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RESEARCH ARTICLE

Exploring Bionic Architecture Inspired by Nature

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Abstract

This paper explores the concept of bionic architecture, which draws inspiration from the natural world to innovate architectural design. It presents four distinct architectural proposals inspired by natural forms: an octopus-shaped building, a sea star-shaped airport, a cowrie shell-inspired sports stadium, and a rocket-shaped building. Each design integrates functional elements derived from natural efficiency and aesthetic appeal, showcasing how nature's forms can inform and enhance modern architecture. The octopus building exemplifies organic design principles with its multi-level spaces and panoramic views, blending functionality with aesthetic allure. Similarly, the sea star airport adapts radial symmetry and characteristics of the sea star to optimize space for structural arrangement and efficiency, reflecting nature's elegance in architectural functionality. The cowrie shell stadium showcases resilience and aesthetic beauty, mirroring the protective shell's form to create a versatile sports venue. Meanwhile, the rocket-shaped landmark building highlights aerodynamic efficiency and technological prowess, serving as both a functional structure and a cultural icon, although the rocket is a man-made object, not from the nature, it original purpose is for launch space crafts, not for architecture. Overall, these examples illustrate how bionic architecture bridges the gap between natural inspiration and human innovation, creating buildings that not only serve practical purposes but also inspire awe and appreciation for the natural world's design perfection.

Keywords: Bionic Architecture, Octopus Building, Starfish Airport, Cowrie Shell Sport Stadium, Rocket Building.

1. Introduction

Architectural design is a multifaceted discipline that blends artistic creativity with scientific principles to create spaces that are not only aesthetically pleasing but also functional, sustainable, and responsive to human needs. From ancient civilizations to modern skyscrapers, architecture has played a central role in shaping the built environment and influencing how we live, work, and interact with our surroundings. At its core, architectural design is an art form that encompasses the creative expression of ideas, concepts, and emotions through the built environment. Architects harness their imagination and vision to conceptualize and visualize spaces that inspire, uplift, and evoke a sense of wonder.

In modern society, architectural science and technology are highly developed, and modern buildings are ubiquitous. One of the important branches of architectural design is the bionic architecture, which studies the functionalities and the structures of natural objects to obtain inspirations for designing and constructing expressive buildings [1-2]. The Bionic architecture has a long history, can be traced back to 2707 -2150 BC in ancient Egypt [3].

Although humans are adept at designing and constructing various geometric shapes, nature is the ultimate architect. It has crafted all the geometric shapes of the universe, from the grandeur of spiral galaxies to the intricate double helix of DNA and complex three-dimensional protein structures. In the vastness of the universe, humans are just an insignificant speck. Countless geometric objects have naturally formed in our environment on Earth, many of which can serve as architectural templates.

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The Bird's Nest Stadium in Beijing is an outstanding example of bionic architectural design. Located in the heart of China's capital, this iconic edifice stands as a testament to human ingenuity while seamlessly blending with the organic forms found in nature. It fully embodies the fusion of modern architectural aesthetics and natural beauty. Another excellent example of bionic architectural design is the "City of Arts and Sciences" which takes the shape of a whale's skeleton, designed by Spanish architect Santiago Calatrava. Several other excellent examples of bionic architectural designs include:

The Lotus Temple, located in New Delhi, India: Inspired by the lotus flower, a significant element in Buddhism, this building has become a prominent city attraction. Qatar National Convention Center: The building's façade resembles the structure of the Sidra tree, symbolizing perseverance and nourishment in the harshest environments across the Arab world.

The Kunsthaus Graz, Austria: Often called the "Friendly Alien," its biomorphic shape and outer skin are inspired by living organisms. The Gherkin (30 St Mary Axe), London, UK: Its shape and exoskeleton structure are inspired by sea sponges and radiolarians.

Nature offers us countless stunningly beautiful objects. Despite the existence of several outstanding bionic buildings worldwide, the research and development of bionic architecture remain seriously insufficient. I believe that bionic architecture must adhere to at least three basic principles:

1. The building should possess the major morphological characteristics of the natural object, preserving its original aesthetics.
2. The building should fully satisfy all functional aspects required of the structure.
3. The building should be durable, strong, long lasting, and cost efficient.

This paper will explore the possible applications of the elegant profiles of natural objects in architectural structures following these three principles. It will present four examples of architectural designs that exemplify the beauty of natural objects and showcase the transformative power of bionic design principles. All drawings are created using the SketchUp 3D program.

2. Octopus Shaped Building

The octopus is one of our most beloved marine animals, and octopus shaped toys are some of the most common toys for children. Its mesmerizing appearance and remarkable intelligence stand as marvels of the natural world. The unique shape, beauty, and adaptive capabilities of the octopus make it one of the most fascinating creatures on Earth, capturing the imagination of scientists, artists, and enthusiasts alike.

The octopus, as shown in my sketch drawing of Figure 1, is bilaterally symmetrical along its dorso-ventral (back to belly) axis. The head and foot are located at one end of an elongated, bag-shaped body and function as the anterior (front) of the animal. The head includes the mouth, brain and big eyes, while the foot has evolved into a set of eight long, slender, and flexible arms that surround the mouth and are connected near their base by a webbed structure. Each arm is equipped with rows of suction cups that provide unparalleled dexterity and grip.

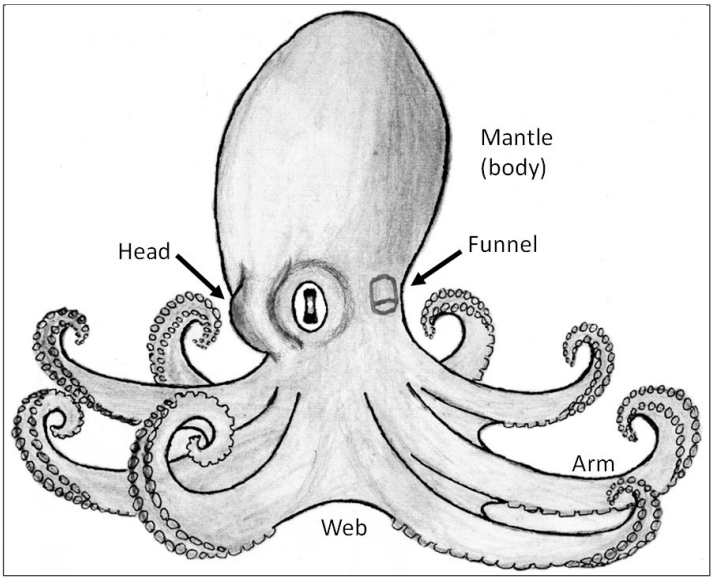

Figure 1. *The sketch drawing of the octopus* **source:** *Author*

The octopus possesses a shape that is both elegant and efficient, perfectly suited for its marine habitat. The symmetry of its form is striking, a testament to the evolutionary forces that have sculpted its design over millions of years. This streamlined shape allows the octopus to navigate through the water with grace and agility, propelling itself with jet-like bursts of water expelled from its mantle.

