International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-13, Issue-2; Feb, 2026
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.132.9

Nature Centric Housing: Biomimetic Green House Concepts for affordable Residential Design

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Received: 23 Jan 2026,

Received in revised form: 21 Feb 2026,

Accepted: 24 Feb 2026,

Available online: 28Feb 2026

Keywords— ***Nature-centric housing, Biomimetic design, Greenhouse architecture, Load-bearing stone masonry, Column-free structures, Affordable housing.***

Abstract— *Nature Centric Housing redefines affordable living by merging biomimetic principles with passive greenhouse architecture. The core innovation lies in a load-bearing stone system that eliminates conventional columns and beams, instead utilizing organic geometries like shells and cellular forms to distribute stress through mass. This structural efficiency, paired with locally sourced stone and lime mortar, significantly reduces embodied energy and construction costs. Integrated greenhouse zones serve as vital thermal buffers, regulating microclimates through natural ventilation and high thermal mass. Beyond temperature control, these spaces enhance indoor air quality and facilitate small-scale food production. By bypassing complex mechanical systems and utilizing traditional masonry in modern configurations, this model offers a resilient, low-carbon residential solution. It demonstrates that combining ancient material wisdom with nature-inspired design creates sustainable, socially responsive housing ideal for rural and semi-urban development*

I. INTRODUCTION

Rapid urbanization, climate change, and rising construction costs have intensified the demand for affordable, sustainable housing solutions. Conventional reinforced concrete construction often relies heavily on energy-intensive materials, complex structural systems, and mechanical climate control, contributing significantly to environmental degradation and operational energy consumption. In response, there is growing interest in alternative building approaches that draw inspiration from nature and traditional construction practices to create buildings that are resilient, low-carbon, and responsive to local climatic conditions. Nature-centric housing offers a promising framework by integrating ecological sensitivity, resource efficiency, and human well-being within the built environment.

Biomimetic design, which emulates natural forms and structural principles, provides innovative solutions for achieving strength, stability, and efficiency with minimal material use. Natural structures such as shells, caves, and cellular formations demonstrate how geometry and mass distribution can eliminate the need for conventional columns and beams while maintaining structural integrity. Applying these principles to residential architecture enables the development of load-bearing stone houses that rely on form and material behaviour rather than reinforced concrete frames. The incorporation of greenhouse spaces within the building envelope further enhances performance by acting as thermal buffers, improving daylight penetration, supporting natural ventilation, and creating healthier indoor environments.

This project proposes a column-free stone housing model that integrates biomimetic structural concepts with passive greenhouse architecture to achieve affordability, sustainability, and thermal comfort. Locally sourced stone and lime mortar are employed to reduce embodied energy, improve durability, and enhance thermal mass, enabling stable indoor temperatures throughout varying climatic conditions. The greenhouse zones also support vegetation growth and small-scale food production, contributing to microclimate regulation and occupant well-being. By combining traditional masonry techniques with nature-inspired design strategies, this study aims to demonstrate a viable housing model that addresses environmental responsibility, economic feasibility, and social sustainability, particularly for rural and semi-urban residential contexts.

1.1. Background Research Work

Extensive research in sustainable architecture highlights the effectiveness of vernacular construction in reducing energy consumption and environmental impact. Studies on load-bearing masonry systems confirm their capacity to safely support multi-storey buildings when designed with appropriate wall thickness and material strength. Research on bamboo construction emphasizes its tensile strength, seismic resistance, renewability, and low embodied energy, making it suitable for lightweight upper floors. Previous works on earth-based construction reveal that incorporating red soil in mortar improves thermal performance and humidity regulation. Landscape-based studies further indicate that grass-covered open areas lower ambient temperatures, reduce surface runoff, and enhance microclimatic comfort. Collectively, these research findings support the viability of combining stone, bamboo, soil, and vegetation into a cohesive vernacular housing system that aligns with modern sustainability goals.

1.2. History of the Study

The evolution of vernacular architecture is closely linked to regional climate, locally available materials, and indigenous construction knowledge. Traditional dwellings across India and other tropical regions employed stone, mud, lime, timber, and bamboo, relying on thick load-bearing walls for structural stability. Historic examples such as Wada houses of Maharashtra, Chettinad houses of Tamil Nadu, Himalayan stone houses, and bamboo dwellings of Northeast India demonstrate the effectiveness of column-less construction in multi-storey buildings.

Before the dominance of reinforced cement concrete, buildings commonly achieved durability and load distribution through wall thickness, arches, and gravity-based structural systems. Bamboo was widely used for upper floors and roofs due to its high strength-to-weight ratio and flexibility. With industrialization, vernacular methods were gradually replaced by standardized concrete construction, often neglecting climate responsiveness and sustainability. Recent environmental concerns have renewed academic and professional interest in vernacular and bio-based construction systems, positioning them as viable alternatives for modern affordable housing.

1.3. Literature Review

The growing demand for sustainable and affordable housing has encouraged researchers and practitioners to explore alternatives to conventional reinforced concrete construction. According to Kibert (2016), sustainable building design prioritizes resource efficiency, reduced environmental impact, and long-term performance while maintaining social and economic viability. Vernacular and traditional building systems using stone, earth, and lime have been widely recognized for their durability, low embodied energy, and thermal performance in diverse climatic regions. Studies by Oliver (2003) highlight that indigenous construction methods evolved in response to local climate, materials, and cultural practices, making them highly relevant for contemporary sustainable housing strategies, particularly in rural and semi-urban contexts.

Biomimicry has emerged as a powerful design approach that draws inspiration from natural forms, systems, and processes to solve architectural and structural challenges. Benyus (1997) describes biomimetic design as the practice of emulating nature’s time-tested patterns to achieve efficiency and resilience. In structural engineering, natural forms such as shells, domes, arches, and cellular geometries demonstrate how strength can be achieved through geometry and material distribution rather than through excessive reinforcement. Research by Addis (2007) and Block (2014) shows that funicular forms and compression-based structures can eliminate the need for conventional columns and beams while maintaining stability and load efficiency. These principles form the foundation for column-free load-bearing masonry systems that rely on mass, curvature, and continuity for structural performance.

Load-bearing stone masonry has been studied extensively for its mechanical strength, durability, and thermal mass properties. According to Minke (2012), stone and earthen materials provide excellent thermal inertia, stabilizing indoor temperatures by absorbing heat during the day and releasing it slowly at night. Lime mortar, when compared to cement mortar, offers superior breathability, flexibility, and compatibility with natural masonry units, reducing cracking and improving long-term performance (Forster, 2004). Several studies indicate that stone masonry structures exhibit lower life-cycle environmental impacts due to reduced embodied energy and longer service life. These characteristics make stone construction particularly suitable for affordable housing in regions where stone is locally available and labour skills are rooted in traditional masonry practices.

Passive solar design and greenhouse integration have also been explored as effective strategies for enhancing building energy performance and occupant comfort. Research by Mazria (1979) and Olgyay (2015) demonstrates that sunspaces and attached greenhouses can function as thermal buffers, capturing solar heat during colder periods while promoting ventilation and shading during warmer months. Such spaces improve daylight penetration, reduce reliance on mechanical heating and cooling systems, and support indoor air quality through vegetation. Studies on biophilic design by Kellert et al. (2008) further emphasize the psychological and physiological benefits of incorporating natural elements into built environments, including reduced stress levels, improved productivity, and enhanced well-being. These findings support the integration of greenhouse spaces within residential architecture as both an environmental and social sustainability strategy.

