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Evidence-Informed Biophilic Public Library Design for Humid-Tropical Makassar

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ABSTRACT
Public libraries in growing tropical cities need to function as inclusive civic-learning infrastructure rather than as book repositories. This study develops an evidence-informed framework for a biophilic public library and study center in Makassar, Indonesia. A research-by-design method integrated 2020–2024 demographic data, comparison of two candidate sites, humid-tropical climate conditions, activity-based spatial programming, precedent studies, and biophilic-design literature. Analysis combined descriptive statistics, compound annual growth, ordinary least-squares trend estimation, program normalization, and directional interpretation of sun, wind, potential noise exposure, and access. Potential users increased from 410,000 to 429,000, corresponding to 1.14% compound annual growth. The 2034 planning range is approximately 474,700–484,000 potential users. The selected approximately 1.6-ha site requires responses to eastern traffic exposure, western afternoon heat, high humidity, and monsoon rainfall. The 5,696 m² program assigns 70% to primary learning activities. The three-level proposal combines planted buffers, a semi-open atrium, reading stairs, flexible spaces, a shaded envelope, and mixed-mode conditioning. The resulting framework provides a traceable process for connecting user demand, climate, program, landscape, envelope, and operation within a testable design hypothesis. Environmental and behavioral performance remains subject to simulation, stakeholder review, and post-occupancy evaluation.

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1. Introduction

Makassar is a major metropolitan center in eastern Indonesia and a regional hub for government, education, commerce, and culture. Continued urban and educational growth has intensified demand for public places that support literacy, concentrated study, collaboration, digital access, and community learning. Public libraries are strategically positioned to address this demand because they provide non-commercial access to information and safe study settings across age and income groups. The IFLA–UNESCO public-library framework defines the institution as an inclusive gateway to information, culture, lifelong learning, and civic participation [1]. In Makassar, this public role intersects with a substantial school- and university-age population and with the designation of Tamalanrea as an education and public-service district [2].

The architectural problem is therefore broader than the provision of collections. A contemporary public library must accommodate individual reading, group work, digital production, informal exchange, workshops, exhibitions, and community events while preserving environmental conditions suitable for concentration. Library occupancy is dynamic: users select among available seats and environmental conditions, and patterns vary through the day, making spatial choice relevant to both service planning and building operation [3]. A viable design must consequently organize diverse modes of learning within a legible civic environment rather than assemble specialized rooms without a coherent spatial hierarchy.

Environmental quality is central to this task. Reading, discussion, and creative work are affected by thermal and acoustic comfort, daylight and glare, air quality, spatial legibility, perceived safety, and the ability to alternate between social stimulation and retreat. Studies in educational settings associate contact with natural environments with place attachment, supportive social experience, satisfaction, and perceived productivity, although the magnitude of these outcomes varies with user group, context, and method [4-7]. In a humid-tropical city, such experiential objectives must be reconciled with solar heat, high moisture, heavy rainfall, traffic exposure, and the preservation requirements of books and digital equipment.

Biophilic design offers a useful framework for this reconciliation when it is understood as more than visible greenery. It links built environments with natural systems and sensory experience through light, air, vegetation, water, views, material cues, environmental variability, prospect, refuge, and spatial sequence. Critical reviews show, however, that biophilic design is often conceptually fragmented and insufficiently connected to measurable performance, climatic context, and maintenance [8-10] . A recent design study from Makassar illustrates how youth-centered public architecture can combine flexible collaborative zones, natural light, vertical greenery, and organic materials to address psychological and social needs in a tropical urban context [11]. Such precedents are valuable as design

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propositions, but their anticipated benefits must not be presented as measured outcomes unless they have been empirically tested.

Two related research gaps follow. First, many proposals describe vegetation, natural materials, skylights, courtyards, or green roofs without demonstrating how these features emerge from demographic demand, site constraints, activity patterns, or operational requirements. Sustainable rating systems and biophilic criteria are not automatically compatible because the former often emphasize quantitative performance while the latter may remain experiential and qualitative [9]. A checklist approach can therefore encourage symbolic compliance rather than an integrated environmental relationship [12]. Demographic projections and room schedules are likewise frequently treated as technical appendices instead of evidence that should influence form, zoning, circulation, and adaptability.

Second, the transfer of library precedents across climates remains insufficiently resolved. Atria, transparent edges, planted roofs, and indoor–outdoor continuity from temperate or highly controlled buildings cannot be copied directly into Makassar. Assessment of semi-open educational atria in Southeast Asia indicates that roof opening, proportions, cross-ventilation, green area, and ground-floor openness jointly influence thermal, visual, and biophilic quality [13]. Hot–humid design similarly requires coordinated responses to solar load, airflow, moisture, and energy rather than generic transparency [14]. Natural ventilation may introduce acoustic conflict, while daylight and views can improve perception yet create glare and heat if exposure is uncontrolled [15-17].

