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Nature Deconstructed: A Critical Examination of Biomimetic Design Translation Processes

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Abstract

This paper establishes critical distance from conventional biomimetic design discourse by scrutinizing the translation mechanisms through which nature-based models transform into architectural applications. Moving beyond celebratory accounts of biomimetics, this research interrogates the epistemological foundations of a field that often presents itself as objective despite relying on inherently subjective interpretive processes.

Through methodical deconstruction of selected case studies, this investigation reveals significant gaps between nature-based models and their architectural manifestations—gaps that emerge not merely as technical limitations but as systematic distortions embedded in the translation process itself. The research demonstrates how designers' disciplinary backgrounds, cultural frameworks, socioeconomic positions, and cognitive biases fundamentally shape which aspects of nature's systems are privileged, which are neglected, and how they are subsequently abstracted and recontextualized.

This analysis codifies specific patterns of bias: reductive simplification of complex biological systems; confirmation bias that selectively emphasizes biological features aligning with predetermined design goals; morphological fixation that privileges visible forms over processes; and disciplinary myopia that interprets biological phenomena through narrow professional lenses. These biases are not incidental but structural components of biomimetic translation that remain largely unacknowledged in the field's theoretical foundations.

By methodically exposing the gap between nature-based inspiration and architectural implementation, this study challenges biomimetics' claims of direct derivation from nature. The paper argues that acknowledging these interpretive dimensions does not diminish biomimetics but rather enhances methodological rigor by fostering critical self-awareness. This critical perspective provides a foundation for more transparent biomimetic practices that consciously navigate the inherent subjectivity of translating between natural and designed systems, opening new pathways for genuinely innovative cross-disciplinary approaches.

Résumé

Cette étude établit une distance critique vis-à-vis du discours conventionnel sur la conception biomimétique en examinant minutieusement les mécanismes de traduction par lesquels les modèles biologiques se transforment en applications architecturales. Dépassant les récits célébratoires de la biomimétique, cette recherche interroge les fondements épistémologiques d'un domaine qui se présente souvent comme objectif malgré sa dépendance à des processus interprétatifs intrinsèquement subjectifs.

Par une déconstruction méthodique d'études de cas sélectionnées, cette investigation révèle des écarts significatifs entre les modèles biologiques et leurs manifestations architecturales—écarts qui émergent non pas simplement comme des limitations techniques mais comme des distorsions systématiques intégrées dans le processus de traduction lui-même. La recherche démontre comment les formations disciplinaires des concepteurs, leurs cadres culturels, leurs positions socioéconomiques et leurs biais cognitifs déterminent fondamentalement quels aspects des systèmes biologiques sont privilégiés, lesquels sont négligés, et comment ils sont ensuite abstraits et recontextualisés.

Cette analyse codifie des schémas spécifiques de biais : la simplification réductive des systèmes

biologiques complexes ; le biais de confirmation qui souligne sélectivement les caractéristiques biologiques s'alignant avec des objectifs de conception prédéterminés ; la fixation morphologique qui privilégie les formes visibles au détriment des processus ; et la myopie disciplinaire qui interprète les phénomènes biologiques à travers des prismes professionnels étroits. Ces biais ne sont pas fortuits mais constituent des composantes structurelles de la traduction biomimétique qui demeurent largement non reconnues dans les fondements théoriques du domaine.

En exposant méthodiquement l'écart entre l'inspiration biologique et l'implémentation architecturale, cette étude remet en question les prétentions de la biomimétique à une dérivation directe de la nature. L'article soutient que reconnaître ces dimensions interprétatives ne diminue pas la biomimétique, mais renforce plutôt la rigueur méthodologique en favorisant une conscience critique de soi. Cette perspective critique fournit une base pour des pratiques biomimétiques plus transparentes qui naviguent consciemment dans la subjectivité inhérente à la traduction entre les systèmes naturels et conçus, ouvrant de nouvelles voies pour des approches transdisciplinaires véritablement innovantes.

1. Introduction

1.1 Nature as references: tracing creative pathways

Nature has served as a profound source of inspiration across philosophical thought, artistic expression, architectural design, and health-focused approaches throughout human history. This foundational relationship between nature and human creativity reveals not only our innate connection to the natural world but also the evolution of how we interpret and apply natural principles to enhance human experience.

In philosophical thinking, nature has been a fundamental reference point across diverse cultures and historical periods[1, 2]. Pre-Socratic philosophers like Heraclitus (c. 535-475 BCE) conceptualized nature as a process of constant change, famously declaring "panta rhei" ("everything flows"), while Empedocles (c. 494-434 BCE) and Anaximander (c. 610-546 BCE) proposed that nature is governed by fundamental elements and opposing forces. Plato (427-347 BCE) viewed the natural world as a mere shadow of a higher reality in his Theory of Forms, utilizing natural metaphors such as the Allegory of the Cave to illustrate the journey toward knowledge. For Aristotle (384-322 BCE), nature served as a guide to ethics and purpose, with everything possessing a "telos" or inherent goal.

The Stoics, including Zeno of Citium (c. 334-262 BCE) and Marcus Aurelius (121-180 CE), advocated living in accordance with nature's rational order. In Chinese philosophy, Laozi (6th century BCE) described the Dao in the "Tao Te Ching" as the natural flow of the universe, encouraging effortless harmony with nature. Jean-Jacques Rousseau (1712-1778) idealized nature in his "Discourse on Inequality," suggesting humans are naturally good but corrupted by civilization. Later philosophers such as Immanuel Kant (1724-1804) explored nature's sublime qualities, while Friedrich Nietzsche (1844-1900) viewed nature as embodying struggle and transformation. Martin Heidegger (1889-1976) criticized technology's alienation from nature, advocating for deeper engagement with the natural world to understand being. Contemporary environmental philosophers like Arne Naess (1912-2009) and Vandana Shiva (b. 1952) have further expanded these relationships through deep ecology and ecofeminism.

In religious symbolic representations, nature has served as a profound metaphorical and literal source of divine representation. The Hindu deity *Ganesha*, with his distinctive elephant head, exemplifies how natural forms are integrated into spiritual iconography. This anthropomorphic representation demonstrates how natural elements are not merely decorative but carry deep philosophical and spiritual significance, bridging the material and divine realms through recognizable natural forms (Fig. 1).


Figure 1. Hindu deity *Ganesha* with his distinctive elephant head exemplifies the integration of natural forms into religious iconography, demonstrating how elements from nature serve as vehicles for divine representation and spiritual significance.

In artistic domains, nature has been equally influential. Abstract artists like Wassily Kandinsky ("Composition VII," 1913) and Georgia O'Keeffe ("Red Canna," 1924) transformed natural inspirations into expressive compositions. Still life masters such as Vincent van Gogh ("Sunflowers," 1888) and Rachel Ruysch (17th century) used natural elements to explore themes of mortality and beauty. In dance, Isadora Duncan (1877-1927) rejected rigid ballet techniques in favor of movements inspired by trees and waves, while Martha Graham's "Appalachian Spring" (1944) incorporated natural imagery to reflect human connection to the land. Cinema has also embraced nature as a reference, evident in Terrence Malick's "The Tree of Life" (2011) and Hayao Miyazaki's "Princess Mononoke" (1997), which use natural imagery to explore existential themes and environmental harmony[3].