Beyond its functional design, the octopus possesses a beauty that transcends mere aesthetics. Its body is adorned with a mesmerizing array of colors and patterns, ranging from vibrant hues of red, orange, and blue to intricate patterns of spots, stripes, and iridescence. These markings serve not only as camouflage, allowing the octopus to blend seamlessly into its surroundings, but also as a form of communication and expression. During moments of excitement or aggression, its skin may undergo rapid color changes—a dazzling display known as cephalopod chromatophores—that mesmerizes observers and confounds predators alike.

I believe that the unique and beautiful shape of the octopus can be perfectly adopted into architectural design. Figure 2 shows the proposed architectural design inspired by the shape of the octopus.

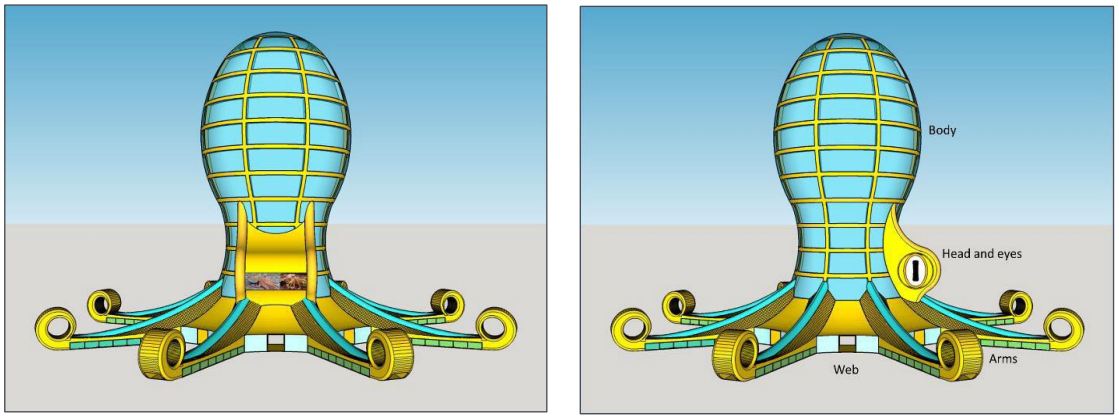

Figure 2. *Proposed building with shape of the octopus, left: front view, right: side view* **source:** *Author*

The morphology of each major portion of the proposed structure closely mirrors that of the octopus, the funnel part is omitted, can be added if desired. The main vertical body features multiple levels that can be used for offices, stores, guest rooms, or government administration. A restaurant or business club, as shown in Figure 3, can be located at the top of the main body, accessible by an elevator or stairs. This area has dome shaped roof which can be covered with glasses providing a 360° view. Here, people can enjoy food and drinks, dance, socialize, watch the sunrise and sunset, and stargaze, the dome roof can be made by other non-glass materials also depending on the preference.

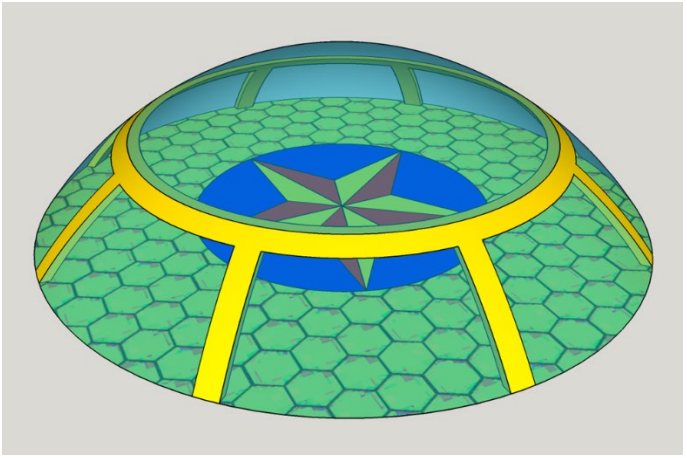

Figure 3. *A restaurant or business club on the top of the octopus building with a glass dome roof or other non-glass materials* **source:** *Author*

As depicted in Figure 4, the main building entrances are located at each web section. At the top of each arm structure, an emergency evacuation tunnel, indicated by the red arrow, extends from the main body of the building to the end of the arm. In the event of an emergency, people on higher levels (such as the fourth floor and above) can quickly evacuate through these eight emergency tunnels, rather than descending to the ground floor, which can be time-consuming and dangerous in crowded situations. In emergencies, every second counts, and these tunnels could mean the difference between life and death.

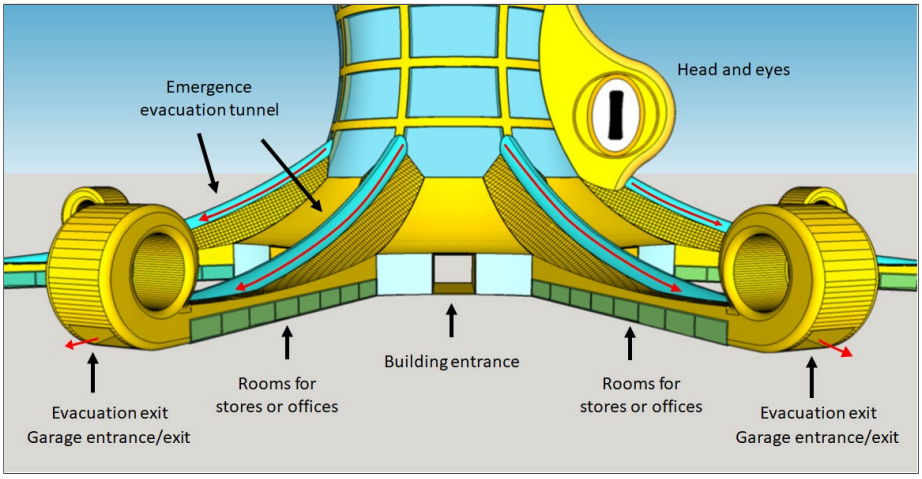

Figure 4. *Description of functions of various building structures* **source:** *Author*

If the building includes an underground parking garage, the exits at the ends of each arm structure can serve as entrances and exits for vehicles, as marked in Figure 4. Many rooms are located at the bottom of each arm structure, suitable for use as business stores or offices.

