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Vernacular Wisdom in Mountain Architecture: Timber and Bamboo Adaptation to Pelaga Village Microclimates

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ABSTRACT

This research documents and analyzes the vernacular wisdom embedded in the traditional timber and bamboo architecture of Pelaga Village, a highland settlement in Badung, Bali, Indonesia, situated at 650–1,100 meters above sea level. Through field surveys, architectural documentation, and environmental monitoring, this study examines how indigenous construction techniques and local material knowledge adapt to the cool tropical mountain microclimate. Key findings reveal that local hardwood timber and bamboo are the primary structural materials, joined using mortise-and-tenon (sambungan pen dan *lubang*) interlocking systems that allow complete disassembly and reassembly. Field measurements demonstrate that elevation difference is the dominant factor influencing outdoor microclimate, with mountain areas showing 43.6% lower temperatures than coastal regions. Traditional passive design strategies including woven bamboo walls for cross-ventilation, clay tile roofs for thermal mass, wide overhangs for shading, and strategic building orientation maintain indoor thermal comfort without mechanical systems. The study documents seven case buildings, all employing dismantlable construction that provides structural flexibility and seismic resilience critical in volcanic regions. Contemporary challenges threatening this heritage include scarcity of traditional materials, modernization pressures replacing natural with artificial materials, and loss of indigenous building knowledge. The research demonstrates that Pelaga's vernacular architecture embodies sophisticated climate-responsive design principles applicable to contemporary sustainable mountain architecture, particularly regarding local material utilization, passive thermal regulation, and community-based construction practices.

Keywords: vernacular architecture, local wisdom, mountain microclimate, bamboo construction, timber structures, Pelaga Village, passive design

INTRODUCTION

Vernacular architecture represents centuries of accumulated local wisdom in climate-responsive design, shaped by indigenous knowledge, available materials, and environmental conditions rather than formal architectural practice [1][2]. This accumulated knowledge—passed down through generations of builders via direct practice, oral instruction, and communal construction—encodes sophisticated responses to local climate, ecology, and cultural values that formal design methods often replicate only partially [3][4]. In tropical highland contexts specifically, traditional buildings must address a unique thermal challenge: maintaining warmth during cool nights while managing moisture and heat gain during the day, a condition fundamentally different from both coastal tropical and temperate mountain climates [5].

Research on Indonesian vernacular houses has established that elevation is the single most dominant factor influencing outdoor microclimate, with mountain dwellings recording temperatures 43.6% lower than their coastal counterparts [6][7]. This finding is particularly significant for Balinese highland settlements, where thermal comfort strategies must be calibrated to cool-humid conditions rather than the heat-rejection strategies common in lowland architecture. Studies across Southeast Asian and Indonesian vernacular contexts document how permeable wall systems, elevated floors, and strategic courtyard placement collectively regulate airflow and thermal mass [8][9][10]. On the

material dimension, bamboo used with appropriate vernacular joinery techniques has been shown to reduce the embodied carbon of dwellings to approximately 40% of conventional brick construction [11], while locally sourced hardwood timber in well-established building traditions achieves service lifespans exceeding 60 years without chemical treatment [12]. The transmission of this building knowledge-from master builders to apprentices through communal construction practice—is itself a critical component of vernacular heritage, one increasingly threatened by modernization and generational discontinuity [13][14].

Despite this broader body of research, comprehensive documentation of timber and bamboo construction in Balinese mountain villages remains limited [15][16]. Pelaga Village in the highlands of Badung Regency—situated at 650–1,100 meters above sea level—has evolved distinctive architectural responses to tropical mountain microclimate over centuries, yet these building traditions remain largely undocumented in academic literature. This research addresses that gap through four objectives: (1) document traditional local hardwood timber and bamboo construction techniques including joinery systems and material sourcing; (2) analyze passive design strategies and their microclimate adaptation effectiveness; (3) evaluate spatial organization principles rooted in the Balinese Tri Hita Karana cosmological framework; and (4) identify contemporary threats to vernacular heritage and extract lessons applicable to sustainable highland architecture. Through field surveys and architectural documentation of seven case study buildings, this research contributes to the preservation of endangered indigenous building knowledge and offers actionable insights for climate-responsive design in highland tropical contexts.

RESEARCH METHOD

Study Area

This research was conducted in Pelaga Village (Desa Pelaga), located in Petang District, Badung Regency, Bali Province, Indonesia (8°16'13.13"S, 115°13'12.37"E). As illustrated in Figure 1, the village occupies a highland position at elevations ranging from 650 to 1,100 meters above sea level, surrounded by major volcanic peaks-Gunung Catur to the north, Gunung Batur and Gunung Abang to the east, and Gunung Batukaru to the west. Figure 2 presents the general settlement overview, showing how Sungai Bangkung and Sungai Cengkedek form the eastern and western natural boundaries of the village territory. Land use is predominantly agricultural (95.5% plantations and dry fields, 3.2% rice paddies, 1.3% settlement area), producing a dispersed built environment embedded within a productive landscape. The village population of 6,953 inhabitants across 1,894 households maintains livelihoods centered on coffee, vanilla, asparagus, and ornamental plant cultivation, supplemented by emerging agrotourism.

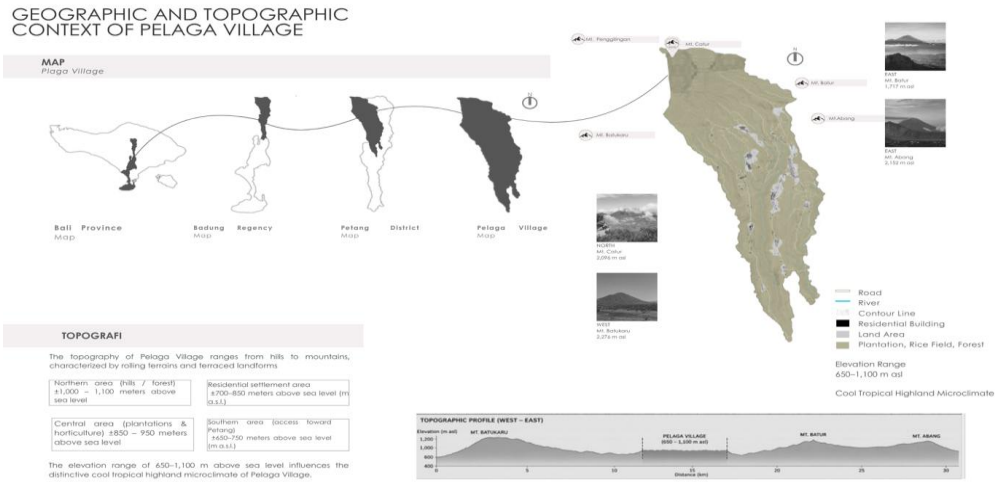


Figure 1. Geographic and topographic context of Pelaga Village, showing its position in Petang District, Badung Regency, Bali Province, Indonesia, at 650–1,100 meters above sea level, surrounded by major volcanic peaks.