In the emerging field of bioart, nature becomes a dynamic medium for technological exploration and critique. The genetically modified pink chicken represents a provocative intersection of biotechnology, artistic expression, and scientific manipulation. Such bio-artistic interventions challenge traditional boundaries between natural and artificial, inviting critical reflection on humanity's capacity to redesign living organisms (Fig.2).


Figure 2. Bright pink chicken specimen illustrating the intersection of biotechnology and artistic expression, challenging distinctions between natural and human-modified organisms.

Architecture and design have approached nature from both utilitarian and aesthetic perspectives. Ancient Egyptian and Greek architects incorporated natural principles, with the latter employing the Golden Ratio found in natural forms. Roman architect Vitruvius (1st century BCE) established principles of strength, functionality, and beauty in "De Architectura," drawing parallels to natural structures. Leonardo da Vinci (15th century) studied natural forms for engineering solutions. Eastern architectural traditions, including Chinese Feng Shui and Japanese Zen gardens, emphasized harmony with nature. More recent architectural innovators like Frank Lloyd Wright (1867-1959) with "Fallingwater," Antoni Gaudí (1852-1926) with "La Sagrada Familia," and Le Corbusier (1887-1965) all incorporated natural principles into their distinctive approaches[4, 5].

The concept of salutogenesis, introduced by Aaron Antonovsky[6], has further evolved our understanding of nature's role in fostering health and well-being. Biophilic design integrates natural elements to promote health, exemplified by Maggie's Centres for cancer patients. Alvar Aalto's Paimio Sanatorium (Finland, 1933) utilized natural light and forest views to aid patient recovery. The High Line (New York City, 2009) transforms urban space into green parkland to enhance mental well-being. This health-oriented approach extends to art and design, where artists like Andy Goldsworthy create ephemeral natural sculptures, and architects like Zaha Hadid (1950-2016) incorporate fluid, nature-inspired forms[7].

Drawing from the rich tapestry of nature's influence across disciplines, we can observe how nature has served as a reference in multiple contexts. However, the relationship between humans and nature has evolved significantly beyond mere reference or inspiration. Using nature as models in design processes, combined with scientific investigation and methodical analysis, has transcended simple mimicry to become an integral component of the creative process itself. Nature has become deeply involved in design methodology, playing an important role in the cognitive processes and fundamental biases of each designer and creator. This integration influences not only the aesthetic or functional outcomes but shapes the very thought patterns and creative frameworks through which designers and artists approach problems.

The cognitive engagement with natural principles transforms how creators perceive challenges and envision solutions. Rather than simply borrowing visual elements or structural concepts from nature, contemporary approaches, such as biomimicry, involve a deeper dialogue with natural systems—understanding their underlying principles, evolutionary strategies, and adaptive mechanisms[4, 5]. Yet this raises critical questions about our interpretation of nature's "wisdom": To what extent are we projecting human values onto natural systems? Does biomimicry risk idealizing nature while overlooking its inherent inefficiencies and limitations? As we move toward more sophisticated applications of biomimetic principles, we must confront whether these approaches truly capture nature's complexity or merely reinforce our selective understanding of natural phenomena. These tensions and possibilities set the stage for examining of this contemporary biomimetic concept.

1.2 Contemporary biomimetics: assumptions and limitations

The concept of biomimetics emerged from the pioneering work of Otto Schmitt in the 1950s. Working at the intersection of electrical engineering and biology, Schmitt studied squid nerve propagation and successfully applied this biological knowledge to develop a new electronic circuit—the Schmitt trigger—that mimicked the neural pulse transmission of squids. This direct translation from biological system to technological innovation led him to coin the term "biomimetics" in 1950, defining it as an interdisciplinary process of drawing inspiration from natural systems to create novel technical inventions[8].

Schmitt's approach represented a straightforward biology-to-technology interpretation, focusing primarily on functional mimicry rather than broader ecological considerations. It wasn't until the 1990s that Janine Benyus significantly expanded this concept through her introduction of "biomimicry" in her influential 1997 book, "Biomimicry: Innovation Inspired by Nature." Benyus broadened the scope of biomimetics beyond pure innovation to encompass ecological awareness and sustainability principles. She proposed that nature should be viewed not just as a source of creative inspiration but as "model, measure, and mentor" for human design[9]. This evolution from Schmitt's functional biomimetics to Benyus's holistic biomimicry marked a crucial shift in how designers and engineers approached nature-inspired design. Biomimicry has since been popularized and adopted across numerous domains, including industrial design, materials science, architecture, and urban planning. Since the last decade, environmental and technology philosophers has begun to grapple with several questions and issues raised by biomimicry (10,11,12). Among others, Henry Dicks emphasizes that biomimicry is not just a method for technological advancement but also a deeper philosophical and ecological approach to innovation. He suggests that nature is not merely a collection of models to be imitated for efficiency or functionality but a vast source of wisdom, particularly in the ecological sense.

> « If nature is a profound source of wisdom, and in particular of the ecological wisdom so urgently required today, it follows that biomimicry is more than just a strategy for technological innovation based on imitating models abstracted from nature[10] *»*.

However, despite its growing popularity and apparent success stories, biomimicry faces significant constraints that often remain unacknowledged. Perhaps the most problematic is what might be termed the "black box interdisciplinary, hybrid creative process" that underlies biomimetic design. This process – '*how exactly are we to understand and put into practice the biomimetic view of nature'* -the translation of biological knowledge into practical applications—remains largely mysterious and frequently subject to misinterpretation.

The core challenge lies in the fact that biomimicry is not, despite common perception, a purely objective, scientific process. Rather, biomimetic applications are heavily influenced by what designers and architects selectively observe and interpret based on their domain-specific backgrounds, cultural contexts, socioeconomic factors, and individual cognitive frameworks. This subjective filter means that what is presented as "learning from nature" may actually represent a highly selective and potentially biased interpretation of natural phenomena.

Biomimicry is often guided by the assumption that nature serves as an optimized model, offering solutions refined through evolutionary processes. However, nature does not design with efficiency or optimization as an explicit goal; rather, biological systems evolve through adaptation, environmental pressures, and historical contingencies. What persists in nature is what has survived, not necessarily what is universally optimal. While nature's forms, materials, and processes can inspire innovative solutions, direct application to human design must account for differences in context, scale, and functionality[5, 11, 12].

A central challenge in biomimetic design is the necessity to think beyond conventional constraints. While nature provides a vast source of inspiration, translating biological principles into human applications requires abstraction and recontextualization. Creativity in biomimicry extends beyond imitation—it demands an ability to recognize underlying principles and adapt them to novel challenges. This process is inherently complex, requiring designers to balance biological accuracy with practical feasibility, often resulting in selective interpretations that may introduce bias. System thinking is fundamental to biomimicry; as natural systems operate through interdependent relationships rather than isolated functions. However, translating this complexity into human systems is not straightforward. While biological models illustrate resilience, adaptability, and efficiency within specific ecosystems, their transferability to artificial environments requires careful consideration. Oversimplifying the interconnectedness of natural systems can lead to misapplications, where essential ecological dynamics are overlooked in favor of aesthetically or superficially biomimetic designs[13, 14, 15].