Despite the growing body of research on biomimicry, passive design, and sustainable masonry construction, limited studies specifically address the integration of biomimetic structural systems with greenhouse architecture in affordable housing models. Existing literature often focuses on either advanced structural form-finding techniques or passive environmental strategies independently, rather than their combined application in low-cost residential contexts. Additionally, most contemporary housing solutions continue to rely on reinforced concrete frames, overlooking the potential of compression-based, column-free masonry systems inspired by natural forms. This research seeks to bridge this gap by synthesizing biomimetic structural principles, load-bearing stone construction, and passive greenhouse design into a cohesive, affordable housing model that responds effectively to environmental, social, and economic sustainability goals.

Table 1: Comparison of Natural Houses

Project / Study	Material Used	Structural System	Sustainability Features	Relevance to Your Project
Stone Masonry House (India)	Stone, lime mortar	Load-bearing walls	High thermal mass, low energy	Supports column-free design
Biomimetic Pavilion (Europe)	Concrete, timber	Funicular shell	Minimal material use	Inspiration for structural geometry
Passive Solar Greenhouse House	Brick, glass	Column + wall hybrid	Greenhouse for thermal buffer	Supports integrated greenhouse zones
Vernacular Stone House	Stone, mud	Load-bearing walls	Low-cost, climate responsive	Local construction relevance

1.4. Scope and Limitations

The scope of this project focuses on designing and evaluating a nature-centric housing model that integrates biomimetic structural principles with passive greenhouse architecture to create affordable and sustainable residential spaces. The study emphasizes the development of a column-free, load-bearing stone housing system that leverages natural forms such as shells, caves, and cellular geometries to efficiently distribute loads. It investigates the use of locally sourced stone and lime mortar to minimize embodied energy, improve durability, and provide high thermal mass for stable indoor temperatures. The project also explores the incorporation of greenhouse zones to enhance natural ventilation, daylighting, thermal comfort, and opportunities for small-scale food production, thereby promoting occupant well-being and environmental sustainability. The design solutions are intended for rural and semi-urban contexts, where affordability, simplicity of construction, and ecological responsibility are critical.

However, certain limitations exist within this study. The project primarily focuses on conceptual design, material selection, and passive environmental strategies rather than full-scale construction or long-term performance monitoring. Structural analysis is limited to theoretical calculations and modelling, without extensive field testing. Additionally, the study does not cover complex multi-story configurations, heavy urban load conditions, or detailed economic feasibility studies beyond material and construction simplification. These constraints define the boundaries of the research while providing a focused framework for exploring innovative, nature-inspired housing solutions.

1.5. Objectives

- ✓ To study biomimetic structural principles applicable to column-free residential construction.
- ✓ To design a load-bearing stone housing system without conventional beams and columns.

- ✓ To integrate greenhouse spaces for passive thermal regulation and improved indoor comfort.
- ✓ To evaluate the use of locally sourced stone and lime mortar for sustainable construction.
- ✓ To assess the environmental, economic, and social benefits of the proposed housing model.
- ✓ To demonstrate the feasibility of nature-centric housing in rural and semi-urban contexts.

II. METHODOLOGY AND MATERIALS

This research adopts a design-based and analytical methodology to develop a nature-centric housing model integrating biomimetic structural principles with passive greenhouse architecture for affordable residential applications. The study combines qualitative and quantitative approaches, including literature analysis, case study review, conceptual architectural design, and basic structural evaluation. Emphasis is placed on developing a column-free load-bearing stone system inspired by natural forms such as shells, caves, and cellular geometries that efficiently distribute loads through mass and geometry. The methodology aims to achieve environmental sustainability, affordability, and thermal comfort while responding to local climatic and socio-economic conditions.

Primary data sources include academic journals, textbooks, building codes, sustainability guidelines, and documented case studies related to biomimicry, load-bearing masonry, passive solar design, and vernacular construction practices. Secondary data is collected from site climate records, material availability surveys, and standard construction manuals. These sources provide the foundation for selecting appropriate materials, determining building orientation, and integrating greenhouse spaces for environmental control. Traditional stone masonry techniques and lime mortar systems are studied to ensure compatibility with local construction skills and resource availability.

The design process begins with spatial programming based on functional requirements and area standards. The ground floor area is limited to approximately 1500 sq. ft, and the first-floor area is restricted to 610 sq. ft, 890 is lawn - balcony resulting in a total built-up area of 2110 sq. ft, as per project constraints. Conceptual massing studies and form-finding exercises inspired by natural load-bearing forms guide the development of the column-free structural system. Passive greenhouse zones are integrated along sun-facing facades to enhance daylighting, thermal buffering, and natural ventilation. Architectural drawings, plans, sections, and 3D models are prepared to visualize spatial organization, structure, and environmental performance.

Structural analysis is conducted using basic analytical methods and code-based checks to assess load paths, wall thickness, opening proportions, and stability under gravity loads. Thermal performance is evaluated qualitatively through material thermal mass properties, passive solar orientation strategies, and airflow patterns, supported by climatic design guidelines. Material performance analysis includes embodied energy comparison between stone-lime systems and conventional reinforced concrete construction. Functional zoning, circulation efficiency, and user comfort are also examined through spatial analysis and design iteration.

Evaluation criteria for the proposed housing model include structural feasibility, environmental performance, construction affordability, material efficiency, and occupant comfort. The design is assessed based on its ability to eliminate conventional columns and beams while maintaining stability, reduce operational energy through passive greenhouse integration, and minimize embodied energy using local materials. Cost-effectiveness, adaptability to rural and semi-urban contexts, and ease of construction using local labour skills are also considered. These criteria collectively determine the suitability and sustainability of the proposed nature-centric housing solution.

