The Art & Science of Animal Architects

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Abstract— As a human being, we have always considered ourselves as the most intelligent, innovative and superior-most creature on earth and since history immortal, have at all times, claimed our supremacy over all other creatures on planet earth. However, Charles Darwin – father of the evolution theory, differed from the general perception, by saying- perhaps rightly so- 'Animals, whom we have made our slaves, we do not like to consider our equal'. This clearly indicates Darwin's belief and trust on the caliber of the animals too. Let us therefore, try to testify Darwin's perception as well as his faith on the caliber and scientific advancements in the field of the habitats of non- human creatures i.e. the animals, birds, insects and aquatic animals etc. This study is important to architects as they are responsible for the creation of manmade built- spaces and structures, which so far have been based on their own perception, while many built spaces and structures created by non human beings are far-far superior to our own; thereby providing us a golden opportunity to improvise our understanding of built- spaces through the study of the creations of these 'substandard creatures'.

Key words: Animal Architect, Termite Mound, Groundhog, Biomimicry, Eastgate Centre, Beaver, Bees-Honeycomb, Paper Wasp, Spider Web, Baya Weaver, Sociable Weaver, Red Oven Bird, Predator, Coral Reefs

I. INTRODUCTION

Almost every day we come across many astonishing structures built by animals and get thrilled. The beehive structure makes us ponder as to how the tiny bees make such uniform hexagonal cells out of natural wax. Similarly, the intricately woven baya bird nests amaze us. We have also heard that some of the animals built habitats which provide air conditioned environment within it. This creates an urge to study the details of such amazing structures. The present study looks in to habitats created by some of the outstanding animal architects viz. termites, rodents, bees and birds etc and is categorized into the habitats of (A) Terrestrial Animals; (B) Areal or Winged Animals and (C) Aquatic or Marine Animals.

A. Terrestrial Animals

Terrestrial animals are animals that live predominantly or entirely on land (e.g., cats, ants, rodents). Terrestrial invertebrates include Ants, Flies, Honey Bees, Crickets, Grasshoppers and Snails.

Although, all animals require a shelter or an habitat of some kind, studied done so far indicate superior built structures being created by animals like White Ants (Termites), Rodents (Groundhog or Woodchucks) , Spiders and Bees etc. Let us therefore study the art and science of the Habitats of these animals.

1) Termite Mounds

Termites Mounds which are abundantly found in Africa, South Asia, and Australia, to a common man appear to be just some sort of irregular shaped heap of mud and dirt. But for the bio – scientists, these ugly looking structures are research objects of immense importance. Even architects and building scientists are curious to learn about the most intricate natural air conditioning system in-built in them.

