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# BIOMIMICRY-INSPIRED HOUSING MODELS FOR RESILIENT COMMUNITIES IN PERI-URBAN GHANA

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## ABSTRACT

Peri-urban areas in Ghana face escalating challenges due to rapid urban growth, informal development, and inadequate infrastructure, all worsened by the impacts of climate change. This study explored how biomimicry, a design philosophy rooted in nature's adaptive strategies, can inform sustainable, resilient housing solutions tailored to these vulnerable communities. Using a critical review methodology, the research examined relevant literature and global case studies to identify natural systems with functional relevance to the built environment. Drawing inspiration from termite mounds for passive ventilation, honeybee hives for modular and lightweight structure, cactus spines for water collection, mycelium fungi for regenerative materials, and sunflower phototropism for solar tracking, the study proposed three biomimicry-inspired housing models. The Biomimicry-Inspired Housing for Adaptive Urban Sustainability (Bio-HAUS) Model incorporates passive cooling, modularity, and water-sensitive design, mimicking termite mounds, honeycombs, and cacti. The Nature-Inspired Engineered Solutions for Thermal Efficiency (NEST) Model focuses on energy performance and circular construction, guided by the humidity-responsive behavior of pinecones and the solar efficiency of sunflowers. The Biomimicry-Inspired Circular Yield for Community Livability and Ecology (Bio-CYCLE) Model replicates forest floor ecosystems and wetland processes to create closed-loop systems for organic waste, water reuse, and biogas generation, drawing from mycelium networks, wetlands, termite soil regulation, and ruminant digestion. Together, these models prioritize affordability, adaptability, and environmental integration, offering practical alternatives to conventional high-energy construction. The study concludes that biomimicry offers a viable path toward climate-adaptive housing and recommends that such models be integrated into Ghana's urban housing policies, design education, and local development strategies to scale innovation in the Global South.

**Keywords:** Biomimicry, Peri-Urban Housing, Climate Resilience, Sustainability, Thermal Efficiency, Circular Waste Systems.

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## INTRODUCTION

### Background of the Study

Over the years, cities have expanded at a rapid pace. This acceleration causes a growing number of challenges including risk of flooding, heat extremes, and resource shortages due to climate change according to Bonye et al. (2021). Hence, there is a pressing need for resilient and sustainable infrastructure for urban and peri-urban areas. Adu-Gyamfi et al. (2022) mentioned that Ghanaian cities face overcrowding and mounds of unregulated growth in informal settlements. According to the Ghana Statistical Service (GSS), recent estimates suggest that Ghana's urban population is growing at a rate of 0.4% per year, with over 56% of the national population now living in urban areas (GSS, 2022). Peri-urban zones, particularly around Accra, Kumasi, and Tamale, have become hotspots of this expansion, often outpacing infrastructure development. It was estimated that informal settlements in Ghana accommodate over 45% of urban residents, with limited access to services like water, sanitation, and durable housing (UN-Habitat, 2020). This rapid, unregulated growth places enormous pressure on land use, housing supply, and ecological systems in these fringe areas. Peri-urban communities experience inadequate infrastructure, youth unemployment and environmental degradation which result into deficiencies in housing, services and climate-responsive infrastructure (Bonye et al., 2021).

### Environmental and Socio-Economic Impacts

Unsustainable housing practices in peri-urban Ghana contribute to multiple interlinked challenges. According to Ahiabu (2023), environmentally, widespread use of high-carbon materials such as concrete and steel exacerbates greenhouse gas emissions and depletes natural resources. Poor construction standards often result in flood-prone housing and heat-vulnerable structures, reducing resilience to climate impacts. Socio-economically, these conditions perpetuate inequality, as low-income households remain trapped in inadequate shelters without access to basic services or secure tenure. This has long-term implications for public health, education, and economic mobility. Furthermore, traditional urban development strategies have not adequately adopted adaptive solutions from nature that promote energy efficiency, climate resilience, and sustainability (Boateng et al., 2023). We now need a new trend that designs things according to nature's design.

### Policy Frameworks and Sustainable Development Initiatives

Ghana's urban development agenda has recognized these issues through frameworks like the National Urban Policy Framework (NUPF, 2012), which emphasizes inclusive,

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environmentally sustainable growth. Additionally, the Revised National Housing Policy (2015) and the National Climate Change Policy (NCCP, 2012) outline strategies for climate-resilient housing, infrastructure improvement, and sustainable land use. However, implementation gaps persist, particularly in peri-urban settings, where enforcement of planning regulations and investment in alternative housing models remain limited according to Ghana Urbanisation Think Tank (GUTT, 2019).

According to Pedersen (2020), biomimicry, the practice of drawing inspiration from nature's adaptive strategies, offers a promising alternative for addressing these challenges. Nature has evolved efficient mechanisms for structural resilience, energy conservation, and climate adaptation over millions of years. By applying these principles to architecture and urban planning, biomimetic housing models can create self-sustaining, resource-efficient, and climate-adaptive communities (Jamei, 2021). However, the application of biomimicry in peri-urban housing in developing countries like Ghana remains largely unexplored.

**Identification of the Knowledge Gap**

Despite growing global interest in biomimicry, its application within Ghana's peri-urban housing context remains underexplored, particularly in ways that are practical, affordable, and scalable. Much of the existing literature focuses on high-tech, resource-intensive sustainable buildings (Owusu, 2024; Tekpe et al., 2022), with limited attention to nature-based solutions appropriate for developing regions. This reveals a knowledge gap in applying biomimicry principles to low-cost housing.

In addition, while global examples like the Eastgate Centre illustrate biomimetic success in architecture, empirical data specific to Ghana's environmental and socio-economic conditions is sparse. Most studies fail to assess how biomimicry can be localized, tested, or prototyped in the peri-urban context. This presents a clear empirical gap.

There is also a theoretical gap: existing green housing models do not adequately draw on biomimicry as a guiding theory for resilience and ecological integration. Similarly, although many biomimetic ideas have been proposed, there's little guidance on how to translate them into practical housing systems suited to real-world constraints in Ghana's peri-urban areas.

Most crucially, this research addresses a methodological gap. Past studies have typically applied conceptual analysis or cited high-cost international case studies without testing or adapting biomimicry for local peri-urban application. This study responds by proposing, contextualizing, and structuring three novel design models, **Bio-HAUS,**

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**NEST, and Bio-CYCLE**, using a multidisciplinary, design-led research approach that integrates local materials, conditions, and community needs.

*Table 1. Summary of Research Gaps Identified*

| Type of Gap | Explanation | How This Study Responds |
|---|---|---|
| **Knowledge Gap** | Limited research on applying biomimicry to peri-urban housing in Ghana [Owusu, 2024] | Explores biomimicry strategies contextualized for peri-urban Ghana |
| **Empirical Gap** | Lack of real-world data or pilot studies [Sá et al., 2023] | Develops and evaluates three practical models for Ghana's local conditions |
| **Theoretical Gap** | No clear conceptual integration of biomimicry into housing design for resilience and sustainability [Hussein et al., 2024] | Introduces Bio-HAUS, NEST, and Bio-CYCLE models rooted in ecosystem-level biomimicry |
| **Practical Gap** | Disconnect between theory and real-world application [Azizkhani 2022] | Designs models that use local materials and conditions for affordable housing |
| **Methodological Gap** | Overreliance on international case studies. Repeated use of limited methods; need for new approaches [Verbrugghe et al., 2023] | Uses a multidisciplinary, nature-inspired design methodology to propose contextual models |

*(Source: Authors' Construct)*

These gaps were identified through a combination of concept-centric literature review and thematic synthesis of over 60 scholarly works, using search engines such as Scopus and Google Scholar. This structured gap analysis guided the development of nature-inspired housing models that are adaptable, inclusive, and environmentally aligned.

**Research Objectives**

This study explores how we can take lessons from nature to rethink housing in Ghana's growing peri-urban areas. These communities face real challenges, from overcrowding and poor infrastructure, to the growing threat of climate change. The research aims to


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find out how nature-inspired, or biomimicry-based, housing designs can offer practical, affordable, and sustainable alternatives that work in local contexts. The specific objectives of the research are:

1. To examine the socioeconomic, environmental, and infrastructure issues that lead to housing shortages and climate vulnerability in Ghana regarding peri-urban dwelling.
2. To investigate natural systems that provide adaptive solutions for enhancing resource efficiency, climate responsiveness, and structural resilience to investigate biomimetic concepts pertinent to sustainable housing
3. To create dwelling models for peri-urban Ghana that are influenced by biomimicry. putting forward creative housing ideas grounded in biomimetic principles that consider the local climate, financial limitations, and viability of building.

