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Designing a Biophilic Cocoa Hub for Integrated Processing, Education and Tourism in Humid-Tropical Indonesia

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ABSTRACT

This study develops an architectural framework for a biophilic cocoa processing, education, and tourism hub in Masamba, Luwu Utara, Indonesia. A research-by-design method combined site observation, rainfall and population data, precedent analysis, user–activity mapping, space programming, and iterative design synthesis. Quantitative evidence was used descriptively to test the consistency of site and program decisions. The available monthly rainfall series totals 3,064 mm over 154 rainy days; rainfall depth and rainy-day frequency show a strong descriptive association (r=0.947). The selected 2.5-ha site accommodates a 3,482.1-m² gross program for education–processing, greenhouse and drying, dining–retail, prayer, storage, and waste-management functions. The visitor route follows a farm–process–product sequence, while production and service flows remain separate for safety and hygiene. Biophilic strategies include cocoa-landscape views, controlled cross-ventilation, filtered daylight, shaded transitions, natural materials, rainwater harvesting, and composting. The result is a testable architectural hypothesis linking rural value addition, experiential learning, and humid-tropical design. Hydrological, thermal, daylight, operational, economic, and post-occupancy validation remain necessary before implementation.

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1. Introduction

Cocoa-producing landscapes can generate value far beyond the farm gate, yet much of that value is realized only when cultivation is connected to post-harvest knowledge, processing, product development, interpretation, and market access. In Luwu Utara, the architectural design dataset that underpins this study identifies cocoa as an important regional commodity and records a need for better public understanding of the production chain. Local studies also show that farm performance is affected by practical knowledge, including pruning, fertilization, sanitation, harvest frequency, and good agricultural practices [1,2]. These conditions suggest that rural value addition is not solely a question of production equipment. It also depends on places where knowledge can circulate among producers, students, visitors, entrepreneurs, and institutions.

The spatial problem is fragmentation. Cultivation occurs in productive landscapes; processing is commonly separated from public access; education is delivered in classrooms or periodic training; and tourism often concentrates on scenery, consumption, or isolated attractions. When these functions are planned independently, visitors may see cocoa as a finished product without understanding biological growth, post-harvest handling, labor, quality control, or waste. Agro-ecological tourism studies in other rural settings similarly identify infrastructure and visitor organization as prerequisites for presenting authentic agricultural processes [3]. Sustainable rural tourism therefore requires more than an attractive building. It requires site planning that coordinates agricultural livelihoods, environmental protection, movement, services, interpretation, and visitor demand [4]

Educational tourism provides a useful bridge because it turns production into an observable sequence. Recent edu-agrotourism studies emphasize the integration of recreation, learning, productive landscape, and community participation rather than treating agriculture as a decorative background [5]. Environmental education centers extend this principle by making the building itself part of the lesson: architecture can demonstrate ecological processes as well as house exhibitions and teaching activities [6]. Museum research also shows that sustainable features do not automatically educate. Their value depends on whether systems are visible, explained, maintained, and incorporated into programming [7,8]. For a cocoa facility, this means that cultivation, drying, processing, water, energy, and waste should be legible without compromising hygiene or operational safety.

Biophilic design offers a framework for organizing this relationship between productive landscape, environmental performance, and experience. Studies of educational environments repeatedly identify daylight, vegetation, views, outdoor access, fresh air, spatial flexibility, and natural materials as important components of nature-integrated learning settings [9,10]. Empirical work also associates biophilic learning environments with perceived restorativeness, attention, and affiliation with nature, while post-occupancy studies emphasize that outcomes depend on the configuration of features and user experience rather than on greenery alone [11,12]. Accordingly, this study treats biophilic strategies as spatial and environmental hypotheses

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that must later be tested, not as proof that an unbuilt design already improves health or learning.

