Identifying the Relationship Between Nest Architecture and Strength

Grant Proposal

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Author Note

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Abstract

Past research has demonstrated that the placement of materials within bird nests is deliberate, with thicker materials placed on the outer portions of the nest and thinner materials placed in the inner portions. Bird nests have also been found to have an overall structure that shows promise to enhancing and strengthening man-made structures. Yet, little is known about the relationship between the material placement within a bird nest and the overall strength. To understand this relationship further, I will be collecting nests from the surrounding community to measure four main things: material orientation, diameter, and placement, and analyzing the relationship between those properties and the nest strength. To measure the orientation, I will be taking a picture of the nest and measuring the average steepness of the materials. To measure nest strength, I will be using the Vernier Structures and Materials Tester, which I can use to calculate the bending rigidity of the nest. Finally, to measure the properties of the materials, I will dissect the nest and separate the materials into the top outer, bottom outer, and cup. Then, I will find the diameters of the materials to understand how material properties and placement may influence the stability of a nest. With this information, I will determine the relationship between the strength and these individual properties, that being thickness, steepness, and location. Finding the optimal thickness and steepness of materials in the nest and how that influences strength could be used to improve domes in the real world to make them stronger. In addition, understanding the characteristics that make a nest strong could make it easier to determine how environmental and other such factors may influence a bird's need for a stronger nest. At the conclusion of this project, I will have analyzed the material dimensions, properties, and placements within a bird nest and how that pertains to the nest strength, which helps gain a greater understanding of what makes a nest strong. I hypothesize that as the thickness of materials within the nest increases and, more specifically, as the thickness of materials in the bottom or outer portions increases, the nest will be stronger. In addition, when the materials are less steep, the strength of the nest will also increase.

Keywords: bird nests, material orientation, materials tester, nest construction

Identifying the Relationship Between Nest Architecture and Strength

Animals across many environments and climates have endeavored to build structures that support their way of living. One of those animals is birds, famously known for the construction of bird nests, which are capable of withstanding many climactic events and protecting their young. In addition, birds have been found to deliberately place their materials within certain regions of the nest. The crossover between strength and deliberate material placement bears a need to examine the relationship between nest strength and nest architecture.

Material Choice

There is much dispute regarding why birds choose the materials they do and why they format their nests in specific ways. Thus far, researchers have hypothesized that material placement aids in the protection and reproductive performance of the bird. It was found that birds with complex nests, such as those shaped like pendants, had higher and longer developmental periods, suggesting that the birds had more protection from predators and less urgency to leave the nest (Street et al., 2022). Nest architecture was also believed to influence the fledgling survival rate. However, researchers quickly found that there was no significant correlation between the architecture of the nest and reproductive performance (Lombardo, 1994).

Researchers also believe that the material choice relates to the strength of the bird nest. In addition, they hypothesized that the material choices are based on the properties of the individual materials. Across many different bird species, researchers found that, in many bird species, the outer parts of the nest had a stronger bending strength compared to the bending strength of the materials within the inner portion of the nest, which was determined using a three-point bending test. In a three-point bending test, a stick is placed between two supports, and a probe pushes down onto the stick until it fails, creating a force versus displacement graph that can be used to calculate the bending strength and rigidity of a material. It was found that weaker materials are chosen for the inner portions of the nest.

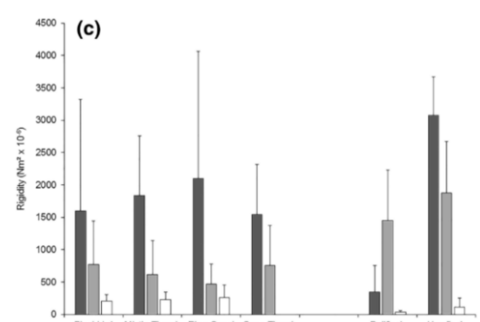

Figure 1: Rigidity (Nm^2x10^{-6}) of the sticks in different bird species separated by the materials found in the top outer nest (dark grey), bottom outer nest (light grey), and cup lining (white).

In contrast, stronger materials are chosen for the outer portions of the nest to provide structural support. As seen in Figure 1, in most nests, the bottom of the outer nests contained materials that were weaker than those found in the top of the outer nests (materials above the base of the cup) (Biddle et al., 2017). However, it was found that the Bullfinch has stronger materials at the bottom of the nest. This is reflected by their position in the tree, because these birds nest in the outer branches of the tree, which are thinner, meaning that they will have less support from the branch itself and will need to compensate for that by placing stronger materials in the base of the nest (Biddle et al., 2018). The differences in material placement based on the structural needs of the nest suggest a significant relationship between nest architecture and strength. These studies have relied on using materials as a forecaster of the structural stability of the nest; however, material strength is not always a good indicator of the overall strength of a structure.

