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RESEARCH ARTICLE

ECONEST: A DETERMINISTIC, PROVENANCE-AWARE COMPUTATIONAL FRAMEWORK FOR CLIMATE-RESPONSIVE SUSTAINABLE RESIDENTIAL DESIGN IN INDIA

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Abstract

Sustainable residential design involves a multitude of constraints like climate, location, cost, energy, water and indoor environmental quality. EcoNest is a web-based computational design system developed for the Indian residential context that takes in a requirement specification for the house and outputs a canonical HouseDesign for the house. EcoNest uses the specified location and housing requirements to resolve the local climate of the area using its knowledge base and selects suitable climate-responsive materials and design strategies, after which the system generates a floor plan for the house. Based on the building geo metry and climate of the location it determines conceptual photovoltaic and rainwater system capacities, generates a Bill of Quantities (BOQ) and the cost estimate of construction. It evaluates the sustainability of the house with a 100-point sustainability score and performs a Vastu Purusha Mandala analysis of the house. Also, the software allows users to view their design in 3D, as an SVG file of the floor plan and as various other views of the house. The software also includes a proposed service layer for active botanical biofiltration of the house's interior spaces. The active botanical biofiltration service layer is treated as a separate research module because the literature shows that active botanical biofiltration is effective for improving indoor air quality but also shows that there are important differences between passive and active botanical biofiltration systems. As a future extension EcoNest is proposed to be incorporated with more features, such as the ability to perform a multi - objective optimization of the house design that considers factors like passive comfort, life cycle carbon emissions, cost, water resilience and indoor air quality. Overall, Eco Nest is intend ed to serve as a bridge between the current state of sustainable residenti al design and future software that will incorporate physics - based simulations of the house design.

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Introduction:-

The universal need for a home is now complicated by challenges posed by climate change and rapid urbanization. Modern construction practices are as cost effective as they are flexible. Design of structures must consider many factors such as local climatic conditions. Thermally efficient walls could lead to increased moisture and greater costs. Large windows promote better air circulation but allow greater solar gain. These examples indicate the challenges facing designers of modern homes in India. The 2025–2026 Global Status Report for Buildings and Construction recognizes that buildings and construction contribute about 37% of total CO_2 emissions and nearly 50% of total resource extraction (United Nations Environment Programme [UNEP] & Global Alliance for Buildings and Construction [GlobalABC], 2026). Buildings have become a major source of CO_2 emissions. Rapid urbanization presents challenges with providing affordable housing and climate altering construction practices while adhering to cultural norms of how a housing unit should be structured.

Many of the digital design tools present limited, fragmented solutions. Building performance simulations can determine comfort and energy needs, and generative design tools allow designers to quickly explore and develop various patterns. However, every design system must consider a given structure's dimensions, materials, and costs. The EcoNest design strategy shifts this paradigm; computational geometry and other determining factors are controlled by structure and evidence-based design while generative AI tools are reserved for design text.

The EcoNest framework incorporates a structured knowledge base containing five climate zones: hot-dry, warm-humid, composite, temperate, and cold along with climate-responsive strategies, materials, and vernacular techniques. The knowledge base is drawn from building standards, government and technical guidance. EcoNest represents each generated design through a canonical HouseDesign structure, libraries of templates for one to three story structures, sizing for photovoltaics and rainwater collected, a geometry-based BOQ, a 100-point sustainability measure, and a Vastu analysis for nine different zones. The provided templates for multi-story implementation do not just mean a repeated plan. The provided templates establish a fixed stair location among the vertical connections, and distinguish programs at various levels of public, private, and semi-private (Figure 1).

The primary focus of this paper is to establish EcoNest as an evidence-based design tool and not just a software for creating renderings. This paper also extends its design concept from ‘Green Features’ where the focus is more on prioritizing multiple objectives to best respond to the needs of climate, cover cost and reduce carbon footprint, utilize water and offer optimal indoor environmental quality and design it in a culturally appropriate way.

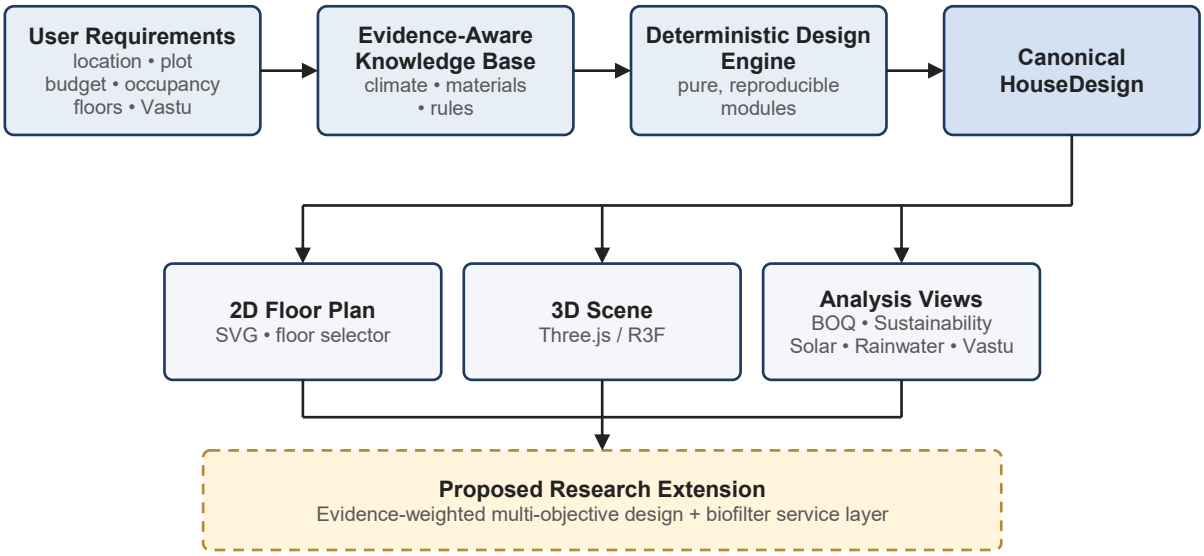


Figure 1. EcoNest evidence-grounded architecture and proposed research extension.