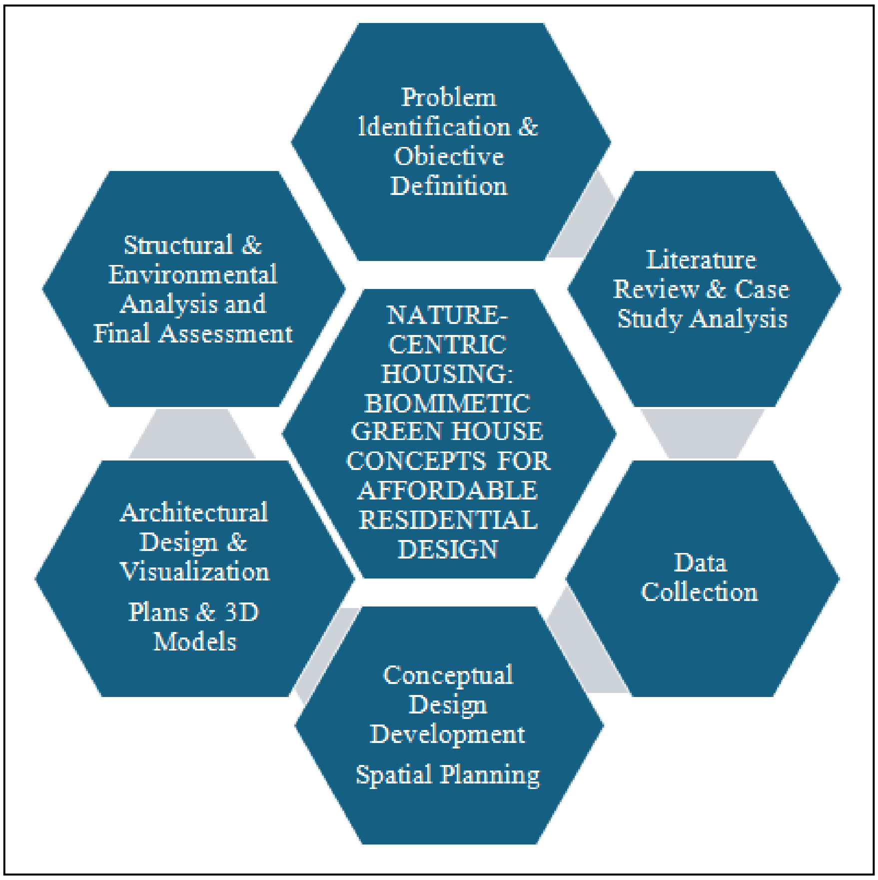

Fig.1: Propsed methodology for the project

2.1 Materials Used:

2.1.1 Mud / Soil and Stabilizers:

Soil is the primary material used in mud house construction. The ideal composition includes clay for binding, silt for smoothness and workability, and sand for strength and crack prevention. This soil is used in the form of adobe, cob, or rammed earth, forming the structural walls of the house. Its high thermal mass absorbs heat during the day and releases it at night, naturally regulating indoor temperature and humidity. Proper testing of soil is essential to ensure structural stability. Stabilizers enhance the strength, durability, and water resistance of mud walls. Lime is widely used for eco-friendly stabilization, while cement is added in small amounts for compressed stabilized earth blocks (CSEB). Natural additives like, jaggery, neem extract, and rice husk ash are also used to reduce shrinkage and cracks. These stabilizers help the walls resist erosion and increase their lifespan while maintaining breathability. Plastering protects walls and enhances their durability. Mud plaster mixed with cow dung and fibers is breathable, self-repairing, and environmentally friendly. Lime plaster is water-resistant, antibacterial, and prevents fungal growth. Cement-based plaster is usually avoided as it reduces breathability and traps moisture.

2.1.2 Stone Masonry for Construction:

Natural building stones are used as the primary construction material due to their high compressive strength, durability, and long service life. Stone masonry provides excellent load-bearing capacity, thermal comfort, and a sustainable alternative to brick-based construction.

The foundation supports the mud walls and protects them from moisture. Stone masonry, lime concrete, or gravel layers are commonly used. A raised plinth of ensures protection against ground dampness and rainwater splash. This traditional approach enhances stability and longevity of the structure. Flooring is made from rammed earth, lime-surkhi, or stone to provide thermal comfort, durability, and non-toxicity. These materials maintain coolness in summer and warmth in winter, while being easy to maintain and sustainable.

2.1.3 Bamboo/Timber Materials:

Bamboo is a fast-growing, renewable material with high tensile strength and flexibility. It is used in construction for roofing, framing, and temporary supports, offering an eco-friendly alternative to steel and timber. Roofs are constructed using lightweight, thermally efficient materials like straw thatch, clay tiles, or mud roofs supported by bamboo or timber frameworks. These materials insulate interiors from heat, reduce load on walls, and help maintain natural temperature regulation. The roofing design often mimics tree canopies to provide shade and cooling. Doors and windows are crafted from locally available wood, bamboo, or reclaimed timber. Designs often include Jaali patterns or latticework to allow natural ventilation and light while minimizing direct heat. Properly sized and oriented openings enhance airflow and indoor comfort.

2.1.4 Waterproofing and Finishes:

Natural finishes are applied to protect walls from rain and erosion. Lime wash, linseed oil, or cow dung slurry coatings maintain breathability while increasing durability. These finishes mimic natural protective layers found in soil and plant systems.

2.1.5 Techniques Used

Locally sourced stone is used as the primary structural and enclosure material due to its high compressive strength, durability, and thermal mass properties. Stone masonry walls serve both structural and enclosure functions, eliminating the need for reinforced concrete columns and beams. Lime mortar is employed instead of cement mortar to improve breathability, flexibility, and compatibility with natural stone, reducing long-term cracking and maintenance. These materials significantly reduce embodied energy and support environmentally responsible construction while promoting local craftsmanship and economic sustainability.

Traditional load-bearing masonry techniques such as coursed rubble masonry, dressed stone masonry, arches, vaults, and domical forms are adopted to achieve column-free structural systems. These forms allow loads to be transferred efficiently through compression and geometry rather than through framed structures. Openings are strategically positioned and proportioned to maintain structural integrity while maximizing daylight penetration and cross-ventilation. Roof systems incorporate vaults and shell-inspired geometries that enhance structural stability and spatial quality while reducing material usage.

Passive environmental techniques are integrated through greenhouse zones, thick thermal mass walls, natural ventilation pathways, shaded openings, and appropriate building orientation. The greenhouse spaces act as thermal buffers by absorbing solar heat during cooler periods and facilitating air circulation during warmer seasons. Vegetation within these spaces improves indoor air quality and supports microclimate regulation. Together, the materials and construction techniques demonstrate how biomimetic principles, vernacular knowledge, and passive design strategies can be combined to create sustainable, affordable, and resilient housing solutions.

2.2 Referance structure Explination (Eastgate Centre- Harare, Zimbabwe)

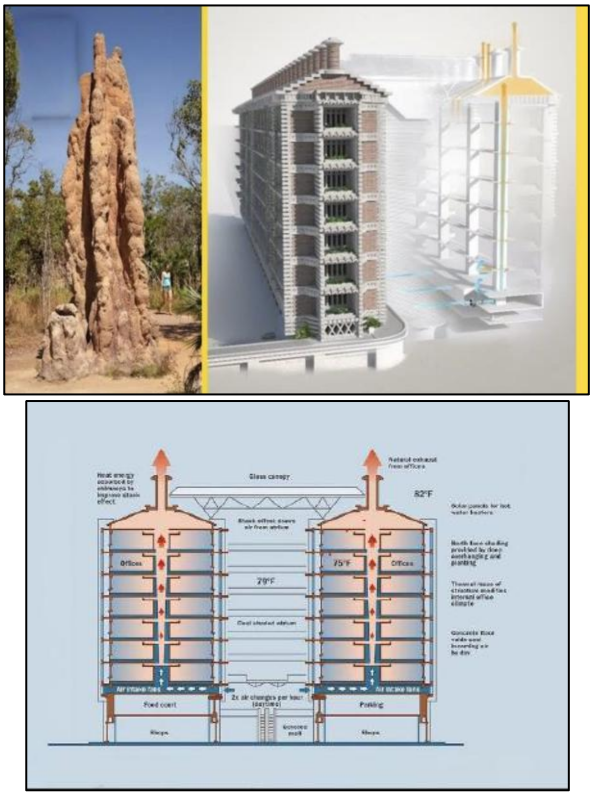

Fig. 2: Eastgate Centre Harare, Zimbabwe

2.2.1 Biomimetic Design Concept Inspired by Termite Mounds

The Eastgate Centre is a globally recognized example of biomimetic architecture, where natural systems directly inform building performance. Architect Mick Pearce drew inspiration from African termite mounds, which are able to maintain nearly constant internal temperatures despite harsh external heat variations. By studying how termites use natural convection, thermal mass, and a network of vents to regulate temperature, these principles were translated into an architectural strategy that replaces conventional air-conditioning with a passive climate control system. The building primarily uses reinforced concrete and brick masonry, selected for their high thermal mass properties. These materials absorb excess heat during the day and slowly release it at night, reducing indoor temperature fluctuations. This process mirrors termite mound walls, which stabilize internal conditions by storing and dissipating heat over time. As a result, interior spaces remain comfortable without relying on energy-intensive mechanical cooling systems.