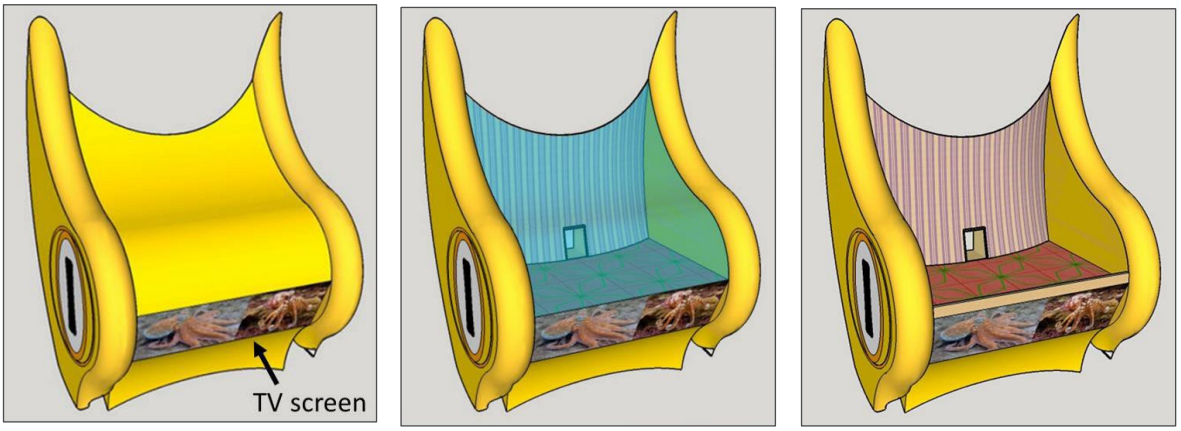

Figure 5. *Proposed structure of the octopus head with three different covers. Left: non-transparently covered; middle: transparently covered by glass; right: opened without cover* **source:** *Author*

Figure 5 shows the design of the head structure. The head structure can be divided into upper and lower rooms. The upper room can serve as a conference room, dance/music hall, business store, or restaurant. It can be covered with non-transparent materials, as shown in Figure 5 (left), or with transparent glass to allow natural light to illuminate the space (Figure 5 middle). Alternatively, it can be left open without any cover (Figure 5 right). A giant TV screen is placed on the exterior of the lower room, which can display advertisements, TV programs, events, and other information.

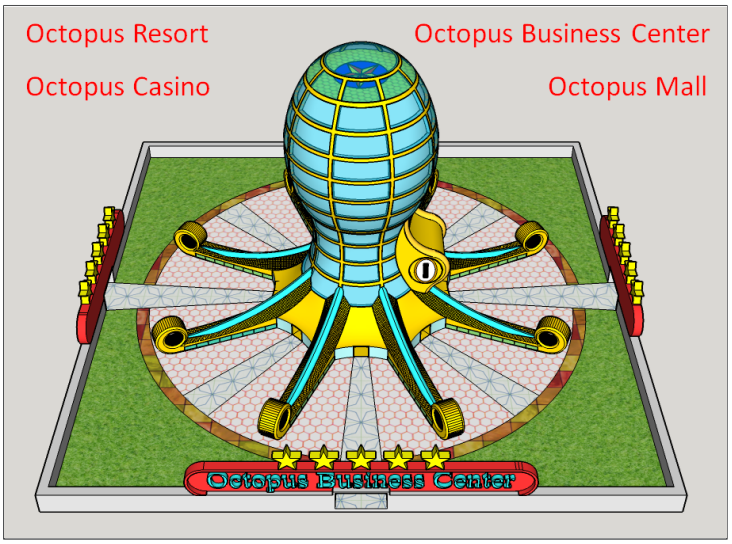

Figure 6. *Bird's eye-view of the Octopus Skyscraper with possible names* **source:** *Author*

Figure 6 presents a panoramic view of the proposed octopus shaped building along with potential building names, constructed on a real site. This building could be located near a beach, at a popular tourist site, or in a busy business district, becoming a famous landmark building and a "must-see" destination.

3. Star Fish Airport

Starfish, also known as sea stars, are some of the most fascinating and visually striking creatures found in the ocean. Their unique shape and captivating beauty have intrigued marine biologists and nature enthusiasts alike for centuries. With their radially symmetrical form and vibrant colors, starfish embody both the complexity and elegance of marine life.

One of the most distinctive features of a starfish is its shape. Typically, starfish have a central disc from which five arms, or rays, extend. This pentaradial symmetry is a defining characteristic, although some species can have more than five arms. The shape of a starfish is not just for aesthetic appeal, it plays a crucial role in its survival and functionality.

Approximately 2,000 species of starfish inhabit the seabed in all the world's oceans, from warm tropical zones to frigid polar regions. The shapes of these species vary dramatically. The arms of many kinds of starfish are covered with hundreds of tiny, hair-like tube feet, which they use for locomotion and feeding. Other species may lack apparent tube feet. These tube feet operate through a hydraulic system, allowing the starfish to move with slow, deliberate grace across the ocean floor. The arms can regenerate if they are lost, showcasing the resilience and adaptability of these creatures. This ability to regenerate is not only a fascinating biological process but also contributes to the starfish's enduring beauty.

In addition to their ecological importance, starfish have held symbolic and cultural significance in various human societies. They are often seen as symbols of renewal and regeneration due to their ability to regenerate lost arms. In many cultures, starfish represent divine love, intuition, and guidance. Their presence in art, literature, and mythology reflects humanity's long-standing fascination with these remarkable creatures.

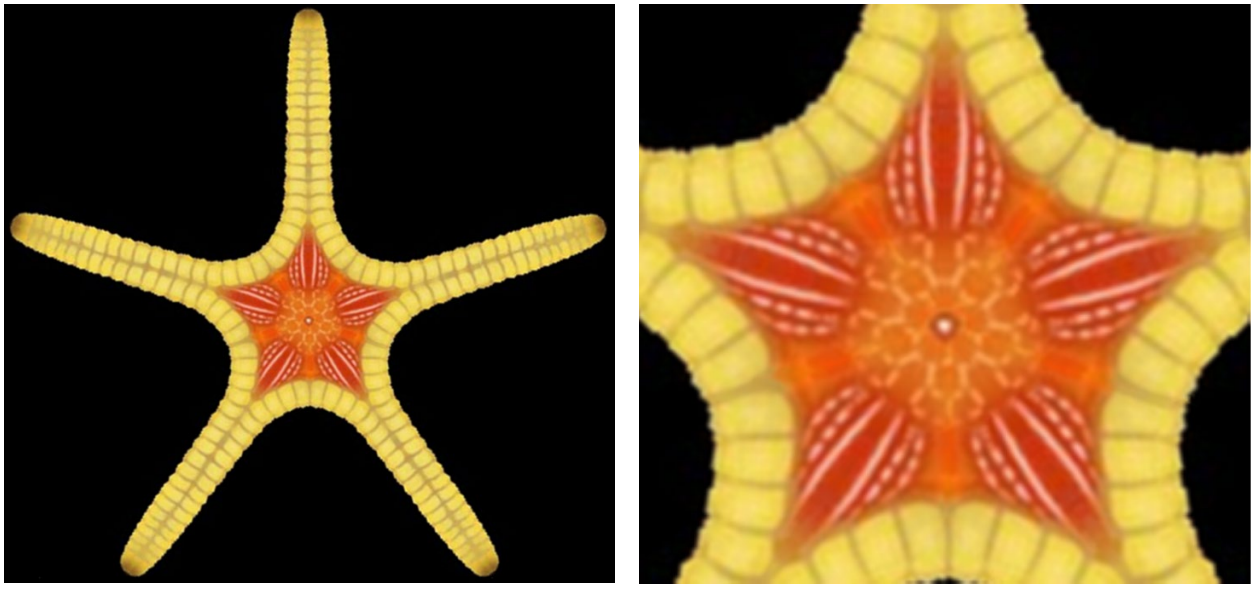

Figure 7. *Australia's Red & Yellow double sea star, scientific name is Iconaster longimanus, left is the top view of the starfish, the right is the zoom-in of the central red star area. Very unique and beautiful pattern* **source:** *Author*

