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Carbon Neutral Luxury Dog House

ME450 Section 5 Team 22 - Winter 2021
University of Michigan

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Executive Summary

Dogs need adequate shelter to protect them from hazardous weather conditions. In Michigan, most shelters are only operational during the warmer months due to harsh winter weather. Although some luxury dog houses exist that are operational year-round, they use a lot of energy to maintain a comfortable interior for the dog. Due to the ongoing global climate crisis, solutions need to be carbon neutral to be valid long term. The carbon neutral luxury dog house aims to reduce the impact of modern dog shelters on the environment while also providing a safe, comfortable place for the dog while being outside.

Information for this project was gathered using three main methods: benchmarking, stakeholder meetings, and industry standards. Benchmarking was utilized to identify problems with modern dog shelters that our design should do differently. Regular stakeholder meetings were used to identify the wants and needs of the stakeholder Dr. Skerlos. These wants and needs were then used to determine the requirements and specifications for the shelter we will be designing for Dr. Skerlos's golden retriever puppy. Standards were utilized to determine the parameters and values stated in our specifications to achieve the requirements.

Based on feedback from our stakeholders and our design processes, we have designed a carbon neutral dog shelter for a large dog. Our design processes involved many different steps to ensure that we created the best product possible. Our first step was initial research and benchmarking. This involved looking up already existing dog house designs and determining what we think is important for our shelter to include. The next step was to create requirements and specifications. We created 12 requirements that we wanted our shelter to include, and we then ranked them on order of importance for us. We created specifications for each of these requirements so that we could later validate that we achieved this requirement. Our next phase was concept generation, in which each team member generated concepts that would hit many of our requirements. We also used design heuristics to come up with even more concepts. Then by eliminating concepts that were out of scope, we began concept selection. We created a Pugh chart and completed design ideas to come down to 3 final designs. Next, we created a revised Pugh chart that was used to adapt these 3 designs and incorporate ideas from each of our concepts in order to create one final design to excel in meeting all of our requirements.

The final product is a CAD model of our design with engineering drawings, manufacturing plans, assembly instructions, and an approach to offset carbon output, as well as data which analyzes the temperature and environmental impact of the design.

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Problem Description & Background

What is an Adequate Shelter?

As outlined in the Michigan Penal Code Section 750.50,[1] a shelter must provide adequate protection from the elements and weather conditions suitable for the age, species, and physical condition of the animal, so the animal can remain in good health. Good health is defined as freedom from disease and illness as well as in a condition of proper body weight and temperature for the age and species of the animal. According to the Michigan legislature, shelter for a dog must include one or more of the following:

- The residence of the dog's owner or other individual.
- An enclosed dog house with a roof that is of appropriate dimensions for the breed and size of the dog. When the outdoor temperature is or is predicted to be below freezing, the dog house must have dry bedding.
- A structure, including a garage, barn, or shed, that is sufficiently insulated and ventilated to protect the dog from exposure to extreme temperatures.

Dangers of an Inadequate Shelter

The length of time that a dog can spend outdoors is highly dependent on the weather conditions. Exposure to extreme temperatures can severely impact a dog's medical condition, potentially even resulting in death. In hot weather, dogs can experience dehydration, heatstroke, and even sunburn. Animals are at an increased risk for heat stroke if they are old, young, overweight, or have pre-existing conditions that affect the function of their heart or respiratory systems.[2] If not treated for this condition in a timely manner, the dog can suffer internal organ damage which could result in death. During prolonged exposure to the sun, dogs are at risk of sunburn, primarily on the ears and nose.[3]

High humidity can also put the health of an animal at risk. Panting enables animals to control their body temperature by evaporating moisture in their lungs to remove heat from their bodies. Dogs with short muzzles have more labored breathing and are at higher risk from overheating due to high humidity. If humidity levels are too high, dogs are unable to cool their body sufficiently by panting which could result in them becoming overheated.[2]

During extremely cold weather, dogs are at risk of frostbite, hypothermia, and even death. Frostbite primarily affects a dog's ears, feet, and tail. If a dog is subjected to prolonged exposure to cold temperature and more heat is being lost than the dog's body can produce, the dog can suffer from hyperthermia. If the dog does not receive sufficient medical treatment in a timely fashion, the dog will freeze to death. A dog suffering from extreme hypothermia can experience several neurological conditions, including a coma, heart problems, and kidney failure.[3] Animals are at an increased risk in cold environments if they are old, young, ill, or underweight.[2]

Shortcomings of Modern Dog Shelters

Modern dog houses have made significant improvements on their predecessors, however, there are still a few problems that need to be addressed. The biggest problem with current dog houses is that some dogs do not use their dog house.[4] The shelter cannot protect the dog from hazardous weather if the dog will not enter the shelter. Another problem with current dog house designs is the easy accessibility for bugs, especially fleas and ticks, to enter the shelter and make a nest. This creates an unsafe environment for the dog, but this problem is difficult to fix without using harmful chemicals.

Our design aims to address these two shortcomings of modern dog houses. Our luxury dog shelter will be an appealing, safe, and comfortable environment for a dog to access whenever the dog is outside. To make the shelter more appealing for the dog to use, we will be incorporating 2 or more sources of "dog motivation." We will also utilize bug-resistant materials and building practices to allow for maximum pest control.

What is Carbon Neutrality?

Carbon neutrality is the idea of balancing out the greenhouse gases an entity puts into and takes out of the atmosphere. To be carbon neutral, the carbon emissions to and from this entity must sum to zero. To achieve this status, any emissions created by the entity must be offset by emissions the entity reduces in other areas.

Being environmentally conscious is of the utmost importance nowadays with widespread pollution and a global climate crisis impending. If the world wants to prevent climate change, carbon neutrality must be achieved at a global level. For our shelter design to be valid long term, it needs to be carbon neutral.[5]

Stakeholder Identification and Engagement

The main stakeholder and project sponsor is Dr. Skerlos. The end-user, another stakeholder, is Skerlos's golden retriever puppy. Additional stakeholders are members of Skerlos's household (his family) and anyone else directly interacting with the dog's outdoor shelter.

We met with the primary stakeholder on multiple occasions. During these meetings, the stakeholder identified his wants and needs for the shelter. These wants and needs were used as the basis for identifying and developing the requirements and specifications for this project. These requirements and specifications are listed and explained in detail in the Requirements and Specifications section of this report.

Although our primary objective is to create a shelter for Dr. Skerlos's puppy, considerations could be made to develop a design that would be appealing for a larger market in the future. In this case, additional stakeholders would include dog owners in Michigan, their dogs, and kennels.