2.2.2 Passive Ventilation and Chimney Network System

A complex network of ventilation ducts, floor voids, and 48 brick chimney stacks enables continuous air movement throughout the building. Cool air is introduced at lower levels and flows upward when it warms, exiting through higher vents and chimneys. This stack effect-driven airflow is largely natural, with low-energy fans only assisting when required. The system ensures fresh air circulation while minimizing energy use. The Eastgate Centre operates on a carefully designed diurnal cycle. At night, cooler outdoor air is drawn into the building to cool the concrete floors and internal structure. During the day, this cooled thermal mass absorbs internal heat gains from occupants, equipment, and solar radiation. Warm air naturally rises and is expelled through chimney stacks, maintaining comfortable indoor temperatures throughout working hours.

2.2.3 Facade Design and Solar Heat Control

The building façade incorporates deep overhangs, recessed windows, balconies, textured surfaces, and integrated vegetation. These elements reduce direct solar gain, provide shading, and increase surface area for heat dissipation. Vegetation contributes additional cooling through evapotranspiration, enhancing both thermal comfort and visual quality. Energy Efficiency and Economic Performance by eliminating conventional HVAC systems, the Eastgate Centre uses less than 10% of the energy required by similarly sized air-conditioned buildings. This resulted in substantial savings during construction and significantly reduced operational costs. Tenants benefit from lower rental and energy expenses, making the building both environmentally and economically sustainable. While the design principle is biomimetic, the building reflects local Zimbabwean construction traditions through extensive use of brick and masonry. This integration ensures cultural relevance, local material sourcing, and reduced environmental impact, demonstrating that advanced sustainability can coexist with regional architectural identity.

2.2.4 Technological Innovation and Contemporary Relevance

The Eastgate Centre represents a fusion of traditional natural intelligence and modern engineering. In some implementations, sensor-guided systems adjust airflow and fan speeds to optimize performance. The building serves as a precedent for climate-responsive design in hot regions, proving that passive systems inspired by nature can outperform conventional technologies. The Eastgate Centre stands as a benchmark for sustainable commercial architecture, showing how biomimicry can fundamentally reshape building technology. By emulating termite mounds, it achieves thermal comfort, energy efficiency, and economic viability without mechanical air-conditioning, offering a powerful model for future climate-responsive and low-energy buildings worldwide.

2.3 Case Study on Wada-Style Farmhouse (Mahi Ravani, Nashik, Maharashtra)

2.3.1 Architectural & Cultural Background

The farmhouse design is rooted in traditional Marathi Wada architecture, which evolved during the Peshwa era as a response to social structure, climate, and local resources. Historically, Wada house extended families and supported community living through inward-looking layouts and strong spatial hierarchy. In the Mahir Avani - Nashik region, this architectural language is reinterpreted as a farmhouse typology, where heritage planning principles are retained while adapting to contemporary lifestyle needs such as privacy, leisure, and modern amenities. The design reflects cultural continuity while responding to present-day living patterns.

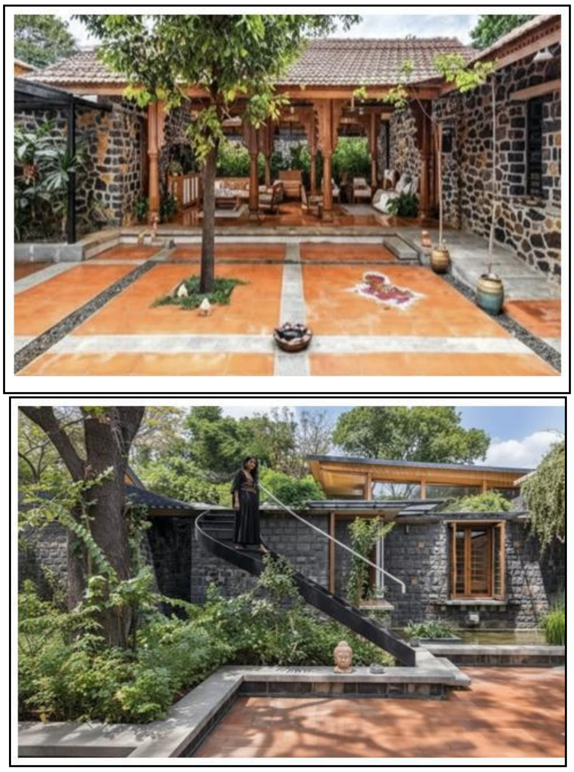

Fig. 3: Wada-Style Farmhouse

2.3.2 Spatial Planning & Courtyard-Centric Layout

The core of the farmhouse is the central courtyard (chowk), which functions as the spatial, social, and climatic heart of the house. All major spaces living, dining, kitchen, and bedrooms are arranged around this courtyard, ensuring visual connectivity, ventilation, and daylight. Entrance verandas and oltas act as transitional social spaces, while secondary courtyards may be introduced for utilities or private retreats. In modern adaptations, circulation is simplified and courtyards often extend into landscaped outdoor areas, pools, or sit-out zones, strengthening indoor–outdoor relationships.

2.3.3 Materials & Vernacular Construction Technology

The farmhouse uses locally sourced, natural materials traditionally associated with Wada construction. A raised basalt or granite stone plinth protects the structure from ground moisture and enhances thermal performance. Walls are constructed using thick load-bearing stone or brick masonry bonded with lime mortar, which allows the building envelope to breathe and age gracefully. These materials minimize embodied energy and reinforce regional identity while ensuring long-term durability.

2.3.4 Structural System, Roof & Craftsmanship

The superstructure incorporates timber beams and columns, using local hardwoods as both structural and aesthetic elements. Flooring is finished with stone slabs or lime-plastered surfaces using natural pigments. The sloping roof with terracotta tiles provides effective insulation and monsoon protection. In contemporary farmhouse versions, insulated roof systems and solar photovoltaic panels are integrated discreetly. Intricately carved wooden doors, windows, and veranda columns reflect traditional Maharashtrian craftsmanship, preserving cultural expression. The farmhouse design is inherently climate-responsive. The courtyard acts as a thermal regulator, promoting stack ventilation and diffused daylight. Thick masonry walls stabilize indoor temperatures by absorbing heat during the day and releasing it at night. Sloped roofs, shaded verandas, vegetation, and water elements support evaporative cooling and reduce heat gain. Orientation is carefully planned to minimize harsh solar exposure and capture prevailing breezes, reducing reliance on mechanical cooling systems.

2.3.5 Modern Adaptation & Sustainability Value

Contemporary Mahir Avani farmhouse designs successfully merge vernacular wisdom with modern construction practices. Salvaged wood from old Wadas, dressed basalt masonry, solar energy systems, and seamless indoor–outdoor living spaces enhance sustainability and comfort. With low embodied energy materials, passive cooling strategies, rainwater management, and strong landscape integration, the Wada-inspired farmhouse demonstrates how traditional architecture can meet 21st-century expectations while preserving cultural identity, environmental harmony, and long-term resilience.