Related Work and Research Gap:-

Rule-based and knowledge-based systems form a basis for automated design systems that allow for interpretable design rules. While generative and diffusion-based systems further support design through improved visualization, connecting visualizations to measurable design and performance statistics remains a research challenge. The recent literature on the

optimization of building systems tends to view energy, thermal comfort, indoor air quality, construction cost, and carbon emissions not as separate goals to achieve, but as competing goals to manage (Al Mindeel et al., 2024; Chen et al., 2022; Sood et al., 2025; Xue et al., 2022).

This is especially true at the scale of housing. A 2024 review of multi-objective building optimization viewed energy, thermal comfort and indoor air quality as conflicting issues, and identified simulation-optimization coupling as the dominant research methodology (Al Mindeel et al., 2024). Sood et al. (2025) employed a metamodel/NSGA-II approach to balance energy, discomfort and CO_2 exposure in a residential construction focus. Overall, these publications support EcoNest's approach to move forward with a visible, deterministic, front-end model to drive physics-based simulation, or a validated surrogate model, to evaluate design alternatives.

Another major gap is in material selection. EcoNest's knowledge base includes thermal properties, thermal mass class, moisture behavior, embodied carbon classification, local availability, and maintenance and indicative cost (Chaturvedi et al., 2025; Vishnubhotla, 2022). This provides better depth than selecting only materials labeled 'eco-friendly.' Recent studies on compressed earth blocks (CEBs) provide a reason for taking a systems-based approach because earth can provide hygrothermal behavior and low embodied energy, but strength, moisture exposure, erosion, and stabilization and standardization are still important constraints (Gharbage et al., 2025). Research on waste-enhanced and bio-CEBs provide further opportunities for circular material strategies and the need for performance and environmental assessment (Paula et al., 2024).

Similar cautions are needed with regard to indoor environmental quality. The research on biofiltration with plants provides that, with proper airflow through the growing medium, a green wall can be an effective system for the removal and biodegradation of VOCs (Alvarado-Alvarado et al., 2024; Pettit et al., 2018). However, providing a lot of potted plants around the house is not enough to say that the air will be cleaned. In fact, a large review concluded that passive potted plants would need to be at a very high density in order to remove air pollutants at a rate comparable to normal air exchange (Cummings & Waring, 2020). Thus, EcoNest should not consider a 'biofilter' a sustainability label to apply to a potted plant.

Vastu Shastra is a unique type of knowledge. For the EcoNest system, we've included a 3x3 Vastu Purusha Mandala grid. It also maps out zones within a room that are considered ideal, acceptable, or not good, based on traditional Vastu texts. However, we've made it clear that this information is meant as cultural advice, not as a strict rule for building or a regulation. This difference is key to how the system works. It allows us to acknowledge cultural preferences without claiming that Vastu is a scientifically proven way to predict health, safety, or energy efficiency.

Research Architecture:-

EcoNest has been designed as a TypeScript/React client using Vite, with a Node.js/Express server. An example of how this client-server setup could be used is shown here. A custom SVG renderer is also being developed to display the 2D representation of the building design. The computation part of EcoNest implements the Requirement Spec to House Design process and the same canonical object represents both the visualization (in terms of panels) and analysis (the same canonical object). In order to contribute to the body of research, a Single-Source-Of-Truth architecture is crucial in that it minimizes the chance that the 3D view, the 2D floor plan, BOQ, and the sustainability report all refer to different geometries.

The knowledge base is explicitly typed by evidence class: code/standard, government guidance, technical guidance, research/climatic data, vernacular precedent, and internal heuristics. Examples of representative input include BEE's Eco-Niwas Samhita (Bureau of Energy Efficiency [BEE], n.d.); BIS documents (Bureau of Indian Standards, 1991); CPWD/HUDCO Guidance (Central Public Works Department, n.d.); MNRE Rooftop-Solar Guidance (Ministry of New and Renewable Energy, n.d.); BMTPC Material Literature (Building Materials and Technology Promotion Council, n.d.); TERI Passive-Cooling Work (The Energy and Resources Institute, n.d.); NASA POWER/Open-Meteo Climate Data; and Classical Vastu Sources (Manasara, n.d.; Mayamata, n.d.; Varahamihira, n.d.). Newer BEE resources include Eco-Niwas Samhita 2024 and the Energy Conservation & Sustainable Building Code 2024. Therefore, when updating versions of the knowledge base, reference updates should occur when possible from previous references (BEE, n.d.).

Each rule should have at least the following attributes: a source identifier; an evidence type (e.g., code/standard); a confidence level; a climate or context applicable; a parameter value(s) or range; a rationale; and a version. Since each rule will have these attributes, they provide the basis for creating an "Evidence Graph" -- trace back to what rule and evidence lead to the selection of a specific final room, wall, material or system. Although the decision records and

source references are currently exposed through the API -- this Evidence Graph is proposed as a formal research artifact (Table 1).

Table 1. Current platform and research-grade extension.

System layer	Current EcoNest implementation	Research-grade extension
Input	Location, plot, occupants, bedrooms, floors, facing, budget, courtyard, solar/RWH	Structured constraints + user priority profile
Knowledge	Typed climate, materials, vernacular, sources, rates, systems, Vastu	Versioned evidence graph + confidence propagation
Geometry	14 templates; 1–3 floors; deterministic envelope	Constraint-based multi-floor synthesis
Energy/Water	Conceptual PV and rainwater sizing	Physics simulation + uncertainty bounds
Cost	Geometry-derived BOQ + regional index	Time/region/supplier-aware LCC
Culture	9-zone Vastu analysis	Soft constraint / Pareto objective
Interior	Reference room images; proposed biofilter service layer	Validated IAQ + biofilter engineering model
AI	Reserved for parsing/explanation; geometry remains deterministic	LLM as interface only; validated optimization downstream

Deterministic Design Pipeline:-

The generation pipeline is climate resolution, multi-floor space planning, design strategy selection, envelope generation, site-data construction, solar and rainwater sizing, count and cost estimation, passive comfort analysis, sustainability score estimation, Vastu analysis, list of warnings, and the final HouseDesign (Figure 2). A deterministic run is such that using the same RequirementSpec and knowledge-base version provides the same architecture and numerical outputs. However, timestamps and runtime identifiers are not included in this reproducibility guarantee.

