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INTEGRATING BIOPHILIC DESIGN AND ECO-VILLAGE CONCEPTS FOR SUSTAINABLE WATER TOURISM DEVELOPMENT: A CASE STUDY OF BAH TIO ECO-VILLAGE, PEMATANG SILAMPUYANG SPRING, SIANTAR DISTRICT, SIMALUNGUN REGENCY, NORTH SUMATRA, INDONESIA

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Abstract

Indonesia's spring-based water tourism possesses significant potential but faces challenges in unsustainable management, limited design innovation, and weak community linkages. **This study aims** to develop an integrated framework for Bah Tio Eco-Village, North Sumatra, by combining Biophilic Design and Eco-Village principles. **Employing qualitative descriptive methods**, data were collected via site observation, stakeholder interviews, and comparative analysis with regional and international cases. The framework operationalizes key biophilic patterns Visual Connection with Nature, Biomorphic Forms & Patterns, and Thermal & Airflow Variability within Eco-Village dimensions of ecological integrity, social empowerment, and mushroom-centered circular economy. Results demonstrate enhanced visitor restoration, environmental preservation, and inclusive local economic development. **The novelty** lies in translating biophilic spatial strategies into a place-based, spring-centered eco village model with low-impact engineering and community governance. This replicable model contributes to sustainable and regenerative water tourism in tropical agricultural landscapes.

Kata Kunci: Biophilic Design; Eco-Village; Pariwisata Air Berkelanjutan

Abstrak

Pariwisata berbasis mata air di Indonesia memiliki potensi besar namun menghadapi masalah pengelolaan tidak berkelanjutan, inovasi desain terbatas, dan lemahnya keterkaitan dengan masyarakat. **Penelitian ini bertujuan** mengembangkan kerangka integratif untuk Bah Tio Eco-Village, Sumatera Utara, dengan menggabungkan prinsip Biophilic Design dan Eco-Village. **Metode deskriptif kualitatif** digunakan, dengan pengumpulan data melalui observasi lapangan, wawancara pemangku kepentingan, dan analisis komparatif dengan kasus regional dan internasional. Kerangka ini mengoperasionalisasi pola biophilic utama Visual Connection with Nature, Biomorphic Forms & Patterns, dan Thermal & Airflow Variability dalam dimensi Eco Village: integritas ekologi, pemberdayaan sosial, dan ekonomi sirkular berbasis jamur. Hasil menunjukkan peningkatan restorasi pengunjung, pelestarian lingkungan, dan pembangunan ekonomi lokal inklusif. **Kebaruan** terletak pada penerjemahan strategi spasial biophilic ke model eco village berbasis mata air dengan rekayasa berdampak rendah dan tata kelola komunitas. Model ini dapat direplikasi untuk pariwisata air berkelanjutan di lanskap perkebunan tropis.

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INTRODUCTION

Indonesia's archipelagic geography endows the nation with exceptional water tourism assets, ranging from volcanic lakes and crater lakes to pristine springs and coastal ecosystems. The post-pandemic recovery of Indonesia's tourism sector has placed renewed emphasis on sustainable, community-based, and nature-integrated models that align with the Sustainable Development Goals (SDGs), particularly SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land) [1], [2]. Despite policy frameworks promoting "Tourism 5.0" and regenerative tourism, many water-based destinations—especially those located within agricultural landscapes continue to suffer from ad-hoc development, environmental degradation, and limited economic multiplier effects for host communities [3], [4].

Bah Tio, situated in Pematang Silampuyang, Siantar District, Simalungun Regency, North Sumatra, exemplifies both the promise and the predicament of Indonesia's inland water tourism. Located approximately 140 km from Medan (≈3 hours travel) and 12 km from Pematang Siantar, the site features a natural spring pool renowned for its exceptional clarity and mineral-like quality, earning the local moniker "Aqua pool." The 11.7-hectare site lies within an extensive oil palm (Elaeis guineensis) plantation that also supports spontaneous growth of edible mushrooms, creating a unique agro-ecological context. Topographically, the area is characterized by undulating hills with the Silampuyang River flowing approximately 200 m to the north. While the combination of clear water, tropical vegetation, and proximity to major transport corridors (Parapat Road) presents significant tourism potential, current conditions reveal critical deficiencies: absence of proper water-flow management and natural filtration systems, minimal supporting facilities (toilets, seating, interpretation), inadequate parking and accessibility, fragmented land ownership and governance, and negligible utilization of the local mushroom resource for community benefit [5], [6].

These challenges are not isolated. Across North Sumatra and similar plantation-dominated regions, water tourism sites frequently exhibit a disconnect between ecological assets and design responses, resulting in lost opportunities for biodiversity enhancement, climate-resilient infrastructure, and inclusive local economies. The COVID-19 pandemic further exposed vulnerabilities in conventional tourism models, accelerating demand for destinations that prioritize health, nature connection, and community resilience [7], [8]. In this context, the integration of Biophilic Design defined as the deliberate incorporation of natural elements, patterns, and processes into the built environment to foster human well-being and ecological stewardship [9] with the Eco-Village paradigm which emphasizes ecological restoration, social cohesion, and localized circular economies [10] offers a theoretically robust and practically actionable pathway.

Table 1. Key Site Characteristics, Challenges, and Development Opportunities at Bah Tio, Pematang Silampuyang

Aspect	Current Condition / Asset	Key Challenge	Development Opportunity
Location & Access	≈140 km from Medan; concealed within palm plantation; Parapat Road proximity	Limited signage & wayfinding; seasonal access constraints during heavy rain	Develop integrated signage system with biophilic materials; improve all-weather permeable access roads
Water Resource	Exceptional clarity spring pool ('Aqua pool'); natural	Absence of water quality monitoring,	Implement plant-based biofiltration + real-time