This study therefore develops an evidence-informed architectural framework for a biophilic public library and study center in Makassar. It examines what the available demographic data imply for future adaptability; how access, climate, potential traffic disturbance, vegetation, and orientation can be translated into spatial and environmental responses; and how biophilic principles can be integrated with program zoning, circulation, material selection, and building systems without overstating unverified performance. The contribution is methodological, architectural, and conceptual. It combines demographic analysis, spatial normalization, site interpretation, and design synthesis in a traceable workflow; proposes a three-level learning environment organized around an atrium, reading stairs, flexible age-specific and collaborative spaces, and vegetated outdoor rooms; and treats biophilia as a relationship among users, climate, program, and natural experience. The resulting framework constitutes a design hypothesis for subsequent environmental simulation, stakeholder review, and post-occupancy evaluation.

2. Methods

2.1 Research design

The study used a research-by-design case-study method in which the architectural proposal functioned both as an object of inquiry and as a medium for synthesizing evidence. The workflow comprised six linked stages: (1) compilation and harmonization of demographic, climatic, planning, site, and program data; (2) estimation of demand trends; (3) comparison and selection of candidate sites; (4) normalization of the spatial program and organization of access and acoustic gradients; (5) translation of biophilic principles into architectural and environmental strategies; and (6) evaluation of each strategy against an explicit intended function and future validation requirement. The study does not test a completed building. It reconstructs how available evidence was converted into design decisions and therefore treats the final proposal as a testable architectural framework rather than as proof of realized performance.

2.2 Data sources

Fifteen quantitative and qualitative inputs were compiled from official demographic and climatic records, field observations, site mapping, spatial-program calculations, precedent analysis, and architectural design documentation developed for the Makassar case study. Annual population, school-student, and university-student data for 2020–2024 were drawn from the demographic tables attributed to [2]. The term potential users refers specifically to the sum of school students from primary through senior-secondary level and university students; it is a planning constituency, not a count of actual or unique library visitors. Climatic inputs include annual rainfall of approximately 2,000–2,500 mm, average temperatures of 25–33°C, relative humidity of 85–90%, and seasonally varying prevailing winds [18]. Planning inputs include the role of Tamalanrea as an education and public-service area and the applicable spatial-plan information [19]. The room program was checked against the national standard for public libraries [20].

Primary site information was derived from field observations and site mapping. Two alternatives were examined: an approximately 1.6-ha site on Jalan Alternatif Perintis Kemerdekaan and an approximately 1.1-ha site on Jalan Bumi Tamalanrea Permai. Recorded variables included road access, public-transport connection, surrounding land uses, potential noise exposure, existing vegetation, solar orientation, topography, and suitability for an educational public facility. The program dataset comprised room capacities, area standards, circulation allowances, and aggregate floor-area categories for primary, supporting, management, and service activities.

2.3 Literature evidence selection and synthesis

Literature published primarily between 2022 and 2026 was screened for direct relevance to five themes: biophilic learning environments; humid-tropical environmental response; indoor environmental quality and post-occupancy evaluation; implementation and maintenance; and methods for assessing biophilic quality. Sources were retained when they reported empirical findings, evaluation frameworks, or transferable design mechanisms. Evidence from non-library building types was used only when the mechanism—such as daylight, acoustic adaptation, greenery configuration, or operational maintenance—was applicable to public learning environments. The synthesis was focused rather than systematic: no claim is made that all relevant databases or studies were exhaustively covered.

2.4 Data harmonization and quality control

During data harmonization, the tabulated 2023 potential-user value of 423,000 was applied consistently throughout the analysis. Potential-user shares were calculated using the population series reported together with the student data to preserve consistency across the analytical dataset. Spatial calculations were subsequently verified against the total programmed floor area of 5,696 m². The tabulated value was retained because it formed part of the explicit five-year series. Population totals also differed across sections of the source documentation; calculations of potential-user share therefore used the population series presented in the same table as the student data. Spatial calculations were checked against the reported aggregate of 5,696 m². The four category totals—3,985.5 m² for primary activities, 1,288 m² for supporting activities, 318.7 m² for management, and 103.8 m² for services—sum to 5,696 m². Room capacities were not added to derive a single occupancy value because several spaces serve overlapping populations, operate at different times, or function flexibly.

2.5 Statistical analysis of demand

The potential-user series was 410,000, 414,500, 418,000, 423,000, and 429,000 for 2020–2024, respectively (Table 1). Three descriptive measures were calculated: absolute change, compound annual growth rate (CAGR), and an ordinary least-squares trend. CAGR was calculated as:

$$CAGR = (U2024 / U2020)^{(1/4)} - 1,$$

where U is the reported potential-user population. Third, an ordinary least-squares model was fitted to the five annual observations:

$$U_t = \beta_0 + \beta_1(t - 2022) + \varepsilon_t.$$

The linear model was evaluated using R^2 and a 95% confidence interval for the annual slope. Because the series contains only five observations, projection was treated as scenario analysis rather than as a deterministic forecast. The principal planning horizon was 2034. The baseline scenario extended the estimated trend of 4,650 additional users per year, while a higher-growth sensitivity scenario used 5,500 additional users per year. Corresponding 2044 values were retained only as long-range sensitivity because the 20-year horizon substantially exceeds the historical series.