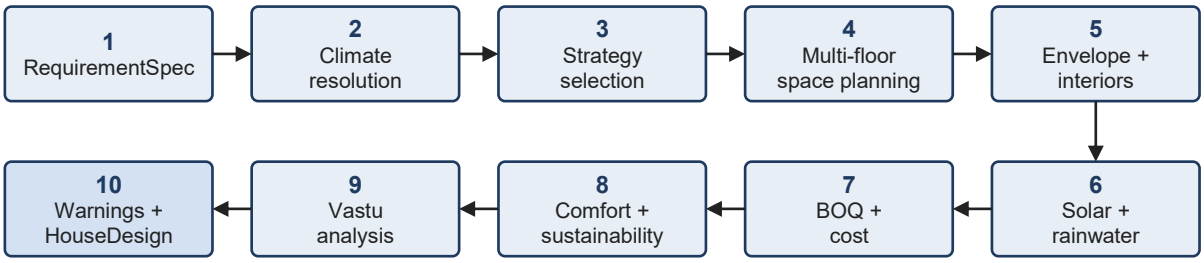


Figure 2. Deterministic EcoNest design pipeline.

If a known location is requested, the climate engine will resolve it to indicative coordinates, rainfall and solar-resource, and climate zone. If the location is unknown, it will revert to composite/default assumptions, and issue a warning. The design strategy engine selects wall/roof material, window-wall ratio, chajja depth, ventilation strategy, type of courtyard and renewable systems along with DecisionRecord (justifications and supporting evidence).

The EcoNest tool does not calculate the climate zone based on the raw weather data itself. For each location from the database, the climate zone classification (among five zones) according to the building energy efficiency codes (BEE, 2024a, 2024b) is provided. Currently, the lookup is provided for 19 cities from all five zones. The rain and sunshine levels stored for each city are averaged and marked as estimates (NASA Langley Research Center, n.d.).

The space planner has a library of 14 templates, which vary in the number of bedrooms (one to four), whether the building has a courtyard, the number of stories (one to three) and in how other floors differ as to programming (rather than being the same as on the bottom story). The location of the fixed staircase is preserved. Room adjacency is computed independently for each storey. If the number of floors or bedrooms is beyond the supported range, it will instead switch to the closest supported template and throw a warning (instead of a geometry error).

The envelope generator converts room plans into BuildingComponent records for walls, floors, roofs, windows, doors, chajjas, jali, columns, verandahs and courtyards. Solar sizing follows a demand-based approach, then constrained by roof packing capacity. The current documented model assumes 400 W mono-crystalline panels, a 0.75 derating factor

and an illustrative 23/180 orientation rule. Rainwater potential derives from roof catchment, rainfall and runoff assumptions. Both remain conceptual estimates requiring engineering verification.

Material Intelligence:-

A research-grade material engine should not just give materials a "green" score. For this very reason EcoNest keeps the data on heat transfer, heat capacity, moisture, type of carbon footprint, availability, level of maintenance, and cost at the same time (Table 2).

Table 2. Material intelligence matrix.

Material family	Potential role	Key constraints EcoNest should track
Compressed earth / CEB	Thermal mass, low-carbon/local construction	Strength, water exposure, stabilization, standardization
Natural stone	Durability, thermal mass, local vernacular fit	Extraction impacts, embodied carbon, transport, cost
Masonry	Robust envelope and availability	Cement intensity, thermal bridging, moisture
Timber/bio-based	Low-density renewable components	Durability, sourcing, fire, local availability
Glazing	Daylight and ventilation	Solar gains, heat loss, cost, shading dependence
Reused/waste-derived materials	Circularity and waste diversion	Quality control, provenance, health/durability

The emerging reasoning behind materials used in buildings can be viewed as a set of conditions and desires: climate appropriateness is the first-level filtering, moistures and durability constitute safety-level filtering, availability and cost as the feasibility-level filtering, whereas the optimization-level preferences include green aspects and local compatibility.

For areas with hot-dry and composite climates, it makes sense to use materials of high thermal mass that would help delay and reduce temperature extremes. Therefore, earthen and masonry buildings would be very suitable where there are no issues with moisture exposure and structural requirements. Research of CEB published recently supports that earthen materials are thermally and hygrothermally advantageous but strength, vulnerability to water, and standardization are factors that must be considered (Gharbage et al., 2025). That is why, rather than stating that "earth is the absolute best" all the time, EcoNest should disclose how the compromises are justified.

One possible way of making the database more helpful in selecting materials would be to create a Feasibility Material Vector M = [T, H, C, E, A, Mnt], where T is thermal appropriateness, H is compatibility between the material and the environment in regards to moisture, C deals with feasibility in a construction and cost perspective, E is how green the material is, A is how close the material is to hand, and Mnt is the level of care that needs to be given to the material in question.

Every feature will be standardized in such a way as to be able to compare them with the rest of the material information held by the database. Instead of reducing the overall set of the characteristics of a given material to just one score, the program could be displaying the reasons for preferring a material and suggesting similar alternatives in cases where one factor becomes an obstacle.

Another important aspect of the plan is to have a circular design that focuses on using resources efficiently. When information is available, the engine prioritizes material sourcing within the locality for building products, reuse/recycling material content, removable finishes, and low-waste assemblies.

This is in agreement with the growing demand to bring down the environmental impact of carbon and material of buildings around the world (UNEP &GlobalABC, 2026). Studies on cement-stabilized earth-based blocks made with waste indicate a technically fascinating development opportunity for the future. Yet, any new material should not be introduced as a component of EcoNest until the physical properties and durability data have been thoroughly validated and confirmed (Paula et al., 2024).

Vastu-Integrated Multi-Floor Sustainable Planning:-

The EcoNest's Vastu module first plots the centroid of each room in a 3x3 grid and then maps it to one of eight directional zones or the central Brahmasthan. Each room type is associated with different directional preference zones (ideal, acceptable, and inauspicious) along with weighted significance, explanation, and direction suggestions. A check is made that these rooms (toilet, kitchen, staircase) do not end up in the Brahmasthan. The total scores are aggregated to give an overall result between 0 and 100 and a grade. Along with that, the system also provides per room remediation suggestions (Manasara, n.d.; Mayamata, n.d.; Varahamihira, n.d.).

