International Journal of Design & Nature and Ecodynamics
Vol. 21, No. 10, October, 2026, pp. 2957-2968
Journal homepage: http://iieta.org/journals/ijdne

Engineering Assessment of Contemporary Balinese Bamboo Buildings: Passive Environmental Performance, Material Carbon, and an Integrated Design Model

I Wayan Wirya Sastrawan[1,2], Ngakan Ketut Acwin Dwijendra[1*], I. Made Adhika[1], Ni Made Yudantini[1]

[1] Faculty of Engineering, Udayana University, Denpasar 80232, Indonesia
[2] Faculty of Engineering and Planning, Warmadewa University, Denpasar 80239, Indonesia

Corresponding Author Email: acwin@unud.ac.id

Copyright: ©2026 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).

https://doi.org/10.18280/ijdne.211009

Received: 11 August 2026
Revised: 9 October 2026
Accepted: 21 October 2026
Available online: 31 October 2026

Keywords:
bamboo architecture, building performance, evidence audit, integrated design, material carbon, passive design

ABSTRACT

Renewable materials and vernacular resemblance do not independently establish environmental performance. This study develops an engineering-oriented secondary assessment of four Balinese bamboo projects and converts the Integrated Balinese Bamboo Sustainable Architecture Model (IBBSAM) into a minimum decision workflow. Source-reported quantities, arithmetic reconstructions, conditional scenarios, and proposed mechanisms are explicitly separated. The source-reported simulated-zone areas provide a consistent accounting basis, but unknown energy end-use coverage and service assumptions prevent efficiency ranking. Reported energy intensities are 32–55 kWh m^{-2} y^{-1}; reconstructed annual totals are 9,600–15,960 kWh y^{-1}. The listed material quantities yield partial carbon totals of 1,649–2,215 kg CO_2e. Concrete and steel account for 77.2–93.7% under the source factors, whose production boundaries, geographical representativeness, and biogenic-carbon treatment remain unverified. Rounding-aware checks establish arithmetic compatibility between predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD), but do not demonstrate actual thermal comfort. Inconsistent principal-component and regression summaries remain unverified and cannot supply model weights. Claim-specific decision gates halt unsupported ranking, require evidence to resolve cross-domain disagreement, and retain structural safety as non-compensatory. The contribution is an auditable decision protocol and verification agenda, not new simulation, whole-building life-cycle assessment, or causal validation.

1. INTRODUCTION

Bamboo architecture connects material renewability, cultural continuity, and environmental performance; however, these dimensions should be assessed independently rather than assumed to be mutually indicative. Renewable construction does not prove low operational energy, thermal comfort, structural safety, or low whole-building embodied carbon. Reviews identify opportunities alongside requirements for treatment, specification, workmanship, and maintenance [1, 2]. Mechanical research further distinguishes engineered products from whole culms rather than treating bamboo as a uniform material [3].

Energy research examines uncertainty and scenario optimization [4]; life-cycle research requires consistent product boundaries [5]. Neither supplies missing project inputs. The question is whether each claim follows from traceable quantities, compatible definitions and adequate validation.

Building-performance evaluation provides the methodological context. The Post-occupancy Review of Buildings and their Engineering (PROBE) initiative combined technical investigations and occupant feedback to evaluate buildings in use [6]. Performance-gap research distinguishes discrepancies between predicted and measured performance [7]. Model calibration involves comparing simulated building performance with measured data and adjusting model parameters to improve agreement between predictions and observations [8]. Furthermore, recent critical research highlights the need to examine causal explanations carefully and avoid conclusions that are not supported by empirical evidence [9]. Together, these studies motivate evidence checks before comparison. This article is a secondary evidence audit, not a new post-occupancy evaluation or measured performance-gap study.

Vernacular knowledge supplies requirements, not engineering verification [10]. Balinese hierarchy [11] and Indonesian climate-responsive housing research [12] provide context. Cultural meaning, configuration and environmental effect remain distinct: communal space raises ventilation, spanning, privacy and rain-protection questions without proving ritual authenticity or energy savings.

The research gap is how to turn mixed-quality summaries into admissible engineering decisions. This audit asks which quantities are traceable, which definition choices change interpretation, and which missing inputs must stop ranking, comfort claims or weighting. Reproducible calculations and Integrated Balinese Bamboo Sustainable Architecture Model

(IBBSAM) decision gates expose verification priorities rather than identify the best building.

2. MATERIALS AND METHODS

2.1 Research record, case selection, and analytical boundaries

The empirical basis for this secondary assessment is the unpublished 2026 doctoral dissertation manuscript by Sastrawan [13]. Source inputs are grouped by subject: energy, thermal and daylight records (Tables 5.79–5.84 in dissertation [13]); material-carbon and area-boundary records (Tables 5.91–5.97 in dissertation [13]); perception summaries (Tables 5.73–5.76 in dissertation [13]); and statistical reporting (Tables 5.63–5.71 and Section 5 in dissertation [13]). Figures 3.1 and 7.1 in dissertation [13] inform the conceptual synthesis, not evidence of implemented model validation. Supplement S1 maps the source locations to the article. The source record is not a publicly archived, independently peer-reviewed dataset. No new field campaign, respondent recruitment or solver run is attributed to this revision.

The four purposively selected projects are ZIN Canggu Resort & Villas (ZC), Bali Countryside Sidemen (BC), BaleBio (BB), and Cinnamon Villa (CV). Their contrasting functions, openness, and material systems are analytically useful because they expose how denominator and service definitions affect interpretation [14]. They do not form a matched efficiency sample. Table 1 distinguishes source-documented descriptions (E1) from source-reported model areas (E2). Penglipuran remains a cultural reference, not a technical control; a differently named Mertasari pavilion from an earlier manuscript is not substituted for BB. Architectural configurations are described in Table 1. Documentary photographs are not reproduced in this revision; no dimensional or performance evidence is inferred from images.

The survey record reports 120 respondents, not 120 independent building-performance observations. The analytic sample for each statistical model, per-case participation, repeated ratings, and missing-data exclusions are not established by the available summaries. Buildings, simulated zones, material inventories, and respondents are therefore not pooled into one statistical dataset.

Table 1. Case identity and the primary accounting boundary

Case	Function and Configuration (E1)	Material System (E1)	A^{sim} (m²; E2)	Separate Profile Area (E1)
ZC	Hospitality; communal pavilion and privacy transitions	Whole-culm/hybrid	420	Main pavilion: approximately 280–320 m²
BC	Communal wantilan in a rural landscape	Whole-culm frame	380	Wantilan: approximately 200–220 m²
BB	Open experimental/community pavilion	Engineered laminated bamboo	300	Main structure: approximately 250–350 m²
CV	Private villa, connected volumes and terraces	Whole-culm/hybrid	260	Main building 180 m²; semi-open area 90 m²

Source: Authors' case-data compilation, based on dissertation [13] (case profiles and Table 5.79 in dissertation [13]).
Note: ZC = ZIN Canggu Resort & Villas, BC = Bali Countryside Sidemen, BB = BaleBio, CV = Cinnamon Villa.

2.2 Evidence classification and audit sequence

Figure 1 summarizes the evidence classes. E1 denotes source-documented architectural descriptions and listed material quantities; E2 denotes source-reported model outputs, survey statistics, and adopted emission factors; E3 denotes arithmetic reconstructions from E1/E2; E4 denotes proposed mechanisms and decision rules. An E3 conditional scenario changes an expressly stated assumption while holding other inputs fixed. These are provenance classes, not quality scores. E3 is neither observed truth nor a newly modelled building outcome. Each quantitative table labels source-reported, reconstructed, or conditional quantities.

