Nests of Passerine birds: shapes, fibers and fabrication

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DECLARATION BY STUDENT

I hereby declare that the data presented in the Dissertation report entitled, "Nests of Passerine birds: shapes, fibers and fabrication" is based on the results of investigations carried out by me in program Zoology at the School of Biological Sciences and Biotechnology, Goa University under the supervision of Dr. Minal Desai Shirodkar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations/experimental or other findings given in the dissertation. I hereby authorize the University authorities to upload this dissertation on the dissertation repository or anywhere else as the UGC regulations demand and make it available to any one as needed.

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COMPLETION CERTIFICATE

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INTRODUCTION

A nest is a unique structure built by birds which provides them with a shelter, a place to lay the eggs and raise their offsprings and provides protection from the predators. Nests are a specific component of a bird's extended phenotype and serve as a permanent physical record of the activity that led to their formation (Collias 1986, Zyskowski *et. al.*1999). Nearly all bird species create nests, which can be as simple as a scratch on the ground or as intricate as woven buildings suspended in trees (Hansell M. Bird Nests and Construction Behavior Cambridge University Press, 2000, Fang *et. al.* 2018). Nests offer protection from predators, a place for eggs and nestlings to live, and a microclimate for maturing eggs and developing nestlings (Lombardo M.P. 1994). The availability of food for parents and young, the presence and behaviour of conspecifics, the likelihood of predation, the availability of nest material in the area, and the climate's suitability for the birds' growth and flourishing have all been examined in relation to nest building in birds (Mainwaring *et. al.* 2014, Acharja I.P. 2019). Birds of the same genera and species prefer to build their nests in environments and habitats that are similar to one another, on particular kinds of trees, and at particular heights. While others have been found to be able to survive in any environment, including those that are close to human habitations.

Avian nests vary greatly in design amongst families, which results in a variety of functionalities (Jessel *et. al.* 2019). Some characteristics of nests, like as size and the specific building materials utilized, can differ between species and even within the same species (Heenan C.B. 2013, Guillette and Healy 2015, Price and Griffith 2017). Nests are transient structures, but they are essential to the survival of species (Hansell 2000, Perez *et. al.* 2020). Bird nest structural complexity varies greatly between species, from crudely built stick platforms to precisely woven cups and domes (Hansell M.

2000, Hansell M. 2007, Mainwaring *et. al.* 2014, Street *et. al.* 2022). The designs and sizes of the bird nests vary. Some birds build open nests whereas some build the closed ones.

The broadest evolutionary radiation of birds, with enormous ecological and behavioral diversity, is seen in the Passerines (Barker *et. al.* 2002, Barker *et. al.*2004). As a result, they exhibit a considerable deal of variability in their nest building too (Collias N.E., Collias E.C., 1984, Hansell M.H. 2000). More of open nests than closed nests are found worldwide, and 71% of all passerine families have open nests (Price and Griffith 2017). The most common design is open cup-shaped nests (Collias N.E. 1997, Price and Griffith, 2017) which have the benefit of being quite simple in construction pattern. At the same time, the eggs, nestlings and the parent birds are exposed to predators and climatic changes (Mainwaring and Hartley 2013, Heenan C.B. 2013, Price and Griffith 2017). Apart from the open cup shaped nests, there are pendant , purse , dome shaped nests, mud nests, cavity, scrape, burrow, mound, platform nests and many more such nests built by different species of birds. The high energy requiring nests built which are limited in availability i.e. the cavity nests provide protection to the young like the domed nests (Collias N.E. 1997, Price and Griffith, 2017).

Studying nest development offers a means of comprehending the evolution of complex behaviour in general since it is believed that variations in nest building among species reflect variations in the finely coordinated motor patterns and underlying genetic programmes of nest builders (Weber *et. al.* 2013, Price and Griffith 2017). Given that a variety of factors can affect nest building behavior and morphology, it is crucial to use caution when drawing conclusions about the causes behind nest construction flexibility. Predation pressure, anti-parasite advantages, sexual selection, other parental techniques, and the availability of nest material are a few of them that have been identified (Perez *et. al.*2020). Predation and hatching failure brought on by inclement weather or the nest microclimate are two major threats to nests (Collias and Collias 1984, Hansell 2000, Warning and Benedict 2014).

As a result, many species have evolved sophisticated behavioral adaptations to combat these potential nest failure causes by following a definite architectural pattern in the nest building (Martin 1995, Hansell 2005, Warning and Benedict 2014). By hiding nests or preventing predator access, certain nest architecture can reduce predation on both adults and young (Martin1995, Weidinger 2002, Feeney *et. al.* 2012, Warning and Benedict 2014). One significant biotic element that could be considered for the evolution of domed nests is predation stresses (Mainwaring *et. al.* 2014, Mainwaring *et. al.* 2015).Birds appear to alter nest building site rather than nest shape in response to the risk of predation (Forstmeier and Weiss, 2004; Peluc *et. al.* 2008, Perez *et. al.* 2020).

It is common to see nests similar in construction built by birds belonging to the same taxonomic groups (Sheldon *et. al.* 1999, Fang *et. al.* 2018). Within a species, the material selection might be rather stable (Biddle *et.al.* 2018a). Males frequently choose nest materials to improve the aesthetics of the nest and thereby their attractiveness. They may also choose materials with anti-parasite properties (Veiga *et. al.*, 2006; Mennerat *et. al.*, 2009, Perez *et. al.* 2020). Many bird species reuse their nests, and in some species, the male's capacity for nest construction is a sexually chosen characteristic. This evidence suggests that nest building requires a lot of energy and time (Mainwaring and Hartley 2013). Predation pressure versus microclimate variation has been the focus of explanations for the development of nest form in passerine birds overall (Martin *et. al.* 2017, Perez *et. al.* 2020). Nest shape is frequently thought of as a crucial taxonomic characteristic that is perfect for mapping onto phylogenies in order to do ancestor reconstruction (Perez *et. al.* 2020). This is because nest shape is thought to vary at higher taxonomic levels yet remain constant within families and genera (Price and Griffith 2017; Fang *et. al.* 2018; Medina 2019, Perez *et. al.* 2020). The body size of the builder is the primary predictor of nest size and varies significantly between species (Muller 2005; Deeming 2013, Perez *et. al.* 2020). Hence the size of the nest's owner is a significant biotic aspect in determining nest architecture (Martin *et. al.* 2017, Heenan 2013, Medina 2019).

The composition and design of nests are crucial to the breeding cycle of birds (Hansell 2000, Botero-Delgadillo *et. al.*2017). The clutch microclimate is significantly influenced by any type of nest structure per se, for example, a cup nest or a mat of plants versus scrapes on the ground (Perez *et. al.* 2020). Despite the fact that there is currently a wealth of information about nesting practices and nest morphology in thousands of species (Del Hoyo *et al.* 2017, Mainwaring *et. al.* 2014, Medina 2019) very little is known about the evolution of these structures (Guillette *et.al.* 2015, Medina 2019). The evolution of these structures may have been influenced by biotic and environmental factors in addition to phylogenetic inertia (Guillette and Healy 2015, Hall *et.al.* 2015, Medina 2019). Martin *et. al.* (2017) and earlier writers (Mainwaring *et. al.* 2014, Price and Griffith 2017, Heenan 2013, and Medina 2019) have suggested that a nest's thermal characteristics are a key factor in determining the architecture of the nest based on the fibers chosen by birds. Phylogenetic relationships can be demonstrated by nest architecture (Whitney *et. al*. 1996, Zyskowski *et. al.* 1999) by comparing and understanding the similarities and differences in the shapes, fibers used and their fabrication within the nests.

Birds serve as good bioindicators of the environment that they live in. Hence nidology is one of the contributory studies towards conservation practices of birds. So, studying their nesting habits and the architecture of the nests with respect to the fibers used, it can provide us with an idea about the changes in our surroundings and their behavior in response to the increasing anthropogenic activities over a period of time. Order Passeriformes being the largest order of birds shows a great diversity in terms of their plumage, feeding, breeding, nesting habits etc. Out of different species of birds across different orders, only a few bird species have extensive descriptions of the construction methods and materials employed in avian nests up to this point (Biddle *et. al.* 2014, Biddle *et. al.*2017, Jessel *et. al.* 2019).

Therefore, taking these factors into account, this study is conducted by examining the nesting habits of seven chosen Passerine birds, namely House crow (*Corvus splendens*), Ashy prinia (*Prinia socialis*), Common tailorbird (*Orthotomus sutorius*), Red-whiskered bulbul (*Pycnonotus jocosus*), Purple sunbird (*Cinnyris asaiticus*), Baya weaver (*Ploceus philippinus*), Scaly-beasted munia (*Lonchura punctulata*) considering the design of their nests based on the nest shapes, fibers used and fabrication patterns in their nests.

The X-ray techniques are widely used in research on architectural heritage and often entail lab-based techniques (Zhao *et. al.* 2019). Hence this technique was employed to study the overall structure including the nest shapes, fibers and fabrication patterns of the chosen nests. For analyzing the edge and texture, Gabor filters can be used which are the orientation sensitive filters and most importantly they are quite similar to the human visual system. The X ray images of the nests were analyzed further by applying the Gabor filters to understand the few parameters of the architecture of the chosen nests by considering only their shapes, fibers used in building them and their fabrication patterns.

REVIEW OF LITERATURE

In 2019, Acharja I.R. evaluated the White-bellied Heron *Ardea insignis'* nest habitat, site choices, and architectural features in Bhutan. An abandoned but intact nest's dimensions, contents, quality, and size were all measured in order to analyze the nest architecture. The findings indicated that the White-bellied Heron constructs a basic platform nest at an average of 74 meters from water bodies on the tallest, lone trees at an average height of 18.3 meters on an elevated position with a clear overview of the surroundings and is sensitive to environmental changes. Similarly, Bhattacharya *et. al. (*2016) studied the behavioral ecology of Red-Whiskered Bulbul in Halisahar, West Bengal, India. The nesting and parental care were studied between two sites, one in the human habitation and the other away from it. The height, type, size, and other aspects of the nests were examined. In the middle of populated regions, the majority of the nests were constructed in 2.5–3.0-foot-tall thorny trees, however 8–9-foot-tall mango trees in open spaces had also been discovered to have nesting birds. Another similar study was done by Chishty *et. al*. (2020) on the nesting behavior of Red vented Bulbul (*Pycnonotus cafer*, Linnaeus 1766) in Udaipur District, Rajasthan, India. The height, depth, weight, and circumference of the abandoned nest were measured in order to determine some significant characteristics. According to an analysis of the abandoned nests, different trees were employed to provide the building materials for various components/parts of the nest. According to the study's findings, they mostly focus their selection of nesting places and materials on what is readily available.