SW	S	SE
W	**Brahmasthan**	E
NW	N	NE

Current implementation classifies room centroids; plot-facing is accepted but not yet used in zone rotation.

Figure 3. 9-zone Vastu Purusha Mandala abstraction used by the engine.

The main approach here is domain separation. Vastu cannot dictate structural safety, buildings code compliance, climate physics, and professional engineering requirements. The separation is necessary in a research setup; it is a safeguard against mixing up cultural preference with actual building performance. One known drawback of the current system has been recognized and it is reported: plot-facing direction is accepted but zone classification is still based on the room centroid rather than the Mandala rotated according to plot facing.

Vastu shall be further enhanced such that it acts as a soft optimization objective instead of a post-hoc score. Suppose, V represents the weighted Vastu score and, ΔV is a change in Vastu score due to a room swap or a local geometric transformation. Only the candidate layouts that fulfill the hard constraints are considered, yet the value of V shall influence Pareto ranking. That way the right to culture remains intact: the user will not be presented with one answer for all but will be able to choose from 'Vastu-prioritized', 'balanced' or 'performance-prioritized' modes.

Interior Biofiltration and Indoor Environmental Quality:-

This layer of the interior space is expanded upon within the setting of the research project: an active botanical biofilter is considered to be a service to the building itself, rather than simply a decorative feature. Reviews of existing research on the topic show that botanical biofilters are systems that consist of plants, a substrate and microorganisms and that they are capable of degrading volatile organic compounds (VOCs) at relatively low levels of energy input (Alvarado-Alvarado et al., 2024; Pettit et al., 2018). Also, experiments on such systems have indicated that the airflow through the biofilter is necessary for the removal of VOCs from the air and that the microbial communities within the biofilter contribute to the degradation of VOCs (Pettit et al., 2018).

Passive potted plants cannot provide the same level of air filtration as a traditional building-scale filtration system. Cummings and Waring's study found that the density of plants required to provide the same level of air filtration as a typical building is impractical (Cummings & Waring, 2020). The proposed EcoNest module would control airflow, substrate, irrigation, drainage and maintenance of the plants, and could include sensors to monitor the health of the plants (Figure 4).

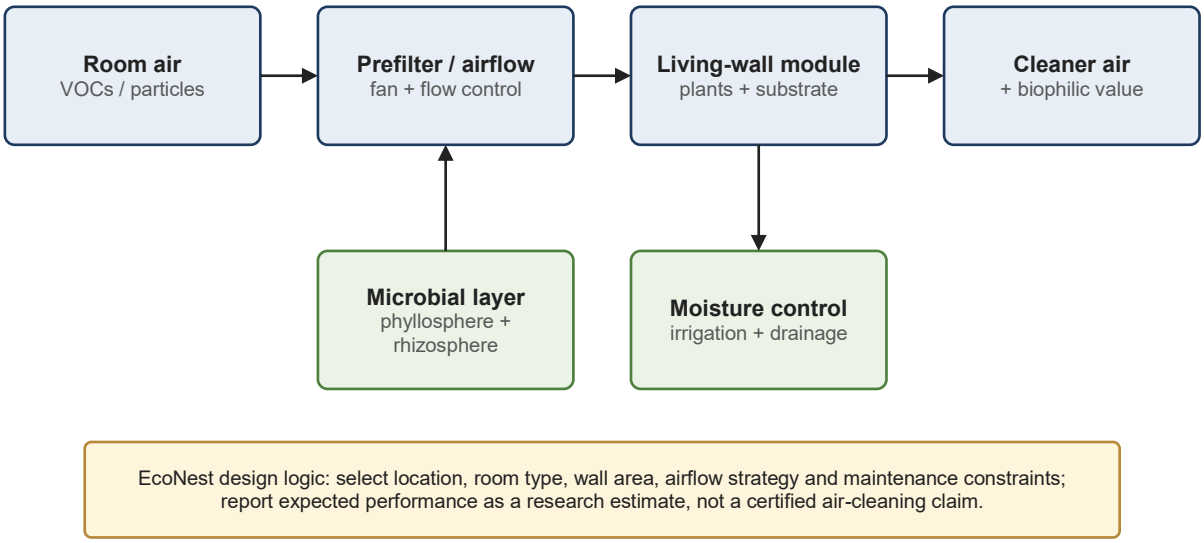


Figure 4. Research model for an active botanical biofilter service layer.

For an EcoNest implementation, the biofilter record should include parameters such as the volume of the room in which the filter is to be placed, the class of contaminants that the filter is to remove from the air, the area of the walls of the filter, the configuration of plants and media within the filter, the airflow rate through the filter, the pressure drop across the filter, the demand for irrigation of the plants within the filter, the provision of drainage for the filter, the maintenance interval for the filter, the expected lifespan of the filter and the confidence level in the accuracy of the estimates made by the user of the EcoNest software.

If the user does not have measurements of these parameters available, the software should show that the estimate was made by research rather than a percentage removal claim.

The proposed subscore for indoor air quality can include parameters such as source control, ventilation, filtration, daylight/biophilia and maintenance. ASHRAE Standard 62.2-2025 sets standards for residential ventilation and indoor air quality and includes ventilation, local exhaust and source control as parameters for achieving acceptable indoor air quality; botanical biofiltration should therefore be considered supplementary to these parameters unless it has been validated against the ventilation requirements of the standard (ASHRAE, 2025).

Sustainability, Energy, Water and Cost Model:-

EcoNest analyzes the local climate conditions of the land in order to recommend the most suitable systems for the home's renewable energy and water management needs. The software will determine the appropriate solar panel system for the rooftop of the home, along with the required ability of that system in kWp. Also, the software will estimate the potential for collecting rainwater from the home's rooftop to recharge the groundwater beneath the home. These calculations will allow the system to recommend a suitable solar capacity and rainwater-harvesting potential for the EcoNest home.

