RUSTIC: Jurnal Arsitektur
Vol. 6, issue No. 2, July-December 2026, pp. 100~112
e-ISSN: 2775-7528, DOI: doi.org/10.32546/rustic.v6i2.3523

Grown, Not Mined: Hybrid Bamboo Construction as a Low-Carbon Alternative to Concrete and Steel in a Tropical Restaurant

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Article Info

Article history:

Received June 16, 2026
Revised July 02, 2026
Accepted July 04, 2026

Keywords:

Sustainable material;
Bamboo;
Hybrid construction;
Embodied carbon;
Vernacular commercial architecture

ABSTRACT

The construction sector is a major source of global carbon emissions, driven largely by cement, whose manufacture accounts for roughly 7–8% of worldwide CO_2. Heavy reliance on energy-intensive, non-renewable concrete and steel intensifies this burden, prompting a search for renewable structural alternatives such as bamboo: fast-growing, renewable, and an active carbon sink. This study evaluates how bamboo performs as an alternative structural material in an in-service commercial building, and how its known limitations are managed. Using a qualitative single-case design at Kampung Kecil Cinere Restaurant, Depok, data were gathered through field observation of 38 dining units (saung), visual documentation of structural details, a management interview, and a literature-based comparison with concrete and steel. The building relies on two local species used by function: black bamboo (Gigantochloa atroviolacea, "Wulung") as load-bearing columns, and rope bamboo (Gigantochloa apus, "Apus") for curved members, joined by traditional ijuk and rattan lashings. Durability, bamboo's main weakness in a hot-humid climate, is managed through a hybrid strategy: ceramic clad concrete plinths isolate columns from moisture, and a metal roof replaced the original thatch while a woven bamboo ceiling preserves the interior. The study's contribution is to reframe bamboo's feasibility as a matter of configuration: species selection, hybrid detailing, and moisture management; rather than of the raw material, offering transferable guidance for low carbon tropical commercial architecture; it did not include load testing or quantitative life cycle carbon assessment.

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1. INTRODUCTION

The intensification of human activity since the mid-twentieth century has accelerated the accumulation of atmospheric greenhouse gases and, with it, global warming [1]. The built environment is deeply implicated in this trend. Conventional structural materials, principally concrete and steel, are non-renewable resources whose extraction, processing, and assembly are highly energy intensive, so that their continued, large scale use both depletes finite mineral reserves and adds substantially to carbon emissions [2], [3]. Cement, the binder in concrete, is the single most consequential case: its manufacture accounts for roughly 7–8% of global CO_2 emissions, on the order of three times the emissions of the entire commercial aviation industry, because heating limestone clinker releases CO_2 chemically as well as through fuel combustion [4]. With the Global Cement and Concrete Association reporting on the order of fourteen billion cubic metres of concrete cast each year, the scale of this dependence is itself the problem [4].

This pressure has pushed architects toward renewable, lower-impact materials, and bamboo recurs as a leading candidate [5], [6]. Several properties explain its appeal. Bamboo matures in three to five years rather than the decades required by timber, allowing repeated harvest from the same clump and making it genuinely renewable even at volume [7], [8]. As a living stand it is an effective carbon sink, on the order of twelve tonnes of CO_2 sequestered per hectare per year during growth [9], and its extensive root system stabilises soil and conserves water, making it valuable for reforestation and land rehabilitation [10]. Mechanically, bamboo combines a high strength-to-weight ratio with flexibility, and life-cycle studies generally credit it with a markedly lower Global Warming Potential than steel or concrete [11], [12]. Yet wider adoption in modern construction still depends on resolving practical pre-conditions: material standardisation, reliable connection systems, durability treatment, and clear regulation [7].

It is precisely on these practical pre-conditions that the gap in knowledge lies. Much of the Indonesian literature establishes bamboo's ecological promise and its laboratory mechanical properties, but comparatively little examines how an actual, occupied commercial building resolves the material's well-known weaknesses, its susceptibility to moisture, fungi, and powder-post beetles, and the difficulty of detailing joints in a member that is strong in tension but weak in shear [13], [14]. This is the problem the study addresses: whether, and how, bamboo can serve as a durable primary structure in an occupied tropical commercial building rather than in laboratory or rural conditions alone. A working restaurant that has used bamboo as its primary structure for several years offers a rare opportunity to read these resolutions directly: which species are chosen for which task, how joints are made, how the structure is kept dry, and what has had to change over time.

This study takes that opportunity through a single case, the Kampung Kecil Cinere Restaurant, a semi-open, naturally themed eating place in a dense peri-urban buffer zone immediately south of Jakarta. The research is guided by two questions: (1) How does bamboo function as an alternative to conventional materials in the structure of this building, and through what configuration of species, jointing, and moisture management is it made durable? (2) What are the comparative advantages and limitations of bamboo relative to concrete and steel for this building type, as evidenced by the case and the literature? The objective is to produce an evidence-based account of in-service bamboo construction: its technical strengths, its environmental rationale, and the adaptive strategies that close the gap between bamboo's promise and its practical durability; and from it to derive transferable design guidance for low-carbon commercial architecture in the humid tropics. The contribution is twofold: empirically, the study links species-by-function selection and hybrid detailing to observed in-service performance in a building rarely documented in this depth; conceptually, it reframes bamboo's feasibility as a property of *configuration* (material, detail, and microclimate together) rather than of the raw material alone.