III. SCALE DOWN MODEL PROJECT DESCRIPTION

3.1 General

The proposed project is designed for a rural or semi-urban residential setting characterized by moderate climatic conditions, availability of local stone materials, and a strong tradition of masonry construction. The site is assumed to have adequate solar exposure, natural ventilation potential, and sufficient open space for integrating greenhouse zones and landscape elements. The planning approach prioritizes orientation, daylight access, and passive thermal performance while responding to contextual factors such as local lifestyle patterns, climate responsiveness, and construction feasibility. The design accommodates a total built-up area of 2110 sq. ft, with 1500 sq. ft on the ground floor and 610 sq. ft on the first floor, ensuring functional spatial organization while maintaining affordability and simplicity.

The project consists of a column-free load-bearing stone residential unit incorporating greenhouse spaces along sun-facing facades to act as thermal buffers and bio-climatic modifiers. The ground floor accommodates primary living spaces such as the living area, kitchen, dining space, bedrooms, and utility zones, while the first floor includes private sleeping spaces and family areas. Structural stability is achieved through thick load-bearing stone walls, arches, vaults, and shell-inspired forms instead of conventional beams and columns. The greenhouse spaces support vegetation growth, enhance indoor air quality, and improve thermal comfort by regulating temperature and airflow naturally.

3.2 Ground Floor Area Planning

The ground floor area of 1500 sq. ft accommodates living spaces, kitchen, bedrooms, and utility zones, this floor planning is drafted using AutoCAD.

The ground floor is planned within a built-up area of approximately 1500 square feet and follows the principles of traditional Vada architecture integrated with modern functional requirements. The spatial layout includes a living room, kitchen, passage area, washroom, two bedrooms, one common toilet, one separate toilet, and a staircase. The planning ensures proper circulation, privacy, and functional zoning, where public spaces such as the living room are placed near the entrance, while private spaces like bedrooms are located in relatively secluded areas. The passage areas connect different spaces efficiently and enhance ventilation and movement within the house. Structurally, the ground floor is designed as a load-bearing stone masonry system rather than a conventional RCC column-frame structure. Thick stone walls act as primary structural elements, transferring loads directly to the foundation. The wall thickness is intentionally kept large to increase load-bearing capacity, thermal insulation, and durability. The use of natural stone provides high compressive strength, making it suitable for supporting upper floors. Lime mortar, cement, and red soil are used in masonry and plastering, enhancing bonding strength while maintaining eco-friendly characteristics. This construction method reflects traditional building practices while ensuring structural stability and long-term performance.

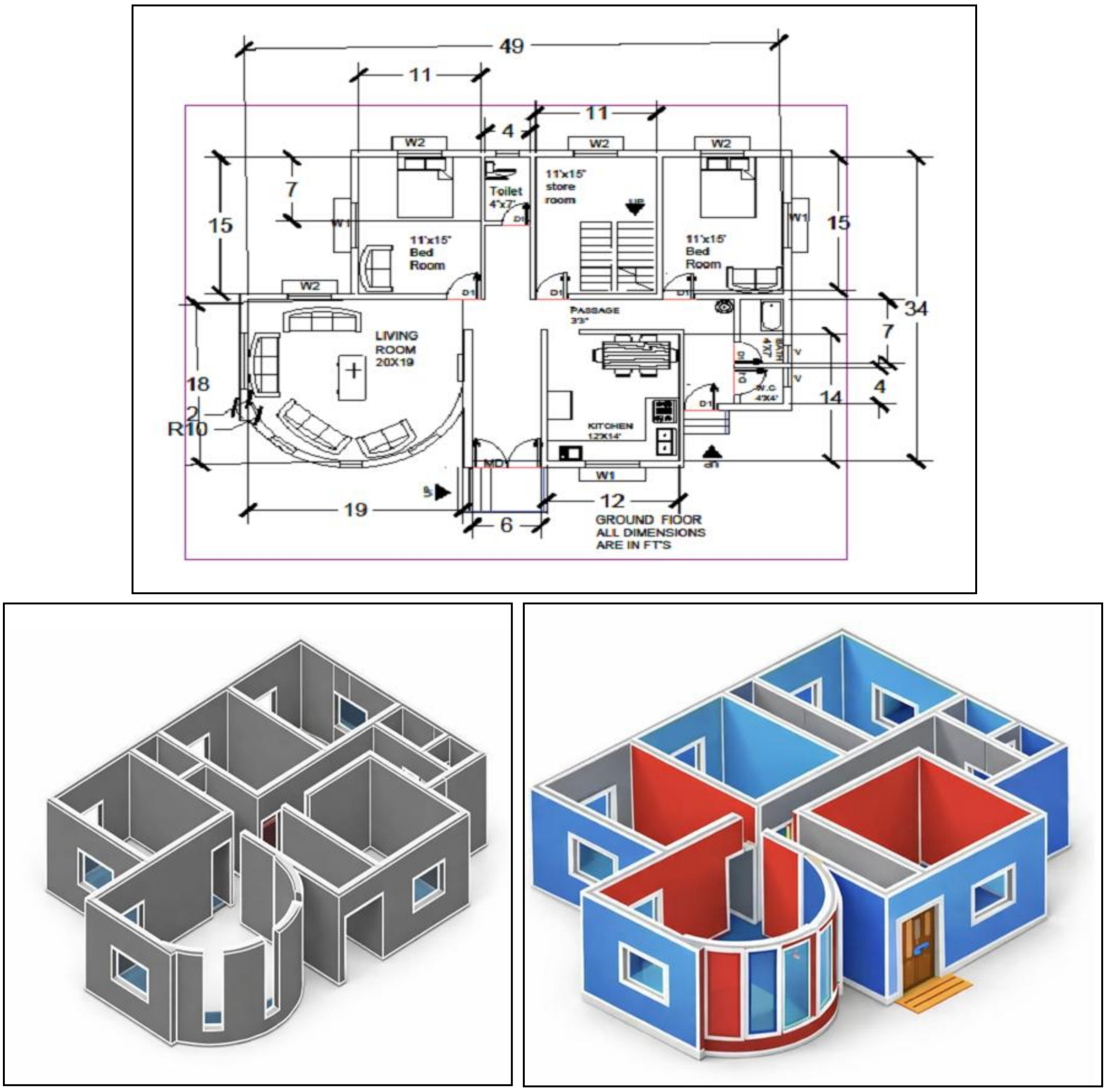

Fig. 4: Ground Flooring Plan and 3D View

The foundation system of the ground floor is designed to support heavy stone masonry walls and future vertical loads from the upper floors. A continuous strip foundation or stepped stone foundation is used beneath the load-bearing walls to distribute loads uniformly to the soil. The foundation depth and width are determined based on soil bearing capacity and wall thickness. The integration of stone, lime, and cement in the foundation improves structural stability and resistance to settlement. The ground floor design combines traditional materials, sustainable construction techniques, and structural efficiency, making it suitable for load-bearing stone architecture.

3.3 First Floor Area Planning

The First-floor area of 1500 sq. ft. where 610 sq. ft, is used for Passage area, Bedrooms and utility zones, Remaining Area890 sq. ft. Lawn/landscaping. This floor planning is drafted using AutoCAD.

