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Hydroponic laboratory design using biophilic approach: A new sustainable urban agriculture supporting system

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ABSTRACT

Urban agriculture facilities are increasingly expected to accommodate productive cultivation, environmental learning and public participation within land-constrained cities. Yet the architectural translation of hydroponic operational requirements into public-facing biophilic spaces remains underexplained. This article examines an unbuilt multifunctional hydroponic laboratory proposal in Pekanbaru, Indonesia, using an exploratory, evidence-informed architectural case-study approach. Original project documents, site observations reported by the design team, spatial schedules and design drawings were reviewed against criteria derived from hydroponic resource-performance research and the biophilic-design literature. An explicit assessment matrix connects site selection, functional zoning, cultivation control, human–nature experience and maintainability to observable architectural responses. The proposed scheme comprises a basement, three above-ground storeys, differentiated laboratories and community functions organised through a tiered cycle-inspired massing strategy. An arithmetic audit identifies an inconsistency between the narrative programme total (21,887.6 m^2) and the sum of the tabulated allocations (21,234.6 m^2); this discrepancy remains subject to original drawing verification. Analysis further identifies design tensions between natural ventilation and cultivation hygiene, extensive glazing and thermal control, and public access and laboratory biosecurity. The contribution is a transferable set of criteria for critically evaluating integrated hydroponic–biophilic proposals, rather than a claim of demonstrated environmental or social performance. Further measured assessment is required before operational benefits or scalability can be established.

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1. INTRODUCTION

Hydroponics enables crop production without field soil and may improve water-use efficiency or area-based productivity in some configurations, but these advantages cannot be separated from climate-control, lighting and operational energy demands. For example, Barbosa et al. [1] found marked land and water advantages alongside substantially higher energy requirements in a specific lettuce-production comparison; Graamans et al. [2] likewise demonstrate that resource trade-offs depend on

the controlled-environment setting. These findings caution against describing hydroponic facilities as inherently sustainable without examining building and cultivation systems together [3,4].

Pekanbaru, the capital of Riau Province, is the chosen context for the present architectural proposal. The original study positions urban development, agricultural land pressure and limited opportunities for public hydroponic education as motivating concerns. However, the supporting manuscript does not establish a reproducible municipal time series of converted farmland, a representative survey of public awareness, or an inventory demonstrating the absence of comparable facilities. These points are therefore treated as design motivations requiring local data verification rather than as established empirical findings [5-7].

Biophilic design seeks to support meaningful experience of nature within built environments. Browning et al. [8] distinguish nature in the space, natural analogues and nature of the space; Zhong et al. [9] critically discuss the theoretical and evidential limits of biophilic claims. Applying these patterns to an operational hydroponic facility raises unusual integration questions: plants simultaneously constitute productive biological assets and visible natural features, while irrigation, humidity, light and pest-management requirements may conflict with visitor comfort or open circulation [10-13].

The design-research gap addressed here is not the invention of hydroponic technology or biophilic patterns. It concerns the absence, within the supplied architectural case, of an explicit and auditable connection among hydroponic functions, biophilic principles, site-specific spatial decisions and criteria for evaluating the resulting design. Previous manuscript versions described a convincing architectural proposition but did not consistently distinguish drawings and intentions from experimentally validated outcomes. The present revision responds by assessing the proposed design through clearly defined criteria and by identifying the evidence still needed to substantiate performance [14-16].

Evidence from prior studies suggests that hydroponic installations can be evaluated not only as crop-production systems but also as public educational infrastructure [17,18]. Agricultural performance, however, depends on crop management and microclimatic control [3,16,19], while urban integration raises land-use, energy and functional-zoning trade-offs [4,7,20]. Biophilic architecture adds a distinct set of criteria for visual access to vegetation, nature-based experiences and maintenance of integrated green areas [10-13]. These studies provide design considerations; they do not constitute measured validation of the proposed Pekanbaru facility.

1.1. Research Question, Objectives and Contribution

The research synthesis draws on established qualitative and design-case literature [21,22] and on hydroponics, educational applications, and biophilic-design studies [10,14,17,18]. No new interviews, energy simulations or cultivation experiments were performed for this document revision; therefore, the proposed design is assessed as a conceptual case rather than a demonstrated operational building.