## LITERATURE REVIEW

### Challenges of Affordable Housing in Peri-Urban Ghana

Cities in Ghana are growing fast, and with climate change becoming more intense, there's a pressing need to rethink how we build and plan our urban spaces (Adu-Gyamfi et al., 2022). The usual ways of developing cities often miss the mark, they don't do enough to tackle problems like rising urban temperatures, wasteful use of resources, or even the basic strength and safety of buildings. According to Asafo (2020), peri-urban Ghana is facing serious climate challenges, all of which are making the housing situation worse. Some of these issues stem from the lack of use of more sustainable materials and techniques in the construction industry. The old-school building methods, mostly employed, rely heavily on energy-hungry materials like concrete and steel, which just aren't working anymore (Agyekum et al., 2020). They're expensive, not sustainable, and don't offer the flexibility or resilience needed in these communities.

### Socio-Economic Challenges

Affordability remains a major challenge to sustainable housing in Ghanaian peri-urban settlements, according to Adu-Gyamfi et al. (2022). Most peri-urban residents are low- to moderate-income earners and cannot access formal housing due to the expense, high-priced land, and unavailability of finance. As a result, informal settlements are predominant, which are commonly typified by inferior materials, congestion, and insecure tenure. Unemployment and income inequality limit investment in improved

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housing, while land tenure disputes and lack of documentation discourage long-term planning and development (Asafo, 2020).

**Environmental Challenges**

Peri-urban areas are subject to new environmental risks. Sand winning, deforestation, and unplanned development minimize the landscape and maximize flooding (Mensah et al., 2021). Climate change adds to the impact through unreliable rainfall and heat stress. Waste and poor drainage are factors leading to environmental hazard in flood-prone areas like Keta and Kasoa (Asiedu, 2024; Codjoe et al., 2020). Green infrastructure and passive cooling do not exist in most houses, making them ecologically and thermally unsustainable Abass et al. (2020) made contributions.

**Infrastructural Challenges**

Infrastructure in peri-urban Ghana is often inadequate or nonexistent. Roads, water, sanitation, and drainage are poorly developed, leaving communities without basic services (Asafo, 2020). Unplanned growth results in chaotic layouts and limited access to amenities (Adu-Gyamfi et al., 2022). The absence of decentralized infrastructure, like biogas systems, water harvesting, and eco-toilets, limits the sustainability of these areas and exposes residents to health and environmental risks (Mariwah et al., 2022).

**Policy and Institutional Gaps**

Although Ghana has housing policies, implementation in peri-urban areas is weak. According to Asafo (2020), governance is often fragmented between local authorities and traditional landowners, leading to unregulated growth. Adu-Gyamfi et al. (2022) argued that affordable housing programs tend to focus on urban centers, overlooking the unique challenges of peri-urban settlements. The lack of enforceable planning frameworks and building codes contributes to informal development and poor housing quality (Adu-Gyamfi et al., 2022; Asafo, 2020).

**Achieving Sustainable Peri-urban Housing Designs**

Tackling affordable housing issues in peri-urban regions call for integrated, place-based solutions that combine sustainability, community participation, and nature-based design as summarized in Table 2. Advancing resilient, circular housing systems is crucial to improving liveability and reducing climate vulnerability in these rapidly growing areas (Kim et al., 2021; Ziaee et al., 2022).

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*Table 2: Principles for achieving Sustainable Peri-urban Housing Designs*

| Principle | Application in Housing |
|---|---|
| **Ecology** | Housing developments are designed to integrate with natural landscapes, minimizing environmental disruption. Compact, Green roofs, vertical gardens, and natural ventilation enhance ecological balance [Ziaee et al., 2022]. |
| **Energy** | Future housing relies on 100% renewable energy, utilizing solar panels, wind energy, and geothermal systems. Buildings are designed to maximize natural lighting and passive cooling [Aruta et al., 2023]. |
| **Waste** | Waste is repurposed for energy production or reused as sustainable building materials. Housing projects focus on zero-waste construction [Hamid et al., 2020]. |
| **Livability** | Housing prioritizes safety, accessibility, and well-being, incorporating smart technology for automated home management. Walkable neighborhoods with integrated green spaces promote healthier lifestyles [Kim et al., 2021]. |

*(Source: Authors' Construct)*

Building sustainably isn't just a nice idea, it's a necessity. It's one of the smartest ways to address today's development challenges because it helps protect the environment, supports climate resilience, and makes housing fairer and more livable for everyone (Ontoyin et al., 2025). In Ghana's fast-growing peri-urban zones, the demand for decent, affordable housing is becoming urgent. Rapid urban sprawl, rising populations, and uneven development are all pushing the limits. Poor planning, underdeveloped infrastructure, and a lack of investment make things even worsening the housing crisis and leaving many more exposed to the threats of climate change (Asafo, 2020; Awuah et al., 2022).

**Climate-Responsive Building in Warm-Humid Regions**

Design literature on warm-humid climates emphasizes the use of passive cooling, shading devices, and elevated floor systems to promote airflow. In regions like Ghana, strategies such as wide overhangs, permeable façades, and orientation-sensitive layouts have shown potential in enhancing indoor comfort. Works by Amos-Abanyie et al. (2021) and Agyekum et al. (2022) emphasize that effective climate responsiveness must integrate natural ventilation and thermal mass—principles that align with biomimetic strategies derived from organisms like desert snails and termite mounds. A shift toward biomimicry, using local, renewable materials inspired by nature, could make housing in

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peri-urban areas more affordable, more climate-resilient, and far better for the environment (Abera et al., 2022).

**The Concept of Biomimicry**

Derived from the Greek words bios (life) and mimesis (imitation), biomimicry offers a workable substitute by using natures tried-and-true methods to create sustainable design solutions that increase structural durability, support climate adaptation, encourage water conservation, and improve energy efficiency (Pedersen, 2020). Since its popularization by Janine Benyus (1997), the idea has been used in a variety of fields, such as engineering, architecture, product design, urban planning, and building, to provide ecologically friendly and resource-efficient solutions. Buildings that maximize material efficiency, improve structural robustness, and self-regulate temperature are designed using biomimicry (Verbrugghe et al., 2023). Biomimicry operates at three levels: organism, behavior, and ecosystem illustrated in Figure 1.

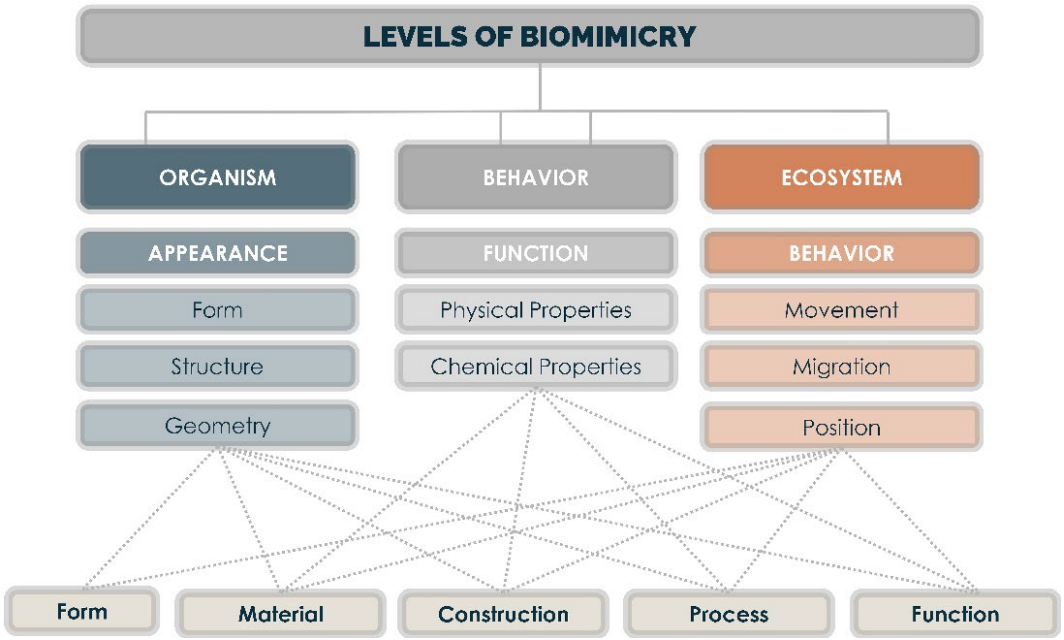



*Figure 1. Levels of Biomimicry (Source: Adapted from Sommese et al., 2022)*

The physical attributes of a living thing, such as its shape, form, and geometry, are the emphasis of the organism level, which might stimulate material and design advances (Sommese et al., 2022). The behaviour level looks at how living things work, including their physical and chemical characteristics, and offers insights into effective mechanisms


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and systems. Finally, the ecosystem level investigates how organisms move, migrate, and position themselves within their habitats. This information can help develop adaptable and sustainable solutions (Jamei, 2021; Sommese et al., 2022; Verbrugghe et al., 2023). As seen in Figure 1, these levels relate to different design factors, such as form, material, construction, process, and function, emphasizing how nature shapes robust and effective solutions.