The humid-tropical context adds a technical constraint to that ambition. Semi-open educational buildings in Southeast Asia demonstrate that roof openings, cross-ventilation, daylight, green area, and ground-floor openness influence thermal and visual conditions, but each strategy also introduces trade-offs in heat gain, glare, humidity, and weather exposure [13]. Indonesian green-building research similarly highlights the importance of climate-responsive shading, ventilation, water conservation, and performance assessment in tropical climates [14,15]. A proposed agricultural school in an Amazonian rural context further shows how site-specific climate analysis and biophilic strategies can be integrated with educational infrastructure [16]. In Luwu Utara, frequent rainfall, wind-driven moisture, biological growth, and food-processing requirements mean that environmental connection must be selective and technically controlled.

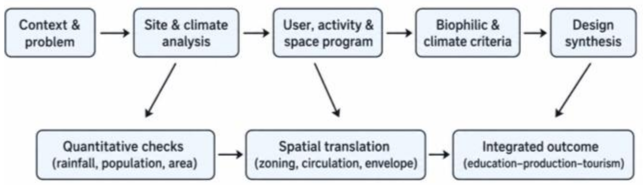
Regional architectural research provides a useful comparison. Biophilic public projects in South Sulawesi have combined natural light, ventilation, vegetation, cultural identity, social programs, and creative-economy functions in collaboration and creative-hub settings [17]. A rural religious-education project in Wajo similarly integrates light, air, vegetation, water, privacy, and daily spiritual routines within a biophilic spatial framework [18]. These studies demonstrate the regional relevance of biophilic design, but they do not address the particular operational challenge of joining an active agricultural processing chain with public interpretation, tourism, commerce, and circular resource management.

The research gap therefore lies at the intersection of biophilic educational architecture, rural tourism, and agro-processing. Existing studies commonly examine schools, campuses, museums, accommodation, or destination planning as separate typologies. Less attention has been given to an architectural system in which a living crop, supervised processing, public learning, product development, food service, retail, worship, storage, waste handling, and humid-tropical passive design are organized as one campus. This study asks two questions: how can a cocoa hub integrate production, education, tourism, and local commercialization while maintaining clear operational boundaries; and how can biophilic and climate-responsive principles be translated into traceable decisions about site, circulation, massing, envelope, landscape, water, and waste? The objective is to formulate a testable evidence-to-design framework rather than to claim realized building performance.

2. Methods

The study uses a research-by-design approach in which contextual analysis, program development, design synthesis, and critical evaluation are iterative. The evidence base comprises site observations and mapped information developed during the architectural design process; monthly rainfall and rainy-day data; district population data; two candidate-site assessments; precedent studies; user and activity schedules; room programs; site and circulation diagrams; utility concepts; and architectural drawings and visualizations. These materials were treated as design evidence rather than as post-occupancy data. Consequently, rendered images and stated design intentions were not interpreted as measured environmental performance.

The analysis was organized into five evidence groups: regional and socioeconomic context; climate and site conditions; users, activities, and operational requirements; spatial and area schedules; and architectural outputs. This classification was used to connect each design decision to a documented condition. Site analysis considered access, terrain, adjacent land use, views, solar exposure, reported wind direction, rainfall, noise, and available landscape. User analysis separated visitors, education participants, staff, production workers, service personnel, and community users. Activity mapping then identified which functions could be public, supervised, controlled, or service-only. Functional analysis is particularly important in sustainable educational buildings because environmental and social objectives depend on how activities and long-term operations are spatially coordinated. The evidence-to-design sequence is summarized in Figure 1. It shows how contextual and quantitative evidence is translated into spatial decisions, biophilic criteria, and an integrated design synthesis.



Source: Authors' analytical framework.

Figure 1. Evidence-to-design workflow linking context, quantitative checks, spatial translation, biophilic criteria, and design synthesis.

Two sites in Masamba were compared qualitatively. Alternative 1 along Jalan Lingkar Utara covers approximately 2.5 ha, has relatively level terrain, access from two principal directions, basic utility availability, and a cocoa-plantation setting. Alternative 2 covers approximately 1.8 ha near Jalan Ahwin Sanjaya but is smaller, steeper, and more constrained by surrounding settlement. Alternative 1 was selected because it provides greater capacity for productive landscape, outdoor learning, planted buffers, stormwater space, service separation, and future adjustment. The comparison was not a weighted multi-criteria decision model because the source evidence does not include validated criterion weights or expert scores.