EcoNest's current sustainability metric includes seven categories: Passive Thermal Design (20), Energy Efficiency & Renewable (20), Water Conservation (15), Materials & Resources (20), Site & Landscape (10), Indoor Environmental Quality (10), and Waste & Circularity (5). This structure serves as an effective early-stage decision tool, but it cannot be considered as IGBC or GRIHA certified. IGBC Green Homes itself deals with site, water, energy, materials, indoor environmental quality, and innovation/design process (Indian Green Building Council, n.d.). These elements are why a category-based early screen is meaningful even though certification claims necessitate certification by means of certified procedures.

The cost engine is bottom-up: generated component quantities match material or assembly rates, grouped in structure, envelope, finishes, systems, solar and water, and then modified by a regional index and contingency. Currently, the basis of the rates comes from a Jaipur BOQ and is openly described as illustrative and not live market pricing. An

accurate research implementation would save the price date, region, supplier class, tax assumptions and confidence along with each rate.

The proposed objective formulation is given in Figure 5 and Figure 6.

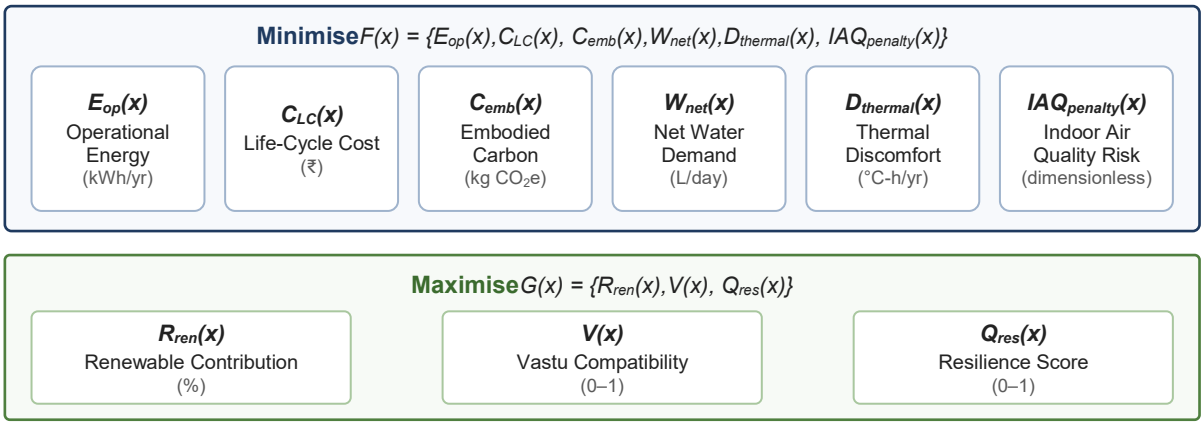


Figure 5. Proposed multi-objective formulation: objectives to minimize and maximize.

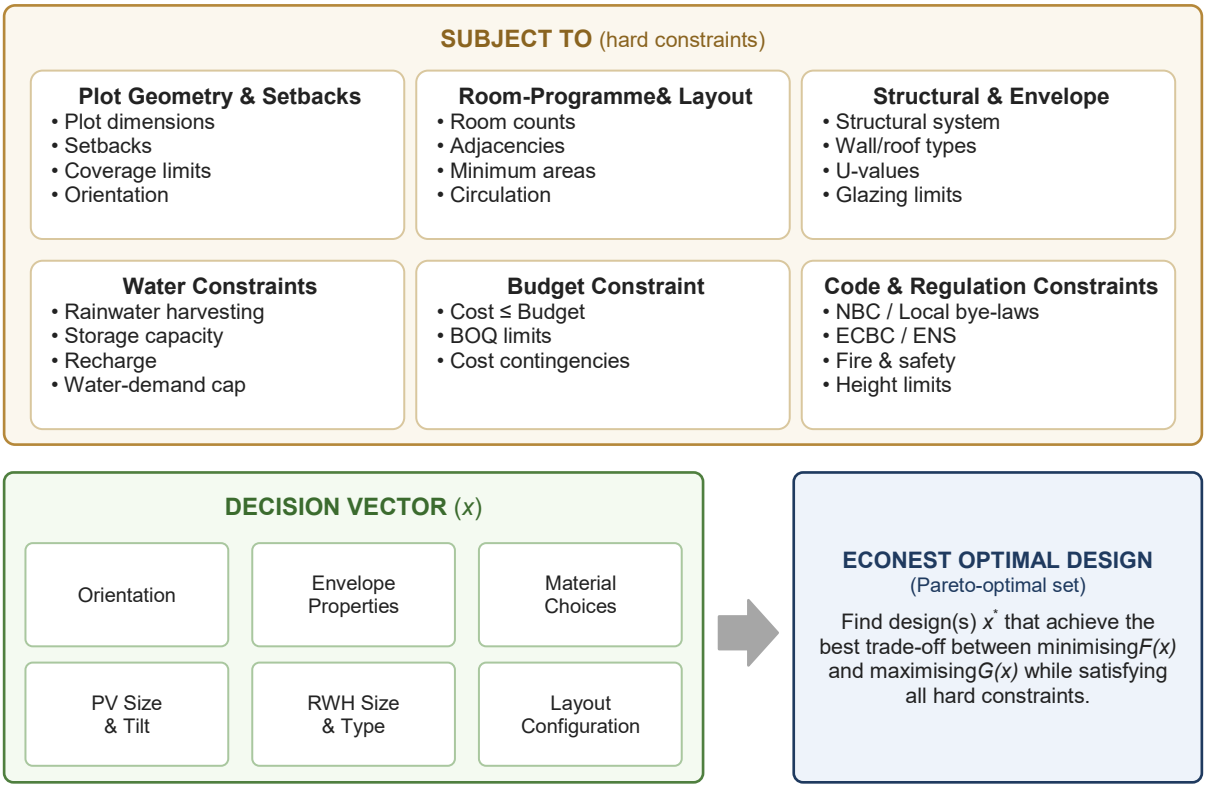


Figure 6. Hard constraints, decision vector and Pareto-optimal design set.

The method used to evaluate the formulation should be the Pareto method instead of simply using one arbitrary weighted sum.