According to Hassan et al. (2023), there are two primary methods for applying biomimicry: problem-based (top-down) and solution-based (bottom-up), as shown in Figure 2 which summerised the steps under both methods.

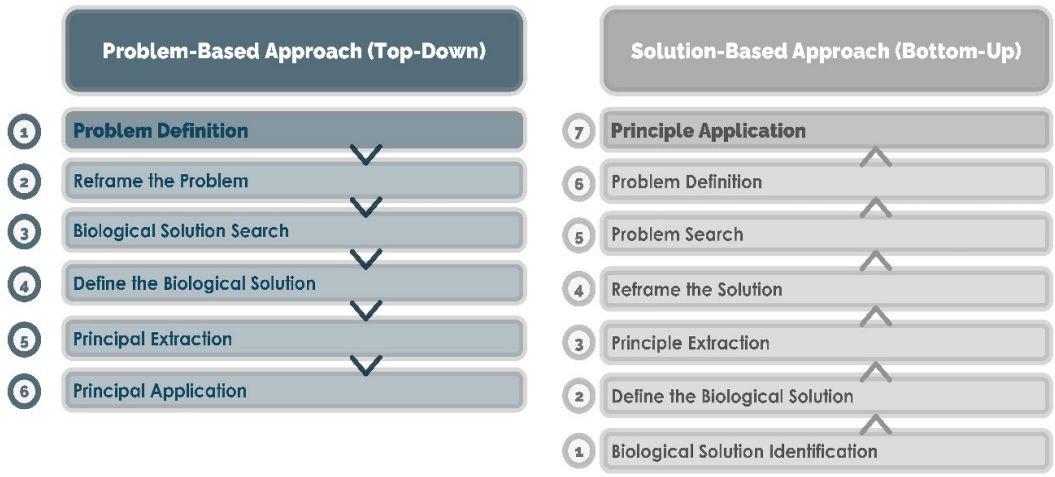



*Figure 2. Approaches in Applying Biomimicry (Source: Adapted Hassan et al., 2023)*

In the problem-based approach, a particular obstacle is first identified, and then biological solutions that solve that challenge are sought after. In this approach, the problem is reframed and defined, biological similarities are examined, important concepts are extracted, and they are then applied to design (Sun, 2024). According to Sun (2024), the solution-based approach, on the other hand, begins with an established biological method or mechanism and searches for pertinent issues where it can be used. This approach entails finding and characterizing a biological solution, deriving its guiding principles, rephrasing possible uses, looking for issues, defining their extent, and then putting the knowledge gained into practice. Both strategies show how biomimicry fosters effective and sustainable design solutions by bridging the gap between human ingenuity and nature's wisdom (Hassan et al., 2023; Sun, 2024).

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**The Potential of Biomimicry Architecture**

Biomimicry architecture offers a transformative approach to sustainable design by drawing inspiration from nature's strategies to create resilient, efficient, and adaptive buildings (Ilieva et al., 2022). Mimicking systems like termite mounds for passive cooling, honeycomb structures for strength, and lotus leaves for self-cleaning surfaces enhance energy efficiency, reduces resource use, and improves climate adaptability (Chaudhary, 2024). This study explored biomimicry-inspired housing models as a sustainable solution to peri-urban housing challenges in Ghana. By drawing from nature's adaptive strategies, the research proposed climate-responsive, cost-effective housing solutions integrating biomimetic principles (Srisuwan, 2020). Insights from biological strategies (Figure 3) highlight how self-movement in plants like Oxalis triangularis and Mimosa pudica can inspire adaptive shading and ventilation. The self-cleaning lotus leaf suggests water-repellent materials, while cacti's water storage mechanisms inform rainwater harvesting. Sunflowers' phototropism offers a model for solar panels that track sunlight, enhancing energy efficiency.

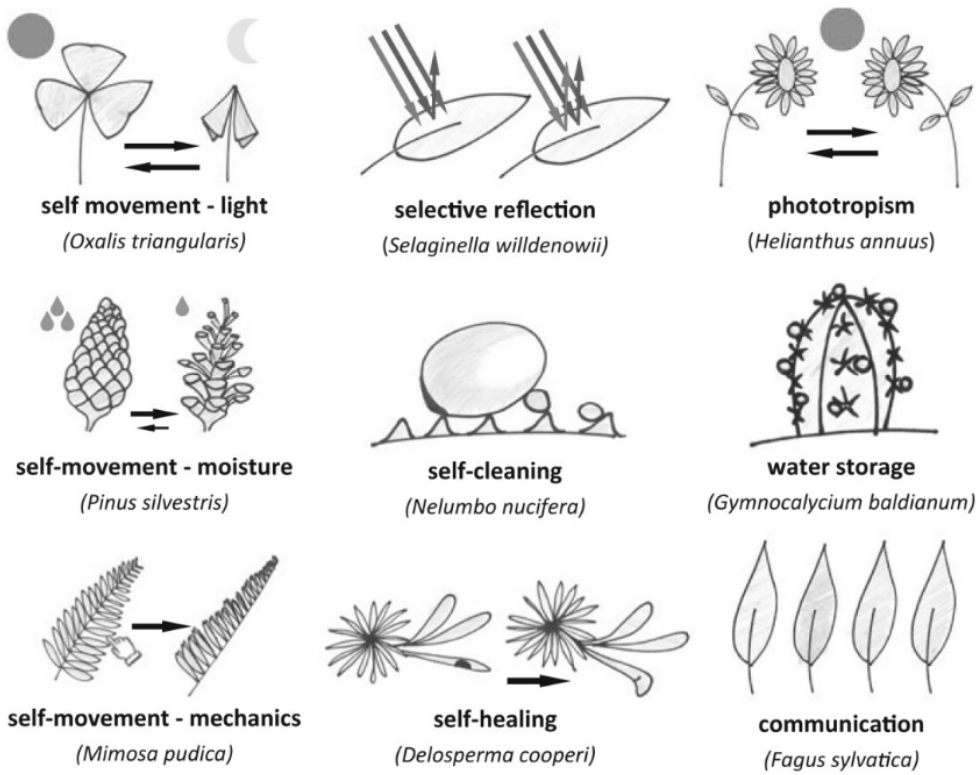



*Figure 3. Examples Biomimicry in Plants (Source: Srisuwan, 2020)*

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These nature-inspired strategies highlighted by Srisuwan (2020), could be adopted to support sustainable, resilient housing in Ghana's peri-urban areas. Additionally, adaptations of other organisms offer valuable lessons for structural resilience and climate responsiveness. For instance, termite mounds' passive cooling systems inspire natural ventilation in buildings, while the lightweight yet strong structure of bird bones suggests efficient material use in construction (Saker, 2024). By incorporating these nature-inspired strategies, housing in peri-urban Ghana can become more sustainable, resilient, and better suited to local environmental conditions.

**Biomimicry in Housing and Infrastructure**

Studies have demonstrated how biomimetic principles can enhance urban resilience, improve resource management, and mitigate the environmental impact of construction (AlAli et al., 2023; Dikou et al., 2023; Helmrich et al., 2020). For example, research has shown that biomimetic designs modeled after termite mounds enable passive cooling in warm climates, reducing energy consumption in buildings (Juanga et al., 2024). Table 3 summarized some importances of biomimicry in housing design.