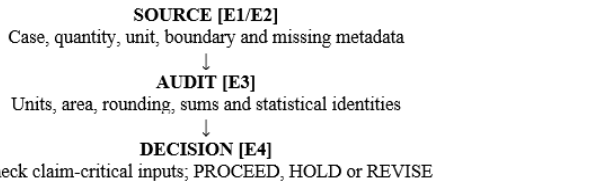

Figure 1. Evidence audit and claim-specific decision sequence

Source: Developed by the authors for the present study, drawing on the methodological concepts presented in Figure 3.1 of Sastrawan's unpublished doctoral dissertation [13]. The present diagram introduces an explicit evidence-audit sequence distinguishing source-documented information (E1), source-reported analytical outputs (E2), arithmetic reconstructions and consistency checks (E3), and proposed decision rules (E4), leading to three operational outcomes: PROCEED, HOLD, and REVISE.

Figure 1 presents an evidence-audit procedure developed for the present secondary assessment. Although informed by the methodological framework of the original dissertation [13], the diagram introduces a more explicit distinction between source-documented information, source-reported analytical outputs, author-reconstructed calculations, and proposed decision rules. These distinctions establish a traceable sequence for assessing the admissibility of engineering claims. The procedure leads to three operational outcomes: PROCEED when the available evidence supports a bounded decision, HOLD when critical evidence is insufficient, and REVISE when additional verification or modification of the proposed design is required.

One primary accounting rule is used: each reported energy intensity and cooling-load density is paired only with its own source-reported simulated-zone area A^{sim}. This aligns the denominator class without asserting physical service equivalence. Alternative profile areas are confined to a separate fixed-total sensitivity analysis. No undocumented allocation of energy to the main pavilion, terrace, or ancillary space is attempted.

2.3 Energy scope, area alignment, and reconstruction

Unknown end-use coverage is the primary limitation in comparing building energy performance. The available research record does not establish whether the reported energy use intensity (EUI) represents total delivered electricity,

cooling-related electricity consumption, or another subset of building energy use. The inclusion of domestic hot water, kitchen equipment, lighting, plug loads, swimming pool pumps, and shared building services cannot be confirmed. Furthermore, the energy carrier and system boundaries remain insufficiently documented. Therefore, the reconstructed annual energy quantity (E^{rec}) represents only the value calculated from the source-reported EUI and its corresponding simulated-zone area, rather than verified metered electricity consumption.

$$E_i^{\mathrm{rec}} = EUI_i^{\mathrm{src}} A_i^{\mathrm{sim}} \tag{1}$$

where, EUI has units kWh m^{-2} y^{-1}, A is in m^2, and E^{rec} is in kWh y^{-1}. Cooling-load density q is thermal power per area, not electrical consumption. The corresponding scenario power is:

$$\dot{Q}_i^{\mathrm{rec}} = q_i^{\mathrm{src}} A_i^{\mathrm{sim}} / 1000 \tag{2}$$

$\dot{Q}^{\mathrm{rec}}$ is in kW when q is in W m^{-2}. Cooling schedules, efficiency, and time-series loads would be needed to estimate electrical energy. At fixed reconstructed totals, an alternative documented area gives the conditional normalization:

$$EUI_i^{\mathrm{alt}} = \frac{E_i^{\mathrm{rec}}}{A_i^{\mathrm{alt}}}; q_i^{\mathrm{alt}} = \frac{1000 \dot{Q}_i^{\mathrm{rec}}}{A_i^{\mathrm{alt}}} \tag{3}$$

Eq. (3) is a denominator test, not a correction of geometry or a new simulation. Changing the physical area in a building model could change the numerator as well. Consequently, primary accounting, conditional normalization, and same-service comparison have explicitly different statuses.

2.4 Thermal and daylight checks

The source assumes a metabolic rate of 1.2 met and clothing insulation of 0.5 clo, and reports air temperature, mean radiant temperature, air speed, relative humidity, predicted mean vote (PMV), and predicted percentage of dissatisfied (PPD). The present audit checks only the Fanger PMV–PPD transformation [15], rather than independently reproducing PMV calculations or establishing compliance with ASHRAE Standard 55 [16, 17].

$$f(x) = 100 - 95e^{-0.03353x^4 - 0.2179x^2} \tag{4}$$

For a PMV x printed to two decimals, the rounding interval $x \pm 0.005$ is used. All four intervals are positive, where f is increasing; the endpoint values therefore bound compatible PPD. The resulting interval describes reporting precision, not uncertainty in the actual environment or occupant response.

Daylight factor (DF) uses simultaneous interior and unobstructed exterior illuminance under defined sky conditions [18]:

$$DF = 100 \frac{E_{\mathrm{in}}}{E_{\mathrm{out}}} \tag{5}$$

Daylight glare probability (DGP) depends on luminance and view conditions rather than horizontal illuminance alone [19]. Uniformity may mean $E_{\mathrm{min}}/E_{\mathrm{avg}}$ or $E_{\mathrm{min}}/E_{\mathrm{max}}$; the record does not specify which. Reported area coverage is not interpreted without its illuminance threshold.

2.5 Partial carbon accounting and factor sensitivity

This is a partial, inventory-based production-stage-type sum of printed material items; it does not claim compliance with a full modular building life cycle assessment (LCA) under EN 15978 or the complete ISO 14040/14044 framework [20-22]. Production modules A1–A3 are the intended conceptual boundary, not a verified assignment of every factor. A4–A5, use and replacement stages, end-of-life stages, and beyond-boundary benefits are not calculated. Even a complete A1–A3 total is not claimed.

The original research refers to the Inventory of Carbon and Energy (ICE) database and relevant material-related literature but does not provide specific emission-factor dataset identifiers, database versions, product records, or geographical metadata. Consequently, the adopted emission factors are treated as unverified source-reported assumptions rather than independently validated ICE entries, locally representative production factors, or verified environmental product declarations (EPDs). The original emission-factor values are retained to ensure transparency and reproducibility of the arithmetic assessment, rather than being replaced with values from other literature sources [5, 23-25].

$$EC_i^{\mathrm{rec}} = \sum_j m_{ij} EF_j; s_{ij} = \frac{m_{ij} EF_j}{EC_i^{\mathrm{rec}}} \tag{6}$$

Material mass (m) is expressed in kg, the emission factor (EF) in kg CO_2e kg^{-1}, and reconstructed partial carbon emissions (EC^{rec}) in kg CO_2e, while the material contribution share (s) is dimensionless. The available research record does not establish whether the adopted bamboo emission factors include cultivation, material treatment, drying, adhesive production, or biogenic carbon uptake and storage. Furthermore, consistent production-stage system boundaries, the global warming potential (GWP) assessment method and time horizon, and the accounting treatment of fossil and biogenic carbon cannot be verified across the assessed materials. No additional carbon storage credit is applied in the present calculations; however, this does not establish whether the source-adopted emission factors already incorporate such credits.

$$EC_i(\delta) = \sum_j m_{ij} EF_j (1 + \delta_j) \tag{7}$$

For fixed printed masses, Eq. (7) gives an exact linear sensitivity. Uniform ±20% and adverse-group perturbations are conditional scenarios, not empirical confidence intervals or evidence that the factors are harmonized. A partial sum remains useful for verifying arithmetic and prioritizing quantity/factor checks, but cannot establish material superiority, verified environmental hotspots, or a whole-building embodied carbon footprint.