1.1. Literature Review

1.1.1. Sustainable Architecture and the Carbon Logic of Material Choice

Sustainable architecture is the design approach that seeks to minimise a building's negative environmental impact through moderation and efficiency in the use of material, energy, and space, without lowering occupants' quality of life [15]. In the face of escalating climate pressure, the construction sector is expected to shift from energy-profligate conventional practice toward more ecologically responsible methods, integrating passive design (daylight optimisation, cross-ventilation) with materially responsible specification [1], [7]. Two analytical lenses discipline this ambition. Life Cycle Assessment (LCA) evaluates environmental impact across all stages of a material's life, from raw-material extraction to end-of-life; under LCA, bio-based materials such as bamboo can reduce greenhouse-gas emissions substantially because of the carbon captured during growth, yielding a lower carbon footprint than cement and concrete [12]. The complementary lens, the strength-of-materials tradition, ensures that ecological gains are not bought at the cost of safety: parameters such as bending, tensile, and compressive strength confirm whether an alternative material can in fact carry the loads imposed on columns and beams [14]. This study is positioned at the intersection of the two, treating bamboo at Kampung Kecil Cinere not as a nostalgic aesthetic choice but as an environmentally measurable and technically testable proposition.

1.1.2. Green Materials and Embodied Carbon

A green material is one whose procurement, use, and disposal carry a low ecological footprint and pose no health hazard, the aim being to reduce the *embodied energy* locked into a material by intensive extraction and manufacture [15]. Embodied (as opposed to operational) carbon is the share of a building's emissions attributable to its materials; because cement and steel are produced at high temperature, they carry high embodied carbon, and substituting bio-based materials such as bamboo is an effective mitigation strategy that can sharply lower emissions per square metre relative to brick or concrete walls [11], [4]. Bamboo qualifies as one of the most promising green materials in Indonesia by virtue of its renewability and abundance, and being a poor heat store, it tends to produce a cooler indoor microclimate than concrete or metal [6], [7].

1.1.3. Bamboo: Botany, Morphology, and Mechanical Behaviour

Bamboo is a woody member of the grass family (Poaceae, subfamily Bambusoideae), distinguished by a hollow, segmented culm and exceptionally fast growth [16], [17]. Worldwide there are more than 1,640 species across roughly 100 genera; Indonesia hosts an estimated 176 species, about 12% of the global total, of which only a handful are economically significant for construction [18], [19]. Morphologically, the culm is a cylinder partitioned by a diaphragm at each node, which stiffens it against buckling; fibres run parallel to the axis and are denser toward the outer skin, giving the surface hardness and the member as a whole an efficient strength-to-weight ratio and good flexibility under dynamic load [14], [15].

Mechanically, bamboo is best harvested at biological maturity (about 3–5 years), when fibre strength peaks [20]. It is exceptionally strong in tension, often called “natural steel,” with some specimens exceeding the yield stress of medium-grade steel, and certain species (notably Petung) show high compressive strength parallel to the grain, qualifying them as primary structural elements [21], [22]. Its critical weakness is low shear strength, which makes the design of connections the decisive factor in structural safety [14]. Ecologically, bamboo releases up to 35% more oxygen than comparable trees and, as noted, sequesters carbon vigorously while growing [7]. Its principal vulnerability in service is biological: a high starch content invites powder-post beetles and fungi, so that untreated bamboo may last only 2–5 years, making preservation a precondition for durability [13], [22].

Among Indonesian construction species, six recur in the literature; Table 1 summarises those most relevant to this case.

Table 1. Indonesian bamboo species commonly used in construction (source: compiled by the authors from Kusuma Bhudi & Studi Arsitektur (2024) and species references cited therein)

Species (local name)	Height/Diameter	Distinguishing Features	Typical Structure Use
Wulung — *Gigantochloa atroviolacea*	≈15 m / 6–8 cm	Deep black culm; strong visual character	Roof frames; exposed columns where aesthetics matter
Legi — *Gigantochloa atter*	≈16 m / 6–8 cm	Similar dimensions to Wulung	Structural frames, wall frames, fencing
Petung — *Dendrocalamus asper*	≈20 m / 20–25 cm	Massive section; green culm with lichen flecks	Heavy structure: bridges, houses, primary columns
Ampel — *Bambusa vulgaris*	≈20 m / ≤10 cm	Yellow/ivory sub-species used ornamentally	Posts and uprights; urban ornamental planting
Gombong — *Gigantochloa pseudoarundinacea*	≤15 m / 2–10 cm	Green culm with yellow striping	General framing
Apus — *Gigantochloa apus*	≈22 m / 4–15 cm	Straight green culm; flexible	Bent/curved members; lashings and ties

1.1.4. Conventional Materials: Concrete and Steel

Conventional materials are those long established by industry convention: cement, sand, brick, and, pre-eminently, concrete and steel [23], [24]. Concrete, a hydrated mixture of Portland cement, aggregate, and water, offers massive compressive strength and formability and reaches design strength at about 28 days; steel, an iron carbon alloy, offers superior tensile strength, ductility, and predictable behaviour under load [25], [26]. Reinforced concrete, combining the two, has been the backbone of urban infrastructure for over a century. From a sustainability standpoint, however, both are non-renewable: their feedstocks: limestone, silica, iron ore; are mined, slowly exhausting finite reserves [7]. The environmental cost is concentrated in cement: globally about 7–8% of CO_2 emissions, sourced both from clinker calcination and from the energy intensity of production, with extraction adding land degradation and ecosystem loss [4], [15]. These figures supply the comparative baseline against which bamboo is assessed in Results and Discussion section.