*Table 3: The Importance of Biomimicry in Housing Design*

| Importance | Relevance to Housing Design |
|---|---|
| **1-Structural Innovation** | Nature-inspired structural systems can enhance the durability and resilience of housing, making them better suited to environmental challenges [Ibrahim, 2021]. |
| **2-Sustainable Design** | Biomimetic housing can reduce energy consumption, minimize waste, and lower environmental impact by mimicking efficient natural processes [Pugalenthi et al., 2024] |
| **3-Efficiency Optimization** | Incorporating biomimicry in housing improves natural ventilation, temperature control, and energy efficiency [Pugalenthi et al., 2024]. |
| **4-Climate Adaptation** | Housing designed using biomimicry principles can respond to local climate conditions, reducing energy demand while improving resilience to extreme weather [Saker, 2024]. |
| **5-Sustainable Materials** | Using biomimetic approaches in material selection can lead to more durable, locally sourced, and environmentally friendly housing solutions [Ibrahim, 2021]. |

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| | |
|---|---|
| **6-Enhancing Biodiversity** | Housing that integrates biomimicry can promote ecological balance by preserving green spaces, supporting local biodiversity, and improving environmental quality [Ilieva, 2022]. |
| **7-Aesthetic Inspiration** | Nature-inspired housing designs can create visually appealing and harmonious living spaces while fostering a sense of well-being and connection to nature [Tambe et al., 2023]. |
| **8-Resilience & Adaptability** | Biomimicry enables housing designs that adapt to changing environmental and social needs, ensuring long-term sustainability and functional flexibility [Zaki, 2023]. |
| **9-Water Management** | Implementing biomimetic water management strategies, such as natural filtration and rainwater harvesting, can enhance housing sustainability [Blanco et al., 2021]. |
| **10-Biophilic Design** | Nature-integrated housing improves residents' health, well-being, and productivity by incorporating biophilic elements that strengthen the human-nature connection [Kanwal et al., 2020]. |

*(Source: Authors' Construct)*

**Integrating Local Materials and Vernacular Knowledge into Biomimicry**

Traditional Ghanaian construction methods provide a wealth of sustainable design practices that align with the principles of biomimicry, particularly in relation to thermal regulation, material circularity, and ecological integration. Earthen construction techniques such as adobe blockwork, rammed earth, and laterite stone masonry have long been used across the rural settlements of Ghana due to their affordability, availability, and inherent thermal mass, which helps regulate indoor temperatures in warm-humid climates. These materials exhibit low embodied energy and can be locally sourced, minimizing the environmental costs of transportation and industrial processing (Ontoyin et al., 2025).

Similarly, bamboo—a fast-growing, renewable resource—which has been traditionally used for wall panels, trusses, and scaffolding in Ghana and presents a viable alternative to imported steel or cement when treated properly for durability. Thatch roofing, although less common today, provides natural ventilation and shading benefits that are well suited to Ghana's climatic conditions. Agyekum et al. (2020) argue that when traditional materials are improved with modern preservation techniques (e.g., thermally treated bamboo, stabilized earth blocks), they can meet modern building standards while retaining their environmental and cultural relevance.

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These practices mirror biomimetic approaches that favor locally adaptive, resource-efficient systems. For example, the use of earth blocks mimics termite nest construction, which relies on passive thermal control and natural material cycling. Integrating such materials with contemporary biomimicry-inspired design could create hybrid housing models that are both ecologically resilient and economically accessible for peri-urban communities in Ghana.

**Limitations of Biomimicry in Resource-Constrained Settlements**

While biomimicry presents a compelling design philosophy, its application in resource-constrained environments such as peri-urban Ghana is not without challenges. Many biomimetic building strategies, such as dynamic façades, advanced thermal regulation systems, or self-healing materials, require technologies, materials, or manufacturing capabilities that are not yet locally accessible or affordable. As observed in studies by Pawlyn (2019) and Pedersen Zari (2020), most biomimetic architecture case studies are situated in high-income contexts, with little discussion on adaptation for informal or low-resource settlements. Although several biomimetic strategies have been adapted into high-performance buildings, where solutions to some of the issues facing peri-urban housing have been effectively localized for low-cost housing environments, the focus remains largely on technologically advanced settings, leaving a gap for scalable adaptation in peri-urban contexts.

Moreover, there is limited empirical evidence on the long-term maintenance and cost-efficiency of biomimicry-inspired housing in developing regions. This underscores the need for locally grounded models that simplify nature-inspired principles without relying on expensive infrastructure bridging the gap between design innovation and socioeconomic feasibility.

**Synthesis of Key Themes and Research Gaps**

Current scholarship converges on the potential of biomimicry to offer climate-resilient, energy-efficient housing (Butt, 2024). Yet, key gaps remain. Few studies explore the intersection of biomimicry and affordability in low-resource settings, and empirical work on scalable models tailored to peri-urban Africa is scarce. Additionally, while biomimicry often emphasizes material and performance innovations, the integration of social equity and cultural relevance into its frameworks is underdeveloped (Owusu, 2024; Tekpe et al., 2022). This study addresses these gaps by proposing context-specific models grounded in both ecological principles and socio-economic realities.

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## METHODS: A CRITICAL REVIEW

This study adopts a critical review methodology (Sommese et al., 2022), following a structured four-phase framework: data collection, data screening, data analysis, and synthesis. This approach allows for the consolidation of knowledge from literature and practical case studies, ultimately resulting in the proposal of three biomimicry-inspired models (Bio-HAUS, NEST, and Bio-CYCLE) for resilient housing solutions in peri-urban Ghana. The methodology integrates theoretical, analytical, and applied components to evaluate and propose adaptive, sustainable housing frameworks rooted in nature's principles. Figure 4 shows the four phases of the methodological framework used in this paper: data collection, data screening, data analysis and synthesis, considering both architectural and natural aspects and characteristics.

### Phase 1: Data Collection

Data collection was conducted through systematic searches of academic databases and digital libraries such as Scopus, ScienceDirect, and Google Scholar. The search was guided by keywords including "biomimicry in architecture," "sustainable housing," "peri-urban housing," "biomimetic materials," and "bio-inspired building systems." The literature review focused on current and relevant literature within a 5-year period including journal articles, conference proceedings, and case studies from 2020 to 2025, with particular attention to biomimetic approaches applied to warm-climate regions and low-income urban contexts. Additional data was gathered from policy documents and sustainability reports. This initial phase yielded approximately 180 relevant documents for further screening.

### Phase 2: Data Screening

The screening process began by applying inclusion criteria: English language, peer-reviewed status, relevance to biomimicry and housing considering practicality and local Ghanaian context, and publication within the selected timeframe. Newspaper and magazine articles were excluded. Abstracts, paper structures, and content alignment with the research focus were evaluated, leading to the removal of irrelevant or duplicate entries. This filtering process as illustrated in Figure 4 refined the dataset to 58 scholarly works considered directly relevant to biomimetic housing design.

### Phase 3: Data Analysis

The refined selection of literature and case studies (58 outputs) was analysed through thematic coding and comparative evaluation. Case studies were assessed for their use of biomimetic strategies, including structural resilience (e.g., honeycomb formations),

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passive cooling (e.g., termite mound ventilation), and resource efficiency (e.g., cactus-inspired water systems).

A taxonomy was developed to classify projects based on biomimicry levels, organism, behaviour, and ecosystem (Sommese et al., 2022), and mapped according to performance outcomes, scalability, material sustainability, and socio-economic relevance. This stage also emphasized the potential of biomimicry in housing design.