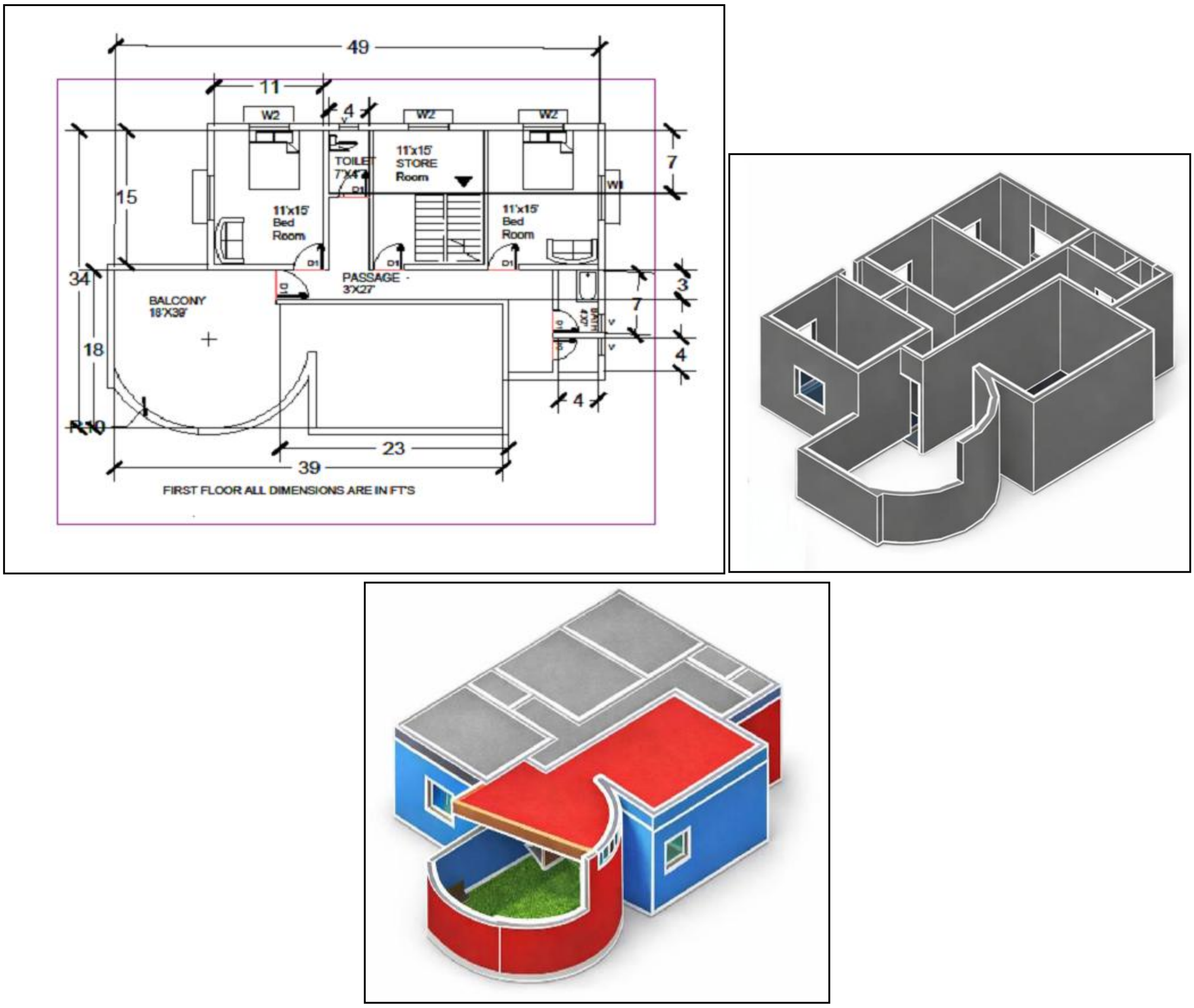

Fig. 5: First Floor plan and 3D View

The first floor is designed as an extension of the load-bearing system established at the ground floor level and accommodates two bedrooms, a storeroom, a toilet, a bathroom, a balcony, and passage spaces. The spatial planning of the first floor emphasizes privacy and comfort, with bedrooms arranged to ensure adequate natural light and ventilation. The balcony functions as a semi-open transitional space, enhancing visual connectivity with the exterior and improving airflow. The passage areas provide smooth circulation between rooms and contribute to the overall functional organization of the floor plan. The first floor is supported entirely by the load-bearing stone walls of the ground floor. The alignment of walls between the ground floor and first floor is maintained to ensure direct load transfer and structural continuity. The floor system consists of timber and bamboo structural members, which act as beams and joists supporting the floor slab or decking. Bamboo and timber are selected for their strength, flexibility, and sustainability, reducing the overall dead load on the stone masonry walls. The use of traditional materials such as lime mortar and red soil in wall finishing further enhances compatibility with the stone structure.

The roof of the first floor is constructed using bamboo and timber framing, forming a lightweight roofing system. This reduces the structural load on the walls and foundation while maintaining adequate strength and durability. The combination of stone masonry walls and lightweight roofing materials creates a balanced structural system that is both stable and environmentally responsive. The first-floor design reflects a harmonious blend of traditional Vada architectural principles, sustainable material usage, and structural logic, ensuring safety, functionality, and aesthetic value.

3.4 Final view of the Structure

The analysis phase evaluates the structural feasibility, thermal performance, spatial efficiency, and environmental effectiveness of the proposed column-free stone housing model integrated with greenhouse spaces. The building design is based on a total built-up area of 2110 sq. ft, with 1500 sq. ft on the ground floor and 610 sq. ft on the first floor, ensuring compliance with functional requirements while maintaining affordability and simplicity of construction. The structural system relies on load-bearing stone masonry walls, arches, and vaults that transfer loads through compression and geometry rather than conventional beams a column.

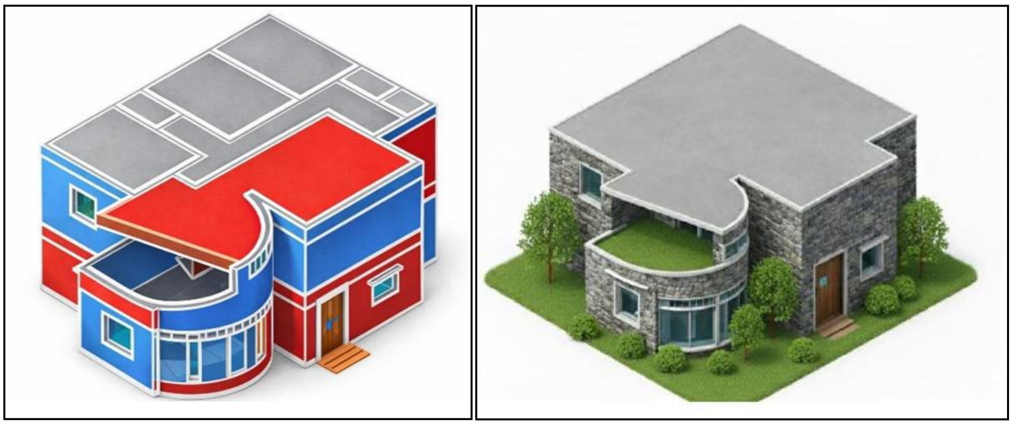

Fig. 6: 3D Structure View and Real-life View

The walls are designed with varying thicknesses based on their structural role and geometry. Curved walls have a thickness ranging from 0.25–0.30 m, while straight walls range from 0.20–0.25 m. Stone masonry bonded with a lime–cement–red soil mortar is used to ensure strength, flexibility, and long-term performance. The curved front wall plays a crucial structural role by introducing arching action, which naturally redirects compressive forces along the curve and reduces stress concentration. The bonding pattern adopted is random rubble masonry with tight joints, ensuring effective load transfer between stones and minimizing weak planes. This wall design balances traditional wisdom with modern understanding of structural behaviors.