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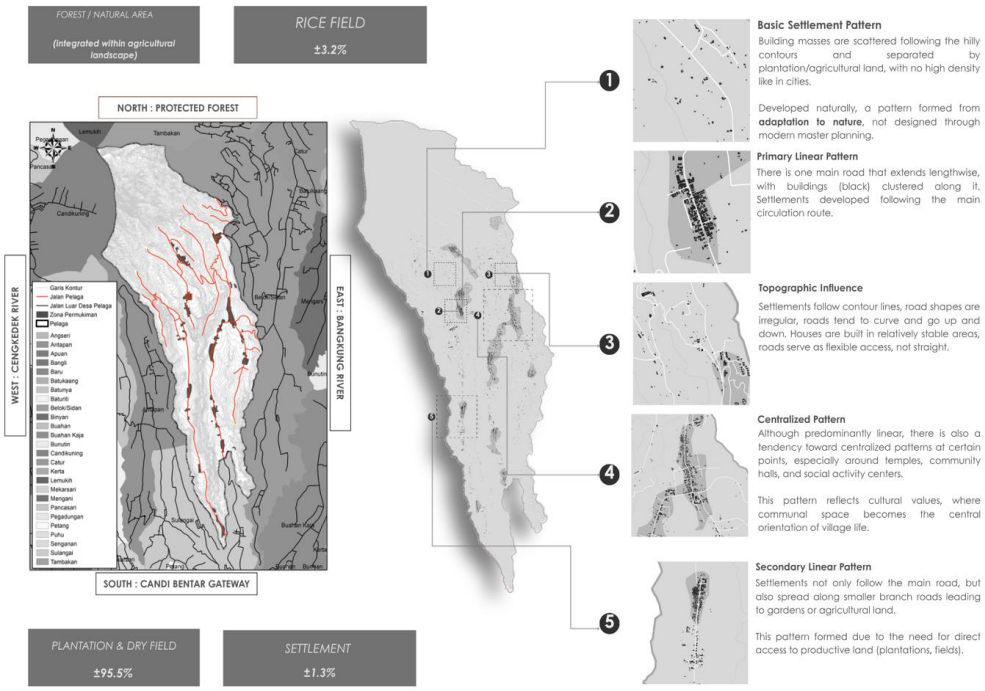


Figure 2. General overview map of Pelaga Village showing settlement distribution, primary road network, river boundaries (Sungai Bangkung and Sungai Cengkedek), and relationship to surrounding agricultural landscape.

Research Approach

Environmental and microclimate data were drawn from existing field measurement studies on Indonesian vernacular houses in comparable highland settings [6][7], which employed continuous monitoring of outdoor and indoor temperature and humidity over five-day periods across rainy season phases. Architectural documentation followed a typological assessment protocol: building form and spatial organization were analyzed relative to Balinese cosmological principles; construction techniques were recorded through measured drawings and photographic series focusing on joinery details and structural assemblies; and passive design strategies were identified through correlation of envelope characteristics with recorded thermal conditions [8][9]. Material properties were documented through field observation of existing buildings, literature review, and interviews with traditional builders on material selection, sourcing, and durability [11][12]. Seven case study buildings were selected to represent the range of building types, ages, and material combinations present in the village, with comparative analysis used to identify consistent underlying principles across the sample.

RESULTS AND DISCUSSION

Geographic and Climatic Context

Pelaga Village's elevation gradient—from 650 meters at the southern access zone to 1,100 meters in the northern forested hills—produces pronounced microclimatic stratification that directly governs building form and material selection. Cool daytime temperatures averaging 18–24°C and nighttime temperatures occasionally dropping below 15°C contrast sharply with Bali's coastal zones where temperatures consistently exceed 28°C. High relative humidity (75–85%), substantial cloud cover, frequent precipitation from November to March, and winds channeled through mountain valleys complete a microclimate that eliminates any need for mechanical cooling while shifting the thermal challenge toward nighttime heat retention and moisture protection. Research on Indonesian vernacular houses confirms that elevation difference is the dominant driver of this outdoor

microclimate differential, exceeding the influence of envelope material or building form [6]. The position of Pelaga between major volcanic peaks, as shown in Figure 1, creates site-specific orographic precipitation effects and wind patterns that traditional builders have learned to read and respond to through building placement and orientation across generations.

Traditional Settlement Pattern and Spatial Organization

The settlement morphology of Pelaga reflects pragmatic adaptation to steep terrain rather than a formally planned layout. As shown in Figure 3, buildings align linearly along the main road (Jalan Catur and Jalan Raya Pura Pucak Mangu, 6–8 meters wide), from which secondary paths of 1–3 meters branch organically along natural contours to reach individual homesteads and agricultural plots. This hierarchy minimizes earthwork, preserves natural drainage, and integrates residential and agricultural movement without imposing a rigid grid on complex topography. The low solid-to-void ratio—only 1.3% of land area built upon—means individual compounds are separated by gardens, terraces, and plantations, preventing heat accumulation and ensuring each structure receives natural ventilation from multiple directions [10]. Settlement nodes coalesce around pura (temples), balai banjar (community halls), and pura desa (village temples) at topographically and cosmologically significant locations, giving the dispersed pattern a legible social structure beneath its apparent informality. Figure 4 traces the morphological evolution of dwelling forms across five phases from before 1900 to the present, documenting the progressive material substitution—from bamboo, timber, and thatch toward cement, brick, and corrugated metal—that characterizes the contemporary threat to this building tradition [15].