The guiding question is: How can hydroponic operational requirements and selected biophilic patterns be translated into traceable design criteria for an integrated public hydroponic laboratory in a tropical urban context? This study (i) documents the case context and its functional programme; (ii) maps biophilic theory onto specific spatial interventions; (iii) evaluates compatibility and trade-offs between educational access and controlled cultivation; and (iv) specifies a validation agenda for the unbuilt proposal. The contribution is an evidence-informed architectural evaluation framework applied to one documented design case, not a verified prototype of urban food-security performance [17,18,23].

2. RESEARCH METHODS

2.1. Research Design and Boundary

An exploratory single-case architectural design-study approach is employed, informed by case-study principles [21]. The case is the conceptual Hydroponic Laboratory at Jalan Petalabumi, Suka Mulia, Sail District, Pekanbaru. The unit of analysis is the proposed building and associated site programme; it is not a built facility, a sample of hydroponic farms or an intervention in a measured user population. The primary analytical material consists of the project's existing spatial schedule, site narratives, diagrammatic plans, design illustrations and descriptions of proposed technical systems [22].

The original manuscript describes observation and documentation of land use, plot boundaries, sun orientation, prevailing winds, vegetation, access, utilities and surrounding functions. It also mentions expert interviews and possible NVivo-supported coding, but supplies no interview instrument, participant roster, transcript extracts, coding table or exported project records. Consequently, interview-derived themes and NVivo findings are not presented as validated results in this revision. They can be reinstated only after source records are supplied and the analysis can be audited [17,22].

2.2. Evidence Extraction and Analysis Procedure

The revision follows four analytical operations. First, source assertions are extracted from the existing design manuscript without treating proposed interventions as measured outcomes. Second, programme areas and stated planning constraints are subjected to internal consistency checks. Third, design features are mapped to conceptual criteria derived from biophilic-design and controlled-environment-agriculture literature [1,2,8,9]. Fourth, each design response is critically considered against operational conflicts and assigned a future verification method. This procedure creates a traceable interpretation of the supplied case but does not imply that additional fieldwork or simulations were retrospectively conducted [19,20]. The research and design analysis workflow is shown in Figure 1.

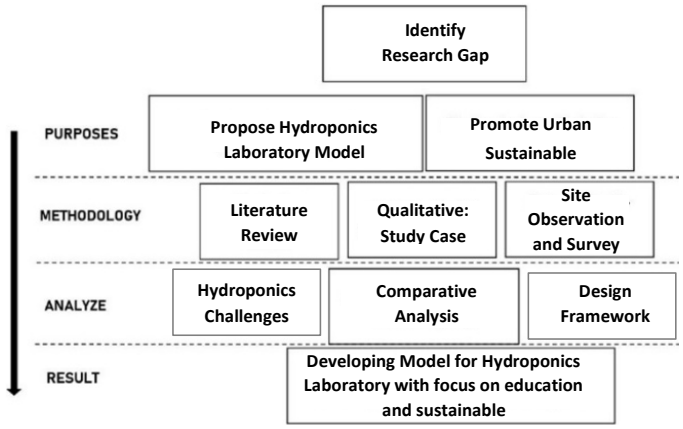


Figure 1. Research and design-analysis workflow adapted from the original project diagram; the revision distinguishes documented design evidence, criterion-based interpretation and future validation.

2.3. Operational Assessment Criteria

The criteria form an interpretative matrix; they are not statistically validated scales. Each criterion is assessed qualitatively for its representation in the original drawings, the design logic that motivates it, and the evidence required to test whether its stated benefit is achievable (see Table 1).

Table 1. List of operational assessment criteria.

Assessment domain	Observable design response	Evidence or validation required
Site/context	Access points, orientation, plot limits and zoning	Survey drawings, transport evidence, planning records
Functional zoning	Separation of public, teaching, production and service routes	Scaled plans, circulation analysis, accessibility audit
Biophilic experience	Views, planted courtyards, materiality, spatial prospect and refuge	Sightline mapping and future user study
Cultivation and hygiene	Nursery, pest laboratory, water loops and controlled plant-growth rooms	Crop protocol, clean/dirty zoning, environmental specification
Environmental performance	Daylight, shading, mixed ventilation and mechanical services	Climate-based daylight, thermal and energy simulations
Feasibility and resilience	Maintenance access, equipment capacity and water treatment	Costing, maintenance planning, technical reviews

3. RESULTS AND DISCUSSIONS

3.1. Site Location and Environmental Setting

The original proposal selects an approximately 10,000 m^2 parcel at Jalan Petalabumi in Suka Mulia, Sail District (reported coordinates 0°31′07″ N and 101°27′22″ E). The manuscript describes a comparatively flat site, access from Jalan Petalabumi, nearby services and an orientation towards the northeast (see Figure 2). A building coverage ratio of 50% and a minimum green-area ratio of 10% are reported as project assumptions. They should be confirmed against current, site-specific planning documents; the stated percentages alone do not establish regulatory compliance.

