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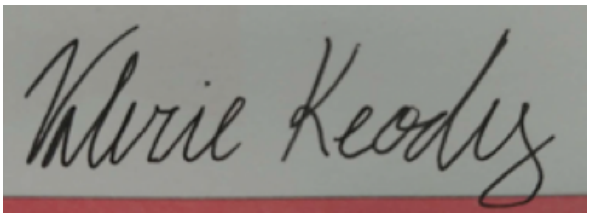

Rize Martins de Oliveira

Home Tweet Home

Bird and Bat Nest Box Project

ENGR 215: Introduction to Design
Spring 2021

Team Wingineers:
Alex Garza
Valerie Keody
Rize Martins de Oliveira

Table of Contents

Table of Figures

Table of Tables

1 Problem Formulation

1.1 Introduction

Formulating the problem is the first phase of the design process. The problem formulation includes sections 1.1-1.3, and it provides information regarding the problem that Team Wingineers plan to solve: the implementation of upcycled bird boxes on campus at Zane Middle School.

1.2 Background

Zane Middle School is located in Eureka, CA. The instructors teach their students using a STEAM based curriculum (science, technology, engineering, art, and math). The Environmental Resources Engineering department at Humboldt State University has worked with Zane in the past to add bird boxes to preexisting housing for migratory birds. Figures 1-1 and 1-2 are pictures of the previous birdhouse project by Engineering 215 students in Team Applicateers. Zane is interested in implementing several more bird boxes that are composed primarily of upcycled materials and that work well with the school's aesthetic. Julie Stewart is a teacher at Zane, and she provides the Wingineers with perspective and deep knowledge as a teacher at the middle school; she is the client representative for this project.

Figure 1-1: Team Applicateer's "Don't Draw Pot"

Figure 1-2: Team Applicateer's Chickadee Cottage

1.3 Objective

The objective of this project is to create upcycled bird boxes that provide shelter for migratory birds in forested areas surrounding Zane Middle School. Additionally, the project seeks to encourage students to reuse and upcycle existing materials while sparking an interest in engineering. Figure 1-3 is a visual representation of what the project will accomplish. The input is the current state of Zane, and the output is the state that Zane will be in after the implementation of this project.

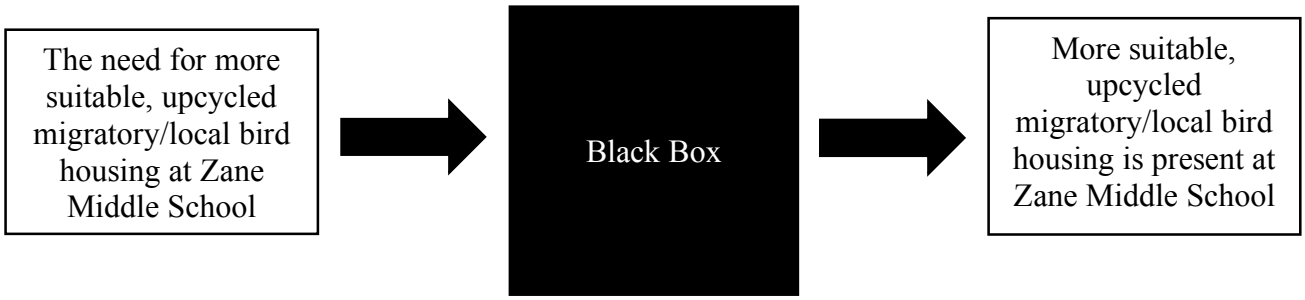

Figure 1-1: A black box model representing the objective of the project

2 Problem Analysis and Literature Review

2.1 Literature Review

The Literature Review section is an accumulation of the preparatory research conducted for the purpose of creating solutions that satisfy the need for additional bird boxes in the migratory corridor surrounding Zane Middle School.

2.1.1 Climate in Humboldt County

Humboldt County is an area of moderate temperatures and considerable precipitation (HumCo). Temperatures along the coast vary only 10 degrees from summer to winter. Rainfall is common, and can be experienced in each month of the year. The moderate temperature mixed with moisture creates a humid environment.

2.1.2 Geography/Habitats of Humboldt County

This bioregion is characterized by its rocky coastline, wetlands and forested montane areas. Bays and estuaries and other tidal inlets provide a variety of habitats supporting many species of resident and migratory wildlife. The county is composed mainly of coastline and mountainous areas with dense coniferous forests interspersed with grass or chaparral covered slopes (U.S. Fish

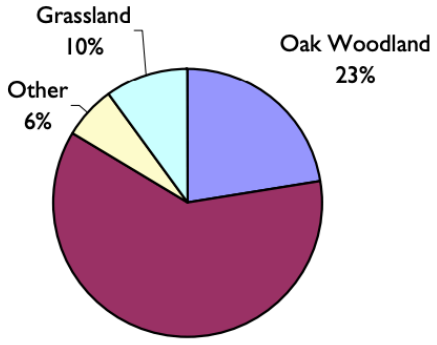

Figure 2-1: Pie Chart representing biodiversity of Humboldt County (CA Dept. of Forestry 2002).

and Wildlife Service 2017). Figure 2-1 shows numerous vegetation types and their proportion as a percentage of the total acreage of Humboldt County.

2.1.3 Pacific Flyway

The Pacific Flyway is a major flight path that stretches north and south for migratory birds in America. It extends from Alaska to Patagonia. Every year, migratory birds travel a section or all of this flyway in spring and fall, following food sources, heading to breeding grounds, or travelling to overwintering sites (Audubon 2015). Figure 2-2 shows the flight path, more precisely in California, and it can be seen that the coastline, specifically Humboldt County, is a notable avenue in the Pacific Flyway.

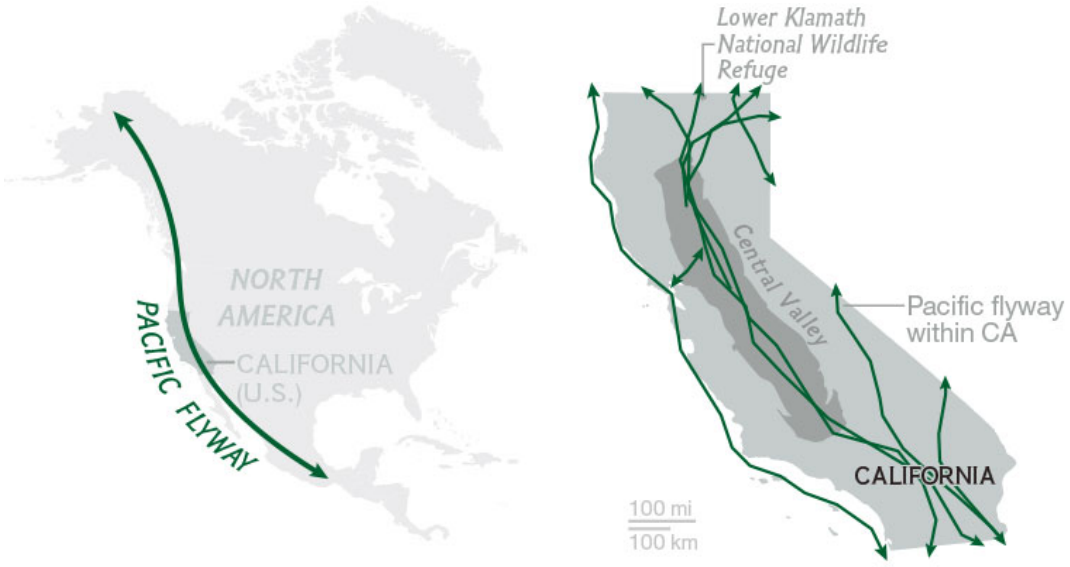

Figure 2-2: Migratory flight path, north-south (left), Pacific Flyway with CA (right) (National Geographic 2015).

2.1.4 Humboldt Bay

Humboldt Bay is considered an internationally significant area for migratory birds. Large numbers of shorebirds, raptors, songbirds and other species depend on the habitats the Bay and Refuge provide during all seasons of the year for foraging, roost sites, and breeding (U.S. Fish and Wildlife Service 2013). The area's importance is due to the need for wintering and stopover habitats for migratory birds. Over 260 different species of birds occur during fall and spring months as birds are migrating through the Pacific Flyway. The dune forest and riparian areas (wetlands) are rare habitats that support large numbers of breeding and non-breeding songbirds and attract migrants moving along the coast (U.S. Fish and Wildlife Service 2013).

2.1.4.1 Local Bird Species of Humboldt County

This section is a description of a number of different species of birds that are commonly seen in Humboldt County as resident birds and during the migrating season; they are potential candidates for the bird box project.

2.1.4.1.1 Black-Capped Chickadee

The Black-Capped Chickadee is very local to the coastal district in Humboldt County, although it can be found in the mountains and the basin district in Shasta Valley, Siskiyou County. They reside in riparian vegetation where fresh water courses are bordered by dense tangles of shrubs and trees (De Benedictis 1988). They build nests out of rough materials like moss and fur. Although they prefer to build their nests in the branches of dead trees, they will also utilize bird boxes with wood shavings that are placed between 1.5m and 7m high (Cornell 2019).

2.1.4.1.2 Chestnut-Backed Chickadee

The Chestnut-Backed Chickadee is present locally in the interior district in the hills west of Central Valley, but during the winter, they are residents of the lower elevations along the Pacific Coast (De Benedictis 1988). These songbird's habitat is mainly where trees with rounded crowns (pines and conifers) are the dominant vegetation. Their nest sites are commonly 1-12 feet off the ground where they reside in holes in rotted trees and stumps; they also readily use bird boxes (Cornell).

2.1.4.1.3 Mountain Chickadee

The Mountain Chickadee is common in the forests of the Western mountains, but in fall and winter, they tend to wander to lower elevations, reaching the northern part of California's coastal region in the counties of Humboldt and Del Norte (De Benedictis 1988). They live in evergreen forests where cone bearing trees are the dominant vegetation. Mountain Chickadees cannot excavate cavities on their own, so they typically rely on holes made by other birds, natural crevices, or bird boxes (Cornell 2019).

2.1.4.1.4 Bushtit

Bushtits are very common across a wide range of districts including coastal, interior, mountainous, and valley regions. They restrict their district to the lower elevations come nesting season where they can be found among the open woodlands of Humboldt County. Bushtits do not usually build their nests in a bird box, although it is not unheard of. They create remarkable hanging nests using spider webs and plant material, and then it is later insulated with materials such as fur and downy plant matter (Cornell).

2.1.4.1.5 Red-Breasted Nuthatch

These songbirds are fairly common residents in the coastal district (De Benedictis 1988). They live in coniferous forests where vegetation is rather widely spaced. They mainly excavate cavities on their own for their nest sites, and rarely use existing holes or bird boxes (Cornell 2019).

2.1.4.1.6 Pygmy Nuthatch

The Pygmy Nuthatch prefers the redwoods in the coastal district, but they are not as common as the other nuthatches (De Benedictis 1988). They live in a variety of different places such as live and dead trees, bird boxes, and parks. They reside in natural cavities or previously existing holes created by woodpeckers or other species of nuthatches. These songbirds like their nests to be approximately 10in x 6in (Cornell 2019).

2.1.4.1.7 White-Breasted Nuthatch

The White-Breasted Nuthatch is a bird that lives among woodland edges where there are open areas with large, mature trees. They are commonly attracted to feeders and bird boxes as they enjoy parks, wooded suburbs, and yards (Cornell 2019).

2.1.4.1.8 Golden-Crowned Kinglet

Golden-Crowned Kinglets are small insectivorous songbirds that like to nest in deciduous and mixed forests (Cornell 2019). During migration, they stop in a broad range of habitats including forests, fields, parks, and yards where bird boxes and refuges are commonly utilized among this species (Cornell 2019).