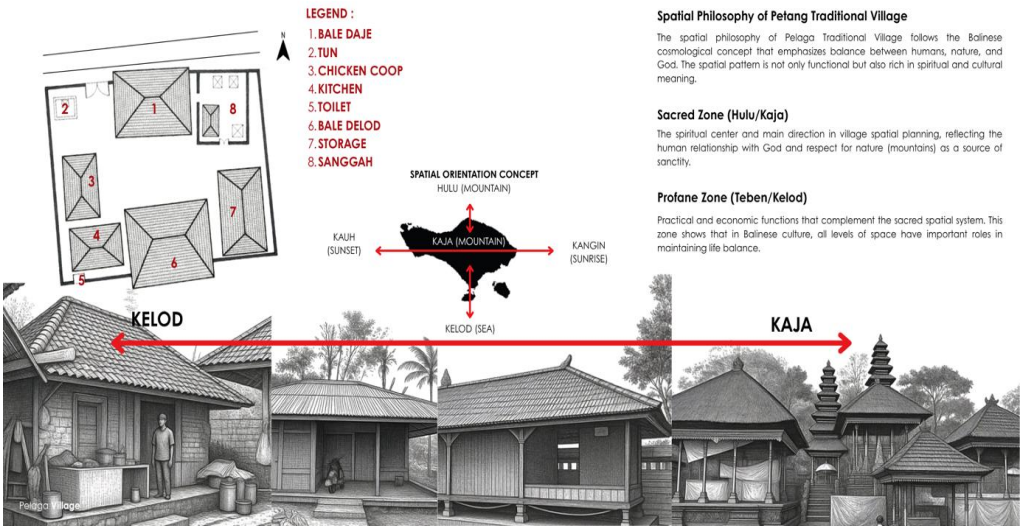


Figure 3. Spatial orientation of Pelaga's settlement, showing primary linear development along the main road, secondary branching paths following topographic contours, and low solid-to-void ratio integrating built fabric within productive agricultural landscape.

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Figure 4. Morphological evolution of traditional mountain dwelling models in Pelaga from before 1900 to the present across five phases: (1) pre-1900—fully traditional bamboo, timber, and thatch; (2) 1900–1960—spatial divisions formalized; (3) 1960–1980—material transition toward cement and brick; (4) 1980–2000—reduction of ornamental elements; (5) 2000–present—selective retention of traditional forms alongside contemporary materials.

Traditional Building Typology and Spatial Philosophy

Traditional Pelaga house compounds are organized according to the Tri Hita Karana cosmological principle—balance between the human, natural, and divine realms—expressed spatially through the Kaja-Kelod (mountain-sea) axis and the Kangin-Kauh (east-west) solar orientation [16][17]. Within each compound, this framework generates a precise spatial hierarchy: the sanggah or merajan (family temple) occupies the Kaja-Kangin (northeast) corner as the most sacred zone; sleeping and guest pavilions (bale daje, bale dangin) occupy elevated status in the northern and eastern sectors; the kitchen (paon) and working pavilions occupy the central and western areas; and toilet, livestock, and waste zones are relegated to the Kelod (southern) periphery. Figure 5 identifies the locations of the seven case study buildings across the village, showing how individual buildings are positioned within this broader settlement cosmology. Figure 6 illustrates the application of Tri Angga zoning—upper (Uttama), middle (Madya), and lower (Nista) zones—across the documented buildings, demonstrating how the vertical hierarchy of architectural elements mirrors the horizontal spatial hierarchy of the compound. This arrangement is not purely symbolic: sleeping areas in the northeast receive cool evening breezes descending from the mountains; kitchen heat is isolated from primary living spaces; and the central natah (courtyard) functions simultaneously as ceremonial space and ventilation node, drawing cool air through ground-level openings and exhausting warmed air upward. The spatial philosophy and the passive climate logic operate as the same system expressed in different registers [17].

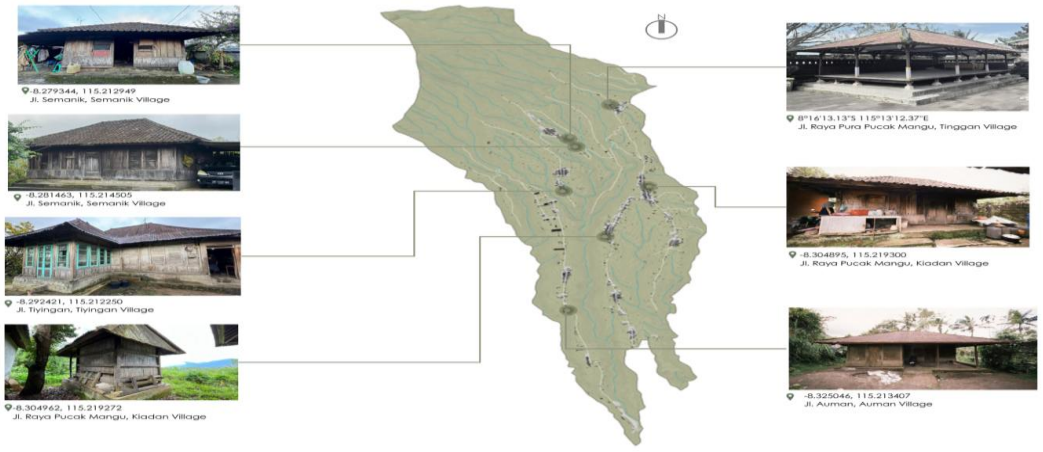


Figure 5. Location map of the seven case study buildings in Pelaga Village: key plan showing spatial distribution across the settlement, with individual site markers indicating each building's position relative to topographic contours, main roads, and settlement clusters.