Figure 7 shows the beautiful pictures of Australia's Red & Yellow double sea star, scientifically named Iconaster longimanus. It appears not to have visible hair-like tube feet, but its detailed texture pattern is truly eye-catching. No words can adequately describe its unique texture and beauty. It has fine, long, and slender arms symmetrically extending from the central disc. Bright yellow small "rectangle" cells are symmetrically distributed along the outer profile, and the central disc section has a bright red five-star pattern with a unique, beautiful texture. This texture includes five bulged water-drop-like features with white stripes and dots symmetrically spread on both sides of the central line. Additionally, the central area has a hexagon-shaped pattern made by white dots symmetrically distributed around the center. Such an amazingly beautiful and colorful texture pattern is a super work of art, created by nature, the truly omnipotent craftsman, far beyond what we humans can compare to.

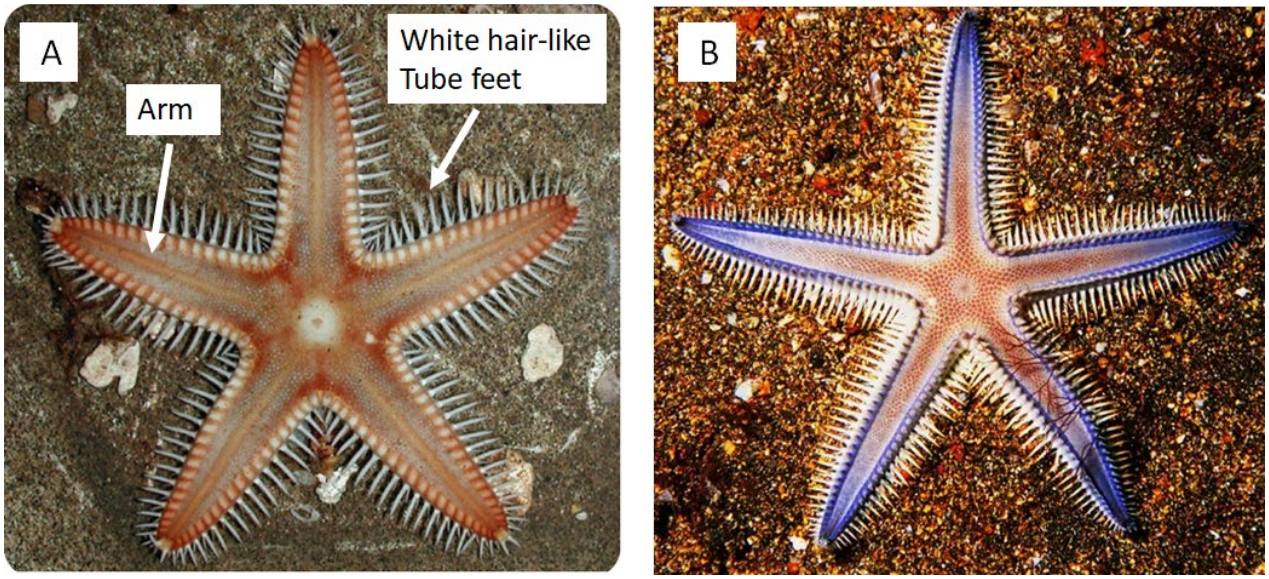

Figure 8. *Two Starfishes (downloaded from internet) with slender long arms and tube feet neatly distributed along the two sides of the arms. Credit to the anonymous persons who made these amazing images available from internet. The two images are duplicated from internet and credited to the original anonymous copyright owners* **source:** *Internet*

Figure 8 shows two kinds of starfish with five long, slender arms featuring white, hair-like tube feet neatly distributed on both sides of the arms.

The shapes of the beautiful starfish perfectly match the characteristics of airport buildings. Typically, airport buildings are not very tall, with about one to three levels; terminal buildings are usually long and thin, with numerous boarding gates where airplanes regularly park on both sides; the space between the terminal building are large to allow airplanes taxiing in and out. Figure 9 shows the proposed airport building design, completely adapted from the shapes of the starfish depicted in Figures 7 and 8.

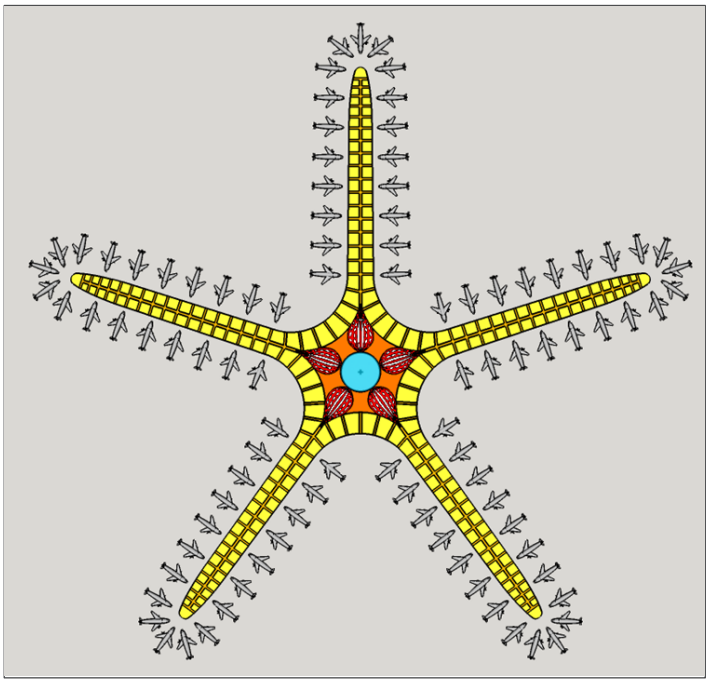

Figure 9. *The proposed starfish shaped airport building with airplanes parked at each side of long arm terminals. The airplanes are equivalent to the tube feet* **source:** *Author*

This proposed airport structure has five terminals extending from a central disc, with many boarding gates equivalent to the yellow cells of the Red & Yellow double starfish. Airplanes are parked on each side of the arm-shaped terminals, analogous to the hair-like tube feet of the starfish shown in Figure 8. The central section features decorative textures adapted from the Red & Yellow starfish, including five bulged water-drop structures and a central glass dome, which allows natural light to enter the building and save electricity. However, the central red star-shaped texture can be designed with various patterns and colors depending on preferences. Figure 10 shows three examples of the different patterns.