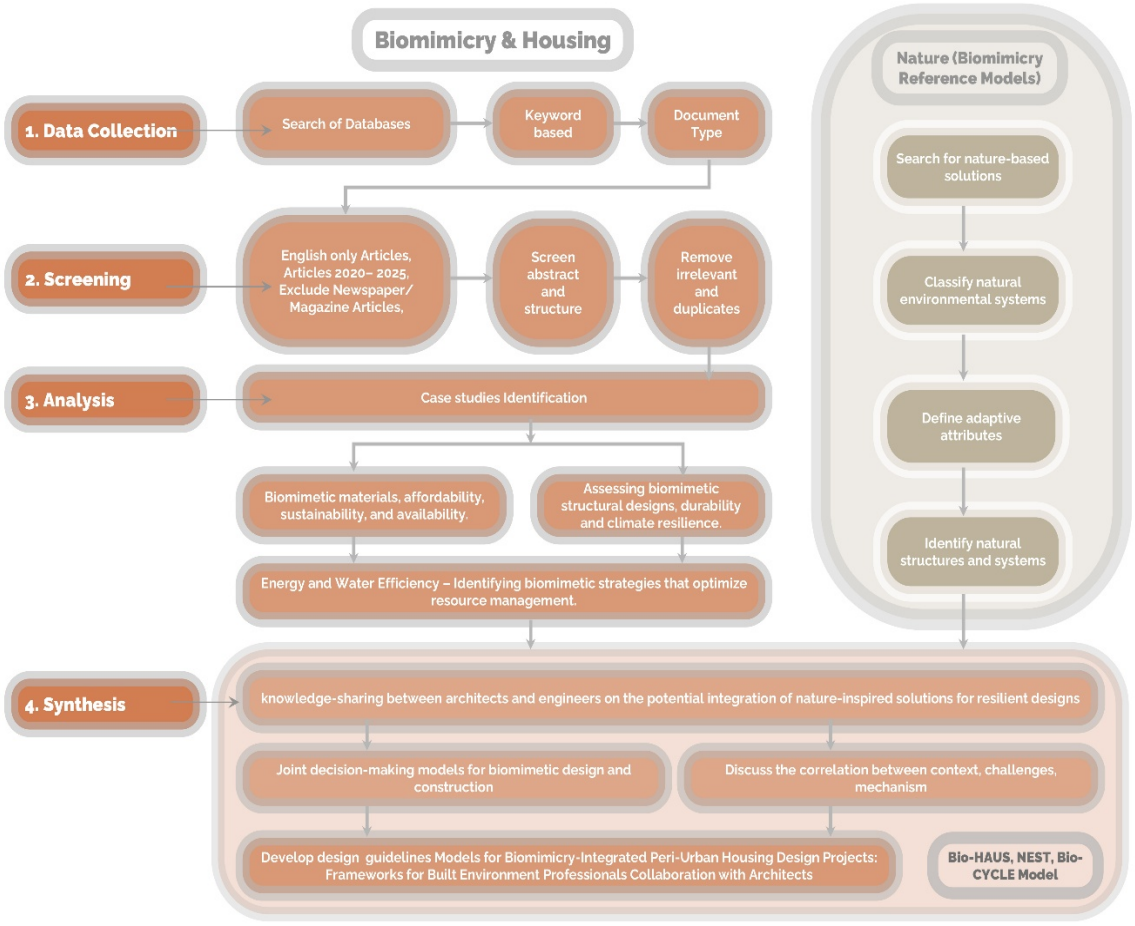



*Figure 3. Methodological framework (Author's own construct)*

**Phase 4: Synthesis**

Insights from the theoretical and analytical phases were synthesized to propose three integrated biomimicry-driven housing frameworks suitable for the peri-urban context of Ghana. These are:

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- **Bio-HAUS Model:** Focuses on climate-responsive, self-regulating housing based on adaptive strategies from nature such as termite mound ventilation and bamboo modularity *(see Figure 12).*
- **NEST Model:** Emphasizes thermal efficiency, modular construction, and circular economy through design stages that prioritize biomimicry principles and sustainable materials *(see Figure 13).*
- **Bio-CYCLE Model:** Incorporates closed-loop systems inspired by natural ecosystems, promoting decentralized waste management, rainwater harvesting, and regenerative landscaping *(see Figure 14).*

Each model was derived based on biological analogues with considerations regarding practical constraints, aiming to enhance climate resilience, reduce resource consumption, and ensure social adaptability (Kim et al., 2021; Ziaee et al., 2022). This final phase also outlines knowledge-sharing mechanisms and policy recommendations to facilitate cross-disciplinary collaboration between architects, engineers, and urban planners in implementing biomimicry-driven housing.

## RESULT

### Case Study Findings – Biomimicry in Housing

To evaluate the real-world application of biomimicry in housing, the study examined successful case studies. These case studies provided insights into sustainable design strategies, material selection, and climate-responsive construction. Several case studies demonstrate the successful application of biomimicry in architecture and urban planning. The Eastgate Centre in Zimbabwe (Figure 5a.), inspired by termite mounds, remains a benchmark in passive cooling systems (Andrew et al., 2023; Hammond, 2024). Another notable example is the HIVE House in Surat, India, designed by Openideas Architects (Figure 5b.), which is a sustainable housing project inspired by biomimicry learning from the beehive (Mehta, 2020; Nair, 2020). More recently, research has explored the potential for integrating biomimicry into informal settlements and low-income housing.

a  b. 

*Figure 5. a. The Eastgate Centre in Zimbabwe; b. The Hive House in Surat, India*

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Table 4 presents a framework for applying biomimicry in housing, using bees as an example. It outlines three levels of biomimicry, organism, behavior, and ecosystem, and demonstrates how buildings can mimic bee in form, material, construction, process, and function (Jamei, 2021).

*Table 4. Examples: A Building that Mimics a Bee*

| Level | Aspect | Description |
|---|---|---|
| **1-Organism Level (Mimicry of a Specific Organism)** | Form | The building takes inspiration from the shape and structure of a bee's body. |
| | Material | The building utilizes materials that replicate the composition of a bee's exoskeleton, such as lightweight, flexible, and durable bio-based materials. |
| | Construction | The building is constructed using a process that mirrors a bee's ability to build efficiently, using self-assembling structures and bio-inspired adhesives. |
| | Process | The building functions similarly to an individual bee, efficiently managing energy, thermoregulation, and resource distribution. |
| | Function | The building operates like a bee, adapting to environmental conditions, maximizing efficiency, and working as part of a larger system. |
| | | |
| **2-Behavior Level (How the Organism Relates to its natural setting)** | Form | The building looks like it was made by bees, resembling the organic, structured patterns found in honeycombs. |
| | Material | The building incorporates natural and engineered materials like those used by bees, such as wax-like composites and lightweight structural elements. |
| | Construction | The building is constructed using modular, interlocking components, like how bees build hives layer by layer. |
| | Process | The building functions like a beehive by efficiently organizing internal spaces and promoting air circulation. |
| | Function | The building operates as it would if constructed by bees, maintaining a stable internal environment with natural ventilation and thermoregulation. |
| | | |

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| | | |
|---|---|---|
| **3-Eco-System Level (Mimicry of an Environment)** | Form | The building resembles a beehive, acting as an interconnected and self-sustaining system. |
| | Material | The building is constructed from materials similar to those found in a beehive, such as natural fibers and porous materials that allow for breathability. |
| | Construction | The building is designed similarly to a beehive, following principles of modularity, self-expansion, and interconnectivity. |
| | Process | The building functions like a beehive ecosystem, harnessing passive climate control, resource-sharing, and adaptive growth. |
| | Function | The building operates as a beehive ecosystem, integrating into a larger sustainable urban framework |

At the organism level as depicted in Table 3, a building can mimic a bee's form, use exoskeleton-like materials, and adopt self-assembling construction methods. At the behavior level, it can replicate beehive structures, employing modular design, efficient spatial organization, and natural ventilation. At the ecosystem level, a building can function like a beehive, utilizing passive climate control, resource-sharing networks, and adaptive expansion (Penick et al., 2022).

**Biomimicry Principles in Sustainable Housing**

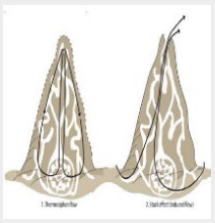
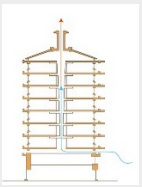
Key biomimetic principles relevant to housing include passive cooling, structural resilience, and adaptive shading, which take inspiration from biological systems to improve energy efficiency, material efficiency, and climate responsiveness (Andrew et al., 2023; Hammond, 2024). By mimicking termite mounds, passive cooling systems enable natural ventilation and temperature regulation. Structural resilience is achieved through honeycomb structures, which provide lightweight yet strong load-bearing designs. Adaptive shading mechanisms, inspired by conifer cones, lead to self-adjusting façades that optimize heat absorption (Srisuwan, 2020).

Table 5 illustrates some of the examples of projects, demonstrating how nature-inspired solutions can be effectively applied to housing design for enhanced performance and sustainability.