The team met with the primary stakeholder on several occasions during the second phase of this project. The purpose of these meetings was to gain additional information for the project as well as provide updates and receive feedback in regards to the development of concepts and solutions. One stakeholder meeting was held with Dr. Skerlos's daughter, Andrea, to gain useful insight on the dog's personality traits. We learned that the family's golden retriever puppy, Tula, loves to look out of windows, lay in the sunlight, and carefully chews on her toys. She explained that Tula is very active and loves to play, but will crash after long periods of activity. Toys and items Tula likes to engage with include playing tug of war with ropes, bones, chew toys, stuffed animals, and fetching balls (although she does not fully comprehend the concept of fetch yet). She generally will not sleep on bare, cold floors instead preferring to sleep on the couch cushions or a rug. Tula is also very alert of animals; she likes to chase and bark at rabbits and other local wildlife. She is fond of several sounds, including whistles, music, squeaky toys, bird song, and deer noises; however, she does not like the sound of the vacuum cleaner.

During this same meeting, the team inquired about Andrea's ability to help construct and maintain the shelter. She is about 5 feet tall and can lift standard sized weights. Andrea expressed a willingness to clean the shelter at least once a week and indicated she does not mind extended cleaning periods to take care of her dog.

Once solutions had been generated and evaluated in a Pugh chart based on the project requirements, the top three solutions were presented to the primary stakeholder. Feedback on the designs were received, including a preference of the stakeholder to prioritize cooling of the shelter rather than heating it.

Problem Description

The purpose of this project is to design a premium, outdoor shelter meant for a large dog around 70-80 pounds, specifically Dr. Skerlos's golden retriever, Tula. Due to typical Michigan weather patterns, outdoor dogs need to have adequate shelter to keep them safe and comfortable during hazardous weather. An outdoor shelter is mutually beneficial for owners and their dogs as it allows the dogs to be safe when outside the residence, whenever necessary, and also gives the pet a personalized space of their own.

As defined by our primary stakeholder, the shelter must be carbon neutral, generally safe, weather-resistant, bug free, easily cleaned, operational between outside temperatures of 20-85°F, and made out of sustainable materials. The interior of the shelter should stay warm in the winter and cool in the summer, while still offering the dog convenient access whenever needed. The shelter also needs to be comfortable and appealing to the dog for repeated use.

The overall goals of the project are to create a detailed engineering design and assembly plan for the carbon neutral dog shelter. The team will also draft a bill of materials, establish key requirements and specifications, generate and narrow down design concepts, create a model of temperature control characteristics, and conduct a full environmental analysis of the system.

The shelter design and assembly plan should be made simple enough so that the average person could build it by themselves. The budget to purchase materials and create a prototype for this project is $500. Although we had the option to adapt a successful design into a market opportunity providing an effective how-to guide for building carbon neutral luxury dog shelters, we ultimately decided against it in order to optimize our design for one specific household of end users.

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Requirements & Specifications

After identifying the problem statement, a list of requirements and specifications were created. The requirements are from the stakeholders and cover their wants and needs and the specifications are measurable parameters that set goals to meet the stakeholder requirements. The list of requirements and specifications can be seen below in Table 1. They are ordered in terms of priority with #1 being the highest priority and #12 being the lowest.

Table 1: Project Requirements and Specifications

Requirement	Specifications
#1: Durable	● Interior is 100% French linen, jute, or rubber ● Exterior is 100% treated wood, aluminum, stainless steel, brick, or stone
#2: Easy access to the outdoors	● Entrance/exit must be at least 18 inches tall and 11 inches wide ● Dog can access shelter and outside with 0 humans assistance
#3: Suitable for a large dog	● Width/Length between 42 inches and 52.5 inches ● Overall height between 40 inches and 48 inches
#4: Stable	● Able to withstand > 991 N/m^2 applied to the walls ● Floor can hold ≥ 80 pounds
#5: Generally safe	● 0 wires exposed ● 0 exposed sharp surfaces/edges ● 0 VOC (Volatile Organic Compound) on material surfaces
#6: Functional under all seasonal temperatures	● Operational between outside temperatures of 20-85 °F
#7: Appealing to dog	● ≥2 sources of dog motivation
#8: Maintainable	● 100% of the shelter interior is accessible by owner ● 0 cleaning chemicals that could be harmful to dog
#9: Easy to assemble	● Build time < 20 steps which can be achieved one day

	● ≤ 12 tools
#10: Affordable	● Less than $500 for materials (excludes labor)
#11: Carbon neutral	● 0 carbon emissions over life cycle of shelter
#12: Aesthetically pleasing	● ≥2 customizable style options ● ≤8 shelter faces

Durable

In order for our design to be safe for dogs to use, it must be durable. The shelter should be able to withstand normal wear and tear from a dog as well as typical weather conditions in Michigan.

The first specification for this requirement is the interior of the shelter must be 100% French linen, jute, or rubber. These materials are commonly used in items that are bite and scratch resistant when tested with dogs. French linen and jute are commonly used to make bite suits for military and police K-9 training.[6] These materials do not rip or tear, and can be difficult for dogs to grip enough to bite. On the other hand, hard rubber is typically used to make durable dog toys.[7]

Based on the requirements for an adequate dog shelter in Michigan, our design must also be waterproof. Our second specification states the exterior of the shelter will be constructed from 100% treated wood, aluminum, stainless steel, brick, or stone. These materials are commonly used for outdoor buildings.[8] They are waterproof and will not degrade in very low or very high temperatures.

Easy Access to the Outdoors

The dog needs to be able to enter and exit the shelter with ease. A standard for dog houses is having an entrance/exit that is at least 75% as tall as the dog's shoulder to ground measurement.[9] Golden retrievers have an average shoulder to ground height of 24 inches.[10] Taking 75% of that measurement results in 18 inches, so the entrance/exit of the shelter must be at least 18 inches tall.

Another specification for this requirement mandates that the entrance must be at least 11 inches wide. Multiple sources recommend that the entrance width be 3 inches wider than the dog's widest point. The widest point is generally located at the dog's chest area.[11,12] Using photographic images to approximate the height difference from a golden retriever's chest to its back as 12 inches and combining this value with the circumferential girth of a golden retriever's chest from standard vest size,[13] the width of a golden retriever can be approximated. Evaluating the chest as an ellipse, the equation Perimeter = $2*pi*sqrt((R^2 + r^2)/2)$ produces a chest width of

8 inches for an adult golden retriever.[14] Adding 3 inches to the chest width determines that the final shelter entrance/exit should be no less than 11 inches wide.

The last specification for this requirement necessitates that the dog can operate the shelter with 0 human assistance. The dog must be able to enter, exit, and reside within the shelter independently while the owner is not around. This ensures the safety of the dog by providing shelter without the need for constant supervision.

Suitable for a Large Dog

In order to be accessible for a large dog, the shelter needs to be large enough for the dog to fit comfortably. Dimensional requirements for the dog shelter were found using the A-B-C method.[15] The width and length of the shelter should be the same as or no more than 25% larger than the dog's full length measurement. A golden retriever's full length is around 42 inches on average.[10] Therefore, the overall width and length of the dog shelter need to each be between 42 inches and 52.5 inches.