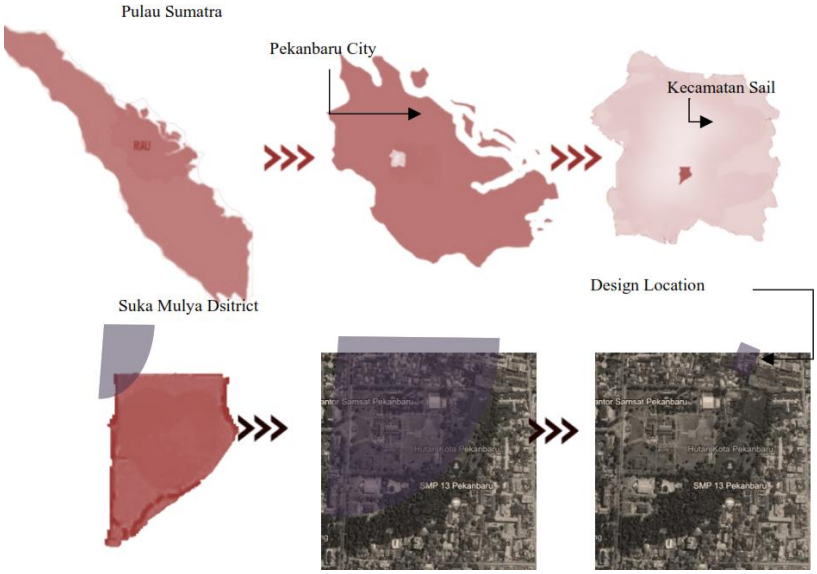


Figure 2. Pekanbaru urban context and location of the selected hydroponic laboratory site (original project map).

The site narrative identifies nearby residential, institutional, commercial and transport functions, including the proximity of the urban forest and an existing public-transport connection (see Figure 3). These characteristics suggest plausible demand for both public learning and productive uses. Nevertheless, the source does not provide a comparative multi-site scoring matrix; the selected location therefore cannot yet be described as demonstrably optimal among all candidate sites.



Figure 3. Detailed project site location, boundaries and surrounding land uses at Jalan Petalabumi, Pekanbaru (original project map; verify labels and scale).

The sunlight diagram is used as a design-stage orientation study (see Figure 4). Openings and a courtyard are proposed to permit daylight penetration to public interior areas and selected cultivation spaces. Because the source provides neither a measured daylight factor nor a climate-based model, increased daylight availability is a plausible design intention, not a quantified improvement.

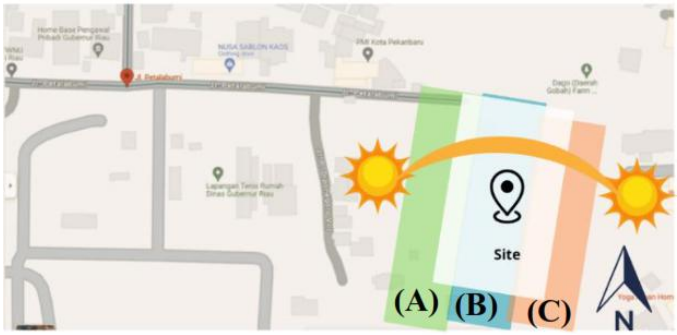


Figure 4. Site solar-exposure and building-orientation analysis used to inform daylight openings, shading and building massing.

Wind diagrams from the original study are interpreted as preliminary cues for positioning openings along northwest–southeast and northeast–southwest directions (see Figure 5). These directional assumptions require confirmation with local meteorological observations, wind roses or site measurements before they are used in a performance claim. The central courtyard may provide an airflow pathway, although its actual effect depends on pressure differences, obstruction, humidity and building geometry.