2.6 Statistical identities and decision-model synthesis

The source reports principal component analysis (PCA) followed by Varimax rotation. For standardized-variable correlation-matrix PCA, retained variance can be checked against the number p of variables [26]:

$$V_p = \frac{100 \sum_{r=1}^{K} \lambda_r}{p} \tag{8}$$

The reported acceptance model is $Y_h = b_0 + b_1F_{1h} + b_2F_{2h} + b_3F_{3h} + \varepsilon_h$, where h indexes a respondent and F_1–F_3 are reported cultural–aesthetic, thermal–environmental, and perceived material-sustainability scores. Score construction and coefficient standardization remain unverified. For ordinary least squares (OLS) fit with an intercept, n analytic observations and k predictors:

$$R^2_{\text{adj}} = 1 - \frac{(1 - R^2)(n - 1)}{n - k - 1} \tag{9}$$

$$F = \frac{R^2(n - k - 1)}{k(1 - R^2)} \tag{10}$$

Eqs. (8)–(10) test internal compatibility only. They do not recover the actual analytic sample, exclusions, coefficients, or p-values. Section 4.1 consolidates these unresolved issues with the prohibition on using them as IBBSAM weights. Section 4.2 operationalizes claim-specific gates: Any missing critical input halts the affected claim, while traceable descriptive accounting may continue. These are proposed evidence rules, not newly validated regulatory thresholds.

3. RESULTS AND CRITICAL ANALYSIS

3.1 Case heterogeneity and boundary reconciliation

The E1 descriptions in Table 1 distinguish communal openness, hospitality transitions, and private accommodation. The source model areas of 420, 380, 300, and 260 m² do not establish an identical boundary with architectural profiles or material inventories. Ancillary-zone inclusion could explain some differences, but is not demonstrated. CV's separately listed 180 + 90 m² equals 270 m² rather than 260 m². BB's model area lies within its profile range, but overlap does not verify floor-versus-roof scope. No as-built area is inferred from photographs.

Table 2 uses only A^{sim} for accounting; Table 3 isolates denominator scenarios. Conditioned area, end-use coverage and inventory-covered area remain unaligned, preventing performance ranking.

3.2 Area-aligned accounting and end-use comparability

Table 2 aligns all four records to the same denominator class: source-reported simulated-zone area. EUI, q, and A^{sim} are E2 source-reported quantities; E^{rec} and $\dot{Q}^{\text{rec}}$ are E3 arithmetic reconstructions, not observations or newly modelled outputs. The calculation provides a reproducible accounting baseline without selecting convenient pavilion areas.

Comparability statement. EUI is not used as a same-service efficiency ranking. End-use coverage is unknown, including domestic hot water, kitchens, lights, plug loads, pumps, and shared services. Verification additionally requires energy carriers, zone polygons and area convention, conditioned versus naturally ventilated zones, weather file, solver/version, occupancy and internal-gain schedules, ventilation controls, heating, ventilation and air conditioning (HVAC) schedules/setpoints and efficiencies, and calibration records. Area alignment alone cannot resolve these omissions.

Table 2. Primary area-aligned accounting on the source simulated-zone basis

Case	A^{sim} (m²), E2 Source	EUI (kWh m⁻² y⁻¹), E2 Source	q (W m⁻²), E2 Source	E^{rec} (kWh y⁻¹), E3 Reconstruction	$\dot{Q}^{\text{rec}}$ (kW), E3 Reconstruction
ZC	420	38	34	15,960	14.28
BC	380	35	30	13,300	11.40
BB	300	32	28	9,600	8.40
CV	260	55	42	14,300	10.92

Source: Authors' arithmetic reconstruction (E3) based on source-reported simulated-zone areas, energy use intensities, and cooling-load densities (E2) from Tables 5.79–5.80 in dissertation [13], using Eqs. (1) and (2) of the present study. E2 values are reproduced from the source record, whereas E3 values are calculated by the authors and do not represent independently measured or newly simulated building performance.

Table 3. Alternative-area sensitivity using source-documented profile areas (E1) and conditional reconstructed intensities (E3)

Case	Alternative Source Profile A^{alt} (m²)	Conditional EUI (kWh m⁻² y⁻¹)	Conditional q (W m⁻²)
ZC	280–320; main pavilion	49.9–57.0	44.6–51.0
BC	200–220; main wantilan	60.5–66.5	51.8–57.0
BB	250–350; profile range	27.4–38.4	24.0–33.6
CV	180; main building only	79.4	60.7
CV	270; main plus semi-open	53.0	40.4

Source: Authors' conditional area-sensitivity analysis (E3), using source-documented profile areas (E1) from Table 5.97 in dissertation [13], reconstructed annual energy and cooling power from Table 2, and Eq. (3) of the present study.

Note: ZC = ZIN Canggu Resort & Villas; BC = Bali Countryside Sidemen; BB = BaleBio; CV = Cinnamon Villa. The two CV rows represent alternative area-denominator scenarios for the same building. The 270 m² scenario combines the documented 180 m² main-building area and 90 m² semi-open area. All conditional intensities are E3 calculations, not new simulation results.

Table 4. Source thermal summaries and reconstructed rounding checks

Case	T_a/T_r (°C; E2)	v/RH (m s⁻¹/%; E2)	PMV (E2)	PPD (%), Source E2	PPD (%), Reconstructed E3	PPD Interval (%), E3 Rounding Scenario
ZC	27.4/27.6	0.8/68	0.32	7.12	7.129	7.063–7.196
BC	28.1/28.3	0.7/70	0.67	14.54	14.433	14.291–14.575
BB	27.0/27.1	1.0/69	0.06	5.07	5.075	5.063–5.087
CV	27.8/28.0	0.9/70	0.46	9.44	9.417	9.321–9.514

Source: Authors' PMV–PPD consistency analysis, based on dissertation [13] (Table 5.81 in dissertation [13]), and Eq. (4) in this study; assuming 1.2 met and 0.5 clo. Note: ZC = ZIN Canggu Resort & Villas, BC = Bali Countryside Sidemen, BB = BaleBio, CV = Cinnamon Villa.

Table 3 combines source-documented alternative profile areas (E1) with conditional intensity calculations (E3). The conditional energy use intensities and cooling-load densities are obtained by dividing the reconstructed annual energy and cooling power in Table 2 by the corresponding alternative area denominators. For CV, the combined 270 m² profile area is itself an E3 arithmetic reconstruction from the source-documented 180 m² main-building area and 90 m² semi-open area. These calculations assess denominator sensitivity only; they do not represent new simulations, changes in physical building performance, or verified comparisons between equivalent conditioned spaces.

For CV, two alternative area-denominator scenarios are evaluated for the same building. The first scenario considers only the documented main-building area of 180 m², whereas the second includes the additional 90 m² semi-open area, resulting in a combined profile area of 270 m². Both scenarios retain the same reconstructed annual energy consumption of 14,300 kWh y^{-1} and cooling power of 10.92 kW. Consequently, the conditional EUI changes from 79.4 to 53.0 kWh m^{-2} y^{-1}, while the conditional cooling-load density changes from 60.7 to 40.4 W m^{-2}. These differences arise solely from the alternative area denominators and do not represent changes in physical building performance or new simulation results.

Alternative areas reverse the printed ZC–BC EUI order without changing a physical model. Likewise, density and total power can have different orders because area enters the calculation. These are accounting effects, not design-performance rankings.