2.1.4.1.9 Ruby-Crowned Kinglet

These songbirds are common in Humboldt County in the seasons of fall and winter (De Benedictis 1988). They live in a wide variety of habitats including mixed woods, mountain-shrubs, floodplain forests, and dry, widely spaced coniferous areas (Cornell 2019). Ruby-Crowned Kinglets can nest as high as 100ft where they suspend a globe-shaped nest from the branches. They will use bird boxes with their mated pair in the winter months (Cornell 2019).

2.1.4.1.10 Cedar Waxwing

The Cedar Waxwing restricts its breeding district to the coastal region where they prefer the mixed woodlands, particularly along streams (De Benedictis 1988). They are common in towns and suburbs where they will nest anywhere from 3 to 50 feet high in cedars, pines, oak, or bird boxes.

2.1.4.2 Bat Species

In Humboldt County, there are thirteen local bat species. The redwood forest is a hot spot for not only the local bats but bats that rest in the redwood forest while migrating. Some bat species local to Humboldt County include the hoary bat, California myotis, and the long-legged myotis. Within the species found in Humboldt, some bats will migrate or hibernate while the hoary bats are capable of doing both. The hoary bat is also one of the few species in Humboldt that does not use bat boxes; however, the other species will use them.

2.1.4.2.1 Bat Housing Tips

Bat houses should be at least two feet tall and made up of chambers that are at least twenty inches tall and fourteen inches wide. There should be an entrance area that is between three to six inches so the bats can enter the bat house. For insulation purposes, the wood should be three fourths of an inch to an inch wide. The chambers should also be spaced out between three fourths of an inch and an inch wide. The house should feature side vents in locations where the temperatures exceed 85 degrees. Screws should be used to increase the lifetime of the bat house. The paint or color of the bat house is dependent on the average daily high temperatures over the summer. The bat house should be mounted on a pole of building at a height between twelve and twenty feet. Bat houses mounted on trees are less successful due to the difficulty there is of entering and leaving the house. It makes the bats more vulnerable to predators.

2.1.4.3 Bird Housing Tips

This section includes specific preferences that have been proven to support habitation by the targeted bird species as well as features of a good bird box.

2.1.4.3.1 Chickadee Nesting Preferences

For Chickadees, the dimensions of the nesting box should be about 8 inches in height and 5 1/2 inches wide and long. The entrance hole should be no smaller than 1 1/8 inches in diameter. They are particular with their height, and the bird box should be placed at 5-15 feet high. There should be about 160 feet radius between the nesting tree and other bird boxes, and it is also preferred that the entrance hole faces east or southeast. Chickadees will be more interested in a bird box that already has wood shavings or sawdust in the box floor (Cornell 2019).

2.1.4.3.2 Nuthatch Nesting Preferences

Nuthatches prefer that their entrance faces south as well as being 1 1/4 inches in diameter. They are comfortable with the same dimensions as the Chickadee: 8 inches deep and 5 1/2 inches wide and long. They also more commonly reside in boxes with about an inch of wood shavings in the box floor (Cornell 2019).

2.1.4.3.3 Kinglet Nesting Preferences

The dimensions for a bird box for a warbler like the Kinglet can vary. The only preference is that the entrance hole is 1 1/4 inches in diameter and 4 inches from the bottom of the box. The nesting site should be placed 5 to 10 feet high (Rosener 2021).

2.1.4.3.4 Cedar Waxwing Preferences

These birds are not particular about the mount height, but it should be at least 6 feet above ground. The typical bird box for a Cedar Waxwing should be 8 inches wide and long and 14 inches in height. The entrance hole only needs to be 1 1/2 inch in diameter (Rosener 2021).

2.1.4.3.5 Building a Safe, Successful Home

The safest option for bird box material is untreated, unpainted wood. Galvanized screws should be used rather than nails for a tighter seal. Roofs are commonly sloped to keep out driving rain. Ventilation and drainage holes should be included. Perches are not recommended because predators can easily gain access to the box. The bird box should at least have a hinged door or roof with a sturdy closing mechanism for cleaning and monitoring (Cornell 2014).

2.1.5 Materials

2.1.5.1 Wood

Bird houses are most often constructed out of wood. Thinner materials like metal or plastic are not commonly used because they do not provide necessary insulation. Wood is also non-toxic to animals as long as untreated forms are used (Alaska Fish and Game). Any species of wood could be considered, but using a variety common to the area would be preferred. The split-log construction is a popular method of constructing birdhouses out of whole wood logs. This

method produces a much more natural looking structure that blends in with the environment as shown in Figure 2-3.

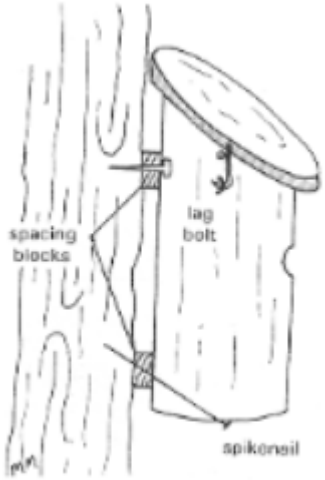

Figure 2-3: Basic wood construction for a natural look (Alaska Fish and Game).

By far the most common birdhouse design is the dimension-board construction, shown in Figure 2-4. This design is constructed of precut wood that is then cut to size and fitted together with nails. This design is much more recognizable and easy to identify from a distance.

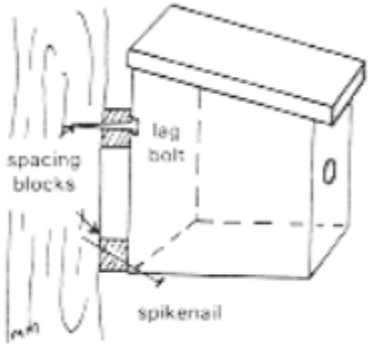

Figure 2-4: The most common birdhouse design: Dimension-Board Construction (Alaska Fish and Game).

2.1.5.2 Ceramic

Ceramic is less commonly used for birdhouses, but for an upcycled application this could be considered, as shown in Figure 2-5. Ceramic has a similar R-value to that of wood (1.00 per inch vs 1.10 per inch respectively (Houseneeds). A birdhouse can be sculpted out of clay and then fired in a kiln to harden it, or an already fired piece of clay like a discarded clay pot or ceramic kitchenware.

Figure 2-5: Upcycled application of ceramic (Houseneeds)

2.1.5.3 Gourds

Gourd birdhouses are uncommon, but they have some advantages over other constructions. Gourd birdhouses are made of bottle gourds that are biodegradable, shown in Figure 2-6. These houses require little assembly. Only a hole needs to be drilled into the dry gourd in order for birds to be able to enter. The only limitation of this construction is that gourds only come in certain shapes and sizes so that houses could not be constructed with a specific bird in mind. This could easily be done with a wooden birdhouse however.

Figure 2-6: Dry gourd birdhouse (Audubon)

2.1.5.4 Nest Material

Certain cavity-nesting bird species require a nest material inside of the bird house. This could be fulfilled by 2-3 inches of dry sawdust or wood chips.

2.1.5.5 Adhesives

Many different adhesive materials exist for use in an environment where birds will be present. The most common form of adhesives is Polyvinyl Acetates. PVA glues are toxic only when eaten, fairly water resistant, and bond almost as strongly as two-part epoxies (WoodByWright). Two-part epoxy is another commonly used adhesive. Two part epoxies are used by mixing a formulated resin and hardener. This hardens into a nontoxic plastic material. This material can withstand extreme heat, cold and humidity (3m). It bonds stronger than PVA glue and holds longer (WoodByWright).

2.1.5.6 Paint

Paints are often made with toxic additives. As birds would be negatively impacted by these compounds non-toxic paints must be used. Paints that are made without toxic additives are free of VOCs (volatile organic compounds). Some paints that fit this constraint are Behr Premium Plus, ECOS paint, and Sherwin Williams Harmony (GoodTrade).

2.1.6 Previous Projects

2.1.6.1 ZMS Songbird Refuge

The previous bird box project, The Zane Middle School Songbird Refuge, came up with 4 designs that were put up near ZMS. These are the Bird Bungalow, Chickadee Cottage, Don't Draw-Pot and Wood Duck Inn. The Chickadee Cottage and Wood Duck Inn are both dimension-board constructions: one sized to fit chickadees and the other sized for wood ducks. As they have stated, these two are proven designs that have been tested and built all over the world. As for the Don't Draw-Pot, this design is a ceramic/dimension-board hybrid consisting of an upcycled ceramic teapot mounted in a dimension-board frame with one open side. The Bird Bungalow is a unique design, which has a total of 4 birdhouses contained in it. This design uses 4 upcycled metal cans encased on two sides by wood. This design creates much more housing for birds at the expense of insulation, as metal cans are extremely thin and conduct heat very easily. Although these designs were tested for rigidity, observations were not made as to which of the birdhouses became inhabited by birds. (Songbird Refuge 2014).

2.1.7 Client Criteria

In this section, the topics discussed during the primary meeting with the client representative of the project will be reviewed to guide the project design. Julie Stewart, the client representative at Zane Middle, was interviewed regarding any criteria and parameters necessary for the design of the project. Specifications include making the birdhouses out of upcycled materials that are durable. The birdhouses should be safe for the students, wildlife and habitat. The materials used should be nontoxic. As far as aesthetics, the birdhouse should include the schools' mascot, the Falcons (Figure 2-7). Red, yellow, and black, the school's colors, are preferred (Figure 2-8). Lastly, the birdhouses should have an educational purpose for the students.

Figure 2-7: An image that was previously used as a profile photo for Zane Middle School's Facebook page. The icon shows the school mascot, colors, and year of establishment. (Zane Falcons Icon, 2013)

Figure 2-8: An icon that is currently used as Zane Middle School's profile picture on Facebook. The icon includes the school colors, name of the school, and symbolism of the location. (Zane Middle School Eureka City Schools Logo, 2017)

2.1.8 Middle School

The Middle School research topic is intended to provide information regarding the best ways to educate and interest the students in the upcycled birdhouses. Understanding which ways work best are crucial to meeting the educational purpose criteria as given by the client representative.

2.1.8.1 Pedagogy

According to research from Project Zero, a project conducted under a research center at the Harvard Graduate School of Education, playful learning can be used to advance both academic and social skills while creating meaningful educational opportunities. Teachers can act as support for students to meet specific goals in playful learning. However, playful learning will look different depending on location and culture. The shaping factor is the playfulness aspect in the learning which can also vary depending on the ages of the students. The three indicators of play are ownership, curiosity and enjoyment. Some examples of playful learning provided in the study include allowing students to design their own schedules, drawing, and debating facts (Tatter, 2019).

Research conducted by the Kentucky Department of Education was used to develop a list of characteristics, pertaining to both the students and teachers, that support effective teaching and learning. A teacher's ability to orchestrate meaningful learning experiences while encouraging creative inquiry is crucial for student engagement and preparation for the future. Teaching and learning is effective when there is a clear, known learning intention and teachers draw connections across multiple academic disciplines (KDE, 2020).

2.1.8.2 Science and Curriculum

This section will go over the different learning outcomes that students in middle school are expected to learn as noted by California educational standards. Each grade will be separated and given focus on overarching ideas with the mention of skills that will be developed to use for that class and classes moving forward.

2.1.8.2.1 Sixth Grade

In sixth grade, students take a class on earth science. This class will focus on the earth and space. Students are expected to develop and use Earth-sun-moon models. Furthermore, students should be capable of describing the role of gravity with models of galaxies and the solar system. Students will learn how to determine the scale properties of objects within the solar system. The final learning outcome is explaining how the geologic time scale is used based on rock strata evidence. These core ideas are intended to teach students how to develop and use models, analyze and interpret data, and design solutions to problems. These additional learning outcomes are general and will continue to apply in further courses and the real world (CDE, 2015).