The program was developed from user–activity relationships and organized into six principal facilities: a main education and processing building; greenhouse and drying facility; café, restaurant, and marketplace; prayer facility; storage; and waste bank. Facility-level areas reported in the design schedule were summed and converted to proportional shares. The total gross program is 3,482.1 m². Dividing this value by the 25,000 m² site gives a gross program-to-site ratio of 13.9%. Because the main building and food facility include more than one level, this ratio is used only as a scale indicator; it is not a legal building-coverage ratio.

Monthly rainfall and rainy-day data were analyzed descriptively. Annual total, monthly mean, median, sample standard deviation, coefficient of variation, minimum, maximum, and wettest-to-driest ratio were calculated.

Pearson's correlation coefficient was used only to describe the association between monthly rainfall depth and rainy-day frequency. With only 12 aggregated monthly observations and no documented multi-year record, daily intensity, return period, or seasonal frequency distribution, no inferential significance or long-term climatological claim is made. District population data for 15 listed districts were summarized using total, mean, median, sample standard deviation, proportional shares, and concentration in the three largest districts [19].

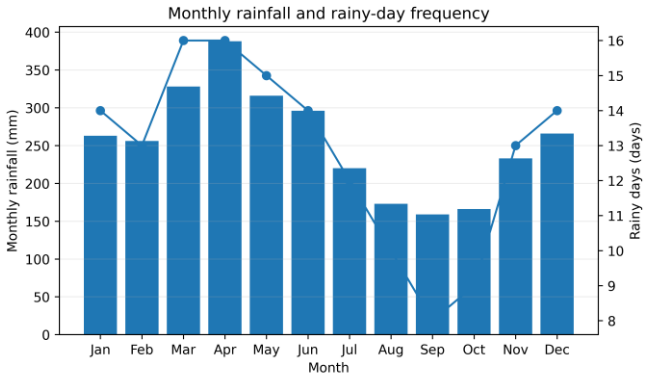
Design synthesis was assessed against four criteria. First, learning legibility required a coherent farm–process–product sequence that allows visitors to understand the cocoa value chain. Second, operational integrity required separation among public circulation, production, storage, loading, kitchen support, and waste handling while retaining controlled observation. Third, climatic and biophilic responsiveness required rain protection, shading, selective natural ventilation, daylight control, landscape contact, and material choices appropriate to a wet tropical environment. Fourth, circular resource logic required that rainwater and organic cocoa residues be spatially accommodated and made interpretable. The resulting proposal is evaluated internally against these criteria and against relevant literature; it is not presented as proof of measured comfort, energy, learning, health, or economic performance.

The study excludes detailed flood modeling, thermal simulation, computational fluid dynamics, daylight modeling, structural calculation, life-cycle assessment, production-throughput engineering, business feasibility, biodiversity assessment, and post-occupancy evaluation. These exclusions are deliberate. Research on certified green buildings demonstrates that modeled and measured performance can diverge because of assumptions, occupancy, operation, and user behavior [20]. The output of the present study is therefore a design hypothesis with an explicit validation agenda.