3.3 PMV–PPD arithmetic, not demonstrated thermal comfort

Table 4 retains E2 environmental inputs and PMV–PPD summaries, then separately reports E3 conversions and rounding bounds. Mean radiant temperatures only 0.1–0.2 °C above air temperatures reflect source assumptions, not monitored radiative equivalence. Reported air speeds of 0.7–1.0 m s^{-1} require explicit treatment of air movement and control before any comfort interpretation.

Every source PPD falls within the corresponding rounding interval. The BC difference of approximately 0.11 percentage points is therefore compatible with PMV rounding. This establishes mathematical consistency between printed PMV and PPD only; it does not demonstrate any case's actual thermal comfort level. Accurate multiplication or conversion cannot validate an assumed radiant temperature or an undocumented sampling condition.

Future comfort assessment needs measurement-point coordinates and heights, occupied-zone coverage, dates and sampling windows, temporal averaging, calibrated instruments, concurrent air/radiant temperatures, humidity and air-speed variability, activity, clothing, and contemporaneous occupant votes. An adaptive route additionally requires evidence of model eligibility, including an occupant-controlled naturally conditioned indoor space, actual opportunities to operate openings, conditioning status, and the required outdoor-temperature history. An open pavilion is not automatically eligible [16, 17].

3.4 Daylight and glare: A verification checklist

Table 5 contains E2 source-reported values only, not recomputed lighting performance. DF, illuminance, uniformity, area coverage, and DGP describe distinct conditions; no annual lighting saving or visual-comfort category is assigned. Higher DF and lower glare are not interchangeable outcomes.

Table 5. Source-reported daylight indicators (all quantities E2)

Case	DF (%)	E_{in} (lx)	Uniformity*	Area (%)*	DGP
ZC	4.5	450	0.40	82	0.32
BC	3.2	320	0.25	64	0.41
BB	4.8	470	0.47	88	0.29
CV	4.1	410	0.41	79	0.34

Source: Authors' data compilation, from dissertation [13] (Tables 5.83–5.84 in dissertation [13]).
Note: *Uniformity definition and area-coverage threshold are unspecified in the source. DGP = daylight glare probability.

Table 6. Minimum metadata for thermal and visual verification (E4 checklist)

Domain	Information Required	Status in Reviewed Record/Claim Held
Thermal sampling	Point coordinates/heights; instrument calibration; sampling interval, dates and occupied windows; synchronized six-input data	Not supplied in sufficient detail; hold actual-comfort and compliance claims
Adaptive eligibility	Naturally conditioned indoor-space eligibility; occupant control; actual conditioning operation; outdoor-temperature history	Not established; do not apply the adaptive route automatically
Daylight factor (DF)	Sky model; simultaneous exterior reference; working-plane height; orientation and surface reflectance	Numerical DF printed; evaluation metadata incomplete
Grid and area coverage	Sensor spacing, coverage and area weighting; illuminance threshold and occupied schedule	Area percentages printed; grid and threshold not defined
Uniformity	Specify E_{min}/E_{avg} or E_{min}/E_{max}, sampled plane and aggregation	Ratio printed; denominator not specified
Daylight glare probability (DGP)	Observer position/eye height, gaze direction, timestamp/sky, luminance distribution and glare-source treatment	DGP printed; view metadata and calibrated luminance images not supplied
Annual daylight	Weather file, time step, occupancy schedule and annual metric definition	Not available; do not infer annual autonomy or lighting savings

Source: Authors' proposed verification checklist, informed by references [16-19] and the research evidence in dissertation [13].

Table 6 summarizes the minimum metadata required to verify the reported thermal and daylight performance indicators. It distinguishes the information needed for technical assessment from the evidence currently available in the reviewed research record. Missing or insufficiently documented inputs are explicitly identified to establish the corresponding verification requirements and prevent unsupported performance claims. The proposed checklist represents an evidence-based verification framework (E4), rather than completed monitoring or independently validated building performance.

Calibrated luminance images were not available in the

reviewed research record. Their historical existence therefore remains unverified rather than being assumed absent.

If DF and illuminance describe identical sky conditions and spatial summaries, Eq. (5) implies exterior illuminance of 10,000 lx for ZC, BC and CV, and approximately 9,792 lx for BB. This conditional E3 diagnostic flags metadata to check; it does not correct source values or establish annual daylight performance.

3.5 Printed-item carbon totals and factor provenance

Table 7 presents the reconstruction of partial material-carbon emissions for the four bamboo-building cases. The assessment combines source-listed material masses (E1) with source-adopted emission factors (E2), applying Eq. (6) to calculate individual material contributions and partial totals (E3). The reconstructed totals are 1,649 kg CO_2e for ZC, 2,049 kg CO_2e for BC, 2,215 kg CO_2e for BB, and 1,658 kg CO_2e for CV. These values represent only the material quantities explicitly included in the source inventory and should not be interpreted as complete whole-building embodied-carbon emissions or verified life-cycle assessment results for production modules A1–A3. Unlisted materials are treated as outside the documented inventory rather than assumed to be physically absent.

Table 8 examines the provenance and documentation limitations of the adopted emission factors. Although the source dissertation refers generally to the ICE database and relevant material literature, the available records do not provide factor-specific dataset identifiers, database versions, verified EPDs, or sufficient information on production processes and geographical representativeness. Consequently, the adopted factors remain source-reported assumptions (E2), while the identification of missing provenance information constitutes a documentary audit rather than independent factor validation.

The reconstruction establishes a transparent accounting basis for the listed material quantities while retaining the limitations of the original source data. In particular, the production-stage system boundaries, treatment of biogenic carbon, allocation procedures, and consistency of GWP assessment methods cannot be independently verified. These limitations are retained explicitly rather than resolved through undocumented substitutions of emission factors. The numerical implications of changing the adopted factors are examined separately in Section 3.6.

Table 7. Partial printed-item inventory: Source inputs and reconstructed carbon

Component	EF (E2), kg CO_2e kg^{-1}	ZC Mass/Carbon	BC Mass/Carbon	BB Mass/Carbon	CV Mass/Carbon
Non-laminated bamboo	0.03	5,800/174	4,300/129	900/27	5,100/153
Laminated bamboo	0.07	—	—	2,900/203	—
Concrete	0.15	6,500/975	8,800/1,320	5,900/885	5,600/840
Steel	2.00	250/500	300/600	550/1,100	220/440
Brick	0.25	—	—	—	900/225
PARTIAL total (E3)	—	1,649	2,049	2,215	1,658

Source: Authors' partial-inventory reconstruction, based on dissertation [13] (Tables 5.91–5.95 in dissertation [13]), and Eq. (6) in this study.

Table 8. Emission-factor provenance and unresolved carbon-accounting boundaries

Factor Group	Source Attribution/Adopted Value	Unresolved Process and Accounting Information
Non-laminated bamboo	Generic ICE/material-literature attribution; 0.03 kg CO_2e kg^{-1}	Cultivation, treatment, drying, processing, allocation and biogenic uptake/storage inclusion unknown
Laminated bamboo	Same generic attribution; 0.07 kg CO_2e kg^{-1}	Cultivation, drying, adhesive production, lamination energy, allocation and biogenic treatment unknown
Concrete/steel/brick	Same generic attribution; 0.15/2.00/0.25 kg CO_2e kg^{-1}	Product mix, recycled content/allocation, manufacturing technology and process boundaries not identified
All factors	No factor-specific dataset ID/version or verified EPD supplied	Local production representativeness, common A1–A3 boundary, GWP method/time horizon and fossil/biogenic conventions not confirmed

Source: Authors' audit of emission-factor provenance, based on dissertation [13] (Section 5 in dissertation [13] and Table 5.91 in dissertation [13]).