Similar observation was done by Borges *et.al.*, (2002**)** who studied the selection of nest platforms and the differential use of nest building fibers by the Baya weaver bird in an agricultural land in Goa. Five plants were chosen for nesting by these birds. It was recorded that they preferred tall eucalyptus trees to dwarf and medium-sized coconut trees among them. These birds provided as an example of how nest fiber is used to construct various nest components. The first research to report the discovery that female weavers build their nests in Eucalyptus came from this study. Biddle *et. al.*(2017) examined the construction patterns of birds' nest and studied Bullfinch and its nest which was used as a model for open nesting song bird species and tested the hypothesis that materials in different parts of the nest serve different functions. Before analyzing the sample, they noted down the nest's floor, rim, and the volume of material inside. Following sample examination, it was discovered that the sidewalls and cup fibers were thick and loose in comparison to other parts, while the bottom of the outer part of nest was made of the thickest, strongest, and toughest fibers.

Similarly, Mainwaring *et.al. (*2014) reviewed on the design and function of birds' nests wherein the importance of nest building and its use and nesting behavior of some birds were highlighted along with the structure and purpose of bird nests, significance of nest construction, and about nest locations, nest materials, various bird behavior etc. was reviewed. The authors called for further investigation into how nesting behavior and nest design are impacted by climate change. One investigatory study reported the role of the environment in the evolution of nest shape in Australian passerines by Medina (2019). The results of this study, which included the extraction of environmental and nesting data for songbirds on the Australian mainland, indicate that open and closed nest types are dispersed in similar climates. A thorough examination of the evolution of nests in Australia's largest beetles (Meliphagoidea), which expand to construct a shallow, supporting nest from below, indicated that adult body size—rather than the environment—was a key influence in nest shape. One such review based on the association of climate and nest morphology was done by Perez *et.al.* (2020) who reviewed on climate as an evolutionary driver of nest Morphology in birds based on the relationship between nest morphology and climate across species' distributions. A substantial collection of data has been gathered to support relationships between internal and external factors and slot-specific characteristics. Phylogenetic history's influence on nest form, how nest quality may be impacted by climate security, and instances where phenotypic plasticity of nest behavior results in heterogeneity in nest quality were discussed. They claimed that the nests are an essential component of a bird's continuous phenotypic, aiding in their growth and maybe influencing which species can withstand long-term climate change.

Desai *et. al.* (2012) researched the ecology and variety of birds in Goa, India's Taleigao highlands, and they emphasized the importance of safeguarding highland ecosystems. This study demonstrates that 10 distinct bird species breed and lay their eggs at various times of the year in various nesting locations. Birds are known to choose their nesting sites based on various factors like food, nesting material availability, low chances of predation etc. In a comparative study reported by the same authors, Desai *et. al*. (2007) on the unmanaged plantations of three tree species namely Cashew, Teak and Australian acacia with special reference to bird population. They reported the nesting of 11 bird species in these three plantations overall. The choice of breeding and nesting sites by birds in this study was found to be dependent on the food availability. Some other factors related to nesting in birds were considered and comparative studies on urban and rural areas chosen by birds were reported by the scientists as follows:

Mazumdar *et. al.* (2007) investigated and compared the nesting ecology of Red-Whiskered Bulbul at city centre and peripheral areas among farmlands and dense vegetation in Lucknow, Northern India. The nests in the cities had thin walls, an average depth, a tiny average nest size, an average height, a long average duration, and are occasionally perceived as manufactured due to a lack of available food. These nests had greater mortality rates and reduced nest productivity, which may be related to inadequate food supplies, subpar nest construction, and inadequate weather protection. The same authors Mazumdar *et. al.*in the year 2014 compared the nesting ecology of the Purple sunbird (*Nectarinia asiatica*) between the urban and rural areas in New Delhi, India. This study highlighted the contrasts between the nests found in the two environments, such as the usage of wire and paper in urban nests that were not present in rural nests. Some urban nests were observed to be suspended from wire and pipes and others from twigs. But all rural nests were suspended from branches and twigs. The height and depth of the nests in the two areas also varied. In urban nests, the death rate was greater. The study came to the conclusion that increased food availability and nesting in rural regions account for the difference in the nesting ecology of birds between the two habitats.

Another study was done in the rural areas by Sohi *et. al.*(2017) who examined the adaptations in avian nesting behaviour in relation to indigenous trees and housing structures in Punjab in two villages. In both areas, 15 distinct bird species' selection of nesting places, various nesting patterns, and use of nesting materials were noted. Ten different bird species' nests contained plastic parts, animal hair, textile fragments, wires, bangles, and other items. According to the study, different bird species have varying preferences for nesting sites in relation to house structures, farmed crops, trees, and ornamental plants, as well as nest predation at each location. In contrast to this study, a study was done in the urban areas by Zuria *et. al. (*2010) provided the information on the biology of breeding and the characteristics of nest sites for the six most common nesting birds in an urbanized area of Mexico. On seven plant surfaces, the nests were discovered. The study provided information on the plants that were utilized for nesting, average tree and nest heights, clutch size, length of the breeding season, and specific causes of nest failure for each species. Fang Y-T. (2018) studied the asynchronous evolution of interdependent nest characters across the avian phylogeny by examining the evolution of three nest characters namely structure, site and attachment across all bird families. This analysis showed that nest quality had a clear evolutionary trend and the three qualities evolved through time rather than changing considerably throughout the bird phylogeny. Additionally, it offers crucial insights into how bird nests have evolved through time and raises the possibility of a connection between nest diversity and the genetic alterations that have shaped birds today.

As can be understood through various studies done so far that the choices of different birds vary with respect to the nest sites. Similarly there is diversity seen in the architecture of the nests built by birds belonging to different orders and families**.** Lombardo M.P. (1994) studied the nest architecture and reproductive performance in Tree swallows (*Tachycineta bicolor*).The authors compared nest patterns produced in boxes by sub-adult and adult females in southeast Michigan and checked for any differences if they occur. In case if some differences were found, they further checked whether it has anything to do with the differences in ages linked to the reproductive performance. The cup index [total egg volume/nest] cup volume shows that older females generated more chicks and had larger nests but older females with already many chicks and full in the nests produced fewer chicks.

Sheldon *et.al. (*1999) reviewed on the nest architecture and avian systematics. The authors discussed about the structure, location and construction patterns etc of the nest as well as how it aids in identifying the bird that built it. They talked about the relationships between other birds that have entirely comparable nest designs. The authors discussed about how distinct swallows' nesting habits have changed as well as about this group's ecological and behavioral characteristics, such as its distribution, relationships, and reproduction. Up to that point, all recent research had relied on molecular or morphological data to support and provide insight into the nesting data, it is claimed that no modern worker had attempted to reconstruct the phylogeny of the bird family that made good use of the nests. Street *et. al.* (2022) carried out a study on the convergent evolution of elaborate nests as structural defences in birds**.** The two bird species, weaverbirds (Ploceidae) and icterids(Icteridae), were studied to better understand how nest construction and developmental period length, a proxy for offspring mortality, interact to one another. These are the two bird families whose highly elaborate pendent nests have independently evolved and the researchers used phylogenetic comparative methods for the same. They discovered that longer developmental times were linked to more complex nests in both families, especially those with entrance tunnels. This result holds up well to the possibility of confusing influences from body mass, evolutionary relationships, nest site, and latitude. According to this study, building intricate, protective structures may act as a buffer against environmental risks, lowering extrinsic mortality and promoting the evolution of shorter life cycles in a variety of animal lineages, including humans.

Warning and Benedict (2014) carried out a study based on the architecture of the nest of Rock Wren. They examined how stones obstruct the nest chambers and calculated the number of stones used by Rock Wren. Additionally, they investigated whether Rock Wrens modified their individual stone-carrying effort in response to the size of the nest cavity opening. Stone pavements reduced nest cavity openings by a mean of 34%, with bigger apertures having noticeably more stones. Individual nest pavements had up to 1.4 kg of stones, which varied in size but were generally homogeneous in thickness. According to this study, Rock Wrens modify the amount of stones used in nests in accordance with cavity parameters to reap a variety of advantages. The nest architecture of the nest in *Thripadectes* Tree hunters (Furnariidae) was reviewd by Zyskowski *et. al.* (2010) with the descriptions of fresh nests from Ecuador. By examining six nests of four different Thripadectes species and adding unpublished museum data, they examined the data already available on the nests of *Thripadectes* Treehunters and reported additional field findings from Ecuador. Additionally, they provided the first description of the nests of two different species, *T. flammulatus* and *T.holostictus.* The *T. holostictus* mostly utilized rootlets, while T. *flammulatus* also made use of grass, bamboo, and tree fern plant materials. Before that could be determined if the pattern of material specificity that was described in this study reflected the true species-specific preferences and if the use of a material is influenced by its availability, the authors encouraged the study of many more nests from various parts of each species' range.

Similar study was done by the same author in the year 1999 who reviewed on the phylogenetic analysis of the nest architecture of neotropical ovenbirds(Furnariidae) based on the literature, museum collections and some field observations. The Furnariidae family's patterns of variation in nest form and construction behaviour were examined, and the family's cladistic analysis was done using the nest characteristics. The evolutionary examination of the Furnariidae's enormous diversity in nest architecture revealed that higher taxa, rather than individual species, exhibited the majority of the variance in nest structure. According to a study by Botero-Delgadillo et al. (2017), site-specific solutions to deal with heat loss and humidity were recommended based on the inter-population heterogeneity in nest construction in a secondary cavity nesting bird. In total 123 nests from two different locations were gathered, their sizes were assessed, and the materials they were made of were enumerated. The nest's hygroscopic qualities (ability to absorb moisture) and thermal properties (which simulate heat loss through convection and conduction) were studied. General linear models, correlation tests, the quality of the nest's morphology, and functional relationships were used to test and compare the nest's thermal properties (which simulate heat loss through convection and conduction) and hygroscopic properties (ability to absorb and lose water). The findings from examining the impacts of convection, conduction, and humidity individually reveal that trade-offs (insulation-absorption) can have an impact on these birds' nesting habits. In order to adapt to the local climate, spiny-tailed lizards may utilize region-specific methods. Birds show diverse patterns of nesting in different habitats and diversity in their nests with respect to their shapes, sizes, materials used and their packing patterns and arrangement in making up their unique nests.

Weiner *et. al.* (2020) presented a perspective on the mechanics of randomly packed filaments—The "bird nest" as meta-material reviewing packing statistics, mechanical response characterization, and consideration of boundary effects. This viewpoint tried to connect the size and regional behaviour of a wad of cotton with a mound of sand, illustrating the relationship between each and outlining prospective avenues for useful applications. The structure of several nests, including platform nests, cup-shaped nests, and weaver bird nests, was discussed by the writers. The authors emphasized that additional cross-disciplinary research on bird nesting behaviour, with controlled material inputs, output mechanical characterization, and complementary experiments and simulations of artificial analogues, could reveal generalizable construction algorithms with substantial biological and technological implications.