Bird Nest Strength

Bird nests have long been studied for their unique and distinct structures. One of the many unique characteristics of the structure in a bird nest is the entanglement, or the weave-like structure, of their materials. It is hypothesized that the entangled nature of the materials in a bird nest aids in the strength of the overall structure. For this reason, researchers wanted to isolate solely entangled structure of materials in a nest. To do so, they applied pressure to groups of bamboo rods, and as the rods moved closer together, forming a stiffer structure (Bhosale et al., 2022). Similarly, another group of researchers found that entanglement is more prevalent in the thin and long rods, compared to the wide and short rods, which had more difficulty staying together (Harvard John A. Paulson School of Engineering and Applied Sciences, 2025). Similarly, birds use long and thin sticks in their nests, and therefore, the properties of entanglements can be applied to bird nests to explain why the composition of these materials is able to prevent the bird nest from failing.

Researchers Jessel et al. realized the dearth of information surrounding the overall strength of bird nests and sought to create a model to measure the construction of the nest. They were able to successfully create an algorithm, which researchers can use to convert a CT scan of a nest into a 3D model, which can be used to test for further structural analysis of the nest as a whole, as compared to the individual parts of the nest (2019). Similarly, Jessel et al. successfully created a 3D model for the nest of *Aerodramus fuciphagus.* As seen in Figure 2, their findings demonstrated that the stress was farther from the attachment to the wall and on the base, ensuring that the connection between the wall and nest would not fail (2019). This research indeed suggests that nests are built with the intention of being strong. Despite the success in the models, these models only look at one bird nest type. Furthermore, that bird nest type was made from biological material (spit from the bird); therefore, these models cannot be used as an accurate representation of all nests. For this reason, it is essential to physically test nests.

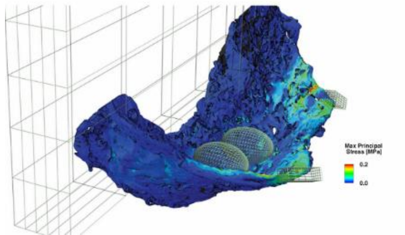

Figure 2: Stress distribution in the nest of *Aerodramus fuciphagus* when two eggs are placed in the center of the nest.

The strength of the bird nest can be applied beyond simply the bird nest itself. Specifically, research has shown that the unique composition of the bird nest has properties that allow for hanging structures, such as a hanging chair, to be stronger in the shape of a weaver nest. Utilizing the weaver nest shape for the hanging structure led to the structure having a higher stiffness and stability rate compared to the typical rectangular and octagonal models of a bird nest (Sindhu Nachiar et al., 2023). Understanding what is special about the bird nest structure that made the hanging structure stronger in the form of a bird nest could be used to apply these properties to other such structures to make them stronger as well. More specifically, looking into the nest architecture has the potential to demonstrate what specifically makes a nest strong.

Section II: Specific Aims

This proposal’s objective is to analyze the properties of the materials, the location of the materials, and the orientation of the materials in relation to the load strength of the nest.

My long-term goal is to gain a deeper understanding of the relationship between the properties of the materials in the nest and where they are placed in the nest, and how strong the nest is. The central hypothesis of this proposal is that as the thickness of materials in the nest increases and, more specifically, as the thickness of materials in the bottom or outer portions increases, the nest will be stronger. In addition, when the materials are less steep, the strength of the nest will also increase. The rationale is that birds tend to place materials with higher diameters in the outer portions of their nest, so if these placements are deliberate, there is a high likelihood that the placement of materials with higher diameters in the outer nest contributes to the overall strength of the nest.

Specific Aim 1: To understand the relationship between material orientation and nest strength as well as patterns in material orientation within bird nests.

Specific Aim 2: To understand how the diameter of the materials within the nest relates to where they are located in the nest.

Specific Aim 3: To determine which factors within the nest architecture have the greatest influence on nest strength.

The expected outcome of this work is to gain a greater understanding of nest architecture and the relationship between nest strength and architecture.

Section III: Project Goals and Methodology

Relevance/Significance

Understanding the intricacies of nest architecture could give insight into what choices a bird could make in order to make their nest stronger. With this information, researchers can analyze which of these choices birds in different climates make and what ecological drivers may influence a bird to choose these properties to make their nest stronger. In addition, understanding what makes a nest strong could be used to improve man-made structures. For example, understanding which diameters within a bird nest make the nest the strongest could be used to apply that same diameter of materials to bio-inspired structures, or structures similar to the bird nest, such as domes.