Table 9. Conditional factor sensitivity with printed quantities fixed (E3)

Case	Partial Baseline (kg CO_2e)	Uniform ±20% (kg CO_2e)	Concrete + Steel Share (%)	Adverse-Group Share (%)
ZC	1,649	1,319.2–1,978.8	89.4	85.0
BC	2,049	1,639.2–2,458.8	93.7	90.8
BB	2,215	1,772.0–2,658.0	89.6	85.2
CV	1,658	1,326.4–1,989.6	77.2	69.3

Source: Authors' conditional factor-sensitivity analysis, using Table 7 and Eq. (7) in this study.

3.6 Factor sensitivity versus inventory verification

Table 9 presents conditional emission-factor sensitivity scenarios (E3) calculated using Eq. (7), with the source-listed material masses held constant. A uniform ±20% adjustment to all adopted emission factors produces deterministic changes in the reconstructed partial-carbon totals. These scenarios are arithmetic sensitivity checks rather than statistical confidence intervals or empirically established uncertainty bounds.

A separate adverse-group scenario reduces the concrete and steel emission factors by 20% while increasing the remaining material factors by 20%, without changing the documented material quantities. Under this scenario, the combined concrete-and-steel contribution remains above 50% of each reconstructed partial total, with corresponding shares of 85.0% for ZC, 90.8% for BC, 85.2% for BB, and 69.3% for CV. Additional single-factor calculations show that a 10% increase in the concrete emission factor increases the ZC and BC partial totals by approximately 5.91% and 6.44%, respectively, while a 10% increase in the steel factor increases the BB total by

approximately 4.97%. Doubling only the laminated-bamboo emission factor increases the BB partial total by approximately 9.16%. These results identify the numerical sensitivity of the reconstructed totals to specific factor assumptions.

The sensitivity scenarios do not verify the completeness or accuracy of the underlying material inventories, the suitability of the adopted emission factors, or the consistency of their life-cycle boundaries. Uniform proportional factor changes preserve the ordering of partial totals by construction and therefore cannot demonstrate robustness to material-specific or case-specific uncertainty. Furthermore, omitted materials, inaccurate quantities, and inconsistent production boundaries could alter both the absolute emissions and the relative contributions of individual material groups. Accordingly, the sensitivity assessment provides a reproducible diagnostic of factor dependence rather than evidence of verified environmental superiority or whole-building carbon performance.

3.7 Construction evidence and non-compensatory safety

Source construction narratives distinguish whole-culm and laminated systems. BC's profile gives approximately 10 m span and 7.25 m height, whereas its later structural table reports 12–15 m and 10–12 m. The discrepancy may concern different structures but cannot be resolved; neither set supports verified structural calculations.

Foundations and connectors may be essential to load transfer, moisture separation and durability. Their conditional carbon contribution cannot justify removing them without structural verification. Culm design and testing standards have specific scopes [27, 28]; engineered products require appropriate product and joint evidence [3]. Durability needs independently documented protection and inspection [29]. No member capacity, adhesive suitability, fire resistance or residual service life is inferred from the environmental summaries. The construction discussion relies on the source's written descriptions, not on reproduced photographs, and does not establish connection capacity, material treatment or safety compliance.

3.8 Separate perception and technical profiles

Table 10 presents source-reported perception and PMV summaries (E2) alongside reconstructed partial material-carbon totals (E3). For BC, the source-reported mean spatial-comfort score is 4.48, while the corresponding reported PMV is 0.67. In comparison, BB has a mean spatial-comfort score of 3.79 and a reported PMV of 0.06. These contrasting case-level profiles indicate differences between perceived spatial comfort and calculated thermal sensation. However, the available records do not establish synchronized environmental exposure, equivalent respondent samples, or direct statistical relationships between the two indicators. Consequently, the comparison is descriptive and does not establish either perception-based or simulation-based results as independently verified ground truth.

Spatial comfort includes privacy, shelter and social experience, whereas PMV represents a thermal calculation. Perceived sustainability is not a carbon inventory. Unmatched exposure, missing per-case sample sizes and dispersion preclude significance testing; four case summaries cannot establish a respondent-level relationship.

Table 10. Source perceptions and separately reconstructed technical quantities

Case	Cultural Identity E2	Aesthetics E2	Spatial Comfort E2	Material Sustainability E2	PMV E2	Partial Carbon kg CO_2e; E3
ZC	3.87	4.08	4.33	4.12	0.32	1,649
BC	4.42	4.36	4.48	4.41	0.67	2,049
BB	3.41	4.51	3.79	4.55	0.06	2,215
CV	4.18	4.21	4.17	4.26	0.46	1,658

Source: Authors' comparative synthesis, using E2 perception and PMV summaries in dissertation [13] (Tables 5.73–5.76 and Table 5.81 in dissertation [13]), and E3 carbon results in Table 7.

4. INTEGRATED BALINESE BAMBOO SUSTAINABLE ARCHITECTURE MODEL DECISION WORKFLOW AND DISCUSSION

4.1 Unverified statistics cannot supply model weights

Table 11 consolidates source-reported statistical information (E2) and conditional arithmetic consistency checks (E3). The original dissertation reports 16 initial indicators across the X_1–X_4 constructs, whereas only 14 indicator rows are displayed in the rotated component matrix. The two X_4 indicators not displayed are "citra arsitektur Bali" (Balinese architectural image) and "daya tarik visual" (visual appeal). Although their absence from the displayed matrix is identifiable, the available documentation does not establish whether these indicators were excluded from the original PCA, the reasons for any exclusions, or the actual number of variables included in the fitted model.

The three source-reported eigenvalues (5.82, 3.14, and 2.18) sum to 11.14. Under correlation-matrix PCA, this corresponds to a cumulative explained variance of 69.63% for 16 variables, 74.27% for 15 variables, or 79.57% for 14 variables. Although the value calculated for 15 variables is consistent with the reported cumulative variance of 74.3% after rounding, this numerical agreement does not independently verify that 15 variables were included in the original analysis. Consequently, the actual PCA variable count, indicator-exclusion procedure, and analytical sample size remain unresolved.

Table 11. Statistical reporting audit and restrictions on model interpretation

Item	Source-Reported Information (E2)	Reconstruction, Verification Status, and Permitted Use (E3)
PCA variables and analytical sample	16 initial indicators (X_1–X_4); 14 rotated-matrix rows; 120 survey respondents.	Actual PCA variable count (p) and analytical sample size (n) unverified. Indicator exclusions and case-processing records unavailable.

PCA retained variance	Eigenvalues: 5.82, 3.14, 2.18 (sum = 11.14); reported cumulative variance: 74.3%.	Conditional checks using Eq. (8): 69.63% (p = 16), 74.27% (p = 15), 79.57% (p = 14). The reported 74.3% is compatible with p = 15 after rounding, but the actual p is unverified.
OLS specification	Y regressed on F_1, F_2, F_3 with intercept; R^2 = 0.613; adjusted R^2 = 0.598; F = 38.47.	Actual analytical n is unknown. Assuming n = 120 and k = 3 gives model, residual, and total degrees of freedom of 3, 116, and 119.
OLS statistical identities	Reported regression statistics cannot be reconciled with an available original output file.	Conditional checks using Eqs. (9)–(10): adjusted R^2 = 0.60299; F = 61.247. Diagnostic calculations only; not replacement fitted statistics.
Implications for IBBSAM	Respondent-level data, complete statistical outputs, and scoring specifications unavailable for independent verification.	PCA and OLS summaries cannot support quantitative weights, predictive validation, mediation analysis, or causal interpretation of IBBSAM.