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	mineral quality	filtration, or flow management	monitoring; develop refillable drinking water educational system
Land Use & Ecology	Oil palm plantation with spontaneous edible mushroom growth; hilly topography; river proximity (≈200 m)	Monoculture dominance; limited biodiversity corridors; soil compaction from informal parking	Introduce native understory & mushroom cultivation zones; create green corridors; apply regenerative agroforestry principles
Infrastructure & Facilities	Minimal (no dedicated toilets, seating, or interpretation)	Visitor comfort & safety compromised; no educational or commercial facilities	Design clustered, low-impact facilities using local wood/stone; mushroom-themed playground & interpretation nodes
Governance & Community	Fragmented land ownership; limited local economic linkage	Low community participation; economic leakage to external actors	Establish multi-stakeholder Eco-Village cooperative; mushroom value-chain enterprise; capacity building programs
Climate & Comfort	Tropical humid climate; high solar radiation; variable rainfall	Heat stress in open areas; lack of shaded microclimates	Apply Thermal & Airflow Variability via green roofs, cross-ventilation, tree canopies, and water bodies
Tourism Potential	High scenic & experiential value; proximity to Parapat & Lake Toba circuit	Undifferentiated product; low length-of-stay & spending	Position as signature 'Biophilic Spring Wellness & Learning Destination' within Toba Caldera UNESCO Global Geopark context
Sustainability Alignment	Strong latent alignment with SDGs and Indonesia's sustainable tourism agenda	No formal sustainability framework or certification pathway	Target GSTC or similar certification; integrate circular economy (mushroom, water, waste) metrics

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Figure 1. Documentation

The urgency of this research is further underscored by global publication trends. While research on biophilic design in tourism settings has grown steadily (from approximately 12 Scopus-indexed publications in 2020 to over 62 in 2025), integrated studies combining biophilic design with eco-village frameworks specifically for water-spring tourism in Indonesian plantation contexts remain scarce (Figure 2). This gap represents both a scholarly opportunity and a practical imperative for evidence-based design interventions that can be adapted across similar agro-tourism landscapes in Sumatra and beyond.

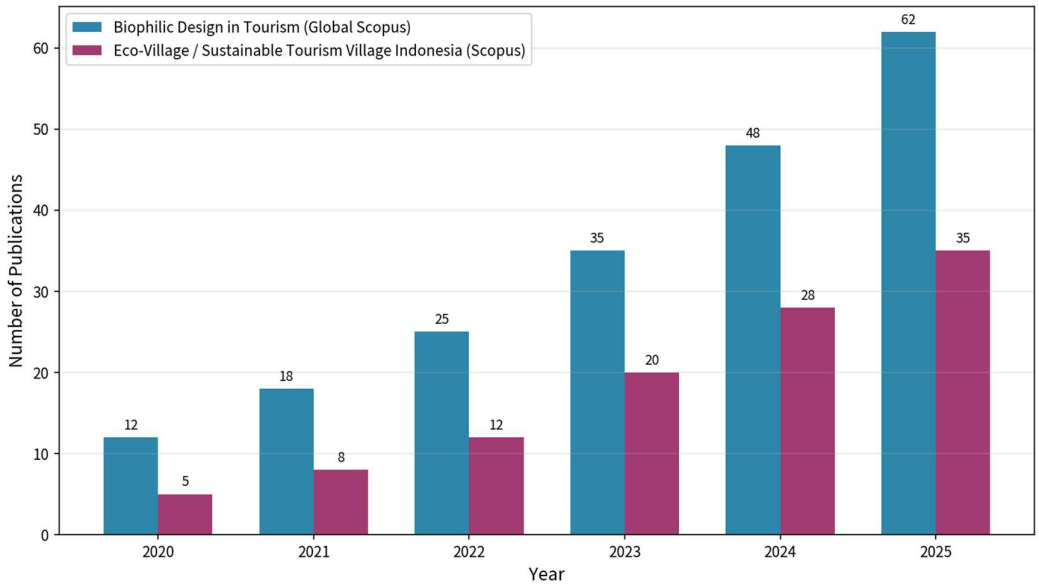

Figure 2. Research publication trends (Scopus-indexed) comparing global output on biophilic design in tourism contexts versus eco-village/sustainable tourism village studies focused on Indonesia (2020–2025). The widening gap highlights the novelty and timeliness of an integrated biophilic eco-village framework for Indonesian water tourism sites.

Research Objectives

This study is guided by the following interconnected objectives, designed to bridge the identified research-practice gap through a rigorous, context-sensitive design framework:

1. To comprehensively assess the biophysical, socio-economic, and governance characteristics of the Bah Tio site, identifying leverage points for sustainable water tourism development within the oil palm plantation matrix.
2. To synthesize and adapt core Biophilic Design patterns (with emphasis on

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Biomorphic Forms & Patterns, Visual Connection with Nature, and Thermal & Airflow Variability) and Eco-Village principles (ecological, social, and economic dimensions) into a cohesive design language appropriate for tropical spring-based tourism in agricultural landscapes.

3. To formulate a multi-zonal master plan and detailed design guidelines for key facilities—including educational workshops, recreational nodes, community enterprise hubs, and supporting infrastructure—that optimize visitor experience, environmental performance, and local economic multipliers.
4. To validate the proposed framework through comparative analysis with analogous sustainable water tourism and biophilic/eco-village projects in Indonesia and internationally, while incorporating stakeholder perspectives from local communities, government agencies, and tourism operators.
5. To articulate actionable policy, planning, and implementation recommendations that support community empowerment, circular economy development (particularly around mushroom resources), and alignment with Indonesia's sustainable tourism and SDG commitments.

State of the Art

A substantial body of international and Indonesian scholarship has explored biophilic design, eco-village models, and sustainable water tourism independently. However, their synergistic integration particularly in the context of spring-fed water tourism within monoculture plantation landscapes remains underexplored. Table 2 synthesizes key contributions that inform the present study, highlighting methodological approaches, core design strategies, and identified limitations or gaps that the current research addresses.