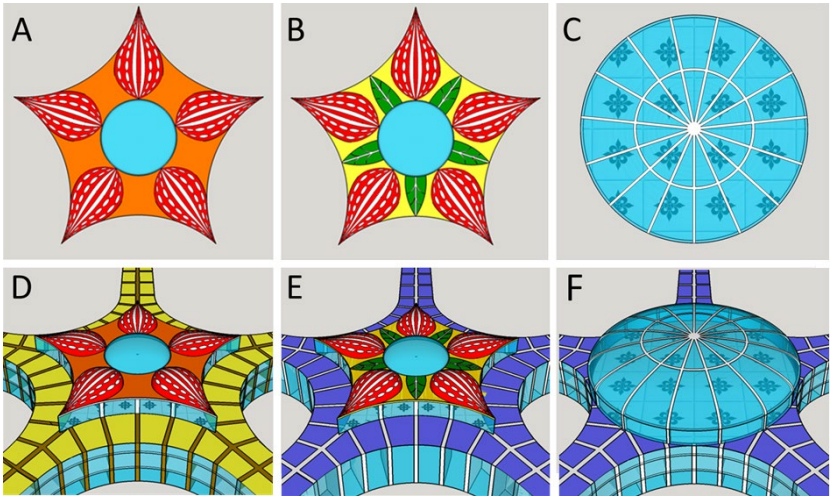

Figure 10. *Three central decoration patterns of the proposed starfish-like airport building* **source:** *Author*

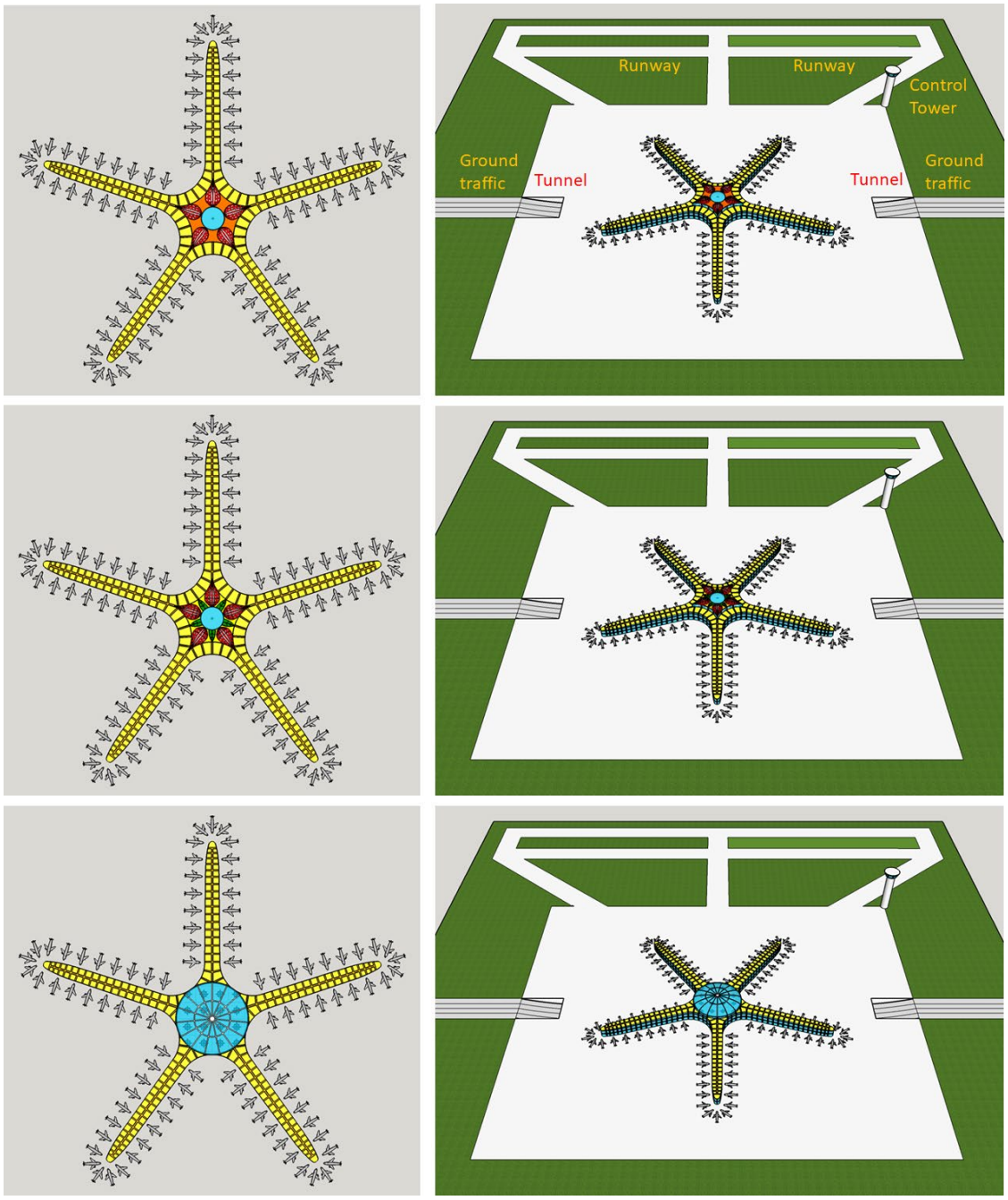

Figure 11. *Starfish airport building with non-solar roof and three different central structures, left: top view; right: bird's eye view of the whole airport* **source:** *Author*