At the heart of these challenges lies the 'black box' problem in knowledge translation. This issue emerges in the processes of focus, abstraction, and analogy, where the complexity of biological knowledge is filtered through human perception, disciplinary biases, and epistemological constraints[16]. How can biomimetic design avoid the pitfalls of selective interpretation and misrepresentation of natural principles? To what extent do designers impose their own biases in the abstraction process, and how can we critically assess the legitimacy of biomimetic claims? Addressing these questions is crucial for establishing a more transparent and self-reflective biomimetic design process that moves beyond superficial imitation toward a more sophisticated dialogue with natural system and a more profound comprehension of nature's intrinsic wisdom.

1.3 The complexity of biomimetic knowledge transfer: navigating the epistemological landscape of interdisciplinary knowledge translation

The journey of biomimetic design represents a profound intellectual challenge: how does human creativity transform biological principles into innovative design solutions? At the heart of this process lies a complex epistemological puzzle—a "black box" of knowledge translation that demands rigorous examination.

> « Although abstractions are fabricated by the human mind, the stimulus motivating their formation comes from outside the mind. Therefore, abstractions are not timeless, but contingent on given social and political conditions. Within human history, the power of abstraction developed in proportion to social complexity, and indeed abstractions become a **conditio sine qua non** with the rise of early large-scale societies*[17]* »

Building upon this framework, biomimetic design translation exists at the intersection of nature, human cognition, and sociocultural context. The abstractions derived from biological models are not objective truths but contingent constructions shaped by specific historical and social conditions.

In biomimetic architecture, the translation process is fundamentally mediated by the architect's cognitive apparatus. As philosopher Michel Serres observed, seemingly objective biological "solutions" are readings filtered through distinctly human perceptual frameworks. The architect doesn't simply "discover" biological principles but engages in an interpretive act influenced by their education, professional background, and philosophical orientation.

Implementation is further shaped by the material conditions of practice—client expectations, regulatory frameworks, available technologies, and economic constraints. An architect in a resource-constrained environment may interpret biological efficiency through an economic lens, while one working within sustainability-focused systems might emphasize ecological performance metrics.

This explains why different architects observing identical biological phenomena extract entirely different design principles. What appears as a structural solution to one might represent a material innovation to another—these varying interpretations reflecting not just personal preference but deeper socio-professional conditioning.

This perspective suggests that advancing biomimetic architecture requires not just deeper biological knowledge, but greater critical self-awareness of these interpretive filters. This understanding opens the door to considering Dedre Gentner's work on analogical reasoning as a more structured approach to biomimetic translation. Gentner's work on the "analogical mind" provides crucial insights into this translation process[18]. Abstraction is not merely an academic exercise but a fundamental human cognitive capability. As Gentner argues, "*The arts of abstraction always take part in the human mind since the beginning of all, and are part of daily life*." Consider language itself—an abstract system that allows complex ideas to be communicated across diverse contexts[17, viii]. Each word is an abstraction, a metaphorical bridge connecting conceptual domains. In biomimetic design, this process of abstraction becomes even more complex, requiring translation between biological principles and design strategies. Knowledge transfer in biomimetic design is not a simple, linear process. It involves: Identifying core principles in the source domain (biology) - Abstracting these principles - Recontextualizing them in the target domain (design).

> « One must understand that nature presents no blueprints for its structures, and its processes are not always simple to appreciate, let alone to implement. Nonetheless, they are available for our observation[19, preface] »

In the seminal cross-disciplinary work in "Biomimetics for Architecture & Design," by architect Göran Pohl and biologist Werner Nachtigall articulate a profound framework for understanding how humans can learn from nature's sophisticated design strategies. Their triadic model—*Erkennen à Abstrahieren à Umsetzen* (Recognize → Abstract → Implement)—provides a critical roadmap for interdisciplinary knowledge translation[20]. They outline three critical stages:

- I. *Erkennen* (Recognization): Recognizing and observing biological principles in nature.
- II. *Abstrahieren* (Abstraction): Extracting core functional and structural principles from biological models.
- III. *Umsetzen* (Implementation): Translating these principles into technical or design solutions.

This framework emphasizes that nature does not present clear blueprints for its structures, nor are its processes always straightforward to interpret or implement. Instead, biomimetic designers must engage in a form of *analog research* that establishes functional similarities and analogous structures only *a posteriori*—after a deliberate process of analysis and synthesis (Fig.3).

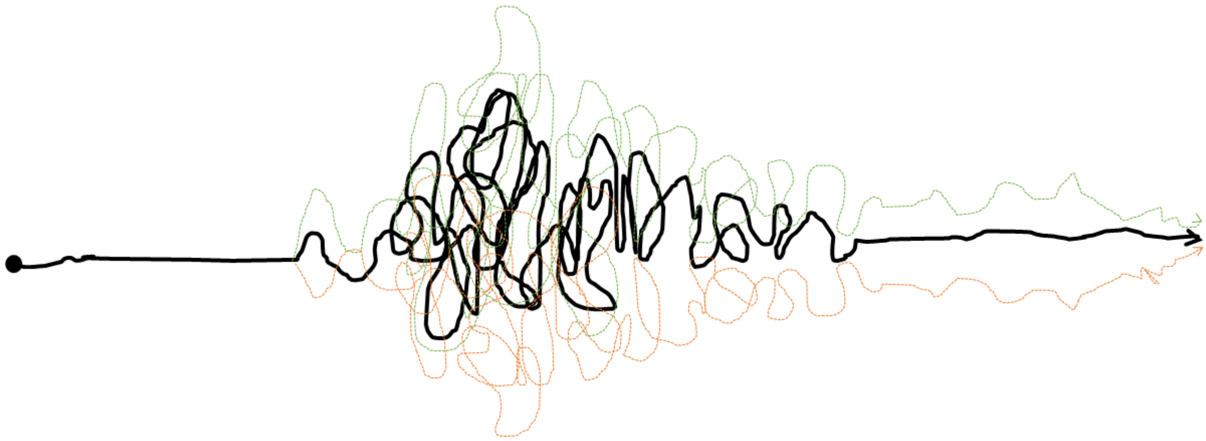

Figure 3. The illustration shows a complex, tangled path (in black) that represents the non-linear design process in biomimetic research. The path begins at a clear point on the left and eventually reaches a destination on the right, but in between contains a chaotic, overlapping middle section with additional colored (light green and orange) lines representing parallel or alternative pathways.

The discourse on biomimetics often assumes a seamless translation of biological principles into design strategies. At the core of this assumption lies the concept of the "hybrid brain", a cognitive framework explored in studies by Chayaamor-Heil and Vitalis[21] suggesting that architects with a background in both design and biology engage with biomimetic transfer differently than those trained solely in architecture.

This proposition raises critical questions: To what extent can architects genuinely internalize and apply biological knowledge without distorting its fundamental principles? Does the hybrid brain—one that navigates both biological and architectural domains—offer a more nuanced and faithful translation of nature's strategies, or does it, too, impose architectural biases on biological models? More fundamentally, does interdisciplinary expertise mitigate the epistemological tensions between these fields, or does it introduce new cognitive filters that shape the biomimetic design process in unforeseen ways?