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*Table 5. Key Examples of Biomimetic Strategies Identified*

| Biomimetic Strategy | Biological Inspiration | Application in Housing |
|---|---|---|
| **1-Passive Cooling** | Termite mounds  | Natural ventilation and temperature regulation   E.g. The Council House 2 (CH2) Designed by DesignInc [Hammond, 2024 |
| **2-Structural Resilience** | Honeycomb structures  | Lightweight yet strong load-bearing designs  E.g. Hive Designed by Openideas Architecture [Archdaily.com |
| **3-Adaptive Shading** | Conifer Cones plants  | Self-adjusting façades to reduce heat absorption  E.g. Hygroskin Meteorosensitive Pavilion designed by Achim Mengesm [Source: Menges, 2013; Srisuwan 2020] |

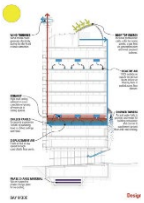
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**Energy-Efficient Biomimetic Building Systems**

Energy-efficient systems inspired by nature have been a focal point of research in biomimicry-driven architecture (Pugalenthi et al., 2024). A study by Nalcaci et al. (2020) highlighted the potential of biomimetic building façades to significantly lower energy demand across different climate zones. Table 6 summarizes urban housing examples that incorporate biomimicry principles for sustainability and environmental resilience

*Table 6. Environmental Conservation Principles (Biomimicry in Housing Design)*

| Aspect | Description | Example |
|---|---|---|
| 1-Renewable Energy | Biomimicry can inspire energy-efficient urban housing by mimicking natural systems to optimize renewable energy use. For instance, solar panels that track the sun like sunflowers improve efficiency (Omidvarnia et al., 2024; Regassa et al., 2023) | The Smart Flower is a ground-mounted solar system that emulates the sun-tracking behavior of sunflowers. [Ost, 2023]  (solar.com) |
| 2-Utilizing Resources Efficiently | Drawing inspiration from natural organisms, urban housing can maximize resource efficiency and minimize waste. Buildings modeled after termite mounds use passive cooling techniques [Hammond, 2024] | The Council House 2 (CH2) in Melbourne integrates passive cooling using the stack effect principle from termite mound   [Hammond, 2024] |
| 3-Energy Efficiency | Learning from ecosystems, urban housing can integrate interconnected spaces and systems to form self-sustaining structures. Just as a tree transports water and nutrients efficiently, buildings can optimize heating, cooling, and ventilation through | The Secret Garden House in Singapore designed by Wallflower Architecture + Design features green roofs, vertical gardens, passive cooling, and rainwater harvesting, enhancing sustainability and energy efficiency. |

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| | biomimicry [Abazari et al., 2024] |  [Lauren, 2024] |
| 4-Ecosystem Restoration | Urban housing projects can incorporate green roofs, vertical gardens, and living walls to mimic natural habitats, restoring biodiversity while improving air quality (Saker, 2024, Salvador, 2024). | Hill House by Snegiri Architects is a passive home in Saint Petersburg, Russia, featuring a living green roof that blends seamlessly with its woodland surroundings. It incorporates photovoltaic panels and rainwater collection, promoting sustainability and energy efficiency in modern residential design.  [Mitra, 2021] |
| 5-Climate Resilience | Biomimetic buildings can adapt to changing climates by incorporating features like "breathing walls," inspired by animal skins that regulate temperature and moisture levels. These systems help cities withstand extreme weather conditions (Lee, 2021). | The Wall House by Creative Architects demonstrates a ‘breathing wall’ concept for healthier interior living enhancing climate resilience.  [Shiell, 2020] |

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| | | |
|---|---|---|
| 6-Reduced Environmental Footprint | Inspired by nature's efficiency, urban housing can reduce its ecological footprint through sustainable materials, waste reduction, and integrated renewable energy systems (Chaudhary, 2024). | The Zero Island concept depends entirely on renewable energy from local environmental resources, including water, sun, and wind.  [Saker, 2024] |

**Biomimicry-Inspired Housing Models for Peri-Urban Ghana**

The research findings informed the development of a biomimicry-inspired housing models suited to Ghana's peri-urban challenges considering the parameters summarized in Table 7.

*Table 7. Models Evaluation and Feasibility*

| Parameter | Proposed Biomimetic Housing Model | Conventional Housing |
|---|---|---|
| Cooling System | Termite mound-inspired ventilation to maintain thermal comfort without mechanical cooling [Hammond, 2024]. | Mechanical air conditioning |
| Structural Efficiency | Lightweight, high-strength honeycomb structure to optimize strength and material efficiency [Mehta, 2020; Nair, 2020]. | Heavy concrete and steel |
| Water Management | Cactus-inspired rainwater harvesting to improve sustainability in water-scarce regions [Srisuwan, 2020]. | Municipal supply reliance |
| Material Sustainability | Locally sourced bio-based materials like bamboo, mycelium composites, and bio-concrete [Ibrahim, 2021]. | High-carbon cement and steel |

*Source: Authors' Construct*

The study proposed three biomimicry-inspired housing models tailored to address the unique challenges of peri-urban communities in Ghana. Each model draws from nature's adaptive strategies to enhance sustainability, climate responsiveness, and livability. The **Bio-HAUS Model** emphasizes modular, adaptable housing inspired by the honeybee hive; the **NEST Model** focuses on passive thermal efficiency, drawing lessons from organisms like cacti, pinecones, and desert snails; and the **Bio-CYCLE Model** mimics forest ecosystems to promote waste-to-resource systems and circular living. Together, these models offer a nature-based, context-sensitive framework for resilient urban housing.

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**Biomimicry-Inspired Housing for Adaptive Urban Sustainability (Bio-HAUS)**

The Biomimicry-Inspired Housing for Adaptive Urban Sustainability (Bio-HAUS) model (See Figure 6) derived from the research follows a structured biomimicry-driven approach to developing sustainable housing solutions for peri-urban Ghana.

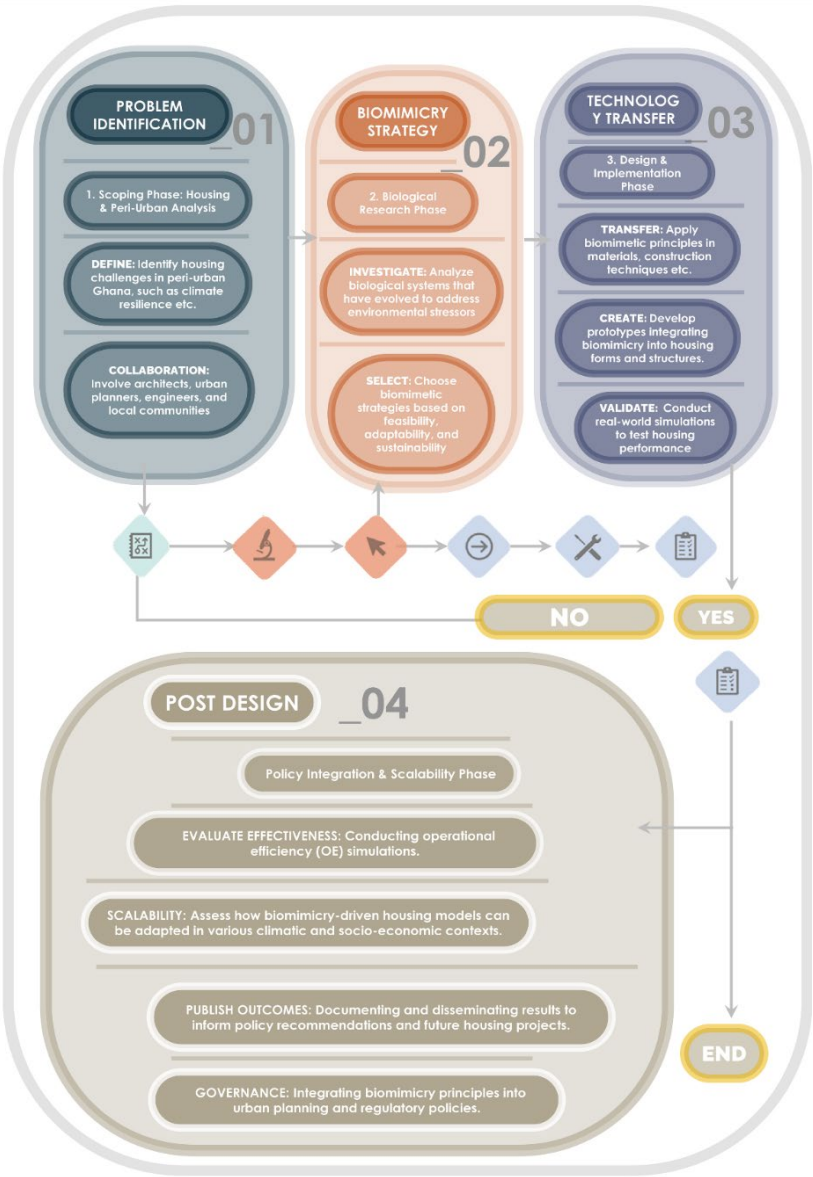



*Figure 6. The Biomimicry-Inspired Housing for Adaptive Urban Sustainability* ***Bio-HAUS Model*** *(Authors' Construct)*

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The honeycomb geometry informed interlocking units that are scalable, flexible, and material-efficient, ideal for rapid housing deployment using low-carbon, prefabricated, and self-supporting units. It begins with problem identification, analyzing housing challenges such as climate resilience, affordability, and infrastructure gaps. The biomimicry strategy phase investigates biological systems that have adapted to environmental stressors, selecting feasible and sustainable design principles like termite-inspired passive cooling.