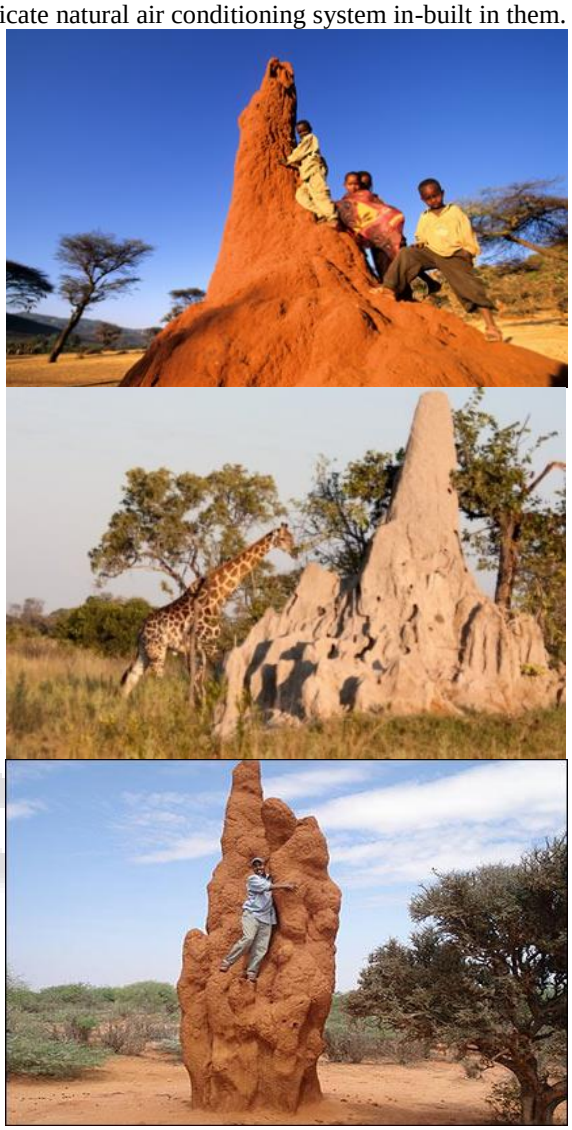

Fig. 1: Terrestrial Animals

The mound structure consists of 2 parts- the above-ground mound, which sometimes are as high as 30 feet, have an outer wall riddled with holes, which lead to a labyrinth of tunnels that themselves lead to a series of chimneys, and below the mound is a large, oval nest, where the queen resides and food in the form of Fungus is stored at a constant temperature of 35.5 degree centigrade.

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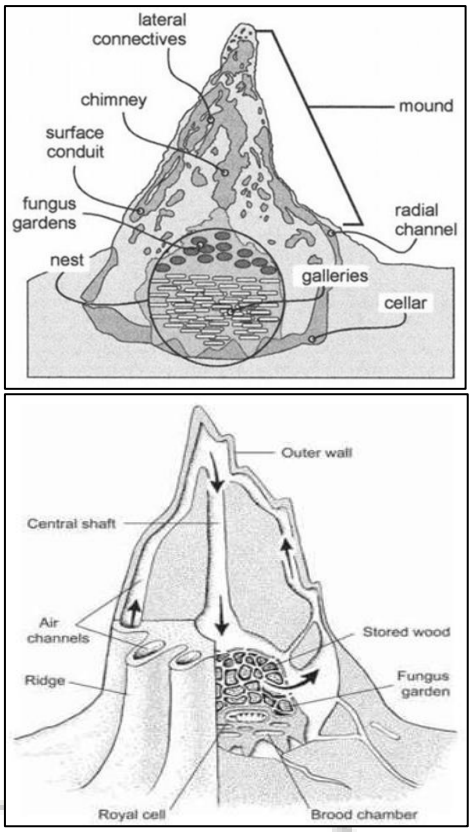

Fig. 2: Mound Structure

A termite nest is like a city, with houses and streets. The queen and king have their own house or chamber, it is the largest in the 'city'. The 'streets are busy day and night, with long lines of busy worker termites. They have to see that there is enough food. They must care for the eggs the new termites are developing. They must repair and enlarge the nest. The 'streets' are ventilated, or supplied with air, by a system of air-conditioning. The air is never too hot or too dry.

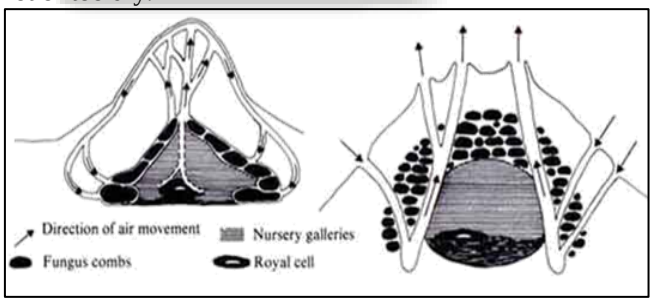

Fig. 3: Macrotermes michaelseni & Macrotermes subhyalinus

As mentioned earlier the intricate air-conditioning systems of these mounds is matter of great research for the scientists. As of now two theories are in place. According to earlier research, the mound dissipates air through its network of holes. As the sun moves through the sky during the day, the air in the thinner chimneys on the outer edges of the mound heat up quickly, while the air in the mound's big, central chimney stays relatively cool. Hot air rises up through the outer chimneys and cool air in the central chimney sinks, circulating air continuously—injecting oxygen and flushing out carbon dioxide. At night, the flow reverses as the outer chimney air cools down quicker than the inner chimney air.