By applying one such algorithm, Jessel *et. al.* (2019) worked on a modeling algorithm for exploring the architecture and construction of bird nests as this is not a much-explored area in terms of the mechanics involved in constructing these biological structures and studying these digitally can provide the opportunity to know their structural properties and understand bird behavior under particular situations by means of computational manipulations, simulations, and analyses. The generic algorithm was used in this study for exploring the Dead-Sea Sparrow *(Passer moabiticus*) nest located on tree branches. The computerized tomographic scans of the nest were used as the inputs in the algorithm and analyzed the scans with three dimensional data and the branch properties were obtained at the end. Finally, the three-dimensional digital model of the nest that contained a complete geometric dataset with respect to the dimensions, contact points with neighboring components and density distribution and network structure was obtained. One such research work by Andrade-Silva *et. al.*(2021) focused on studying the cohesion of bird nests by analyzing the assembly of mono disperse flexible fibers. They characterized the geometry of the initial assembly, the number of contact points, and the mean curvatures of the fibers using X-ray micro tomography. By adjusting the geometry of the fibers, the mechanical properties of the fibers, and the packing of the preparation, they were able to characterize the aggregate's macroscopic cohesive strength using force displacement measurements. The macroscopic mechanical behaviour of the assemblage was associated with the filament rearrangement at the microscopic size at the end of the investigation.

A similar work to this was done using the X-ray micro tomography by Varoudis *et. al.*(2018) who explored the nest structures of acorn dwelling ants using this technique and studied them with surface-based three-dimensional visibility graph analysis. High-resolution 3D scans of the

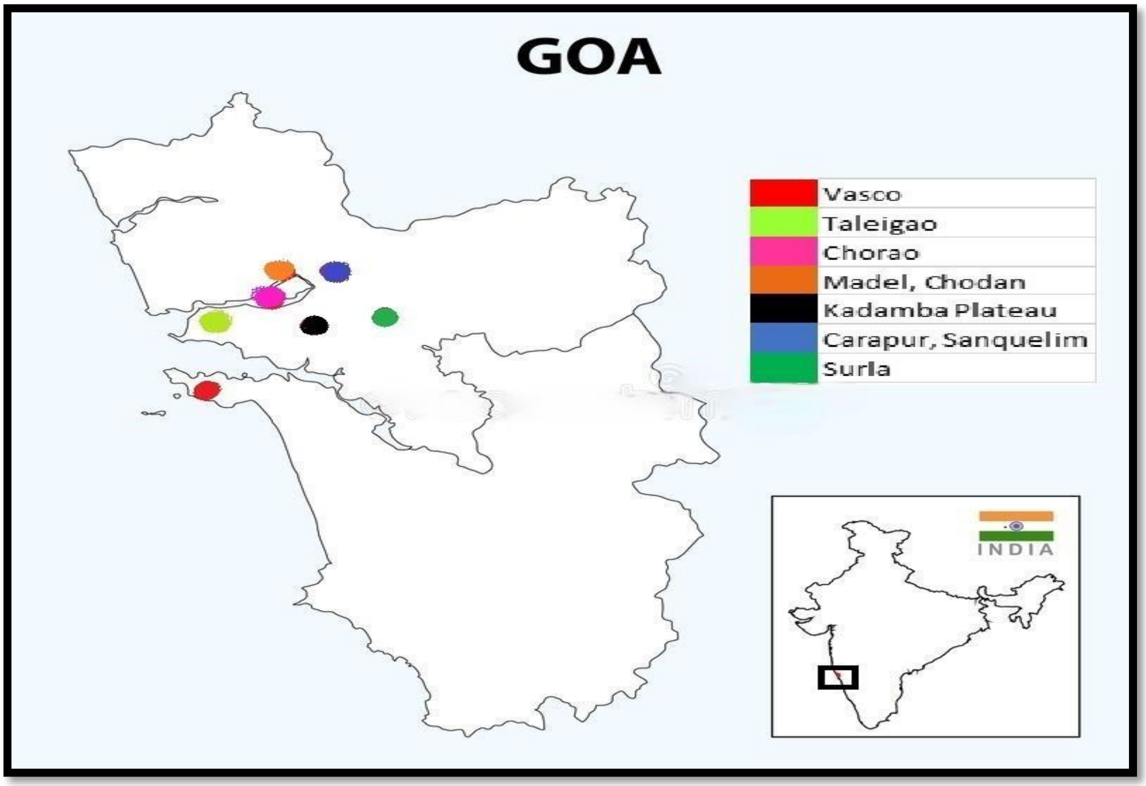
Temnothorax ant's colonies within its acorns were taken using X-ray micro tomography. The data was also quantified using picture segmentation and a surface-based 3D visibility graph. It was discovered that some areas were substantially more suited to connectivity than others, such as those connected to the locations of the queen and the brood. So, till date, very few such studies have been done to explore the construction methods and materials used by the birds in their nests (Biddle *et. al.*2014, Biddle *et. al*. 2017, Jessel *et. al.* 2019).

So far only one study has been reported by Bailey *et. al.*(2015) on the image analysis of the weaverbird nests, *Ploceus* species, which reveal the signature weave textures using the Gabor filters. In this study they checked if the computer-aided image texture classification approaches are useful in analyzing the variations in texture in this bird's nest. They found that this approach is very useful in understanding not only the individual variations in the structures of the nests of birds but most of the animal built structures as well. They used the six rotation filters at four different spatial scales considering the frequencies from 0.5 to 0.4.

The advanced technologies like the X rays are not been used much to understand the structure of birds' nests, their shapes, fibers and the fabrication based on analysis using the Gabor filters. Hence the current study is designed to understand the architecture of seven nests of seven different species from the order Passeriformes, since this order has the largest and abundant diversity of bird species, using the Gabor filters to analyze the nests in detail.

STUDY AREA

Figure 1- A map showing the seven nest collection sites



The seven study sites were chosen randomly. The exact locations of the study sites are mentioned in table 2. These areas area s follows: **1.Vasco(South Goa):** An urban area

2.Taleigao- A plateau

3. Chorao- Partly human inhabited area along with an agricultural land.

4. Madel, chodan- Partly occupied for human settlement, partly agricultural land

5.Kadamba plateau- A plateau, major part is human occupied for settlement

6.Carapur, Sanquelim- An urban area, used for human settlement

7.Surla, Sattari- An agricultural area

MATERIALS AND METHODS

This study was carried out from May 2022-April 2023. Few sites were scanned randomly in search of the presence of any nests of the selected families of Passerine birds and during the fieldwork, the nesting habits and architecture of nests of seven species of the chosen families were studied. The nests that were located on different substrates were first observed with the Celestron Upclose G2 binoculars to know if they were active (in use) and if any bird was found nearby or inside the nest. As per the guidelines mentioned (Barve *et. al.* 2020) a distance of 12-15 m was maintained in case of the active nests and care was taken that no active nest and the birds were disturbed when observing the nests. The active nests were observed at noon time as per the guidelines.

The observations were made considering some set parameters like the type of habitat in which the nest was found, the substrate or the host trees were identified and the height at which the nest was built was noted down. The GPS map camera app version 1.4.8 was used to click the geo-tagged pictures of the located nests in Realme Narzo 50 A phone camera. Few photos were clicked with the camera Nikon D6500 fitted with 500mm lens. In case of the abandoned nests, after noting down the above details the nests were collected, taking care while handling them such that their structure was not disturbed. The dimensions of the nests such as the length, diameter and depth were measured with the scale and the type of fibers and the materials used in making the nests was noted down. The thickness of the fibers was measured with the Vernier caliper as shown in figure 1. The nests were later packed and kept in the boxes separately. Further, the normal colored images of the nests, and the X ray images were captured along the three views i.e., the front view, back view and the lateral view of the nests by changing the nest positions. Table 1 gives the details of the details of the samples of each type of nest. For this study, the colored and X ray images of only the front views of the nests (figure 1) were analyzed by applying the Gabor filters at 5 scale and 8 different orientations that corresponds to 40 different representations of filters (as shown in figure 2) to understand and compare their architecture in terms of the orientation and density of the fibers in seven nests of different shapes. The signals passed through the Gabor filters perpendicular to the edges i.e. the fibers of the nests. The frequencies used for this study were 0.06Hz, 0.09Hz, 0.13Hz, 0.18Hz and 0.25Hz. The orientations used were along 0 deg, 23 deg, 45 deg, 68 deg, 90 deg, 113 deg, 135 deg and 158 deg. Further interpretations regarding the fabrication and the density of nest fibers in all the selected nests were done based on the frequency and orientation of the X ray images.The Kruskal-Wallis test, a non-parametric test was used to compare the diameter of fibers in two data sets i.e. set 1-outer fibers of all the seven nests and set 2- inner fibers of all the nests.

Table 1: Sampling of the images of 7 studied nests

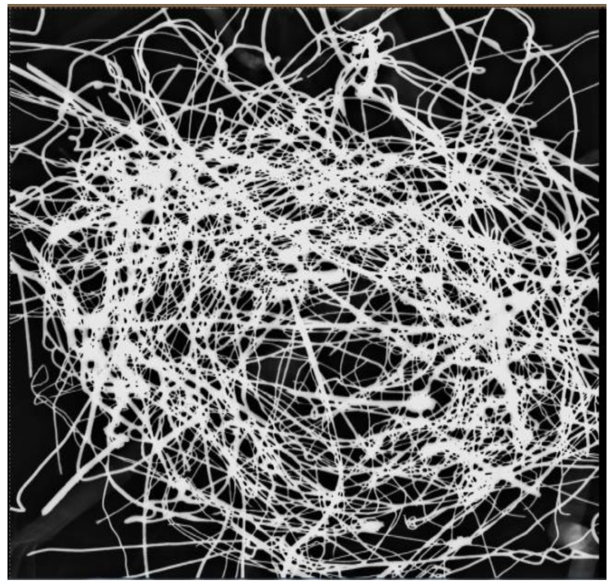
Birds	Nest shape	Number of samples(images)		Total samples(images)
		Colored	X rays	
House crow	Platform	3	3	6
Ashy prinia	Oblong	3	3	6
Common tailorbird	Leaf tunnel shaped	3	3	6
Red-whiskered bulbul	Cup	3	3	6
Purple sunbird	Purse	3	3	6
Baya weaver	Pendant	2	2	4
Scaly-breasted munia	Dome	3	3	6