By examining the cognitive mechanisms at play, we can begin to unpack whether an architect's disciplinary background influences the fidelity of biomimetic transfer—or if the very act of interpretation inherently reshapes biological knowledge to fit architectural paradigms.

The critical insight emerges not from the quantity of knowledge, but from the quality of translation process. As philosopher Ludwig Wittgenstein might suggest, the limits of our translation are not defined by the volume of our knowledge, but by our ability to conceptualize and bridge different epistemological frameworks[22]. The act of translating biological principles into architectural design is fraught with systematic distortions. These distortions emerge not only from disciplinary biases but also from the underlying epistemological structures that govern each field.

There are some keys distortions and open questions in the biomimetic translation processes. One of the most pervasive distortions in biomimetic design is the privileging of visual and structural features over functional and process-based insights. Architects frequently fixate on biological morphology, leading to what can be described as "aesthetic biomimicry[23, 24]." To what extent does this visual fascination limit the potential of biomimetic strategies? If the goal is to develop a truly knowledge-based approach, *should biomimetic design shift away from visual metaphors toward* *deeper systemic understandings?*

The selective abstraction of biological models raises further concerns. Architects tend to extract principles that align with pre-existing architectural paradigms while disregarding more complex or inconvenient biological functions[25, 26]. This selective process leads to functional misalignment, where biomimetic principles are either misunderstood or reinterpreted to fit within conventional architectural logics. *Is this tendency an inherent limitation of cross-disciplinary work, or can more rigorous methodologies mitigate such distortions?*

The way biological knowledge is framed during the design process significantly impacts its translation. Analogies, while useful, can become cognitive constraints that shape how biomimetic insights are applied. Goel's framework of analogy levels[27] — ranging from surface-level similarities to deep structural analogies—raises an important question: *Are architects operating at the level of functional and process-based analogy, or do they remain confined to superficial parallels?* Furthermore, *is there a risk that these analogies simplify biological complexity to the extent that they no longer retain their original scientific validity?*

The hybridization of biology and architecture is often presented as an interdisciplinary ideal, but it remains fraught with asymmetries[28]. The methodologies and epistemologies of these two fields are fundamentally distinct—biology operates through empirical, evolutionary, and ecological paradigms, whereas architecture is driven by formal, aesthetic, and functional considerations. *Can these epistemologies truly be reconciled, or does biomimetic design inevitably reduce biological knowledge to a metaphorical resource for architectural innovation?* Moreover, *should the concept of the "hybrid brain" be critically reassessed to acknowledge the cognitive and disciplinary limitations that prevent seamless knowledge transfer?*

> « Every creative process is an intricate intertwining of complex thinking, perception and discovery processes which are significantly determined by a person's cultural and aesthetic knowledge (identity). Thus, a substantial examination of fundamental methods of thought and action, of design, perception, and interpretation is the basis of our curriculum[29, p.151] »

Professor Stephen Craig's observation offers a vital lens for understanding biases embedded in design processes. The creative process is not an objective endeavor but one shaped by a designer's unique epistemological landscape. Every designer carries an individual curriculum—an epistemic framework formed by educational background, cultural context, socioeconomic experiences, disciplinary training, and cognitive biases. In the biomimetic context, this curriculum functions as a subtle yet powerful filter determining how biological information is perceived, interpreted, and translated into architectural solutions.

This individual curriculum influences which biological phenomena capture attention and how these phenomena are understood; it is not a limitation but a rich, complex lens through which biomimetic innovation emerges. By understanding and deliberately navigating these intricate personal filters, designers can transform potential bias into a source of creative potential. As Henri Bergson aptly stated, "*The eye sees only what the mind is prepared to comprehend*[30, 31]."

Given these systematic distortions, epistemological challenges and personal cognitive biases, the need for a rigorous methodological framework becomes evident. The next chapter will demonstrate how these problems manifest in specific case studies, offering a structured analysis of bias in biomimetic design. By employing cognitive mapping and comparative case study analysis, this investigation will attempt to disentangle the layers of distortion that shape biomimetic practice today. Ultimately, the objective is not merely to critique but to propose new methodological avenues that ensure a more precise and epistemologically grounded integration of biological knowledge into architectural design.

2. Methodology

2.1 Critical analysis framework

The critical analysis framework developed for this research establishes a comprehensive methodology for examining the complex translation processes occurring in biomimetic architecture. Moving beyond simplistic evaluations of biomimicry, this hybrid framework specifically interrogates the multifaceted biases that influence how biological models are selected, interpreted, and implemented in architectural design.

Central to our approach is the recognition that biomimetic translation is fundamentally shaped by cognitive and individual curriculum biases. Architects' educational backgrounds, professional experiences, and design philosophies significantly influence which biological phenomena capture their attention and how they interpret these models. This framework systematically examines how these individual filters create preferential selection patterns and interpretation tendencies that may limit exploration of optimal biological solutions.

The analysis framework incorporates *architecturology* theory[32, 33] as a foundational analytical structure, utilizing its twenty distinct scales to dissect biomimetic translation across multiple dimensions[34]. Through this lens, we can examine how biological principles are variously interpreted through technical scales (emphasizing construction know-how), functional scales (focusing on usage adaptation), formal symbolic scales (prioritizing representational aspects), or economic scales (highlighting cost considerations). This multi-scalar analysis reveals how different aspects of biological models are emphasized or diminished based on which architectural scales dominate the design process[16].

The framework deliberately expands beyond individual cognitive biases to examine broader socioeconomic, cultural, and climatic influences. Socioeconomic factors often determine which biomimetic approaches receive funding and institutional support, potentially privileging visually striking solutions over subtler but effective ones. Cultural biases shape which biological narratives resonate with specific audiences and contexts. Climate considerations influence not only which biological adaptations seem relevant but also how thoroughly their environmental performance is evaluated.

For evaluating translation success, the author establishes rigorous comparative parameters that extend beyond the architect's own framing. Working collaboratively with biologists[35], we identify alternative biological models that might address the same design challenges, potentially more effectively than those selected by designers. This cross-disciplinary analysis asks critical questions: Why were certain biological models chosen over others? What functionality was lost in translation? Were more optimal biological solutions overlooked due to their visual subtlety or complexity?

Through this comprehensive framework, we can identify previously unexamined biases in biomimetic architecture, including confirmation bias (selecting biological models that confirm preexisting design preferences), disciplinary myopia (inability to recognize valuable biological principles outside one's expertise), technological determinism (allowing available construction methods to dictate biological model selection), and market-driven bias (prioritizing biomimetic narratives with commercial appeal).

By applying this framework to our selected case studies, we demonstrate how these various biases manifest in realized projects and identify opportunities for more rigorous, cross-disciplinary approaches to biomimetic translation. This critical analysis moves beyond celebratory accounts of biomimicry to develop a more nuanced understanding of how biological knowledge is filtered, transformed, and sometimes distorted through architectural interpretation and implementation.