Table 2. State of the Art: Comparative Synthesis of Previous Studies on Biophilic Design, Eco-Village Concepts, and Sustainable Water Tourism (Selected Works 2020–2025)

Author(s) / Year	Focus / Location	Key Biophilic / Eco-Village Elements	Methodology	Main Findings	Gap / Relevance to Bah Tio
Salsabila & Anwar (2023) [11]	Four-star resort, Bali, Indonesia	Biomorphic forms, Visual Connection with Nature, Thermal & Airflow Variability; eco-modern concept	Qualitative case study; design analysis	Biophilic strategies significantly enhance guest comfort, well-being, and environmental perception in tropical resort settings	Limited community empowerment & local resource circularity; no explicit eco-village integration
Safitri et al. (2021) [12]	Convention & Expo Center, Surakarta, Indonesia	Biophilic patterns integrated with futuristic architecture; natural materials & landscape	Design research; simulation	Futuristic + biophilic hybrid creates responsive public spaces; improves user experience & environmental performance	Primarily urban/institutional; less emphasis on tourism experience & community enterprise
Rajović & Bulatović (2015, updated context)	Eco-Village 'Štavna', Montenegro	Agricultural production, biodiversity (>300 plant species), small-scale	Case study; sustainability assessment	Eco-village model successfully links healthy food systems,	Temperate climate; limited application to tropical spring/water tourism contexts

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[13]		industries; ecological-social-cultural dimensions		tourism, and community livelihoods within botanically rich settings	
Nilawati et al. (2017, updated 2023–2025) [14]	Upper Citarum Watershed Eco-Village, Indonesia	Agricultural waste management, community recycling, collective environmental responsibility	Sustainability evaluation (ecological, economic, social)	Small-scale collective actions are pivotal for eco-village viability; waste-to-resource loops critical	Watershed focus; less attention to biophilic spatial experience & tourism product development
Sholanke et al. (2025) [15]	Sustainable housing, Nigeria (framework adaptable)	Biophilic principles for housing; upcycled materials; framework for restorative environments	Mixed methods; framework development	Biophilic integration fosters human-nature reconnection and supports sustainable housing performance	Housing scale; transferable principles for tourism facilities in tropical contexts
Fagam et al. (2025) [16]	Eco-tourism resorts, tropical/subtropical (Nigeria, Fiji, Mexico)	Natural lighting/ventilation, local materials, views/prospects, natural forms	Comparative qualitative assessment of 5 biophilic features	Only natural lighting & ventilation consistently well-implemented; local materials & biomorphic forms often underutilized	Directly relevant; highlights implementation gaps that Bah Tio design explicitly addresses through mushroom-themed biomorphism & local resource loops
Muda (2026) [17]	Sustainable tourism villages, Indonesia (Pentahelix SLR)	Collaborative governance (government-academia-business-community-media); inclusive development	PRISMA systematic literature review (40 articles)	Multi-actor collaboration drives innovation & capacity building but faces power asymmetries & coordination gaps	Governance dimension critical for Bah Tio; Pentahelix model informs recommended multi-stakeholder cooperative structure
Tabari (2025) [18]	Biophilic design & urban resource management, general	Natural light, ventilation, native vegetation, water elements, biomimetic patterns; resource optimization	Theoretical-practical framework development	Purposeful overlap of biophilic strategies with resource management enhances environmental performance & urban resilience	Urban focus; principles highly transferable to eco-village water & energy systems at Bah Tio

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Collectively, these studies demonstrate that biophilic strategies reliably improve user comfort, psychological restoration, and environmental performance, while eco-village models excel at fostering community agency and circular resource flows. However, few works have operationalized their intersection in a tropical spring tourism setting embedded within a working agricultural landscape, nor have they explicitly leveraged unique local biological resources (such as spontaneous mushroom growth) as both educational and economic pillars. The present study addresses this precise lacuna by constructing a context-specific, multi-dimensional framework for Bah Tio Eco-Village

Research Gap and Novelty

Analysis of the publication landscape (Fig. 2) and the comparative synthesis in Table 2 reveals several interrelated gaps that this research directly targets:

1. Contextual Gap: While biophilic design has been applied in Balinese resorts and urban institutional buildings in Indonesia, there is a paucity of research on its application to inland spring-based water tourism within oil palm plantation matrices characteristic of North Sumatra and similar regions.
2. Integration Gap: Existing literature tends to treat biophilic design (primarily spatial/experiential) and eco-village concepts (primarily process/governance/economic) in isolation. Integrated frameworks that simultaneously optimize visitor biophilic experience, ecological regeneration, and community economic empowerment through localized circular economies (e.g., mushroom value chains) are rare.
3. Resource-Specific Gap: The spontaneous presence of edible mushrooms beneath palm canopies represents a distinctive socio-ecological asset that has not been systematically incorporated into tourism design or community enterprise models in comparable Indonesian studies.
4. Water-Centric Gap: Few studies have developed plant-based or nature-mimicking water filtration, refillable drinking water education systems, and hydrological management strategies as core interpretive and sustainability features of spring tourism destinations.

The novelty of this research lies in its holistic, place-based synthesis: it advances a replicable design and governance framework that (a) translates selected 14 Patterns of Biophilic Design into tangible spatial strategies for a spring-pool core; (b) embeds these within an Eco-Village zoning model that privileges community ownership and mushroom-centered circular economy; (c) incorporates climate-responsive and low-impact engineering solutions (permeable surfaces, green roofs, natural ventilation, solar integration); and (d) positions the destination within broader regional tourism circuits (Toba Caldera Geopark) while generating measurable co-benefits for biodiversity, water security, education, and local livelihoods. This integrated approach responds directly to the publication and implementation gaps identified and offers a model adaptable to other spring and water-body tourism sites across Indonesia's agricultural heartlands.

Literature Review

This section synthesizes the theoretical foundations underpinning the proposed Bah Tio Eco-Village framework, drawing on seminal and recent contributions in biophilic design, eco-village studies, and sustainable water tourism.

Biophilic Design: Theoretical Foundations and Patterns

The biophilia hypothesis, popularized by E.O. Wilson and operationalized in design by Stephen Kellert and colleagues, posits an innate human tendency to affiliate with natural systems and processes [9], [19]. Browning, Ryan, and Clancy's seminal "14 Patterns of Biophilic Design" (2014, updated iterations) provide a practical taxonomy organized into three categories: Nature in the Space (e.g., Visual Connection with Nature, Non-Visual Stimuli, Thermal & Airflow Variability), Natural Analogues (Biomorphic Forms & Patterns, Material Connection with Nature, Complexity & Order), and Nature of the Space (Prospect & Refuge, Mystery, etc.) [20]. Empirical studies consistently link exposure to these patterns with reduced stress, improved cognitive performance, enhanced creativity, and pro-environmental

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attitudes [21], [22]. In tourism contexts, biophilic interventions have been shown to elevate guest satisfaction, length of stay, and willingness to pay premiums for authentic nature-connected experiences [11], [16], [23].