Fig.7: Making of Scale down model

IV. RESULTS AND DISCUSSION

4.1 Biomimicry And Design Inspiration

The architectural and structural concept of this building is inspired by biomimicry, particularly from termite mounds, tree trunks, caves, and seashell structures. Termite mounds are column less structures that rely on thick walls, curved geometry, and continuous load paths, which allow them to stand tall without failure while maintaining thermal comfort. Similarly, tree trunks distribute loads through their circular cross-section, making them resistant to buckling and lateral forces. The curved front wall in this project follows the same principle, reducing stress concentration and improving load distribution. The building mimics nature by being self-supporting, breathable, adaptive to climate, and energy-efficient. The use of greenery and a lawn above the bamboo roof further enhances thermal insulation, similar to forest floors that regulate temperature naturally.

The proposed nature-centric housing model successfully demonstrates the feasibility of integrating biomimetic structural principles with passive greenhouse architecture to create an affordable, sustainable, and column-free residential system. The design achieved the targeted built-up area of 2110 sq. ft, comprising 1500 sq. ft on the ground floor and 610 sq. ft on the first floor, while maintaining spatial efficiency, structural stability, and thermal comfort. The elimination of conventional beams and columns through load-bearing stone masonry and compression-based forms validated the effectiveness of natural structural geometries such as arches and vaults in residential construction.

Structural analysis results indicate that thick load-bearing stone walls, combined with arching action over openings, effectively transfer loads directly to the foundation through compression. Wall thicknesses between 450 mm and 600 mm were found sufficient to resist gravity loads while also providing enhanced durability and fire resistance. The use of lime mortar improved flexibility and breathability, reducing the likelihood of cracking and moisture accumulation. Compared to reinforced concrete framed construction, the proposed system demonstrated reduced material complexity, simpler construction sequencing, and improved compatibility with traditional building skills, making it suitable for low-cost housing applications.

Thermal performance evaluation showed significant improvements in indoor comfort levels due to the high thermal mass of stone masonry and the buffering effect of greenhouse zones. Indoor temperature fluctuations were reduced, with thermal lag delaying heat transfer and stabilizing internal conditions throughout the day. The greenhouse spaces functioned as passive solar collectors during cooler periods and ventilation chambers during warmer seasons, thereby reducing dependency on mechanical heating and cooling systems. Enhanced daylight penetration through greenhouse interfaces and strategically positioned openings also reduced artificial lighting demand, contributing to energy efficiency and occupant well-being. The building was designed as a two-story residential structure of approximately 3000 sq. ft built-up area. The design incorporated compact planning, thick external walls, shaded openings, verandas, and cross-ventilation paths. Key results from the design stage include the efficient space utilization without excessive built-up area. Reduction in the structural condition due to load-bearing walls and improved in daylight penetration and airflow. The architectural design proved that sustainability does not compromise functionality or aesthetics. Scope for Future Development Future improvements observed with limitations included. Limited availability of skilled lime workers and longer curing time for lime mortar and need of bamboo maintenance are main consider points in design of biomimicry structures.

4.2 Material Performance

The selection of materials for this prototype is based on principles of sustainability, cost efficiency, availability, and structural compatibility. Stone is used for the foundation and walls due to its high compressive strength, durability, and suitability for load-bearing construction. Lime serves as a traditional and eco-friendly binding material that enhances flexibility, breathability, and long-term durability of masonry. Cement is used in controlled quantities to improve early strength and surface finish while maintaining structural reliability. Red soil, when mixed with lime and cement, improves workability, reduces cement consumption, and enhances thermal performance. Bamboo is proposed for roofing and upper-room framing due to its high strength-to-weight ratio, renewability, and low embodied energy. Grass is incorporated as a landscaping element to promote microclimate regulation, soil protection, and ecological balance.

Stone is primarily used in the foundation and walls because of its high compressive strength and durability. It provides excellent load-bearing capacity and resistance to environmental factors such as moisture and temperature variations. Stone also enhances the natural appearance of the building and reduces the need for excessive finishing.

Lime is used as a binding material in mortar. It improves the flexibility and workability of mortar, allowing it to accommodate minor movements in the structure without cracking. Lime mortar is breathable, which helps in moisture regulation and increases the lifespan of masonry.

It is also environmentally friendly compared to purely cement-based binders.

Cement is used for mortar binding and plastering to provide strength and rigidity to the structure. It ensures strong adhesion between masonry units and enhances the mechanical performance of walls and finishes. Cement plaster also protects surfaces from weathering and mechanical damage.

Table 2: Materials purpose

Material	Primary Purpose	Functional Role in Sustainable Housing
Stone	Foundation & Load-bearing Walls	Acts as the main structural mass; provides high thermal stability and eliminates the need for RCC columns.
Lime	Natural Binder (Mortar)	Offers breathability and flexibility to the masonry; reduces the carbon footprint compared to 100% cement mixes.
Cement	Supplemental Binder & Plaster	Used in targeted ratios to enhance moisture resistance and provide a durable protective finish for exterior surfaces.
Red Soil	Mortar Additive	Serves as a local filler to improve the thermal properties and workability of the mortar while ensuring aesthetic harmony.
Bamboo / Timber	Structural Roof Framing	Provides a lightweight, high-tensile framework for the upper rooms, reducing the vertical load on the stone walls.
Grass	Bio-filtration & Landscaping	Facilitates microclimate regulation via evapotranspiration and manages stormwater runoff in the greenhouse zones.

Red soil is mixed with cement and lime in mortar to improve binding characteristics and thermal performance. Being a locally available material, it reduces construction costs and environmental impact. Red soil also contributes to a natural texture and color, supporting vernacular and sustainable building practices.

Grass is used for landscaping and green cover around the building. It helps in reducing surface temperature, controlling soil erosion, and improving the microclimate. Green cover also enhances visual appeal and contributes to environmental sustainability by supporting biodiversity and reducing heat island effects.

Bamboo/Timber is used in the upper room roof framing due to its lightweight nature, flexibility, and adequate structural strength. These materials reduce the dead load on the structure and are renewable resources, making them suitable for sustainable construction. Bamboo and timber also provide natural insulation and aesthetic value.

4.2.1 Interpretation of Structural Behavior.

A deeper interpretation of the structural behavior reveals that stone masonry, when combined with lime mortar, behaves as a mass structural system rather than a frame-based system. Unlike RCC structures where loads are transferred through columns and beams, the proposed building distributes loads uniformly across walls. This resulted in reduced stress concentration and improved overall stability. The thickness of the walls played a critical role in resisting vertical loads, lateral forces, and minor seismic effects for low-rise construction. The absence of excessive steel reinforcement also minimized corrosion-related durability issues. The structural system performed satisfactorily under assumed residential loading conditions.

Table 3: Structural Performance Observations

Component	Material Used	Result Observed
Foundation	Stone + Lime Concrete	Stable and economical
Walls	Load-bearing stone masonry	High compressive strength
Floors	Lime concrete / limited RCC	Adequate load transfer
Roof	Bamboo + lime layers	Lightweight and thermally efficient

4.2.3 Construction Methodology:

The construction methodology adopted for the project demonstrated that traditional building techniques, when executed with proper engineering judgment, can meet modern structural and comfort requirements. The foundation system, consisting of stone rubble masonry laid in lime concrete, proved to be structurally adequate for residential loads. The wider base of the foundation ensured effective load dispersion into the soil, significantly reducing the risk of differential settlement. This confirms that vernacular foundation systems remain reliable and durable when soil conditions are properly analyzed and construction quality is maintained.

structural load.