2.2 Case studies - Comparative Analysis of Biomimetic Translation through Full-Scale Architectural Projects

The author investigates two full-scale architectural projects—the Esplanade Theater in Singapore and Waterloo Station in London—which have been selected from the broader set of 19 biomimetic design cases developed under the project *BiomimArchD* (*Construction d'une base de connaissances pour l'architecture biomimétique*) research initiative[36]. These two examples are intentionally chosen for their status as completed architectural implementations, in contrast to more experimental projects such as Neri Oxman's Silk Pavilion[37] or the ICD/ITKE research pavilions[38]. While the latter are situated within laboratory conditions and benefit from interdisciplinary collaboration and fewer real-world constraints, the Esplanade and Waterloo Station exist within fully built environments. As such, they offer a more appropriate basis for investigating the translation of biomimetic principles into architecture under the pressures of functional, cultural, economic, and climatic realities—and critically, for identifying biases and gaps that occur throughout this translation process.

To uncover the underlying dynamics of these biomimetic translations, a comparative case study approach is applied. This approach is enriched through a multi-method framework that includes cognitive and psychological analysis—such as think-aloud protocols and interviews with the architects—as well as discourse and textual analysis of design narratives and project documentation. By examining the process from the designers' initial inspirations to final execution, the analysis seeks to identify key decision points where biological complexity is abstracted, simplified, or selectively interpreted. The use of Architecturology's twenty-scale framework further enhances this analysis. It enables a multi-scalar evaluation of how different layers of influence—symbolic, functional, technical, economic—shape and, at times, distort the transfer of biological strategies into architectural solutions. This theoretical lens allows the study to trace where biases emerge in abstraction and translation, and where gaps persist between biological functionality and architectural performance.

Case I: Esplanade Theater, Singapore (41) (Fig.4)

The first case centers on the Esplanade Theater in Singapore, a project situated in a dense tropical urban environment where solar heat gain presents a critical design challenge. The initial architectural concept envisioned a fully glazed façade to capitalize on panoramic city views. However, such a solution would have been unsustainable in Singapore's equatorial climate, resulting in significant overheating and increased energy demands. The design process took a pivotal turn when the architect, while walking through a local market, encountered the durian fruit—known regionally as the "king of fruits." Initially drawn to the durian for its strong cultural resonance, the architect began to explore its spiky outer skin as a biological metaphor for solar protection. This sociocultural cue served as the entry point for the biomimetic strategy.

The final design integrates a double-skin envelope, mimicking the durian's spiked husk. This façade allows solar heat to be modulated while maintaining exterior views, thereby fulfilling both aesthetic and environmental objectives. However, when analyzed through architecturology's multi-scalar lens, several biases become evident. At the symbolic scale, the choice of the durian reveals a representational bias, where cultural familiarity shaped the biological model selection more than functional performance. At the formal scale, the abstraction of the durian's skin prioritized visual analogy over a deeper exploration of its thermoregulatory mechanics. As a result, the biomimetic translation in this case leans heavily on aesthetic and symbolic fidelity, while making compromises in biological functionality.

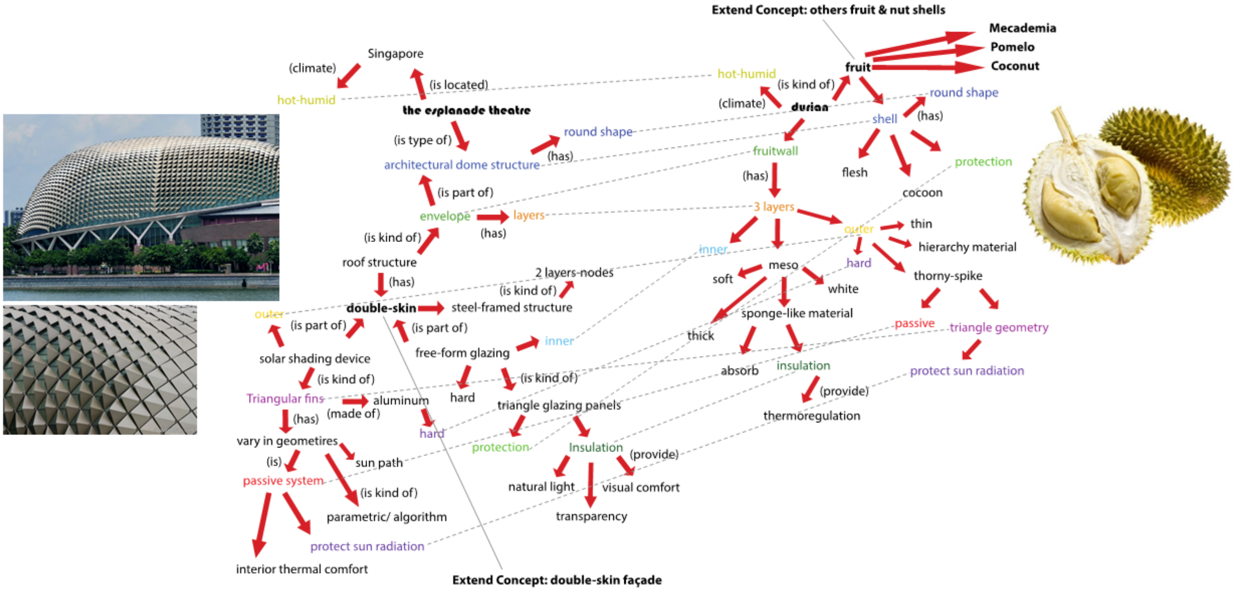

Figure 4. The concept map examines Singapore's Esplanade Theatre, with its durian-inspired architectural design branching into "artificial fruit shells" and "double skin façade" features. Red arrows connect structural elements, environmental considerations, and visual characteristics throughout the diagram.

Case II: Waterloo Station, London (42) (Fig.5)

The second case examines the Waterloo Station terminal extension in London, developed in response to the need for architectural adaptability to dynamic air pressure changes caused by high-speed trains entering and exiting the station. The structure—composed largely of glass and steel—required a design that could maintain its integrity under fluctuating pressure conditions. The architect, inspired while watching a nature documentary, observed the overlapping scale structures of fish and pangolins, which allow for flexible, adaptive movement. This observation became the basis for a biomimetic concept focused on mechanical flexibility.

The final architectural solution employed a glass roof system with overlapping panel joints inspired by biological scales. This enabled the façade to flex subtly under varying air pressure, thus ensuring performance and durability. Here, the biomimetic strategy was not merely symbolic but deeply functional. Through the lens of architecturology, we can identify the technical scale as dominant, where construction feasibility and mechanical logic drove the abstraction of biological principles. At the functional scale, the translation maintains fidelity to the biological system's core behavior—flexibility in response to force. The economic scale also played a role, as the design had to remain cost-effective while incorporating dynamic systems. Unlike the Esplanade Theater, the Waterloo Station project demonstrates a bias toward pragmatic implementation and structural functionality, rather than symbolic interpretation.

