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A Study of Biomorphic Forms in Architecture

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Abstract: Nature has always Served as a great source of inspiration for architectural forms, offering a paradigm that moves away from the straight lines and geometric forms. The natural environment provides a vast repository of solution that an architect tries to solve in built environment. Biomorphic architecture can be defined as an approach to form which makes use of organic, curves lines and forms reminiscent to nature such as shells, intricate network of cells. This type of architecture is often characterized by a design process that is highly collaborative, environmentally sensitive and climate responsive. It is a design approach that places a strong emphasis on the environment and on the nature world. This research paper explores the biomorphic forms in architecture and how fundamental natural patterns and processes of growth, forms and function are influences the conception and the development of building forms.

Keywords: *Biomorphic Architecture, Natural Forms, Structural Analysis.*

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I. INTRODUCTION

Biomorphic architecture is fundamentally defined as a building design inspired by a natural form such as plants, animal and living organisms. In similar to conventional geometric buildings thar are heavily constrained by straight lines and angles, biomorphic architecture embraces fluid, organic curves [8]. This approach allows architect to move beyond to spatial planning and create dynamic, environment that seamless reflect to efficiency and aesthetic harmony of living organisms.

Biomorphic as a distinct architecture movement emerged in the 20th century, utilizing the natural pattern of living organisms, geometric shapes that dominated modernism.

The primary aim of this study to explore biomorphic forms in nature are developed in architecture and to understand, how these shapes natural forms can be translated into built forms with particular reference to relationship between natural inspiration, geometry and built form. Therefore, Biomorphic forms have to consider two aspects the natural ideas that a designer starts with, and the work that covers the idea building that stands, and can be built.

Table 1 Terms of Nature-Inspired Architecture

Term	What Is taken from nature	Main Concern
Organic architecture	Principles and a relationship with site	Harmony between building and setting
Biomorphic architecture	Visual and geometric form	Form, expression symbolism

II. LITERATURE STUDY

The study of biomorphic forms in architecture is supported by a rich body of literature that connects natural morphology, design theory, structural engineering and historical practice.

- *The Origins and Definition of Biomorphic:*

Biomorphic refers to the use of organic shapes and forms that resemble living organisms. The term is derived from the Greek word “bio” (life) and morphic (form). Biomorphic as an architectural and artistic concept, emerged in the early 20th century, inspired by an increasing interest in organic forms and patterns found in nature. The organic architecture of the 20th century was greatly influenced by the art movement and attempted to translate the natural forms into architectural structure.

- *Biomorphic vs Biomimicry:*

Biomimicry is an interdisciplinary field of science, that looks for sustainable solutions to design problem by being inspired by nature models, system and elements. Biomorphic architecture can enhance the functionality of building by applying natural systems.

Moreover, it can be economically efficient and provide human comfort by minimizing environmental impact.

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➢ *Natural Form as the Result of Forces:*

The concept of natural form with in the field of architectural theory and evolutionary biology does not refer to shapes which are merely created. Instead, natural forms are viewed as manifestations of the physical force exerted on them by the environment [9].

The morphological characteristics (e.g. branches of trees, cellular matrices of bones) of all biological entities represent a direct, physical solution to both the internal growth process and the external physical constraints such as gravity, tension and fluid dynamic. This perspective represents a significant change in paradigm for biomorphic architecture. Rather than simply mimicking the appearance of plants or animals, true organic design involves utilizing the same structural principles of nature to develop highly optimized and dynamic structures that are capable of responding to the structural and ecological demands of the environment in the same way that living organisms do.