To accommodate an adult golden retriever, the overall height of the shelter should be between 25% and 50% more than the dog's height. The height is measured from the dog's head to its toes.[15] The average height for this measurement is 32 inches for golden retrievers, so the height of the shelter needs to be between 40 inches and 48 inches.

Stable

The shelter must not tip or buckle while being used by the dog. The first specification states the shelter will be able to withstand greater than 991 N/m^2 when applied to the walls of the shelter. This limit was found using engineering standards ASCE 7-02 and ASTM D3161; ASCE 7-02 discusses the standard of using 85 mph winds to test the walls of a 30 foot building[16] while ASTM D3161 tests asphalt shingles for roofs at velocities of 60, 90, and 110 mph, using different classifications for each.[17] These standards do not directly apply to the objective we are testing; however, they provide a good baseline of wind speeds tested for outdoor structures. Using these standards as well as outside research, 90 mph winds were selected as the test velocity. Using the formula $F_w = (½)\rho v^2 A$, where F_w is the wind force (N), ρ is the density of air (kg/m^3), v is the velocity of the wind (m/s), and A is the surface area (m^2), we found the minimum required force to be 991 N/m^2. The dimensions of the dog shelter have ranges, which affects the surface area being tested. As a result, the minimum requirement for force of the wall is a range of values: 1,075 - 1,612 N.

The second specification for this requirement is that the floor of the shelter must be able to hold at least 80 pounds. This weight can be converted to a downward force of 356 N. This number was determined from a stakeholder requirement as well as the top end of the weight of a golden retriever. This parameter would enable the shelter to hold an adult golden retriever who would weigh 70-80 pounds.

Generally Safe

To ensure no hazards are posed to the dog when using the shelter, the shelter must be generally safe. This requirement is defined by several specifications. First, there will be 0 exposed wires within reach of the dog. Electrical wiring may be considered during solution development, so we need to ensure there are no risks of electrocution or choking hazards for the dog while in the shelter.

The next specification requires 0 exposed sharp edges or surfaces that are accessible to the dog. This eliminates the risk of physical harm to the dog from the shelter.

The last specification is for all material surfaces to have 0 VOC (Volatile Organic Compound). VOCs contain carbon molecules and are released from material surfaces into the indoor atmosphere at average room temperatures through a process called off-gassing. VOCs are found in many materials. Once VOCs escape into the air, they can cause illness and allergic reactions,[18] which can be harmful to a dog's health. In other words, there must be 0 toxic materials exposed or accessible to the dog. This ensures that ingestion by respiration and excessive chewing will be harmless to the dog.

Functional Under All Seasonal Temperatures

In order for our design to be appropriate year-round in Michigan and conform to Michigan law, the shelter needs to be operational in all seasonal conditions. The specification of being operational between outside temperature of 20-85 °F was explicitly stated by the primary stakeholder. According to our preliminary research, the safe temperature range for large dogs to be outside is 20-80 °F.[19] Within this temperature range, the shelter will provide the dog with a safe, comfortable place to stay in whenever needed.

Appealing to Dog

To encourage the dog to use the shelter, the design must be appealing to the dog. The goal of creating a shelter is that it will be utilized by the dog to stay safe and relax when outside. To achieve this goal, our design must include motivational tools to persuade the dog to want to be in the shelter. Dog motivation can come in many forms, including food, toys, and encouragement from the owner.[20] Additional sources of dog motivation can include a vantage point or window to see outside, sounds that are appealing to the dog that will draw its attention, and comfort, such as warmth in the winter, coolness in the summer, or blankets and cushions to lay on. The specification for this requirement is that the shelter will include 2 or more sources of motivation for the dog.

Maintainable

To keep the shelter safe and ready for the dog to use, it needs to be easy for the owner to maintain. The first specification for this requirement is 100% of the shelter's interior must be accessible by the owner. Access to the entire shelter is important to ensure that the owner will be able to clean the interior and prevent harmful insects from nesting in the dog's area. The cleaning process needs to be simple and practical for the dog owner to complete on a regular basis. The second specification for this requirement is that the cleaning process will require 0 chemicals that could be harmful to the dog. This will eliminate the risk of an allergic reaction or ingestion of any chemicals that could endanger the health of the dog.

Easy to Assemble

For our design to be practical for dog owners to make, the shelter must be easy to assemble. There two specifications needed to fulfill this requirement. First, building the shelter will require less than 20 instructional steps per day. Second, assembly of the shelter will require 12 tools or less. These specifications will enable the average person to build the shelter correctly in one day following a simple set of instructions that only require tools readily available by most people.

Affordable

The cost to construct the shelter needs to be affordable for most families. The budget needs to be less than $500 and effectively cover the required costs for parts & assembly of the shelter. The $500 price point was explicitly outlined by our project stakeholder during our first meeting. Based on average building costs, $500 should be more than enough to properly create our carbon neutral dog shelter.[21]

Carbon Neutral

For a design to be valid long term, the shelter must be carbon neutral. The specification for this states the shelter will produce less than or equal to 0 carbon emissions over its life cycle. This is standard for most dog shelters as they typically do not require any form of energy to operate.

Aesthetically Pleasing

The shelter must be aesthetically pleasing for dog owners to want to use our design. This is the lowest priority requirement as it does not directly serve to solve the problem statement. The specification to achieve this requirement is the shelter must have two or more customizable options. The custom options will allow the shelter to blend in appropriately any environment by adapting a color palette that fits with the surrounding land and buildings. This will prevent the shelter from being obtrusive on the dog owner's property while it is being used. Another specification for this requirement is for the shelter to be made up of fewer than or equal to 8 different faces.This specification will ensure that the shelter is not designed to be an odd shape and that it has a clean overall appearance.

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Concept Generation & Development

Before our team could start generating concepts, we first needed to identify the key aspects and functions of the desired shelter. Our team identified seven main functions: entrance/exit, type of shelter, dog motivations, energy sources, accessibility/maintainability, temperature control, and materials. Before any group activities were completed, each team member ideated concepts for each of the main functions we identified for the shelter. A table containing the generated concepts during the individual concept generation for each function can be viewed in Table B.1 of Appendix B.i. Below in Figure 1, are two examples of concepts generated by function during the individual activity.