2.1.8.2.2 Seventh Grade

In seventh grade, students take a class on life science. This class will focus on cells, energy, and ecosystems. Students are expected to prove that all living things are made of cells while being capable of describing cell functions with use of a model. Additionally, students should learn that the body is a system of cell groups. Within ecosystems, students are expected to learn how energy is cycled through both living and nonliving things. Through analyzing patterns, students should recognize that changes to either physical or biological components in an ecosystem will impact the population of said ecosystem. Aside from the core learning outcomes, the class will encourage the analyzing of data and recognition of patterns while also using models to support and describe functions (CDE, 2015).

2.1.8.2.3 Eighth Grade

In eighth grade, students take a class on physical science. This class will focus on atom composition, energy, and chemical reactions. Students are expected to describe the atomic composition of molecules through models. Students must also be able to determine whether a reaction occurred between substances by analyzing the substance properties before and after interacting. They are expected to describe that all synthetic materials and objects are made from natural resources. Students should have enough understanding to predict and describe changed in particle motion, temperature, and substance state purity when thermal energy is added or removed from a substance. Aside from the core learning outcomes, the class will encourage the development and use of models while recognizing patterns in data to make predictions (CDE, 2015).

2.2 Problem Analysis

The Problem Analysis section investigates the project more specifically in order to narrow down solutions to the problem. This section is a detailed summary of the specifications, considerations, and criteria regarding the implementation of additional bird boxes at Zane Middle School. It also includes how the product will be used and how many bird boxes will be made.

2.2.1 Specifications

Specifications are the requirements that must be fulfilled by the design process. Our project follows the following specifications: The bird boxes must be primarily made up of sustainable materials, the bird boxes have an educational purpose, the design should cater to either local or migratory bird species while being safe for wildlife, the environment, and students. Additionally, the bird box should have a logo of the middle school on the exterior.

2.2.2 Considerations

Considerations are factors that need to be taken into account in order to meet the needs of the client. Considerations include:

- The birdhouses use upcycled and/or reused materials in a way that reduces the total carbon footprint involved in construction compared to a traditional birdhouse construction
- The birdhouses' designs take influence from Zane Middle School teacher and student culture
- The birdhouses will be installed outside and will be expected to remain outside permanently

2.2.3 Criteria and Constraints

Criteria	Constraints	Weight
Cost	Project must not exceed a total of $325	3
Durability	Constructed bird boxes must be inhabitable by birds for at least 3 years	7
Aesthetics	Project must look as good or better than standard Zane infrastructure while not drawing attention from predators	8
Safety	Nontoxic/untreated materials must be used and project shall meet existing Zane safety standards as to not harm students, faculty, and community members	10
Sustainability	All materials used will come to less embodied energy than a new bird house	9
Reproducibility	Each box can be reproduced within 5-10 hours with proper materials by a single student	5

Habitability	The bird boxes must encourage specific bird species to make their nest and not harm them	8

Table 2-1: Criteria and Constraints weighted by importance for this project specifically (Wingineers)

2.2.4 Usage
The birdhouses that are to be constructed will be used as shelter for local and migratory birds. They will be expected to withstand Humboldt weather conditions for 3 years at a minimum, and only possibly requiring maintenance or repair after those 3 years. These birdhouses will not require any regular maintenance.

2.2.5 Production Volume
Three birdhouses will be constructed and installed in the migratory bird corridor behind Zane Middle School.

3 Alternative Solutions

3.1 Introduction
Alternative solutions for the nest box project have been created as a result of a collaborative brainstorming session held between the members of Team Wingineers. These solutions are designed to satisfy all specifications, considerations and requirements of this project. A total of nine alternative solutions have been generated.

3.2 Brainstorming
One brainstorming session lasted a total of 2 hours and was held in order to come up with viable alternative solutions. A bubble map was utilized in order to organize solutions (See Appendix). Nine designs that meet the objective statement and client criteria requirements were chosen to be outlined in further detail.

3.3 Alternative Solutions
Below are nine designs that were chosen during our brainstorm sessions. Descriptions and visual representations of each alternative solution are included and will be used to select a total of three final designs that will be constructed. Alternative solutions include:

- Nuthatch Homestead
- Wren Residence
- Chickadee Condo
- Mailbox Birdhouse
- Single Log Construction
- Log Condo
- Cedar Waxwing Cottage
- Wooden Bat Cave
- Upside Down Bat Housing

3.3.1 Nuthatch Homestead

The Nuthatch Homestead features a single occupancy bird box designed to accommodate Pygmy, Red-Breasted, and White-Breasted Nuthatches. As shown in Figure 3-1, this design is constructed of a wooden 5 ½ inch by 5 ½ inch base, two identical wooden sides with a slanted top going from 10 inches to 8 inches, a slanted roof, and an extended back of 12 inches for mounting. The entrance hole is 1 ¼ inches in diameter that is 6 inches above the base of the box to meet the precise preferences of this specific songbird species. The bird box is made up of recycled plywood to embed less energy than a brand-new birdhouse while being safe for wildlife and the environment to meet the sustainability requirement of this project. This model is the correct size to support Nuthatches along with proper ventilation to meet the inhabitability requirements. The bird box is placed 5 feet to 20 feet above the ground. Galvanized screws, rather than nails, are used in this design for a tighter seal to produce a more durable model. This model is also completely constructible within the given budget of $325.

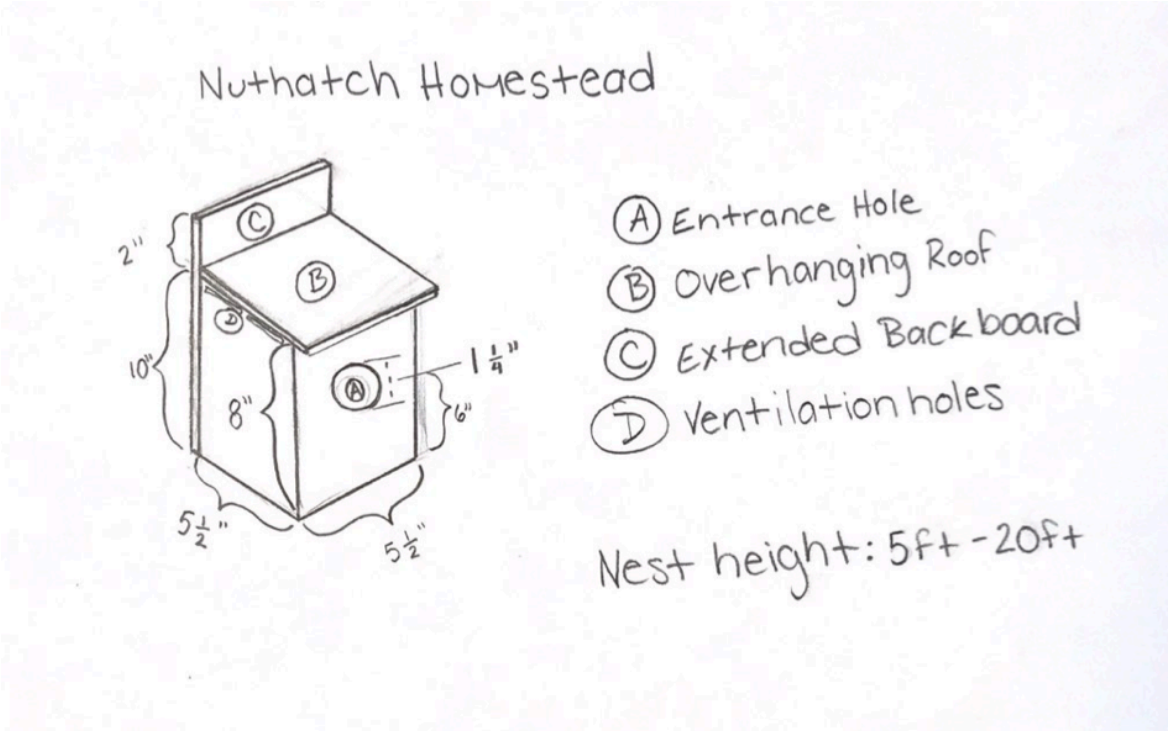

Figure 3-1: Dimension-Board Construction drawing of Nuthatch Homestead with dimensions and labels by Rize Martins de Oliveira

3.3.2 Wren Residence

The Wren Residence features a single occupancy bird box designed to accommodate Pacific Wrens and Wren-tits. As shown in Figure 3-2, this design is constructed of a wooden 5-inch by 5-inch base and a pentagonal face with 3 ½ inch sides and 6 inch tops that make contact with the roof. The roof is made up of two identical 7 inch by 7 inch panels. The entrance hole is 1 ¼ inches in diameter that is 5 inches above the base of the box to meet the precise preferences of this specific songbird species. The handle is made of thick, unmalleable wire for mounting the bird box 3 feet to 6 feet above the ground. The bird box is made up of recycled plywood to

embed less energy than a brand-new birdhouse while being safe for wildlife and the environment to meet the sustainability requirement of this project. This model is the correct size to support Wrens along with proper ventilation to meet the inhabitability requirements. Galvanized screws, rather than nails, are used in this design for a tighter seal to produce a more durable model. This model is also completely constructible within the given budget of $325.

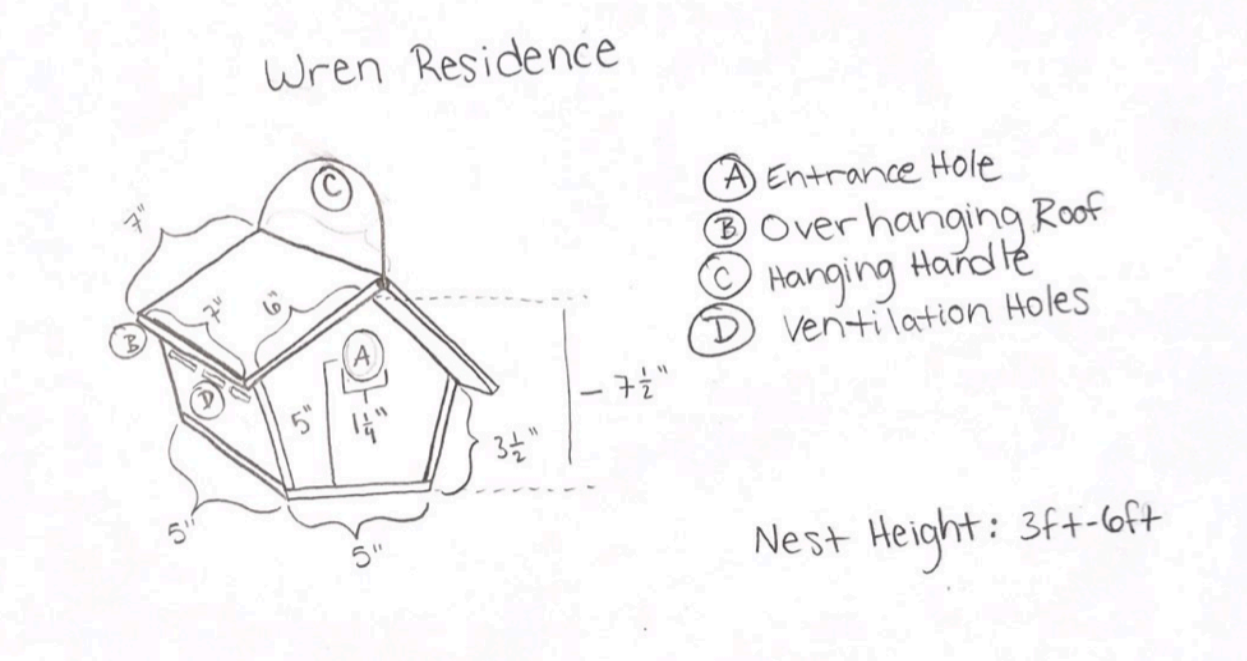

Figure 3-2: Dimension-Board Construction drawing of Wren Residence with dimensions and labels by Rize Martins de Oliveira

3.3.3 Chickadee Condo

The Chickadee Condo features a triple occupancy bird box designed to accommodate Mountain, Black-Capped, and Chestnut-Backed Chickadees. As shown in Figure 3-3, this design is constructed of three bird boxes, the outer two having a base of 5 ½ inches by 5 ½ inches, two sides with slanted tops going from 10 inches to 8 inches, and a slanted roof with a panel that is 7 ½ inches by 7 ½ inches. The entrance holes are both 1 ¼ inches in diameter, and they are 6 inches above the base of the box. The nest box in the center has a base of 5 ½ inches by 5 ½ inches, two identical side panels that are 12 inches in height, and the front and back panels reach a peak of 13 inches. The roof consists of two panels, each 3 ½ inches by 6 inches, and the floor of the box is 6 inches below the entrance hole which is 3 inches below the peak of the front facing panel. The entrance hole for the center nest box is also 1 ¼ inches in diameter. This design includes a backboard for easy mounting. The bird box is made up of recycled plywood to embed less energy than a brand-new birdhouse while being safe for wildlife and the environment to meet the sustainability requirement of this project. This model is the correct size to support Chickadees along with proper ventilation to meet the inhabitability requirements. Galvanized screws, rather than nails, are used in this design for a tighter seal to produce a more durable model. This model is also completely constructible within the given budget of $325.