3. Findings and Discussion

3.1 Quantitative context and design implications

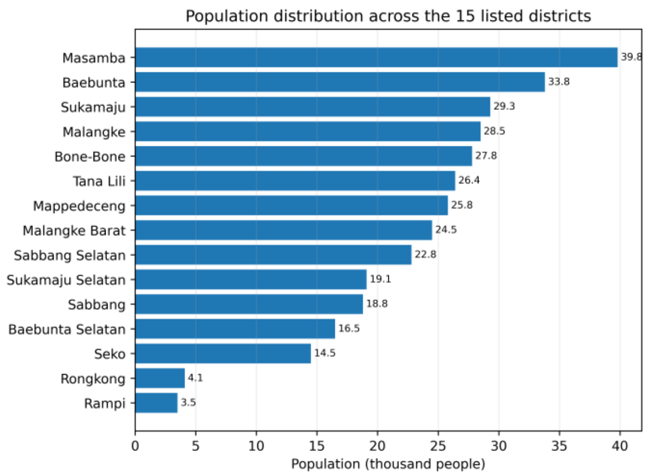
The available rainfall series describes a persistently wet environment with meaningful monthly variation. The 12 monthly values total 3,064 mm. Mean monthly rainfall is 255.3 mm, the median is 259.5 mm, and the sample standard deviation is 70.2 mm, producing a coefficient of variation of 27.5%. April is the wettest month at 388 mm and September the driest at 159 mm, so the wettest month receives approximately 2.44 times the rainfall of the driest. The series reports 154 rainy days, or 12.8 rainy days per month on average. Rainfall depth and rainy-day frequency are strongly associated descriptively (r = 0.947). The result is not used as an inferential climate model; it indicates that higher monthly rainfall generally coincides with more frequent wet days in the available record. As shown in Figure 2, months with greater rainfall generally also have more rainy days, with April as the wettest month and September as the driest.



Source: Author's calculation from the architectural design dataset

Figure 2. Monthly rainfall and rainy-day frequency in the available design dataset

These values support a design regime in which rain protection is part of normal operation rather than an occasional response. External learning cannot depend on exposed paths. Covered pedestrian links, deep eaves, protected thresholds, non-slip surfaces, visible drainage, and sheltered waiting areas are required to keep the campus usable during frequent wet conditions. Roof drainage must direct water away from entrances and observation points, while overflow routes should remain inspectable. Rainwater harvesting is plausible because supply is substantial, but tank sizing requires longer-term rainfall, catchment coefficients, storage objectives, water-quality criteria, and actual demand. Blue-green planning research supports this integration of water infrastructure, planting, and public interpretation, while emphasizing that technical performance depends on site-specific hydrology [21].



Source: Authors' calculation based on population data from BPS Kabupaten Luwu Utara [19].

Figure 3. Population distribution across the 15 listed districts.

The district population dataset totals 335.2 thousand people across 15 listed districts. Mean district population is 22.35 thousand, the median is 24.5 thousand, and the sample standard deviation is 9.97 thousand. Masamba is the largest listed district at 39.8 thousand people, followed by Baebunta at 33.8 thousand and Sukamaju at 29.3 thousand. Together, the three largest districts account for 30.7% of the listed population. Locating the hub in Masamba therefore places it near the largest population concentration and administrative service center represented in the dataset.

This supports accessibility, but it does not establish tourism demand, school visitation, production capacity, or economic feasibility; those variables require separate mobility, market, and stakeholder studies. Figure 3 shows that Masamba has the largest population among the 15 listed districts, followed by Baebunta and Sukamaju. Table 1 consolidates the principal site, rainfall, population, and program indicators and links each quantitative result to its corresponding design implication.

Table 1. Quantitative context and design implications

Indicator	Derived value	Design implication
Selected site area	25,000 m² (2.5 ha)	Campus arrangement with productive landscape and outdoor learning
Available rainfall total	3,064 mm	High-capacity drainage and rain-protected circulation
Monthly rainfall	255.3 ± 70.2 mm; CV 27.5%	Year-round wet-climate response
Rainy days	154 days	Covered links and weather-resilient learning areas
Rainfall–rainy-day association	r = 0.947	Frequent wet days shape visitor comfort and operations
Population represented	335.2 thousand	Regional catchment; not a demand forecast
Largest listed district	Masamba: 39.8 thousand	Supports location near the service center
Gross facility program	3,482.1 m²	Measurable cross-facility planning basis
Gross program/site ratio	13.9%	Land retained for planting, access, drainage, and buffers

Source: Authors' calculations based on site, rainfall, population, and architectural program data.