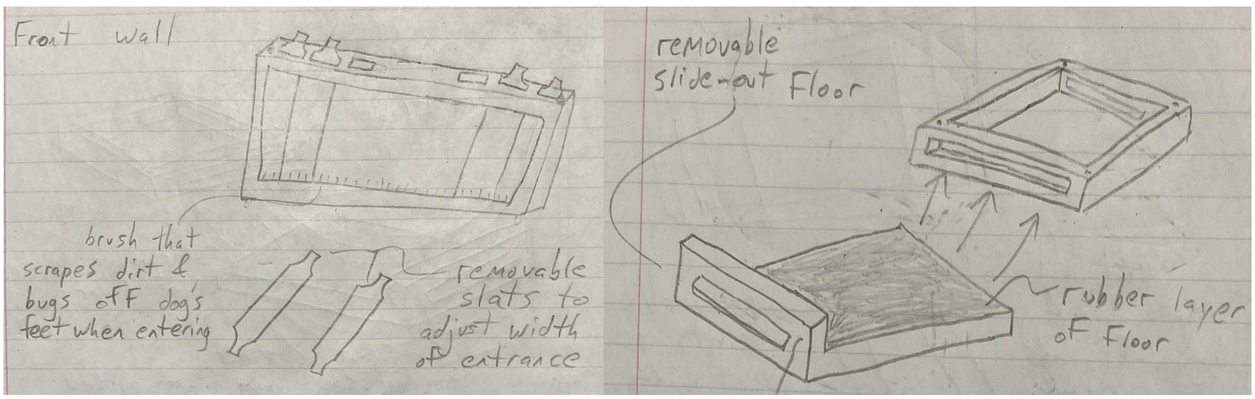

Figure 1: The figure on the left is a conceptual sketch for an adjustable entrance/exit to the shelter utilizing removable, vertical slats. The figure on the right is a conceptual sketch for a removable slide-out floor.

After completing the individual functional breakdown, the team shared their ideas with one another and began brainstorming additional concepts by building off each other's ideas. During this brainstorming session, the team maintained a focus on generating concepts to fulfill the seven functions identified earlier. The concepts that resulted from the group brainstorming session can be viewed in Table B.2 within Appendix B.ii.

Another group activity our team used to generate new and divergent concepts for the key functions of the shelter was design heuristics. By using 13 design heuristics, we were able to diverge further from the traditional dog house concept and explore a wider range of possible solutions. Prompts we utilized during this phase of concept generation include: make components attachable/detachable, add levels, use different energy source, adjust functions for specific users, change direction of access, and incorporate user input. Table B.3 in Appendix B.iii. shows a full breakdown of design heuristics used along with concepts generated.

After generating a wide range of divergent concepts, we needed to evaluate the list and remove any concepts that were inadequate for our project. Concepts were evaluated on three factors:

ability to achieve functional requirements of the project, relation to the scope of work, and feasibility to implement. The first set of concepts eliminated were the ones that did not fulfill our project requirements and specifications, such as an open entrance that did not provide temperature control. Requirements and specifications are the driving factors and goals of the project, so concepts that do not fulfill these parameters will not result in a successful solution. The second set of concepts eliminated were outside of the scope of our project, such as training Tula to run on a dog wheel to generate energy for the shelter. Any concepts that would require any extra evaluation, like real-life exploration, were cut due to the nature of the online project guidelines. The last set of concepts were eliminated because they were unattainable ideas. These concepts included ones that we felt would be too expensive and too long to create by the end of the semester, such as using nuclear energy to power the shelter. The elimination of concepts is shown in Table B.4 in Appendix B.iv.

After evaluating each concept against the three factors of ability to achieve requirements, relation to project scope, and feasibility, a list of adequate concepts was identified. Using this list of concepts, each team member created two shelter designs. Each of the ten designs generated is shown and described in Appendix B.v.

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Concept Evaluation & Selection

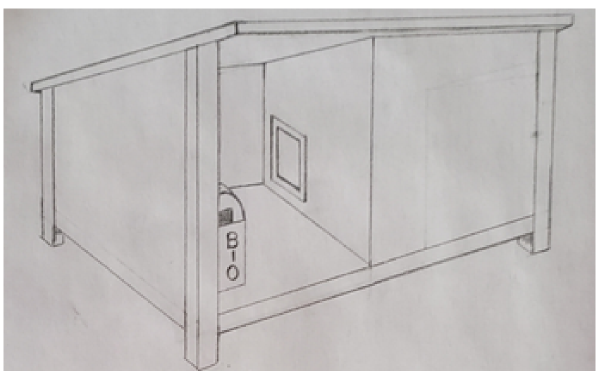
Once all of the designs were generated, we evaluated them in a Pugh chart using our project requirements. The project requirements were weighted based on the order of priority. Durable, easy access to outdoors, and suitable for a large dog were weighted the highest at a value of 4 due to needing a design that is practical and applicable to the dog we are designing our solution for. Next, stable, generally safe, and functional under all seasonal temperatures were weighted at a value of 3 because they determine if the design is safe for the dog to use. Appealing to dog, maintainable, and easy to assemble deal with the practicality of the design and whether or not the dog will want to use the shelter, so we weighted these requirements at a value of 2. Lastly, Affordable, carbon neutral, and aesthetically pleasing were our lowest priorities, so they were weighted at a value of 1. The first design was used as a baseline. All other designs were compared to the initial design to see if they achieved the requirements better (1), the same (0), or worse (-1) than the baseline design. The results of our Pugh chart are shown in Table 2.

Table 2: Pugh chart for concept evaluation of Designs 1-10

Requirement	Weight	Design 1 ZW 1	Design 2 ZW 2	Design 3 MA 1	Design 4 MA 2	Design 5 JS 1	Design 6 JS 2	Design 7 RD 1	Design 8 RD 2	Design 9 CG 1	Design 10 CG 2
Durable	4	0	0	0	1	-1	0	0	0	0	-1
Easy access to outdoors	4	0	-1	-1	1	1	-1	0	0	0	1
Suitable for a large dog	4	0	-1	1	0	-1	-1	0	0	0	0
Stable	3	0	0	-1	1	0	-1	0	-1	0	0
Generally safe	3	0	-1	0	-1	-1	0	0	0	0	0
Functional under all seasonal temperatures	3	0	0	0	1	1	0	0	0	-1	-1
Appealing to dog	2	0	0	1	0	-1	1	1	1	1	1
Maintainable	2	0	0	1	1	-1	-1	1	-1	-1	-1
Easy to assemble	2	0	-1	0	0	1	-1	0	-1	-1	-1
Affordable	1	0	-1	0	-1	1	0	0	0	-1	-1
Carbon Neutral	1	0	0	1	0	0	0	0	0	0	0
Aesthetically pleasing	1	0	-1	1	1	-1	-1	0	0	-1	0
TOTAL:		0	-15	**+3**	**+13**	-6	-14	**+4**	-5	-7	-6

The leading designs identified from the Pugh chart evaluation were Designs 3, 4, and 7. A common quality among these top performing designs is the shape of the roof. All three designs utilized a traditional roof with one or two sloped faces. This could be attributed to several factors. First, these types of roofs are easy to assemble. They are also appropriate for Michigan's various weather conditions as the slant provides adequate drainage of precipitation and relief from snow piling up too heavily. This helps maintain the health and structural integrity of the roof by preventing the roof from leaking or collapsing. A slanted roof also creates a wind break which provides stability for the structure during inclement weather. Lastly, we believe sloped roofs are aesthetically pleasing and appealing to owners.