Table 1. Demographic dataset used to define potential library users, 2020–2024

Year	Total Population	School Students	University Students	Potential Users
2020	1,508,154	285,000	125,000	410,000
2021	1,514,302	287,500	127,000	414,500
2022	1,529,120	289,000	129,000	418,000
2023	1,529,120	291,000	132,000	423,000
2024	1,537,500	294,000	135,000	429,000

Note: Potential users equal school students plus university students. The series is a planning constituency, not observed library attendance. The tabulated 2023 value of 423,000 was used in all calculations.

2.6 Spatial-program analysis

Each spatial category was divided by the total programmed floor area of 5,696 m² and multiplied by 100 to determine its program share. Spaces were then classified as public, semi-public, private, or service functions and arranged according to access, acoustic sensitivity, environmental requirements, and operational relationships. Public functions include arrival, information, waiting, children's reading, café, and informal lounge areas. Semi-public functions include general and age-specific reading, individual study, reading stairs, atrium, collections, gallery, workshops, community rooms, computer facilities, co-working, discussion rooms, auditorium, worship spaces, and visitor toilets. Private functions serve management and staff, while service functions include storage, utilities, electrical and mechanical rooms, cleaning facilities, and staff toilets.

2.7 Site-selection and environmental-response method

The candidate sites were compared using five non-weighted criteria: planning compatibility, infrastructure and access, land availability, relationship to surrounding educational and public facilities, and environmental comfort (Table 2). Numerical weighting was not introduced because no empirical basis for relative weights was available. The Jalan Alternatif Perintis Kemerdekaan site was selected because its larger area, visibility, direct metropolitan connection, proximity to educational institutions, and existing infrastructure outweighed its higher potential exposure to traffic disturbance. The Jalan Bumi Tamalanrea Permai site offered a quieter residential setting but had a smaller development area and more constrained local-road access.

Table 2. Qualitative comparison of the two candidate sites

Criterion	Jalan Alternatif Perintis Kemerdekaan	Jalan Bumi Tamalanrea Permai	Interpretation
Approximate area	1.6 ha (16,000 m²)	1.1 ha	The larger site provides greater flexibility for landscape, circulation, and phased use.
Access and visibility	Direct connection to a major urban corridor and public transport	Accessed from a smaller local road	The first site offers stronger metropolitan access and civic visibility.
Surrounding functions	Close to universities, schools, housing, commerce, and institutions	Embedded in educational and residential surroundings	Both support a learning function; the first has broader regional reach.
Environmental condition	Greater potential traffic noise and roadside exposure	Quieter neighborhood setting	The first site requires stronger buffering; the second offers greater baseline quietness
Development potential	Larger area and stronger infrastructure support	Smaller area and more constrained access	The first site was selected despite its environmental mitigation requirements.

Note: The comparison is qualitative because empirically justified criterion weights were not available.

After selection, the site was interpreted as a set of directional forces. The eastern edge provides the principal road connection and civic visibility but also represents the main potential exposure to traffic noise and roadside pollutants. The western and northwestern sectors contain stronger vegetation and a quieter visual setting, while western solar exposure creates afternoon heat risk. The relatively flat land supports accessible movement but requires drainage attention during intense rainfall. These conditions informed entrance placement, vegetated buffering, façade shading, pedestrian–vehicle separation, and the distribution of quiet and active functions.

2.8 Biophilic design translation

The architectural proposal was evaluated through three biophilic domains: Nature in the Space, Natural Analogues, and Nature of the Space. Nature in the Space was operationalized through vegetation, planted outdoor rooms, daylight, framed views, air movement, and a central atrium. Natural Analogues were represented through the stacked-book massing metaphor, natural textures, timber-like surfaces, stone, exposed concrete, patterned screens, and a subdued material palette. Nature of the Space was expressed through prospect and refuge, vertical visual connection, transitional terraces, reading stairs, layered thresholds, and a range of open, semi-enclosed, and quiet settings. Each strategy was linked to an intended function and a required validation method rather than to an assumed performance outcome.

2.9 Architectural synthesis and evaluation criteria

The relationship between each evidence source, the analytical operation applied, and its architectural use is summarized in Table 3.