The solar electricity model can be expressed in formulae as $C_{PV} = N_p P_p$, where N_p is the number of PV modules and limited by the demand side and roof packing. Annual energy production E_{PV} is approximated using $E_{PV} \approx C_{PV} \times H_{sun} \times PR$ with the help of a site-specific solar equivalent sun H_{sun} hours and a performance ratio PR.

The engine's current derating factor of 0.75 is an example only, not the fundamental physical constant. This has been pointed out by several researchers.

As for water harvesting, the amount can be roughly estimated by $V_{RWH} = P \times A_c \times C_r$, where P is the rainfall depth, A_c denotes the roof catchment area, and C_r is the runoff coefficient. These are very rudimentary formulas for the first estimation of the size of the system; a proper engineering study must follow.

PROPOSED 4C+I OPTIMIZATION AND EVIDENCE-AWARE DESIGN:-

The proposed concept of the paper is the 4C+I framework: Climate, Cost, Carbon, Culture and Indoor environmental quality. Climate: The way climate change is managed and how much someone is resistant to the weather. Cost is a measure of the affordability of a thing, especially at the outset and throughout its duration. Carbon (CO_2) is the amount of CO_2 used in the construction of the building and the amount used while it is operating. Culture is basically the choice of the person over the home and whether it is congruent with the Vastu concepts. Indoor quality is related to the air, the quality of the air, the daylight and the air temperature. The + I part ensures sustainability is not an issue of the outside world. The optimizer itself is not part of the validated current implementation.

EcoNest does not gloss over the compromises in one score. Rather, it will display a collection of designs to the user. If a home owner chooses to select a design they can choose either a low cost/high carbon or a high cost/low carbon or a combination of both. The system will show how the features of the house changed due to decisions regarding walls, window size, overhang depth, open space, location of rooms, solar area, water collection, natural cleaning area or location of rooms (Table 3).

Table 3. Proposed multi-objective formulation.

Objective	Representative variables	Direction
Climate/comfort	WWR, chajja, orientation, courtyard, mass	Minimize discomfort
Energy	Envelope, PV, ventilation strategy	Minimize energy
Carbon	Material quantities, EPD/LCA factors	Minimize $kgCO_2e$
Cost	CAPEX, OPEX, replacement	Minimize LCC
Water	Catchment, storage, fixtures	Minimize net demand / maximize resilience
IAQ	Ventilation, filtration, source control, biofilter	Minimize pollutant risk
Culture	Vastu room-zone compatibility	Maximize preference score

The evidence-aware layer provides an option to compare the results. There is a degree of certainty for each of the scores. There may be two possibilities that have predictions for carbon, but different levels of trust in the material data. Evidence with low trust should not be treated in the same way as evidence with high trust. One possible solution would be Evidence Adjusted Utilities: $U_e = U.g(q)$ where g(q) is a function that is tested and is dependent on one's trust in the evidence, and q is the level of trust. The idea is to not say that an architecture is incorrect, but to demonstrate that there is uncertainty in the decision-making process.

This architecture is compatible with future LLM integration. The LLM can translate free-text statements such as 'I want a cool, low-maintenance three-floor home with Vastu and a natural air-cleaning wall' into a RequirementSpec, but the LLM should not invent dimensions, prices, solar capacity or performance claims. The deterministic engine remains the computational authority, preserving reproducibility and auditability.

EVALUATION METHODOLOGY:-

The concept is well supported by the current literature. However, there is a lack of real-world studies published showing how energy saving, IAQ, embodied carbon, cost errors and user satisfaction are related. Therefore, the paper does not claim validated performance data. It reports demonstrator-level outputs from the current implementation and focuses on how to validate EcoNest and transform it from a demonstrator to a research output that is researchable in academic communities.

1) For the purpose of the comparison experiments between the generated HouseDesign and the standard HouseDesign a clean environment should be used, each test case should be run multiple times. This part is called the determinism test. Whatever architectural outputs will always be the same, regardless of the order of the runs.

2) With software check the wall intersections, room overlaps, staircase continuity. Also measure the floor spacing, the minimum clearance of the wall from floor.
3) Quantity validation: the quantities produced by the software should be compared to the manually measured ones and a mean absolute percentage error is provided between them.
4) Cost validation: determine the error rate by comparing the BOQ estimates (Professional) and then analyze the error rate per category and region.
5) Performance validation: move the models that represent the performance aspect to EnergyPlus or another simulator that is also validated and compare the energy/passive comfort proxies to the simulation.
6) Biofilter validation: The VOC levels in the controlled environment (lab) and actually in the tested room as a site together with airflow, pressure drop, humidity levels, effect of watering maintenance as well as effect of maintenance are to be measured.
7) Human evaluation of the system: The users architects, engineers and home users are expected to evaluate the system from several aspects, namely: its usefulness, clarity, users' trust and perceived controllability by employing a ranking system.

The ideal research project at the University could be in three modes of design: traditional manual design for the early stages, design using generative AI but without control of quantity of determinants and EcoNest. Time-to-first-viable-plan, quantity consistency, cost deviation, energy performance error, number of unresolved constraints and user trust can be part of the measured outcomes. It is not assumed that EcoNest will always produce the optimum building, but rather that it will generate an architecture that offers a more transparent and repeatable user decision making surface, and a far fewer number of unexplainable numerical outputs (Table 4).

Table 4. Validation matrix for the current system and research program.

Metric	Current status	Recommended validation
Determinism	Designed as deterministic	Repeated-run hash comparison
Geometry	Template-based conceptual	Automated constraint and clash tests
Cost	Indicative BOQ	Benchmark against professional estimates
Solar	Demand + roof packing heuristic	PVWatts/validated simulation + measured generation
Rainwater	Catchment/rainfall/runoff heuristic	Measured rainfall + storage/yield model
Thermal	Rule-based proxy	EnergyPlus/hygrothermal simulation
Vastu	Centroid-based cultural score	Expert review + user preference study
Biofilter	Research concept / reference layer	Chamber + occupied-room measurements

CASE STUDY AND RESULTS:-

Case configuration:-

The case study is a two-floor, three-bedroom house with solar and rainwater systems on a 12.5 m × 18 m plot in Jaipur (Tables 5–9). The platform identifies the location, selects thermally massive and shaded measures, creates a multi-story envelope, sets up conceptual solar and rainwater systems, a BOQ and calculates the sustainability score and reports Vastu compliance.