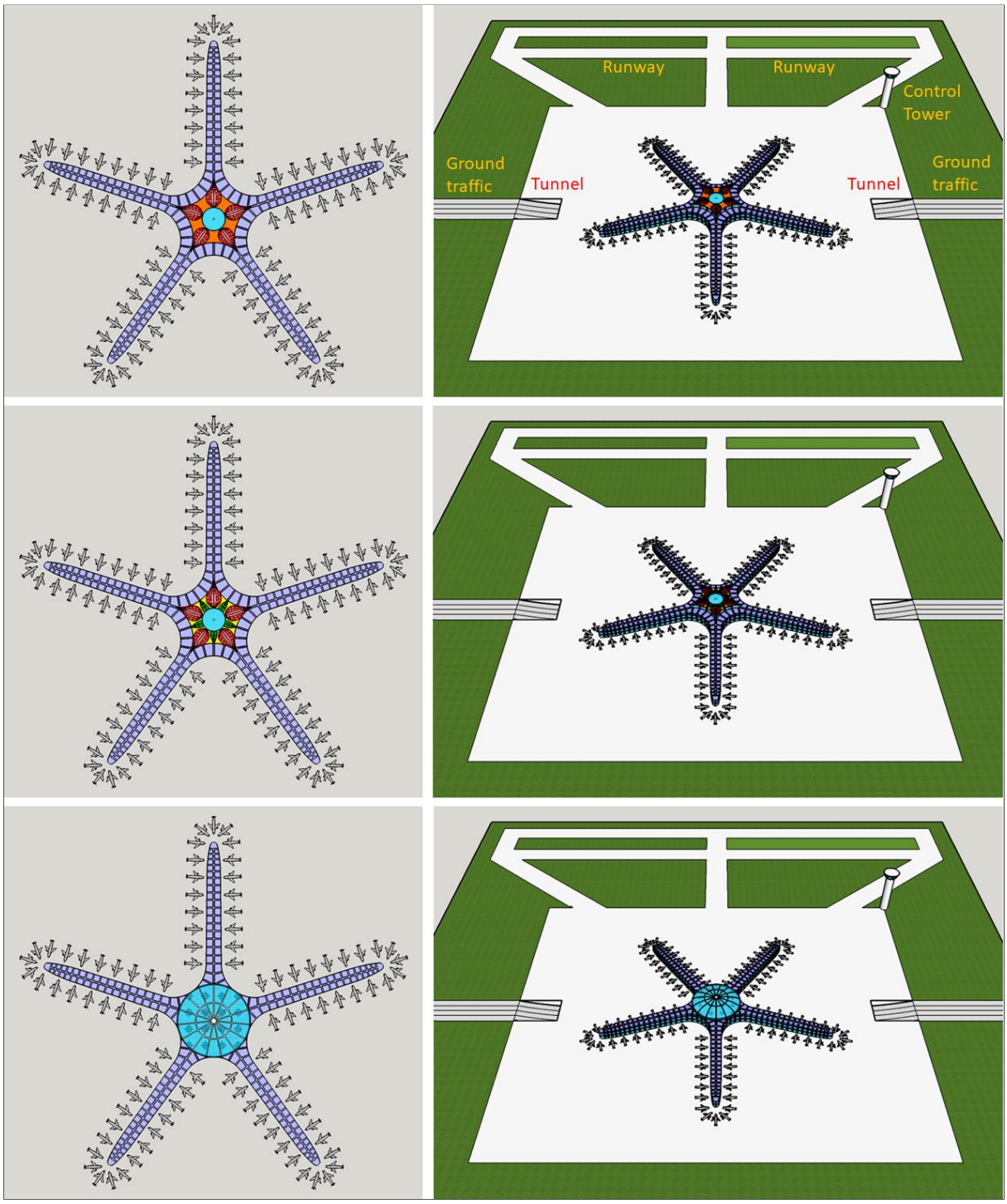

Figure 12. *Starfish airport building with solar roof and three different central structures, left: top view; right: bird's eye view of the whole airport* **source:** *Author*

Figure 10A: Simplified central texture patterns with five bulged water-drop shapes in bright red, featuring white stripes and dots symmetrically arranged on both sides of the central lines. A glass dome is located at the center to allow natural light into the building, saving electricity.

Figure 10B: The central star texture of Figure 10A is enhanced with green leaves, creating the appearance of a fully opened blooming flower. Each red water-drop-like bulge with a green leaf on each side forms a flower bud ready to bloom, adding additional aesthetic appeal, the blue roof represents the solar panels installed on the top of the building.

Figure 10C: A glass dome covers the entire central disc area, providing a different visual and functional approach.

Figures 10D to 10F provide perspective views of the central sections on the tops of the airport building, showcasing different decorative texture patterns as shown in Figures 10A to 10C. These figures illustrate a single level of the central structure, which can be

used for offices, commercial stores, restaurants, and professional lounges. This area offers a 360° view of the entire airport. The design can also accommodate multiple levels based on actual requirements. Figure 10D features a non-solar panel roof, while Figures 10E and 10F showcase blue solar panel roofs that will provide sufficient electricity for the airport building during the daytime.

Figure 11 and Figure 12 show the visual renderings of the proposed starfish airport buildings with different central star sections and different roofs. Left sides are the top views of the airport buildings and the right sides are the visual renderings of the airport buildings constructed at the lands. Ground traffic vehicles can reach the airport through the tunnels to arrive at the center of the buildings; the subways can also reach the airport through the underground tunnels.

4. Cowrie Stadium

The cowrie shell boasts a shape that is both aesthetically pleasing and functionally resilient as shown in Figure 13. Its smooth, glossy surface is typically ovate or half-egg-shaped, with a ventral opening resembling a slit or aperture. This distinctive form evolved over millions of years of natural selection, providing protection and camouflage for the marine gastropod that once inhabited it. The shell's symmetrical curvature and tactile smoothness invite touch and exploration, making it a favorite among collectors and artisans alike.

Figure 13. *Cowrie shell, left: side view; right: bottom view* **source:** *Author*

Beyond its functional form, the cowrie shell is renowned for its intrinsic beauty. Adorned with intricate patterns and markings, ranging from simple spots and stripes to elaborate designs reminiscent of tribal art, these patterns often reflect the unique characteristics of the species and habitat from which the shell originates. Each specimen carries a sense of individuality and cultural significance. Moreover, the shell's lustrous sheen and subtle variations in color from creamy whites to rich browns and deep blacks further enhance its visual appeal and allure.

Throughout history, the cowrie shell has held profound cultural significance for societies worldwide. Ancient civilizations in Africa, Asia, and the Pacific Islands prized cowrie shells as symbols of wealth, fertility, and protection. Used as currency, adornments, and ritual objects in ceremonies ranging from birth and marriage to death and divination, cowrie shells continue to play a prominent role in traditional ceremonies and spiritual practices today, serving as talismans of prosperity and spiritual connection.

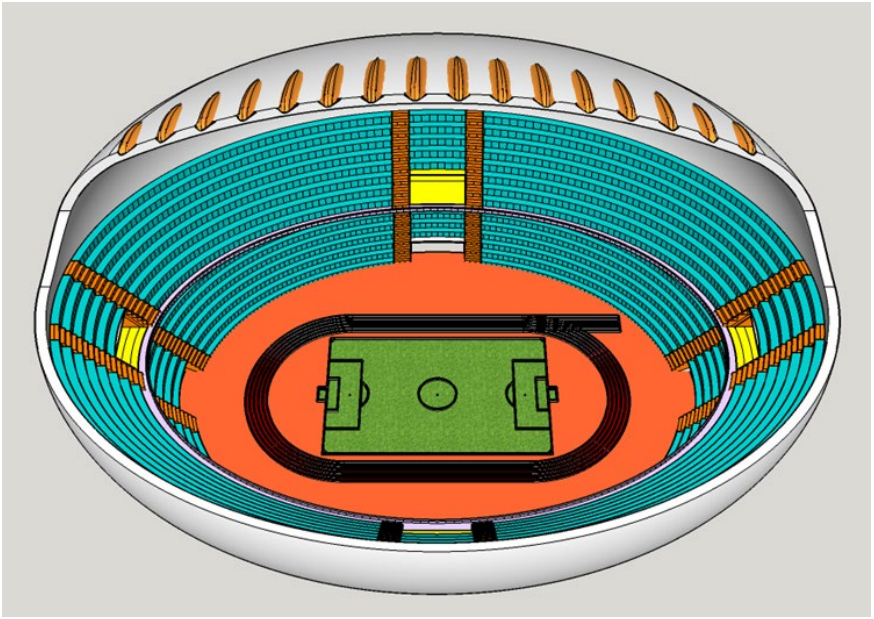

Figure 14. *Inside of the proposed Cowrie shell stadium* **source:** *Author*

The unique shape of the cowrie shell finds a perfect match in the design of a giant, all-weather sports stadium. Figures 14 to 16 illustrate the proposed stadium inspired by the cowrie shell's shape.