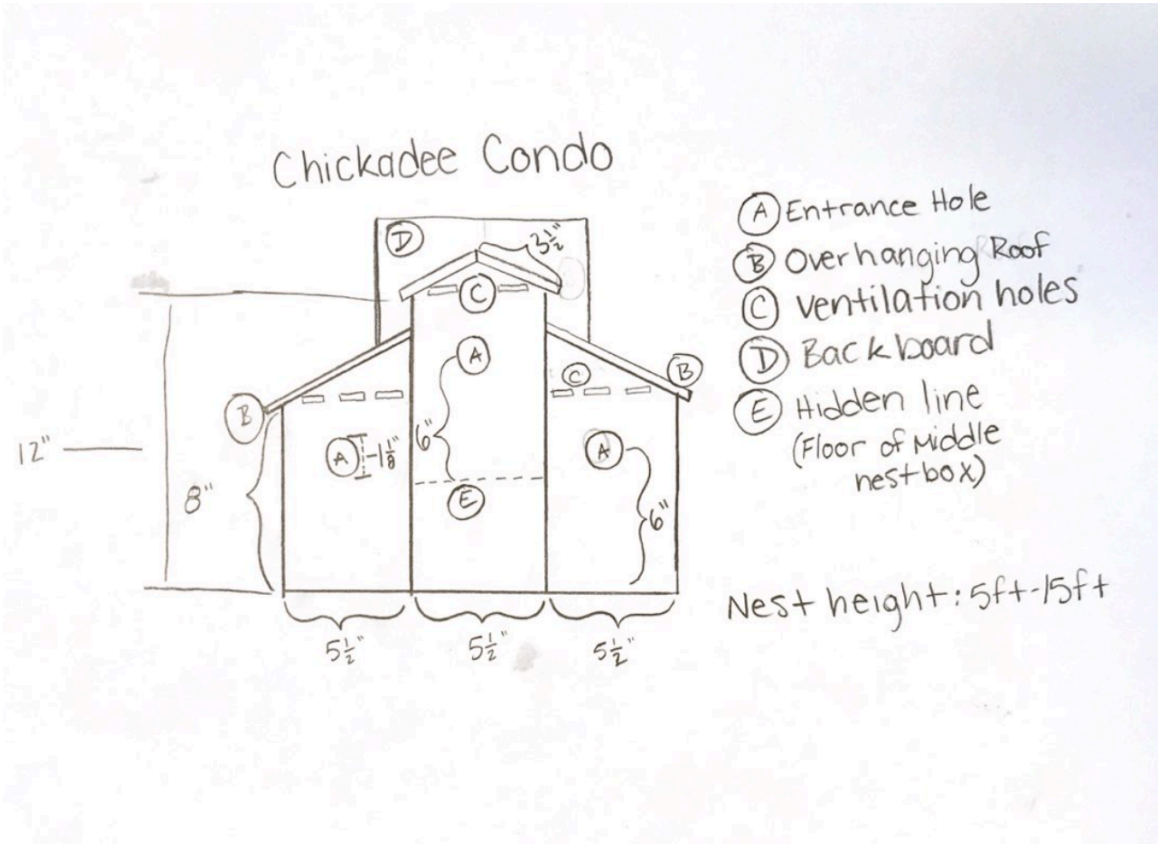

Figure 3-3: Dimension-Board Construction drawing of Chickadee Condo with dimensions and labels by Rize Martins de Oliveira

3.3.4 Mailbox Birdhouse

The Mailbox Birdhouse (shown in Figure 3-4) utilizes a repurposed standard USPS mailbox, measuring 19”x6.5”x8.75”. After the mailbox flag is removed to prevent any unintentional pollution, two ¾ inch plywood pieces are cut to fit the inside of the mailbox. They are then screwed into place through the aluminum mailbox. Three holes with 1.5 inch diameters are drilled into the front face of the mailbox. These will be the entrances to the birdhouse. The rough edges of the drilled holes are then filed down to be smooth. This birdhouse has 3 compartments and targets chickadees with its design. The cost of this project is estimated to be around $20 using new materials. This design, being made of aluminum and plywood, would be durable. This design also has smooth surfaces, which could easily be painted to fit student considerations. The materials in this design are also easy to upcycle, as mailboxes and wood are common items. Aluminum and untreated plywood are also both materials that fulfill the environmental safety requirements. As for inhabitability, this design’s thin aluminum walls may be too thin to provide adequate insulation.

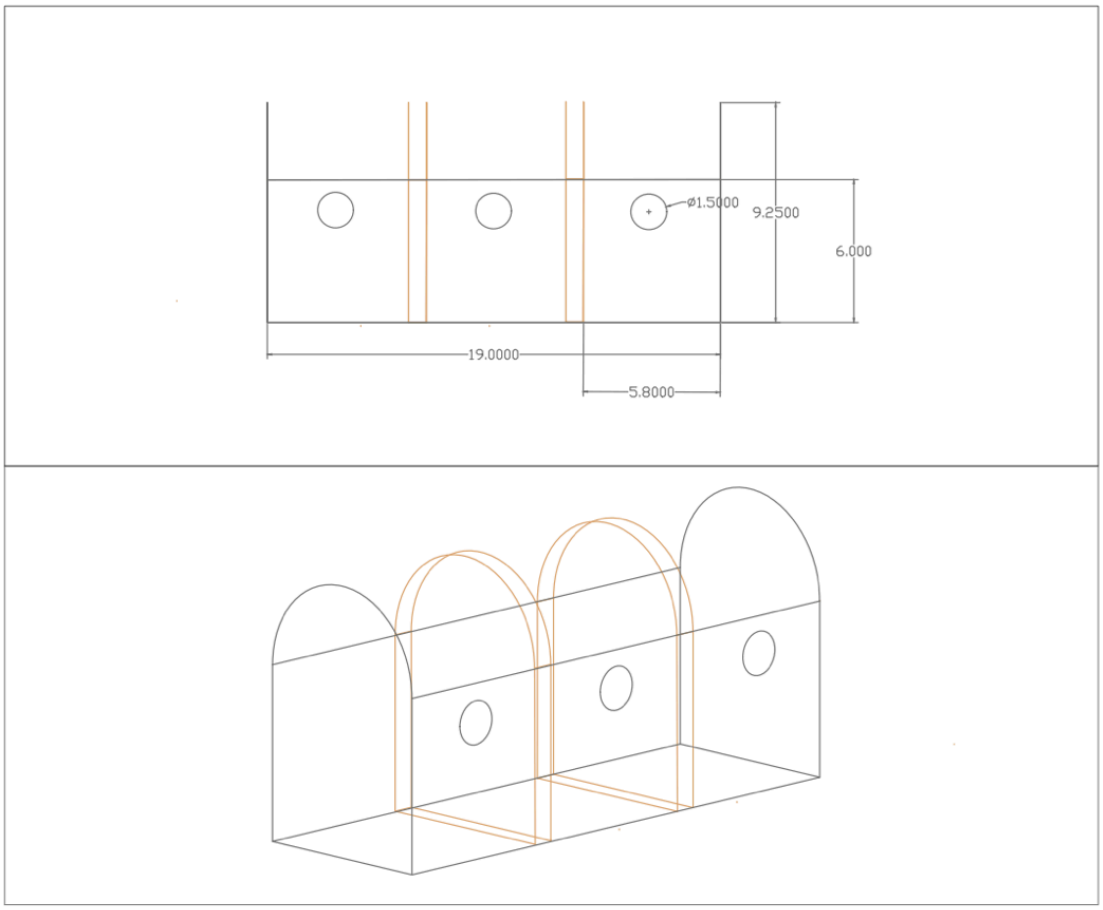

Figure 3-4: Digital Drawing of Mailbox Birdhouse with dimensions by Alex Garza

3.3.5 Single Log Construction

The Single Log Construction is a design that is easily scalable to many different birds because of the variations in sizes of logs. First a one inch disk is cut off the top of the log. The log is then hollowed out and ventilation and entrance holes are drilled. Then the top disk is screwed onto the log to complete the birdhouse. This birdhouse is insulated well and meets inhabitability requirements for many different birds due to its ability to meet the dimensions many birds prefer. It also provides a sustainable construction, as wood logs are a renewable resource and are biodegradable. It is very durable as it is made up of only two pieces: a hollowed log and a lid. Wood is also non-toxic. This box may be more labor intensive than a dimension-board construction, but it shouldn't exceed the 3-hour time specification. As for the logo requirement, a logo could be screwed into the form of the birdhouse.

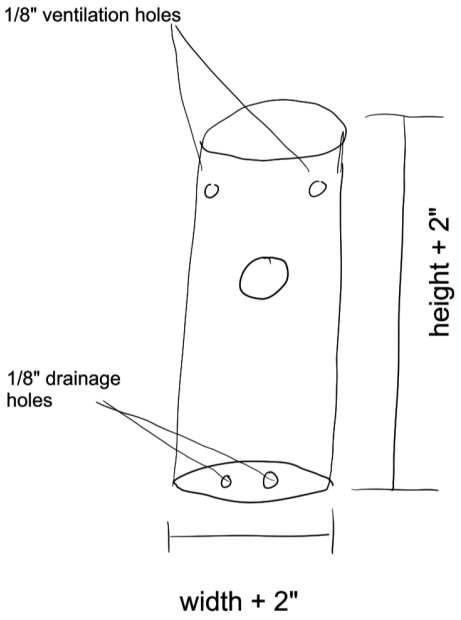

Figure 3-5: Drawing of Single Log Construction with vague dimensions by Alex Garza

3.3.6 Log Condo

The log condo is an extension of the log construction. Three log construction birdhouses will be attached to a 2x4 board to form the log condo. This birdhouse meets the same criteria as the Single Log Construction, but has the added ability to house 3 times the amount of birds.