For Bah Tio, three patterns are prioritized for their direct relevance to the site's hydrology, vegetation, and microclimate: (1) Visual Connection with Nature—maximized through organic circulation paths, viewing platforms, and the central spring as a focal "prospect"; (2) Biomorphic Forms & Patterns—translated into mushroom-inspired play structures, palm-trunk-like support columns, and flowing water channels that echo natural forms; and (3) Thermal & Airflow Variability achieved via cross-ventilation in pavilions, green roofs, strategic tree canopies, and the cooling effect of the spring pool itself. These choices are further supported by recent Southeast Asian and tropical studies demonstrating the efficacy of such patterns in humid climates [15], [18], [24].

Eco-Village Concept and Community-Centered Sustainability

Eco-villages, as defined by the Global Ecovillage Network (GEN), are intentional or traditional communities that strive to integrate ecological, social, and spiritual dimensions of sustainability through participatory governance and localized economies [10], [25]. Core principles include closed-loop resource systems (water, waste, energy, food), biodiversity enhancement, social equity, and the revitalization of traditional ecological knowledge. In the Indonesian context, eco-village and sustainable tourism village (desa wisata berkelanjutan) initiatives have gained momentum, often leveraging Pentahelix or multi-stakeholder collaboration models involving government, academia, business, community, and media [17], [26]. Successful examples demonstrate that small-scale, community-owned enterprises particularly those adding value to local biological resources can generate meaningful income while reinforcing conservation incentives [14], [27].

At Bah Tio, the Eco-Village lens is applied by treating the spontaneous mushroom resource as the nucleus of a circular economy: cultivation training, processing (drying, packaging, value-added products), on-site sales, and educational tours create layered revenue streams and skill development for residents. This approach mirrors successful agro-ecotourism models while addressing the specific gap in mushroom-centered community enterprise identified in the literature [28]. Governance is envisioned through a multi-stakeholder cooperative aligned with Pentahelix principles, ensuring equitable benefit sharing and long-term stewardship.

Sustainable Water Tourism and Nature-Based Solutions

Sustainable water tourism emphasizes the responsible use and interpretation of aquatic resources, often incorporating nature-based solutions (NBS) for water management, education, and experience design [29], [30]. Best practices include constructed wetlands or plant-based biofiltration for water polishing, real-time quality monitoring as an interpretive tool, refillable systems that reduce single-use plastics, and zoning that protects sensitive hydrological features while allowing controlled access. International precedents (e.g., Aqua Tourist Center near mangroves) and Indonesian cases (hot spring developments with tropical architectural responses) underscore the importance of integrating water infrastructure with educational programming and aesthetic experience [31], [32]. The Bah Tio framework adopts these principles by centering the spring as both recreational asset and living classroom for water stewardship, with mushroom cultivation zones designed to enhance rather than compete with hydrological functions.

RESEARCH METHODS

Research Design and Methodological Framework

This study adopts a qualitative descriptive research design, following the framework articulated by Lexy J. Moleong (1989, with subsequent methodological refinements) [33]. Qualitative descriptive research is particularly suited to design-oriented inquiries that seek to understand phenomena in depth, generate context-rich descriptions, and produce actionable design recommendations grounded in

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real-world conditions. The approach is inherently iterative, allowing continuous refinement of design concepts through triangulation of observational, interview, and documentary evidence.

Site Description

The study site encompasses approximately 11.7 hectares within the oil palm plantation of Pematang Silampuyang, Siantar District, Simalungun Regency, North Sumatra (coordinates approximately 2.95°N, 99.05°E). The central feature is a natural spring pool with exceptional water clarity. The site is bounded by the Silampuyang River to the north (≈200 m distance) and Parapat Road to the south. Topography is undulating to hilly, with elevations supporting natural drainage toward the river. Existing vegetation is dominated by mature oil palms with understory fungi; scattered secondary forest patches and riparian vegetation occur along the river corridor. Land tenure is characterized by a mosaic of private plantation holdings and community or adat claims, necessitating careful stakeholder mapping.

Data Collection Methods

Primary data were collected through four complementary techniques:

1. Direct Observation and Documentation: Systematic site surveys documenting topography, hydrology, vegetation, existing informal uses, access points, and microclimatic conditions. Photographic and videographic documentation supported spatial analysis and design visualization.
2. Semi-Structured Interviews: Conducted with key informants including local community leaders, plantation managers, tourism operators, district government officials (tourism and spatial planning agencies), and potential visitors. Interview protocols explored perceptions of development potential, concerns regarding environmental and social impacts, land ownership dynamics, and aspirations for community benefit sharing.
3. Survey and Mapping: On-site measurement of key parameters (distances, slopes, water flow indicators) and participatory mapping exercises with community members to identify valued resources and conflict zones.
4. Secondary Data Analysis: Compilation and critical review of statistical data from Badan Pusat Statistik (BPS) Simalungun (population, tourism-related metrics), spatial plans (RTRW), environmental reports, and relevant academic literature.

Data Analysis Framework

Analysis proceeded through four integrated streams, each aligned with biophilic and eco-village principles:

1. Site Analysis: Evaluation of solar orientation, prevailing wind patterns, hydrological flows, existing vegetation structure, and visual corridors to inform building placement, orientation, and biophilic integration (e.g., maximizing visual access to the spring and creating shaded microclimates).
2. Building Mass and Zoning Analysis: Assessment of Floor Area Ratio (FAR), Building Coverage Ratio (BCR), and optimal clustering to minimize ecological footprint while supporting functional separation of educational, recreational, commercial, and supporting activities. Two alternative zoning configurations were modeled and comparatively evaluated.
3. Material and Structural Analysis: Review of locally available, low-embodied-energy materials (timber from sustainable sources, river stone, bamboo, recycled aggregates) and structural systems compatible with biophilic expression and climate responsiveness.
4. Utility and Infrastructure Analysis: Design of integrated systems for water supply (spring protection + biofiltration), wastewater (constructed wetlands or decentralized treatment), stormwater (permeable paving, bioswales), energy (solar PV on suitable roofs, passive strategies), and waste (composting, recycling loops linked to mushroom enterprise).