The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature.

However, according to the second and the recent (2008) theory, which has been propogated by Dr. J. Scott Turner of the State University of New York College of Environmental Science and Forestry (SUNY-ESF) in Syracuse, New York, the mounds function more like lungs, inhaling and exhaling through walls that appear impenetrable but are actually quite porous. Inside the mound, a series of bubble-like chambers connected to branching passages absorb changes in outside pressure or wind and pass them through the mound. To regulate the mix of gases and maintain a stable nest environment, the termites are forever remodeling the mound in response to changing conditions. According to Dr. Turner "A termite mound is like a living thing, dynamic and constantly maintained."

a) Eastgate Centre, Harare (Zimbabwe) - Biomimicry of Termite Mounds

Having known about the astonishing air-conditioning properties of termite mounds, few architects in the world are trying to bio- mimicries this concept in their buildings. The best example is the the award-winning Eastgate Center in Harare, Zimbabwe designed by Mick Pearce, a Zimbabwean Architect. It has no conventional air-conditioning or heating, yet stays regulated year round with dramatically less energy consumption using design methods inspired by indigenous Zimbabwean masonry and the self-cooling mounds of African termites. According to architect Pearce, there is a saving of about 10 percent of energy as compared to a normal building of this size. As amatter of fact, the East gate Centre in Harare, Zimbabwe, typifies the best of green architecture and ecologically sensitive adaptation. It is indeed an architectural marvel in its use of biomimicry principles.

The Eastgate Centre, largely made of concrete, has a ventilation system which operates similar to the termite mounds. Outside air that is drawn in is either warmed or cooled by the building mass depending on which is hotter, the building concrete or the air. It is then vented into the building's floors and offices before exiting via chimneys at the top. Air is continuously drawn from this open space by fans on the first floor. It is then pushed up vertical supply sections of ducts that are located in the central spine of each of the two buildings. The fresh air replaces stale air that rises and exits through exhaust ports in the ceilings of each floor. Ultimately it enters the exhaust section of the vertical ducts before it is flushed out of the building through chimneys.

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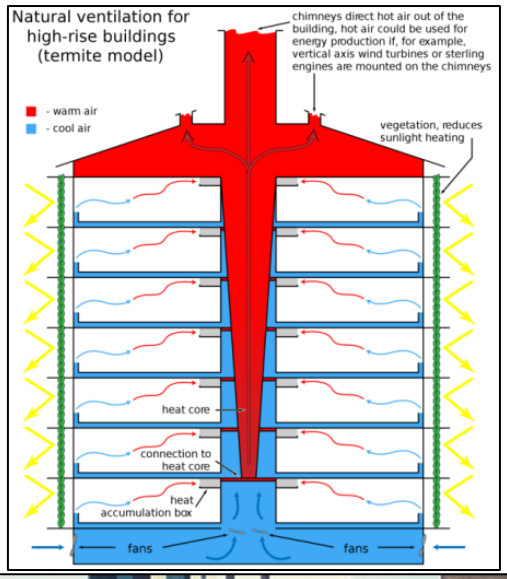