Source: Authors' statistical-consistency audit (E3), based on source-reported information (E2) in Sections 4.7 and 5.4 and Tables 5.63–5.71 of dissertation [13], using Eqs. (8)–(10) of the present study.
Note: PCA = principal component analysis; OLS = ordinary least squares; IBBSAM = Integrated Balinese Bamboo Sustainable Architecture Model; p = number of PCA variables; n = analytical sample size; k = number of OLS predictors excluding the intercept.

The statistical inconsistencies identified in Table 11 limit the interpretation of the original multivariate analyses. In particular, the survey total of 120 respondents cannot automatically be treated as the analytical sample size for every statistical model. The conditional OLS calculations assume n = 120 and k = 3, producing model, residual, and total degrees of freedom of 3, 116, and 119, respectively. However, these values cannot be confirmed without the original case-processing and regression outputs. Accordingly, neither the PCA nor the regression summaries are used to derive sustainability weights, establish predictive relationships, or claim empirical validation of the proposed IBBSAM workflow.

4.2 Integrated Balinese Bamboo Sustainable Architecture Model design-decision procedure and stop/go rules

Figure 2 links project context and cultural requirements to spatial/bamboo-technology alternatives and separates technical and user-acceptance outcomes. Gate G0 defines the intended claim, evidence source, and assessment scope; gates G1–G5 guide the corresponding technical, environmental, cultural, and integrated assessment checks; and Gate G6 maintains structural safety as a non-compensatory requirement throughout the decision process. Communal use, landscape relations, and cultural meanings shape design questions about openness, spanning, shelter, and moisture, but do not by themselves prove performance or cultural authenticity [10, 11].

Table 12 specifies the evidence requirements and corresponding design actions for each decision gate (G0–G6). The proposed IBBSAM employs three operational decision outcomes: PROCEED, HOLD, and REVISE. PROCEED permits a specific design or assessment decision when the available evidence adequately supports the intended claim within clearly defined boundaries. HOLD temporarily suspends the affected decision when critical evidence is missing, inconsistent, or insufficient to establish the required level of confidence. REVISE requires modification of the design alternative, analytical assumptions, or evidence-collection strategy before reassessment. Missing noncritical information may restrict the scope of an assessment without necessarily preventing all subsequent work. Cultural, technical, environmental, and user-experience evidence are evaluated as distinct domains, while structural safety under Gate G6 remains a non-compensatory requirement throughout the decision process. This procedure is proposed as an evidence-governed decision framework and has not yet undergone prospective empirical validation.

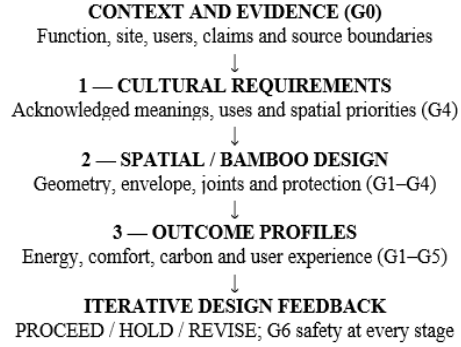

Figure 2. Three-layer Integrated Balinese Bamboo Sustainable Architecture Model (IBBSAM) design-decision workflow with evidence gates
Source: Adapted and redrawn from Figure 7.1 and the conceptual framework in Chapter VII of Sastrawan's unpublished doctoral dissertation [13]. The present study introduces explicit evidence gates (G0–G6), operational outcomes (PROCEED, HOLD, and REVISE), and a non-compensatory structural safety requirement. The resulting workflow is proposed and has not yet been prospectively validated.

Table 12. Integrated Balinese Bamboo Sustainable Architecture Model (IBBSAM) operational decision gates: Evidence requirements and design actions (E4)

Decision Gate	Required Design Evidence	IBBSAM Decision Rule and Design Action
G0–Scope and provenance	Cultural intent, function, site/users, claim boundary and traceable sources; permissions and ethics where applicable	Define objectives and evidence ownership. PROCEED with permitted, traceable inputs; HOLD an affected claim until critical context or authorization is resolved.
G1–Energy and climate	Zone/area definitions, energy-service scope, weather and operational assumptions; comparable outputs	Compare alternatives on aligned boundaries. HOLD unsupported rankings; REVISE envelope, openness or shading options and reassess with adequate inputs.
G2–Thermal and visual comfort	Applicable criteria, representative thermal and daylight data, airflow, solar control, glare and occupant operation	Evaluate openings, ventilation, roofs and shading jointly. HOLD unsupported comfort claims; REVISE spatial or envelope parameters and repeat assessment.

G3–Materials and carbon	Material quantities, comparable function and life-cycle scope, traceable emission factors, durability and safety requirements	Compare alternatives at equivalent function. REVISE quantities, products or joints only after checking carbon assumptions, durability and structural adequacy.
G4–Cultural-performance trade-offs	Stated cultural priorities, spatial relationships and distinct technical/occupant evidence	Identify agreement or conflict across objectives. REVISE form or spatial configuration; record explicit cultural, climate and material trade-offs.
G5–Integrated assessment	Separate performance and user-acceptance profiles; sufficient statistical basis before weighting	PROCEED with evidence-bounded profiles; HOLD unsupported weights, predictions or rankings; REVISE the evidence plan when indicators disagree.
G6–Safety and feedback	Load path, member/joint evidence, exposure, fire, protection, inspection and maintenance requirements	Safety is non-compensatory at every gate. HOLD unsafe or unsupported options; REVISE, recheck and record the responsible reviewer, evidence and decision.

Source: Authors' proposed IBBSAM design-decision protocol, informed by dissertation [13] and the evidence classification in Section 2.2 in this study.

Case-based illustrations show how the design gates would be used. ZC–BC permit source-basis accounting (Table 2), but G1 holds an efficiency ranking until energy-service scope is matched. BB's bamboo-led appearance and printed 1,100 kg CO_2e steel contribution (Table 7) activate G3/G4 quantity, connection, and functional-equivalence checks before material substitution. BC–BB comfort–perception differences (Table 10) call for matched conditions under G2/G4 before altering openings or shading. G6 safety governs every option. These are procedural illustrations, not completed design interventions.

4.3 Ecodynamic trade-offs, transferability and verification

Thermal conditions, airflow, daylight, and moisture interact in shaping building performance [30, 31]. Porosity can admit ventilation, rain and noise; deep roofs alter shade, daylight, material demand and uplift. Protective bases and joints may increase initial material use while extending service. An arithmetic share never justifies removal without equivalent function, safety and durability.

Transferability concerns the procedure, not Balinese meanings or numerical results. Purposive selection limits population inference; function, exposure, designer practice and operation remain alternative explanations. Formulation cases cannot independently validate the workflow.

Prospective testing should prerecord claims and required inputs, recover model/survey outputs, and log decisions through design and post-occupancy evaluation. Independent reviewers and matched new cases can test gate reproducibility and design hypotheses. No validated feedback benefit or regulatory approval is asserted.

4.4 Limitations and reproducibility

The reproducibility of this secondary assessment is limited to the arithmetic reconstructions, alternative area-denominator scenarios, PMV–PPD rounding checks, emission-factor sensitivity calculations, statistical consistency checks, and the explicit logic of the proposed IBBSAM decision gates. It does not extend to independent reproduction of the original field observations, building simulations, or respondent-level statistical analyses. Incomplete energy end-use definitions, inconsistent spatial and material-inventory boundaries, unavailable simulation and calibration files, insufficient monitoring metadata, and unresolved PCA and OLS statistical outputs constrain the verification and interpretation of the reported findings. Consequently, the reconstructed results should not be interpreted as independently validated building performance, verified whole-building embodied-carbon assessments, or empirical validation of the proposed decision workflow.