1.1.5. Naturally Themed Restaurants and Vernacular Commercial Architecture

Naturally themed restaurants integrate ecological principles and natural elements into both design and the visitor experience, pursuing a synergy between dining and landscape that goes beyond visual styling to the substantive use of natural components [27]. This reflects an organic-architecture philosophy of harmony between the built and the natural [28]. In commercial buildings, modern vernacular approaches increasingly fold local materials (bamboo, timber, natural stone) into contemporary design to build a visual and psychological connection with nature, in line with green architecture principles [29]. For restaurants on a "village" (*kampung*) or rural theme in particular, bamboo offers a double advantage: a warm, unique texture that factory products cannot imitate, and thermal comfort in semi-open settings because the material does not store heat, well suited to the tropical open air typology [30].

1.1.5.1. Design Criteria for Bamboo Structure in Public Buildings

As a public building, a restaurant demands a high standard of structural safety under dynamic live loads. Following Gaffar Bakri [21], bamboo structures in public use should satisfy: (i) *structural safety* under combined dead and dynamic live loads; (ii) *super-structure capacity*, with tensile and compressive strength sufficient for columns and roof frames to substitute for steel or concrete over wide spans; (iii) *appropriate jointing*, since the joint is the weakest point, using sound traditional or mechanical connections (bolts, pegs) to distribute load stably; (iv) *weather protection* against UV and direct rain through wide eaves or coatings, to match the durability of conventional materials; (v) *function-led species selection*: large, thick-walled species such as Petung for primary columns, Wulung or black bamboo where exposed aesthetics matter; and (vi) *integration of structure and aesthetics*, exposing structure as an experiential feature rather than concealing it.

1.1.6. Precedents: Commercial and Institutional Bamboo Buildings

Two precedents bracket the range of contemporary bamboo practice relevant to this case. **Guha**, by Realrich Sjarief (Realrich Architecture Workshop), is a renovation and extension of a residence and architecture studio set within a dense urban neighbourhood. Its significance lies in demonstrating that bamboo can coexist harmoniously with concrete, steel, and red brick in a hybrid structural system, and that—through neat, inventive joinery using bolts, pegs, and modern ties, bamboo can be worked to factory-like precision in a metropolitan context. Guha also exploits bamboo's thermal behaviour, using it to admit natural ventilation and passive light and so reduce reliance on mechanical systems. **Bamboo U/Kul Kul Farm** in Bali, founded within the Green School ecosystem, pairs traditional bamboo craft with modern engineering: bolted steel connections, precise 1:10 structural models, and *bundled-bamboo* techniques that achieve stable organic curves, all preceded by standardised borax preservation to secure long-term durability. Together the precedents establish that bamboo is neither a "second-class" nor a merely rural material when species selection, preservation, and connection design are handled rigorously, the same triad this study reads at Kampung Kecil Cinere.

2. METHOD

2.1. Research Design

The study adopts a qualitative single-case design, appropriate for an in-depth, contextual reading of a phenomenon in its natural setting rather than for statistical generalisation [31], [32]. The case study structures the choice of subject, site, and data techniques and supports systematic interpretation toward valid conclusions [32]. The design combines three complementary strands: field observation, visual documentation, and a management interview; triangulated against a literature-based material comparison, so that what is built, what is reported, and what is known from prior research can be read together.

2.2. Case and Setting

The case is Kampung Kecil Cinere Restaurant, at Jl. Telaga Warna, RT.07/RW.05, Pangkalan Jati, Cinere District, Depok, West Java (approx. 6°19′23″S, 106°46′53″E), on a 4,392 m² site. Cinere is an active buffer zone immediately south of Jakarta, marked by dense, rapidly growing urban and commercial development; the restaurant's use of natural materials there represents a deliberate counter-move to the concrete-dominated peri-urban norm. The building is a semi-open, naturally themed restaurant of about 120-person capacity, organised as a themed "village" of named lanes and units, with three dining typologies: a central non-*saung* area, 16 land-based seated *saung* (non-pond), and 22 seated *saung* over a fish pond.

2.3. Data Collection

Fieldwork ran over four months (October 2025–January 2026), with two scheduled observation visits (December 2025 and January 2026; Table 2). Three primary techniques and one secondary technique were used.

2.3.1. Field Observation

Systematic direct observation and recording of the physical object [33]. All 38 *saung* (16 non-pond, 22 over-pond) were mapped for species use, member function, connection type, and moisture-management detailing. Particular attention was paid to where Wulung versus Apus was used, and to the ceramic-clad concrete plinths beneath over-pond seating. Findings were recorded as schematic diagrams and an existing-condition plan.