Table 5. Inputs used for the Jaipur illustrative case.

Input	Value
Location	Jaipur, Rajasthan (resolved to the composite climate zone)
Plot size	12.5 m × 18 m (about 41 × 59 ft; 225 m²)
Floors / bedrooms	2 (ground + first) / 3
Household size	4
Budget	Not specified
Plot-facing direction	East
Options selected	Covered car parking/porch; pooja room; study/home office; utility/laundry; balconies and open terraces; rooftop solar PV; rainwater harvesting
Option not selected	Courtyard

Results:-

Table 6. Key outputs of the Jaipur case (conceptual estimates, not validated).

Output	Value
Climate zone and strategy	Composite; CSEB walls, terracotta roof tiles, WWR 20–35%, adjustable shading, cross-ventilation
Rooms / components	17 rooms (9 ground floor, 8 first floor); 148 building components
Rooftop PV	18 panels, 7.2 kWp on 152 m² usable roof; about 10,800 kWh/yr
Rainwater harvesting	190 m² catchment, 600 mm rainfall, runoff coefficient 0.80; about 91,200 L/yr; 7,600 L tank; 9,120 L recharge pit
Water demand coverage	About 62% of 146,000 L/yr (4 persons × 100 L/day)
Indicative cost	₹29,95,524 (low confidence): materials ₹24,93,109; labor ₹2,80,523; 8% contingency ₹2,21,891; transport not modeled; PV 50% of total; 50 items unpriced
Sustainability score	76/100 (passive comfort proxy 80/100)
Vastu score	78/100; 15 of 17 rooms compliant

Table 7. Traceability of the Jaipur illustrative case.

Stage	Input/decision	Traceable output
Site	Jaipur; 12.5 × 18 m; G+1; 3 BHK; East-facing input	Composite climate profile
Strategy	CSEB walls; terracotta roof tile; WWR 20–35%; shading and cross-ventilation	Material and strategy DecisionRecords (5 materials selected)
Planning	Distinct ground-floor (9 rooms) and first-floor (8 rooms) programs	Room graph and floor geometry (17 rooms)
Envelope	Walls, openings, chajjas, jali screens, columns	148 BuildingComponent records
Systems	Solar and rainwater enabled	18 panels, 7.2 kWp (about 10,800 kWh/yr); 190 m² catchment, about 91,200 L/yr, 7,600 L tank
Economics	Regional rate base + 8% contingency	Itemized indicative BOQ: ₹29,95,524 (low confidence)
Sustainability	Seven-category internal score	76/100 (Table 8)
Culture	9-zone Vastu analysis	78/100; 2 rooms flagged for adjustment

Table 8. Sustainability Score Breakdown forthe Jaipur Illustrative Case.

Category	Score	Main sub-scores reported by the tool
Passive Thermal Design	16/20	Orientation 75, solar control 90, ventilation 65, thermal mass 85 (each out of 100)
Energy Efficiency & Renewable Energy	17/20	Solar PV 7.2 kWp (12/15); envelope efficiency 95/100 (5/5)
Water Conservation	9/15	Coverage 62% (7/12); water-efficient design 2/3; greywater not modeled
Materials & Resources	15/20	Local materials 5/5; low-carbon materials 2/5; traditional/renewable bonus 4/4
Site & Landscape	7/10	Courtyard 2/5 (no courtyard); rainwater recharge 5/5
Indoor Environmental Quality	8/10	Daylighting 3/5 (no courtyard); non-toxic materials 5/5
Waste & Circularity	4/5	Modular/reusable material present
Total	76/100	

Interpretation and observed limitations:-

The main part of this research is the interpretation of the findings rather than the presentation of results. All outputs of analysis in this context are based on the same database – HouseDesign. For example, if the plot area was different, it would affect room sizes, envelope area, roof area, the amount of solar equipment required, the amount of rainwater that can be collected, the quantity of materials and costs required, but not generate estimates independently. Similarly, when

the number of floors is adjusted, only the room planning and circulation system would be impacted and the ground floor drawing would be reproduced upwards.
This example has not yet been tested using the validation table suggested in Table 4. It's deliberately a distinction between the evidence of the now and the evidence of the future, as this paper does not claim evidence of platform performance at the current development stage.

Table 9. Observed limitations of the Jaipur case.

Issue	Detail
Plot-facing direction	Input was East, but the entrance is generated on the south side. The direction is accepted but not yet used to rotate the layout or the Mandala.
Vastu zoning	Living room, dining room, family lounge and one bathroom fall in the Brahmasthan (centroid-based 3×3 classification). Bathroom 2 and the utility room score 15/100 and are flagged.
PV cost share	PV is 50% of cost: all-inclusive rate ₹2,00,000/kWp (₹2,10,000 after regional index) from one illustrative BOQ; to be benchmarked against market and MNRE data.
BOQ coverage	Excludes transport, plaster and finish layers, and internal doors.

LIMITATIONS, ETHICAL POSITION AND FUTURE WORK:-

EcoNest isn't any sort of structural, seismic, MEP, building-code, quantity-surveying or construction-documentation systems, it is a decision support system primarily for the concept stage. The data regarding solar, rainwater and cost shown here is rough estimate only, and there is a possibility that it will be incomplete. The database of materials has several missing items; generation of multilayered models in the first version is limited to a maximum of 3 floors and 4 bedrooms; interior wall volumes are simplified.

The Vastu system, at first, is nothing but advisory. It is understood that no one would like to be using this system for any reason to show the unsafe structural design, poor ventilation or things like that. The same applies to the substitution of biofilters by the system.Also, it is literature itself which highlights that the fields of standardized testing and more robust building simulations need more attention before botanical biofiltration gets implemented at building scale.

The future work direction will be fivefold: (i) to change over from the fixed templates to design a multi-floor design based on constraints, but still the deterministic approach for reproduction will be used;
(ii) connecting the system to the live or regularly updated Bee standards and climatic and material databases;
(iii) integrating EnergyPlus/daylight/hygrothermal simulation with life cycle assessment;
(iv) designing the 4C+I optimizer module and the knowledge-confidence layer;
Finally, (v) to empirically confirm different configurations of biofilters and transfer validated results into the knowledge base.