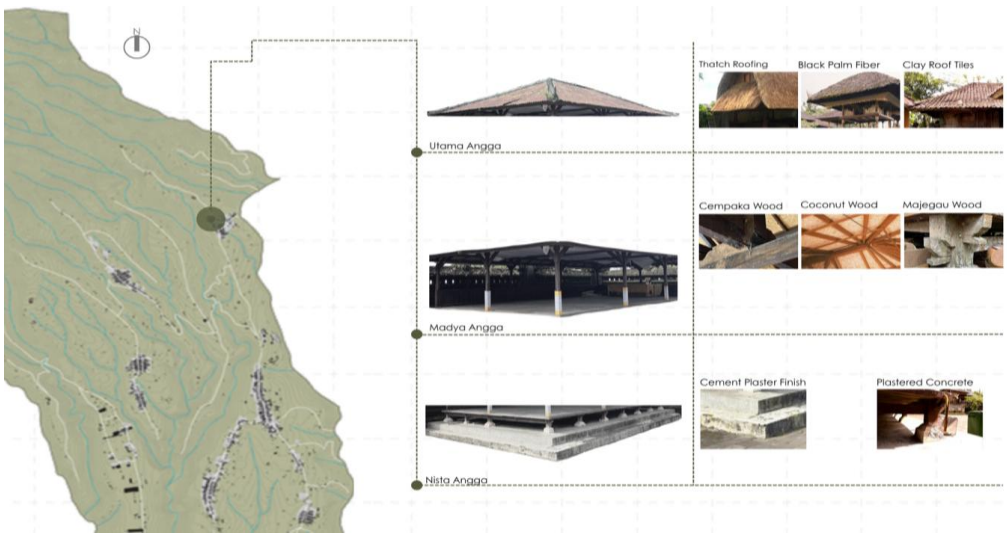


Figure 6. Application of Tri Angga cosmological zoning across the seven case study buildings: upper zone (Uttama/sacred), middle zone (Madya/human), and lower zone (Nista/utilitarian), illustrated with plan diagrams and corresponding sample location on the village map.

Timber and Bamboo Material Properties

Pelaga's traditional material system is organized hierarchically as Utama Angga (superior), Madya Angga (middle), and Nista Angga (utilitarian) elements—a locally developed performance classification that reflects empirical knowledge of each material's structural capacity, biological durability, and renewable supply. Local premium hardwood timber occupies the Utama Angga category as the primary structural material for saka (main columns), usuk and reng (rafters and battens), and lantai (elevated flooring). Its dense fiber structure confers high structural capacity; its natural chemical composition provides termite and fungal resistance; and its dimensional stability under moisture fluctuation suits the highland humid climate. Field documentation records a kitchen building constructed in 1965 from locally sourced hardwood timber—obtained within 60 meters of the building site—that remains structurally sound after nearly 60 years of continuous use, demonstrating the performance potential of locally matched material knowledge. However, premium local hardwood is now critically scarce: local informants report near-extinction of accessible mature trees within the last decade, the result of slow growth cycles combined with historical overharvesting without regenerative management.

Bamboo occupies a complementary role in the material hierarchy, functioning primarily as anyaman bambu (woven wall panels) while also appearing in secondary roof structure and scaffolding. Its 3–5 year harvest cycle makes it a genuinely renewable resource in contrast to the multi-decade regeneration required for hardwoods [11][18]. The woven wall system embodies considerable indigenous technical knowledge: split bamboo strips interlaced in diagonal or orthogonal patterns produce openings of 0.5–2 cm that allow continuous air and diffuse light penetration while blocking direct solar radiation and driven rain. This controlled permeability is the primary passive cooling mechanism in Pelaga's cool-humid highland conditions, where cross-ventilation rather than thermal insulation governs occupant comfort [9]. The full material composition of all seven case study buildings—structural timber species, wall systems, roofing types, and joinery methods—is presented comparatively in Figure 8.

Construction Techniques and Joinery Systems

The defining technical feature of Pelaga's traditional architecture is the sambungan pen dan lubang (mortise-and-tenon) joinery system, in which a precisely carved tenon (pen) on one timber member is inserted into a corresponding mortise (lubang) in the receiving member, with optional wooden pegs (pasak) securing the connection without metal fasteners. This system represents the accumulated local technological knowledge of generations of traditional builders, refined through

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practice rather than formal calculation. Figure 7 presents the structural connection models and detail sketches documented across all seven case study buildings, showing the primary pen dan lubang joints, half-lap (sambungan setengah kayu) secondary connections, and column-to-beam assembly sequences. Figure 8 provides enlarged node diagrams for each building, illustrating how connection typologies vary with building age and function while the principle of dismantlable assembly remains constant throughout.

This mechanical interlock delivers five simultaneous performance properties: structural capacity under static loads; controlled deformation under seismic loading, dissipating energy without catastrophic failure in a region of active volcanic and tectonic activity; complete dismantlability enabling individual component replacement or full building relocation; accommodation of seasonal timber dimensional change without inducing splitting; and construction using hand tools accessible to community members without industrial equipment [19]. All seven documented case study buildings employ this dismantlable joinery regardless of age, building type, or material combination—identifying it as a foundational principle of local building knowledge rather than a stylistic preference. Case Study 1, a traditional kitchen, demonstrates the complete tektonika assembly with local hardwood columns, interlocking roof truss elements, woven bamboo walls, and clay tile roofing. Case Study 7, which incorporates metal roofing as a contemporary substitution, retains the traditional joinery system intact—evidence that this embedded local knowledge persists even where individual material choices modernize [3][12].