➢ *Frei Otto and Form-Finding:*

The conceptual translation of biomorphic shapes into architectural forms, the German architect and structural engineer Frei Otto revolutionized the field. Instead of trying to impose some predetermined geometric shapes on a building, Otto attempted to find the most efficient architectural form by means of form finding [10]. According to Otto philosophy, form finding is a process of discovering of forms that are already determined by active physical laws and that develop in a similar wat to forms in nature

➢ *Levels of Natural Inspiration:*

There are three primary levels of inspiration [11]:

- Visual Inspiration: The most direct and literal form of natural translation where the physical appearance or a living organism to create a architectural forms. These forms are often chosen for their aesthetic qualities such as layered petals of flower [11].
- Conceptual Inspiration: the main focuses on the functional principles and structural logic in biological systems. It analysis how the natural organisms survive and adapt to their environment, resulting in a building that is natural in terms of its materials economy and climate response.
- Computational Inspiration: The advanced level of the biomorphic design [11]. Here, complex digital algorithms are used to stimulates natural growth and evolution. This level of design goes beyond visual and even conceptual inspiration and uses the actual mathematical rules of nature formations to auto optimize a building geometry to form highly complex.

III. NATURAL PATTERNS AND BIOMORPHIC FORM

Biomorphic architecture is based on the observation and the translation of natural forms in the design of a built environment. These natural forms provide much more than aesthetic models to architecture, they are in strong geometric structure for both space planning and structural design. Through the study they can utilize these foundational biological patterns to generate biomorphic forms that inherently possess the same structural efficiency, materials economy, and environmental adaptability.

➢ *Natural Principal Behind Forms:*

Nature's design relies on the economy of material, using the smallest possible amount of materials in order to create the lightest possible structure. The shape of nature is formed by forces of water and wind, allowing organisms to naturally resolve environmental stress in order to survive. To achieve structural integrity without bulk, nature uses continuous geometry such as curves, folds that distribute weight evenly across a surface [12].

➢ *Types of Biomorphic Forms:*

- Shell and Petal Form: These shapes are inspired by the protective casing of seashells and the overlapping of blooming flower. They are incredibly thin but surprisingly strong because of the way they curve.
- Branching Form: This tree like forms is inspired by tree, roots and leaf veins. The architecture uses the branching of the tree in order to create a large open space.
- Wave Form: Wave forms are inspired by the smooth, continuous movement of water wave and blowing winds. These elements flow easily and efficiently because they do not have sharp corners or flat edges. A fluid building features smooth, sloping surfaces that let wind and rain glide seamlessly right over it. It also allows structure to blend beautifully into surrounding environment, making the building look as though it grew organically out of the natural landscape.
- Cellular Form: Cellular forms are inspired by the structural unit of living organisms such as plants cells, hexagonal grids of beehive. These natural shapes are the most efficient way to pack things together. The design makes the building lightweight such as geodesic dome which make building incredibly strong and stable, even if the martials are very thin and light.

IV. BIOMORPHIC ARCHITECTURE IN PRACTICE

The theory of actual implementation of "Biomorphic Architecture in Practice", we explore how natural geometries can be physically constructed in the real world. Architect utilize structural engineering methods to address many issues presented in modern day construction including waste reduction of materials, energy consumption, and providing healthy environment within buildings.

- Structural Optimization and Digital Fabrication: Complex organic curves have been extremely expensive to construct using traditional methods of building with straight lines and flat wooden molds. Structures such as branching columns can be built with far less steel and concrete than would be required using traditional methods of construction, saving both money and resources [13].

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Table 2 Types of Biomorphic Form

Form	Natural reference	Typical character in architecture
Shell and Petal	Principles and a relationship with site	Harmony between building and setting
Cellular	Visual and geometric form	Form, expression symbolism
Branching	Tree, roots	Columns that fork
Wave	Water, wind	Doubled curved surface without sharp edges

- Sustainable and Local Materials: Modern architecture increasingly using the "materials intelligence" in combination with organic forms and sustainable, local materials.
- Climate-Responsive Building Envelopes: Modern Biomorphic buildings have "active" facades which are able to respond to the climate in different ways. Instead of sealing a building up with glass and using air conditioning to control temperature, buildings are designed with organic building which can respond to the local climate.