Table 3. Evidence base, analytical operation, and design use

Evidence component	Variables or content	Analytical operation	Design use
Demographic demand	Population, students, university students, potential users (2020–2024)	Absolute change, CAGR, linear trend, scenario projection	Establish long-term demand and need for flexible capacity
Climate	Temperature, humidity, rainfall, seasonal wind, solar exposure	Directional and risk-based interpretation	Orient openings, shade exposed façades, support mixed-mode ventilation and drainage
Site alternatives	Area, access, surrounding uses, noise, vegetation, visibility	Qualitative comparison using project criteria	Select the 1.6-ha site and define buffers, entrance, and circulation
Activity program	Users, activities, room capacities, area standards	Area normalization and acoustic/social-intensity grouping	Define public, semi-public, private, and service zones
Precedents	Atrium, reading terraces, maker space, flexible seating, green roof	Contextual transfer rather than formal imitation	Inform spatial continuity, community functions, and indoor–outdoor relationships
Biophilic principles	Nature in the Space, Natural Analogues, Nature of the Space	Strategy–function mapping	Integrate vegetation, light, air, materiality, prospect, refuge, and spatial variety

Note. Evidence components were compiled from demographic records, climatic and planning documents, field-based site analysis, spatial-program calculations, precedent studies, and the architectural design process.

3. Findings and Discussion

3.1 Demographic demand and future planning range

The potential-user population increased from 410,000 in 2020 to 429,000 in 2024, an absolute gain of 19,000 users or 4.63% over four years. The CAGR was 1.14% per year. Potential users represented approximately 27.2% of the population reported in the same dataset in 2020 and 27.9% in 2024. These figures should not be interpreted as participation or visitation rates; they identify the scale of the school- and university-based constituency that the facility is intended to serve.

The ordinary least-squares model estimated an annual increase of 4,650 users. The model fit was high ($R^2 = 0.991$), and the 95% confidence interval for the slope was 3,833–5,467 users per year. Because the estimate is based on only five observations, the confidence interval describes uncertainty in the trend coefficient but does not capture policy, migration, enrollment, or behavioral changes that may alter future demand. The observed series and both exploratory planning scenarios are presented in Figure 1.

Under the baseline trend, the potential-user population reaches approximately 474,700 in 2034, while the higher-growth sensitivity scenario reaches 484,000. The corresponding 2044 values—521,200 and 539,000—are reported only as long-range sensitivity because the horizon is much longer than the five-year historical series. The planning implication is therefore not a precise forecast or a requirement to provide a seat for every potential user. It is a need for adaptable capacity: flexible boundaries, multipurpose rooms, distributed seating, digital services, and outdoor learning areas should accommodate changing patterns of use without requiring complete functional reconfiguration.

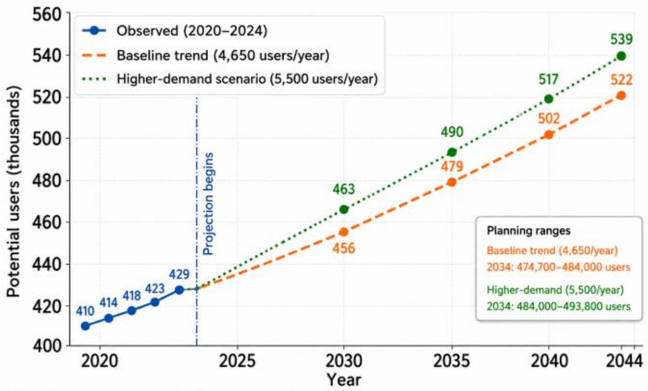

Figure 1. Observed potential users, 2020–2024, and exploratory planning scenarios to 2044. The 2034 values are treated as the principal planning horizon; the 2044 values are shown only as long-range sensitivity and not as deterministic forecasts.

3.2 Site selection and directional environmental forces

The selected site on Jalan Alternatif Perintis Kemerdekaan has an area of approximately 1.6 ha and is located in Tamalanrea, a district characterized by educational, residential, commercial, and institutional activities. Its principal advantage is connectivity. The eastern edge faces a major urban route that can support visibility, public transport access, drop-off activity, and direct recognition of the library as a civic facility. Nearby universities and schools strengthen the relationship between the proposed building and its intended user groups.

The same urban exposure creates the site's most significant conflict. The eastern road edge represents the principal potential exposure to traffic noise and roadside pollutants. The design therefore avoids placing the most acoustically sensitive rooms directly on this boundary. Arrival, plaza, reception, café, event activity, and circulation occupy the front zone, while setback, vegetation, layered façades, and transitional spaces provide a buffer toward protected reading environments.

The site is relatively flat, which supports universal access and a continuous pedestrian network. However, flat topography in a high-rainfall setting can increase the risk of surface-water accumulation. The landscape strategy consequently includes permeable and planted areas, drainage routes, and opportunities for rainwater retention or harvesting. The western side offers stronger existing vegetation and a quieter visual setting, making it suitable for reading gardens, protected study areas, and inward views from the library.

Solar and wind conditions create a second directional logic. Morning light from the east can support arrival spaces and selected reading areas when glare is controlled. Western afternoon exposure presents a greater heat risk and is addressed through deeper shading, second-skin elements, screened openings, planting, and buffer functions. Seasonal winds vary between west–northwest flows in wetter periods and east–southeast flows in drier periods; openings and massing therefore support cross-ventilation from more than one orientation. This regional logic is consistent with [21], who propose cross-ventilation, shading, energy-efficient materials, and combined passive–active strategies for tropical buildings in South Sulawesi. These directional forces and the corresponding site responses are summarized in Figure 2.