Figure 1- Measurement of nest fibers using Vernier caliper

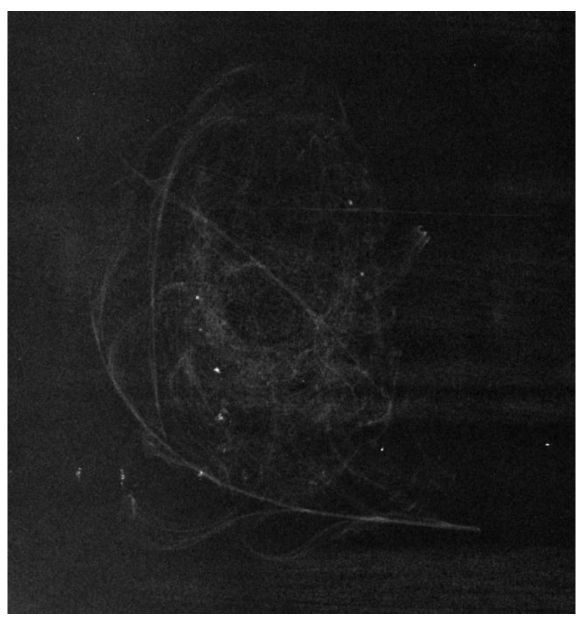
Figure 2: Colored and X ray images of the front view of the studied nest

a. **House Crow's nest**

(i) Colored image **(ii)X-ray image**



b. **Ashy prinia**

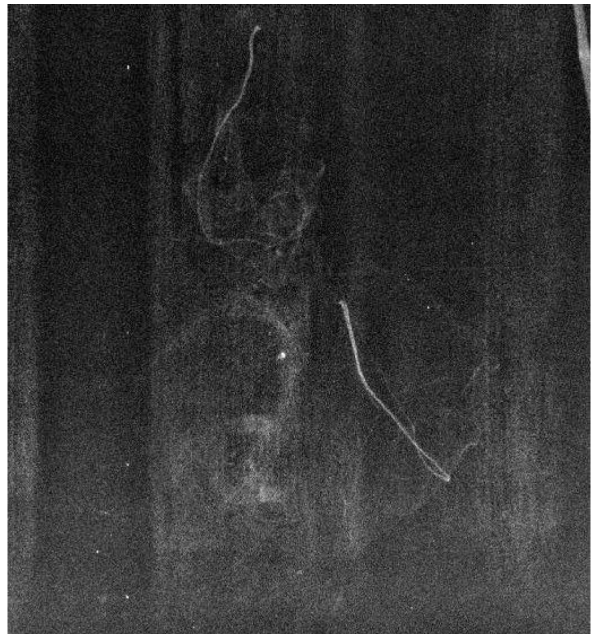


(i) Colored image **(ii)X-ray image**

c) Common tailorbird

(i)Colored image

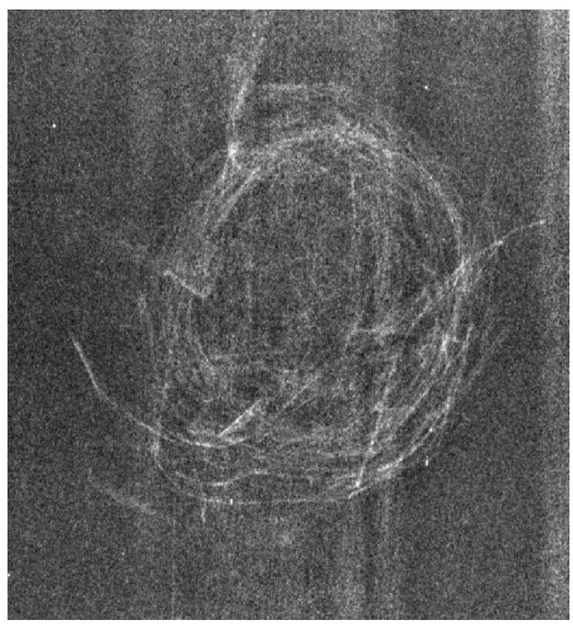
(ii) X-ray image



d) Red-whiskered bulbul

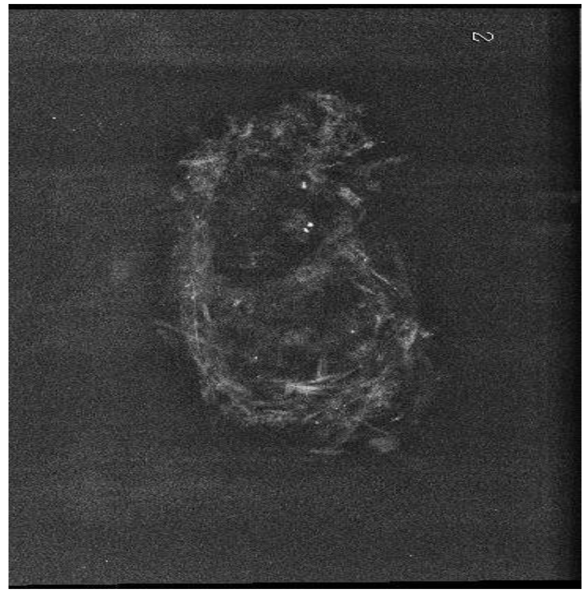
(i)Colored image

(ii) X-ray image



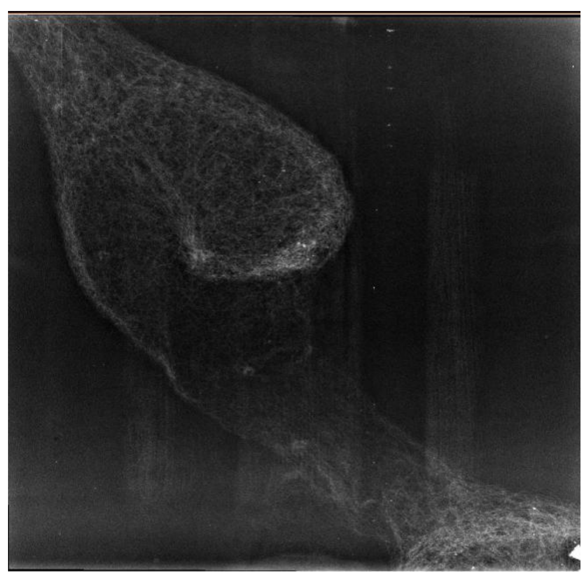
e) Purple sunbird

(i)Colored image **(ii) X-ray image**



f) Baya weaver

(i) Colored image **(ii)X-ray image**



g) Scaly-breasted munia

(i) Colored image

(ii) X-ray image

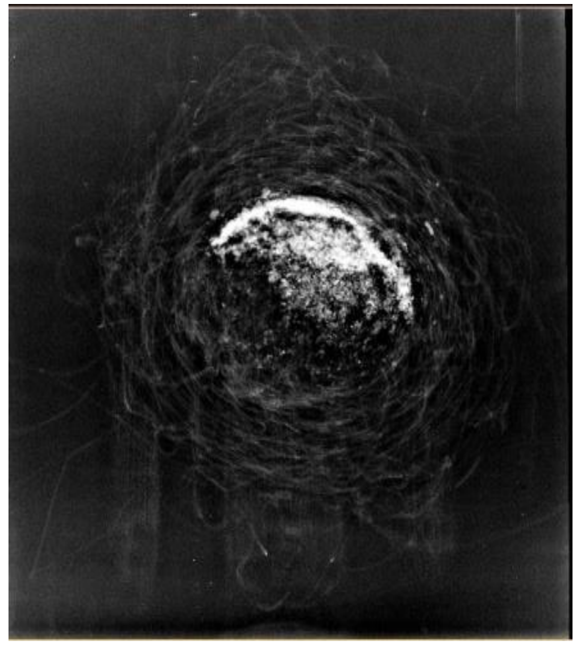
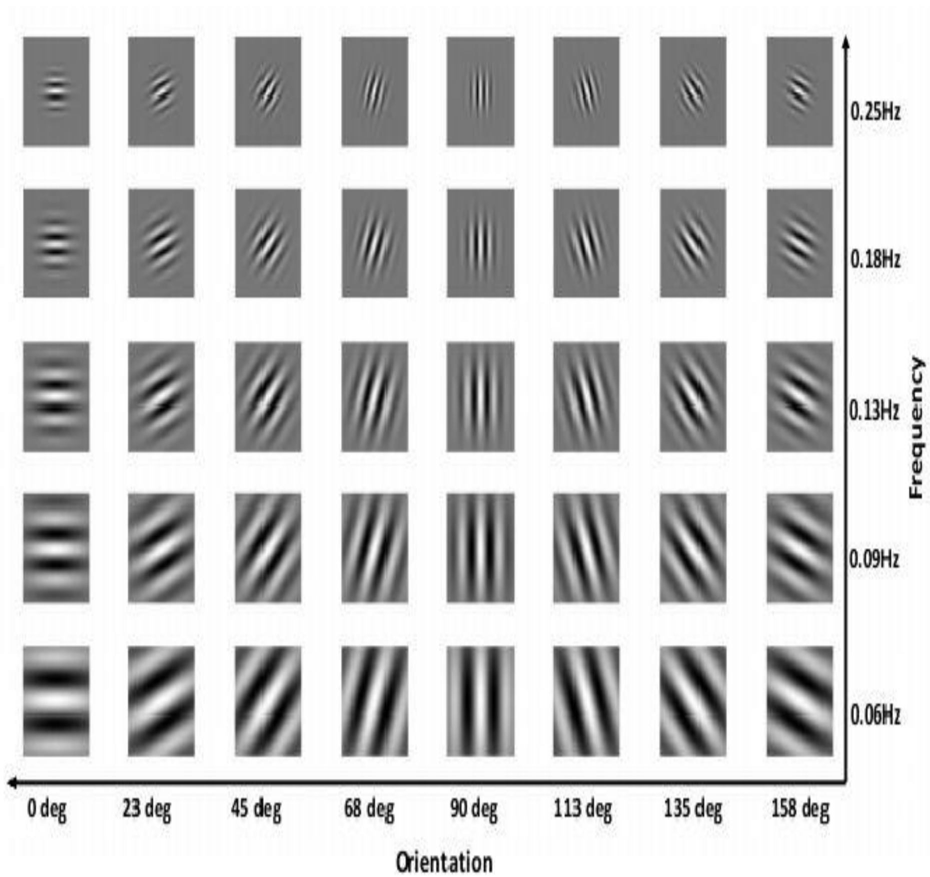


Figure 3- Gabor filters



OBSERVATION

The chosen Passerine bird species for this study showed varied patterns of nesting with respect to the type of nesting habitat chosen, plants of particular type and height and the peculiar nest shapes as shown in detail in table 2. The nests differed in terms of shapes and dimensions such as nest length/height, outer diameter and the depth as mentioned in table 3. Similarly, the nest fibers chosen for making different parts of the nests varied in terms of dimensions and texture according to their use i.e. externally and internally, based on their requirements, which is given in detail in table 4. For example, the fibers lining the base externally and those lining the nest internally where eggs are laid differed from each other. Distinct patterns of arrangement of the fibers such as woven, piled up, intertwined fibers etc in the nests of various shapes were observed. These fibers chosen had specific texture and dimensions in different species of these birds. Following is a detailed description of varied nest shapes along with the nest materials used, their dimensions and different fabrication patterns of nest fibers with their densities in different parts of the nests given by applying the Gabor filters to the selected bird species' nests. (Refer figure 3 for the pictures of the birds and their nests).