Figure 14 illustrates the interior of the cowrie shell inspired sports stadium. All sports activities, including track events, soccer games, and USA football, can be held on the main floor. Multi-level seating is designed to accommodate a large number of spectators. While only four gates are shown here, additional gates can be incorporated as needed.

Figure 15 provides a top view of the stadium. Given the large crowd capacity during events, maintaining fresh air circulation is crucial. A central glass slot, resembling the slit or aperture of a cowrie shell, allows natural light to illuminate the stadium during the day, reducing electricity consumption. This central glass aperture can be retractable for all-weather condition, and in some designs, the entire aperture may also be retractable based on specific requirements. On the top of two sides of the aperture, orange-colored structures can serve as both air vents and control mechanisms for operating the retractable glass aperture.

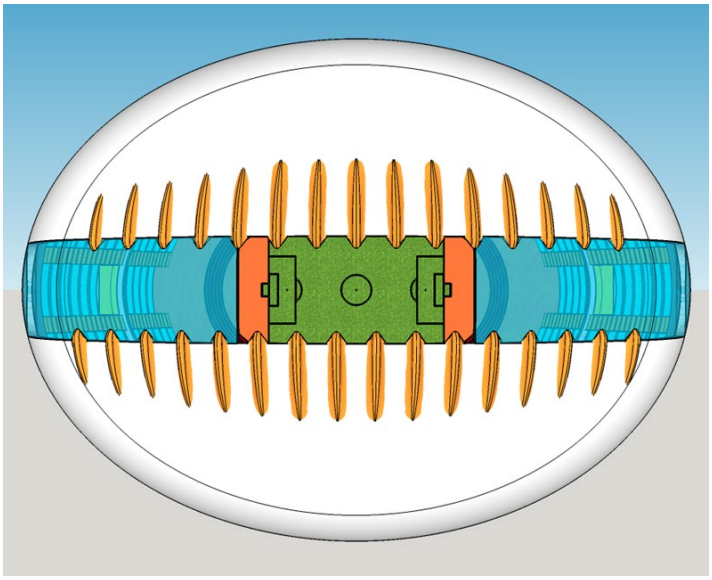

Figure 15. *Top view of the cowrie shell sport stadium with opened central aperture* **source:** *Author*

Figure 16 offers a side view of the cowrie shell sports stadium with the central glass window closed, ideal for unfavorable weather conditions or when controlled climate settings are necessary.

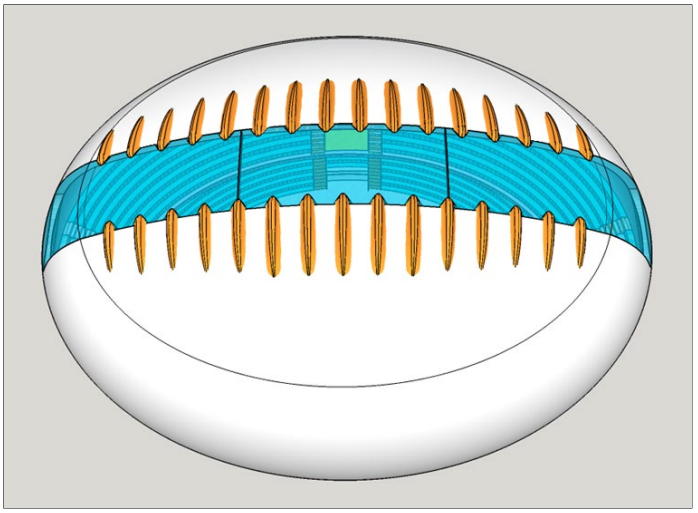

Figure 16. *The side view of the cowrie shell sport stadium with closed central aperture* **source:** *Author*

Figure 17 presents a panoramic view of the cowrie shell sport stadium as it would appear on a real site, showcasing its unique design and functional elements integrated seamlessly into the landscape.

The golden color of the outer shell makes the stadium like a golden egg also reflecting auspiciousness and prosperity, however, it can be any preferred colors. The top portion of the shell can be covered with solar panels to provide the electricity to the stadium.

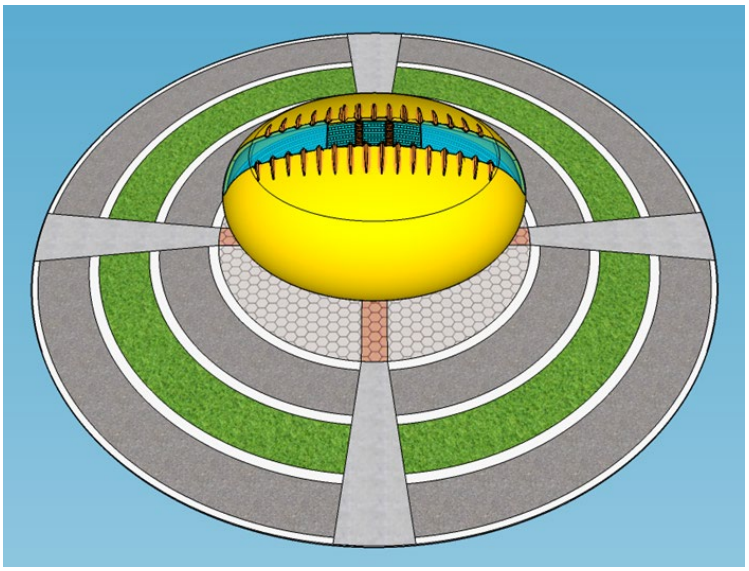

Figure 17. *The panorama of the cowrie shell sport stadium* **source:** *Author*

5. Rocket Building

Rockets are indispensable tools in modern science, enabling the launch of satellites that monitor Earth's climate, provide communications and space exploration expanding our understanding of the universe. Missions to Mars, Jupiter, and beyond have yielded insights into planetary formation, the potential for extraterrestrial life, and the origins of our solar system.

The Hubble Space Telescope, launched by the Space Shuttle which was lifted by rockets, stands as a testament to rocket technology's impact. It has captured breathtaking images of distant galaxies, nebulae, and star-forming regions, revolutionizing our knowledge of the cosmos and inspiring generations of scientists and enthusiasts alike.

Beyond their scientific contributions, rockets have profoundly shaped human life. The satellite technology enabled by rockets underpins global communication networks, GPS navigation, and television broadcasting, becoming integral to daily life and driving economic growth.

The shape of rockets has captivated people's imagination, becoming one of the most recognizable and favored designs globally. Rocket-shaped toys are particularly popular among children worldwide, reflecting the universal fascination with space exploration and technology.

Meticulously designed, rockets typically feature a cylindrical body with a conical or rounded nose, as depicted in Figure 18. This aerodynamic shape is essential for overcoming the challenges posed by Earth's atmosphere and the vacuum of space, ensuring efficient propulsion and stable flight trajectories. This carefully designed shape of rockets minimizes air resistance during ascent, allowing them to efficiently traverse Earth's atmosphere. The nose cone, typically conical or rounded, serves a critical role in housing payloads such as satellites, scientific instruments, or human crews. It is designed to protect these components from aerodynamic forces and extreme temperatures encountered during launch.

