particularly the roof truss, system enable effective load redistribution and prevent local failure, despite experiencing maximum deformation.

Conversely, the column elements demonstrate satisfactory performance in resisting both axial (compressive) and shear forces. The stresses developed in the columns remain below the maximum allowable limits, even under combined loading conditions, including lateral loads such as wind and seismic forces. This indicates that the column structural system provides adequate lateral stability.

Overall, these findings confirm that, although constructed using traditional techniques, the *Uma Lulik* timber structure effectively implements sound engineering principles. The integration of structural elements, material selection, and geometric configuration collectively contributes to the overall strength and stability of the system. Furthermore, the results affirm the applicability and relevance of modern design methodologies such as LRFD in evaluating and validating the performance of traditional timber-based structural systems.

4. Conclusions

The structural analysis of the traditional *Uma Lulik Kapitan Afaia* building demonstrates that the timber structural system generally satisfies strength and stability requirements according to the Load and Resistance Factor Design (LRFD) approach. The beam and column elements are capable of resisting bending, compressive, and shear stresses within safe limits as prescribed by applicable technical standards. Although the cantilever beam (B5) on the second floor has limited capacity to independently support maximum loads, it functions effectively due to its integration with the roof framing, which allows for efficient load redistribution.

The columns exhibit satisfactory performance under axial and shear loads, including lateral forces such as wind and seismic actions, with minimal risk of buckling, thereby ensuring overall structural stability. The use of timber materials with distinctive mechanical properties, combined with traditional jointing methods such as dowels and hooks, contributes to the structural flexibility and durability against external forces.

Overall, the *Uma Lulik* building not only preserves its cultural and spiritual significance but also meets modern technical criteria for structural safety and stability. The analysis results obtained through SAP2000 software reaffirm the relevance and efficacy of applying contemporary engineering principles to evaluate and support the sustainability of traditional construction systems.

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