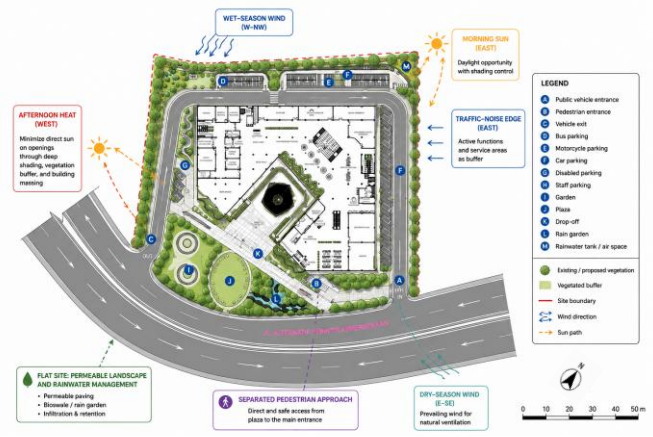

Figure 2. Site–climate response diagram. The schematic identifies the eastern road and public entrance, traffic-noise buffering, western solar protection, seasonal wind paths, vegetated quiet zones, and the separation of pedestrian and vehicular movement.

3.3 Spatial program and functional hierarchy

The proposed program totals 5,696 m². Primary learning and library activities account for 3,985.5 m², or 70.0% of the total. Supporting activities account for 1,288 m² (22.6%), management for 318.7 m² (5.6%), and services for 103.8 m² (1.8%). The distribution demonstrates that the design is not dominated by administration or back-of-house functions; most of the program is reserved for direct public learning, reading, exploration, collaboration, and events. The proportional distribution of the four spatial-program categories is shown in Figure 3.

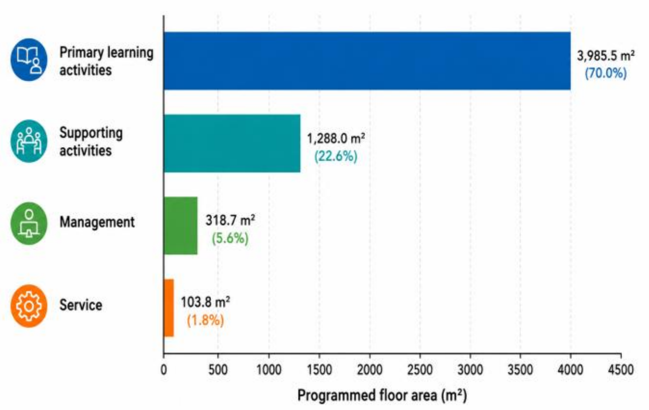

Figure 3. Distribution of the 5,696 m² spatial program. Primary activities constitute approximately 70% of the proposed floor area, followed by supporting, management, and service functions.

3.4 Zoning, circulation, and spatial sequence

A one-way vehicular loop enters from the east, serves drop-off and parking areas, and exits toward the west. Parking for cars, motorcycles, buses, staff, and users with disabilities is differentiated. Pedestrian movement is physically separated from the principal vehicle route and is directed through a planted approach to the plaza and main entrance. Internally, the atrium and reading stairs serve as orientation devices, social condensers, and visual links among floors. Their central position reduces dependence on long, enclosed corridors and allows users to understand the building through visual connection.

3.5 Biophilic integration

Nature in the Space is most evident in the landscape network. Vegetation is placed along the perimeter, plaza, pedestrian routes, parking areas, reading gardens, terraces, and selected interior zones. These elements are intended to provide shade, visual relief, dust filtering, microclimatic moderation, and a continuous experience of greenery from arrival to reading areas. The atrium brings daylight and vertical spatial connection into the center of the building. Large openings frame views toward planted outdoor spaces, while transitional terraces allow direct access to air and vegetation.

3.6 Environmental and building systems

The environmental strategy is mixed-mode rather than purely passive or purely mechanical. Semi-outdoor circulation, shaded terraces, and selected public-transition spaces use cross-ventilation and stack-assisted air movement through the atrium and high-level openings. Enclosed collection, computer, multimedia, and concentration-sensitive spaces use VRV/VRF air conditioning to control temperature and humidity. This distinction is important because high ambient humidity can threaten books, electronic equipment, and user comfort even when natural ventilation is desirable elsewhere. The relationships among source conditions, architectural responses, biophilic domains, and validation requirements are summarized in Table 4.

The evidence-to-design synthesis and future testing agenda are illustrated in Figure 4.