3.2 Site, program, and spatialized cocoa value chain

The selected triangular site allows the proposal to operate as a campus rather than a single object building. Arrival and public functions occupy the most legible road-facing portion, while the central area becomes a pedestrian learning landscape. Greenhouse, cultivation, storage, waste, and service functions are distributed toward more controlled zones. The site plan uses this geometry to establish a gradient from public arrival to productive landscape and operational support. Planted boundaries moderate road exposure, while the plantation-facing edges support cocoa plots, shaded pauses, and longer views. This approach is consistent with rural tourism research that treats landscape, livelihoods, visitor movement, and environmental protection as interdependent spatial assets rather than separate [4]. Figure 4 illustrates the resulting site organization, including the triangular plot, visitor-learning landscape, support facilities, and separated service areas.

Vehicular movement is organized as a loop that separates entry, drop-off, parking, and exit. Service access links receiving, storage, production support, kitchen supply, waste handling, and loading without crossing the principal visitor route. Pedestrians move through the landscaped center between the main building, greenhouse, cultivation areas, café and marketplace, prayer facility, and outdoor learning spaces. This separation is one of the proposal's most important functional results: visitors can see selected production activity through controlled views and supervised zones without entering hygiene-sensitive or hazardous work areas. Tourism-facility research reinforces the importance of circulation, sanitation, and operational compliance as part of visitor experience rather than as technical issues added after [22].

The total gross program is 3,482.1 m². The greenhouse and drying facility is the largest component at 1,000 m² (28.7%), followed by the main education and processing building at 787.2 m² (22.6%) and the café, restaurant, and marketplace at 694.9 m² (20.0%). The prayer facility accounts for 400 m² (11.5%), while storage and the waste bank each account for 300 m² (8.6%). The distribution confirms that exhibition does not dominate the proposal. Cultivation, drying, storage, waste, and processing occupy a substantial share of the program, allowing the visitor experience to remain anchored in productive functions rather than in display alone.

The visitor sequence spatializes the cocoa value chain. Arrival and orientation introduce the regional landscape and the role of cocoa. The main building then presents cocoa history, plant characteristics, cultivation, post-harvest transformation, and controlled views of processing and packing. Participation occurs through supervised product-making and testing activities. The route extends to nursery, greenhouse, drying, and landscape areas before reaching tasting, food service, and retail. In this sequence, purchasing becomes the end of a learning process rather than the organizing purpose of the visit. Experiential-learning research supports the value of linking abstract information to direct observation and inquiry, while multisensory interpretation can deepen understanding when digital media supports rather than replaces physical experience [23].

The route is intentionally legible but not completely rigid. Guided school groups can follow the full sequence, whereas independent visitors can use shorter loops and rest points. This balance matters because restorative and tourism research shows that experience quality depends on coherence, choice, activity, natural settings, and place attachment rather than on a single fixed route [24,25]. The campus therefore includes active courts, shaded social spaces, quieter edges, and optional observation points. These spatial differences support different ages, visit durations, learning objectives, and degrees of participatio. Table 2 summarizes the gross area allocation, primary function, and principal biophilic response of each facility.

Source: Author's architectural design dataset.

Figure 4. Developed site plan showing the triangular plot, visitor-learning landscape, support facilities, and controlled service areas.

Table 2. Gross program allocation and principal biophilic response

Facility	Area (m²)	Share (%)	Primary role	Principal biophilic response
Education & processing	787.2	22.6	Interpretation, processing, workshops	Planted court, daylight, views, mixed-mode ventilation
Greenhouse & drying	1,000.0	28.7	Seedlings, cultivation, drying	Plant contact, airflow, seasonal processes
Café, restaurant & marketplace	694.9	20.0	Retail, tasting, dining	Shaded terraces and indoor–outdoor space
Prayer facility	400.0	11.5	Worship and quiet support	Quiet planting, daylight, ventilation
Storage	300.0	8.6	Harvest and equipment storage	Buffered, durable envelope
Waste bank	300.0	8.6	Sorting and composting	Visible cycles and separate service access