In the technology transfer phase, these insights are applied to material selection, construction techniques, and energy-efficient housing prototypes, which are then validated through real-world simulations. The post-design phase assesses effectiveness, scalability, and governance, ensuring the integration of biomimicry principles into urban planning policies for long-term sustainability as illustrated in Figure 6. The Bio-HAUS Model will promote modular construction and bio-inspired materials including bamboo, adobe, and engineered wood composites offer durable, renewable alternatives for sustainable peri-urban housing enabling fast, low-waste assembly and adaptability which enhance thermal regulation by storing and releasing heat, mimicking natural insulation.

**Nature-Inspired Engineered Solutions for Thermal-Efficiency (NEST) Model**

The NEST Model is a strategic, nature-inspired framework designed to integrate sustainable design principles into affordable housing, especially within peri-urban contexts. Derived from organisms such as desert snails, pinecones, and cacti, this model emphasized passive thermal regulation. Key strategies included hygroscopic material logic from pinecones for moisture balance, spiral shell geometry for heat deflection, and cactus-inspired facades for passive shading and water retention. It unfolds in three major phases, Pre-Design, Design, and Post-Design, following a circular, biomimicry-based process (See Figure 7).

In the Pre-Design Phase, it begins by identifying core challenges such as high material extraction, excessive energy consumption, and poor thermal comfort. It then gathers contextual data, including climate analysis and spatial usage patterns, to inform the identification of performance targets like thermal efficiency, adaptability, and cost-effectiveness.

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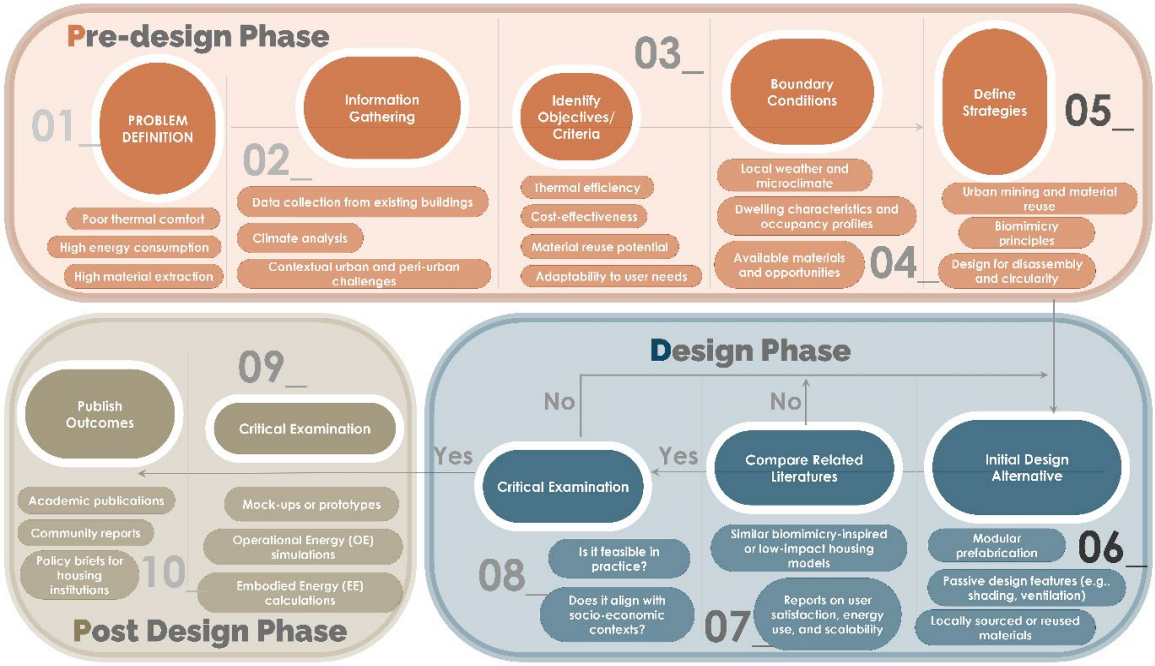



*Figure 7. The Nature-Inspired Engineered Solutions for Thermal-Efficiency – **NEST Model** (Authors' Construct)*

This phase also outlines key boundary conditions, such as local weather, available materials, and site-specific characteristics, to shape design responses. Using insights from urban mining, biomimicry, and design for disassembly, the model then defines sustainable design strategies. In the Design Phase, an initial prototype is developed, incorporating modularity, passive cooling, and resource-efficient materials.

As illustrated in the Figure 7, this concept is then benchmarked against related studies to ensure feasibility and performance. If promising, the model is subjected to critical examination for its practical applicability and socio-economic alignment. The Post-Design Phase evaluates effectiveness through operational energy simulations, embodied energy assessments, and physical mock-ups. Finally, findings are published through academic, community, and policy channels, supporting knowledge sharing and model replication. The NEST Model champions thermal efficiency, resilience, and circularity as foundational to designing affordable, environmentally responsible housing.

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**Biomimicry-Inspired Circular Yield for Community Liveability & Ecology (Bio-CYCLE) Model**

The Bio-CYCLE Model is a comprehensive, nature-based framework designed to transform waste into a regenerative resource while improving livability in peri-urban communities (See Figure 8). Rooted in biomimicry and circular economy principles, the model draws inspiration from natural ecosystems, such as forest floors, wetlands, and termite nest where materials are continuously reused and energy cycles are closed. It included community compost systems, greywater recycling, and biogas digesters to form a closed-loop infrastructure. The framework begins with the Pre-Design Phase, where core challenges are identified, including waste accumulation, poor sanitation, water scarcity, and degraded living environments. This phase also defines sustainability goals focused on waste reduction, resource recovery, water reuse, and social inclusion.

After problem identification is the Design Strategy Phase where goals are translated into practical systems using nature-inspired strategies as illustrated in Figure 8. For example, in the case of organic waste management in peri-urban communities, waste can be managed through mycelium-based composting and vermiculture, mimicking forest decomposition processes. Greywater can be purified through constructed wetlands, while termite-inspired dry compost toilets provide decentralized sanitation. Energy can be recovered via biogas digesters modeled after animal digestion systems, and plastic and metal waste are repurposed through community-scale urban mining hubs, reflecting the resource reuse behaviors of ant colonies for example.

The System Integration Phase which follows then adapts these strategies into the built environment, incorporating features like compost-fed green courtyards, eco-hubs for education and waste collection, modular public spaces, community gardens irrigated with greywater, and green roofs for passive cooling and biodiversity. In the Implementation Phase, these designs are prototyped through pilot households or blocks, where real-time monitoring and community training ensure adoption, performance tracking, and maintenance. Data gathered informs advocacy for policy support and integration into local planning systems and if the pilot projects fail then the process is repeated going back to the previous phase as demonstrated in Figure 8.