Fig. 4: The Ventilating walls and the Chimneys: Eastgate Centre, Harare

2) Groundhogs or Woodchucks

Groundhogs or Woodchucks, found in the majority of central and eastern United States, as well as in parts of Alaska and Canada are a type of a Rodent. They spend most of their time underground in complex burrow systems, which they dig in dry, well-drained soil. A woodchuck burrow is more than just a hole in the ground. It is a complex system of entrances, tunnels, and rooms called chambers. Burrows give woodchucks a place to sleep, raise young, and escape enemies. When a woodchuck hibernates (sleeps through the winter), it makes a simple burrow and plugs the entrance with sand. A woodchuck digs its own burrow. In soft soil, it can dig an entire burrow in one day. The plunge whole, also known as spy- hole is a special entrance which goes straight down two or more feet. When an enemy comes nearby, the woodchuck gives a shrill whistle, and then goes straight down into the hole. The entrances are connected through underground tunnels and chambers. Astonishingly, there is a sleeping chamber, a turn-around chamber, and a nursery chamber and most surprisingly a toilet chamber! The burrows are warm in winter and cool in summer. Similar to termite mounds, there are air chambers to regulate temperature.

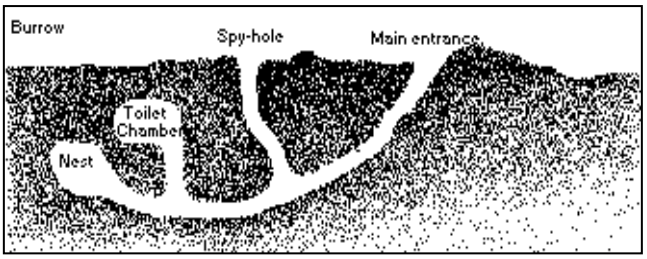

Fig. 5: A sketch of a Groundhog Burrow

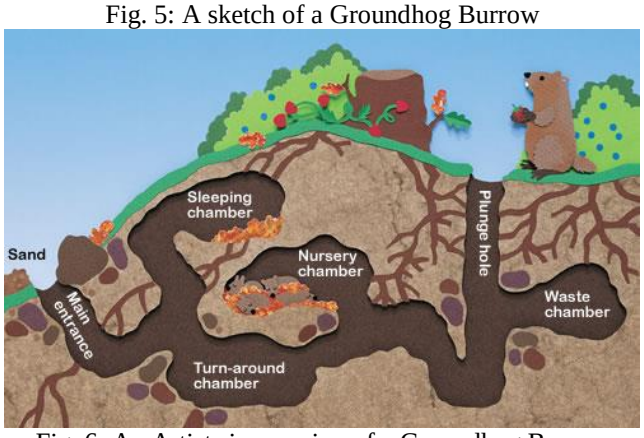

Fig. 6: An Artists impression of a Groundhog Burrow

3) Beaver Dams

Beavers are famous for building dams. They are excellent woodworkers and weather-proofers, and build massive dams to create still ponds and flood woodland areas to a desired depth. These structures modify the natural environment in such a way that the overall ecosystem builds upon the change, making beavers a keystone species. Beavers work at night and are prolific builders, carrying mud and stones with their fore-paws and timber between their teeth. Beavers may be termed as superb irrigation engineers.

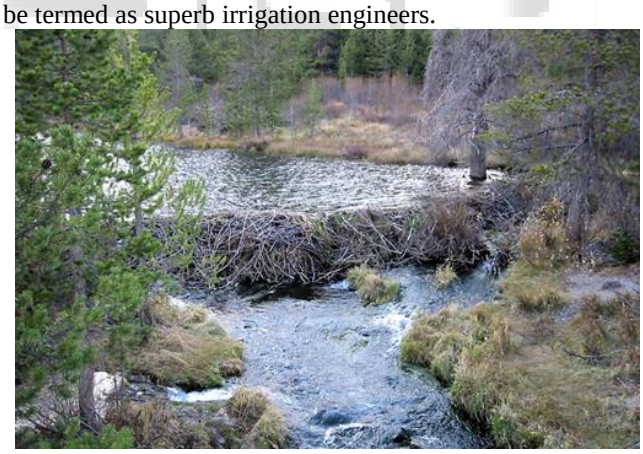

Fig. 7: A Typical Beaver Dam

4) Spider Web

Spider is a very common insect found at all places, which weaves an intricate web with the help of self-producing silk thread. Crafting such a web is a highly cognitive endeavor, requiring a spider to size up a space, pick out anchor points and assess how much silk it has available. The web consists of a durable silk frame made up of the outer bridge lines with internal anchor lines that are pulled downward to create spokes. An elastic capture thread is then used to make the spiral lines that connect the spokes together, giving the web the ability to absorb an oncoming insect. The spirals are bounded by sticky droplets to secure the prey.