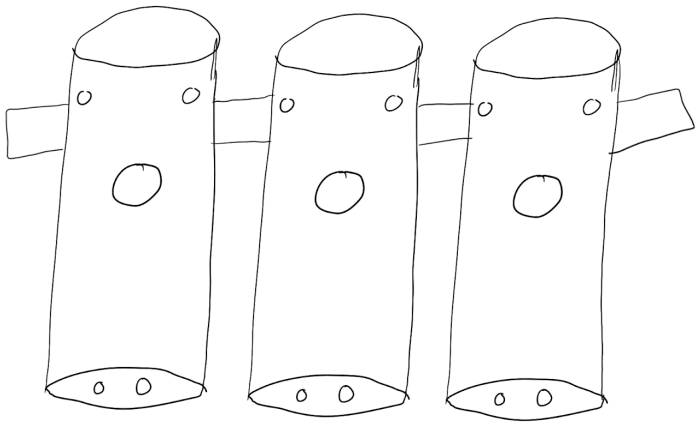

Figure 3-6: Drawing of Log Condo with vague dimensions by Alex Garza

3.3.7 Cedar Waxwing Cottage

The cedar waxwing condo is made up of upcycled wood. This is to meet the sustainability criteria. The use of wood also provides enough insulation for the birds that use the birdhouse. The cottage is made using the cedar waxwing's preferred birdhouse measurements to meet the inhabitability criteria. This means a length and width of 8 in. and a height of 14 in. excluding the

slanted roof. The slanted roof will add 3 inches. The slanted roof is intended to increase the durability of the cottage by allowing anything that falls onto it, to fall down and off. The model meets the sustainability, durability, and inhabitability criteria.

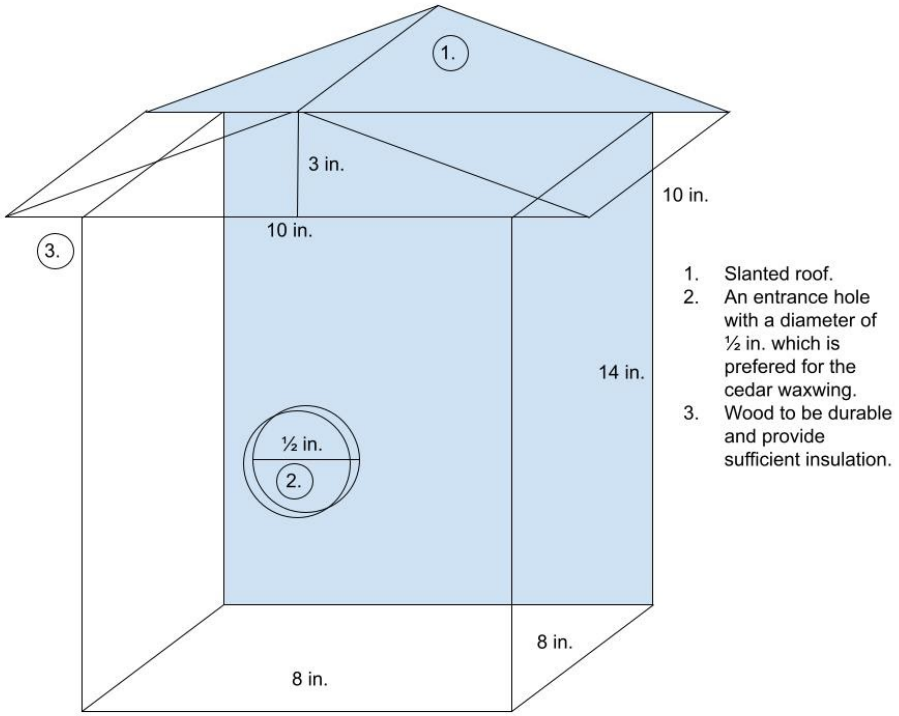

Figure 3-7: Digital 3-D Drawing of the Cedar Waxwing Cottage with dimensions and labels by Valerie Keody

3.3.8 Wooden Bat Cave

The wooden bat cave is a bat box made of donated wood. The wood will be finished with varnish to make it more durable. This meets the criteria of durability. The donated wood is primarily scrap wood from department stores and wood work locations in Arcata, CA. The bat box has a slanted roof to prevent any debris from getting stuck on the roof. The box itself includes numerous dividers to cater towards the bats habitat preferences. The entrance to the box is located at the bottom since bats prefer to hang upside down. The wooden bat cave also utilizes wood because of its thickness for ventilation and because the wood is reused or recycled.

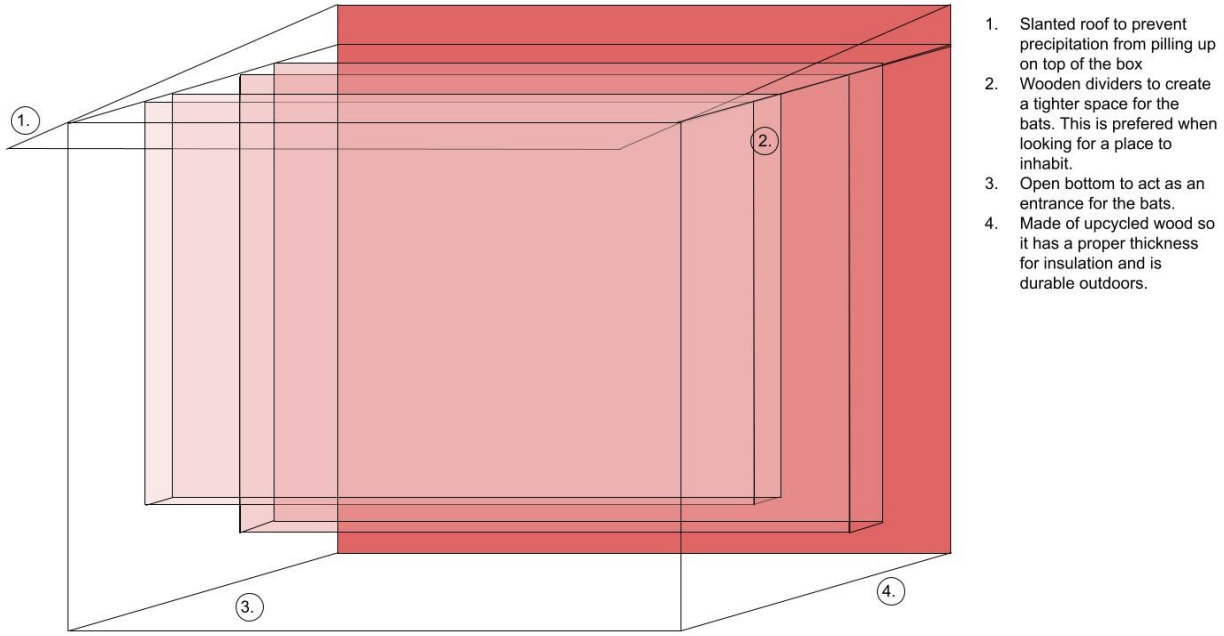

Figure 3-8: Digital 3-D Drawing of the Wooden Bat Cave with labels by Valerie Keody

3.3.9 Upside Down Bat Housing

Upside down bat housing utilizes a reused box or mail holder as the body of the bat box. Because the bat box is primarily made up of a reused box, the bat box meets the sustainability criteria. The bat box is made of wood to make it durable for outdoor weather and thick enough for insulation. The model below meets the criteria because its use of wood makes the bat box both durable and easily inhabitable for bats. The reused box will be hung upside down to provide an underneath entrance which is preferred by bats. As seen in Figure 3-9 the box includes dividers to make the box more inhabitable and comfortable for bats.

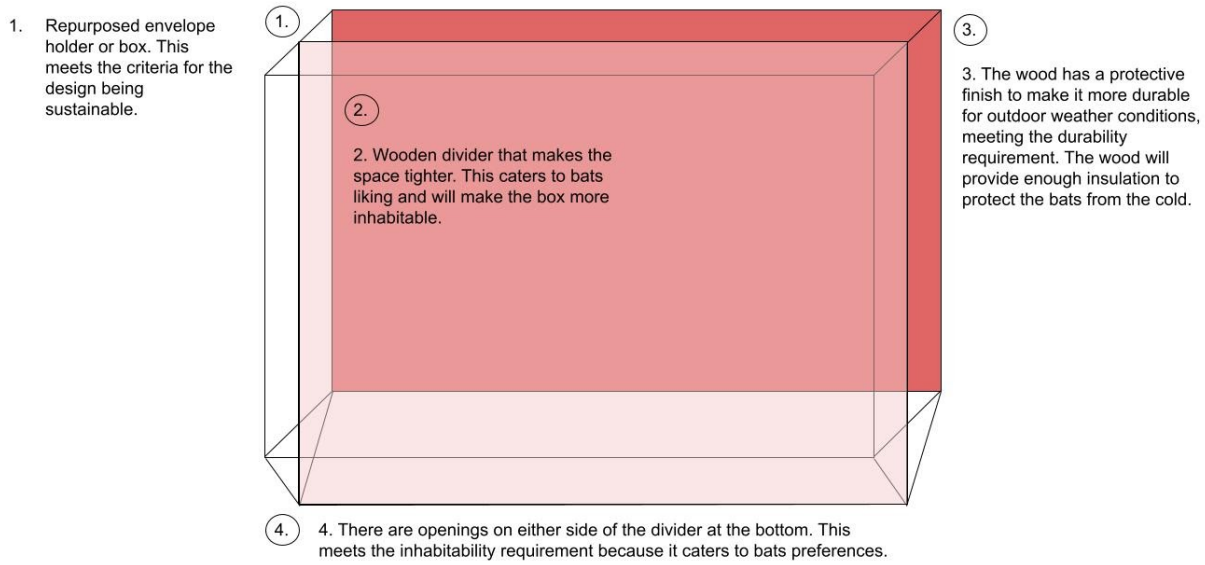

Figure 3-9: Digital 3-D Drawing of Upside Down Bat Housing with labels by Valerie Keody

4 Selection of the Final Design

Section 4 includes an analysis of how the alternative solutions match the given client criteria, and the process of selecting the final three nest box designs. The elements that influenced the selection process for this project were client feedback regarding the alternative solutions, the design criteria, and the accessibility of the proposed materials in some of the designs. A Delphi Matrix is located in Section 4.4, and it presents the combination of the alternative solutions with the design criteria. The Delphi Matrix presents a set of numerals which are interpreted as a score for each alternative solution and its ability to satisfy the needs of the client.

4.1 Criteria

In this section, all design criteria are listed with their definitions. During the decision process these definitions are used to evaluate whether particular designs meet criteria. This will then be used in the final decision process to select three final designs.

Cost- The amount of money spent for acquiring, producing and maintaining the project.

Durability- The ability of the project to withstand weather conditions, use, and middle school students over its designed lifetime.

Aesthetics- The outward appearance of the project that matches the basic infrastructure of Zane Middle School.

Safety- The project will not cause harm to faculty members, students, the community, and the inhabiting species.

Sustainability- The use of materials that have less embodied energy than a brand-new birdhouse such as natural, recycled, or upcycled materials.

Reproducibility- The ability to replicate the project design with ease under a reasonable amount of time.

Inhabitability- The project encourages specific species to inhabit the nest boxes safely.

4.2 Alternative Solutions

The nine solutions considered during our decision process were outlined in Section 3:

- Nuthatch Homestead
  - Relatively cost-effective, meets durability, safety, reproducibility, and inhabitability requirements
  - Average aesthetics and below average sustainability
- Wren Residence
  - Meets criteria for cost, durability, reproducibility and inhabitability
  - Lowest safety rating and does not meet the safety criteria
  - Low sustainability rating and does not meet that criteria Meets aesthetic criteria
- Chickadee Condo
  - Meets cost, aesthetics and sustainability criteria while meeting criteria for durability, reproducibility
  - Lower than average safety and sustainability ratings
- Mailbox Birdhouse
  - This birdhouse has the lowest inhabitability and reproducibility ratings
  - Meets cost, durability and aesthetics criteria
  - Lower than average safety rating
  - Higher than average sustainability rating
- Single Log Construction
  - The Single Log Construction meets all criteria but reproducibility and safety
  - Above average aesthetics and sustainability ratings
- Log Condo
  - The Log Condo meets cost, durability and aesthetics criteria
  - Very low reproducibility and inhabitability scores
- Cedar Waxwing Cottage
  - The Cedar Waxwing Cottage meets all criteria except for aesthetics, sustainability, and safety
  - Highest inhabitability score
- Wooden Bat Cave
  - The Bat Cave meets all criteria except for aesthetics, sustainability, and safety
  - Very high durability score compared to other designs
- Upside Down Bat Housing
  - The Bat Housing has the highest cost rating and the lowest inhabitability and aesthetic scores
  - Meets all other criteria but sustainability

4.3 Decision Process

The decision process consisted of determining the weight of each criteria with the client representative. Table 4-1 represents the weight of each criteria based on a scale of 1-10, with 10 being the most significant. Additionally, all nine alternative solutions were presented to the client representative for the purpose of feedback and opinion.