2.3.2. Visual Documentation

Detailed photographic recording of structural and connection details, lashed (*ijuk*, rattan) and any mechanical joints, and of the roof system's evolution from thatch (*ijuk*/*ilalang*) to metal, including the retained woven-bamboo ceiling beneath the new roof [34]. Photographs serve as authentic evidence of conditions and details that narrative alone cannot convey.

2.3.3. Semi-structured Interview

An in-depth interview with the restaurant's supervisor/management [35], covering operations since 2023 and focused on three themes: the rationale for choosing bamboo in this urban setting; the technical problem of thatch weathering that prompted the switch to metal roofing; and experience of biological degradation (pest/fungal attack) and its maintenance implications. Participation was voluntary; the interviewee was informed of the study's purpose and consented, and no personally identifying information is reported.

2.3.4. Literature Study (secondary)

A structured review of journals, texts, and reports on the physical-mechanical properties of bamboo, sustainable-architecture theory, and carbon-footprint parameters, providing the comparative benchmarks used in analysis [36].

Table 2. Observation schedule (source: authors)

Visit	Period	Focus
Observation 1	December 2025	Building layout and zoning; species-by-function mapping across all 38 *saung*; column and beam survey
Observation 2	January 2026	Connection details; roof and ceiling system; moisture-management detailing (*umpak*, pond-edge seating); management interview

2.4. Data Analysis

Analysis proceeded in three steps. First, observation and interview data were related to sustainability criteria drawn from the literature. Second, a *comparative analysis* set bamboo against conventional materials (concrete and steel) on technical and environmental parameters, drawing the quantitative benchmarks from prior studies rather than from on-site testing. Third, the strands were combined in a *synthesis* that assesses the feasibility of bamboo as a sustainable substitute and distils transferable design guidance. Manual sketching (used during fieldwork to dissect the structural and connection systems and to trace air-flow and circulation) and photographic documentation supported interpretation. Triangulation across observation, interview, and literature was used to limit the subjectivity of any single source.

2.5. Limitations

Four boundaries frame the claims that follow. First, the study is observation- and perception-based: it did not include in-situ structural load testing, so statements about structural adequacy rest on *observed in-service performance* combined with mechanical properties reported in the literature, not on measurements taken at the site. Second, no quantitative life-cycle assessment or site carbon accounting was performed; the carbon and emissions figures cited (e.g., ~12 t CO_2/ha/yr sequestration; cement's 7–8% share of global CO_2) are literature values used as comparative indicators, and the sequestration figure refers to living bamboo stands during growth rather than to carbon dynamics of the harvested members in this building. Third, as a single case the findings are analytically, not statistically, generalisable. Fourth, the durability assessment reflects the building's history to date as reported by management and observed on site, not a controlled longitudinal measurement. These limitations point to the value of pairing this reading with load testing and quantitative LCA in future work.

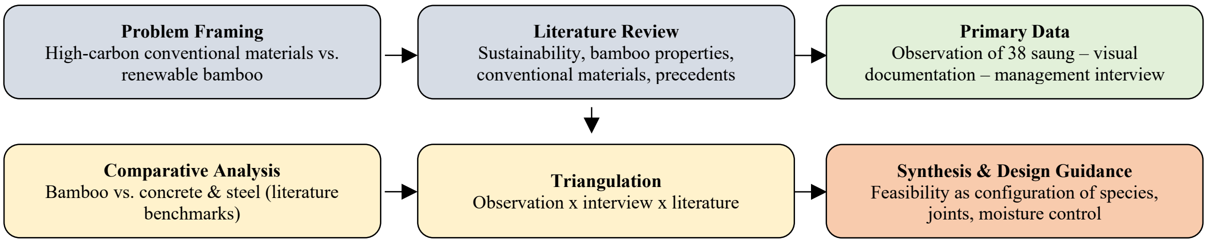


Figure 1. Research flow (source: authors, 2026)

3. RESULTS AND DISCUSSION

3.1. Site and Building Context

Depok comprises eleven districts; Cinere lies on the city's northern edge, bordering South Jakarta, and functions as an active buffer zone for the capital. In this densely built, commercially intensifying setting, the carbon cost of conventional concrete-and-cement construction is a pressing concern, and Kampung Kecil Cinere reads as a deliberate demonstration of natural-material building amid that norm. The 4,392 m² site is organised along a north-running axis with clearly zoned circulation: a one-way vehicle system (entry and exit), separated car and motorcycle parking, a main pedestrian entrance leading to the cashier and a bamboo architecture focal point, a kitchen placed to the side for service efficiency, and edge-placed support facilities (prayer room, toilets, open garden). The three dining typologies: central non-*saung* seating, 16 land *saung*, and 22 over-pond *saung*; are arranged around a large fish pond that doubles as an aesthetic centrepiece and a passive microclimatic device, cooling the semi-open dining areas. The vernacular modern framing: local bamboo, water, and a themed "village" of named lanes; builds the visual and psychological connection to nature that the typology depends on.