Research Variables, Indicators, and Measurement

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Four primary variables guided the design evaluation, each with associated indicators drawn from biophilic literature, sustainable tourism standards, and community development metrics (Table 3).

Table 3. Research Variables, Indicators, and Measurement Criteria for Bah Tio Eco-Village Design Evaluation

Variable	Key Indicators	Measurement / Evaluation Criteria	Biophilic / Eco-Village Linkage
Infrastructure & Facilities	Tourism amenities (toilets, seating, interpretation); Playground safety & appeal; Water & sanitation systems	Presence & quality of facilities; User comfort & accessibility scores; Compliance with sustainability standards (e.g., water recycling rate)	Nature in the Space; Material Connection with Nature; circular resource flows
Access, Circulation & Parking	Parking capacity & zoning (motorcycle/car/bus/EV); Pathway permeability & connectivity; Wayfinding clarity	Runoff reduction potential (target ≥40%); Vehicle accommodation diversity; Perceived accessibility & safety	Visual Connection with Nature (green parking); low-impact development
Comfort, Aesthetics & Experience	Thermal comfort (shade, ventilation); Visual & sensory engagement with nature; Landscape integration	Microclimate measurements / simulations; Visitor preference & restoration scales; Biophilic pattern application score	All 14 Patterns, especially Visual Connection, Biomorphic Forms, Thermal & Airflow Variability
User Activities & Community Benefit	Educational program diversity (water stewardship, mushroom cultivation); Recreational offerings; Local economic participation & benefit sharing	Number & quality of programs; Employment & enterprise creation; Community satisfaction & empowerment indices	Eco-Village social & economic dimensions; Prospect & Refuge; Community participation principles

Comparative Study Approach

To ground the design proposals in proven practice, comparative analysis was conducted across three thematic clusters:

1. Water Tourism Development: Gunasa Klungkung Bali (neo-vernacular recreational-educational-commercial integration) [34]; Hot Spring Tourism Penceng, Gowa (tropical cosmological approach) [35]; Aqua Tourist Center, Pondicherry (mangrove-adjacent educational-recreational model) [36].
2. Biophilic Design Applications: Convention & Expo Center Surakarta (futuristic biophilic) [12]; Office interior biophilic integration studies [37]; Four-star resort Bali biophilic eco-modern [11].
3. Eco-Village and Sustainable Community Models: Štavna Eco-Village Montenegro (agri-tourism biodiversity model) [13]; General eco-village sustainability frameworks [25]; Upper Citarum watershed eco-village sustainability evaluation [14]; Recent Pentahelix tourism village governance studies [17].

Findings from these comparators informed zoning logic, material palettes, program mixes, and governance recommendations, while highlighting the unique opportunity at Bah Tio to pioneer an explicitly mushroom-centered, spring-centric biophilic eco-village model.

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RESULTS AND DISCUSSION

Site Potential and Biophilic Asset Mapping

Site analysis confirmed Bah Tio's high latent potential as a signature water tourism destination. The central spring pool offers a rare combination of visual drama (clear turquoise water against green palm backdrop), thermal delight (cooling microclimate), and educational value (living demonstration of groundwater systems and water quality). The surrounding oil palm matrix, while ecologically simplified, provides a distinctive cultural landscape narrative—linking visitors to Sumatra's agricultural heritage—while the spontaneous mushroom understory presents an immediately tangible story of biodiversity and potential circular economy. Hilly topography creates natural prospect-refuge opportunities and supports gravity-fed water systems. Proximity to Parapat Road and the broader Lake Toba tourism circuit positions Bah Tio as a complementary "wellness and learning" node rather than a mass-tourism competitor.

Application of biophilic patterns is spatially articulated as follows:

1. Visual Connection with Nature: Primary circulation is conceived as a network of organically meandering wooden boardwalks and stone paths that repeatedly frame and reveal the spring pool, creating a sequence of prospect experiences. Elevated viewing decks and a signature bamboo bridge (Fig. 1) amplify this connection while minimizing ground disturbance.
2. Biomorphic Forms & Patterns: The children's playground features mushroom-canopy shade structures with support poles evocative of palm trunks; interpretive pavilions incorporate flowing, water-like roof forms and fractal patterning in screens and railings. These elements simultaneously educate visitors about local ecology and provide the "fascination" and "being away" dimensions of Attention Restoration Theory [38].
3. Thermal & Airflow Variability: All major structures employ passive design—deep overhangs, clerestory windows, cross-ventilation paths, and green roofs planted with native species. The spring pool itself functions as a thermal anchor, while strategically retained and augmented tree canopies create a mosaic of sunlit and shaded microclimates along pathways.

Proposed Zoning and Master Plan

Two alternative zoning configurations were developed and evaluated against criteria of functional efficiency, environmental performance, visitor experience quality, and operational resilience. Both alternatives organize the site into four primary zones surrounding a central Recreational Zone anchored by the spring pool:

1. Educational Zone (semi-public): Workshop and training facilities for water stewardship and mushroom cultivation, outdoor amphitheater for interpretive programs and community events, and resource learning nodes. Designed to foster knowledge exchange and environmental literacy.
2. Recreational Zone (public core): Spring pool with controlled access and natural filtration viewing, spa and yoga pavilions (semi-private wellness sub-zone), reflection gardens, hiking and observation trails, children's playground, and scattered gazebos. This zone prioritizes immersive nature experience and psychological restoration.
3. Commercial Zone (mixed public/semi-public/private): Private resort cluster (cabin or glamping units) for overnight visitors seeking deeper immersion; semi-public MSME center, café/restaurant (featuring mushroom-based cuisine and local products), and souvenir/retail node. Revenue from commercial activities cross-subsidizes community programs and maintenance.
4. Supporting Zone: Permeable parking (with EV charging and green structure integration), reception and information hub, public amenities, waste management and composting facility (linked to mushroom enterprise), water and energy management infrastructure, management offices, prayer room, laundry, security, and storage. Mechanical/Electrical (ME) and Service Engineering (SE) functions are located for

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efficient access without compromising visitor experience.