Criteria	Weight (1-10)
Cost	3
Durability	7
Aesthetics	8
Safety	10
Sustainability	9
Reproducibility	5
Inhabitability	8

Table 4-1: Criteria weighted based on importance to the project

A Delphi Matrix, shown in Table 4-1, was used to determine the ability for each alternative solution to meet the criteria. After comparing the numerical results, the team discussed the client representative's preferred solutions. The numerical values created by the Delphi Matrix were not the sole determining factor of which solutions would be produced. The preferred solutions of the client representative and the ability to produce the designs were also taken into account.

Criteria	Weight	Alternative Solutions (0-50 high)								
	(0-10 high)	Nuthatch Homestead	Wren Residence	Chickadee Condo	Mailbox Birdhouse	Single Log Construction	Log Condo	Waxwing Cottage	Bat Building	Upside Down Bat Housing
Cost	3	35 / 105	35 / 105	35 / 105	40 / 120	40 / 120	30 / 90	40 / 120	35 / 105	40 / 120
Durability	7	45 / 315	40 / 280	35 / 245	40 / 280	45 / 315	40 / 280	45 / 315	35 / 245	40 / 280
Aesthetics	8	35 / 280	40 / 320	45 / 360	45 / 360	50 / 400	40 / 320	30 / 240	25 / 200	25 / 200
Saftey	10	50 / 500	10 / 100	30 / 300	30 / 300	45 / 450	40 / 400	40 / 400	35 / 350	40 / 400
Sustainability	9	35 / 315	35 / 315	35 / 315	40 / 360	45 / 405	40 / 360	35 / 315	35 / 315	50 / 450
Reproducability	5	45 / 225	35 / 175	25 / 125	15 / 75	25 / 125	20 / 100	45 / 225	35 / 175	40 / 200
Inhabitability	8	50 / 400	50 / 400	35 / 280	30 / 240	40 / 320	35 / 280	50 / 400	40 / 320	30 / 240
	Total	2140	1695	1730	1735	2135	1830	2015	1710	1890

Table 4-2: Delphi Matrix used to determine the numerical score of each alternative solution based on criteria and weight

4.4 Final Decision and Justification

As shown in Table 4-2, the Nuthatch Homestead received the highest Delphi score. It is the nest box that is most likely to be inhabited because it is designed with specific dimensions and preferences of Nuthatches. The simple design makes it effective in safety and reproducibility. The Cedar Waxwing Cottage was ranked third but was selected as our second design because of the client representative's preference. Additionally, the design is being altered to incorporate a log cabin aesthetic that will be used to spark interest in the creativity of reusing and upcycling materials for an alternate purpose. Although the Wooden Bat Cave was not ranked very high in the Delphi analysis due to its bulkiness and poor aesthetics, it was still selected as one of the three final designs because the client representative would like a bat box to be incorporated as an educational opportunity for the students at Zane Middle School. Since the design depends on the use of upcycled wood, the design of the box can easily be altered to improve the bulkiness and size. Zane Middle School does not currently have any bat boxes, but there are pre-existing bird boxes from a previous Engineering 215 project.

5 Specification of Solution

5.1 Introduction

Section 5 is a detailed review of the final solution. Three nest boxes, each accommodating to different wildlife were implemented at Zane Middle School. This section contains a complete description of the designs, along with instructions for implementation and use of the nest boxes. Analyses of the capital costs, labor, and the projected cost of maintenance are included in this section as well. The results of the models can be found at the end of this section.

5.2 Description and Solution

The three nest box designs that are modeled in the following section are composed of donated wood and upcycled materials. All adhesives and paints have been researched and chosen to the best of the team's ability to create a safe, non-toxic environment for the inhabiting species so each model of the final solution meets the necessary safety and sustainability criteria while still meeting the aesthetics requirement.

5.2.1 Chickadee Cabin

This model is a slight moderation of the Cedar Waxwing Cottage that was selected as a final design. Jenga Blocks were used in a brick-like fashion to build up the walls of this bird box; This shown in Figures 5-1 and 5-3. As shown in Figure 5-2, the dimensions of the design were too small to accommodate a Cedar Waxwing. During the prototype process, it was concluded that there were not enough Jenga Blocks to complete the Cedar Waxwing design, so it was modified to match the dimension preferences of a Chickadee. Recycled plywood, donated by Ace Hardware, was used for the base of the bird box and also the roof panels. In Figure (), the prototype for a hinge roof is shown. Hinges and a small zinc-plated silver steel hook and eye clasp were used to secure the opening roof panel.

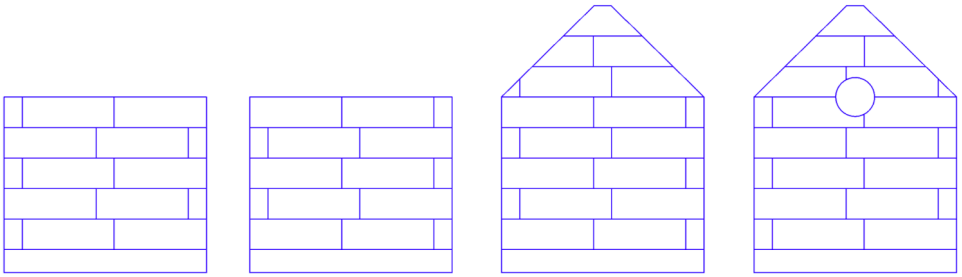

Figure 5-1: AutoCad Drawing by Rize Martins de Oliveira showing the side, back, and front views, respectively, of the bird box without roof panels

As for the name of the design, Chickadee Cottage was the name of a model from the previous bird box project, The Songbird Refuge by The Applicateers, so “cottage” was changed to “cabin.”

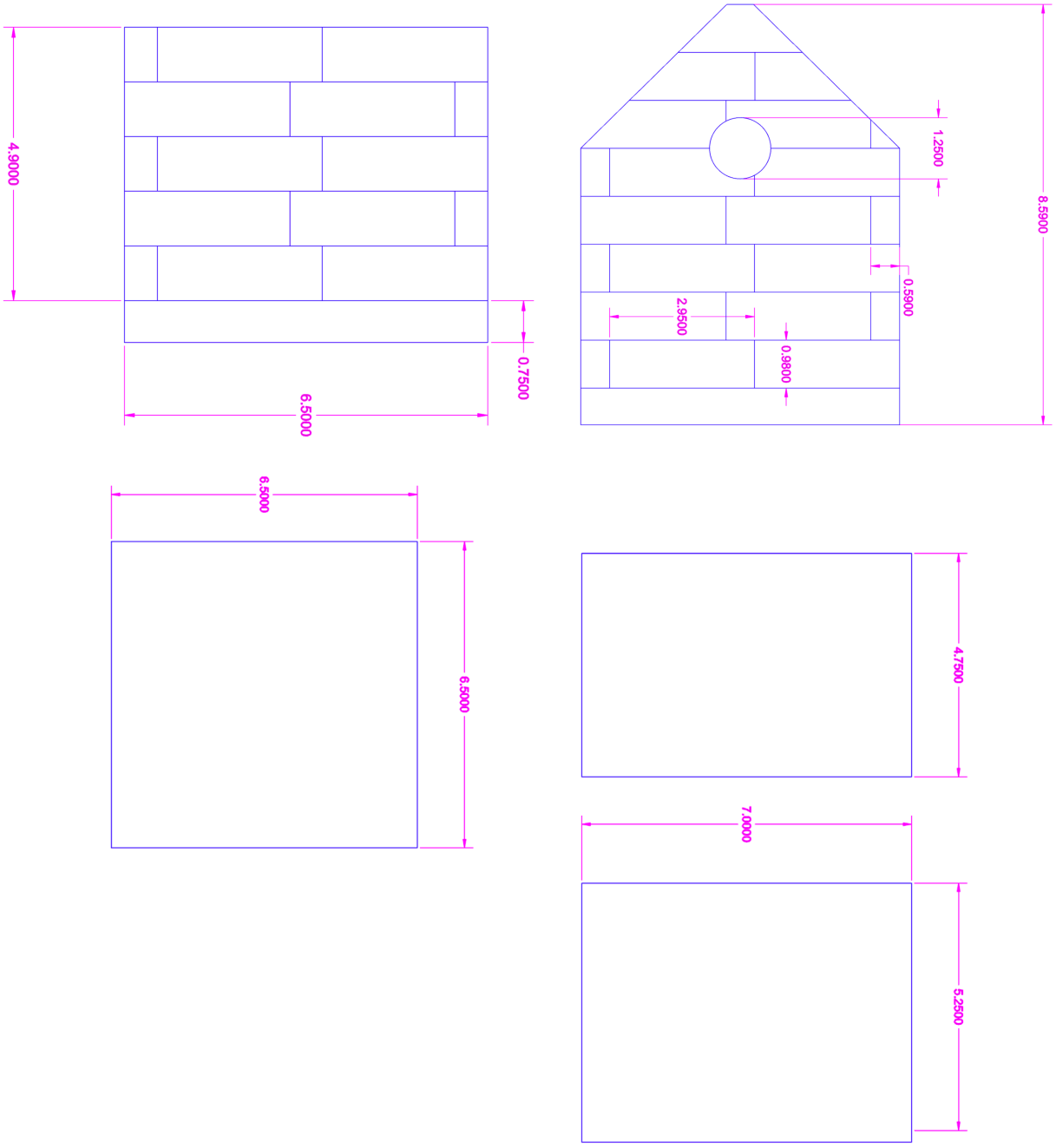

Figure 5-2: AutoCad Drawing by Rize Martins de Oliveira showing the dimensions of an individual Jenga block, the height and width of the bird box, and the roof and floor panels

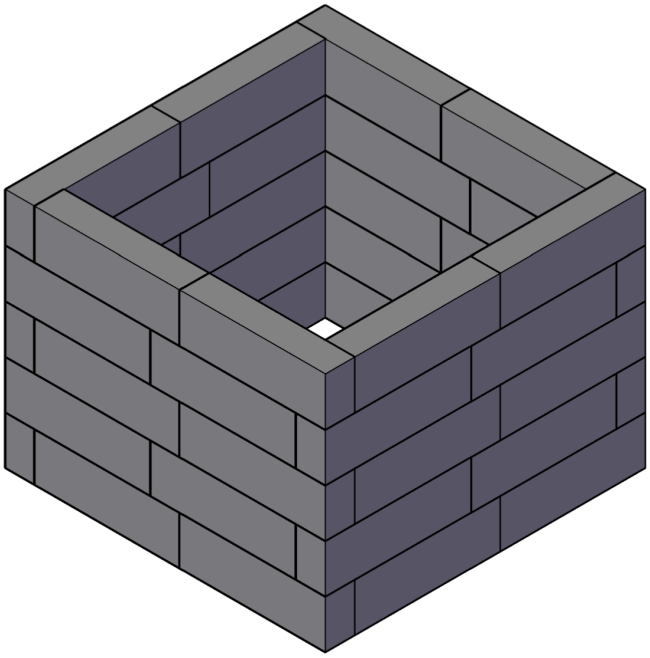

Figure 5-3: 3-D AutoCad drawing by Rize Martins de Oliveira depicting how the Jenga Blocks were placed upon one another in a brick-like pattern

5.2.2 Nuthatch Homestead

The Nuthatch Homestead is a basic dimension construction birdhouse constructed of ⅞ in plywood. The boards are attached to each other using wood screws. The front door panel of the birdhouse is hinged and folds forward for yearly cleaning. This design was one of multiple hinge designs that were prototyped, and was chosen over the previously selected revolving front door as it is much sturdier and allows for a hinge to be used instead of a swinging mount design. When not being cleaned, the panel is held in place by an identical locking hook and eye used in the Chickadee Cabin. The Nuthatch Homestead does not utilize typical ventilation and drainage holes, but instead these demands are fulfilled by ¼ inch gaps at the top and bottom ends of the door panel. The roof panel is weather sealed using non-toxic two-part epoxy. The entire birdhouse is also painted a dark brown color similar to that of redwood bark. The interior of the birdhouse is lined with wood shavings in order to provide nesting material.