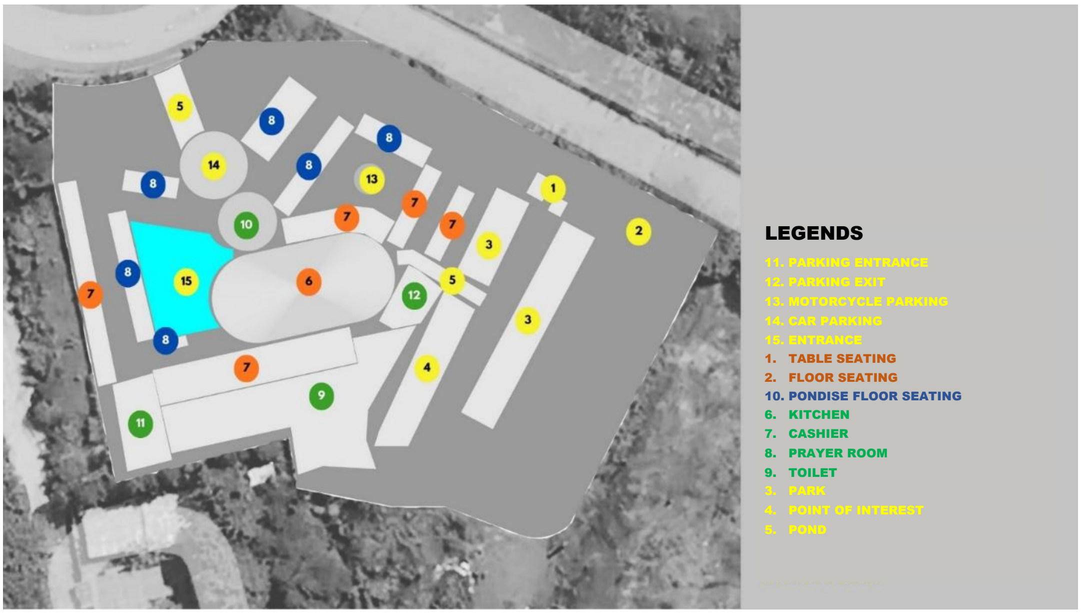


Figure 2. Site location and zoning of Kampung Kecil Cinere (Source: Google Earth, processed by the authors, 2026)

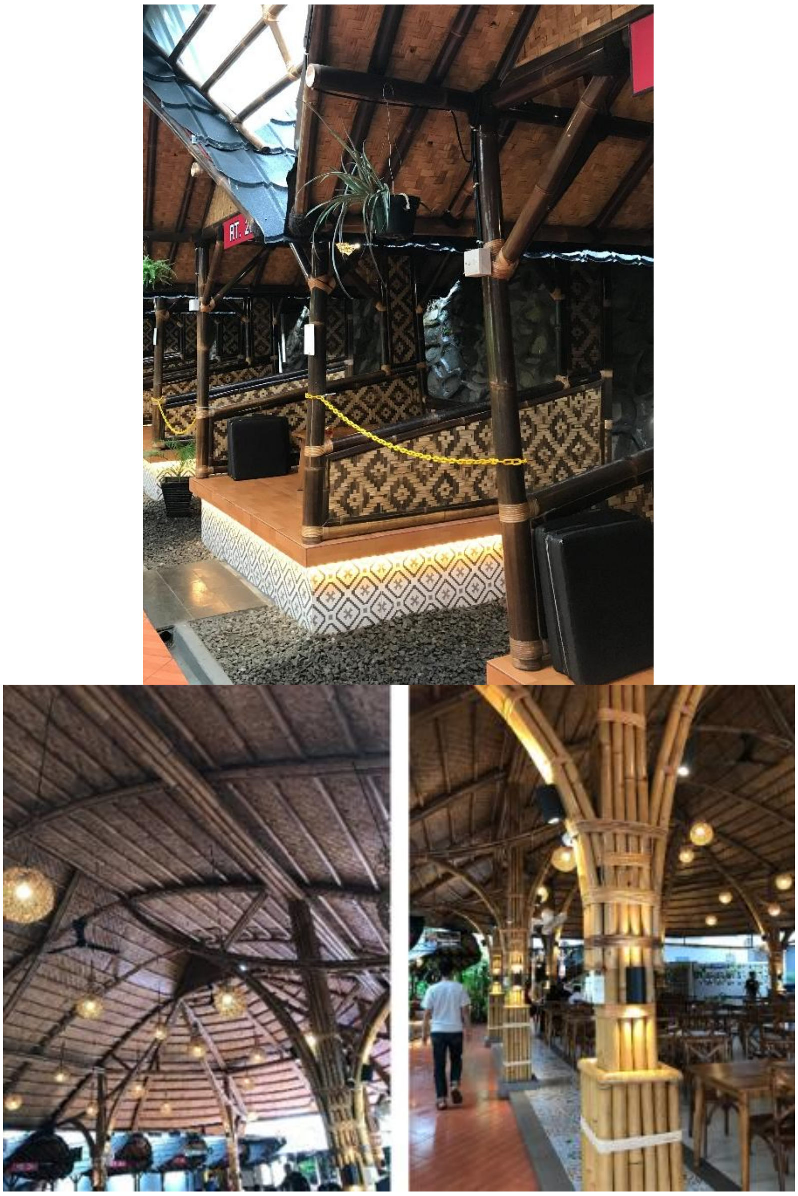
3.2. Structural Application of Bamboo: Species by Function

The building's primary structure relies entirely on bamboo for columns and beams, with species assigned by mechanical character and intended effect:

- **Black bamboo (Wulung, *Gigantochloa atroviolacea*)** serves as the main columns in the seated (*lesehan*) areas, where its deep black culm provides a strong visual identity and the section gives a robust, legible structural presence.