1.Platform nest of House crow (*Corvus splendens*)

The platform nest of the House crow did not have a peculiar shape as such when compared to the other nests. It was the biggest nest among all with respect to its size and the fibers' dimensions. It was very intact and attached to a branch of the host plant very tightly. It was made up of maximum of iron wires and few iron nails with very few wooden twigs intertwined together. The outer fibers used were mostly of iron wires and few iron nails were used of 0.4mm diameter and were found on outer side of the nest with just one on the inner side. The inner part of the nest, where eggs are laid had mostly wooden fragile soft twigs along with thin iron wires and a thin nylon rope of 0.1mm.Two other flat nylon ropes were found lining the upper inner edges of the nest. (Refer figure 4 for the pictures of different materials used in this nest).

The features of platform nest could be clearly seen for all the frequencies only with 0 degree and 90 degrees when the Gabor filters were applied which means that all the fibers of different densities were arranged in these two orientations horizontally and vertically in the nest which are detected by those particular filters. Further, some partial information could be seen for 0.25Hz and 0.18Hz which indicates the presence of few densely packed fibers and the least dense fibers detected at 0.06Hz frequency are present in the nest and detected for all the 8 orientations. Since the fibers used are metallic and wooden with high thickness, their density is high too which is revealed by the higher frequencies at which the filters detect the presence of fibers in the orientations of 0 and 90 degrees. (Refer figure 5 for the picture of Gabor filter and nest features visible in the same).

2.Oblong nest of Ashy prinia (*Prinia socialis)*

This oblong shaped nest on the outer side was lined by few leaves which could be of the plant from Acanthaceae family. Some silky smooth fibers of *Bombax ceiba* are used only on the outer side. Majority of the fibers that made up the nest were dry and thin which were used on both the outer as well as on the inner side of the nest. The circular entrance hole with a diameter of 4.5cm, located on the upper side of the nest was observed. The features of this oblong shaped nest were clearly visible with 0.06Hz frequency for all the 8orientations i.e. from 0 degree to 158 degrees which means that the fibers are very less dense and sparsely packed in various orientations with each other. The fibers can be detected at 0 degree and 90 degree partially for all the frequencies i.e. from 0.06Hz to 0.25Hz which indicates that some of the fibers ranging from highly dense to less dense are arranged horizontally and vertically at 0 and 90 degrees.

3. Leaf tunnel shaped nest of Common tailorbird (*Orthotomus sutorius)*

The two leaves of Cat tail plant (*Acalypha hispida*) were stitched together with the thread and was given the shape of a tunnel. The dry fibers were used to make a small cup which was placed inside the stitched leaves. The outer base was lined with the sponge. Few small black and white feathers were lined on the inner side with some cotton at the inner base and few human hairs were also found inside the nest. For leaf tunnel shaped nest, the features were clearly seen with 0.25Hz frequency indicating the presence of dense fibers and those at 0.06Hz shows the presence of least dense fibers for all the 8 orientations i.e. from 0 degree to 158 degrees. Whereas for 0 degree and 90 degrees the information could also be partially seen for all the frequencies i.e. from 0.06Hz to 0.25H which means that there were few fibers ranging from high to low density which were packed with each other horizontally and vertically at the respective given orientations.

4. Cup shaped nest of Red-whiskered bulbul (*Pycnonotus jocosus*)

The fibers used all over the nest were of same type i.e., dry, thin and long. Three types of leaves were found to be attached at the outer base of the cup, one being of *Grivia nervosa*. The features could be clearly seen with 0.06Hz frequency for all the 8 orientations i.e., from0 degree to 158 degrees which showed the presence of least dense fibers at all these orientations. Also for 0 degree and 90 degrees, the information could be seen for all the frequencies i.e. from 0.06Hz to 0.25Hz.Hence we can say that fibers of different densities i.e. high, medium and low were used in the nest and aligned horizontally and vertically to each other.

5. Purse shaped nest of Purple sunbird (*Cinnyris asiaticus)*

This particular type of nest had a variety of fibers used in it. The outer lining of the nest had small pieces of wood, a dry flower and few small pieces of dry leaves attached to the nest. The inner base at which the eggs are laid had a very smooth layer of silky fibers of *Bombax ceiba*. An entrance hole was located at the upper part of the nest. For this nest, the features could be clearly seen with 0.06Hz frequency for all the 8 orientations i.e. from 0 degree to 158 degrees. It means that the fibers which were least dense were sparsely packed and were used all over the nest. Further, for 0 degree and 90 degrees, the information could also be seen for all the frequencies. So, it is understood that all three categories of fibers namely most dense, medium and least dense fibers were packed in the nest horizontally and vertically at respective orientations.

6. Pendant nest of Baya weaver (*Ploceus philippinus*)

The Baya weaver's nest was the longest and of unique type among others. It was made up of Coconut (*Cocos nucifera*) leaf fibers. It had a long hollow tunnel like entrance from below, a thick egg chamber and an upper hanging portion that usually is attached to the branch. A small quantity of mud was also present inside the egg chamber. Through the X ray image of the nest, one could make out that the fibers were densely packed along the outer lining and the base of the egg chamber and at the upper hanging region.

This was the only nest among all, whose features were observed for all the given frequencies and orientations. So this revealed that the fibers of all three densities were used and fabricated in all the orientations.

7. Dome shaped nest of Scaly-breasted munia

This nest consisted of the long leaves of a grass from Poaceae family from outer side and had fibers of the same grasses lined internally. There was a circular entrance hole on the upper side of the nest which led to quite deep space inside it. For this nest, the features could be clearly seen with 0.25Hz, 0.18Hz, and 0.06Hz frequency for all the 8 orientations i.e. from 0 degrees to 158 degress which showed the presence of dense, medium and least dense fibers packed in all orientations in the nest. Further, for 0 degree, 90 degrees and 158 degrees the information could be seen for all the frequencies i.e. from 0.06Hz to 0.25Hz indicating all three categories of fibers in terms of density to be present in those particular orientations.

Overall, it was observed that maximum of grasses and leaves were used in many of the studied species. There are differences in the size of birds with respect to their nests' sizes. In case of Red-whiskered bulbul, the bird is bigger in size as compared to the nest. But in case of Baya weavers and Scaly-breasted munia, the nest built is much bigger than their body size. The other nests of Ashy prinia, House crow, Purple sunbird and Common tailorbird, were found to be slightly bigger than birds. Also the nest fibers were arranged mostly in the orientations of 0 degree and 90 degrees within the nests. The sticks and metallic materials were reported only in the House Crow's nest and sponge and human hairs were found only in Common tailorbird's nest. Rest all of the nests had natural materials used in them.

The Kruskal-Walis test results for the outer fibers showed, the value of p as: <0.001 which was less than the significance value of 0.050.

Similarly for the diameter of inner fibers of the nests, the value of p was <0.001, which was less than the significance value of 0.050. This showed that there was a significant difference in the diameters within the inner and the outer fibers of all the seven nests. .

Table 2: Details of the studied nests

Family of birds	Nest location	Host plant/object	Height of nest above ground	Type of habitat	Vegetation around the nest	Nest shape
A.Corvidae						
Corvus splendens	Taleigao, $15^0$27'31"N $73^0$49'29"E	*Peltophorum pterocarpum*	3m	Plateau	*Peltophorum pterocarpum* trees, small grasses	Platform nest
B.Cisticolidae						
(i)*Prinia socialis*	Chorao, $15^0$33'15.5" N $73^0$53'47.7" E	*Dypsis lutescens*	1m	Agricultural area and partially human inhabited	Grasses, Flowering plants, Coconut trees	Oblong
(ii)*Orthotomus sutorius*	Vasco, $15^0$23'30"N $73^0$49'43"E	*Acalypha hispida*	1m	Urban area	Garden plants	Leaf tunnel shaped
C.Pycnonotidae						
Pycnonotus jocosus	Carapur, Sanquelim 15.569128^0 74.003044^0	*Ocimum sanctum*	1.5m	Urban area	Flowering plants, Coconut trees	Cup shaped
D.Nectariniidae						
Cinnyris asiaticus	Surla Sattari 15.4980918^0 74.0330971^0	A climber	1.5m	Agricultural land	Cashew plants, grasses, Congress plants	Purse shaped
G.Ploceidae						
Ploceus philippinus	Madel, Chodan 15.523807^0 73.873546^0	*Cocos nucifera*	8m	Agricultural land and partly human inhabited	Coconut trees, small shrubs	Pendant shaped

H. Estrildidae						
Lonchura punctulata	Kadamba plateau, $15^{0}29'19''$N $73^{0}49'35''$E	Inside a house on a chandelier	2.5m	Urban area	-----------	Dome shaped

Table 3: Nest dimensions

Nest shape	**Nest Length/height (cm)**	**Nest diameter (cm)**	**Nest depth (cm)**
1.Platform nest	20	36	8.5
2. Oblong nest	13	8	10
3. Leaf tunnel shaped	8	6	5
4.Cup shaped	5.5	9.5	3
5.Purse shaped	14	7	11
6.Pendant nest	44	18	18
7.Dome shaped	23	15	18

Table 4- Details of materials used in the nests and nest and bird size comparison

Shapes	Materials used		Range of fiber diameter(mm)		Fiber density	Size of nest with relation to bird size
	Outer	Inner	Outer fibers	Inner fibers		
Platform	Twigs, Iron wires, few iron nails	Twigs, Iron wires, thin nylon rope, Iron nail	0.2-0.4	0.1-0.3	Low	Nest slightly bigger than bird
Oblong	Dry thin fibers, leaves of Acanthaceae family plant, cottony material of *Bombax ceiba*	Dry thin fibers	0.03-0.05	0.02-0.03	Medium	Nest slightly bigger than bird
Leaf tunnel shaped	Leaves of *Acalypha hispida,* dry fibers, thread, some sponge	Dry thin fibers, cotton, few feathers and few human hair	0.02-0.03	0.01-0.02	Medium	Nest slightly bigger than bird
Cup	Dry thin fibers, Leaves of *Grewia nervosa* and 2 more types of leaves	Dry thin fibers	0.04-0.05	0.04-0.05	Medium	Nest smaller than bird
Purse	Dry thin fibers,small wooden pieces, a dry flower,few dry leaves	Grasses of Poaceae and Cyparaceae family,soft silky material at the base	0.01-0.03	0.01-0.03	Medium	Nest slightly bigger than bird
Pendant	Coconut fibers, small quantity of mud	Coconut fibers	0.03-0.05	0.02-0.04	High	Nest much bigger than bird
Dome	Grass leaves of Poaceae family	Inflorescence of Poaceae family	0.6-18	0.05-0.08	Medium	Nest much bigger than bird