By integrating these organic geometries with active, climate-responsive facades and local sustainable materials, buildings can have a significantly lower environmental footprint.

V. CASE STUDIES

➢ *Lotus Temple, New Delhi:*

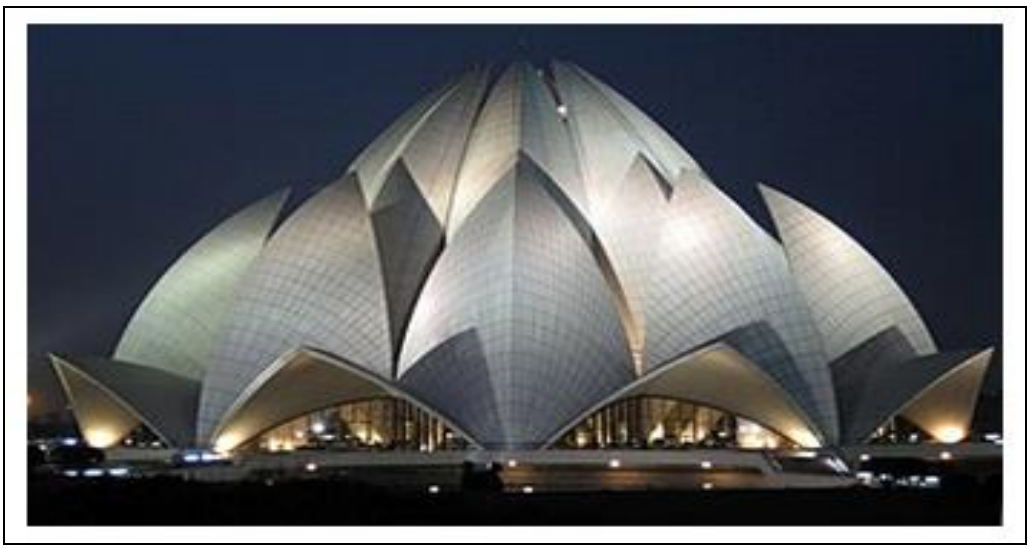

Fig 1 Lotus Temple
Source: https://en.wikipedia.org/wiki/Lotus_Temple

The Lotus temple is Baha I House of Workship for Indian subcontinent, located in Bahadur, South Delhi. Designed by Iranian architect Fariborz Sahba, the Lotus Temple is a half open lotus made up of 27 free standing, marble clad concrete petals arranged in three rings of nine petals each [1]. This is the clearest examples in the study of building whose whole form is a single recognizable natural object.

- *Project Details:*

✓ Architect: Fariburz Sahba
✓ Structural Designer: Flint and Nail partnership of London
✓ Designed In: 1976
✓ Built time: 1978-1986
✓ Constructed By: ECC Construction (Group of Larsen & Toubro Limited)
✓ Total site area: 24 Acres
✓ Climate: Tropical with great variations in temperature
✓ Structural System: Cast in place reinforced concrete shells, clad in marble

- Natural Inspiration and Concept: Before designing the temple, Sahba travelled throughout India to study its architecture and the many sacred symbols of the country's many religions [1]. The temple was to be different from the many temples already in existence. The symbol to be used in the temple was to be common to all of India's religions. The lotus, the sacred flower of India, was chosen as the symbol for the temple. The lotus stands for purity and cleanliness and is a symbol of great importance in Indian religious tradition. It is a symbol that is common to many religions in India.

The Lotus Temple also perfectly embodies the faith of the building. Every Bahá'í House of Worship must be circular and have nine sides, a rule set by 'Abdu'l-Baha. Sahba lotus is built from 27 petals that rise in threes from nine arches set in a

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circle record that each component of the temple is repeated nine times [1].