Innovation

This project proposes a way of assessing the strength of the nest through the assessment of the bending rigidity of the nest. In addition, the steepness of the materials has yet to be assessed. Patterns in the steepness of materials within different sections of the nest could show additional evolutionary characteristics that birds have chosen in their nests. In addition, the steepness of materials is a characteristic that can be easily found. In addition, if the steepness of the materials is found to have a significant influence on the strength of the nest, it is a characteristic that could easily be searched for to determine how strong a nest is and which nests have higher strength without having the need to physically test each nest.

Methodology

Specific Aim #1: Understand the relationship between material orientation and nest strength as well as patterns in material orientation within bird nests.

The objective is to gain a greater understanding of how birds place and organize the materials in their nests to understand the architecture of the nests and patterns in nest construction. My approach (methodology) is to take a picture of the nests from a uniform location and to rotate the nest by ninety degrees four times. Then, those pictures will be imported into the software FIJI. The steepness of the sticks will be determined by measuring the angle the stick makes with the horizontal. From there, around 20 angles will be measured at each rotation of the nest. These twenty angles will all be directly in front of the camera. My rationale for this approach is that only taking a picture from one side of the nest will not give a perspective of all of the angles that the nest could have. If there is a difference in angles between different sides of the nest, then only taking a picture of one side will not give an accurate representation of the angles typically found in the nest. In addition, it is essential to only measure the angles directly in front of the camera because the angles that are not directly in front of the camera are on the curve of the nest, and therefore, a picture of those angles will be skewed towards whichever way the stick is curved.

Justification and Feasibility. Understanding the orientation of the materials is crucial to understanding the architecture of the nest (Kolakkattil et al., 2023). Solely looking at the properties of the materials ignores the idea that the placement and orientation may also significantly influence how the nest responds to different loads.

This is feasible because FIJI is a free online image editing software that can be easily accessed. In addition, any camera can be used, including an iPhone.

Summary of Preliminary Data. To determine if there is a specific distance from the nest that is optimal for taking a picture of the nest for angle measurement, an experiment was set up in which a woven basket was moved backwards from the camera by increments of 2 cm, and the angles of six sticks in the basket were measured at each increment. As seen in Figure 3, the data showed that there was not a significant variation between the angles in the nests as they were moved backward and forwards, unless the angle was on the curve of the nest, not directly in front of the camera, which showed a significant decrease as the nest moved farther from the camera. This data suggests that there is no optimal distance to measure the nest from and that when taking pictures of the nest, the only angles that should be measured are those directly in front of the camera and on the curve(edge) of the nest in the picture.

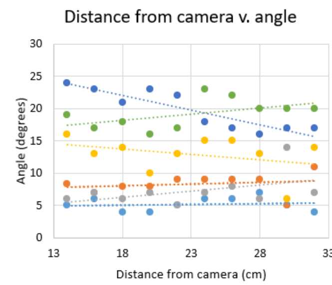

Figure 3: Graph of the relation between the angle of elevation of the sticks right in front of the camera (light blue, grey, orange, yellow) and the sticks on the curve of the basket (dark blue, green).

Expected Outcomes. The overall outcome of this aim is to understand how materials are oriented within a bird nest. This knowledge will be used for comparing to material orientation with the nest strength as well as finding patterns in which birds are orienting the materials in their nests. This information will aid in understanding the orientations of sticks within a nest that optimize nest strength.

Potential Pitfalls and Alternative Strategies. I expect that the turning of the nest ninety degrees may prevent the viewing of all the angles within the nest. An alternative strategy would be to take a 3D scan of the nest to get an accurate reading of all angles in the nest.

Specific Aim #2: Understand how the diameter of the materials within the nest relates to where they are located in the nest.

The objective is to understand the relationship between the properties and placement of the individual materials in relation to the overall structure of the nest and to understand the general patterns that birds tend to follow in terms of material placement during nest construction. My approach (methodology) is to dissect the nest based on the section (Bottom Outer Nest, Inner nest, Top Outer Nest) in which the materials were found in (Biddle et al., 2017). Then, twenty sticks will be chosen at random from each section to have their diameter measured using a digital caliper.

Justification and Feasibility. The nest is made up of many different parts, and in each of those parts, the materials have different diameters and structural properties (Biddle et al., 2018). Therefore, it is quintessential to get a deeper understanding of how this placement of materials in the different locations corresponds to nest strength. In addition, because it was previously determined that, in general, the materials within those locations are generally similar, the sticks in these sections can be grouped together, and the mean diameter for that section can be found. Also, a three-point bending test will not be used to measure the strength of the individual materials because it was found that there is a significant correlation between material diameter and strength (Biddle et al., 2018).