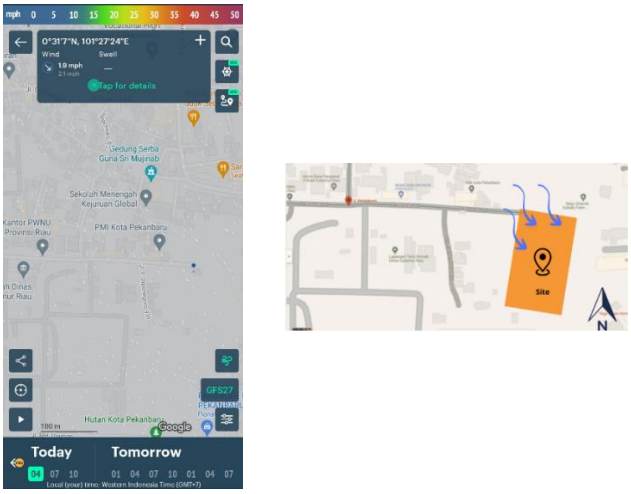


Figure 5. Wind-direction analysis for the proposed site and conceptual implications for openings and courtyard placement.

3.2. Functional Programme and Arithmetic Consistency

The architectural concept combines hydroponic production, laboratories, educational exhibits, training, community facilities, recreation and support services. The arrangement proposed in the source comprises a basement and three above-ground floors. A public–private gradient is implied: community uses are concentrated towards lower visitor levels, technical learning and cultivation functions occupy selected upper areas, and administration is spatially distinct. The absence of a room-by-room schedule with occupancy, servicing and safety requirements limits the present ability to test capacity and circulation performance.

The original area in Table 2 reports the following allocations. Values are reproduced from the source schedule; categories may represent different measurement bases, and external space should not be assumed to be building gross floor area.

Table 2. The original area.

Programme component	Reported area (m^2)
First floor	4,794.0
Second floor	3,252.0
Third floor	3,096.6
Basement	5,092.0
Outdoor facilities	5,000.0
Arithmetic sum	21,234.6

The source narrative also states a total of 21,887.6 m^2, exceeding the sum of the five listed components by 653.0 m^2. On the basis of the tabulated values alone, the internal total for all indoor floor allocations (including the basement) is 16,234.6 m^2 and the outdoor allocation is 5,000 m^2. This is an internal reconciliation, not a verified gross floor area: original CAD/BIM measurements, excluded circulation, double-counting and applicable definitions must be checked before any final submission. A 10,000 m^2 plot with a nominal 50% coverage ratio cannot by itself validate these multi-storey figures.

3.3. Lighting and Environmental Systems

The design specifies complementary daylight and artificial-light strategies (see Figure 6). Glazed openings, skylighting and courtyard exposure are used to establish visual connections with vegetation and reduce reliance on electric lighting during suitable daylight periods. However, human lighting and crop photosynthetic requirements must be distinguished; crop-lighting calculations require photosynthetic photon flux density, photoperiod and species-specific demands rather than general room illuminance alone. Voutsinos et al. [24] provide a relevant comparative context for artificial-lighting and greenhouse production.

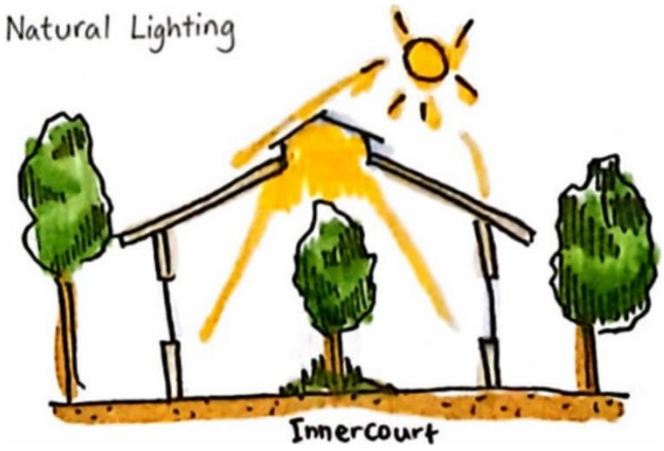


Figure 6. Conceptual natural-lighting strategy showing daylight admission through glazing and building openings.

Downlights, LED fixtures, concealed lighting and accent lighting are proposed for different indoor functions (see Figure 7). Their presence in the design does not establish lighting energy savings, efficacy, photosynthetic adequacy or visual comfort. A subsequent study should evaluate office, gallery and laboratory illuminance separately from productive horticultural lighting and report annual operating schedules.