Our leading design is pictured below in Figure 2. This design scored high on multiple requirements, including durable, easy access to outdoors, stable, maintainability, and functional under all seasonal temperatures. First, the structure is very durable. It is constructed from water-resistant materials and will be appropriate for year-round Michigan weather. The structure also allows for easy access to outdoors through an outdoor patio area and a dog door for the dog to go between the interior and exterior areas. Due to the shape of the structure and its wind reducing features, this design is very stable. It is also easily maintainable as the owner has access to the entire shelter via the outdoor patio and a hatch door on the back of the shelter. Another advantage of the lean-to design is the enclosed area and wind break assist with maintaining adequate temperature control.



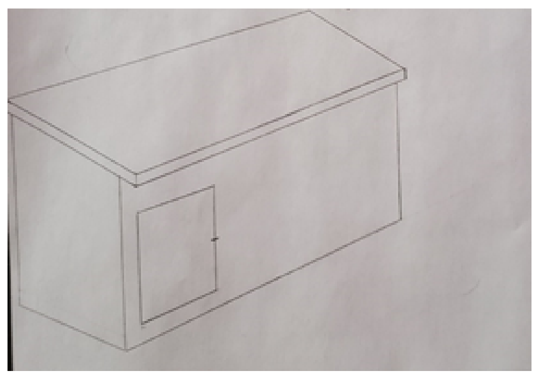


Figure 2: "Lean-to" design. Represented by Design 4 in the Pugh chart in Table 2. Pictured left is the front of the design showing the outdoor deck with access to interior via dog door. Pictured on the right is the back of the shelter which shows the back access hatch for cleaning.

Our second highest performing design is shown in Figure 3. This design has a brick base, increasing the height of the shelter. This added elevation helps the shelter be bug-proof, and the ability to drill into the brick helps with stability. The shelter has a dog door that will open and close as the dog enters and exits, helping with temperature control and bug-proofing. The roof has a foldable hinge in the middle, allowing one of the roof faces to rotate 180 degrees and rest on top of the other roof face. This allows easy access for the owner to clean and maintain the dog house. There is also a window on the side of the shelter, allowing the dog to look at the outdoors. We believe this feature will increase appeal to the dog. We learned in our stakeholder meeting that looking out the window is one of the dog's favorite things to do. There is also a view of the interior of the shelter. Along the back wall there is a concave platform which can be nice for the dog to lay against. This platform would also be raised about halfway up the shelter and there would be a dog bowl and a bone dispenser on top of it. There are also pillows and a removable heating and cooling pad to help with temperature control and comfort. These pads would run on solar energy.

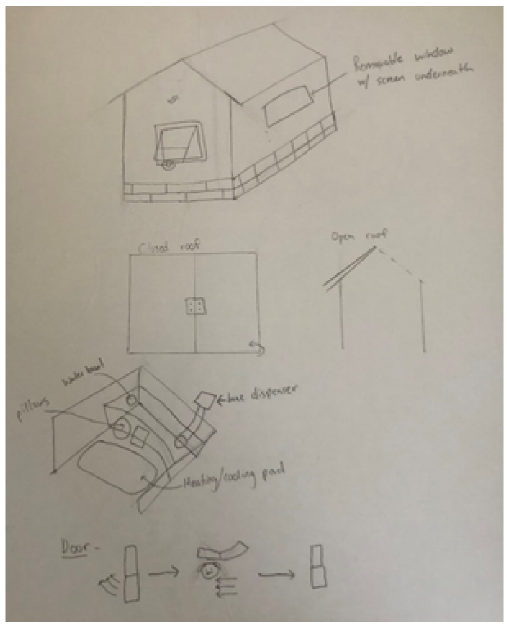


Figure 3: Second leading design. This design looks more like a proto-typical dog house. This is represented as Design 7 in the Pugh chart in Table 2.

Our third highest performing design is shown in Figure 4. This design scored high in appealing to dogs, maintainability, and suitable for a large dog. This design features an elevated dog shelter with two windows for the dog to peer out of. At the front of the shelter is a large window, and on the right side towards the front is another window. This shelter design also features two access points for the owner to enter and clean the interior of the shelter. The first is a hatch on the front right side of the shelter. The hatch utilizes two load-lock bars, so the hatch can be lifted up and locked into place without the owner worrying about it falling down on them while cleaning. The second access point is in the rear of the shelter. On the back panel is a hatch that can be unlocked and folded down to allow easy access to the rear of the shelter. This design utilizes a ramp and has a roomy interior which is suitable for a large dog.

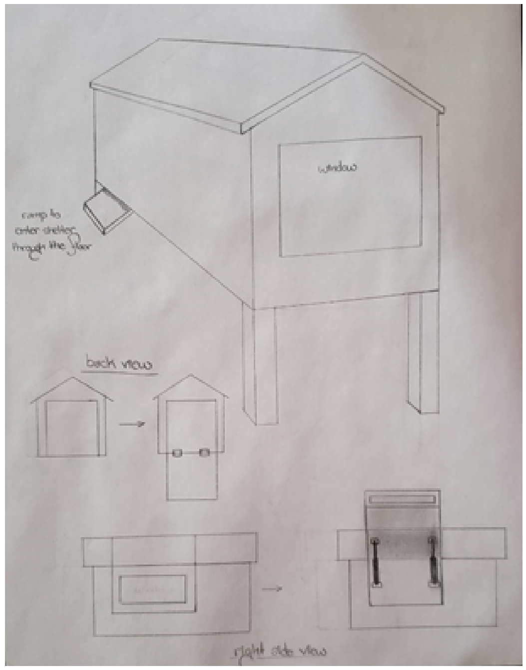


Figure 4: Third leading design. This is an elevated dog house. This is represented as Design 3 in the Pugh chart in Table 2 above.

Revised Pugh Chart

The original Pugh chart completed with the ten designs created individually by all team members had minimal weight differences between requirements and did not accurately reflect the importance of carbon neutral components in the design. To emphasize the prioritization of requirements to identify a leading solution, a revised Pugh chart was created with distinctly weighted groups. In the revised Pugh chart, “must-have” requirements were given a weight of 9, “want-to-have” requirements received a weight of 3, and “nice-to-have” requirements were given a weight of 1. The revised Pugh chart is shown in Table 3.

Table 3: Revised Pugh chart used for concept evaluation.