Spider Silk is well known for some spectacular properties. Its tensile strength is greater than that of

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steel and has much greater elasticity. Its microstructure is under investigation for potential applications in industry, including bullet-proof vests and artificial tendons. New research shows that the material is not only strong but also smart.

It has been found out that web's unique skills come from its ability to react differently to different stress levels. A light wind, for instance, softens the web, allowing it to lengthen but retain its overall structure. If a larger force is applied at a specific location, such as when a particular thread is poked, the silk becomes rigid and breaks. But amazingly, after breaking up of a thread, the Web becomes stronger!

Fig. 8: Spider Web

5) Bees Honeycomb

A bees' honeycomb is one of the wonders of the world. It consists of layer upon layer of hexagonal cells of identical size and shape which are stacked together as precisely as if the whole exercise was drawn on graph a paper or an auto-cad design was prepared. And why the hexagonal shape? The reason is stability and economy. A hexagon is considered to be most appropriate geometric form for the maximum use of a given area. A hexagonal cell requires least amount of wax for construction while it can store maximum amount of honey in to it.

Bees are extremely intelligent and also brilliant mathematicians. They perform a waggle dance which utilizes speed and directionality to communicate the location of resources relative to their current position and the Sun. They start the construction from 2-3 different places and weave the honeycomb simultaneously in 2-3 strings. Though they start from different places, the bees, great in number, construct identical hexagons and then weave the honeycomb by combining these together and meeting in the middle. The junction points of the hexagons are assembled so deftly that there is no sign of their being combined subsequently.

Fig. 9: Bees honeycomb

6) Mud Daubers

They are solitary wasps that construct small nests of mud in or around homes, sheds, and barns and under open structures, bridges and similar sites. The nest comprises of a series of cylindrical cells that are plastered over to form a smooth nest that may attain nearly the size of a human fist. After building a cell, the female wasp captures several spiders. The captured prey are stung and paralyzed before being placed in the nest, and then a single egg is deposited on the prey within each cell. The wasp then seals the cell with mud. After finishing a series of cells, she leaves and does not return. Eventually, the hatching larva will eat the prey and emerge from the nest.

Fig. 10: Urn-shaped mud dauber wasp nest

Fig. 11: Organ pipe mud dauber wasp nest

7) Paper Wasps

Paper wasps get their name to the paper like material which is created to make their nests. This natural material is prepared by mixing fibers from dead wood and plants with saliva. The material is water-resistant. Interestingly, unlike other similar types of hives, paper wasps leave the combs where they lay their eggs open, without a protective outer shell. Nests are usually attached to the sheltering structure by a narrow stem, making the nest look like an upside-down umbrella and therefore these wasps are also known as "umbrella wasps."

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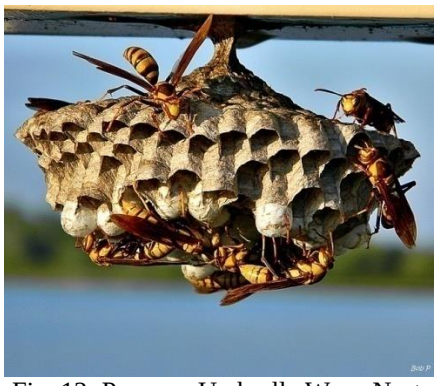