Figure 4- The seven Passerine bird species and their nests

(a) House crow

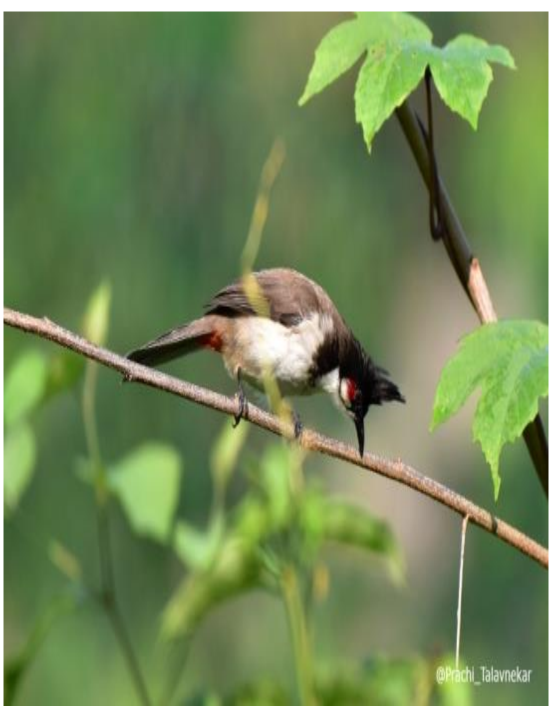
(i) Platform nest

(b) Ashy prinia

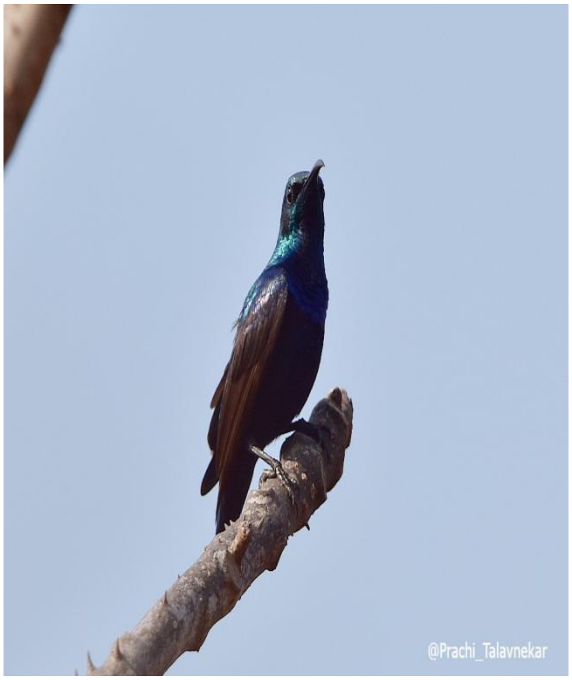
(ii) Oblong nest

(c) Common tailorbird **(i) Leaf tunnel nest**

d) Red-whiskered bulbul **(i) Cup nest**



e) Purple sunbird



(i) Purse shaped nest

f) Baya weaver

(i) Pendant nest

g) Scaly-breasted munia **(i) Dome shaped nest**

Figure 3-a,b,c,d,e- Courtesy-@Prachi_Talavnekar

Figure 3-f-https://ebird.org/species/bayawea1?siteLanguage=en_IN

Fig 3, g-Courtesy-Mr. Anuraj Gaonkar

Figure 4-Materials used in the platform nest

(a)An iron nail used as an outer material (b) A blue thin nylon rope, metal wires and wooden sticks lining the nest internally

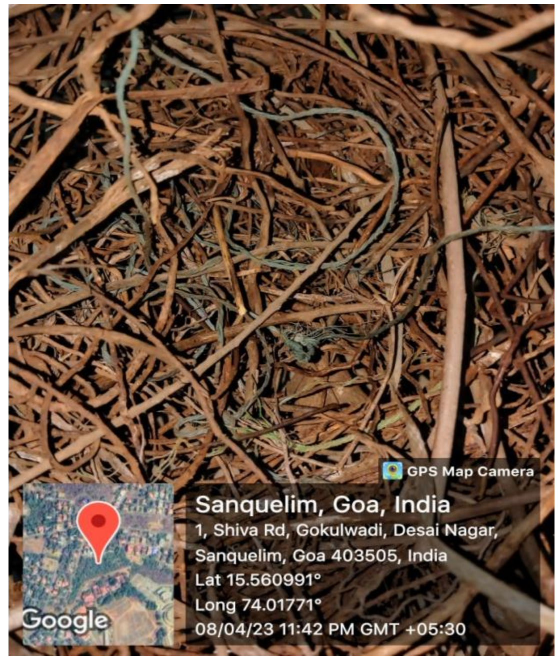


Figure c-Nest features visible in the Gabor filter

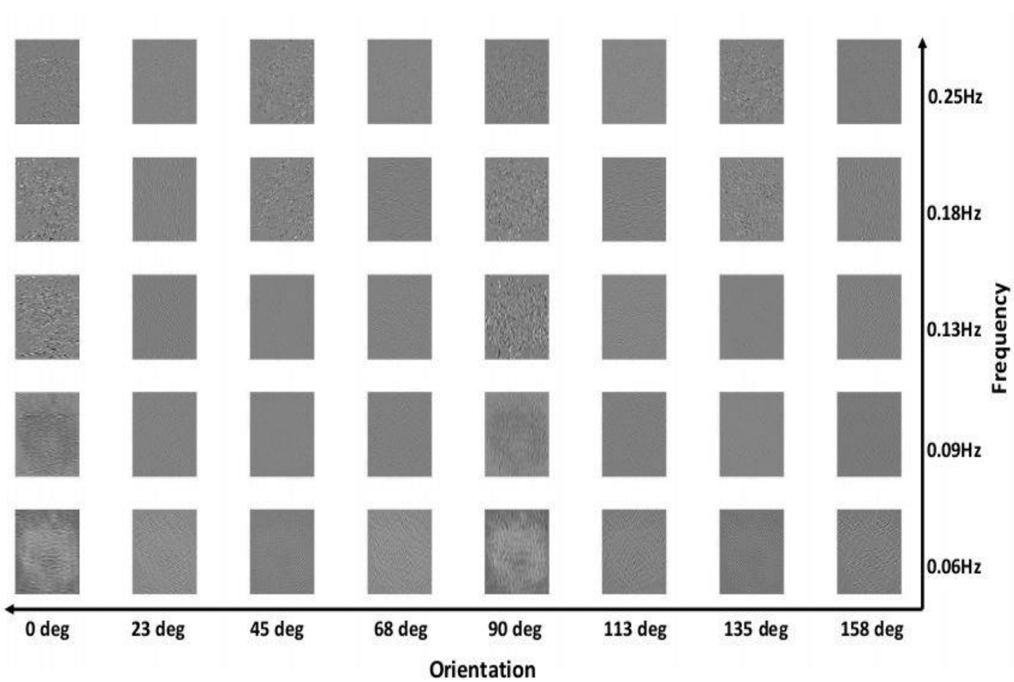


Figure 5- a- Soft fibers lining the oblong nest externally with the leaves of Acanthaceae family plant

Figure:b- Features of oblong nest in Gabor filters

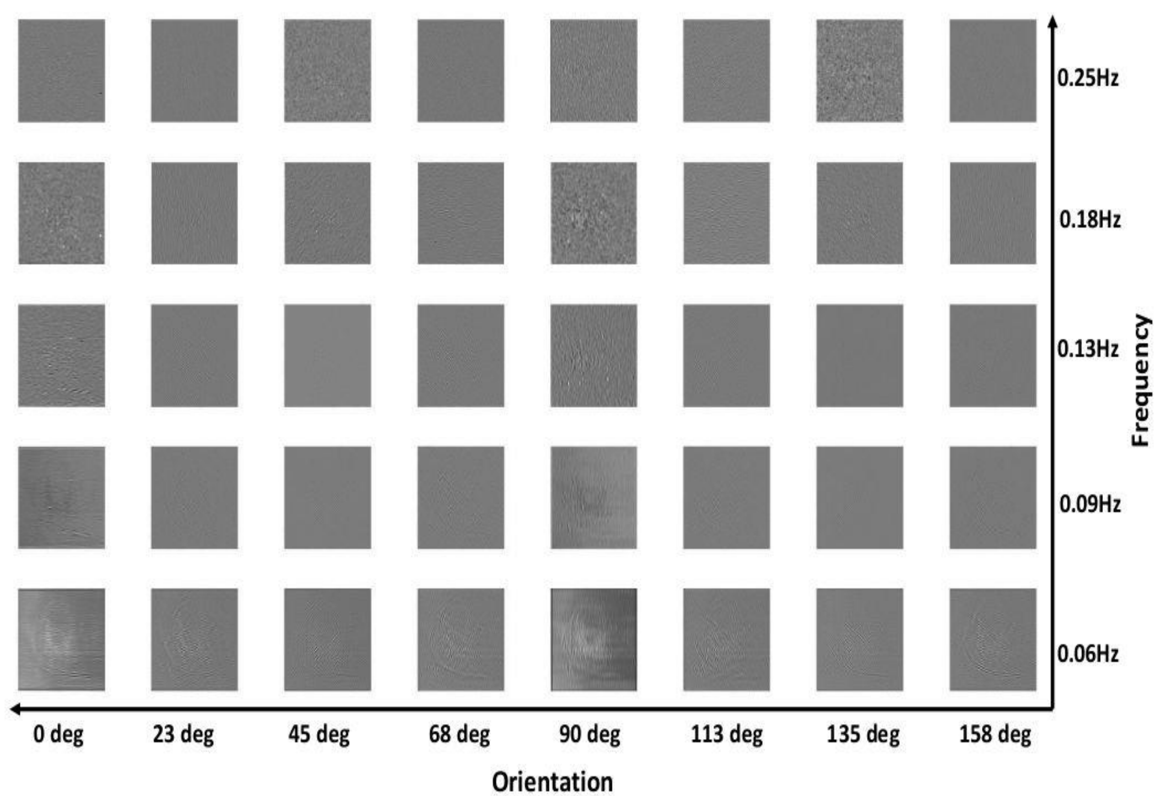


Figure 6- Common tailorbird's nest with:

(a) **Sponge and feathers lining the nest base externally (b) Cotton, feathers and few human hairs found inside the nest**