Requirement	Weight	Design 1 Zach 1	Design 2 Zach 2	Design 3 Michele 1	Design 4 Michele 2	Design 5 Justin 1	Design 6 Justin 2	Design 7 Ryan 1	Design 8 Ryan 2	Design 9 Corbin 1	Design 10 Corbin 2
Durable	9	0	0	0	1	-1	0	0	0	0	-1
Easy access to outdoors	9	0	-1	-1	1	1	-1	0	0	0	1
Suitable for a large dog	9	0	-1	1	0	-1	-1	0	0	0	0
Stable	9	0	0	-1	1	0	-1	0	-1	0	0
Generally safe	9	0	-1	0	-1	-1	0	0	0	0	0
Functional under all seasonal temperatures	3	0	0	0	1	1	0	0	0	-1	-1
Appealing to dog	3	0	0	1	0	-1	1	1	1	1	1
Maintainable	3	0	0	1	1	-1	-1	1	-1	-1	-1
Carbon Neutral	3	0	0	0	1	0	0	0	0	0	0
Easy to assemble	1	0	-1	0	0	1	-1	0	-1	-1	-1
Affordable	1	0	-1	0	0	1	0	0	0	-1	-1
Aesthetically pleasing	1	0	-1	1	1	-1	-1	0	0	-1	0
TOTAL:		0	-30	**-2**	**+28**	-20	-29	**+6**	-10	-6	-5

“Must-have” features consisted of safety standards and accessibility for the dog. The safety requirements included being durable, stable, and generally safe, while the accessibility requirements consisted of easy access to outdoors and being suitable for a large dog. These requirements were essential for a successful design to ensure the shelter is easily accessible as well as safe for the dog to use unsupervised.

“Want-to-have” features focused on the practicality and functionality of the design. These requirements included being functional under all seasonal temperatures, appealing to the dog, maintainable, and carbon neutral.

Features that would be “nice-to-have” in the final design but not crucial consisted of one time occurrences and subjective aspects. These included being easy to assemble, affordable, and aesthetically pleasing.

Despite creating distinct weights for the three prioritization levels of the requirements and raising the priority of carbon neutral features, the three leading solutions identified from the original Pugh chart were the same designs identified by the revised Pugh chart. These were Design 3, Design 4, and Design 7.

Identifying Strengths and Weaknesses of Leading Solution

The leading solution identified by the revised Pugh chart was Design 4: the lean-to. Sketches of the front and back of this design are shown in Figure 2.

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Design Strengths

According to the Pugh chart, this design performed well on several requirements. These consisted of:

- Durable: Design 4 utilized weather-resistant materials. Majority of the design is constructed from treated wood which is water-resistant and does not react adversely to low or high temperatures. This makes the shelter appropriate for all typical weather conditions that can be experienced year-round in Michigan.
- Easy access to outdoors: The lean-to design allows the dog to enjoy the outdoors in two different areas. The first is a large, open porch on the front of the shelter where the dog can sit or lie down. The second is an interior area sheltered from the wind which can be accessed via an appropriately sized dog door to allow the dog to easily walk through and transition between the enclosed interior and open porch areas.
- Stable: The shelter is kept low to the ground and utilizes a slanted, one-sided roof to minimize the effects of strong winds pushing against the shelter. Its higher weight and low center of gravity increase the shelter's stability.
- Functional under all seasonal temperatures: The shelter features two areas, an open porch and an enclosed interior. The open porch will get plenty of airflow and will be great for the retriever to rest upon during hot summer months. The enclosed interior will be warmer than the open porch during colder outside temperatures, so the retriever can comfortably rest in the enclosed area during the spring, fall, and winter.
- Maintainable: All areas of the shelter are accessible to the owner. This allows for easy cleaning of the shelter to keep it safe for the dog and free of any harmful pests. The shelter is raised a few inches off of the ground to deter pests and bugs from entering and creating nests. The front of the shelter can be accessed via the open porch area. The interior dog area can be accessed by the owner by opening a door located on the back of the shelter.
- Aesthetically pleasing: This design utilizes modern shapes and less than 8 faces to achieve a structure that would be aesthetically pleasing to the owner.

Design Deficiencies

Despite the high rating achieved by Design 4 on the revised Pugh chart, deficiencies were identified for several requirements. These included:

- Suitable for a large dog: The dog could find the enclosed area confining to be in and not want to enter that portion of the shelter.
- Generally safe: A biofuel container is stored on the inside of the shelter on the open porch. This could potentially be dangerous if the dog accessed this material.
- Appealing to dog: Design 4 lacks a viewpoint for the dog to look outside while inside the enclosed area.
- Easy to assemble: Due to the large scale of the design, this shelter could pose a challenge for someone trying to build the shelter by themselves. The angle of the roof

and subsequent angles and dimensions of the shelter walls could be challenging to get aligned correctly.
- Affordable: Design 4 was among the largest dog shelter designs generated by the team. The cost of materials to construct this design as well as to implement biofuel processing will be quite high compared to the other designs as well as traditional dog shelters available on the market.

Modifications to the Leading Solution

Considering well-performing components of other designs, modifications were made to Design 4 to address some of its deficiencies. Sketches of the modified design are shown in Figure 5.

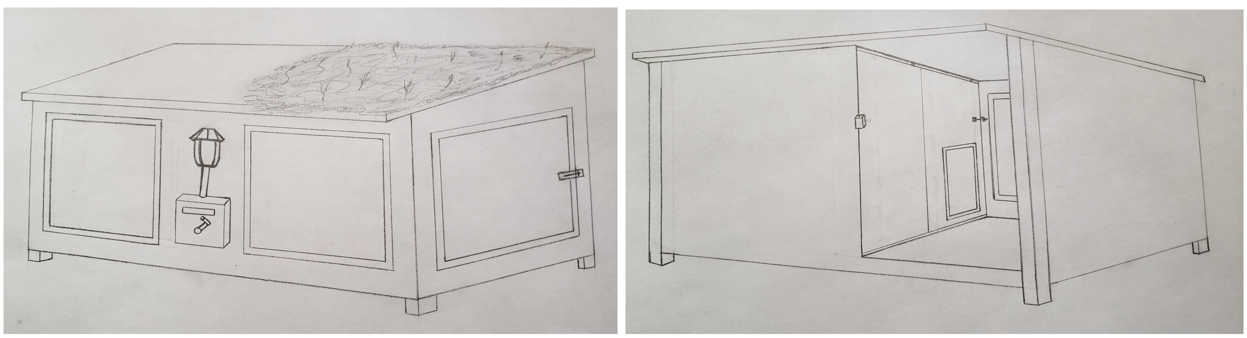

Figure 5: Modified leading solution. Pictured left is the front of the shelter with two large windows, a biofuel container with methane powered lamp,and a green roof and access door on the right side. Pictured right is the back of the shelter with an open porch area and an interior wall that can be in an open or closed configuration by using a pair of hook and eye latches. This shelter was designed to have the left side under the small, protruding portion of the deck leading down to the stairs. The right side of the shelter would protrude from the eastside of the deck and be parallel to the house.