Fig. 12: Paper or Umbrella Wasp Nest

B. Areal or Winged Animals

These are animals that can transport themselves in the air either by gliding or flying. In addition to many species of birds and insects, certain other types of animals like bats, flying squirrels are aerial as well. These animals also require a habitat for rest and breeding. Some areal animals particularly the birds construct extremely intricate and complex structures (nests), which are difficult to be built even by humans. Some of the important attributes of the 'habitats of areal animals' are as follows:

1) Site Selection

The nest building process starts with the selection of a safe nesting site. Birds carefully choose nest-sites in order to maximize their possibilities of a successfully breeding outcome. One or both of the parents decide on the location in which to construct the nest. The selection of a suitable nest site is determined by a combination of five main factors:

- Availability of food for both parents and offspring,
- Risk of predation,
- Presence and behavior of con-specifics,
- Availability of suitable nest material,
- Presence of suitable ambient climate for raising offspring

2) Orientation

Some of the birds orient their nests based on the wind direction. Grasshopper Sparrows and Eastern Meadowlarks build domed nests that are orientated away from prevailing winds and the orientation of the nests shifts temporally over the course of the breeding season as the direction of the prevailing winds changes. Further, Orange-tufted Sunbirds, Horned Larks, Lark Buntings, and Mc Cown's longspurs all select their nest sites that faced away from the prevailing winds, as well as being located away from direct sunshine during the middle part of the day, which prevented the nests from overheating. By contrast, in arid environments, animals select sites that are cooler than randomly selected sites. Desert lark nests in an arid environment are found to be located adjacent to a bush or stone and to face north which provide shade from the midday sun. Furthermore, the orientation of Gila Woodpecker nests changed temporally throughout the year. In the breeding season, northerly facing holes reduced the levels of water loss from nests in the hot summer months, while warmer south-facing nests reduced energy expenditures during the cold winter months

Thus, there exists ample evidence to show that nesting animals select sites that minimize heat loss in cool environments and prevent overheating in warm environments, thereby creating an optimal microclimate in which to raise offspring.

3) Construction Materials

It is well established that almost all birds select nest construction material that provide thermoregulatory benefits for the parents and the offspring within the nest cup. Among ground-nesting birds, one inter-specific study of six species of arctic breeding Shorebirds showed that smaller species, with greater surface-area-to-volume ratios, created nest scrapes with greater amounts of nest lining material than larger species, thereby demonstrating that smaller species invest more in the insulation of their nests than larger species. Pectoral Sandpipers have been shown to excavate a scrape and use lining material, which reduced the rate at which the nests lost heat by 9% and 25%, respectively. Hence, lined scrapes insulate clutches much more efficiently than unlined scrapes. Many birds line their nests with feathers, which is advantageous as when the insulation properties of a range of commonly used lining materials were tested in the laboratory, feathers were found to provide the most insulation to nests, while grasses provided the least. Thus, there is enough evidence to suggest that nest lining materials, such as feathers, serve to create suitable microclimates in which to raise offspring.

4) Construction Economics

It is not only human beings that bother about the cost of construction, the birds are also aware about the concept of 'building economics' and minimize the costs of nest construction. It has been observed that some species exploit the efforts of others by stealing nesting material or completed nests from con-specifics or hetero specifics; while other species breed in old nests despite incurring costs due to ecto-parasitism. Experimental studies have also demonstrated that birds like male Australian Reed Warblers build multiple nests within their territories- nest that is structurally capable of holding eggs and nestlings and nests that are cheap but not structurally capable of holding eggs and nestlings.

5) Nest Design as a Host Defense

Many birds place green plant material and feathers in their nests and usually replenish them on a daily basis throughout the incubation and nestling stages of reproduction. Green plant materials contain volatile secondary compounds such as hydrocarbons, mainly monoterpenes and isoprene, which could have biocidal effects on parasites and pathogens. Also, the majority of bacteria found on feathers are known to produce antibiotic substances which act as antibodies for other bacteria within the nest environment. Consequently, both green plant material as well as feathers may deter the parasites, at the same time providing thermoregulatory benefits.