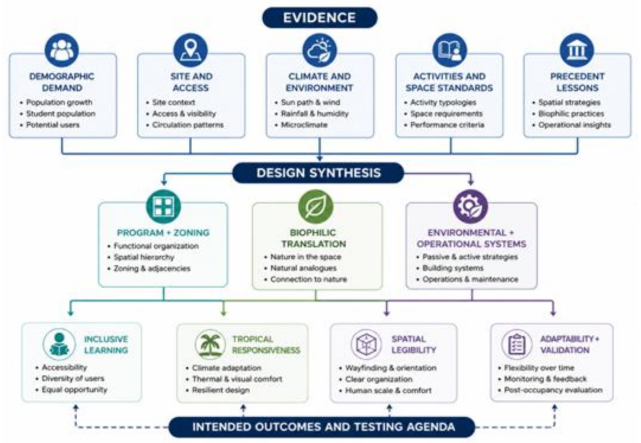

Figure 4. Evidence-to-design framework for the Makassar Public Library and Study Center. Demographic, site, climate, activity, and precedent evidence is translated through programming and biophilic principles into architectural, environmental, and operational responses.

Table 4. Integrated design-response matrix

Source condition or need	Architectural response	Biophilic domain	Intended function and validation
Growing student-oriented user base	Flexible reading, co-working, workshop, community, digital, and outdoor spaces	Nature of the Space	Adaptability and choice; test through utilization studies and post-occupancy evaluation
Eastern road access and traffic noise	Setback, front plaza, active-edge functions, vegetated buffer, layered envelope	Nature in the Space	Civic visibility with reduced disturbance; validate acoustically
Western afternoon heat	Deep shading, second skin, screened openings, planting, buffer spaces	Nature in the Space / Natural Analogues	Lower solar gain and glare; test with solar, daylight, and energy simulation
High humidity and collection sensitivity	Mixed-mode ventilation; conditioned collection and technology spaces	Nature in the Space	Air movement where suitable and stable collection conditions; validate hygrothermally
Need for legible multi-level movement	Central atrium, reading stairs, and visual links among floors	Nature of the Space	Orientation and social awareness; test through wayfinding observation
Need for interaction and concentration	Acoustic gradient from active public edge to quiet interior and western zones	Nature of the Space	Reduce activity conflict; validate with acoustic testing and occupancy mapping
Desire for contact with nature	Reading gardens, terraces, framed views, interior planting, shaded paths	Nature of the Space	Visual restoration and learning choice; validate through user surveys and maintenance review

Note. Intended functions are design hypotheses and require the validation indicated in the final column.

3.7 Architectural design resolution

The architectural resolution is documented through the site-planning and circulation scheme (Figure 5), the exterior massing and façade treatment (Figure 6), and the interior learning environments (Figure 7). Their relationship to the three biophilic domains is illustrated in Figure 8.

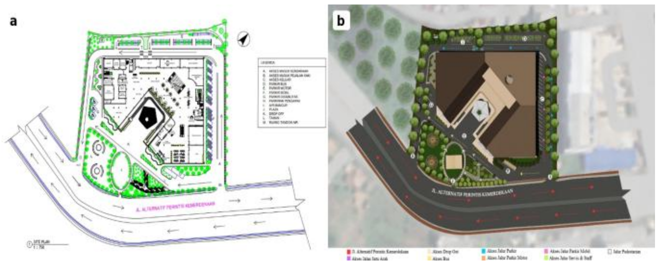

Figure 5. Site planning and circulation: (a) proposed site plan and landscape organization; (b) one-way vehicular loop, differentiated parking, pedestrian access, and planted perimeter. Source: author's design, 2026.

Figure 6. Exterior architectural resolution: (a) aerial view of the selected 1.6-ha site; (b) layered façade and shaded entrance edge; (c) pedestrian garden and landscape canopy. Source: author's design, 2026.

Figure 7. Interior learning environments: (a) general reading area with daylight and warm material cues; (b) active entrance and orientation zone; (c) informal lounge and flexible seating. Source: author's design, 2026.

Figure 8. Biophilic domains in the proposed design: (a) Nature in the Space through planting, light, and multi-level views; (b) Natural Analogues through timber-like finishes, patterned screens, and organic geometry; (c) Nature of the Space through prospect, refuge, and the reading-stair atrium. Source: author's design, 2026.

3.8 Civic learning ecosystem

The principal implication of the design is that a public library should be understood as a civic learning ecosystem. Printed collections remain important, but they are embedded within a wider network of individual study, group discussion, digital access, workshops, exhibitions, community events, youth activities, quiet retreat, informal socializing, and outdoor learning. This diversification is consistent with the public-library mandate for inclusive knowledge access and with systems-oriented educational design, which treats well-being, learning, and environmental quality as interdependent rather than separate objectives [1, 22].

The demographic analysis strengthens this argument. The potential-user series is not a count of actual visitors, yet its scale and trajectory indicate a large educational constituency. An increase from 410,000 to 429,000 potential users within four years suggests that a fixed, narrowly programmed library would risk early functional obsolescence. The design's flexible spaces are therefore not merely amenities. They are a response to uncertainty in demand, learning practices, technology, and community programming. Reading stairs can function as circulation, informal seating, event space, or orientation infrastructure. Workshops can support training, maker activities, or community meetings. Outdoor reading areas can accommodate overflow, low-cost programming, and informal use when weather permits.