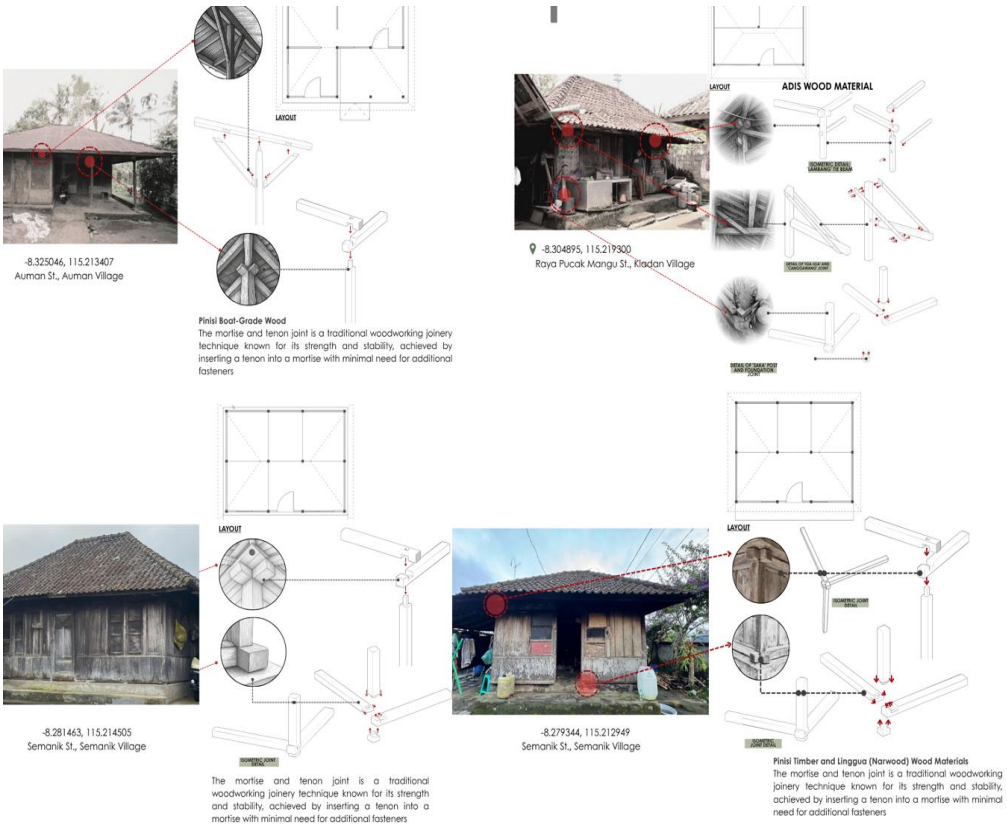


Figure 7. Structural connection models and detail sketches for the seven case study buildings: mortise-and-tenon (pen dan lubang) primary joints, half-lap (sambungan setengah kayu) secondary connections, wooden peg (pasak) fasteners, and column-to-beam assembly sequences.

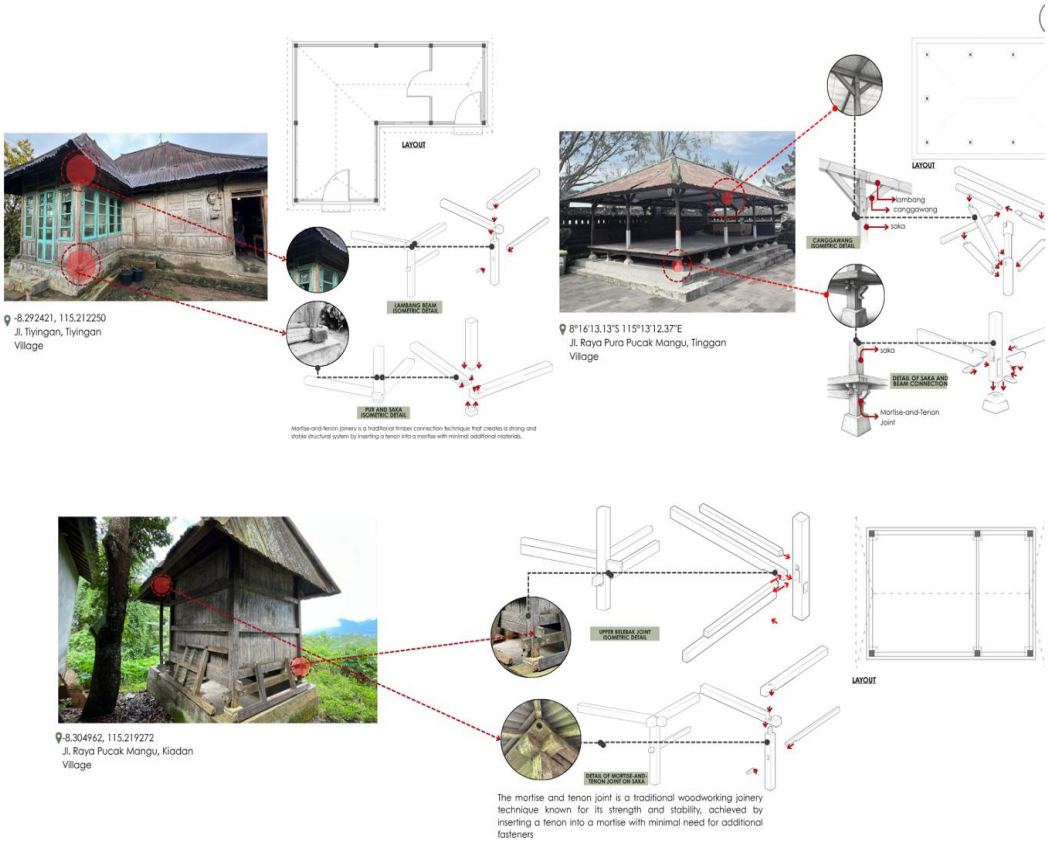


Figure 8. Detailed joinery sketches and structural node diagrams for each case study building, illustrating variation in connection typologies across different building ages and functions while demonstrating consistent application of dismantlable assembly principles.

Microclimate Adaptation and Passive Design Strategies

Pelaga's traditional buildings address climate through a layered system in which each element reinforces the others. Cross-ventilation is the primary thermal regulation mechanism: anyaman bambu walls with 0.5–2 cm openings maintain near-continuous airflow through interior spaces, with building orientation aligning principal openings to prevailing north and east mountain breezes. The natah (central courtyard) amplifies this effect by functioning as a ventilation chimney—cooler air enters at ground level through permeable wall panels while warmed interior air rises and exhausts upward, producing a stack effect without mechanical assistance [20][21]. Thermal mass operates at the roof and foundation level: clay tile roofing (genteng tanah liat) at 10–15 mm thickness absorbs daytime solar radiation and releases it gradually through cool nights, moderating the diurnal temperature swing characteristic of highland tropical climates [7]. Stone foundations contribute additional thermal buffering through the same mechanism. Wide roof overhangs—typically 0.8–1.5 meters beyond the wall plane—shade both walls and openings from direct solar gain while deflecting driven rain away from the permeable bamboo envelope; steep roof pitches of 35–45 degrees minimize roof surface solar exposure and rapidly shed heavy precipitation. Surrounding vegetation integrates into this system as a compound-scale microclimate buffer, providing shading and evapotranspirative cooling.