- **Rope bamboo (Apus, *Gigantochloa apus*)** is used in the non-seated dining area, where its flexibility allows members to be formed by bending—producing the curved geometry that would be awkward and costly in rigid conventional materials.

This division illustrates the function-led selection principle from Section 1.1.5.1. in practice: a stiff, visually dominant species for vertical load paths, a flexible species for shaped members. It is worth noting a point of nuance against the general literature, which often nominates the large-section Petung for primary columns [22]. At Kampung Kecil Cinere the primary columns are Wulung rather than Petung, a choice that trades Petung's greater section for Wulung's aesthetic value and adequacy at this building's spans and loads. The case therefore confirms the *principle* of matching species to task while showing that, for a single storey, wide-roof commercial pavilion, a medium section species can be sufficient when paired with appropriate jointing and moisture control. (Petung remains the literature's recommendation for heavier or longer-span primary structure and is not used here).



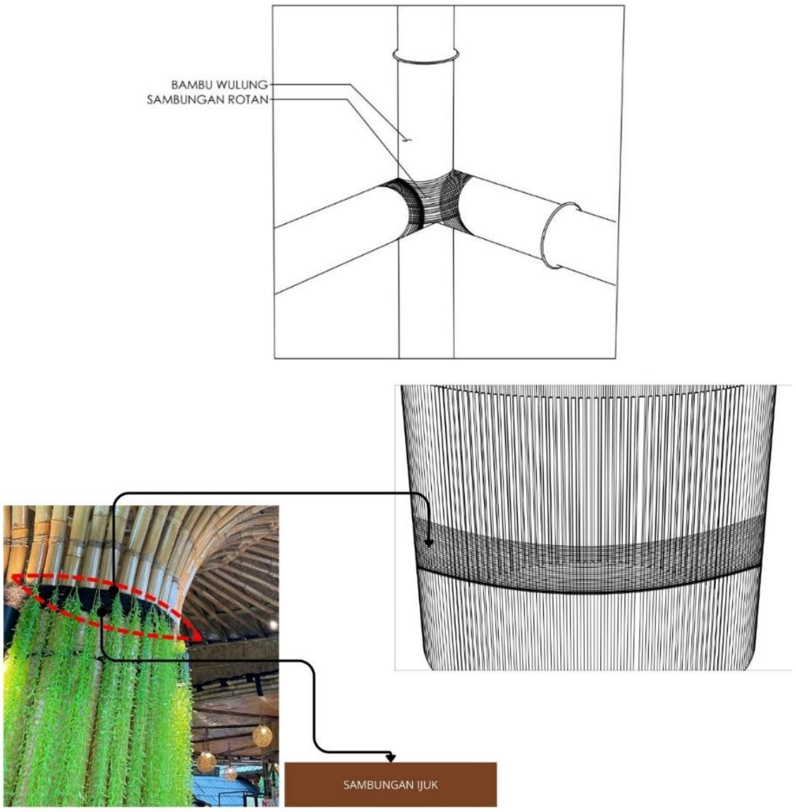
Wulung columns in a seated saung (Above)

Bundled/curved Apus structure in the non-seated area (Below)

Figure 3. Species by function use of bamboo: Wulung columns and bent Apus members (Source: authors' documentation, 2026)

3.3. Connections

Members are joined with traditional lashings of *ijuk* (black palm fibre) and rattan rather than mechanical fasteners. Because bamboo's structural Achilles' heel is shear at the connection [14], the joint detail is the critical determinant of safety; here, lashed joints allow a degree of flexible load distribution consistent with the dynamic behaviour of a natural material and with the building's low-rise, lightweight roof. The reliance on lashings rather than bolts also distinguishes this case from the precedents (Guha and Bamboo U), which adopt bolted/mechanical connections for greater span and predictability. The trade-off is clear: traditional lashings reinforce the vernacular character and are well matched to modest spans, but mechanical connections, identified in both precedents and in the public-building criteria [21], would be the route to larger spans, higher live loads, or multi-storey use. This is a concrete design lever for practitioners scaling the approach.