3.9 Integrated biophilic strategy

The principal conceptual contribution is the treatment of biophilia as an integrated environmental strategy rather than a visual theme. Vegetation addresses shade, orientation, buffering, and visual comfort; the atrium supports daylight distribution, wayfinding, and social connection; terraces create intermediate climatic zones and user choice; material variation contributes sensory identity; and prospect and refuge address the coexistence of participation and focused study. This interpretation aligns with critical literature that connects biophilic experience with building performance and ecological responsibility [8, 23]. A recent educational design study in South Sulawesi likewise illustrates the coordination of light, air, vegetation, water, zoning, and sustainable utilities within a biophilic proposal, supporting a systems-based rather than decorative application [24].

This integrated interpretation is particularly important in a humid-tropical context. Strategies that are beneficial in one domain can be harmful in another. Large windows may improve views but increase glare and cooling loads; natural ventilation may provide air movement while admitting humidity, traffic noise, and pollutants; dense planting may create shade while increasing moisture and maintenance demands. Studies of natural views and daylight show perceptual and energy benefits, but also confirm the importance of controlled exposure [16, 17]. The semi-open atrium evidence from Bangkok similarly demonstrates that opening ratio, geometry, greenery, and cross-ventilation must be evaluated together [13].

The proposed mixed-mode approach is therefore more credible than a blanket claim of natural ventilation. Collections, digital equipment, and concentration-sensitive rooms require stable temperature and humidity, while shaded circulation, terraces, and selected social areas can operate with greater environmental openness. The atrium functions as a visual and climatic mediator rather than as a guarantee of passive comfort. Acoustic adaptation is equally important: research on naturally ventilated spaces shows that green views and auditory biophilic cues may influence comfort, but open windows remain a potential noise pathway [15].

The quantity and configuration of nature should be treated as design variables rather than assumed to be beneficial without limit. Experimental work suggests that increasing greenery can improve belonging and restoration up to a point, while excessive visual density may reduce positive arousal [25]. Façade research further indicates that perceived restorativeness depends on organized complexity as well as vegetation [26]. Green walls and three-dimensional planting require attention to public perception, structural support, irrigation, species selection, fire safety, waterproofing, and long-term maintenance [23, 27-29]. The design therefore concentrates planting where it performs multiple roles—shade, buffering, orientation, view, and spatial definition—rather than applying greenery uniformly.

3.10 Precedent reinterpretation for humid-tropical Makassar

The reviewed precedents demonstrate the social and spatial possibilities of contemporary libraries. Starfield Library Suwon uses dramatic vertical shelving and a multi-level atrium to transform the library into a destination within a commercial environment. Calgary Central Library uses an atrium and layered public programs to create a strong civic interior. Springdale Library integrates a park, green roof, transparent edges, and community technologies. These features informed the Makassar proposal, but the design avoids direct formal replication.

Climate requires reinterpretation. Transparent façades in temperate precedents cannot be copied without solar control. Green roofs and planted terraces require drainage, waterproofing, and maintenance systems appropriate to intense rainfall and humidity. Outdoor reading areas require shade, airflow, rain protection, and seasonal operational strategies. Materials must withstand corrosion, ultraviolet exposure, moisture, and heavy public use. The Makassar design therefore uses filtered transparency, deeper shade, mixed-mode ventilation, and vegetation as a buffer rather than treating openness as an unqualified virtue.

3.11 Inclusion and spatial justice

A public library can advance spatial justice by providing knowledge, technology, and safe study environments without requiring commercial consumption. The proposed combination of free reading areas, digital facilities, co-working, community rooms, children's spaces, worship facilities, accessible circulation, and outdoor public areas supports children, adolescents, university students, adults, researchers, community groups, volunteers, and staff. Evidence from study areas and educational campuses indicates that users value environmental choice and nature contact, but preferences vary across activities and groups [4, 6, 7].

Inclusion, however, cannot be inferred from the presence of multiple room labels. It depends on the detailed design of thresholds, furniture, acoustics, signage, toilets, lighting, sensory load, security, and management policy. The separated pedestrian route and accessible lift are positive starting points, but universal design requires more comprehensive review. Future development should examine tactile guidance, visual contrast, hearing support, accessible furniture, neurodiverse sensory needs, stroller movement, child safety, and equitable access to digital equipment.

3.12 Demand–program relationship

The study demonstrates the value of connecting demand data to the room schedule, but it also reveals the limits of available evidence. The potential-user series provides a broad planning signal, not a direct estimate of daily visits. The proposed 5,696 m² program allocates 70% to primary activities, which is consistent with the project's educational focus. Nevertheless, the appropriate gross floor area should ultimately be tested against service targets, expected visitor frequency, peak-hour occupancy, collection size, staff model, event schedules, and operational budget.