Figure c-Nest features of leaf tunnel shaped nest

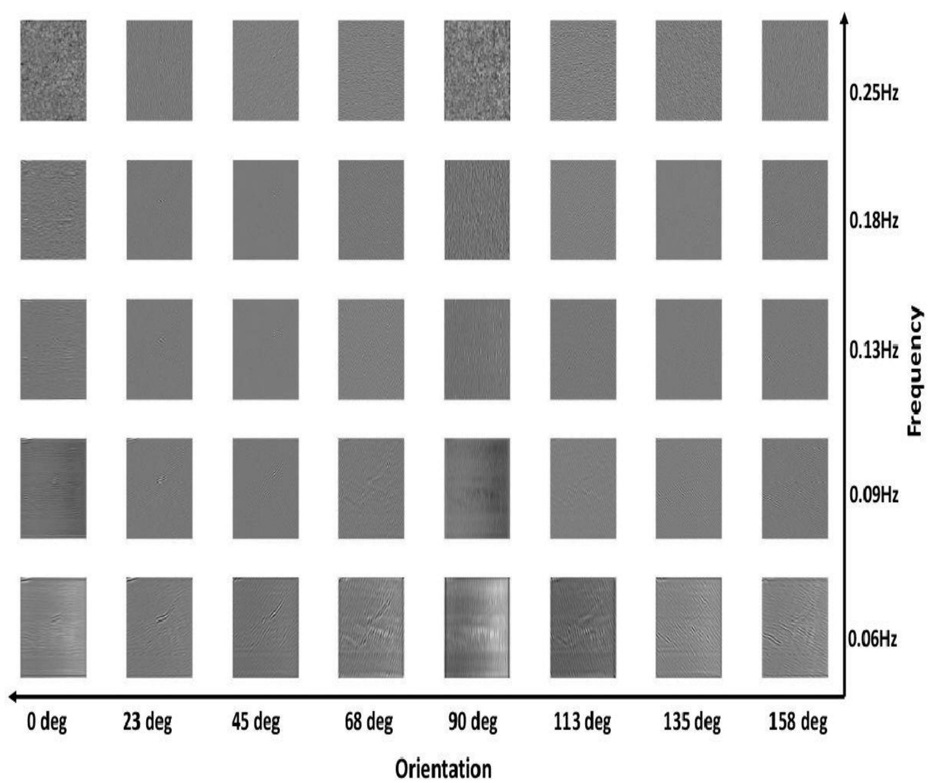


Figure 7-a- Three types of leaves attached to the exterior base of cup nest

Figure-b-Cup nest features observed in Gabor filters

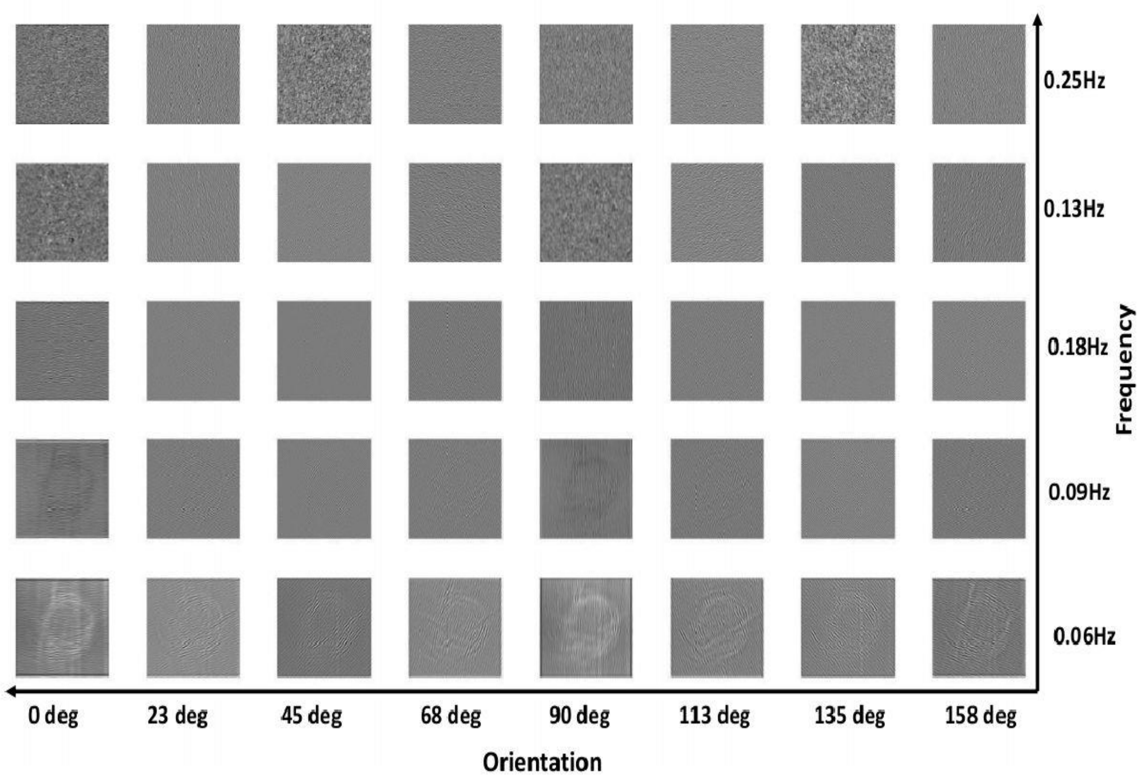


Figure 8-a- Dry fibers, a dry flower and wooden pieces attached externally to the purse shaped nest