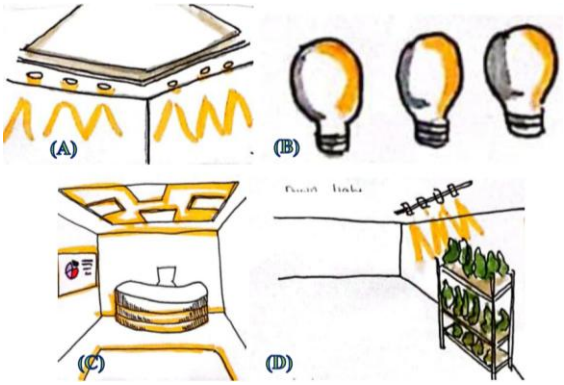


Figure 7. Proposed artificial-lighting typologies: (a) downlights, (b) LED lighting, (c) concealed lighting and (d) accent lighting.

Natural ventilation is proposed through façade openings, planted outdoor margins and a central courtyard (see Figure 8). This strategy is potentially appropriate for public transitional spaces but should not automatically be extended to seedling, pest-pathology and other specialised cultivation zones. Those spaces may require restricted airflow, filtered supply, independent exhaust, humidity control and monitored environmental conditions. The ventilation research of Peiró et al. [15] reinforces the importance of air distribution for crop performance within controlled plant-growth environments.

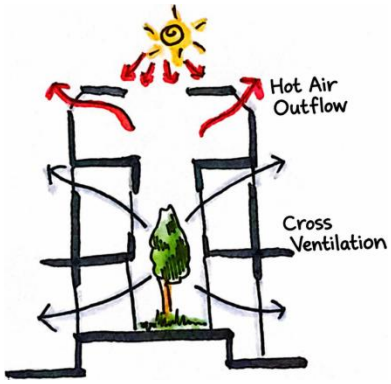


Figure 8. Natural-ventilation concept showing façade openings, cross-flow pathways and the central courtyard.

Mechanical conditioning is proposed using variable-refrigerant-volume equipment and fans to support spaces where passive air movement is insufficient or incompatible with operational requirements (see Figure 9). System zoning should follow actual thermal loads, occupancy and production regimes. The proposal currently lacks equipment sizing, annual load estimates and an integrated ventilation–cooling control schedule, making efficiency claims premature.

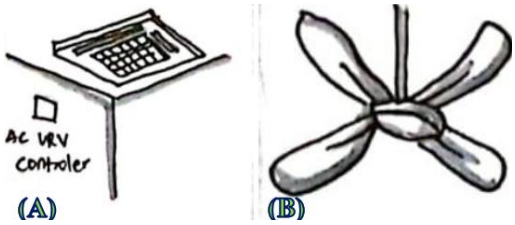


Figure 9. Proposed mechanical ventilation and thermal-control options: (a) VRV air-conditioning system and (b) fans.

3.4. Cycle-Grading Massing Strategy and Biophilic Integration

The design introduces a "cycle grading" concept that interprets the recirculating movement of water and the vertical organisation of hydroponic systems through tiered, partly circular massing (see Figure 10). The concept is a symbolic and spatial design device; it does not, by itself, demonstrate greater production density or energy efficiency. The conceptual diagram should be read alongside subsequent plans to assess whether the form supports coherent circulation, functional adjacency and maintenance access [7,11,14].

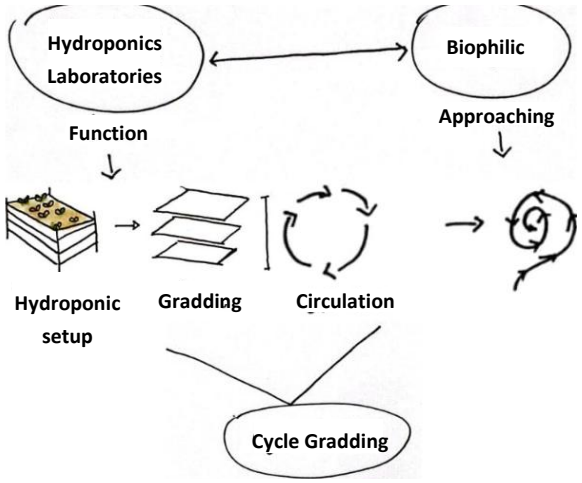


Figure 10. Basic architectural concept: cycle-grading geometry inspired by recirculating hydroponic-water movement and layered planting systems.