The assessment relies on documented secondary research materials and does not reconstruct unavailable building geometry, interview transcripts, participant-level records, or photographic evidence. Third-party project photographs were removed because image-specific permissions for publication under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence were not available. The original research ethics confirmation and dissertation data-reuse authorization are documented separately in the Data, Ethics and Figure Provenance section. These records establish the stated documentary basis for the secondary use of research findings but do not resolve the methodological limitations associated with unavailable primary data, simulation files, or original statistical outputs. Further verification requires access to the original research documentation, clearly defined assessment boundaries, and independently reproducible analytical procedures.

5. CONCLUSIONS

This secondary assessment converts heterogeneous bamboo-building summaries into an auditable accounting and decision workflow. A consistent source-reported simulated-zone-area basis enables the arithmetic reconstruction of annual energy quantities and cooling power, while incomplete energy end-use coverage and service definitions prevent reliable cross-case efficiency ranking. Alternative area-denominator scenarios demonstrate the sensitivity of calculated intensities to accounting assumptions rather than changes in actual building performance. The reported PMV and PPD values are arithmetically compatible within rounding limits; however, this consistency does not independently establish actual thermal comfort.

The reconstructed partial material-carbon totals range from 1,649 to 2,215 kg CO_2e and represent only the material quantities documented in the source inventories, rather than verified whole-building embodied-carbon emissions or complete A1–A3 assessments. Concrete and steel contribute 77.2–93.7% of these partial totals under the source-adopted emission factors. However, uncertainties concerning inventory completeness, production-stage boundaries, geographical representativeness, GWP assessment methods, and biogenic-carbon accounting prevent definitive environmental comparisons. The conditional factor-sensitivity scenarios demonstrate the dependence of the reconstructed results on the adopted assumptions but do not establish empirical uncertainty bounds or verified environmental superiority among the assessed buildings.

Building upon the conceptual IBBSAM previously documented in dissertation [13], the present study proposes a methodological refinement through an explicit evidence-

governed decision procedure. The revised IBBSAM workflow specifies claim-critical evidence requirements, operational decision outcomes (PROCEED, HOLD, and REVISE), and procedures for addressing inconsistencies across cultural, technical, environmental, and user-experience domains. The proposed decision gates (G0–G6) retain structural safety as a non-compensatory requirement. Unverified PCA and OLS regression summaries are not used to establish quantitative model weights, predictive relationships, or causal interpretations. Accordingly, the contribution of this study lies in the operational refinement of an existing conceptual framework rather than the development of an entirely new or empirically validated model. Its practical applicability and reliability require prospective evaluation using recoverable datasets, comparable observations, and independent building cases.

ACKNOWLEDGMENT

The authors acknowledge the Doctoral Program in Engineering Science, Faculty of Engineering, Udayana University, and the Architecture Study Program, Faculty of Engineering and Planning, Warmadewa University. The article introduces no new participant recruitment or field measurement.

DATA, ETHICS AND FIGURE PROVENANCE

Numerical inputs are aggregate summaries from dissertation [13]. The first author is the original investigator and author of dissertation [13]. The signed Institutional Confirmation of Prior Research Ethics Approval, dated 10 January 2025 and provided by the Quality Control Group (GKM), Architecture Study Program, Warmadewa University, states that the original study underwent institutional ethical review and received approval before human-participant research began. The stated review covered questionnaire participation, professional consultations, communication of research purpose, voluntary agreement, confidentiality and responsible information use. The first author's signed Confirmation of Dissertation Research Data Reuse Authorization, dated 20 May 2026, authorizes the responsible secondary analysis and scholarly publication of the relevant dissertation material, including aggregate questionnaire summaries from 120 respondents and technical and statistical information. The present article uses aggregate research summaries, includes no identifiable participant-level information and involves no new participant recruitment. The current Figures 1 and 2 are author-prepared analytical diagrams acknowledging their conceptual source in dissertation [13].

AI-ASSISTED MANUSCRIPT PREPARATION

AI assistance supported language editing, restructuring, tabulation, and explicitly identified arithmetic checks. No field observations, participant records, simulation outputs or permission records were generated to replace missing evidence. The human authors retain responsibility for checking the source data, references, interpretations, declarations and submitted version.

REFERENCES

[1] Adier, M.F.V., Sevilla, M.E.P., Valerio, D.N.R., Ongpeng, J.M.C. (2023). Bamboo as sustainable building materials: A systematic review of properties, treatment methods, and standards. Buildings, 13(10): 2449. https://doi.org/10.3390/buildings13102449

[2] Bredenoord, J. (2024). Bamboo as a sustainable building material for innovative, low-cost housing construction. Sustainability, 16(6): 2347. https://doi.org/10.3390/su16062347

[3] Sharma, B., Gatóo, A., Bock, M., Ramage, M. (2015). Engineered bamboo for structural applications. Construction and Building Materials, 81: 66-73. https://doi.org/10.1016/j.conbuildmat.2015.01.077

[4] Xu, P.Y., Xu, X.X. (2025). Uncertainty analysis and performance optimization of ultra-low energy operation in bamboo buildings: A scenario simulation study in Nanjing, China. Energy, 332: 137158. https://doi.org/10.1016/j.energy.2025.137158

[5] Gan, J.L., Chen, M.L., Semple, K., Liu, X.Y., Dai, C.P., Tu, Q.S. (2022). Life cycle assessment of bamboo products: Review and harmonization. Science of the Total Environment, 849: 157937. https://doi.org/10.1016/j.scitotenv.2022.157937

[6] Cohen, R., Standeven, M., Bordass, B., Leaman, A. (2001). Assessing building performance in use 1: The Probe process. Building Research & Information, 29(2): 85-102. https://doi.org/10.1080/09613210010008018

[7] de Wilde, P. (2014). The gap between predicted and measured energy performance of buildings: A framework for investigation. Automation in Construction, 41: 40-49. https://doi.org/10.1016/j.autcon.2014.02.009

[8] Coakley, D., Raftery, P., Keane, M. (2014). A review of methods to match building energy simulation models to measured data. Renewable and Sustainable Energy Reviews, 37: 123-141. https://doi.org/10.1016/j.rser.2014.05.007

[9] Mahdavi, A., Berger, C. (2025). Ten questions regarding buildings, occupants and the energy performance gap. Journal of Building Performance Simulation, 18(5-6): 676-686. https://doi.org/10.1080/19401493.2024.2332245

[10] Kazimee, B.A. (2009). Representation of vernacular architecture and lessons for sustainable and culturally responsive environment. International Journal of Design & Nature and Ecodynamics, 4(4): 337-350. https://doi.org/10.2495/DNE-V4-N4-337-350

[11] Aryani, N.P., Tanuwidjaja, G. (2013). Sustainable architectural design in a traditional Balinese housing in accordance to the concept of Tri Mandala. In International Conference Green Concept in Architecture Environment, Surabaya, Indonesia. https://repository.petra.ac.id/id/eprint/16637.