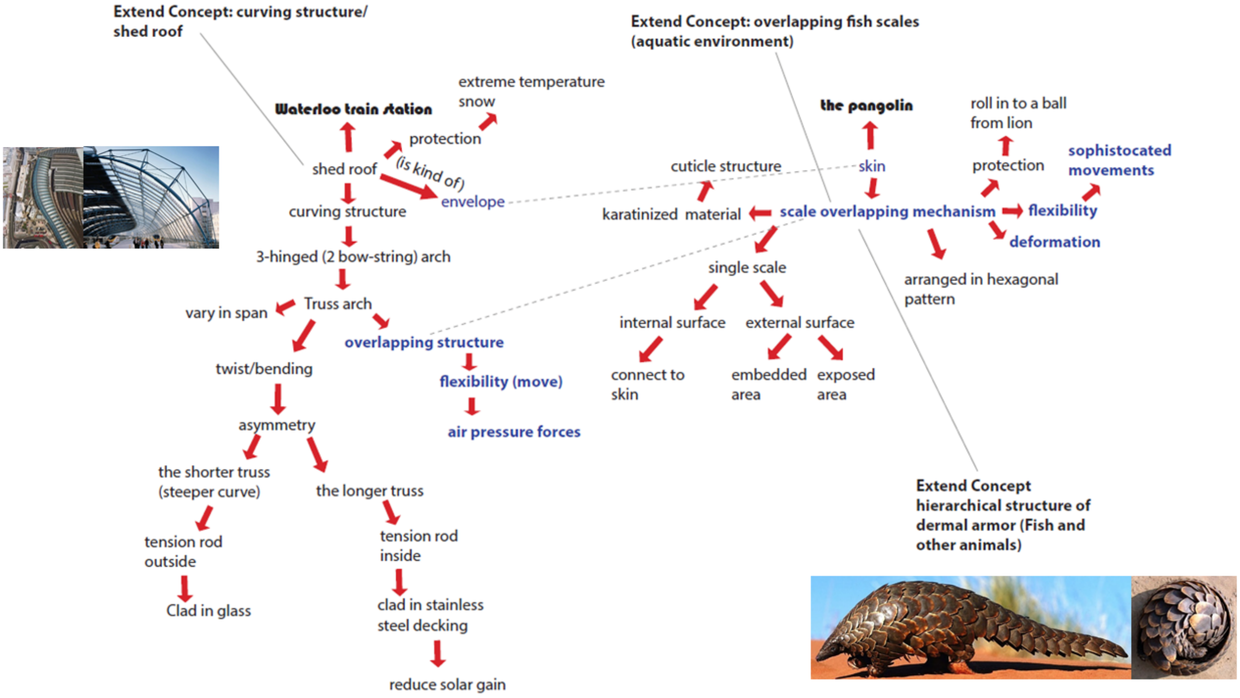

Figure 5. The concept map analyzes London's Waterloo Station roof design, showing biomimetic influences from pangolin and fish scales. The diagram connects structural elements (curved trusses, overlapping glass panels) with biological principles (protection, flexibility, load distribution). Red arrows illustrate relationships between natural scale mechanisms and architectural implementations, demonstrating how animal armor patterns inspired the station's distinctive overlapping glass structure.

2.3 Cross-disciplinary analytical approach

To deepen the understanding of translation biases in architectural biomimicry, the author and a collaborating biologist[35] conducted a cross-disciplinary analytical study. This research aimed to evaluate not only the biological validity of nature-inspired models but also the cognitive processes through which such models are abstracted and translated into architectural form. The methodology employed a combination of research tools—textual and discourse analysis of architectural documentation, semi-structured interviews with project architects, cognitive mapping techniques, and advanced keyword-based queries within the Web of Science database[39]. This integrative approach was designed to critically assess whether the biological models used in two prominent case studies—the Esplanade Theatre in Singapore and Waterloo Station in London—were valid, appropriately abstracted, and functionally transferred, or whether these projects reveal underlying biases introduced by disciplinary, cognitive, and cultural filters.

Case Study I: Esplanade Theatre, Singapore

Biological Model: Durian Fruit Skin (*Durio zibethinus*)

Architectural Function: Thermoregulating outer shell via triangulated louvers

Search Terms: (skin* OR cuticl* OR envelop* OR shel*) AND temperature AND (regulation OR thermoregul*) AND (geometr* OR shape) AND shad* AND climat*[40]

The Esplanade Theatre's double-skin façade was explicitly inspired by the spiked husk of the durian fruit—a symbol of national pride and culinary fame in Southeast Asia. In interviews, the architect recounted a market encounter with the fruit, drawn to its distinctive geometry and cultural symbolism. However, Web of Science searches revealed a lack of biological research supporting the thermoregulatory efficiency of durian skin prior to the project's completion in 2002. The only relevant article emerged in 2014, well after the building's realization. Broader searches pointed to thermoregulation in lizard skins, snail shells, and human tissues—but not durian. This suggests that the biomimetic link was culturally motivated and visually abstracted, rather than scientifically substantiated at the design stage.

Case Study II: Waterloo Station, London

Biological Model: Pangolin or Fish Scales

Architectural Function: Flexible, overlapping roof structure responding to air pressure

Search Terms: overlap* AND hierarch* AND flexib* AND interlock* AND interfac*[41]

Designed to manage pressure changes from high-speed train arrivals, the Waterloo Station roof utilized a system of overlapping steel and glass panels inspired by animal scales. While visually and mechanically effective, this analogy was not supported by biological research at the time of construction in 1993. Web of Science searches found relevant literature on pangolin scale mechanics published only in 2016. Thus, despite the functional merit of the overlapping design, the biological justification was derived from popular knowledge and observational analogy, not scientific reference. Compared to the Esplanade, however, the Waterloo design represents a closer alignment between biological metaphor and architectural performance.

Through this analytical framework, we extracted key biological terms from architects' design narratives—terms such as *skin, thermoregulation, geometrical spikes, flexibility, and overlapping scales*[42]. These terms were then validated against existing biological literature. Notably, both case studies demonstrated a striking disconnect between the design inspiration and the contemporaneous state of biological science. For instance, although the Esplanade Theatre is iconically associated with the durian fruit, no scientific literature prior to the building's conception supports claims about the fruit's thermoregulatory properties. Similarly, Waterloo Station's roof design, inspired by overlapping scales seen in fish or pangolins, lacked biological research underpinning its functional analogy at the time of construction. Relevant scientific publications on pangolin scale mechanics emerged only decades later.

This evidences a prevalent pattern of *post hoc* rationalization—or what might be termed *retrospective biomimicry*—in which visual or cultural associations precede biological validation. Such a process highlights a form of cognitive bias within the abstraction phase, where designers rely on personal or culturally conditioned visual metaphors rather than scientifically grounded analogs. For example, architects are often drawn to organisms that are visually dramatic, culturally significant, or emotionally evocative, regardless of their functional suitability as biological models. The durian's spiky skin and iconic status as the "king of fruits" in Singapore clearly illustrate this symbolic pull, while the visually rhythmic interlocking of fish scales aligns with a fascination for kinetic aesthetics.

Moreover, the transfer of these abstractions into built form reveals additional layers of translation bias. In the Esplanade Theatre, the durian-inspired envelope functions more symbolically than performatively; its triangulated louvers serve primarily as a cultural and visual metaphor rather than an optimized thermoregulatory system. In contrast, Waterloo Station's overlapping roof panels were functionally deployed to respond to fluctuating internal pressures caused by high-speed trains. Yet even in this more functionally aligned example, the biological inspiration stemmed from generalized visual analogies rather than deep biological knowledge.

These findings suggest that the effectiveness of biomimetic design—its *effect design*, or visible and functional impact—is largely shaped by early abstraction decisions. Such decisions are not neutral but are deeply influenced by disciplinary training, exposure to biological systems, and cognitive preferences for certain types of metaphors or organisms. The tendency to privilege iconic over functional analogies can constrain biomimicry's capacity to produce genuinely innovative or ecologically attuned solutions.