Figure:b- Features of purse shaped nest with Gabor filters

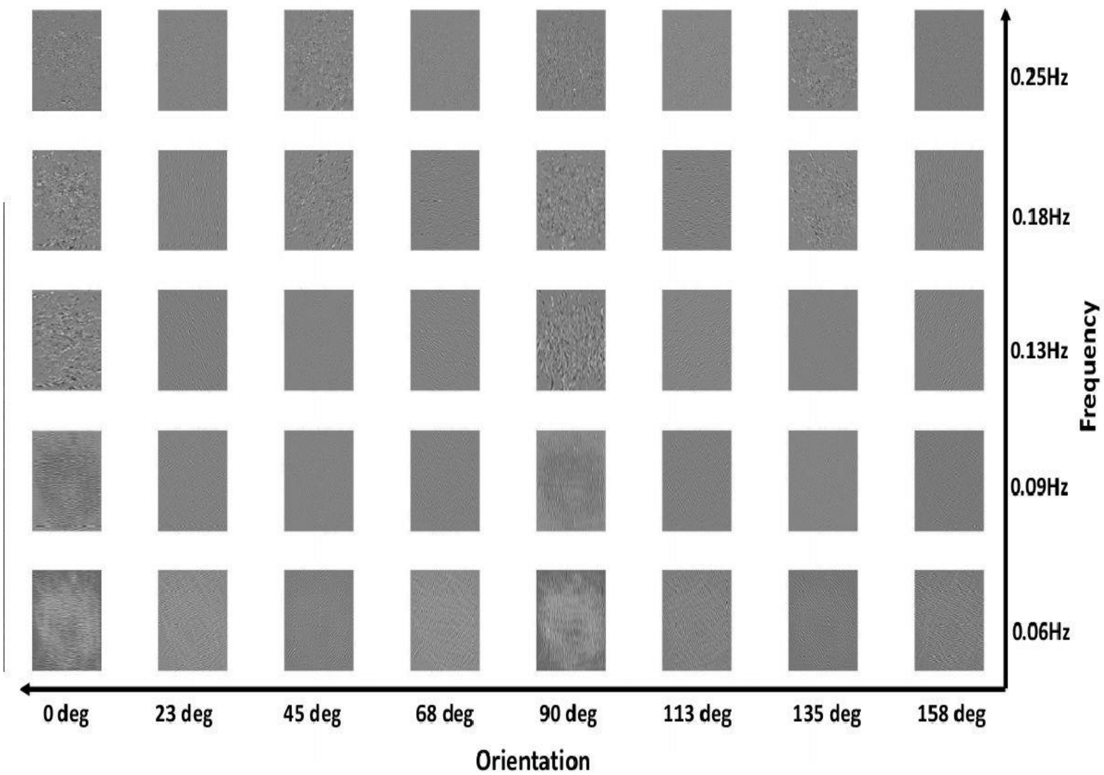


Figure 9-a-Mud in Baya weaver's nest

Figure: b-The features of pendant nest in Gabor filters

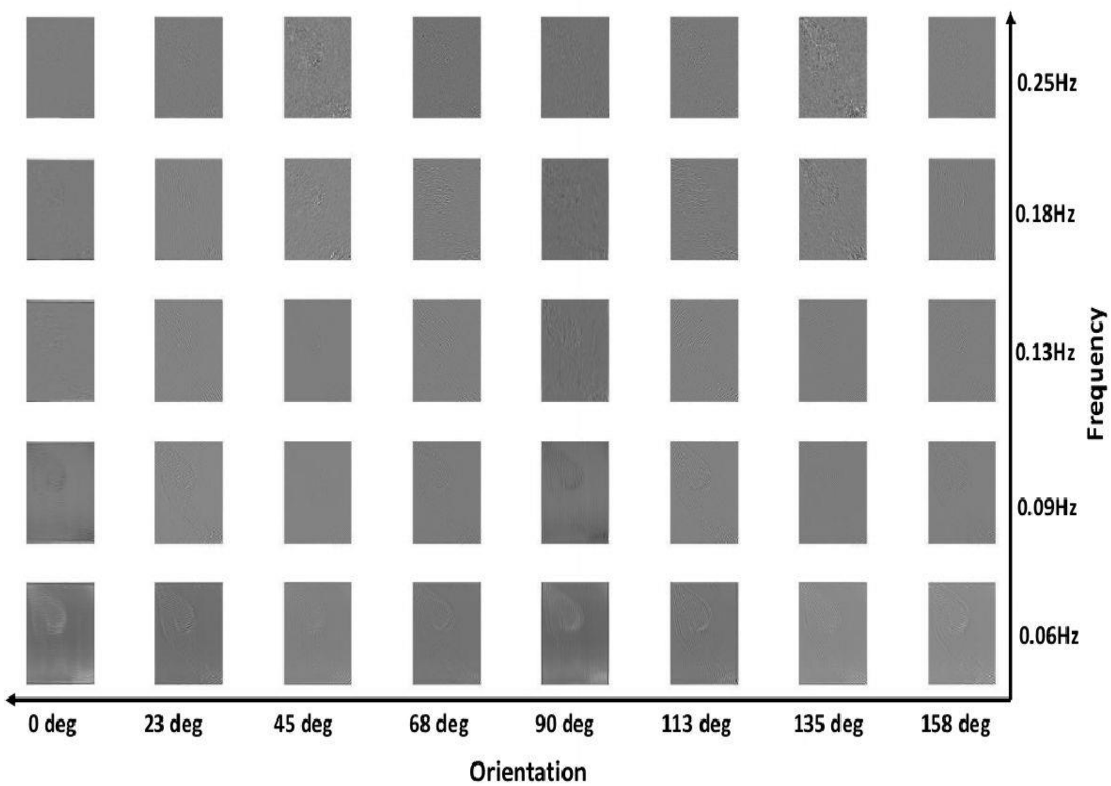
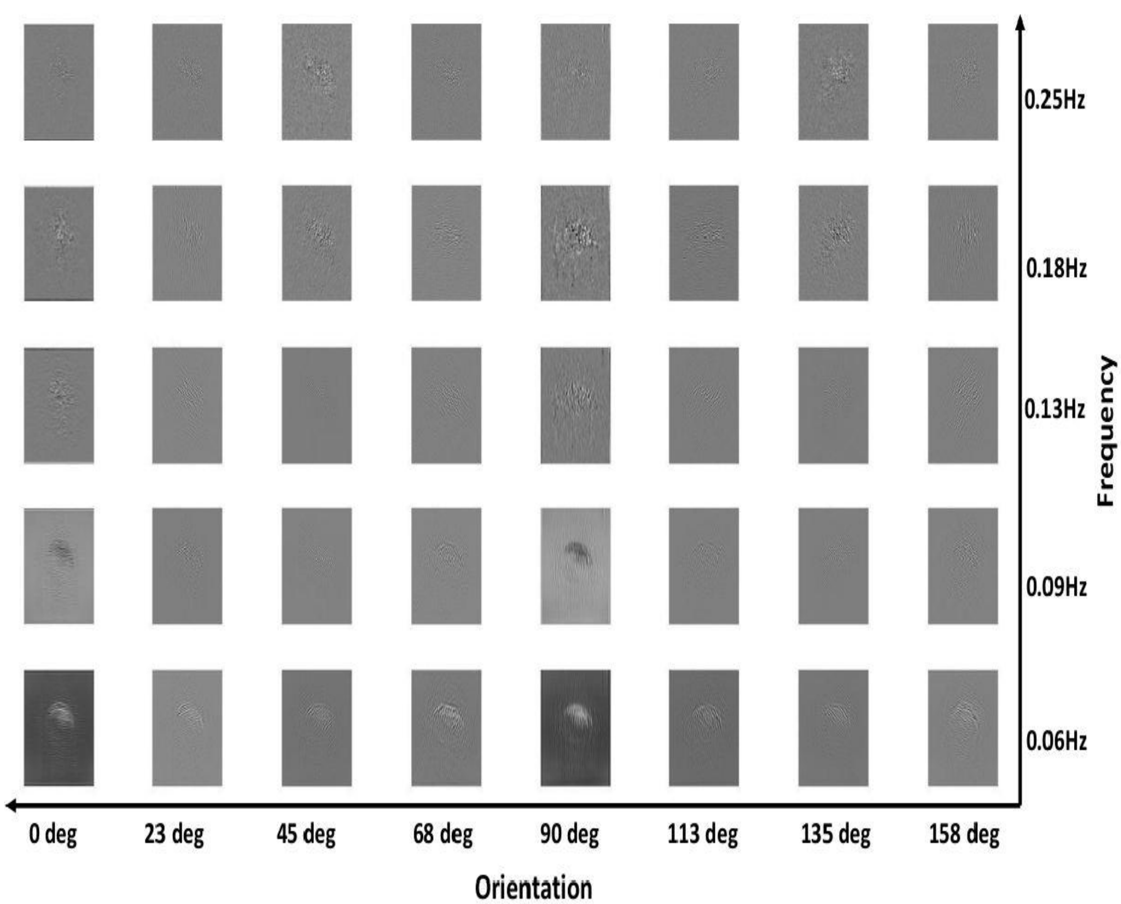


Figure-10-a-Inner grass fibers in dome shaped nest

Figure:b-Features of dome nest in Gabor filter



DISCUSSION

Through this study it is understood that the birds prefer their nesting sites based on the favorable factors for their growth including food, protection from predators, availability of nesting materials etc. They show varied patterns and architecture of their nests with respect to nest shape, size, materials used in making the nest, their dimensions, fabrication patterns etc. The birds either pile up the fibers; they are stuck together, interlocked, sewn or woven in different bird species or could show some other pattern. Birds might use fibers of varying properties and arrange them in a peculiar fashion but the main aim is to make it intact so that it serves the necessary function. The nest fibers also differ in their texture when it comes to their utility for making the outer and inner lining of the nests based on the requirements such as softness in case of inner fibers where the eggs are laid for comforting the chicks while growing and tough fibers on the outer side for the protection from climatic changes including heavy rains.

In the present study, the variety of nesting materials, both natural and artificial, of birds' choices was observed. The House crow's (*Corvus splendens*) nest was the unique one among all. It was found at the construction site on the *Peltophorum pterocarpum* tree which had two more nests of the same species. This suggests that the House crow is a tree nester as already concluded by Dutta (2007). The nesting of these species on the same tree simultaneously, indicates the lesser availability of host plants in that area as well as the potential site for availability of artificial materials like the metal wires as it was close to the construction site. It also suggests that this species is tolerant and cooperative for nesting with the conspecifics. A study by Kaur M. and Khera K.S. (2020) had reported the crows carrying the metallic wires, tree twigs, plastic strings, and dry grass in their beaks. In this study, the House crow's nest was made up of metal i.e., iron wires of varying diameters including the iron nails in the outer lining of the nest. The first report of the metal wire used in a nest was in the nest of Pied crow (*Corvus scapulatus*) by Warren 1933**.**

Few twigs were used on the outer side of the nest in the present study. The inner part of the nest where eggs are laid had soft twigs as well as iron wires of almost uniform thickness along with a thin nylon rope. Similar report to this study was given by Goutam and Kushwaha, (2012) about the presence of 3-4 nests on the same tree. Allan and Davies, (2005) could spot and report up to 10 nests on the single nesting tree in Durban, South Africa. The study done by Kaur M. and Khera K.S. (2020) had reported the use of sticks and twigs intertwined with metal wires, plastic ropes, and polythene bits. Whereas soft materials like dry grass, animal hair, and wool was used on the inner side of the nest. Use of twigs, wires and grass was also observed and reported by Awais *et.al.* (2015). Ryall (2002) recorded the use of much of wire in nest construction in the Crow's nest similar to the current study. A nest built inside a roll of wire mesh by using large quantities of metal pieces was reported by Costa and Mäder (2011) in a Chalk-browed mockingbird.

The nest of Ashy Prinia (*Prinia socialis*) had a peculiar oblong shape and was built with materials like dry thin fibers, dry leaves and cottony material of *Bombax ceiba* on *Dypsis lutescens* plant. In contrary to this, Sawar and Hussain (2018) have mentioned the use of soft twigs, dry herbs and grasses by these birds in their nests which were cup-shaped and had the root hairs of plants lining on the inner side and the nest at a height of 1.74 m above ground. The previous study by Reginald *et. al*. (2014) reported the nesting of this bird within a range of 0.65-0.91m above ground. This attributes to the adaptation of this bird to humans and urbanization.

The Common tailor bird's nest (*Orthotomus sutorius*) appeared like tunnel shaped and was found to be stitched with two leaves with a cup like structure of thin fibers placed inside the space between the stitched leaves. The sponge was used at the base of the nest externally and internally cotton was used at the base. Few small bird feathers and human hairs lined the nest internally. In contrast to this, Rana's study in 2018 observed the nest being funnel shaped and had soft fibers, cotton threads, wooden twigs and wool etc in the nest. Leaves of large plants were folded and stitched along the edges**.** Leaves, twigs, grass blade, cotton, fibers, plastic, coir & cobweb were also reported in Common tailorbird's nest by Jahan *et. al*. (2018).

In case of the cup shaped nest of Red-whiskered bulbul (*Pycnonotus jocosus*), the outer and the inner fibers had the same diameter which suggests that same type of fibers are used to make the entire nest. Few leaves were also attached at the base of the cup externally. Apart from these fibers and leaves, small dried sticks, grasses, threads, creepers and even metal wires are reported, to have been used in the nest, by Mazumdar *et. al*. (2007).

The Purple sunbird's purse shaped nest had the outer lining of fibers such as dry thin fibers, small wooden pieces, a dry flower, few dry leaves, grasses of Poaceae and Cyparaceae family and soft silky material at the base. On the contrary, Jahan *et. al.* (2018) recorded the bark, saliva, honey combs & cobweb in Purple sunbird's nest along with leaves.

The Baya weaver's pendant nest was found on the Coconut (*Cocos nucifera*) tree. The fibers used were of the same host plant. Along with these fibers, a very little quantity of mud was also used inside the nest. A report on the Baya weavers, collecting the fibers from paddy leaves and the nests built on the Indian Palm trees (*Borassus flabellifer)* which were growing naturally near the rice fields, was provided by Siva and Neelanarayanan (2019). In contrary to this, Borges *et. al.* (2002) had reported the nesting of Baya weavers for the first time on Eucalyptus tree. They also provided information that the fibers used for making different parts of the nest varied.

In the current study, the Scaly-breasted munia's dome shaped nest was found in an urban house on a chandelior at a height of 2.5m above ground. It was made up of leaves externally and grass fibers internally. In comparison to this, a study done by Jahan *et. al.* (2018) recorded the nesting of Scaly-breasted munia in *Ixora* sp., *Araucaria cookie* and *Polyalthia longifolia* at 2–7 m height and the use of grass blades, plant fibers & feathers in the nest. Similar findings to the current report were recorded by Conn *et. al* .(2017) for the nest being an enclosed globose ball made of plant material i.e., leaves and grass but had the twigs too.

The results of the Kruskal-Walis test suggests that there are significant differences in the diameters within the outer and the inner fibers used in all the seven nests studied. This depicts the varying preferences of these birds for the fibers of particular dimensions used for lining the nests externally and internally.

This type of study is helpful in understanding the behavior of birds towards the changing environment due to anthropogenic activities increasing day by day. Due to the continuous activities of construction, beautification of land etc in various areas, many trees are being cut, the effect of which have been seen on the bird population which is losing its shelter, food, nesting sites and the natural materials used for building their nests. As a result, birds are forced to use the artificial materials like the metal wires, nylon ropes, plastic materials etc available to them easily in their vicinity. Hence there is a need to save the natural resources to save the bird population dependent on them and maintain the better functioning of the ecosystem for the survival of all the species.

CONCLUSION

This study concludes that as per the diversity in the bird population, there is diversity observed in the nesting behavior in terms of their preferable nesting habitats and environments, nest shapes, sizes, materials used, their dimensions and fabrication patterns etc. The birds, belonging to different orders, families and species, follow a particular pattern of nest constructions and choose different types of nesting materials. The choice of nesting materials can also depend upon the type of habitat that they choose based on the available resources around them for their growth and survival. Based on this understanding, attention can be given towards protecting and conserving the diverse bird population.

This study area is important for the ornithologists and other biologists as it helps them to understand the behavior and evolution of birds over a period of time. Nidology can also provide new design ideas and inspiration for the architects and engineers to improve the construction practices thus contributing towards biomimetics.

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