The cylindrical body, known as the fuselage, houses the fuel and propulsion systems. Its streamlined shape not only ensures structural integrity but also enhances aerodynamic performance, crucial for stable flight trajectories. Fins are sometimes added near the base of the rocket to provide stability and control during the initial phases of flight.

The materials used in rocket construction are carefully chosen for their strength and lightweight properties. Common materials include aluminum alloys and composite materials, capable of withstanding the extreme stresses of launch and space travel.

To increase lifting power, additional boosters may be attached to the lower part of the main rocket. For example, the Falcon Heavy features two boosters, while the Chinese Long March 3B incorporates four boosters, as depicted in Figure 18.

While rockets are man-made objects not found in nature, their shapes are remarkably well-suited for architectural design. Figure 19 illustrates a proposed building whose shape mimics that of rockets. This imitation falls within the realm of bionic architecture, which draws inspiration from natural forms and processes to enhance architectural design and functionality.

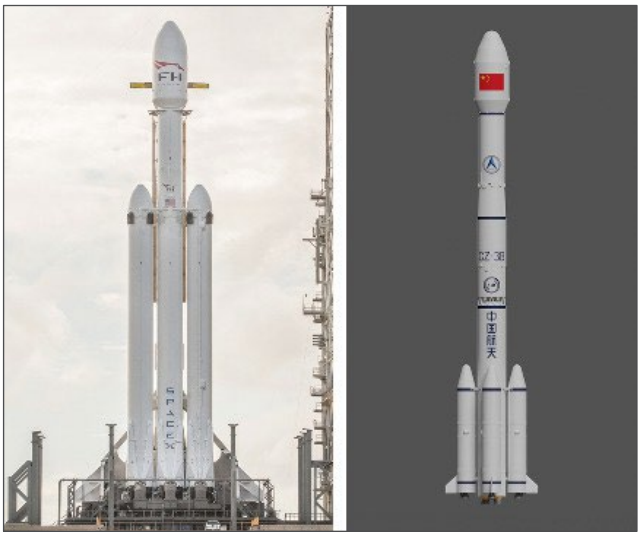

Figure 18. *Left: SpaceX Falcon Heavy rocket; right: Chinese Long March 3B rocket. The two images are duplicated from Wikipedia website under the Creative Commons Attribution-ShareAlike 4.0 International License and credited to the original copyright owners* **Source:** *Wikipedia website*

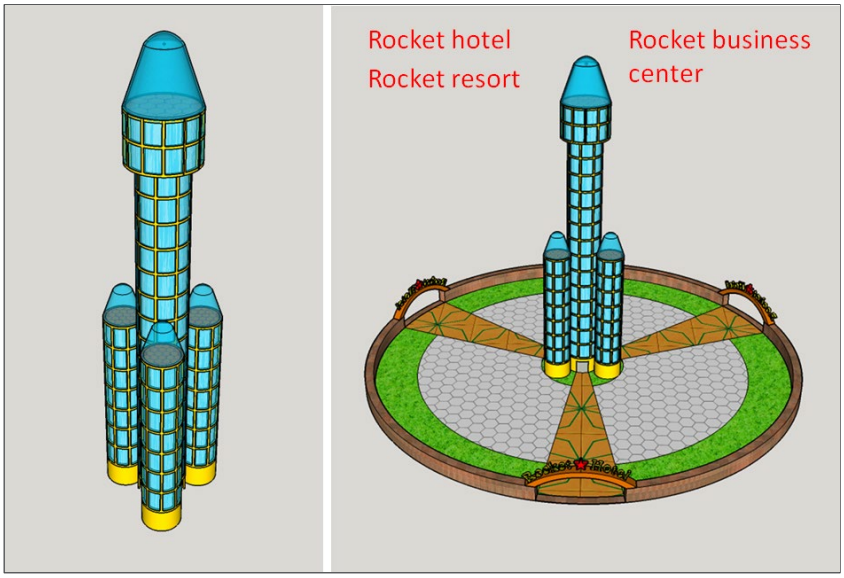

Figure 19. *Proposed building with the shape of a rocket and three booster buildings. Left is the proposed rocket building; the right is the panorama of the rocket building* **source:** *Author*

Figure 19 left depicts the rocket-inspired building with three booster side structures which not only increase the usable area but also enhance stability against ground vibrations and strong winds. Each booster structure and the main building feature rounded nose rooms situated at the top, offering expansive views of the surrounding area. These top rooms can serve as restaurants, exercise areas, or leisure spaces, providing visitors with panoramic vistas and unique experiences.

Figure 19 right showcases the panoramic view of the rocket building, envisioned as a landmark and tourist attraction within the local area. Its distinctive design, inspired by rocket shapes, aims to captivate visitors and residents alike, blending architectural innovation with aesthetic appeal.

6. Summary

Architectural design finds inspiration in nature's diverse forms, from the graceful tentacles of the octopus to the radial symmetry of the sea star and the sleek, resilient shape of the cowrie shell. These natural marvels, with their functional elegance and intricate beauty, serve as blueprints for innovative architectural concepts known as bionic architecture.

The octopus-inspired building, with its undulating, organic contours, exemplifies how natural forms can inspire architectural creativity. From its multi-level offices to its panoramic top spaces, this structure integrates functionality with aesthetic appeal, offering unique environments for work and leisure.

Similarly, the starfish shaped airport demonstrates how radial symmetry and efficient space utilization

can translate into architectural design. Its terminals extend like arms from a central hub, accommodating numerous boarding gates and offering a harmonious blend of functionality and visual intrigue.

The cowrie shell finds its architectural counterpart in a sports stadium, where its protective, smooth shell shape inspires a venue designed for resilience and aesthetic appeal. The stadium's enclosed design and versatile central aperture enhance spectator comfort and operational efficiency, echoing the shell's ability to protect and endure.

Rockets, though man-made, draw inspiration from nature's efficiency in overcoming atmospheric challenges. The unique morphology of the rockets can be nicely translated into template of architectural design. The rocket shapes inspire bionic designs that blend technological innovation with aesthetic appeal. Proposed buildings imitating rocket forms, such as those with booster side structures and panoramic top rooms, aim to become landmarks and tourist attractions, enhancing local landscapes with their striking and functional designs.

In summary, bionic architecture bridges the gap between nature's beauty and human innovation, leveraging natural forms to create buildings that are not only visually striking but also functional and sustainable, may make the design of a specific architecture much easier. With inspirations from the depths of the ocean to the vastness of outer space, these architectural designs reflect humanity's quest to blend technological advancement with the timeless elegance of nature.

The bionic structures presented in this paper are just conceptual proposals. However, the actual designs and decorative pattern textures and colors should be carried out by licensed architects, which can vary depending on the real cases without departure of bionic scopes and original characteristics of selected natural objects. It is certain that in the future, more and more bionic buildings will appear in our lives to provide us with a comfortable and beautiful environment with natural aesthetics. *We are from nature and also are parts of nature.*

Declaration

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7. References

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