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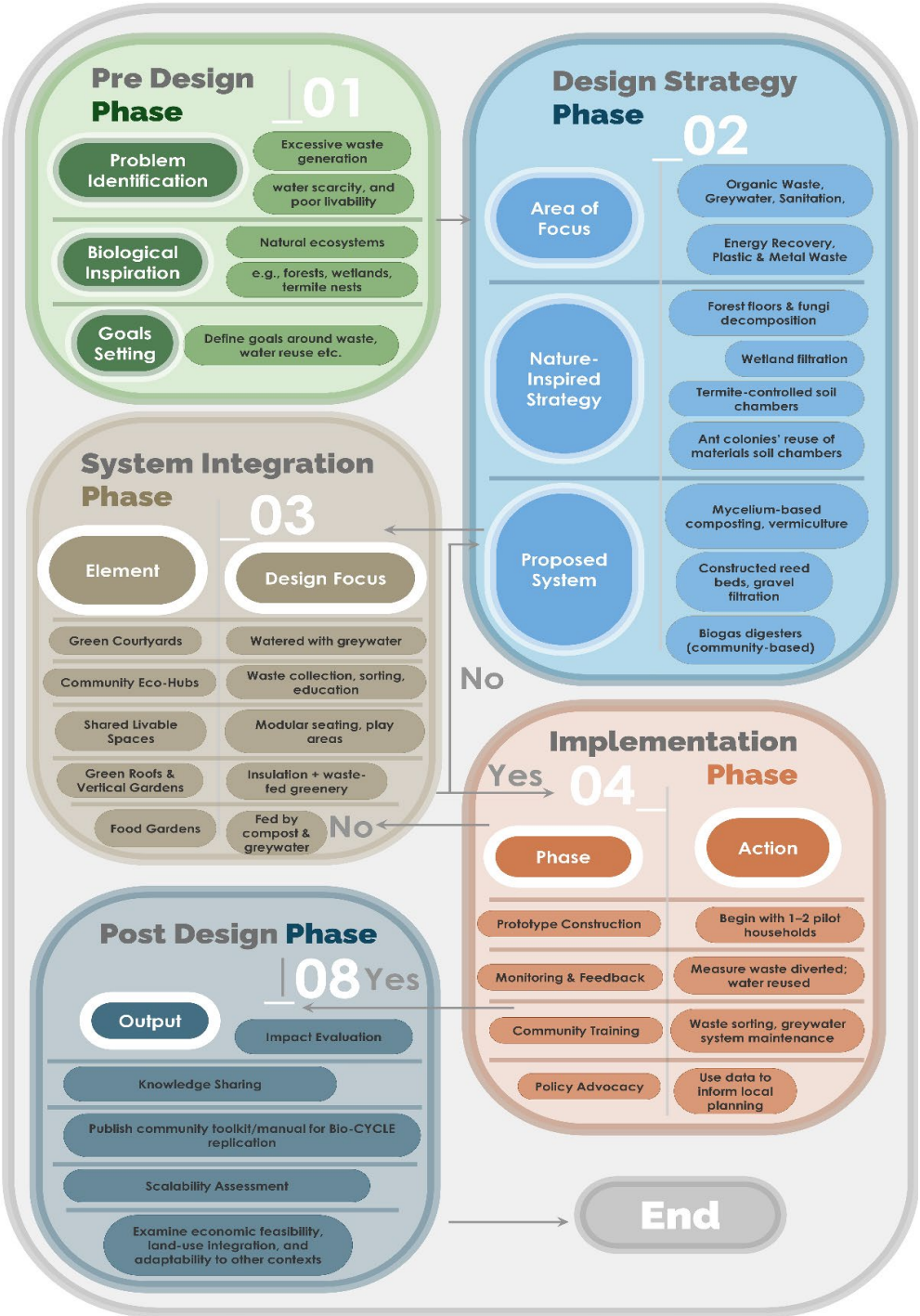



*Figure 8. Biomimicry-Inspired Circular Yield for Community Liveability & Ecology* ***(Bio-CYCLE) Model*** *(Authors' Construct)*

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Finally, the Post-Design Phase focuses on evaluating the model's effectiveness in terms of environmental impact, social benefits, and replicability. Outputs include toolkits, community manuals, and scalability assessments to ensure the model can be adapted across other peri-urban contexts. Altogether, the Bio-CYCLE Model presents a replicable, resilient approach to sustainable urban development—closing resource loops, empowering communities, and building environments that function in harmony with nature.

**Comparative Analysis of the Biomimicry-Inspired Housing Model**

Biological principles were translated through context-driven design choices. For example, the NEST model integrated lightweight insulated wall assemblies, stack-effect chimneys, and adaptive shading modeled after pinecones and cacti. The Bio-HAUS model prioritized interlocking modularity, mimicking hive intelligence for space optimization. The Bio-CYCLE system reimagined community infrastructure to function like a living system, where waste becomes nutrients, aligning with ecological succession principles. A summerised comparative analysis of the proposed housing models is presented in Table 8 looking at the biological analogue, core principles, strengths and weaknesses and suggested applications.

*Table 8. Comparative Analysis of the Biomimicry-Inspired Housing Models*

| **Feature / Model** | **Bio-HAUS Model** | **NEST Model** | **Bio-CYCLE Model** |
|---|---|---|---|
| **Biological Analogue** | Honeybee Hive | Pinecones, Cacti, Desert Snails | Forest Ecosystems, Mycelium |
| **Core Principle** | Modularity & Structural Adaptability | Passive Thermal Control & Energy Efficiency | Circular Resource Use & Ecological Integration |
| **Strengths** | Scalable, prefabricated, context-flexible | Low energy demand, resilient to heat & humidity | Supports waste management, food, and livability |
| **Weaknesses** | May require terrain adaptation | Performance varies with microclimate zones | Requires community training for maintenance |

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| | | | |
|---|---|---|---|
| **Best Application** | Fast urban expansion, limited labor zones | Hot, humid peri-urban environments | Waste-burdened, low-resource dense communities |

*Source: Authors' Construct*

## CONCLUSIONS AND RECOMMENDATIONS

Biomimicry offers a transformative and contextually appropriate solution for addressing the housing deficits and environmental vulnerabilities of peri-urban Ghana. This study introduced three nature-inspired housing frameworks—Bio-HAUS, NEST, and Bio-CYCLE—each grounded in biological analogues and ecological processes. The Bio-HAUS Model draws from honeybee hives and termite mounds to promote modularity, adaptability, and passive climate responsiveness. The NEST Model, informed by organisms such as pinecones, cacti, and desert snails, focuses on thermal efficiency and circular material strategies suited to hot, humid environments. Meanwhile, the Bio-CYCLE Model mimics forest ecosystems and mycelium networks to integrate waste management, greywater recycling, and community-centered green infrastructure. Together, these models present a holistic roadmap for embedding biomimicry principles into sustainable housing. The study contributes to the growing body of knowledge by providing context-specific, nature-based design strategies for climate-resilient housing in the Global South. Importantly, it highlights the potential for interdisciplinary innovation in architectural practice, especially in low-resource settings. Integrating biomimicry into national housing policy, planning frameworks, and architectural education is crucial to institutionalizing these strategies. Future research should focus on the development and prototyping of the proposed models, including real-world performance testing, energy simulations, and cost-benefit analysis, to evaluate feasibility and inform scalable implementation.

### Recommendations

To realize the potential of biomimicry-inspired housing in Ghana, the following specific actions are recommended:

- **Policy and Planning Integration**: The Ministry of Works and Housing should incorporate biomimicry into Ghana's National Housing Policy through dedicated guidelines on nature-based, low-carbon housing. This can be supported by updating the Ghana Building Code to incentivize passive design strategies, use of local materials, and energy-efficient technologies modeled after nature.


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- **Targeted Incentives**: Government and municipal authorities should introduce tax reliefs, expedited permitting, or green building certification points for housing developments that adopt biomimetic features. Financial support could be tied to climate finance sources such as the Green Climate Fund.
- **Architectural Education and Training**: Institutions such as KNUST and Ghana Standards Authority (GSA) should revise architectural and engineering curricula to include biomimicry as a core design philosophy. This should include hands-on workshops, multidisciplinary studios involving biologists and ecologists, and field-based observation of natural systems.
- **Stakeholder Collaboration**: A cross-sector task force comprising the Ghana Green Building Council, Environmental Protection Agency (EPA), NGOs, and academia should be formed to oversee implementation. Pilot projects can be co-developed with community-based organizations to ensure inclusivity and local relevance.
- **Research and Innovation Support**: Funded research hubs should be established to support real-world testing, prototyping, and performance evaluation of biomimicry-based housing. These could serve as living labs and policy-testing grounds for sustainable urban development.

By operationalizing these recommendations, Ghana can pioneer resilient, ecologically integrated housing systems that are both culturally grounded and globally relevant.

**Limitations of the Study**

While the study drew heavily from global biomimetic case studies such as the Eastgate Centre (Zimbabwe), it acknowledges the contextual differences in material availability, cost structures, and climatic conditions in Ghana. To adapt these strategies locally, the proposed housing models (Bio-HAUS, NEST, and Bio-CYCLE) were designed with materials like bamboo, adobe, and rammed earth, abundantly available and affordable in peri-urban Ghana.

Though direct empirical validation (e.g., pilot testing, energy simulations, or cost analyses) was not conducted within this study's scope, the models emphasize low-tech, climate-responsive strategies that have proven cost efficiency in similar environments. Future phases of this research will include prototyping and performance simulations to validate thermal comfort, energy use, and construction feasibility under Ghanaian conditions.

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