CONCLUSION:-

EcoNest introduces a research-backed deterministic computational approach to building design that is a major architectural departure from the unconstrained, 'anything goes' approach to house plan design. The concept is computational responsibility that means, besides others, showing the plan layout, the explanation of the 3D scene, how materials were decided upon, the description of systems, and the list of quantities, the user will need to receive the Sustainability Metrics explanation and a Vastu report, as well. Presently the EcoNest platform also supports climate resolution, deterministic strategy making, multi-story blueprints, envelope construction, estimation of solar/rainwater, costing, sustainability assessment and cultural guidance.

It may not be the case that the next step is just 'business-as-usual AI'. Indeed, there are opportunities to enhance the relationship between the deterministic geometry, verified simulation, life-cycle material data and the development of the quality of indoor air, as well as multi-objective optimization. Our model of 4C+I and the utility function that draws from the evidence should create a system that not only shows the design of the dwelling but also explains to the viewer the rationale of this design, the solution's basis, how strong the base is, and alternatives that could have been reached if priorities were different.Such an approach would make the process of delivering sustainable homes more transparent, culturally aware and open to testing, while leaving the work of architects and engineers in design and construction unchanged.

References:-

1. Al Mindeel, T., Spentzou, E., & Eftekhari, M. (2024). Energy, thermal comfort, and indoor air quality: Multi-objective optimization review. Renewable and Sustainable Energy Reviews, 202, Article 114682. https://doi.org/10.1016/j.rser.2024.114682
2. Alvarado-Alvarado, A. A., Smets, W., Irga, P., & Denys, S. (2024). Engineering green wall botanical biofiltration to abate indoor volatile organic compounds: A review on mechanisms, phyllosphere bioaugmentation, and modeling. Journal of Hazardous Materials, 465, Article 133491. https://doi.org/10.1016/j.jhazmat.2024.133491
3. ASHRAE. (2025). ANSI/ASHRAE Standard 62.2-2025: Ventilation and acceptable indoor air quality in residential buildings.
4. Building Materials and Technology Promotion Council. (n.d.). Technical compendiums on compressed stabilised earth blocks and alternative building materials. Ministry of Housing and Urban Affairs, Government of India.
5. Bureau of Energy Efficiency. (n.d.). Eco-Niwas Samhita (ENS) 2024 and Energy Conservation & Sustainable Building Code (ECSBC) 2024. Government of India. https://beeindia.gov.in
6. Bureau of Indian Standards. (1991). IS 13077:1991: Guidelines for construction of mud mortar in masonry.
7. Central Public Works Department. (n.d.). Delhi schedule of rates and analysis of rates for building works. Government of India.
8. Chaturvedi, P. K., Kumar, N., & Lamba, R. (2025). Multi-objective optimization for visual, thermal, and cooling energy performance of building envelope design in the composite climate of Jaipur (India). Energy & Environment, 36(7), 3545–3569. https://doi.org/10.1177/0958305X241228513
9. Chen, R., Tsay, Y.-S., & Ni, S. (2022). An integrated framework for multi-objective optimization of building performance: Carbon emissions, thermal comfort, and global cost. Journal of Cleaner Production, 359, Article 131978. https://doi.org/10.1016/j.jclepro.2022.131978
10. Cummings, B. E., & Waring, M. S. (2020). Potted plants do not improve indoor air quality: A review and analysis of reported VOC removal efficiencies. Journal of Exposure Science & Environmental Epidemiology, 30, 253–261. https://doi.org/10.1038/s41370-019-0175-9
11. The Energy and Resources Institute. (n.d.). Passive cooling and tropical housing strategy literature. New Delhi, India.
12. Gharbage, I., Benmahiddine, F., &Sebaibi, N. (2025). Mechanical, thermal and hydric properties of compressed earth blocks: A review. Journal of Building Engineering, 104, Article 112387. https://doi.org/10.1016/j.jobe.2025.112387
13. Indian Green Building Council. (n.d.). IGBC green homes rating system. Confederation of Indian Industry. https://igbc.in
14. Manasara. (n.d.). Manasara [Classical Sanskrit treatise on Vastu Shastra and Indian architecture].
15. Mayamata. (n.d.). Mayamata [Classical Sanskrit treatise on Vastu Shastra and Indian architecture].
16. Ministry of New and Renewable Energy. (n.d.). Grid connected rooftop solar programme. Government of India. https://mnre.gov.in
17. Paula, A. C., Jr., Teixeira, E., & Mateus, R. (2024). Improving the mechanical, thermal and durability properties of compressed earth blocks by incorporating industrial waste and by-products: A systematic literature review. Construction and Building Materials, 438, Article 137063. https://doi.org/10.1016/j.conbuildmat.2024.137063
18. Pettit, T., Irga, P. J., & Torpy, F. R. (2018). Towards practical indoor air phytoremediation: A review. Chemosphere, 208, 960–974. https://doi.org/10.1016/j.chemosphere.2018.06.048
19. Sood, D., Alhindawi, I., Ali, U., Finn, D., McGrath, J. A., Byrne, M. A., & O'Donnell, J. (2025). Machine learning based multi-objective optimisation of energy consumption, thermal comfort and CO_2 concentration in energy-efficient naturally ventilated residential dwellings. Building and Environment, 267, Article 112255. https://doi.org/10.1016/j.buildenv.2024.112255
20. United Nations Environment Programme& Global Alliance for Buildings and Construction. (2026). Global status report for buildings and construction 2025–2026. United Nations Environment Programme.
21. Varahamihira. (n.d.). Brihat Samhita [Classical Sanskrit encyclopaedic text including Vastu Purusha Mandala principles].
22. Vishnubhotla, L. V. (2022). Developing climate-responsive passive strategies for residential envelopes in the warm humid climate of South India. Open House International, 47(3), 428–450. https://doi.org/10.1108/OHI-07-2021-0148
23. Xue, Q., Wang, Z., & Chen, Q. (2022). Multi-objective optimization of building design for life cycle cost and CO_2 emissions: A case study of a low-energy residential building in a severe cold climate. Building Simulation, 15, 83–98. https://doi.org/10.1007/s12273-021-0796-5.