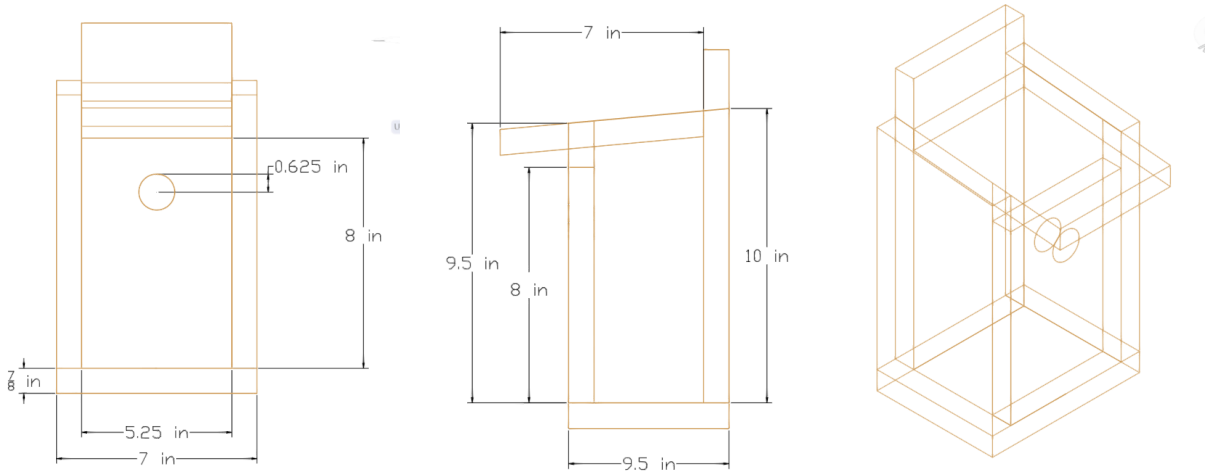

Figure 5-4: AutoCad drawing by Alex Garza depicting front, side and isometric views of the Nuthatch Homestead

5.2.3 Bat BnB

The Bat BnB is designed like common bat boxes with chambers, an exposed bottom, and overhanging roof. The bat box was put together with the use of screws. There is no way to open the bat box because bat box maintenance does not include cleaning due to the fact that there is no bottom floor panel. The bat box was painted a warm brown color that is dark. This was done to absorb heat in the winter due to the soldier temperatures in Humboldt County. The paint used for the bat box is nontoxic for wildlife. The bat box is made of 6 wooden panels. The back of the bat box is longer than the rest of the sides to provide a landing area for the bats. The box has two chambers which means that there is one wooden divider in the box to create chambers that are one inch wide. There is then a front panel that is shorter than the back panel and two side panels that are the same height as the front panel. There is a straight roof that protrudes out of the back panel to create an overhang. The overhang roof element is intended to prevent rain from getting into the bat box. The bat box is intended to be hung along the wall of a building. Bat boxes are more likely to be inhabited if on a building opposed to a tree. Additionally, the bat box will need to be monitored to make sure that a wasp's nest does not form and paint touch ups will be needed every couple of years to maintain the color and appearance.

5.3 Costs

5.3.1 Design

(Data still being collected)

5.3.2 Materials

Material	Quantity	Actual Cost	Retail Cost
Final Construction			
2" hinge	1	6.29	6.29
1" hinge	1	4.49	4.49
safety hook clasp	2	5.38	2.69
non-toxic dark brown interior paint 1qt	1	3.39	16.99
non-toxic light brown interior paint 1qt	1	3.39	16.99
10" hacksaw	1	8.54	8.54
60 grit sandpaper	1	2.2	2.2
1/4" hole saw	1	6.64	6.64
Titebond 3 wood glue	1	9.34	9.34
spray paint	2	6.78	3.39
foam brush	1	0.84	0.84
paint brush 2.5"	1	2.37	2.37
paintbrush 2"	1	2.12	2.12
gorilla wood glue	1	2.78	2.78
loctite epoxy	1	2.97	2.97
whittler's kit	1	5.99	5.99
plywood sheet 3/4" thick, 4'x8'	1	0	60
jenga set	1	0	16.99
Subtotal		73.51	171.62
Total with tax		79.76	
Total Saved		91.86	

Table 5-1: Total cost of materials purchased to construct, implement, and maintain this project

5.3.3 Maintenance

All three designs require minimal maintenance in order to be habitable. The two birdhouses must be cleaned and have their sawdust replaced yearly. This must be done in mid-August, as this is a time when birds are not nesting and breeding young. The low cost of these two tasks is due to the low price of wood shavings and. Due to the fact that exterior paint is not manufactured without VOCs (volatile organic compounds), interior paint was used in order to find a non-toxic paint option. This means that the two birdhouses and bat box will need to be repainted roughly every 3 years. This cost assumes identical paint is purchased from Hensel’s Ace Hardware.

Maintenance Task	Frequency	Estimated Cost/year
Cleaning birdhouses	1 year	$0
Refilling birdhouse nest material	1 year	$0.50
Repainting	3 years	$5.67
Replacing QR Stickers	1 year	1 sticker per year
TOTAL		$7.17

Table 5-2: Cost and frequency of maintenance tasks required to uphold the quality of the project. Approximately 45 extra stickers have been purchased for replacement yearly.

5.4 Prototyping

5.4.1 Hanging Method Prototype 1

Figure 5-5 features a backboard mounting method which a number of the alternative solutions had or could easily be incorporated into. To help add support, there is a strip of cardboard that attaches to the bottom of the box to then connect with whatever the box is hung on. The prototype utilizes pins that would be substituted for screws for the project. All cardboard would also be wood. The angle that the connecting wood and bottom of the bird house should be a 45-degree angle because that is one of the most structural sound angles used in architecture. This method would work best for models that have the back of the bird box in touch with whatever it is hung on. Examples would be buildings or trees.

Figure 5-5: Prototype of wall mounting method with support strip. Built and photographed by Valerie Keody

5.4.2 Hanging Method Prototype 2

Figure 5-6 depicts a method that allows for the birdhouse to be hung on a pole or branch. This gives a variety of placements to not all of the birdhouses would have to be put against tree trunks. The birdhouse would have two holes at the top so rope can be put through. The rope ends will be tied so then the bird house can hang. The cardboard box in this prototype represents the bird box.

Figure 5-6: Prototype of hanging method with rope. Built and photographed by Valerie Keody

5.4.3 Opening Prototype Method 1

Figure 5-7 shows a way to open the bird box in the Nuthatch Homestead design using hinge screws in order to be able to clean out the old nests and refill the box with fresh wood shavings to make the Nuthatches more comfortable. The test proved to be a difficult construction, and with further examination, this test proved harder access.

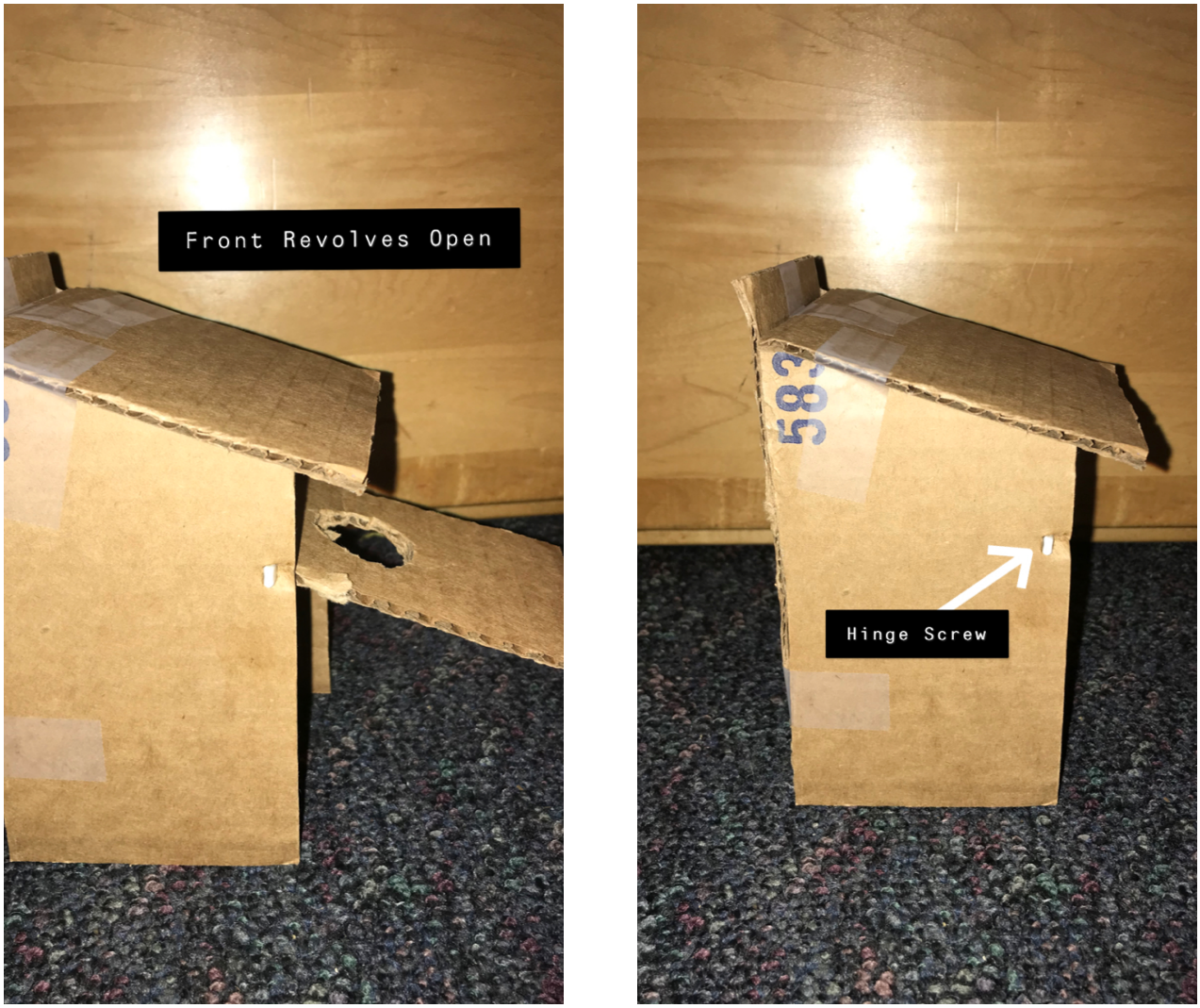

Figure 5-7: Prototype of revolving front panel as an opening method. Built and photographed by Rize Martins de Oliveira

5.4.4 Opening Prototype Method 2

Figure 5-8 shows a way to open the bird box in the Nuthatch Homestead design using a simple hook lock and hinges in order to be able to clean out the old nests and refill the box with fresh wood shavings to make the Nuthatches more comfortable. Although the side hinge method was not utilized in any of the final designs, this test concluded that the hook and eye method was the most effective for keeping a revolving panel in place.