Field measurements from comparable Indonesian highland vernacular buildings show that mountain dwellings with traditional passive features maintain indoor temperatures 2–4°C below outdoor daytime peaks and 1–2°C above nighttime lows, achieving comfort without mechanical intervention [7]. Research on analogous passive strategies in other highland and tropical vernacular contexts confirms that integrated shading, thermal mass, and natural ventilation can collectively yield indoor

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temperature reductions of 3–4°C relative to unshaded, low-mass alternatives [22][23]. What distinguishes Pelaga's approach is the integration of spatial organization, envelope system, structural system, and material selection into a single coherent response to highland microclimate—each decision reinforcing the others rather than operating independently, reflecting the holistic character of indigenous building knowledge accumulated over generations [4][8].

Local Building Knowledge as a Design System

The vernacular building knowledge of Pelaga operates across multiple dimensions simultaneously, integrating material intelligence, structural ingenuity, climate adaptation, and spiritual-ecological frameworks into a single coherent practice [1][3]. Material intelligence is encoded in the hierarchical classification system (Utama-Madya-Nista Angga), which reflects an empirically developed evaluation of each material's structural capacity, biological durability, renewable supply, and cultural appropriateness—a locally developed performance specification system with demonstrable results across generations of buildings. The mortise-and-tenon joinery represents a structural solution that satisfies simultaneous requirements for load capacity, seismic ductility, repairability, and community constructability—criteria that contemporary structural engineers address through sophisticated calculation but which vernacular builders solved through observation and iterative craft refinement [19].

The passive climate system embedded in spatial organization, envelope design, and material selection reflects an empirical understanding of heat transfer, airflow dynamics, and thermal mass behavior that aligns with contemporary building physics, arrived at through occupant experience rather than simulation [9][10]. The Tri Hita Karana spatial framework reinforces this integration: what reads as cosmological prescription also functions as passive climate logic, with sacred zones positioned to receive cool mountain breezes and morning sun, and service zones located downwind in positions of afternoon heat accumulation [16][17]. This convergence of spiritual and environmental rationale in the same spatial decisions is characteristic of indigenous building knowledge systems in which technical and cultural knowledge are not separated into distinct domains but transmitted together through practice [13][14]. The urgency of documenting this system lies here: once the transmission pathway—apprenticeship, communal building practice, oral instruction—is broken, neither the technical knowledge nor the cultural framework can be recovered from physical observation of surviving buildings alone.

Comparative Analysis with Other Highland Vernacular Architectures

Placed in comparative context, Pelaga's strategies reveal both regional specificity and broader convergent patterns in highland vernacular architecture. Within Bali, the Kaja-Kelod spatial orientation, local timber and stone use, and steep-pitched roofing for rainfall management appear across highland settlements, but Pelaga shows distinctively higher prevalence of bamboo wall construction—a material advantage of its 650–1,100 meter elevation zone—and greater retention of dismantlable joinery relative to more tourism-accessible villages where modernization has accelerated [15][16]. Within the Indonesian archipelago, the North Maluku vernacular tradition demonstrates a parallel commitment to a spiritual-human-nature spatial philosophy realized through lightweight local materials and passive environmental adaptation [24], while Sundanese highland settlements such as Bunisakti Village integrate ecological, spiritual, and social relations into vernacular spatial organization in ways structurally analogous to Pelaga's Tri Hita Karana framework [25].

The more instructive comparison is the contrast with cold and temperate mountain vernaculars. Himalayan stone-and-timber architecture prioritizes thermal mass and minimal openings to retain heat through cold seasons, producing massive, closed envelopes that are the structural inverse of Pelaga's permeable bamboo walls [22]. Cold-region traditional villages in northern China similarly develop building knowledge calibrated to heat retention across severe winters, with living inheritance of traditional ecological knowledge serving as the transmission mechanism for climate-adaptive building practices [13]. These divergent strategies confirm a fundamental principle: the local building knowledge embedded in vernacular architecture is always context-specific rather than universal [1][5]. Pelaga's solutions are precisely calibrated to tropical highland conditions—cool-

humid, seismically active, high-precipitation—and their transferability to other highland tropical settings should be evaluated on that basis.

Material Sustainability and Local Resource Utilization

The material economy of Pelaga's traditional construction eliminates transportation carbon from the supply chain: local hardwood timber historically sourced within 60 meters of building sites, bamboo harvested from plots within or adjacent to the compound, clay tiles produced from locally excavated clay in simple kilns. Bamboo's 3–5 year harvest cycle against hardwood's multi-decade maturation represents the material system's own built-in sustainability gradient: rapidly renewable bamboo handles the high-turnover envelope and secondary structural elements, while slow-grown premium timber is reserved for primary structural members where its multi-decade durability justifies the slow regeneration rate [11][18]. Research on comparable vernacular bamboo construction demonstrates carbon footprints approximately 40% of conventional clay brick alternatives [11], and Balinese and Lombok vernacular studies document embedded carbon reductions of up to 45% through local natural material use [2].

The dismantlable joinery philosophy extends material life beyond individual buildings: when a structure is modified or retired, timber columns and beams are salvaged and reused—a circular material economy operating as a function of how the building is assembled rather than through formal recycling infrastructure. The material composition across the seven case study buildings, documented in Figure 9, makes the contemporary transition visible: the distribution of clay tile versus corrugated metal roofing and woven bamboo versus cement block walls across the sample reflects the degree to which each building has undergone material modernization. Field evidence and research on Indonesian vernacular material substitution both confirm that replacement of natural with artificial materials degrades thermal performance while increasing environmental impact [8][9]—a loss that is simultaneously technical, cultural, and ecological.



Figure 9. Material utilization matrix for the seven case study buildings: comparison of structural materials (local hardwood timber, bamboo), wall systems (woven bamboo, timber plank, cement block), roofing types (clay tile, corrugated metal), foundation types, and joinery methods, with dismantlability status for each building.

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Contemporary Challenges and Threats to Vernacular Heritage

Pelaga's traditional architecture faces a convergence of pressures that are individually manageable but collectively erosive. Material scarcity is the most immediate: premium local hardwood timber is approaching local extinction, with slow growth cycles preventing regeneration at any pace relevant to current construction demand, forcing builders toward imported lumber, cement, and metal framing that are cheaper in initial cost but thermally inappropriate and ecologically disconnected from local conditions. Knowledge loss compounds this: the intricate joinery techniques and material selection criteria that master carpenters carry are not documented and are not being transmitted, as the multi-year apprenticeship required competes unfavorably with formal sector employment among younger generations [13][14]. Modernization programs including government housing improvement schemes (bedah rumah) often apply standardized designs with cement block walls and corrugated metal roofs that perform poorly in the highland climate, replacing buildings whose thermal logic was evolved for precisely these conditions [8][9].