In this context, the biologist collaborator plays a critical role. Their expertise ensures that selected models are not only visually or culturally compelling but also biologically accurate and ecologically appropriate. Moreover, this collaboration enables the discovery of underexplored biological systems—such as termite mounds for climate regulation, or biofilms and mollusk shells for flexible yet resilient structures—which may offer more effective templates than those initially considered by architects.

3. Conclusion

The critical examination of biomimetic architectural design reveals substantial gaps in how biological models are interpreted, abstracted, and transferred into architectural manifestations. These gaps often stem from a loss in translation between the complexity of natural systems and the simplifications necessary for design implementation. Many architectural outcomes diverge significantly from the intended biological principles, highlighting a fundamental misalignment between source inspiration and applied design.

This disconnect is shaped by multiple interrelated factors. Disciplinary background plays a pivotal role in shaping how architects perceive and engage with biological models. Architects, engineers, and biologists approach nature with vastly different cognitive tools and expectations, leading to divergent interpretations of the same biological phenomenon. Cultural frameworks also influence this process—architects embedded in particular geographic or socio-political contexts may favor certain organisms or metaphors that resonate locally, sometimes at the expense of functionality or accuracy. Furthermore, socioeconomic positions—such as the intended function, audience, or status of a building—can skew the selection and implementation of biological references. These structural factors combine with cognitive biases, such as selective perception, over-simplification, and analogical misapplication, to distort the translation of biological models into architecture.

To ground this theoretical inquiry, the Esplanade Theatre in Singapore serves as a rich case study for understanding bias in biomimetic translation. The building is famously inspired by the durian fruit, an iconic Southeast Asian symbol. However, this design choice raises critical questions: Was the durian selected purely for its functional potential in shading and cooling, or was it chosen for its cultural recognizability and branding value? Alternative biological models—like cactus skins, pinecones, or termite mounds—might have offered equal or superior performance in passive climate control, yet were overlooked. This suggests a potential bias toward symbolic or aesthetic alignment over functional optimization.

Moreover, the abstraction and transfer of the durian's features into aluminum sunshades expose another layer of bias. While the durian's spikes serve protective purposes in nature, their architectural translation was intended to reduce solar gain—a shift in function that may reflect analogical overreach. Designers appear to have prioritized formal resemblance over deeper environmental functionality, illustrating how visual mimicry can eclipse performance-driven adaptation. The case also brings to light socio-cultural and contextual biases: the design is lauded in Singapore for its cultural resonance, but its success might not translate across different cultural landscapes. This raises broader questions about whether biomimicry in architecture risks becoming symbolic and context-dependent rather than universally performative.

These observations point to recurring patterns of bias in biomimetic design. Reductive simplification of complex biological systems often results in shallow interpretations. Confirmation bias steers design decisions toward pre-established aesthetic or functional goals. Morphological fixation privileges visible forms over dynamic processes, while disciplinary myopia prevents designers from appreciating cross-domain nuances. Together, these biases reinforce a fragmented and often inconsistent application of biomimicry in practice.

To counter these limitations, this research advocates for more transparent and methodologically sound translation processes. This requires investigating the epistemology of biomimetic architectural design—understanding where knowledge originates, how it is filtered, and how it is transformed across disciplines. A promising direction lies in developing a formal ontology engineering approach to structure and make explicit the interdisciplinary knowledge underpinning biomimetic design[43].

By representing biological and architectural knowledge through formal ontologies, the process of translation can shift from an intuitive "black box" to a traceable, justifiable pathway (Fig.6). Ontologies enable explicit mapping between concepts, functions, and relationships in both biology and architecture, supporting more rigorous alignment and reducing the likelihood of misinterpretation. Crucially, these structured knowledge systems do not remove the interpretive nature of design, but rather clarify it—making biases visible, contestable, and improvable.

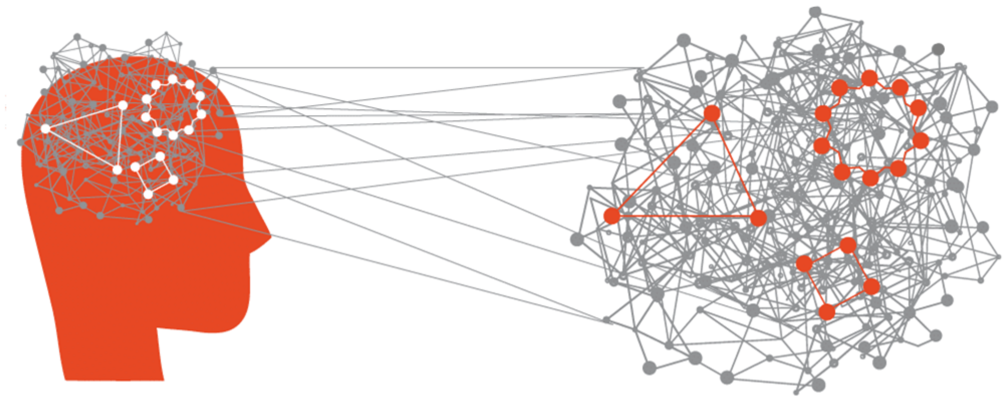

Figure 6. This image illustrates how ontologies function as cognitive frameworks—similar to neural networks in the human brain—connecting concepts (represented by nodes) through meaningful relationships (shown as connecting lines). The orange silhouette with interconnected nodes represents how humans mentally organize concepts, while the complex network structure on the right demonstrates how ontological frameworks similarly link knowledge across multiple domains.

In both the Esplanade Theatre (Fig.7) and Waterloo Station cases (Fig.8), ontologies serve as organizing tools that make explicit the relationships between architectural elements, cultural contexts, and biological inspirations, enabling systematic reasoning across disciplines and facilitating knowledge transfer between seemingly unrelated concepts.