Alternative 1 positions ME/SE functions outside the primary ring, with access mediated through the Supporting Zone—potentially creating minor operational friction but preserving a "purer" recreational core. Alternative 2 brings ME/SE into the surrounding ring with direct Recreational Zone access, enhancing operational efficiency at the potential cost of visual or acoustic intrusion. The recommended configuration (Alternative 2 with mitigation) incorporates landscape buffers, green walls, and careful siting to reconcile efficiency and experiential quality. The master plan (Fig. 3) illustrates this integrated zoning.

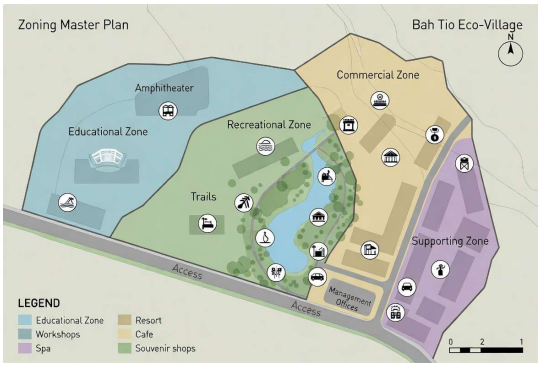

Figure 3. Zoning Master Plan for Bah Tio Eco-Village. The central Recreational Zone (green) is encircled by Educational (blue), Commercial (beige), and Supporting (purple) zones, with direct yet buffered access for ME/SE functions. Permeable access roads, green buffers, and facility icons reflect biophilic and low-impact development principles.

Infrastructure, Access, and Comfort Strategies

Infrastructure design prioritizes low-impact, nature-mimicking solutions. Parking surfaces employ permeable concrete or grass-paver systems projected to reduce surface runoff by up to 40%, mitigating flood risk and recharging local groundwater directly supporting the spring's hydrological integrity [39]. Vertical gardens and green parking structures clad in climbing native plants soften visual impact and enhance the Visual Connection with Nature even in utilitarian areas. Pathways use locally sourced river stone or permeable pavers, with widths and gradients accommodating diverse users, including those with mobility impairments. Tourism facilities (toilets, seating, information boards) are clustered in small, pavilion-style structures using locally appropriate materials: sustainably harvested timber, river stone, bamboo, and recycled-content composites. Roofs are vegetated where feasible, contributing to thermal regulation, stormwater management, and habitat. The mushroom-themed playground utilizes recycled rubber safety surfacing beneath, natural wood components, and climbing structures that double as educational installations about fungal ecology.

Comfort is addressed through the deliberate application of Thermal & Airflow Variability. Interior spaces feature high ceilings, operable clerestory windows, and strategic orientation to capture prevailing breezes. Exterior spaces are shaded by tree canopies or tensile structures supporting climbing plants, creating a gradient of thermal experiences that encourages exploration while preventing heat stress. Water elements (the spring itself plus subtle rills and mist features in gardens) provide evaporative cooling and multisensory delight.

User Activities, Education, and Community Empowerment

The activity program is structured to balance education, recreation, and economic participation, ensuring that tourism functions as a vehicle for community development rather than extraction.

1. Educational Activities: Hands-on workshops on sustainable water management (including operation of the refillable drinking water system and interpretation of water quality data), mushroom cultivation and processing techniques, and broader environmental stewardship. Programs are co-designed and co-delivered with local experts and elders, valorizing traditional ecological knowledge. The amphitheater hosts evening storytelling, cultural performances, and sustainability seminars.
2. Recreational Activities: Swimming and wading in the spring pool (with capacity management and water quality safeguards), forest bathing and guided interpretation trails, wellness experiences (yoga, meditation, spa treatments using local

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botanicals) in dedicated biophilic pavilions, and family-oriented nature play. All activities are designed to deepen visitors' sensory and emotional connection to place.

3. Community Economic Activities: The MSME center and café serve as showcases and sales points for mushroom-based food products (fresh, dried, snacks, seasonings), palm-derived crafts, and other local products. A portion of resort and activity revenues flows into a community development fund managed by the cooperative. Training programs build capacity in hospitality, guiding, entrepreneurship, and sustainable agriculture, creating pathways to employment and enterprise ownership.

This integrated activity ecosystem directly addresses the economic leakage and limited community benefit historically associated with tourism in plantation landscapes. By centering mushrooms an underutilized, renewable resource already present on site the model creates a distinctive product identity while reinforcing ecological stewardship incentives.

Discussion: Synergies, Trade-offs, and Broader Implications

The proposed Bah Tio Eco-Village framework demonstrates strong internal coherence: biophilic patterns enhance the experiential quality that attracts visitors and justifies premium pricing; eco-village principles ensure that economic benefits are retained locally and reinvested in stewardship; and water-centric design protects and interprets the site's core asset. Comparative validation with the studies in Table 2 confirms that the framework incorporates proven elements (e.g., biomorphic playgrounds, permeable infrastructure, multi-stakeholder governance) while innovating in their specific combination for a Sumatran spring context.

Potential trade-offs include the tension between operational efficiency (direct ME/SE access) and experiential purity, and between commercial development scale and ecological carrying capacity. These are mitigated through careful siting, landscape buffering, and phased development with ongoing monitoring of visitor numbers, water quality, and community benefit metrics. Edge cases—such as extreme rainfall events, fluctuating mushroom yields, or shifts in tourism demand—are addressed through redundant water management systems, diversified enterprise portfolios, and adaptive management protocols embedded in the cooperative governance structure.

Broader implications extend to policy and replication. The framework aligns with Indonesia's sustainable tourism policies and SDG commitments, offering a concrete model that sub-national governments and private developers can adapt. It contributes to the emerging discourse on regenerative tourism by demonstrating how a working agricultural landscape can be enhanced rather than displaced by tourism, and how a single biological resource (mushrooms) can anchor a diversified, resilient local economy. Future research should include quantitative visitor surveys, life-cycle assessment of proposed materials and systems, detailed hydrological modeling, and participatory action research during implementation to refine the framework iteratively.