6) Process of Inspection and Acceptance

Similar to manmade construction process, the birds also follow the good practice of inspection and approval of the competent authority. Under this process, the nest being constructed by the male bird is inspected by the Competent Authority i.e. the female bird at an intermediate stage and on being satisfied mainly with the safety and micro climatic considerations, is approved(accepted) by her. In case of non acceptance, its further construction is stopped and the male bird has to restart the construction process at a different location.

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7) Meticulous Construction Schedule

Through extensive research, it has been established that the birds follow a strict construction schedule, including the time slots for different activities. The following table indicated that the Baya Weaver bird takes 18 days to fully construct its nest:

S. No.	Stage	No. of days
1	Wad Stage	2
2	Ring Stage	5
3	Helmet Stage	6
4	Advanced Helmet Stage	2
5	Nest with completed Egg Chamber	1
6	Nest with Short Tube	1
7	Completed Nest	1
8	Total days	18

Table 1: Meticulous Construction Schedule

It has also been observed that the birds undertake certain type of activities during fixed time period only. For example, the construction work of the egg chamber is undertaken between 8 to 9 in the morning and 3.30 and 5.00 in the evening, while the finishing touches to the nest are given next evening between 3.30 and 5.00PM.

8) The Climatic Considerations

Numerous studies have been conducted by bio scientists on the microclimate of the nests. All such studies and research conclude that the nests are scientifically designed with reference to ambient temperatures, day light factor, orientation and wind direction.

After having studied certain commonalities amongst various types of areal animals, let us now look at nests of some specific birds and other flying animals.

a) The Sociable Weaver

The Sociable Weaver bird, a native to Southern Africa builds huge community nests that are a home to hundreds of the little flyers. Using sticks and grass, the weavers make these permanent homes, in such a scientific way that the inner chambers of the nests stay warm during the cold season and vice versa. Their 'housing projects' are as elaborate and decadent as any manmade structure, while their entire decor is made of twigs. One pair of birds occupies each chamber, which is further subdivided into several rooms with entrances below the nest. The inner rooms retain heat and are used during the night, while the outside rooms are actually cooler than their surroundings and are used during the day. The central chambers can retain heat and are for night-time roosting, while the outer ones are for daytime shade, as the temperature maintained can be about 7-8°C, when it is about 16-33°C outside. Social weaver nests are so sturdy that they can last for hundreds of years.

Fig. 13: Sociable Weaver bird

b) Red Ovenbird

The Red Ovenbird which is the national bird of Argentina and Uruguay uses mud or dung as the main material to build earthen bowls using their own saliva. The nests are constructed on top of high tree limbs, poles, posts, etc., where these get baked by the sun, creating a hardened shelter where the birds lay eggs. The nests face away from prevailing winds and never face south side. Thus, these are perfect for the incubation of eggs, and are a home for the nestlings and their parents in all kinds of weather.

Fig. 14: The Red Ovenbird Nest

c) The Baya Weaver

The Baya Weaver nests are considered to be the most astonishing structures built by birds. They use plant fibers and tall plant stems to weave extremely solid nests. First of all the building materials are collected and then long strips from a fresh green leaf are cut. The weaver bird begins by tying the leaf fibers around the twig of a tree. With its foot, it holds down one end of the strip against the twig while taking the other end in its beak. To prevent the fibers from falling away, it ties them together with knots. Slowly it forms a circular shape that will become the entrance to the nest. Then it uses its beak to weave the other fibers together.

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During the weaving process, it calculates the required tension while visualizing the finished structure. Once it finishes weaving the entrance, it proceeds to weave the walls. To do so, it hangs upside down and keeps on working from the inside of the structure. It pushes one fiber under another and pulls it along with its beak, until it accomplishes a stunning weaving project. The construction process is highly methodical and time bound. It knows perfectly well where to thin or thicken the structure, and where to form a curve. The nests are provided strength, elasticity and water proofing through an indigenous mortar by gathering plant fibers from the environment and mixing them with its saliva.