- Development of Form: A lotus cannot be designed as drawn, but the architect concept had to be converted a series of geometrical shapes such as spheres, cylinders, toroid's and cones [1], which are then represented by equations for structural analysis and the generation of drawings for the design of the temple. The resulting shape of the temple is very complex and the detailed drawings for the temple were produced over a period of more than two and a half years by the designers. The surface of the entrance and the outer leaves is defined by a series of spheres with different radii and with their centers located within the temple. For the inner surfaces of the shells and for the outer surfaces of the shells, the centers of the spheres are located on the inner surfaces of the shells and on the outer surfaces of the shells respectively



Fig 2 Model of Lotus Temple
Source: https://www.researchgate.net/publication/342022540_Case_Study_on_Architecture_of_Lotus_Temple

- Organisation of Form: The temple has three groups of nine shells springing form podium, a double layered interior dome, nine arches, nine ponds and walkways [1]. In plan the three rings of petals sit one inside the other, and each rings have a different function, the outermost entrance leaves frame the nine doors, the outer leaves rise behind them, and the inner leaves rise highest and enclose the central hall.

The nine arches carry almost the whole structural load of interior. They are places at angular intervals of 40 degree around the central hall, and the three ribs spring form the crown of each arch to form the interior dome.

- Structure and Materials: The shell and arches are in clad in white marble panels shaped in Italy to the surface profile and the fixed with stainless steel bracket [1].

The shells where cast in place using white concrete. The temple structure formwork was designed in manner that the timber joist supports the panel. The Temple structure in which the reinforcement used in the white concrete shells as well as the binding wires was entirely galvanized so as to prevent the long-term effect of rusting of reinforcement on the white concrete.

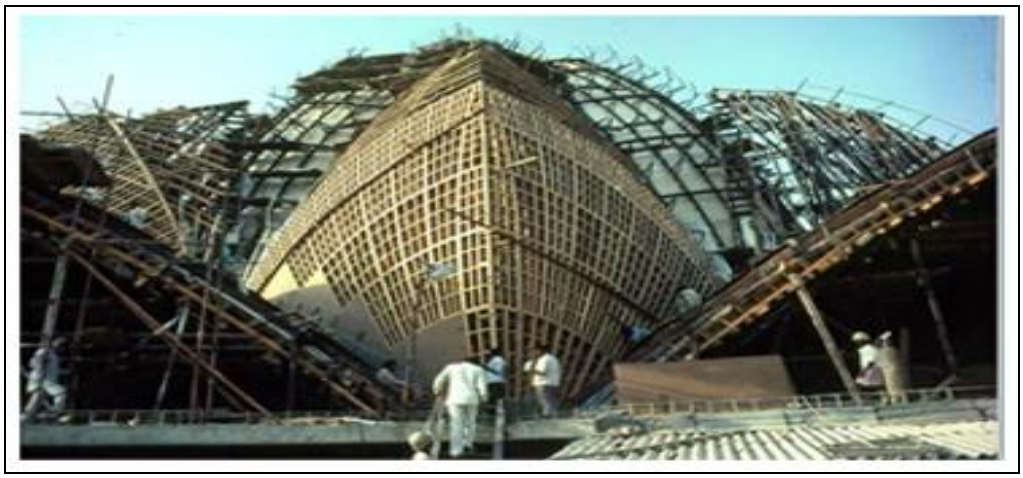

Fig 3 Formwork
Source: https://www.researchgate.net/publication/342022540_Case_Study_on_Architecture_of_Lotus_Temple

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➢ *Qatar Convention Centre*



Fig 4 Qatar Convention Center
Source: Qatar National Convention Centre by Arata Isozaki

The Qatar National Convention Centre is located within Education City in Doha, a campus of the Qatar Foundation. It is most famous for its 250 m front elevation that is supported along its length by a steel structure that is stylized as a Sidra tree [2]. It was designed by the Japanese architect Arata Isozaki. The building was opened on 4 December 2011.For this study its interest lies in the tree: two huge steel columns that create the illusion of two trees in front of a large glass facade, supporting a roof canopy that extends to shelter a public plaza [3].