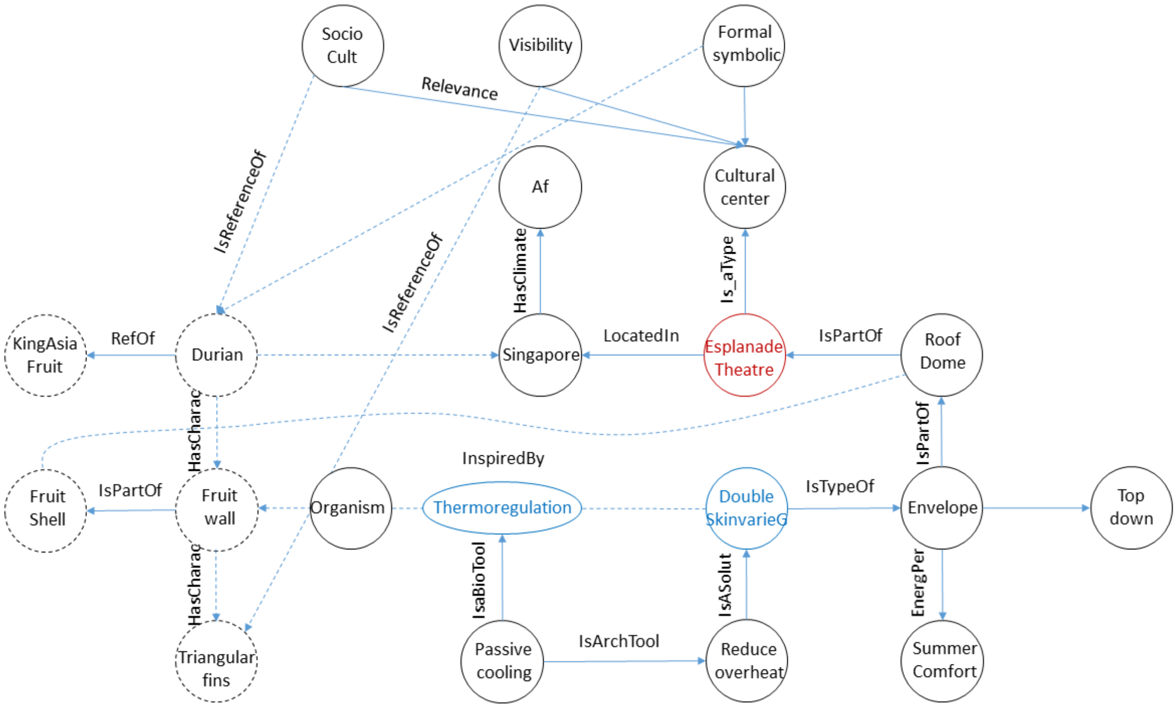

Figure 7. The first conceptual map illustrates the ontological relationships of Singapore's Esplanade Theatre, showing connections between its architectural elements, cultural significance, and design inspiration from the durian fruit. The diagram maps key features including thermoregulation systems, double-skinned envelope design, and formal symbolic elements that establish the building as a cultural center with distinctive triangular fins.

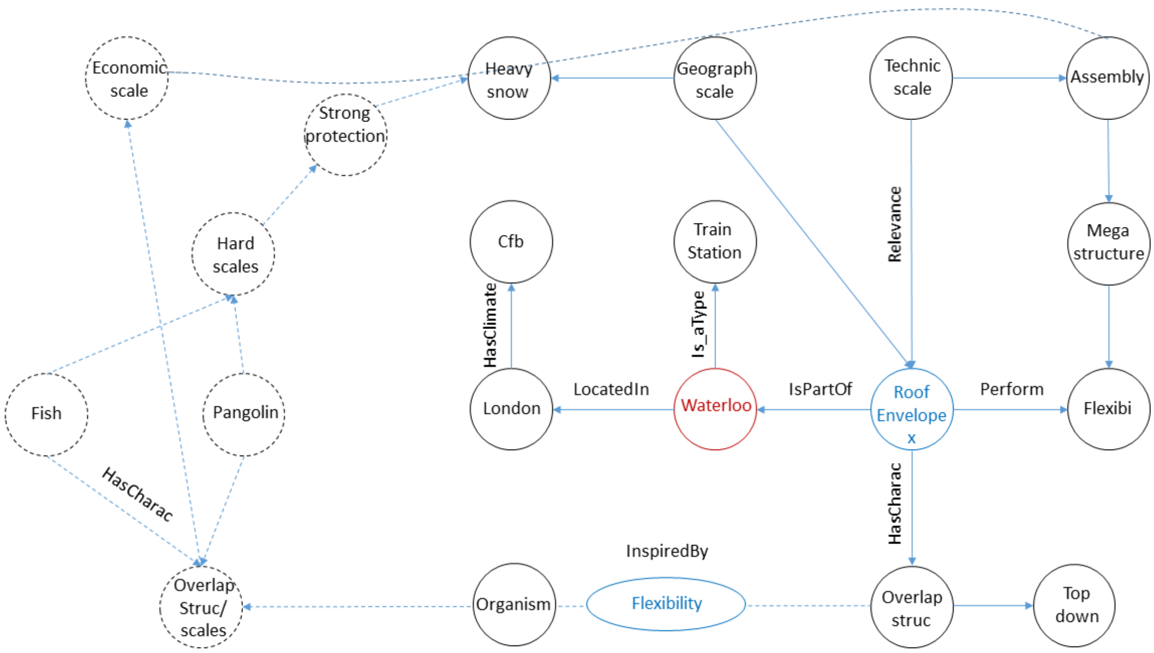

Figure 8. The second conceptual map depicts the ontological framework of London's Waterloo Station, illustrating relationships between its roof envelope design, transportation function, and biological inspirations like fish and pangolins. The diagram connects architectural elements to practical considerations such as protection from heavy snow, geographic and economic scale factors, while showing how flexibility and overlapping structures were inspired by natural organisms.

Ontologies serve as powerful mediators in biomimetic architectural design by making implicit knowledge explicit, connecting biological principles to architectural applications through formalized conceptual relationships. They help architects navigate complex interdisciplinary terrain by systematically linking disparate knowledge domains—including architecturology scales, climate considerations, location constraints, building typologies, construction requirements, and functional systems—creating pathways for knowledge transfer that might otherwise remain undiscovered. Yet, the challenge remains that *creative transfer*—moving from biological inspiration to design solution—is a fundamentally individual and creative act. No ontology can fully prescribe or automate this process. Instead, the proposed core ontology aims to serve as an assistive tool, guiding and informing designers without constraining their cognitive freedom. This approach acknowledges the importance of human subjectivity and creativity while offering a framework to support transparency and critical reflection in biomimetic practice.

In conclusion, the epistemological foundation of biomimetic design must be re-evaluated. Success in biomimetics lies not only in understanding nature but in understanding how humans understand nature. It is shaped by the cognitive structures, disciplinary lenses, and socio-cultural filters that influence how designers extract and apply biological knowledge. As such, biomimetic design should be seen not as a direct transfer from biology to architecture, but as a hybrid epistemological process. This process is inherently shaped by human cognition and should be supported by tools and frameworks—such as ontologies—that enhance interdisciplinary communication and critical design thinking. Future research should continue exploring the boundaries of this epistemology, aiming to create hybrid thinking models that combine creative intuition with scientific depth, ultimately transforming biomimicry from a symbolic gesture into a truly integrative and innovative design methodology.

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Figure 3. The illustration represents the non-linear design process in biomimetic research, ©Natasha Chayaamor-Heil, 2025.

Figure 4. The concept map examines Singapore's Esplanade Theatre, with its durian-inspired architectural design, ©Natasha Chayaamor-Heil, 2020.

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l'architecture biomimétique).

36. Le projet BiomimArchD (Construction d'une base de connaissances pour l'architecture biomimétique) est un projet innovant axé sur la construction d'une base de connaissances structurée pour soutenir les pratiques biomimétiques en architecture en établissant des ponts entre les approches disciplinaires de la biologie et de la conception architecturale. BiomimArchD a reçu le prestigieux prix du Défi Biomimétisme 2019, financé par la Mission pour les Initiatives Transverses et Interdisciplinaires (MITI) du CNRS, en reconnaissance de sa contribution à l'avancement du dialogue interdisciplinaire et des méthodologies de conception innovantes en architecture biomimétique, https://test-maacc.paris-lavillette.archi.fr/spip.php?article343
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41. *Ibid.*
42. *Ibid.*
43. Recherche en cours BiomimArchD : exploiter une ontologie centrale, une interface et une évaluation de test.