3.3 Biophilic and climate-responsive architecture

Biophilic design is translated across landscape, envelope, interior, and infrastructure rather than concentrated in decorative planting. Direct experience of nature is provided by cocoa cultivation, nursery areas, shade trees, water movement, daylight, air movement, and landscape views. Indirect experience appears through timber, bamboo, stone, texture, pattern, and biomorphic geometry. Spatial experience is structured through prospect, refuge, shaded thresholds, planted courts, and transitions among enclosed, semi-open, and outdoor environments. Studies of educational settings support this multi-dimensional reading: nature connection is strongest when daylight, views, outdoor access, materials, and spatial flexibility work together, and user response varies with configuration and context [9,12].

The main building's curved form is derived from the profile of a split cocoa pod, but the formal reference is used only where it supports program and identity. The geometry frames a planted court, creates a recognizable center within the campus, and helps structure the visitor route. It is not treated as environmental performance in itself. Regional projects in Makassar and Luwu similarly demonstrate how biophilic public architecture can connect natural light, ventilation, vegetation, social programs, and cultural identity [17]. The cocoa hub extends this regional design language by adding active processing, supervised interpretation, productive landscape, and resource-recovery functions. Figure 5 compares the campus-scale composition with the architectural expression of the main education-processing building.

Source: Author's architectural design dataset.

Figure 5. Campus-scale and building-scale expression: (a) aerial perspective and (b) main education-processing building.

Natural ventilation is proposed selectively. Galleries, circulation, workshops, dining terraces, and other lower-risk public spaces use opposing openings, high-level outlets, elevated roof volumes, and semi-open transitions to encourage air movement. Processing, packing, cold storage, kitchens, and selected product-development rooms are treated as mixed-mode or mechanically controlled spaces because unrestricted openness could compromise temperature, insects, cleanliness, odor, or product quality. This room-by-room distinction is essential in a wet tropical agro-industrial facility. Tropical educational-building research identifies cross-ventilation as an effective strategy but also shows that thermal and visual performance depends on geometry, roof opening, daylight, and green area [13].

Daylight is similarly moderated rather than maximized. Morning and diffuse light can support galleries, circulation, and workshops, while western exposure is reduced through deep overhangs, vertical or horizontal shading, vegetation, and limited unprotected glazing. Skylights are appropriate only where glare, heat gain, leakage risk, and maintenance can be controlled. Indonesian studies using climate-responsive assessment tools show the potential of natural ventilation, shading, and water-efficiency strategies, but modeled savings remain dependent on climate files and operational assumptions [14,15]. The current design therefore treats passive strategies as configurations to be simulated and measured, not as guaranteed outcomes.

Material selection follows the same performance logic. Timber, bamboo, stone, and textured finishes can strengthen place identity and sensory connection, but frequent rainfall and high humidity demand protected bases, ventilation, replaceable detailing, inspection access, and durable finishes. Natural materials are concentrated in visitor and transition spaces where tactile and visual value is high; food preparation, processing, sanitation, and selected storage areas require washable and moisture-resistant surfaces. The aim is not to maximize the quantity of natural material but to place it where service life and maintenance capacity are compatible with the desired biophilic experience.

Source: Author's architectural design dataset.

Figure 6. Selected learning and visitor environments: (a) greenhouse, (b) café–restaurant, (c) main lobby, and (d) cocoa-history gallery.

Table 3. Design propositions and required validation

Design proposition	Intended function	Required validation before implementation
Rain-protected semi-open network	Year-round learning continuity and shaded movement	Drainage study, weather observation, accessibility and slip-resistance review
Selective natural ventilation	Thermal comfort in suitable public and learning spaces	Air-speed, temperature, humidity and indoor- air-quality assessment
Filtered daylight and shading	Visual comfort with reduced solar exposure	Daylight, glare, solar-gain and façade-maintenance analysis
Productive cocoa landscape	Learning, place identity and microclimatic moderation	Planting plan, irrigation demand, biodiversity and visitor-learning evaluation
Rainwater and blue-green systems	Non-potable supply, runoff moderation and environmental interpretation	Water balance, infiltration, storage, overflow and water-quality design
Waste bank and composting	Visible circularity and reduced organic waste	Waste audit, odor, pest, leachate, hygiene and collection assessment
Natural material strategy	Tactile connection and regional identity	Moisture durability, sourcing, service-life and maintenance review