(a) Rattan-lashed joint detail

(b) Ijuk-lashed connection

Figure 4. Traditional lashed connections in *ijuk* and rattan (Source: authors' documentation, 2026)

3.4. Durability and the Hybrid Strategy

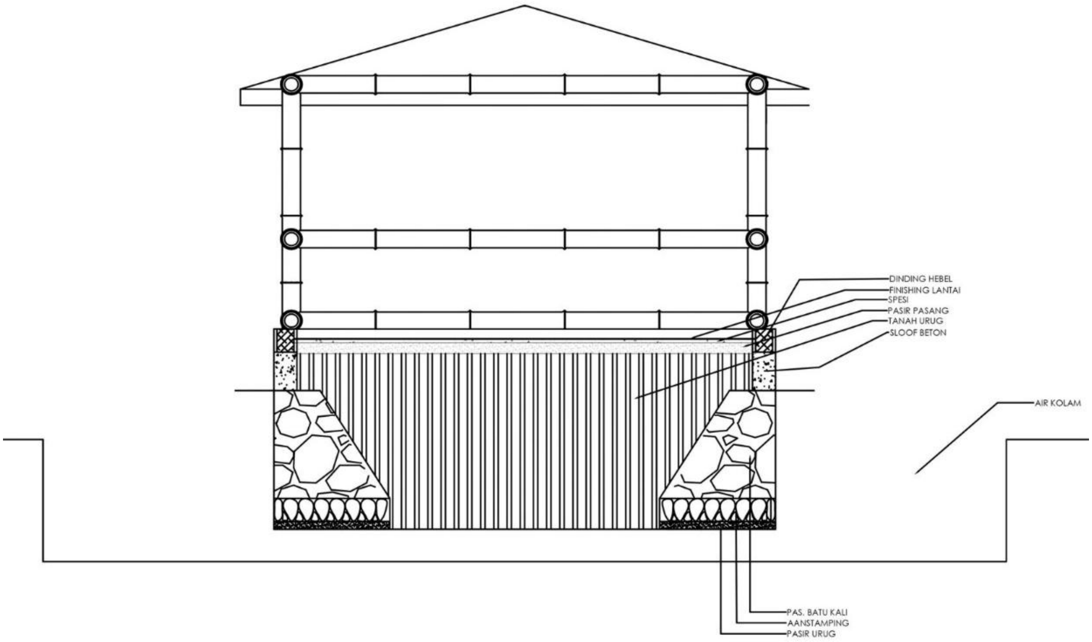
The most instructive findings concern durability, the gap between bamboo's ecological promise and its service life in a hot-humid climate. The restaurant manages this gap not by abandoning bamboo but by combining it selectively with conventional materials, a hybrid strategy with three observed moves:

- **Moisture isolation by concrete plinth (*umpak*).** Over-pond *saung* seating sits on ceramic-clad concrete plinths, preventing bamboo columns and the seating base from direct contact with pond water and ground moisture, and so cutting off the principal pathway to rot and biological degradation. This is the single most important durability device in the building: it preserves the visible bamboo structure while delegating the wet, vulnerable interface to an inert material.
- **Roof evolution from thatch to metal.** The roof was originally thatch (*ijuk*/*ilalang*) but, after about two years of weathering, was replaced with metal sheeting for weather resistance and longer service life. Crucially, a woven-bamboo ceiling was retained beneath the metal, preserving the warm interior character and thermal feel when seen from within the dining area. This is a candid, real-world record of adaptive maintenance rather than an idealised design narrative.

- **Permanent wet-zone construction.** The cashier area uses permanent ceramic-clad walls, giving a functional, easily cleaned, durable surface that contrasts deliberately with the bamboo-dominated dining areas.

Read together, these moves embody the public-building criterion of *weather protection* (Section 1.1.5.1.) and align with the hybrid logic of the Guha precedent, where bamboo is combined structurally with concrete, brick, and steel for optimal performance. The lesson is general: in the humid tropics, exposed structural bamboo is best treated as part of a system in which inert materials guard the moisture-critical interfaces (footings, wet zones, the weather face of the roof) while bamboo carries load and defines character. Notably, the case relies on physical isolation rather than chemical preservation (e.g., the borax treatment standardised at Bamboo U); combining the two would be a logical durability upgrade, and the absence of systematic chemical preservation is a maintenance risk the management itself associates with periodic pest concerns.

(a) Metal roof over a Wulung frame with retained woven-bamboo ceiling
(b) Over-pond saung on a ceramic clad concrete plinth



(c) Section through an over-pond saung: bamboo isolated from pond water by a concrete/stone footing (Indonesian labels retained)

Figure 5. Hybrid moisture-management detailing at the roof and pond edge
(source: authors' documentation, 2026)

3.5. Comparative Parameters: Bamboo versus Conventional Materials

Table 3 consolidates the comparison drawn from the case and the literature. The values for strength, carbon, and durability are literature-based comparative indicators (cited), not site measurements; they are presented to position bamboo relative to the conventional baseline established in Section 1.1.4., not to certify the structural capacity of this specific building.