The original form-transformation sequence includes the composition of a multi-level mass with a circular component, cuts intended to encourage airflow, west-facing extensions, stepped reductions in upper levels, changes in mass diameter and the introduction of a secondary skin (see Figure 11). These interventions can be evaluated through measurable indicators such as solar exposure, circulation distance, net-to-gross efficiency, structure and façade maintenance. Their benefits should not be inferred only from perspective illustrations.

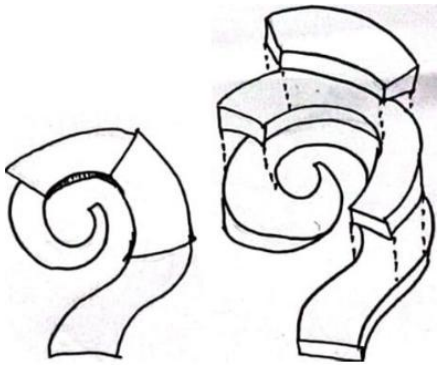


Figure 11. Architectural massing transformation: sequential formation of the tiered laboratory and secondary-envelope design.

The original design also proposes nonvisual nature contact, non-rhythmic sensory stimuli, connection with natural systems, complexity and order, and controlled risk or peril (see Table 3). These are relevant aspirations under the framework of Browning et al. [8], but some illustrations remain conceptual. In particular, bridges or transparent platforms near water features require safety and accessibility review, while the observation of nutrient cycles must be separated from unrestricted access to production systems [10-13].

Table 3. Biophilic design patterns, proposed architectural applications, and critical evaluation issues.

Biophilic category / pattern	Translation in proposed design	Critical issue for evaluation
Nature in the space — visual connection	Views towards hydroponic plants and planted courts	Visitor sightlines versus cultivation access controls
Nature in the space — airflow and thermal variability	Courtyard and selected operable openings	Humidity, heat stress and clean-area separation
Nature in the space — presence of water	Visible irrigation or display water feature	Water hygiene, splash risk and maintenance
Nature in the space — dynamic/diffuse light	Skylights and daylight-responsive spaces	Glare, heat gain and crop lighting requirements
Natural analogues — form and material	Organic geometry, vegetation-derived patterns, wood or stone finishes	Durability, sanitation and sourcing
Nature of the space — prospect/refuge/mystery	Overlooks, protected seating and curved routes	Wayfinding, inclusivity, guarding and emergency egress

3.5. Functional Zoning and Laboratory Typology

The conceptual floor plans distribute parking and utilities to the basement, publicly accessible community and recreation programmes towards the first floor, education and production functions towards the second floor, and management functions towards the third floor (see Figure 12). This broad zoning establishes a basis for avoiding uncontrolled visitor interference with production. Detailed plan scrutiny must still consider wheelchair-accessible routes, lifts, emergency exits, deliveries, waste handling, clean/dirty circulation and maintenance clearances [17,18,23].