Summary of Preliminary Data. To validate the veracity of the section break-up in the nest by diameter, I dissected one nest into three sections: the Top outer nest, the bottom outer nest, and the cup. I then measured the diameters within each section. As seen in Figure 5, the results showed a significant difference between the diameter of the materials in the cup and the bottom outer nest, with the bottom outer nest having the materials with the biggest diameter. This is consistent with past findings (Biddle et al., 2018). In addition, this finding validates the sections that should be analyzed for material diameter to understand how differences in diameter will affect the nest, depending on where in the nest that difference is occurring.

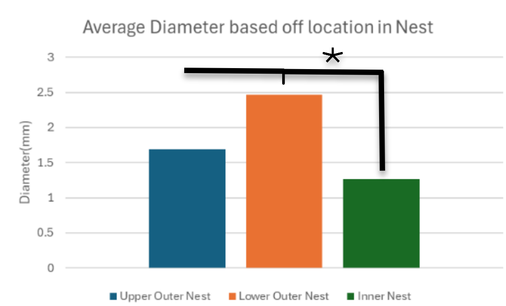

Figure 4: Diagram of the average diameter of the sticks within each section of the nest. *=p-value<.01

Expected Outcomes. The overall outcome of this aim is to understand the relationship between the location of materials and the nest strength. This knowledge will be used to gain a greater understanding of the relationship between the individual properties of the materials in the nest and the strength of the nest.

Potential Pitfalls and Alternative Strategies. I expect that when it comes time to dissect the mud cups, there will not be a cup lining, and a large amount of the nest will be composed of mud. To account for this, the cup lining in mud cups will not be measured.

Specific Aim #3: To determine which factors within the nest architecture have the greatest influence on nest strength.

The objective is to understand the optimal properties of a nest and be able to predict the strength of other nests solely based on architectural properties(e.g., material orientation, material diameter, etc.). My approach (methodology) is to first freeze the nest for 48 hours and then let the nest dry at room temperature. Then, a Vernier Structures and Materials Tester will be used to find a force versus displacement graph for the nest, which can be used to calculate the flexural rigidity of the nest. The supports will be placed at a distance of the longest diameter of the cup of the nest. Equation 1 was used to calculate the flexural rigidity and is based on the methodology in Biddle et al. (2018). In Equation 1, L is the distance between supports, and $\frac{dF}{d\delta}$ is the initial slope of the force versus displacement graph produced by the Vernier Structures and Materials Tester.

$$EI = L^3(\frac{dF}{d\delta})/48 \quad (1)$$

Justification and Feasibility. Freezing the Nest for 48 hours is essential to killing all ectoparasites that may be present in the nest. Later, it is left to air-dry at room temperature to ensure that the freeze will not affect the properties of the nest and the nest materials (Akresh et al., 2024). In addition, this step is important to understanding the strength of the bird nests and how they react to loads. A total of 17 nests have been collected, and the Vernier Structures and Materials Tester, which is located at the Massachusetts Academy of Math and Science, will be used to test them.

Summary of Preliminary Data. To test if the Vernier Structures and Materials is accurate, it was used to measure the bending rigidity of five popsicle sticks, as well as one stick from a nest. As seen in Figure 4, the magnitude of the bending rigidity of the stick from the nest was in the thousands ($Nm^2 \; x \; 10^{-6}$), which is consistent with the bending rigidity of the sticks in past experiments (Biddle et al., 2018)(See Figure 1). These results indicate that the Vernier Structures and Materials tester is an accurate tester for the bending rigidity of sticks.

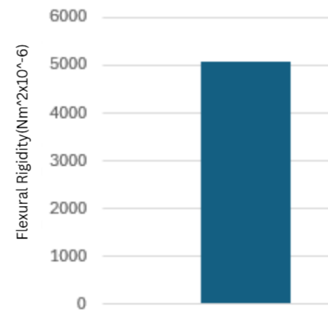

Figure 5*:* Flexural rigidity (Nm^2x10^{-6}) of a stick from a nest.

Expected Outcomes. The overall outcome of this aim is to understand how a nest reacts under loads. This knowledge will be used for determining how strong nests are.

Potential Pitfalls and Alternative Strategies. We expect that humidity may influence the results of the strength of the nest. To account for this difference in humidity, the humidity will be measured every day at the same time during that two-week period after the nest was frozen. Then, humidity will be used as a covariate during statistical testing.

Section III: Resources/Equipment

The Vernier Structures and Materials Tester will be utilized to give a force versus displacement graph as it applies loads to the nest. This allows for the calculation of bending rigidity for each nest. In addition, a digital caliper will be used for stick diameter measurement. Bird nests have been collected from community members in and near Southborough, MA.

Section V: Ethical Considerations

There may be concerns over the destruction of natural resources. However, all nests acquired have been collected in October and have been abandoned by their owners (the birds).

Section VI: Timeline

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Section VII: Appendix

Section VIII: References

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