List of Modifications

Modifications made to Design 4 include:

- Suitable for a large dog: The interior wall is movable in the modified design. This allows the owner to adjust the shelter from a closed configuration with an enclosed interior area to an open configuration. This would allow more room for the dog to lie down and increase airflow in the shelter. This feature is achieved by using a folding interior wall guided by a track on the ceiling of the shelter. The wall is held in the closed and open configurations using a pair of metal eyes on either side that a hook on the interior wall can connect to at a height above the dog.
- Generally safe: The biofuel container was moved from the interior of the shelter to an exterior wall on the opposite end that the dog uses to enter the shelter. Affixing the container to the wall and moving it out of the normal path of the dog will reduce the dog's access and potential exposure to the material.

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- Appealing to dog: Two large windows were added to the front facing wall to allow the dog to view the backyard from inside the shelter. One window is on the open porch side and the other is within the enclosed area of the shelter, ensuring that the dog always has a window to look out of no matter where she is located within the shelter.
- Carbon Neutral: Although Design 4 scored high for this requirement in the Pugh chart, there was not a well-defined plan to achieve carbon neutrality or a purpose for the biofuel. A partial green roof was added to the right side of the shelter to sequester carbon, and a methane-powered lamp was connected to the biofuel system to utilize the biofuel and provide an additional light source in the backyard.

Modifications to address the affordability and ease of assembly were not implemented in this design. These requirements were among the lowest in regards to priority (nice-to-have) and conflicted with higher priority requirements (must-have and want-to-have). Both of these requirements conflicted with the modifications to make the shelter more suitable for a large dog, appealing to the dog, and carbon neutral, as implementing a moving interior door, adding large windows, and incorporating a biofuel system and green roof will increase the cost of materials for the shelter as well as increase the time and steps necessary to build it.

Engineering Analysis

Temperature Modeling

A temperature analysis of the dog shelter was completed to determine the temperature distribution of the shelter to try and avoid getting too hot or too cold.

The temperature analysis was conducted using Simscale, a cloud based thermal simulation software. The goal of the temperature analysis was to find a minimum and maximum temperature of the shelter and create an envelope fit to describe the temperature distribution of the shelter. The parameters of the simulation were based on weather conditions based on Detroit, Michigan. The largest impact on the temperature of the shelter was the solar radiation that hits the shelter. Solar radiation data was found using the National Weather Service Station data[22] as well as the Solar Energy Research Institute.[23] The shelter is intended to be placed in the shade, so the solar radiation numbers were reduced to account for this. Ambient conditions of air were found using a lookup table from Fundamentals of Heat and Mass Transfer.[24] The simulation took into account convection from the surrounding air, conduction from surface to surface, and radiation from the sun.

The focus of the simulations were to create an envelope for the interior section of the shelter. The interior is most likely to overheat and will be the focus for analysis. The temperature analysis was focused on the upper temperature range per stakeholder recommendations being more concerned with the shelter overheating compared to being too cold. The entire shelter was run through three different runs that represent a hot summer day, an average summer day, and a cool summer day. A hot day is the 75th percentile for Michigan, average is 50th percentile, and cool is the 25th percentile. The hot temperature results can be found below in Figure 6.

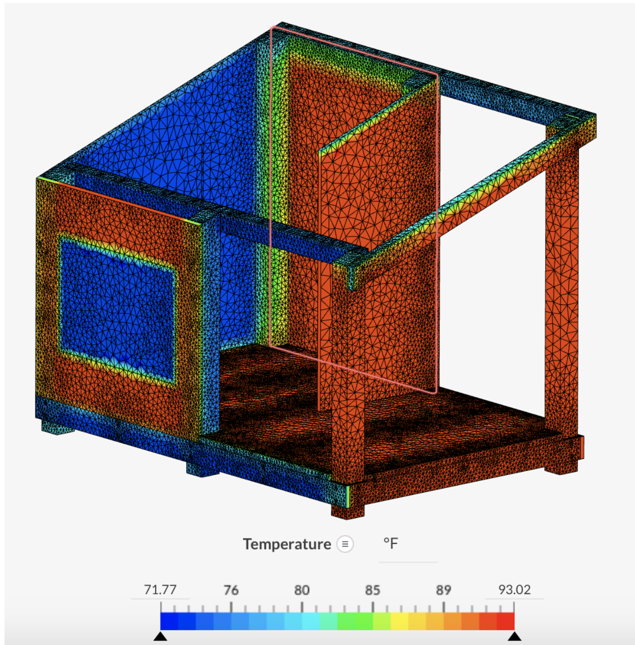

Figure 6: The hot case for the dog shelter during the summer. The roof was removed for clarity, but the tests were run with the roof on the shelter.

The hottest temperature is inside the doghouse and at locations of the highest solar flux. The temperature inside the dog shelter is around 93 °F. The cool case for summer temperature results in the shelter being around 77 °F, with an average summer temperature of 85 °F. The temperature of 85 °F is at the upper threshold for our temperature requirement. The shading of the shelter is difficult to model and this estimate uses a conservative value for shading, having a solar flux of 200 W/m^2. Due to this uncertainty in the model, we include a thermometer to monitor the temperature of the shelter. The temperature inside the shelter will be monitored using a thermometer and a hygrometer to determine if the shelter overheats.

Environmental Analysis

Carbon Neutral Components

Three main components were considered for achieving carbon neutrality with the dog shelter. These include biofuel, a green roof, and materials.

Producing biofuel from the dog's waste would have a carbon negative footprint that could be used to offset emissions of the shelter created from the material procurement, shelter construction, and end of life process. Biofuel also provides an energy source that could be used to power different aspects of the shelter, including a methane-powered lamp on the exterior of the shelter. However, implementing a biofuel system in the shelter has several downsides. First, the amount of energy able to be produced by the system is dependent on the availability of feedstock which in this case is dog waste. With only one dog on the premises, feedstock scarcity could be a problem, resulting in inefficient biofuel production to power the lamp. Without an adequate supply of biofuel, the exterior lamp would be unreliable for the owner to use and may not be worth the added cost to implement it in the shelter. Using a biofuel system that utilizes the dog's waste would also require an active, long term commitment from the owner to collect the fuel and maintain the system on a regular basis.

A green roof on the dog shelter would passively sequester carbon from the air while acting as a natural insulator. This would help manage the temperature fluctuations within the shelter since it will be cooler in the summer and warmer in the winter. Beyond the initial construction, a green roof would not require much commitment from the owner to operate and maintain. However, a lack of sunlight, if positioned under the deck or in a shaded area, could be a problem for growing and keeping the green roof alive.

There is a wide variety of sustainable materials that can be utilized in the construction of the dog shelter. These include wood, low carbon concrete, and biochar.