- *Project Details:*

✓ Architect: Arata Isozaki
✓ Structural Designer: Yamasaki Architect
✓ Designed In: 2006-2009
✓ Built time: 2008-2010
✓ Constructed By: Werner Sobek
✓ Total site area: 40,000 m^2
✓ Structural System: Two steel “tree” with four main branches each

- Natural Inspiration and Concept: The Sidra is an evergreen tree found in Qatar. The Qatar Foundation uses the Sidra as its logo [4] adds that its shade was traditionally sought by scholars for their meetings, an association that suits a building in Education City. The start of Arata Isozaki’s concept for the Qatar National Museum was the Sidrat al-Muntaha, a holy tree in Islam believed to mark the end of the seventh heaven. It provides shade and shelter in a hot climate such as Qatar. Its two trunks divide into many branches which form a column and canopy structure for visitors to walk through.

- Development of Form: The development of the form for the Qatar Convention Center began with conceptual inspiration of the native Sidra tree. The form of the building was generated through abstracting the tree’s organic growth logic into the architecture. The resulting form is that of a monumental entrance, growing up out of the building to provide an expansive, welcoming shelter from the harsh desert sun. The surface is a freeform, curvilinear one and was a conceptually and technically complicated problem for the steelwork contractor.

- Structure and Materials: The organic shape of the Qatar Convention Center tree structure hides a large, hollow steel skeleton. Engineers used these steel tubes to create the complex "Y" shaped branches. Steel is an ideal material to use for this application because of its high tensile strength. It can withstand the pulling and bending stresses of the large branches without breaking. This allows the structure to support the immense weight of the roof.

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Fig 5 Interior (Steel Skeleton)
Source: Qatar National Convention Centre by Arata Isozaki

The two trees grow out of two concrete bases placed about a third of the way along the facade, and each has four main branches, about 7 m in diameter at the base and 4 m at the top. Both the branches and the deck use plate steel up to 60 mm thick [4].

- *Tarang Pavilion, Ahmedabad:*

The Tarang Pavilion, is designed as a flexible space to host exhibition, art, culture and interact with local community. The architects have designed the building as a flowing, corner less space in contrast to the rigid box-like buildings around it [14].

This project continuous series of undulating terracotta masonry vaults make up the roof, walls and space of the "TARANG" pavilion and gallery [15].



Fig 6 Tarang Pavilion
Source: https://www.archdaily.com/1002007/tarang-pavilion-the-grid-architects

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- *Project Details:*

✓ Architect: The Grid Architects, Snehal Suthar and Bhadri Suthar
✓ Structural Designer: Sankalan Hunnarshala
✓ Designed In: 2023
✓ Climate: Passive cooling through continuous cross-ventilation
✓ Total site area: 279 m^2
✓ Structural System: Terracotta brick tile intersecting arches and vaults

- Natural Inspiration and Concept: The architectural concept 'Tarang' is based upon the natural movement and rhythm of the sea. The word "Tarang" means "wave" in Hindi, representing the central idea behind the project. This continuous flow creates a dynamic but harmonious pattern. These qualities of water movement were used to create an organic form of architecture instead of copying a direct representation of a wave. The concept is based on the characteristics of fluidity, continuity, rhythm and transformation, which are expressed by the use of curved and undulating surfaces [5].

- Development of Form: The architectural form of Tarang has developed from the natural motion of waves and the interpretation of their continues, flowing geometry. These forms were then used by the architects to generate a number of undulating curved surfaces which give the impression of rising, falling and flowing in a natural manner throughout the site. The resulting geometry consists of multiple interconnected terracotta brick-tile vaults, which create an organic composition, defining interior exhibition and gathering spaces. Three strategically placed openings or skylights within the curved structure allow natural light into the pavilion, whilst also facilitating air movement within the structure.