The program distribution offers a useful basis for design evaluation. A 70% primary-activity share indicates strong prioritization of user-facing learning functions. The 22.6% supporting share is also substantial, reflecting the importance of arrival, events, worship, sanitation, storage, and social amenities. The relatively small service allocation should be reviewed carefully because modern libraries require significant mechanical, electrical, information-technology, waste, loading, and maintenance infrastructure. Detailed design may increase the service fraction once shafts, plant rooms, loading, security, and facility-management requirements are fully resolved.

3.13 Implementation and operational durability

Implementation is an institutional challenge as much as a design challenge. Studies of biophilic adoption identify awareness, cost, policy support, maintenance capability, and interdisciplinary coordination as recurring enablers or barriers [30]. Emerging evaluation frameworks recommend assessing health, indoor–outdoor connection, and environmental quality together rather than scoring isolated features [31, 32]. The proposed library should therefore be accompanied by a planting-management plan, operational zoning strategy, environmental monitoring protocol, and post-occupancy program. Without these components, the visible design language could survive while the intended ecological and user benefits deteriorate.

3.14 Validation agenda

The proposed design is expected to support improved spatial legibility, diversified learning choice, visual connection to greenery, reduced direct solar exposure, moderated traffic disturbance, and a welcoming civic identity. These are plausible design intentions, not demonstrated outcomes. Post-occupancy studies of biophilic buildings report favorable perceptions of indoor environmental quality, health, and productivity, while also showing that outcomes depend on the completeness of biophilic implementation and on building operation [33-35]. Experimental evidence on indoor interventions likewise supports nature connectedness and acceptance, but does not eliminate the need for real-building evaluation [36].

A rigorous validation program should begin with annual daylight and glare modeling, solar and energy simulation, seasonal airflow analysis, hygrothermal assessment, and acoustic modeling. It should compare façade alternatives, shading depths, glazing ratios, atrium openings, HVAC zoning, and planting configurations. The next phase should include participatory review with children, students, staff, community organizations, and users with disabilities, followed by a post-occupancy protocol measuring environmental conditions, seat choice, utilization, wayfinding, perceived restoration, and maintenance performance. Such a program would connect the early-stage biophilic quality matrix to observed outcomes and avoid treating design certification as evidence of benefit [32].

3.15 Strengths and limitations

This study has several methodological limitations. The demographic series contains only five observations and one documentary inconsistency. Potential users are estimated from student categories rather than observed library demand. The site analysis is qualitative and does not include measured noise, air quality, solar radiation, soil properties, flood levels, or microclimate. The program has not been tested against a detailed operating plan, and the design lacks quantified daylight, energy, airflow, acoustic, structural, lifecycle, and cost results. The literature integration is focused rather than a full systematic review. These constraints are consistent with broader gaps in biophilic-design research, including limited climate-specific evidence and insufficient use of simulation and post-occupancy validation [10].

Accordingly, the study demonstrates a reproducible process for translating demographic, climatic, spatial, and biophilic evidence into a public-library design proposal. It does not establish realized improvements in well-being, energy performance, or social impact. Those outcomes require simulation, stakeholder assessment, and evaluation of an occupied building.

4. Conclusion

This study developed an explicit evidence-to-design framework for a biophilic public library and study center in Makassar. The potential-user constituency increased from 410,000 in 2020 to 429,000 in 2024. The principal 2034 planning range is approximately 474,700–484,000 users, supporting an adaptable rather than fixed single-purpose program. The longer 2044 scenario is retained only as sensitivity because the projection horizon substantially exceeds the available historical series.

The selected approximately 1.6-ha site offers metropolitan access, visibility, and proximity to educational institutions, while also presenting potential traffic disturbance, western solar heat, high humidity, and intense seasonal rainfall. The design responds through an east-facing civic frontage, planted setbacks, protected quiet zones, solar-control elements, mixed-mode environmental systems, separated pedestrian and vehicle circulation, and landscape-based drainage.

The 5,696 m² program assigns approximately 70% of floor area to primary learning and library activities. Its combination of reading, quiet study, co-working, workshops, digital access, community rooms, events, children's learning, and outdoor spaces supports a civic learning ecosystem rather than a book-storage institution. Biophilic principles are integrated through direct contact with light, air, vegetation, and views; through natural analogues in form and material; and through spatial experiences of prospect, refuge, continuity, and choice.

The principal contribution is methodological: demographic evidence, site analysis, spatial programming, biophilic theory, and building systems are organized within one traceable design process. The proposal should therefore be understood as a testable architectural framework whose thermal, daylight, acoustic, energy, behavioral, and maintenance performance remains to be validated through simulation, regulatory review, participatory design, and post-occupancy evaluation.

Declarations

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process. During the preparation and revision of this work, the authors used OpenAI's ChatGPT to assist with language refinement, readability, internal consistency, and checks of figure and table referencing. After using this tool, the authors reviewed and edited the content as necessary and take full responsibility for the content of the published article.

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