Fig. 15: The Baya Weaver Nest

Fig. 16: The Baya weaver Nest

C. Aquatic or Marine Animals

Aquatic animals, either vertebrate or invertebrate, are ones which live in water for most or all of its life. It may breathe air or extract its oxygen from that dissolved in water through specialised organs called gills, or directly through its skin.

Marine ecosystems are a part of the largest aquatic system on the planet, covering over 70% of the Earth's surface. The habitats that make up this vast system range from the productive near shore regions to the barren ocean floor. Some examples of important marine ecosystems are: oceans, estuaries and salt marshes, coral reefs, mangrove forests, lagoons, sea grass beds, and intertidal systems.

Marine ecosystems are home to a host of different species ranging from tiny planktonic organisms that comprise the base of the marine food web (i.e., phytoplankton and zooplankton) to large marine mammals like the whales, manatees, and seals. Fish and birds also use marine ecosystems as their habitats.

1) Coral Reefs

These are one of the most unique animal habitats developed by animals themselves. They are formed in shallow, warm sea water and provide primary habitat for more than 4,000 species of fish, 700 species of coral, and thousands of other plants and animals. About 25 percent of all known marine species rely on coral reefs for food, shelter and breeding. Most of the substantial coral reefs found today are between 5,000 and 10,000 years old. Some of the coral reefs are so large as to become visible even from the outer space. The Great Barrier Reef located in Coral Sea, off the coast of Queensland, Australia covers an area of 2300 kilometers and is the world's biggest single structure made by living organisms.

Coral reefs are complex, multistory structures with holes and crevices shared by various creatures. If a coral reef is linked to a bustling city, then a coral colony is like a single apartment building with many rooms and hallways that house different marine species. The actual architects of coral reefs are hard or stony corals, which are referred to as hermatypic, or reef-building corals. As the polyps of stony corals grow, they produce limestone skeletons. When they die, their skeletons are left behind and used as foundations for new polyps, which build new skeletons over the old ones. An actual coral branch, or mound, is composed of layer upon layer of skeletons covered by a thin layer of living polyps.

Corals are generally classified as either "hard coral" or "soft coral". There are around 800 known species of hard coral, also known as the 'reef building' corals. Soft corals, which include seas fans, sea feathers and sea whips, don't have the rock-like calcareous skeleton like the others; instead they grow wood-like cores for support and fleshy rinds for protection.

The brilliant colours to corals generally come from the zooxanthellae (a type of photosynthetic algae) living inside their tissues, several million of which live and produce pigments in just one square inch of coral. These pigments are visible through the clear body of the polyp that gives coral its beautiful and dazzling colors.

Fig. 17: Coral Reefs

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II. CONCLUSION

The study of animal architects clearly indicate that many animals are blessed with the talent of building highly scientific and eco-sensitive structures which even surpass manmade buildings. These animals are extremely caring for their offspring, for whom they build structures which protect them from their enemies and adverse climatic conditions. For achieving this goal they search for the best possible site and build their nests with thermoregulatory materials. The habitats of some animals are so well designed as to facilitate natural air conditioning within them. The study also reveals that animals follow a strict construction schedule and are quality and cost conscious. Undoubtedly, the structures built by animal architects can provide immense knowledge to human beings. However, there is very little research work which is being undertaken by architects who have so far refrained themselves from doing such type of jobs. As of now, most of such researches fall within the exclusive domain of bio-scientists. Let some entrepreneur architects come forward to undertake research work in this field and design their buildings based on the lessons learnt from the animals 'whom we do not like to consider our equal'.

Note: This article is based on the extensive literature study undertaken by the author through internet & other sources and is not his original research work.

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