The proposal also acknowledges cultural and daily routines. The prayer facility is located in a quieter planted zone with straightforward access from public and staff areas while remaining separated from loading, kitchens, and waste operations. A recent biophilic educational project in Wajo demonstrates how light, air, vegetation, water, privacy, and spiritual routines can be coordinated within a rural institutional environment. In the cocoa hub, the prayer facility contributes to inclusive daily operation rather than functioning as a symbolic add-on. Its performance still depends on clean ablution, privacy, acoustic calm, accessibility, and maintenance. Figure 6 presents four key visitor environments: (a) the greenhouse, (b) the café–restaurant, (c) the main lobby, and (d) the cocoa-history gallery. Table 3 translates the principal design propositions into a validation agenda by pairing each intended function with the analyses required before implementation.

3.4 Circular systems, governance, transferability, and validation

Water, energy, and waste systems are treated as visible parts of the learning environment. Municipal or verified potable supply serves drinking and food-related needs, while roof runoff is reserved conceptually for irrigation and other approved non-potable uses after appropriate treatment. Domestic wastewater and cocoa-process wastewater are separated because their loads and treatment requirements may differ. Planted drainage, swales, storage, and overflow areas can make water movement understandable to visitors while improving site resilience, but final dimensions require topographic survey, soil infiltration data, rainfall intensity, water-quality targets, and maintenance planning [21].

The waste bank distinguishes organic, recyclable, and residual streams. Suitable cocoa pods, leaves, landscape residues, and food organics can be directed toward controlled composting and returned to productive planting, while recyclables are sorted and stored for collection. The educational value of this system lies in showing that value creation also produces residues and that environmental responsibility continues after consumption. The service route keeps waste movement away from primary visitor and food paths, while observation and interpretation remain possible from safe points. Circular tourism research likewise shows that material cycles and participation can strengthen local meaning when they are operationally credible rather than staged [26].

Circularity introduces risks that must be engineered. Composting can generate odor, pests, leachate, and contamination; process wastewater may require treatment beyond domestic systems; and rainwater storage can become ineffective if supply, demand, overflow, and cleaning are not balanced. The current design's contribution is to reserve space, routes, and visibility for these systems. It does not prescribe final technology. Solar panels are likewise treated as a supplementary energy concept whose capacity must follow load reduction, roof-area assessment, orientation, shading analysis, and actual electrical demand.

Architecture alone cannot ensure rural value addition. Governance determines who can access training, operate processing equipment, sell products, use the marketplace, and participate in revenue. Indonesian participatory-design research demonstrates that local ecological knowledge, farming culture, craft, and community priorities are more effectively integrated when stakeholders shape the program rather than merely review a finished design [27]. For the cocoa hub, farmers, processors, schools, women's and youth groups, micro-enterprises, tourism operators, religious representatives, local government, and universities should test the proposed sequence, training model, marketplace rules, and maintenance responsibilities before implementation.

The architectural framework is transferable, but the cocoa-pod form is not the transferable component. The method is: map the commodity chain; identify which stages can be observed safely; separate public, production, and service risks; connect learning to productive landscape; translate climate evidence into envelope and infrastructure decisions; and pair intended benefits with validation measures. Coffee, tea, fruit, spices, or fisheries would require different processing environments and narratives. What can transfer is the use of architecture to make production, ecology, and value creation understandable as one system.

Biophilic studies in schools, campuses, and museums use questionnaires, behavioral observation, environmental measurements, and spatial analysis to examine attention, satisfaction, social interaction, attachment, and perceived restoration [11,28,29]. For this project, evaluation should additionally measure route legibility, learning outcomes, staff efficiency, accessibility, indoor temperature and humidity, air speed, daylight, energy and water use, waste diversion, landscape health, local-product sales, and producer participation. Only these data can determine whether the proposed relationships actually work.