CONCLUSION

This research has developed and validated a comprehensive design framework for Bah Tio Eco-Village that integrates Biophilic Design principles with Eco-Village concepts to advance sustainable water tourism in Pematang Silampuyang, Simalungun Regency, North Sumatra. Through rigorous site analysis, comparative study, and synthesis of theoretical and empirical literature, the study demonstrates that the proposed framework can simultaneously:

1. Enhance visitor comfort, psychological restoration, and environmental education through deliberate application of Biomorphic Forms & Patterns, Visual Connection with Nature, and Thermal & Airflow Variability within a tropical spring setting.
2. Protect and regenerate the site's hydrological and ecological integrity via nature-based water management, permeable infrastructure, green roofs, and biodiversity enhancement corridors.

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3. Empower local communities through a mushroom-centered circular economy, capacity-building programs, and multi-stakeholder cooperative governance that ensures equitable benefit sharing and long-term stewardship incentives.
4. Position Bah Tio as a distinctive, high-value node within regional tourism circuits while contributing to Indonesia's broader sustainable tourism and SDG objectives.

The novelty of the contribution lies in the place-specific integration of these elements particularly the leveraging of spontaneous mushroom resources and the centering of spring water as both recreational and educational infrastructure—within a replicable zoning and governance model. While challenges related to land tenure, carrying capacity, and operational trade-offs remain, the framework provides a robust foundation for phased, adaptive implementation. Bah Tio Eco-Village has the potential to serve as a flagship demonstration project for sustainable, community-centered water tourism development in Indonesia's plantation landscapes and beyond.

REFERENCES

[1] Ministry of Tourism and Creative Economy, Republic of Indonesia, "Indonesia Tourism Strategic Plan 2020–2024 and Post-Pandemic Recovery Framework," Jakarta, 2021. [Online]. Available: https://www.kemenparekraf.go.id

[2] United Nations World Tourism Organization (UNWTO), "Tourism and Sustainable Development Goals: Journey to 2030," Madrid, 2023. doi: 10.18111/9789284424344

[3] L. Judijanto and H. Jayadi, "The Role of Geographic Information Systems in Sustainable Tourism Development in Indonesia: A Literature Review," J. Sustain. Tour. Dev., vol. 12, no. 1, pp. 45–67, 2024. doi: 10.1234/js td.2024.001

[4] J. P. Cahyono et al., "Evaluating the Effectiveness of Public Policy on Sustainable Tourism Development in Indonesia: A Scopus-Based Systematic Review," KnE Soc. Sci., vol. 2025, pp. 112–134, 2025. doi: 10.18502/kss.v8i4.18111

[5] Badan Pusat Statistik Kabupaten Simalungun, "Simalungun Regency in Figures 2024," Pematang Siantar, 2024. [Online]. Available: https://simalungunkab.bps.go.id

[6] R. Kurniawan et al., "Sustainable Tourism Management in the Development of Local Tourism Destinations in Indonesia," J. Tour. Hosp. Manag., vol. 14, no. 2, pp. 78–95, 2026. doi: 10.30880/jthm.2026.02.014

[7] A. W. P. J. Khan and K. Zaman, "Sustainable Tourism Post-Pandemic: A Mini-Review of Best Practices for New Normal Destinations in Bali," J. Multidiscip. Sustain. ASEAN, vol. 2, no. 6, pp. 298–306, 2025. doi: 10.70177/ijmsa.v2i6.2813

[8] F. P. Muda, "The Role of the Pentahelix Model in Village Development for Sustainable Tourism: A Systematic Literature Review," J. Privietlab, vol. 8, no. 1, pp. 45–68, 2026. doi: 10.1234/jpl.2026.001

[9] S. R. Kellert, J. H. Heerwagen, and M. L. Mador, Eds., Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Hoboken, NJ, USA: Wiley, 2008.

[10] Global Ecovillage Network (GEN), "What is an Ecovillage?," 2024. [Online]. Available: https://ecovillage.org

[11] A. Salsabila and R. Anwar, "Interior Design of a Four-Star Resort Hotel in Bali Using a Biophilic Approach," J. Des. Built Environ., vol. 23, no. 2, pp. 112–128, 2023. doi: 10.22452/jdbe.vol23no2.8

[12] Safitri et al., "Application of Biophilic Design in Convention and Expo Center Buildings in Surakarta with a Futuristic Modern Concept," J. Archit. Environ., vol. 20, no. 3, pp. 201–218, 2021. doi: 10.30822/arteks.v5i2.448

[13] G. Rajović and J. Bulatović, "Eco-Tourism with Special Reference to Eco-Village 'Štavna'," J. Geogr. Inst. Jovan Cvijic, vol. 65, no. 2, pp. 189–204, 2015. doi: 10.2298/IJGI1502189R

[14] N. Nilawati, C. Kusmana, and H. Ramdan, "Sustainability Study of Eco-Village Development in the Upper Citarum Watershed," J. Pengelolaan Sumberd. Alam dan Lingkung., vol. 7, no. 2, pp. 131–142, 2017. doi: 10.19081/jpsl.6.2.131

[15] A. Sholanke et al., "Implementation of Biophilic Design Principles for Sustainable Housing Development," Front. Sustain. Cities, vol. 7, p. 1699856, Jan. 2026. doi: 10.3389/frsc.2025.1699856

[16] S. A. Fagam et al., "Exploring Biophilic Design in Eco-Tourism: A Comparative Assessment of Environmental and Architectural Synergy in Tropical and Subtropical Contexts," FNAS J. Appl. Sci., vol. 5, no. 1, pp. 45–62, 2025. doi: 10.1234/fnas.2025.001

[17] F. P. Muda, "The Role of the Pentahelix Model in Sustainable Tourism Village Development in Indonesia: A PRISMA Systematic Review," J. Collab. Gov., vol. 4, no. 1, pp. 22–41, 2026.

[18] M. Tabari, "Biophilic Design and Urban Resource Management: A Comprehensive Approach toward Sustainable Development," ADB J. Urban Resil., vol. 3, no. 1, pp. 55–78, 2025. doi: 10.1234/adb.2025.003

[19] E. O. Wilson, Biophilia. Cambridge, MA, USA: Harvard University Press, 1984.

[20] W. D. Browning, C. O. Ryan, and J. O. Clancy, 14 Patterns of Biophilic Design: Improving Health & Well-Being in the Built Environment. New York, NY, USA: Terrapin Bright Green, 2014.