Terracotta's use also establishes a strong connection between the building's organic form and the surrounding environment by way of its natural color, texture and traditional craftsmanship.



Fig 7 Form
Source: https://www.archdaily.com/1002007/tarang-pavilion-the-grid-architects

- Structure and Materials: Tarang structure is built as a single continuous undulating wave-like organic form using thin terracotta brick-tile masonry vaults. This structure is primarily compression based and can be built without using conventional beams, reinforced concrete frames or extensive shuttering [5]. Multiple layers of locally sourced terracotta tiles are bonded together using mortar to form a strong, lightweight masonry shell.

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VI. COMPARATIVE ANALYSIS

The four case studies are compared against a common set of parameters based on theoretical framework (see table 3).

Table 3 Comparative Analysis of the Case Studies

Parameter	**Lotus Temple**	**Qatar Convention Center**	**Tarang Pavilion**	**Beijing National Stadium**
Place & Date	New Delhi, India 1986	Doha, Qatar 2011	Ahmedabad, India, 2023	Beijing, China 2008
Designer	Fariborz Sahba	Arata Isozaki	The Grid Architects	Herzog & de Meuron
Natural Source	Half-open lotus flower	Sidra tree (native desert tree)	Fluid waves	Avian nest
Form Family	Petal and shell	Branching and tree-like	Wave/fluid	Skeletal / Cellular
Main geometry	Spheres, cylinders, toroids, cones	Splitting "Y" shapes and spreading branches	Intersecting double-curved vaults and domes	Primary grid of 24 trusses with randomized intersecting secondary bands
Main materials	Cast-in-place white concrete marble cladding	Hollow steel tube, GFRC panel cladding	terracotta tiles, natural stone	Interwoven steel framing ETFE/PTFE panels
Role of nature	Symbol and shape; small environmental role	Symbolic entry, passive shade, structural support	Passive cooling,	Porous ventilation, filtered light,

VII. FINDINGS

➢ *Inference from the Case Studies:*

Biomorphic form is meaningful on two levels it is a symbolic idea and a physical form that can be experienced. This research demonstrate that organic forms are developed through process of observation, conceptual interpretation and geometric transformation, not by copying form from nature. The principle of nature translated into various architectural forms into radial arrangements, branching systems, curves etc.

The study shows how organic form affect building design on multiple level like the outer appearance, the spatial experiences, the building core functions, and its relationship with surrounding environment.

➢ *Learning Outcomes:*

The core learning outcomes derived from this research includes:

- Understanding biomorphic form as a design idea and separating it from organic architecture.
- Identifying natural sources of inspiration and the way each become the starting point of a building form.
- Learning the organic shapes can improve the visual and spatial experience of a building.
- Understanding the role of materials and modern technology in creating complex organic forms.
- Exploring hoe complex natural shapes can be simplified, modified and translated into architectural geometry.
- Inspiration for the creation of unique architectural identities and visually expressive buildings is derived from nature.

VIII. CONCLUSION AND WAY FROWARD

Based on the findings of the study it was concluded that biomorphic forms in architecture emphasizes the relationship between nature and the built environment. The various natural elements, patterns, shapes, structure and the processes can serve as a basis for the design of architectural forms that are different from the usual geometric forms. The natural forms and the interconnected patterns that are found in nature can serve as a basic for the development of different architectural concepts, geometric and spatial structure.

The application of biomorphic forms can influence not only the visual appearance of a building but also its spatial organization, circulation, structural expression, lighting and the way it is experienced by its users. Thus, understanding the principles of nature and by translating them into architectural solutions, innovative, functional and meaningful spaces can be created.

➢ *Way Forward:*

In future, biomorphic architecture will be able to translate natural forms, patterns and processes into practical architecture solutions. In addition to creation visually expressive forms, the aim to develop forms that also functional, structurally efficient and user friendly.

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