[12] Nursaniah, C., Qadri, L., Fuady, Z. (2025). Relearning vernacular wisdom for thermal comfort: Assessing climate-responsiveness in modern housing clusters of Banda Aceh. International Journal of Design & Nature and Ecodynamics, 20(9): 2109-2119. https://doi.org/10.18280/ijdne.200915

[13] Sastrawan, I.W.W. (2026). Model desain bambu berbasis integrasi arsitektur Bali dan bangunan berkelanjutan [Bamboo design model integrating Balinese architecture

and sustainable buildings]. Unpublished doctoral dissertation, Doctoral Program in Engineering Science, Faculty of Engineering, Udayana University, Denpasar, Indonesia.
[14] Yin, R.K. (2018). Case Study Research and Applications: Design and Methods, 6th ed. SAGE Publications, Thousand Oaks, CA. https://bibliotheque.tbs-education.fr/Default/doc/SYRACUSE/11006/case-study-research-and-applications-design-and-methods-robert-k-yin?_lg=fr-FR.
[15] Fanger, P.O. (1970). Thermal Comfort: Analysis and Applications in Environmental Engineering. Danish Technical Press, Copenhagen.
[16] ASHRAE. (2023). ANSI/ASHRAE Standard 55-2023: Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers. https://www.ashrae.org/technical-resources/standards-and-guidelines/titles-purposes-and-scopes.
[17] Tartarini, F., Schiavon, S., Cheung, T., Hoyt, T. (2020). CBE thermal comfort tool: Online tool for thermal comfort calculations and visualizations. SoftwareX, 12: 100563. https://doi.org/10.1016/j.softx.2020.100563
[18] Reinhart, C.F. (2014). Daylighting Handbook I: Fundamentals and Designing with the Sun. Building Technology Press, Cambridge, MA. https://web.mit.edu/sustainabledesignlab/projects/DaylightingHandbook/book.html.
[19] Wienold, J., Christoffersen, J. (2006). Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. Energy and Buildings, 38(7): 743-757. https://doi.org/10.1016/j.enbuild.2006.03.017
[20] ISO 14040:2006. (2006). Environmental management—Life cycle assessment—Principles and framework. International Organization for Standardization, Geneva. https://www.iso.org/standard/37456.html.
[21] ISO 14044:2006. (2006). Environmental management—Life cycle assessment—Requirements and guidelines. International Organization for Standardization, Geneva. https://www.iso.org/standard/38498.html.
[22] British Standards Institution. (2026). BS EN 15978:2026 Sustainability of construction works. Assessment of environmental performance of buildings. Requirements and guidance. BSI, London. https://doi.org/10.3403/30478335
[23] Zea Escamilla, E., Habert, G., Correal Daza, J.F., Archila, H.F., Echeverry Fernández, J.S., Trujillo, D. (2018). Industrial or traditional bamboo construction? Comparative life cycle assessment (LCA) of bamboo-based buildings. Sustainability, 10(9): 3096. https://doi.org/10.3390/su10093096
[24] Xu, P.Y., Zhu, J.J., Li, H.T., Wei, Y., Xiong, Z.H., Xu, X.X. (2022). Are bamboo construction materials environmentally friendly? A life cycle environmental impact analysis. Environmental Impact Assessment Review, 96: 106853. https://doi.org/10.1016/j.eiar.2022.106853
[25] Rincón, C.E., Montoya, J.A., Archila, H.F. (2023). Bamboo construction inspired by vernacular techniques for reducing carbon footprint: A life cycle assessment (LCA). Sustainability, 15(24): 16893. https://doi.org/10.3390/su152416893
[26] Jolliffe, I.T., Cadima, J. (2016). Principal component analysis: A review and recent developments. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2065): 20150202. https://doi.org/10.1098/rsta.2015.0202
[27] ISO 22156:2021. (2021). Bamboo structures—Bamboo culms—Structural design. International Organization for Standardization, Geneva. https://www.iso.org/standard/73831.html.
[28] ISO 22157:2019. (2019). Bamboo structures—Determination of physical and mechanical properties of bamboo culms—Test methods. International Organization for Standardization, Geneva. https://www.iso.org/standard/65950.html.
[29] Kaminski, S., Lawrence, A., Trujillo, D., King, C. (2016). Structural use of bamboo. Part 2: Durability and preservation. The Structural Engineer, 94(10): 38-43. https://doi.org/10.56330/TRBW8039
[30] Olgyay, V. (1963). Design with climate: Bioclimatic approach to architectural regionalism. Princeton University Press, Princeton, NJ, pp. 1-189. https://www.scribd.com/document/528226490/Design-With-Climate-Bioclimatic-Approach-to-Architectural-Regionalism-by-Olgyay-Victor-Z-lib-org.
[31] Koenigsberger, O.H., Ingersoll, T.G., Mayhew, A., Szokolay, S.V. (1974). Manual of Tropical Housing and Building: Climatic Design. Universities Press.

NOMENCLATURE

A_i^{sim}	Source-reported simulated-zone area for case i, m²
A_i^{alt}	Alternative profile area for case i, m²
b_0	OLS regression intercept, response-score units
b_1	Coefficient for F_1, response units per F_1 unit
b_2	Coefficient for F_2, response units per F_2 unit
b_3	Coefficient for F_3, response units per F_3 unit
DF	Daylight factor, %
DGP	Daylight glare probability, dimensionless
E_i^{rec}	Reconstructed annual energy for case i, kWh y^{-1}
EC_i^{rec}	Reconstructed partial material carbon for case i, kg CO_2e
EF_j	Emission factor for material j, kg CO_2e kg^{-1}
EUI_i^{src}	Source-reported energy use intensity, kWh m^{-2} y^{-1}
EUI_i^{alt}	Conditional energy intensity for alternative area, kWh m^{-2} y^{-1}
E_{in}	Interior illuminance, lx
E_{out}	Exterior illuminance, lx
E_{min}	Minimum illuminance, lx
E_{avg}	Average illuminance, lx
E_{max}	Maximum illuminance, lx
F	Overall OLS F-statistic, dimensionless
F_{1h}	Cultural–aesthetic score for respondent h, score units
F_{2h}	Thermal–environmental score for respondent h, score units
F_{3h}	Material-sustainability score for respondent h, score units
f(x)	Predicted percentage dissatisfied from PMV x, %
h	Respondent index, dimensionless
i	Building-case index, dimensionless

j	Material index, dimensionless
K	Retained PCA components, count
k	OLS predictors excluding intercept, count
m_{ij}	Mass of material j in case i, kg
n	Analytical sample size, count
p	Variables included in PCA, count
q_i^{src}	Source-reported cooling-load density, W m^{-2}
q_i^{alt}	Conditional cooling-load density, W m^{-2}
$\dot{Q}_i^{rec}$	Reconstructed cooling thermal power, kW
R^2	OLS coefficient of determination, dimensionless
R^2_{adj}	Adjusted OLS coefficient of determination, dimensionless
RH	Relative humidity, %
r	Principal-component index, dimensionless
s_{ij}	Fractional carbon contribution of material j in case i, dimensionless
T_a	Air temperature, °C
T_r	Mean radiant temperature, °C
v	Air speed, m s^{-1}
V_p	Cumulative explained PCA variance, %
x	Predicted mean vote (PMV), dimensionless
Y_h	Acceptance response for respondent h, response-score units
δ_j	Relative emission-factor perturbation, dimensionless
ε_h	Regression error for respondent h, response-score units
λ_r	Eigenvalue of PCA component r, dimensionless

Subscripts

src	source-reported quantity
rec	reconstructed quantity
sim	simulated-zone area
alt	alternative-area scenario
adj	adjusted statistical quantity
μ	dynamic viscosity, kg m^{-1} s^{-1}