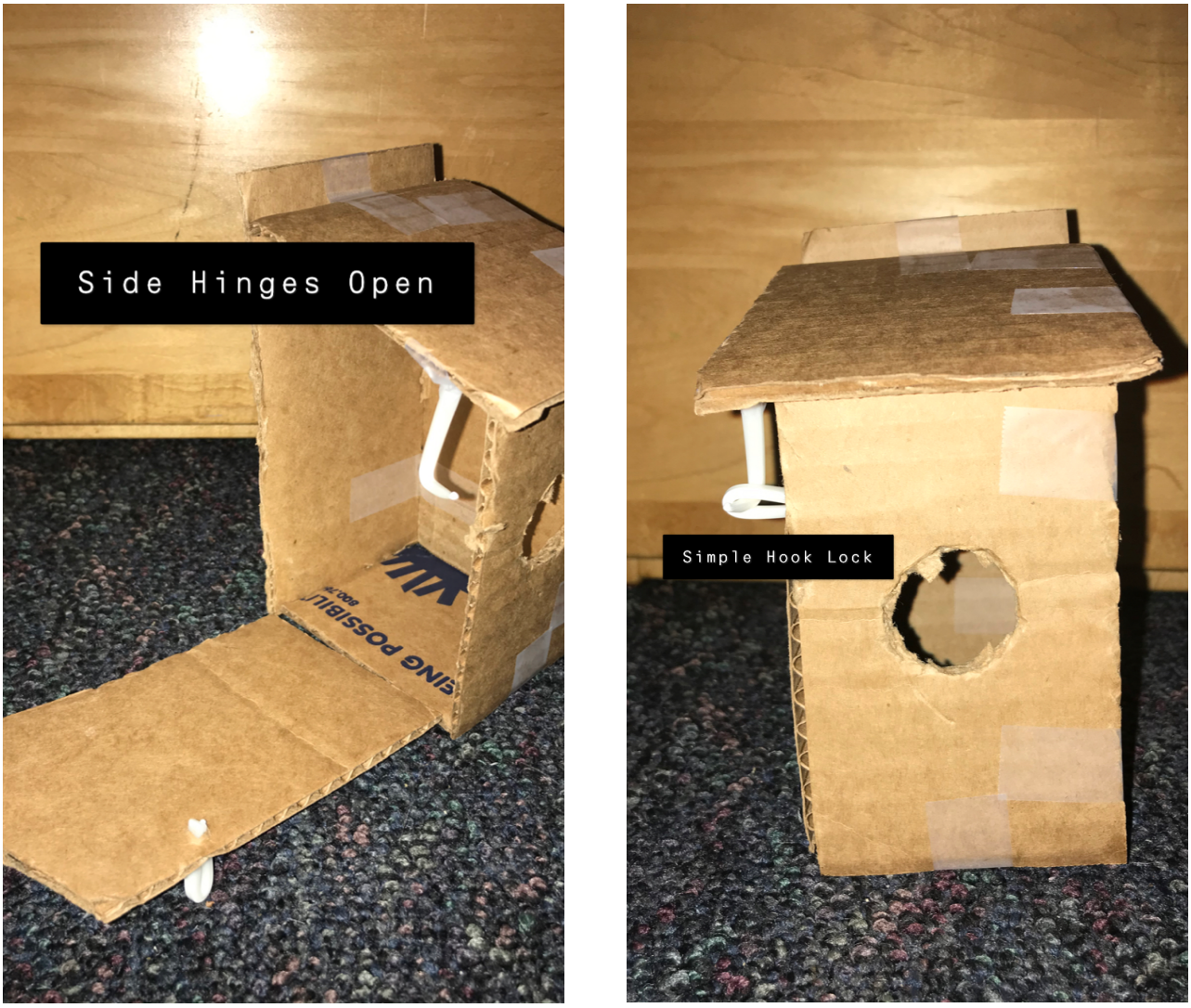

Figure 5-8: Prototype of side hinge as an opening method. Built and photographed by Rize Martins de Oliveira

5.4.5 Opening Prototype Method 3

Figure 5-9 shows a way to open the bird box in the Chickadee Cabin design using roof hinges in order to be able to clean out the old chickadee nests so the next mating pair can build in their new home. This proved to be the most accessible over a revolving side panel when it came to the simple birdhouse design.

Figure 5-9: Prototype of roof hinge as an opening method. Build and photographed by Rize Martins de Oliveira

5.4.6 Adhesive Prototype

This test shown in Figure 5-10 was conducted for the purpose of discovering which adhesives are suitable for use in proposed construction. LOCTITE 2-part epoxy and Gorilla wood glue were selected as two possible choices for construction. Adhesives were applied to 3 similar wooden dowels as per instructions and left to dry for the amount of time directed. The epoxy and wood glue both formed a bond between wood of similar strength, but the epoxy dried in a harder state than the wood glue. This could make it difficult, if not impossible, for birds to pick off pieces of adhesive. In research, it was discovered that when mixed, 2-part epoxy forms inert plastic material that does not give off fumes like its liquid counterpart. Gorilla wood glue's non-toxicity could not be verified. The only other wood adhesive to consider is TITEbond II or III.

Figure 5-10: Adhesive test done to visually compare and test waterproofness between LOCTITE epoxy and Gorilla wood glue. Test conducted and photographed by Alex Garza

5.5 Instructions for Implementation and Use of Model

The nest boxes will be implemented in the migratory corridor behind Zane Middle School. The following three subsections will describe how each model will be mounted and how it will be used.

5.5.1 Chickadee Cabin Implementation and Use

Chickadees prefer their nest box to be placed between 5 and 15 feet above the ground. If possible, the entrance hole should face away from prevailing winds. Possible nesting locations include being attached to a building, post, tree, or pole, but for this project, this model will be hung in a tree in the migratory corridor behind ZMS. To hang the Chickadee Cabin, a well-located, sturdy branch must be found, and then a hook should be secured to the branch where the nest box will hang a very short piece of wire, rope or chain.

Before mounting the nest box, about an inch of wood shavings should be placed in the box floor. This will encourage the Chickadee to use the model because it resembles a freshly dug out cavity. Chickadees mostly nest in the months of April through July in Humboldt County, so the wood shavings should be replaced when cleaning the nest box during the off season in mid-august.

5.5.2 Nuthatch Homestead Implementation and Use

The birdhouse placement that nuthatches prefer is similar to the chickadee's preferences. They prefer boxes be mounted 5-10 feet high. They also prefer the entrance to face away from the wind's direction. An inch of wood shavings placed in the bottom of the birdhouse is preferred by the nuthatch. This box will be attached to a pole or a tree with screws. This box will be hung in the migratory bird corridor behind ZMS. As for maintenance, this birdhouse will also need to be emptied yearly in mid-august as well as its wood shavings replaced.

5.6 Results

The prototyping determined which epoxy would work best for the nesting boxes. This would be especially important for the nesting box that would be made out of repurposed Jenga blocks. Additionally, prototyping different hinge roofing and door methods concluded that having a hinged roof would be best for when maintenance would be done on the nesting boxes. Lastly, the prototyping of the hanging and mounting methods determined that the best bunting method depended on the design of the bird box. For the Nuthatch Homestead, the best method is mounting the nesting box directly onto the tree whereas the Jenga nesting box will do best hanging due to the fact that the Jenga blocks are really thick. Some issues with the prototypes is that it is undetermined how much the Jenga nesting box will move due to the weather conditions and hinging design. Since there was no idea of the weight of the nesting box at the time, it was not able to be tested at the time of prototyping.

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Appendix

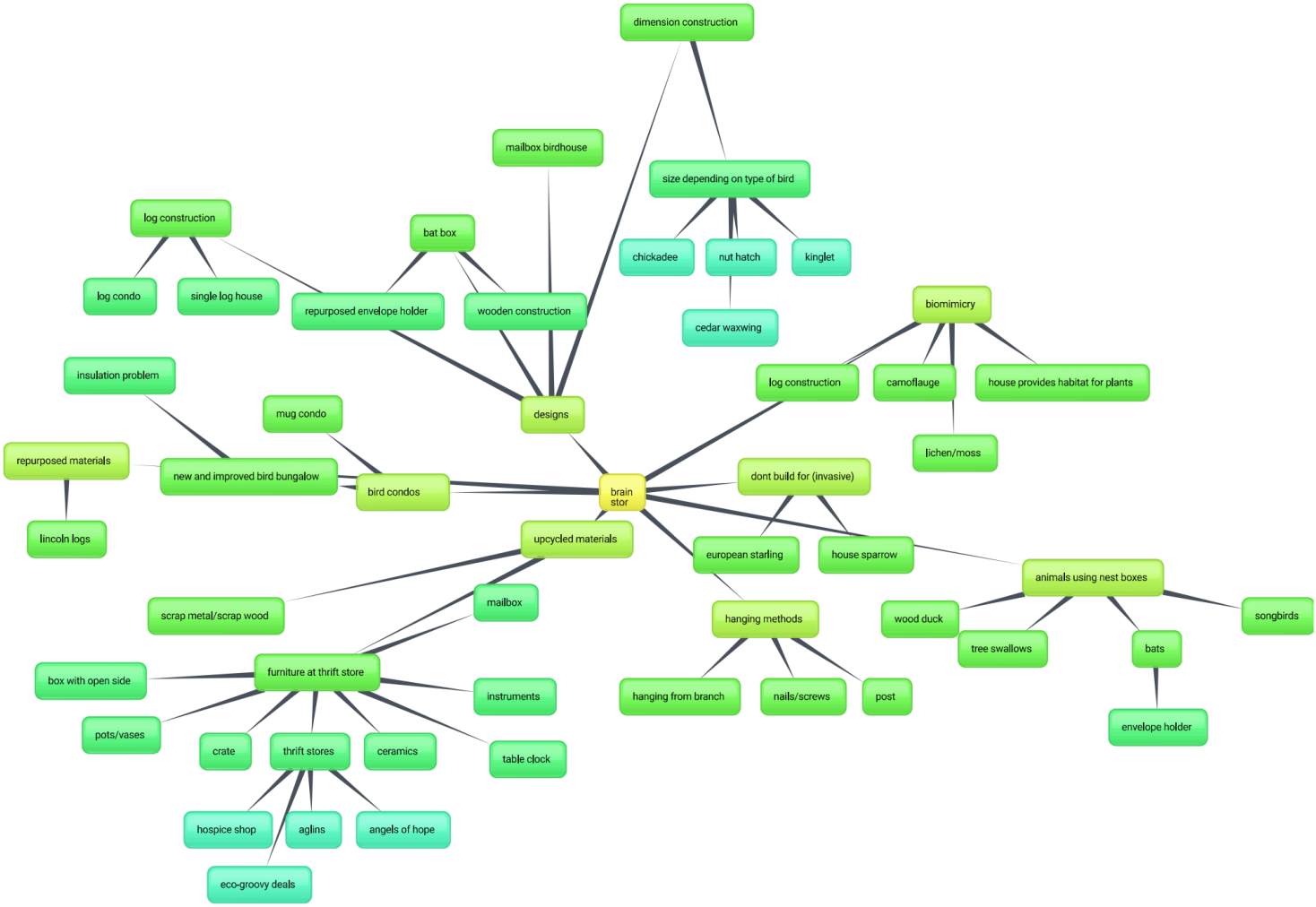

Figure 5-11: Brainstorming process for selecting alternative solutions are referenced in Section 3.2