Table 3. Comparative parameters: bamboo versus conventional materials (concrete, steel) (source: authors, from the cited literature and field observation. Numerical values are indicative comparative benchmarks, not measurements of the case building)

Parameter	Bamboo	Concrete/Steel	Source Basis
Renewability	Renewable; harvest cycle 3–5 years; repeated harvest from one clump	Non-renewable; mined feedstock (limestone, silica, iron ore)	[7]; [20]
Tensile strength	Very high ("natural steel"); some specimens exceed mild-steel yield	Steel high in tension; concrete weak in tension (needs reinforcement)	[21]
Compressive strength	Good parallel to grain (esp. Petung)	Concrete very high in compression	[22]
Critical weakness	Low shear → joints govern; biological decay if untreated	High self-weight; brittle failure (concrete); corrosion (steel)	[14]; [13]
Embodied carbon/GWP	Low; lower GWP than steel/concrete; potential net-negative over life cycle when sequestration is counted	High; cement ≈ 7–8% of global CO_2	[11]; [12]; [4]
Carbon Sequestraction (growth)	≈ 12 t CO_2 / ha / yr by living stands; ~35% more O_2 than comparable trees	None	[9]; [7]
Thermal behaviour	Poor heat store → cooler microclimate; suits semi-open tropical use	High heat capacity; stores/re-radiates heat	[7]; [30]
Durability (untreated)	2–5 years untreated; greatly extended by preservation + moisture isolation	Decades; established standards and predictability	[13]; case observation
Operating-cost implication	Semi-open bamboo design avoids mechanical cooling (no AC) in this case	Sealed concrete/steel buildings typically need active cooling	Case observation

3.6. Interpreting the Environmental Case Honestly

Bamboo's environmental advantage in this comparison is real but must be stated precisely. The ~12 t CO_2/ha/yr figure describes sequestration by *living* bamboo stands during growth; it is not a property of the harvested culms in this building, which instead *store* previously captured carbon and carry a low embodied carbon relative to cement and steel [12]. [11]. The often cited "negative carbon footprint" is therefore best understood as a life cycle potential—plausible when low embodied carbon, biogenic carbon storage, durable service life, and responsible end of life are all achieve, rather than an automatic attribute of any bamboo building. Likewise, cement's 7–8% share of global CO_2 is the macro-scale justification for substitution, not a measured saving at this site. Within these bounds, the case still makes a clear environmental argument: by substituting a renewable, low-embodied-carbon, locally sourced material for concrete and steel in its primary structure, and by avoiding mechanical cooling through a semi-open, heat shedding design, Kampung Kecil Cinere reduces both embodied and operational carbon relative to a conventional equivalent, while the surrounding planted bamboo contributes sequestration at the landscape scale.

3.7. Synthesis: Bamboo Feasibility as a Matter of Configuration

The central finding is that bamboo's success here is a property of *configuration* rather than of the raw material. Three design decisions, working together, convert bamboo's theoretical promise into in-service reality: (1) *species by function*: Wulung for visible load bearing columns, Apus for bent members; (2) *connection logic* matched to scale: traditional lashings for this low rise, modest-span pavilion, with mechanical joints the identified route to larger spans; and (3) *moisture management through hybridity*: ceramic-clad concrete plinths, a metal weather-roof over a retained bamboo ceiling, and permanent construction in wet zones. This configuration directly answers the two research questions: bamboo functions as a credible primary structural alternative in this building type (RQ1), and its comparative profile: renewable, low carbon, thermally benign, but shear limited and decay-prone unless detailed and isolated; defines both why it is attractive and where it must be supported (RQ2). The result reframes the standard "bamboo versus concrete" debate as a question of how to combine them: bamboo for load and character, conventional materials for the moisture critical and high demand interfaces.

4. CONCLUSION

This study examined how bamboo performs as an alternative to conventional materials in an occupied tropical restaurant, using a qualitative single-case design at Kampung Kecil Cinere, Depok. The evidence shows that bamboo can serve as a building's primary structure when it is configured correctly: black bamboo (Wulung) carries the load and defines the architectural character of the seated areas, rope bamboo (Apus) supplies the curved geometry of the non-seated area, and traditional *ijuk* and rattan lashings connect members at a scale suited to a low rise pavilion. The material's decisive weaknesses, shear at the joint and biological decay in a humid climate, are managed through a hybrid strategy in which inert materials guard the vulnerable interfaces: ceramic-clad concrete plinths isolate columns from water, and a metal roof installed after two years of thatch weathering protects the structure while a woven bamboo ceiling preserves the interior.

Environmentally, bamboo offers a renewable, low embodied carbon, thermally benign alternative to concrete and steel, with sequestration benefits at the landscape scale, provided that carbon claims are read as life-cycle potentials rather than automatic attributes. The transferable lesson for low carbon commercial architecture in the humid tropics is to treat bamboo not as a substitute material to be used in isolation but as the load bearing and expressive core of a hybrid system, with species, joints, and moisture detailing designed together. For practice, two recommendations follow directly: place every moisture exposed bamboo member on a permanent plinth or concrete footing, and add systematic chemical preservation (e.g., borax) and periodic protective coating to the physical isolation strategy already in use. For research, the priorities are in-situ load testing of the as-built connections and a quantitative life cycle carbon assessment, together with standardised guidance for mechanical joints in curved bamboo, so that the configuration demonstrated here can be scaled with confidence.

ACKNOWLEDGEMENTS

The authors thank the management and staff of Kampung Kecil Cinere Restaurant for access and for generously sharing the building's history, and the Architecture Study Program, Faculty of Engineering and Design, ITB Ahmad Dahlan, for academic support.

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