Cultural erosion accelerates the process: exposure to urban housing typologies leads younger generations to perceive traditional architecture as outdated, while the compound layout required by Tri Hita Karana spatial organization demands land area increasingly rationalized as underutilized [15][16]. Climate change introduces a further variable: increased precipitation intensity and shifting temperature patterns may alter the calibration of passive strategies that were developed for historical climate norms [5]. None of these pressures is unique to Pelaga—they are documented across Indonesian and global vernacular contexts [1][3]—but their simultaneous intensification here creates an urgency that distinguishes documentation as preservation from documentation as scholarship alone. The knowledge exists now; it may not in a generation.

Contemporary Relevance and Lessons for Sustainable Design

The principles embedded in Pelaga's vernacular building knowledge address core problems of contemporary sustainable design with a directness that formal sustainability frameworks often achieve only partially. Passive-first climate design—the integration of cross-ventilation, thermal mass, solar shading, and vegetation into a single spatial and material system—eliminates cooling energy demand entirely rather than merely reducing it [20][21][23]. Contemporary practice could build from this baseline using computational simulation to optimize ventilation patterns and recalibrate thermal mass properties for projected climate scenarios, translating the empirical logic of traditional builders into quantified contemporary design parameters. The promotion of local material practices and low-tech design approaches within architectural education has itself been identified as a strategy for revitalizing vernacular knowledge transmission [4].

The dismantlable joinery philosophy offers a vernacular precedent for design for disassembly that predates the concept in formal sustainability discourse and has been tested across decades of building use [12][19]. Contemporary engineered timber connections inspired by pen dan lubang principles could enable modular construction with reversible connections, supporting component reuse across multiple building cycles and reducing construction demolition waste. The community-based construction model—sophisticated building outcomes achieved through accessible hand tools, communal labor (gotong royong), and locally sourced materials without professional specialists or industrial supply chains—has renewed relevance in contexts of supply chain disruption and high construction costs [2][14]. The Tri Hita Karana spatial philosophy demonstrates that cultural values, environmental performance, and functional organization can reinforce rather than compete with each other [16][17]. The challenge is not to replicate these solutions literally but to understand the underlying local knowledge well enough to translate it into contemporary highland tropical contexts, where the principles of material appropriateness, structural flexibility, climate responsiveness, and community participation remain as relevant as they were when this building tradition was first established [1][3].

CONCLUSION

This research documents the vernacular wisdom of Pelaga Village's traditional timber and bamboo architecture, revealing a climate-responsive building system evolved over centuries of local knowledge accumulation in highland tropical microclimate. The dominant environmental finding is

that elevation—generating a 43.6% temperature differential relative to coastal areas—is the primary driver of building form, material selection, and passive strategy in this context [6]. The traditional material system, anchored by locally sourced hardwood timber for primary structure and bamboo for permeable wall panels, achieves documented service lifespans exceeding 60 years through material intelligence rather than chemical treatment. The sambungan pen dan lubang joinery system delivers simultaneous structural capacity, seismic flexibility, dismantlability, and community constructability—a multi-criteria solution realized through accumulated local technological knowledge rather than formal calculation [19]. Integrated passive strategies—anyaman bambu cross-ventilation, clay tile thermal mass, wide overhangs, compound courtyard ventilation, and vegetation buffering—maintain occupant comfort without mechanical systems across the full range of highland microclimate conditions. Three practical implications follow. First, passive design strategies calibrated to tropical highland conditions, as documented in Pelaga, can eliminate rather than merely reduce cooling energy demand—providing a tested template for contemporary highland architecture [1][3]. Second, dismantlable timber joinery systems offer a circular construction model with multi-generational proof of performance, directly applicable to contemporary design-for-disassembly goals [19]. Third, the convergence of cosmological spatial organization and passive climate logic in Tri Hita Karana compound design demonstrates that indigenous cultural frameworks and environmental performance are not competing design priorities but potentially the same priority expressed in different vocabularies [16][17]. Study limitations include reliance on secondary microclimate data rather than site-specific longitudinal monitoring, and a case study sample of seven buildings that does not capture the full range of variation across the village. Future research should prioritize quantitative thermal performance monitoring across seasons, life-cycle analysis comparing traditional and contemporary construction, and ethnographic documentation of master builders' tacit knowledge before it is lost. Pelaga's vernacular architecture is not a historical artifact—it is a functioning repository of local knowledge responding to precisely the challenges that contemporary sustainable design is attempting to solve, and its documentation is an act of preservation as much as scholarship.

REFERENCES

[1] J. M. F. Pardo, "Challenges and Current Research Trends for Vernacular Architecture in a Global World: A Literature Review," Buildings, vol. 13, no. 1, p. 162, 2023. https://doi.org/10.3390/buildings13010162

[2] R. S. Saptaningtyas, L. G. K. Puji, L. H. S. Wardi, and N. K. A. Dwijendra, "Low-Carbon Strategies in Traditional Vernacular Architecture: A Case Study of Bale Mangina in Senaru, North Lombok, Indonesia," Journal of Studies in Science and Engineering, 2025. https://doi.org/10.53898/josse2025524

[3] M. Hu, "Exploring Low-Carbon Design and Construction Techniques: Lessons from Vernacular Architecture," Climate, vol. 11, no. 8, p. 165, 2023. https://doi.org/10.3390/cli11080165

[4] K. D. Paramita and Y. A. Yatmo, "Thinking Low-Tech: Promoting Local Practices in Design Studio," Jurnal Kejuruteraan, 2023. https://doi.org/10.17576/jkukm-2023-si6(1)-10

[5] M. Zune, L. Rodrigues, and M. Gillott, "Vernacular Passive Design in Myanmar Housing for Thermal Comfort," Sustainable Cities and Society, vol. 54, p. 101992, 2020. https://doi.org/10.1016/j.scs.2019.101992