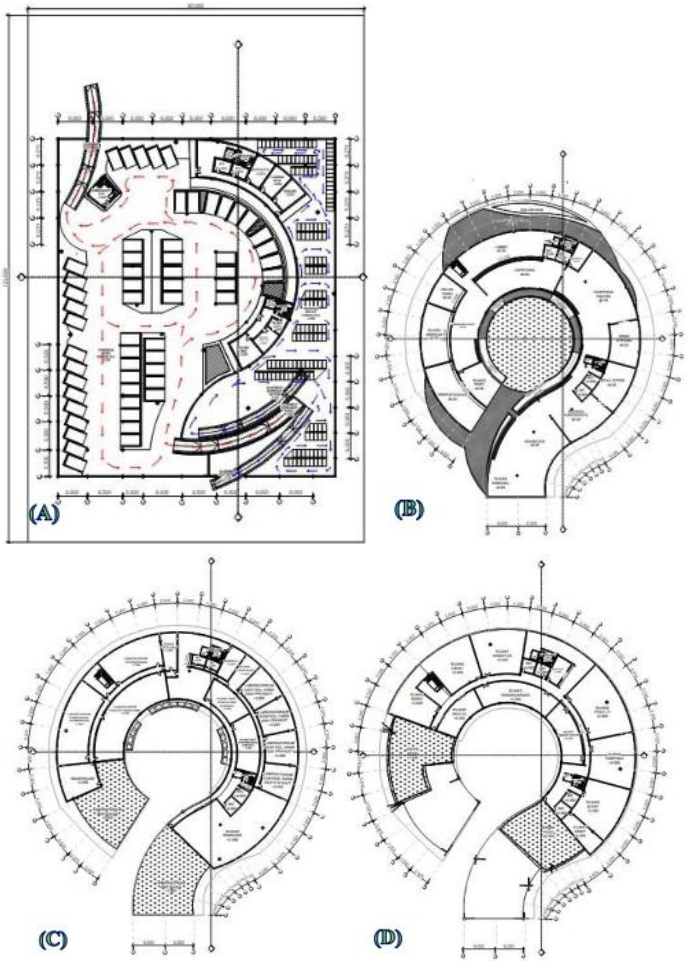


Figure 12. Proposed floor plans: (a) basement, (b) first floor, (c) second floor and (d) third floor.

Five laboratory functions are identified in the original scheme, and their distinction is a substantive element of the proposed programme (see Figure 13). The agriculture laboratory supports crop experiments and sustainable growing studies; the planning laboratory supports production mapping and design analysis; the nursery and seedling laboratory supports germination and propagation; the pest and disease laboratory supports plant-health assessment; and the practice laboratory provides supervised experience of hydroponic growing techniques. These functions are complementary but do not share identical environmental or hygiene requirements [3,19].



Figure 13. Proposed laboratory types: (a) agriculture laboratory, (b) planning laboratory, (c) nursery and seedling laboratory, (d) pest and disease laboratory and (e) hydroponics practice laboratory.

The agriculture laboratory requires flexible benches, safe material storage and appropriate environmental monitoring. The planning laboratory requires data and collaborative work areas rather than a uniformly horticultural microclimate. Nursery and seedling functions require controlled propagation conditions and sanitation protocols. The plant-pathology space should be separated from public routes and protected cultivation to reduce contamination risk. The practice laboratory must accommodate supervised instruction, accessible equipment and safe management of irrigation water and electric components. These requirements highlight why universal use of open cross ventilation, curved room layouts or public transparency would be inappropriate without room-specific assessment [3,16,25].

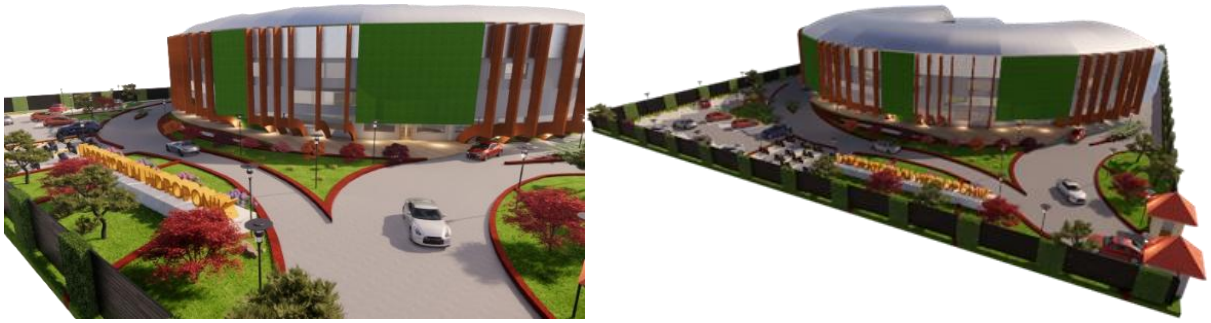


Figure 14. Overall exterior perspective of the proposed multifunctional hydroponic laboratory, illustrating tiered massing and its public-facing architectural identity.

3.6. Exterior Expression and Public Interface

The exterior rendering communicates the tiered architectural concept and its intended urban identity (see Figure 14). As a proposed civic-facing agriculture facility, the building may offer a visi-

ble point of contact between technological cultivation and public learning. This remains a proposition rather than evidence of enhanced public awareness. Its educational effectiveness should be tested through programme design, visitor evaluation and institutional partnership arrangements, while its envelope performance should be tested through site-specific climatic simulation [4,7].

3.7. Interpretation and Design Implications

3.7.1. Architectural Contribution: Translating Patterns Into Testable Criteria

The principal contribution of the case is its attempt to combine productive infrastructure, public education and human–nature experience within a common architectural system. This is more specific than claiming that biofilia or hydroponics is intrinsically innovative. The assessment matrix demonstrates how a drawing-based project can be converted into research questions: which occupants can perceive nature without entering production zones; which environmental conditions must be independently controlled; how irrigation can be made legible as an educational system without compromising hygiene; and how massing decisions can be evaluated rather than merely described [7,14].