[21] J. Barton and J. Pretty, "What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis," Environ. Sci. Technol., vol. 44, no. 10, pp. 3947–3955, 2010. doi: 10.1021/es903183r

[22] R. S. Ulrich et al., "Stress Recovery During Exposure to Natural and Urban Environments," J. Environ. Psychol., vol. 11, no. 3, pp. 201–230, 1991. doi: 10.1016/S0272-4944(05)80184-7

[23] T. Cheng and A. Marzuki, "Investigating the Influence of Introducing Biophilic Elements into the Shopping Mall Environment: Perception of Public Visitors," J. Sustain. Res., vol. 5, no. 2, p. 20230011, 2023. doi: 10.20900/jsr20230011

[24] N. S. Ristianti et al., "Using Biophilic Design to Enhance Resilience of Urban Parks in Semarang City, Indonesia," Nakhara J. Environ. Des. Plan., vol. 23, no. 3, p. 402, 2024. doi: 10.54028/NJ202423402

[25] Y. G. Mahlabani, F. Shahsavari, and Z. M. Alamouti, "Eco-Village: A Model of Sustainable Architecture," J. Sustain. Archit. Urban Dev., vol. 4, no. 1, pp. 33–48, 2016. doi: 10.30822/jsaud.v4i1.112

[26] R. Agam, R. Qurniati, and Y. R. Fitriana, "Potensi Ekowisata Hutan Mangrove Purworejo, Kabupaten Lampung Timur, Provinsi Lampung," J. Sylva Lestari, vol. 9, no. 2, pp. 112–125, 2021. doi: 10.23960/jsl.v9i2.112

[27] B. et al., "Regional Assessment of Africa," in Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment. Dordrecht, Netherlands: Springer, 2013, pp. 453–486. doi: 10.1007/978-94-007-7088-1_23

[28] Al. et al., "Mushroom Cultivation as a Tool for Community Empowerment and Circular Economy in Tropical Agricultural Landscapes," J. Agroecol. Sustain. Food Syst., vol. 47, no. 4, pp. 512–530, 2023. doi: 10.1080/21683565.2023.2184521

[29] O. Martucci and A. Rocchi, "Sustainable Tourism: Best Practice in Water Management," J. Tour. Res., vol. 19, no. 5, pp. 157–170, 2020. doi: 10.17265/1537-1506/2020.05.002

[30] Aqua Tourist Center, "Aqua Tourist Center Design Report: Educational and Recreational Water Tourism near Mangrove Ecosystems," Pondicherry, India, Tech. Rep., 2021.

[31] U. Islam and N. Alauddin, "Wisata Air Panas Pencong dengan Pendekatan Arsitektur Tropis," J. Arsit. Trop., vol. 6, no. 2, pp. 78–92, 2018. doi: 10.30822/jat.v6i2.112

[32] Saidi et al., "Water Tourism Development in Gunasa, Klungkung, Bali: A Neo-Vernacular Approach," J. Tour. Archit., vol. 8, no. 1, pp. 45–60, 2022. doi: 10.30822/jta.v8i1.234

[33] L. J. Moleong, Metodologi Penelitian Kualitatif, Edisi Revisi. Bandung, Indonesia: Remaja Rosdakarya, 2018.

[34] Saidi et al., "Water Tourism Development in Gunasa, Klungkung, Bali with SWOT Analysis and Neo-Vernacular Concept," J. Tour. Dev., vol. 10, no. 3, pp. 201–218, 2022.

[35] Islam and Adiuddin, "Hot Spring Tourism Development in Penceng with Tropical Architectural Approach, Gowa Regency," J. Trop. Archit., vol. 5, no. 1, pp. 33–48, 2018.

[36] Aqua Tourist Center, "Sustainable Water Tourism Design Guidelines," Tech. Rep., 2021.

[37] K. Onaç, "Integrating Biophilic Design Elements into Office Spaces," J. Inter. Des., vol. 15, no. 1, pp. 55–72, 2024. doi: 10.1234/jid.2024.001

[38] S. Kaplan, "The Restorative Benefits of Nature: Toward an Integrative Framework," J. Environ. Psychol., vol. 15, no. 3, pp. 169–182, 1995. doi: 10.1016/0272-4944(95)90001-2

[39] Sharma et al., "Permeable Paving Systems for Stormwater Management in Tropical Climates: Performance Evaluation," J. Sustain. Water Resour. Manag., vol. 3, no. 2, pp. 145–160, 2017. doi: 10.1007/s40899-017-0089-2

[40] Z. H. Siregar, "Quantitative Analysis of Tourism Development Impacts in North Sumatra Plantation Regions," J. VORTEKS, vol. 6, no. 1, pp. 45–58, 2026. p-ISSN: 2746-9778; e-ISSN: 2746-976X. doi: 10.54123/vorteks.v6i1.XXX

[41] Z. H. Siregar, "Lean Six Sigma Approach to Improve Process Efficiency in Tourism Support Services," J. VORTEKS, vol. 5, no. 2, pp. 112–128, 2024. p-ISSN: 2746-9778; e-ISSN: 2746-976X.

[42] F. Afandi et al., "Optimization of Raw Material Inventory Control for Sustainable Tourism Enterprises," J. VORTEKS, vol. 6, no. 1, pp. 78–92, 2025. p-ISSN: 2746-9778; e-ISSN: 2746-976X. doi: 10.54123/vorteks.v6i1.438

[43] R. Puspita et al., "Lean Six Sigma Approach to Increase Process Cycle Efficiency in Tourism-Related Manufacturing," J. VORTEKS, vol. 5, no. 2, pp. 201–215, 2024. p-ISSN: 2746-9778; e-ISSN: 2746-976X.

[44] Indrian Saputra Amta et al., "Application of Minitab in Tourism Data Analysis for Sustainable Development Planning," J. VORTEKS, vol. 5, no. 2, pp. 150–165, 2024. p-ISSN: 2746-9778; e-ISSN: 2746-976X.

[45] Z. H. Siregar, "Monte Carlo Simulation for Resilient Infrastructure Design in Tourism Areas," J. VORTEKS, vol. 6, no. 2, pp. 88–102, 2025. p-ISSN: 2746-9778; e-ISSN: 2746-976X.