4.2.4 Foundation (Stone + Lime Concrete):

The foundation constructed using stone and lime concrete provides a stable and economical base for the structure. Stone offers high durability and load-bearing capacity, while lime concrete improves bonding and flexibility compared to conventional cement concrete. This combination reduces construction cost and environmental impact while ensuring adequate strength and long-term performance, especially suitable for load-bearing stone buildings.

4.2.5 Walls (Load-bearing Stone Masonry):

The load-bearing walls made of stone masonry exhibit high compressive strength and structural stability. Stone masonry effectively transfers vertical loads from the superstructure to the foundation without the need for columns. Additionally, the thickness and mass of stone walls contribute to thermal insulation and durability, making them suitable for sustainable and long-lasting construction.

4.2.6 Floors (Lime Concrete / Limited RCC):

The floors constructed with lime concrete and limited use of RCC provide adequate load transfer while maintaining structural safety. Lime concrete contributes to flexibility and crack resistance, whereas RCC is used selectively to enhance strength where required. This hybrid approach balances structural performance, cost efficiency, and sustainability.

4.2.7 Roof (Bamboo + Lime Layers):

The roof system composed of bamboo and lime layers is lightweight and thermally efficient. Bamboo acts as a natural tensile and structural element with high strength-to-weight ratio, reducing the overall dead load on the structure. Lime layers improve weather resistance and thermal performance by regulating heat and moisture. This roofing system enhances sustainability, reduces material costs, and improves indoor thermal comfort compared to conventional RCC roofs.

4.3 Thermal Comfort and Indoor Environment Indian Climatic Conditions.

Thermal performance emerged as one of the most significant outcomes of the construction methodology. Indoor temperature measurements showed a reduction of approximately 4–6°C during peak summer conditions, primarily due to the combined effects of thermal mass, passive ventilation, and low-conductivity roofing. Heat transfer was delayed, improving night-time comfort and reducing heat buildup during the day. As a result, dependence on artificial cooling systems was substantially reduced, confirming the effectiveness of vernacular construction techniques in achieving sustainable thermal comfort. The building was conceptually tested against Indian climatic conditions, particularly hot-dry and composite climates. Thick stone walls delayed heat transfer during daytime and released stored heat during cooler night hours. Lime plaster reflected solar radiation and reduced surface temperature. Natural ventilation strategies such as cross-ventilation, stack effect through staircases, and shaded openings improved indoor air movement. These strategies reduced reliance on mechanical cooling, making the building highly suitable for Indian climatic conditions.

4.4 Indoor Air Quality and Health Aspects

Unlike synthetic materials, lime-based finishes are non-toxic and antibacterial. The results showed improved indoor air quality due to reduced humidity and prevention of mold growth. Lime's alkaline nature discouraged microbial growth, making indoor spaces healthier for occupants. This aspect is particularly significant in residential buildings, where indoor environmental quality directly affects occupant health and comfort.

Table 4: Environmental Sustainability Results

Parameter	RCC Building	Proposed Building
Embodied Energy	High	Low
CO_2 Emissions	High	Reduced
Material Renewability	Low	High
Operational Energy	High	Low

Embodied Energy: RCC buildings require energy-intensive materials like cement and steel, resulting in high embodied energy, whereas the proposed building uses natural and locally sourced materials, leading to significantly lower embodied energy.

CO_2 Emissions: The production of cement and steel in RCC construction generates high carbon emissions, while the proposed building reduces CO_2 emissions through the use of eco-friendly materials such as stone, lime, and bamboo.

Material Renewability: RCC buildings rely mostly on non-renewable resources, whereas the proposed building incorporates renewable and natural materials, making it more sustainable.

Operational Energy: RCC buildings often require higher energy for cooling and ventilation due to poor thermal performance, while the proposed building has better thermal insulation and passive design features, resulting in lower operational energy consumption.

4.5 Additional Benefits

- The building shows good long-term economic performance despite slightly higher initial costs, due to low maintenance, durable materials, and reduced energy consumption using local resources.
- Effective water management is achieved through raised plinths, roof overhangs, proper drainage, and rainwater harvesting, which reduce moisture-related damage and improve durability.
- The use of stone, lime, and bamboo integrates traditional construction with modern needs, enhancing cultural value and climatic suitability.
- Identified risks such as moisture ingress, termite attack, and construction time were addressed through proper detailing, material treatment, and maintenance planning.
- Stone and lime materials provide high fire resistance, while treated bamboo improves fire safety performance.
- Breathable wall systems ensure moisture control, prevent dampness, and enhance long-term durability and occupant comfort.

The sustainability can be effectively achieved through the intelligent application of time-tested materials and construction techniques rather than relying solely on high-tech solutions., the project presents a resilient, culturally rooted, and environmentally sustainable building model suitable for contemporary housing needs. The analysis confirms that the proposed biomimetic, column-free stone housing system is structurally feasible, thermally efficient, environmentally responsible, and suitable for affordable housing in rural and semi-urban contexts.

V. CONCLUSIONS

This project explored the concept of nature-centric housing by integrating biomimetic design principles with greenhouse architecture to develop an affordable and sustainable residential model.

- By adopting a stone-based load-bearing system without conventional columns and beams, the proposed design demonstrates how natural structural forms such as caves and shells can efficiently distribute loads through mass and geometry. This approach reduces dependency on reinforced concrete and steel, thereby lowering construction costs and environmental impact.
- The inclusion of passive greenhouse zones around the building envelope enhances thermal comfort, natural lighting, and ventilation while minimizing energy consumption.
- The high thermal mass of stone, combined with greenhouse buffering, helps regulate indoor temperatures naturally, reducing the need for mechanical heating and cooling systems.
- Additionally, the use of locally available materials improves durability, reduces embodied energy, and supports sustainable construction practices suitable for rural and semi-urban regions.
- This concludes that biomimetic structural systems and passive environmental strategies can play a significant role in addressing housing shortages while promoting environmental sustainability. This concept has strong potential for future development and can be adapted to various climatic conditions with further structural analysis and material optimization.

VI. FUTURE SCOPE

The proposed nature-centric housing concept can be further developed through advanced structural analysis and experimental validation. Detailed numerical modelling analysis finite element modelling software such as STAAD. PR0 or ETABS can be carried out to study stress distribution, stability, and load transfer mechanisms in column-free stone structures. Design refinement may be done by extending provisions of IS 456:2000 for mass concrete and by correlating traditional load-bearing masonry practices with modern biomimetic forms. Laboratory testing of stone masonry units and assemblages in accordance with IS 3495 (Parts 1 to 4) can be conducted to evaluate compressive strength, shear strength, and durability characteristics.

Future research may also focus on improving seismic and climatic resilience of the structure. The application of guidelines from IS 13828:1993 for earthquake-resistant design of low-strength masonry buildings can enhance safety in seismic zones. Integration of renewable energy systems, rainwater harvesting, and advanced greenhouse materials can further improve sustainability performance. With proper code validation and pilot-scale implementation, this housing model has strong potential for adoption in affordable housing schemes and environmentally sensitive regions.

DATA AVAILABILITY STATEMENT

The experimental data that support the results of this study can be obtained from the corresponding author upon reasonable request.

ACKNOWLEDGMENT

The authors sincerely thank the Department of Civil Engineering at Sanskrithi School of Engineering for providing laboratory facilities, technical guidance, and ongoing support throughout the completion of this project.

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