[6] H. Hermawan and J. Svajlenka, "Building Envelope and the Outdoor Microclimate Variable of Vernacular Houses: Analysis on the Environmental Elements in Tropical Coastal and Mountain Areas of Indonesia," Sustainability, vol. 14, no. 3, p. 1818, 2022. https://doi.org/10.3390/su14031818

[7] H. Hermawan and J. Svajlenka, "The Connection between Architectural Elements and Adaptive Thermal Comfort of Tropical Vernacular Houses in Mountain and Beach Locations," Energies, vol. 14, no. 21, p. 7427, 2021. https://doi.org/10.3390/en14217427

[8] A. M. Nugroho, T. Kubota, M. Alfata, F. A. Putri, and W. Iyati, "Passive Design Strategies of Vernacular Houses in the Hot-Humid Climate of Indonesia," VITRUVIO - International Journal of Architectural Technology and Sustainability, 2026. https://doi.org/10.4995/vitruvio-ijats.2026.24735

[9] A. M. Nugroho, "Passive Design Strategy in Vernacular House of Samin, Indonesia," DIMENSI Journal of Architecture and Built Environment, vol. 51, no. 1, pp. 17–27, 2024. https://doi.org/10.9744/dimensi.51.1.17-27

[10] R. Maligi, A. B, R. Paul, S. Changali, R. Muralidhara, K. Srinivasan, and R. Sundar, "The Role of Vernacular Practices in the Mitigation of Impact of Climate: Insights from the Vernacular Settlement of Guledgudda in India," ISVS e-journal, 2024. https://doi.org/10.61275/isvsej-2024-11-12-06

[11] C. Rincon, J. Montoya, and H. F. Archila, "Bamboo Construction Inspired by Vernacular Techniques for Reducing Carbon Footprint: A Life Cycle Assessment (LCA)," Sustainability, vol. 15, no. 24, p. 16893, 2023. https://doi.org/10.3390/su152416893

[12] E. Franco Rodriguez and M. Bujalance, "La Vera's Vernacular Architecture: Structural Design and Climate Protection in Timber Frame Wall Houses," Proceedings HERITAGE 2022 - International Conference on Vernacular Heritage, 2022. https://doi.org/10.4995/heritage2022.2022.14394

[13] H. Zhao, J. Fang, Z. Lin, J. Tang, S. Zhen, H. Shi, X. Hui, and Y. Liu, "Living Inheritance of Traditional Knowledge and Practical Wisdom of Severe Cold-Region Traditional Villages: A Case Study of Jinjiang Chalet Village," Sustainability, vol. 17, no. 9, p. 4225, 2025. https://doi.org/10.3390/su17094225

[14] W. Thinnakorn, W. Noonsuk, and K. Srimuang, "Cultural Identity, Local Wisdom and Sustainability of Bamboo in Forming Vernacular Architecture: A Case Study of Bang Chak and Khlong Noi Communities," Cogent Arts & Humanities, 2025. https://doi.org/10.1080/23311983.2025.2603722

[15] O. Baskaya, "Traditional and Vernacular Architecture in Bali," Journal of A Sustainable Global South, vol. 8, no. 1, 2024. https://doi.org/10.24843/jsgs.2024.v08.i01.p05

[16] A. N. Aulia and S. Veronica, "Exploring Indonesia's Vernacular Architecture: Comparison of Environment and Culture Responsiveness," Jurnal Koridor, vol. 15, no. 1, 2024. https://doi.org/10.32734/koridor.v15i1.16519

[17] I. K. Merta Wijaya and I. Warnata, "Understanding the Principles of Vernacular Architecture in Designing Environmentally Friendly Architecture," Proceedings of the 1st Warmadewa International Conference on Science, Technology and Humanity (WICSTH 2021), 2022. https://doi.org/10.4108/eai.7-9-2021.2317732

[18] L. Xiao, S. Pang, X. Wang, L. Fan, N. A. Mokhtar, and M. K. A. Mat Sulaiman, "From Parametric Design to Rural Sustainability: Integrating Timber Construction and Craft Revitalization in the IN BAMBOO Project, Sichuan, China," Journal of Asian Architecture and Building Engineering, 2025. https://doi.org/10.1080/13467581.2025.2585641

[19] K. Yudhistira, "Local Wisdom as a Sustainable Building Solution: Bamboo Incremental House Design Concept," Journal of Applied Science and Engineering, vol. 25, no. 1, 2022. https://doi.org/10.6180/jase.202202_25(1).0012

[20] A. Cojocaru and D. Isopescu, "Passive Strategies of Vernacular Architecture for Energy Efficiency," Bulletin of the Polytechnic Institute of Iasi, Construction. Architecture Section, 2021. https://doi.org/10.2478/bipca-2021-0013

[21] C. Yang and A. Misni, "Analysis of Thermal Comfort in Single-Story Courtyard Vernacular Dwellings in Rural China: Passive Design Strategies for Adapting to the Climate," Buildings, vol. 15, no. 21, p. 3964, 2025. https://doi.org/10.3390/buildings15213964

[22] G. Kaundal, P. Sharma, and I. Singh, "Climate-Resilient Traditional Architecture: A Case of Dharamshala, India," Journal of Architectural/Planning Research and Studies (JARS), vol. 22, 2025. https://doi.org/10.56261/jars.v22.272106

[23] P. Moscoso-Garcia and F. Quesada-Molina, "Analysis of Passive Strategies in Traditional Vernacular Architecture," Buildings, vol. 13, no. 8, p. 1984, 2023. https://doi.org/10.3390/buildings13081984

[24] M. Rahim, A. Munir, F. Marasabessy, and Darmawijaya, "Local Wisdom and Sustainable Features of Tidore Vernacular Architecture," Civil Engineering and Architecture, vol. 11, no. 2, pp. 201–210, 2023. https://doi.org/10.13189/cea.2023.110201

[25] S. A. Priarana and N. Rusnandar, "Vernacular Architecture of Bunisakti Village: Settlement Patterns, Traditional Houses, and Local Wisdom in the Nusantara's Perspective," Jurnal Tradisi Lisan Nusantara, vol. 5, no. 2, 2025. https://doi.org/10.51817/jtln.v5i2.1582