Several limitations remain. The rainfall series does not document the observation period and cannot support design-storm or return-period calculations. Wind information lacks speed and seasonal frequency. Noise is qualitative. Population data cannot predict visitor demand. Production throughput, staff numbers, equipment dimensions, capital cost, operating cost, and phasing are not fully specified. The proposal also lacks quantified thermal, daylight, energy, water, acoustic, structural, fire, life-cycle, and economic performance. These limitations do not invalidate the design-research contribution, but they define the boundary between a coherent architectural hypothesis and an implementable building.

Before construction, the proposal should therefore undergo topographic and geotechnical surveys; flood and drainage assessment; verified weather analysis; solar, daylight, and airflow simulation; food-safety and process mapping; equipment planning; universal-access and fire review; structural engineering; water and waste design; cost analysis; and stakeholder co-design. After occupation, measured performance should be compared with design assumptions. This staged validation responds directly to evidence that certified or simulated green performance can differ from actual operation [20]. It also protects the study from equating a visually convincing rendering with environmental success.

4. Conclusion

This study develops an integrated architectural framework for a biophilic cocoa processing, education, and tourism hub in Masamba, Luwu Utara. The central design move is to spatialize the cocoa value chain rather than to create a themed attraction. Cultivation, nursery activity, drying, processing, interpretation, supervised product making, tasting, retail, and resource recovery are arranged as a coherent visitor-learning sequence, while production, loading, storage, kitchens, waste, and other service functions retain controlled circulation. This organization allows selected operations to become educational without sacrificing safety, hygiene, or continuity.

The available quantitative evidence strengthens the spatial argument. The monthly rainfall series totals 3,064 mm and includes 154 rainy days, supporting protected circulation, deep roof edges, robust drainage, shaded transitions, and rainwater management. The 2.5-ha selected site accommodates a 3,482.1-m^2 gross program while retaining substantial land for productive planting, access, outdoor learning, buffers, and stormwater functions. Masamba is the largest listed district in the 335.2-thousand-person population dataset, supporting its role as an accessible hub while not substituting for a future demand study.

Biophilic design is operationalized through cocoa-landscape views, planted courts, selective natural ventilation, filtered daylight, natural materials, prospect and refuge, productive landscape, and visible water and organic-waste cycles. The contribution lies in joining these strategies to a working agricultural and educational system. Nature is treated simultaneously as productive resource, climatic infrastructure, learning content, sensory experience, and place identity. The framework is transferable to other commodity regions through its method—map the value chain, separate operational risks, connect learning to landscape, translate climate evidence into design decisions, and define validation for each intended benefit—rather than through a fixed formal image.

The proposal remains a testable design hypothesis. Hydrological modeling, thermal and daylight simulation, process and hygiene design, structural and fire engineering, life-cycle and economic assessment, participatory co-design, and post-occupancy evaluation are required before implementation. Subject to those steps, the cocoa hub offers a credible architectural model for rural regions seeking to retain local value, strengthen experiential education, and develop tourism without reducing agriculture to branding or biophilia to decoration.

Statements and Declarations

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve the clarity and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Nova Ibrahim: Conceptualization; Methodology; Investigation; Formal analysis; Data curation; Visualization; Writing – original draft; Project administration. Sahabuddin Latif: Conceptualization; Methodology; Validation; Writing – review & editing; Supervision. Citra Amalia Amal: Investigation; Resources; Visualization; Writing – review & editing. A. Syahriyunita Syaharuddin: Investigation; Data curation; Formal analysis; Visualization; Writing – review &

editing. Rohana: Investigation; Resources; Data curation; Writing – review & editing. Muh. Syarif: Validation; Resources; Writing – review & editing; Supervision. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The architectural design data, analysis outputs, and drawings supporting the findings of this study are available from author. Publicly available population data are accessible from the source identified in the reference list.

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