The separation between design intention and measurable outcome is central to the scholarly argument. A view towards plants is evidence of a proposed visual connection, not of lower stress; a shaded court is evidence of a proposed shading strategy, not of an achieved cooling reduction; and vertical organisation is evidence of a spatial strategy, not of verified land-use efficiency. By articulating these distinctions, the paper responds to the reviewer concern that architectural renderings alone do not constitute sufficient scientific evidence [12,13].

3.7.2. Hydroponic–Biophilic Performance Trade-Offs

The combination of daylight, transparent façades, living vegetation and visible water networks may enrich the experience of public visitors. In a hot, humid setting, however, the same features can increase solar gains, latent loads, contamination exposure or maintenance complexity. The hydroponic literature establishes that energy and water outcomes depend strongly on system configuration [1,2]. Environmental strategies therefore require separate metrics for occupant comfort, crop productivity, building energy and water treatment rather than a single general sustainability assertion [16,19,20,25].

The model also creates competing circulation needs. Public visitors benefit from proximity to demonstrative systems; technicians require quick access to production, sanitation and repairs; researchers require controlled experiments and samples. A future spatial test should trace representative user journeys and identify crossings between public, service and controlled zones. For the pest and disease laboratory, this is not merely an experiential question but a requirement for containment and procedural integrity [16,23].

3.7.3. Replicability and Limits of Generalization

The case offers transferable evaluation questions rather than a ready-made building prototype. The validity of any replication depends on local sunlight, temperature, humidity, water availability, planning controls, crop selection, labour skills and financial operating models. The reported site selection and programme demonstrate one conceptual combination under Pekanbaru conditions, but the study does not provide comparative performance across alternative cities or building forms. Generalisation must therefore remain analytical and conditional [4,6,7].

3.7.4. Required Validation Before Strong Performance Claims

A defensible next research phase should combine (i) verification of the site and spatial schedule against scaled CAD/BIM records; (ii) peer review of the functional programme and biosafety zoning; (iii) climate-based simulations of daylight, heat, airflow and annual energy; (iv) calculation of hydroponic water, nutrient, equipment and operating requirements for specified crops; and (v) appropriately designed user or expert studies when claims about learning or well-being are made. If interview data are already available, the authors should document participant selection, consent and analysis before presenting associated conclusions. None of these activities is represented here as already completed [16,19,25].

4. CONCLUSION

The study provides an evidence-informed reinterpretation of a proposed hydroponic laboratory in Pekanbaru as a single architectural design case. The source drawings indicate a multifunctional programme with differentiated laboratories, publicly oriented functions, a central court, tiered cycle-inspired massing and multiple intended biophilic patterns. Their research value lies in the explicit link between each design response and an evaluable criterion, not in an assumption of measured benefits. The analysis identifies important conflicts involving cultivation hygiene, thermal control, water infrastructure and visitor access, and it reveals a 653.0 m^2 inconsistency between the project's stated area total and its component schedule. Accordingly, the proposal should be described as a conceptual architectural framework whose technical and social performance remains to be validated. This bounded conclusion supports further design development without overstating the evidence supplied in the original project. Its potential application should be interpreted against operational and environmental constraints identified in the wider literature.

AUTHOR CONTRIBUTIONS

Sayyidati Khalishah Azzahra: Conceptualization, investigation, architectural design development, data curation, formal analysis, visualization, and writing—original draft. Nangkula Utaberta: Conceptualization, methodology, supervision, interpretation of findings, and writing—review and editing. Muhammad Rijal: Architectural design review, spatial programme assessment, contextual analysis, and writing—review and editing. Mira Dharma Susilawaty: Biophilic design assessment, functional zoning review, interpretation of design considerations, and writing—review and editing. Okfalisa Okfalisa: Methodological refinement, assessment framework review, analytical consistency checking, and writing—review and editing. All authors discussed the findings, revised the manuscript, and approved the final version.

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DECLARATION OF AI USE

The authors declare that no AI tools were used in preparing this manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data supporting this study are included in the article. No separate datasets are available.

ETHICAL APPROVAL

Ethical approval was unnecessary, as no humans or animals were involved.

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