- Wood is great at storing carbon. The exact amount of carbon varies depending on several factors, such as the species of wood and its age. On average, 1 kg of dry wood can hold about 1.80 kg of CO_2.[25] However, if the shelter is burned at the end of its life, the stored CO_2 will be released into the atmosphere. Sourcing materials locally will help reduce emissions due to the transportation and procurement. Types of wood that are local to Michigan include ash, oak, maple, and pine. Another carbon-friendly option would be to utilize reclaimed wood that would otherwise be chipped or burned. Wood could be used to construct a majority of structure for the dog shelter, including the frame, walls, and roof.
- Traditional concrete has a high carbon footprint, but green concrete that is low, zero, or even carbon negative is now widely available across North America. One process used by CarbonCure Technologies involves removing CO_2 from cement production and injecting it into the concrete during mixing. This removes some CO_2 from the air and permanently embeds it in the concrete. This process actually strengthens the concrete and reduces the amount of cement needed.[26] This material could be used as a stabilizer for the shelter or as a layer in a green roof.
- Biochar is a super charcoal made from burnt organic material which is typically wood chips. It is a great soil amendment that offers many benefits for growing vegetation, including bigger yields, healthier soil, lower acidity, better water absorption, reduced dampness, odor control, stronger plants, richer soil life, reduced contamination, higher fertility, and promoted seed germination.[27] Biochar also improves the area's carbon sequestration capabilities. This material could be incorporated into a green roof to increase the amount and rate of carbon sequestered.

Eco-Audit

An eco-audit was completed for the final design of the dog shelter. The results of the eco-audit are shown in Figure 7.

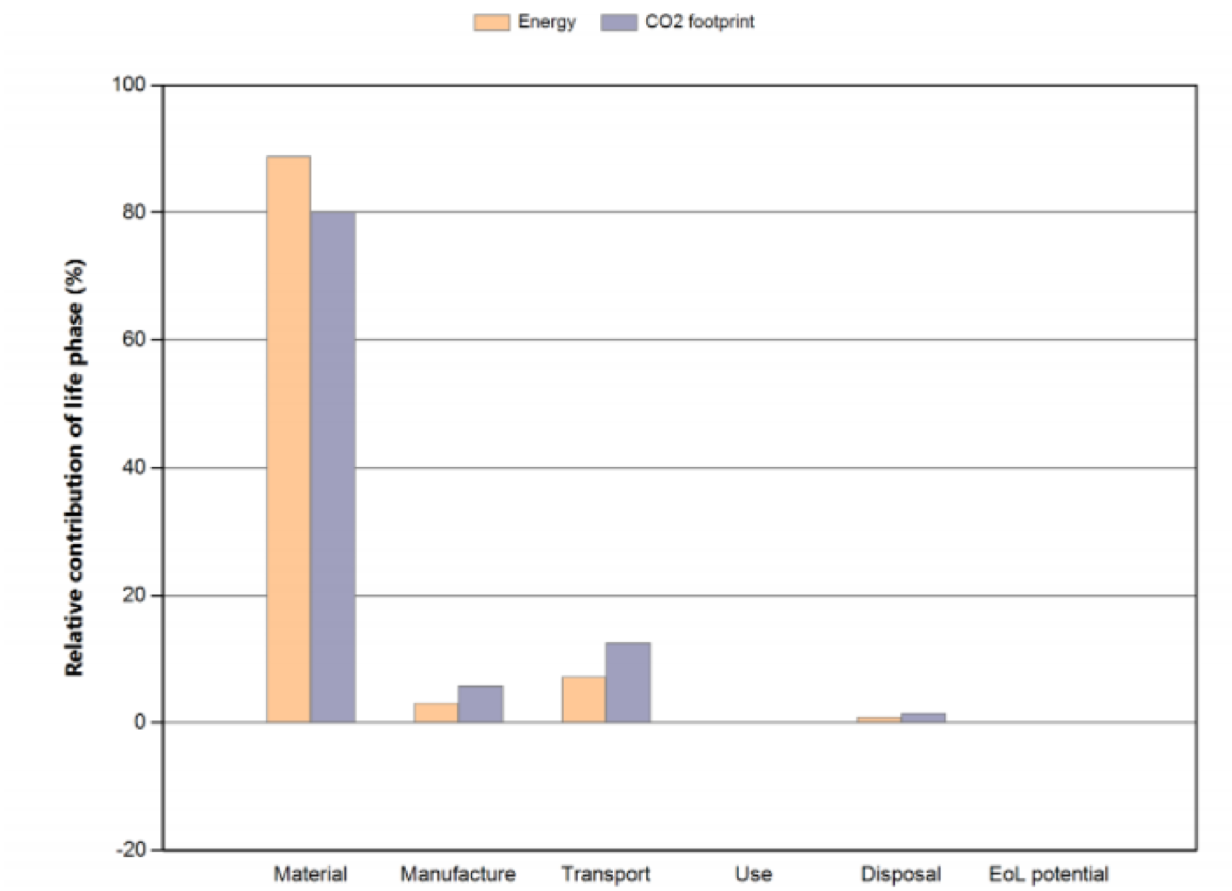

Figure 7: Bar graph depicting the energy use and carbon emissions produced across the five lifecycle phases of the final dog shelter design. The material phase is the main driver of emissions and energy consumption. The shelter is carbon neutral only during its use phase.

As depicted in Figure 7, the main driver of carbon emissions and energy consumption is the materials phase. It accounts for 8.29,000 kcal, 88.8% of the total energy consumed, and 285 pounds of CO_2, 80.1%. This phase consists of the extraction of the raw materials needed to produce the shelter. For the dog shelter, these materials include cedar, pine, and stainless steel. It is important to note that the shelter is only carbon neutral during the use phase.

According to the eco-audit conducted for the final design, the dog shelter would produce an average of 29.7 pounds of CO_2 per year. These calculations assumed the shelter's life cycle would be 12 years, so it would coincide with the average lifespan of a golden retriever. Although the shelter is not carbon neutral, the amount of emissions released each year is extremely small. To put this in perspective, an average American's carbon footprint is 16 tons and the global average is about 4 tons.[28]

It is important to note that these results are likely an underestimate of the total carbon footprint and energy consumption of the dog shelter. Not all materials are accounted for in the eco-audit calculations. This includes the materials, construction, and transport of the thermohygrometer as well as the energy draw associated with operating and accessing this device, such as charging the stakeholder's phone. The eco-audit also does not consider any repairs or maintenance that may be required for the shelter over the course of its use. Components of the shelter will most likely need to be repaired or replaced over the course of the lifespan of the shelter. These actions would increase the energy consumption as well as the emissions of the product. For example, wood can rot, especially when exposed to outdoor elements for an extended period of time. In the case of replacing bad sections of wood, additional energy would be consumed to complete the pairs (i.e. use of any power tools or lighting) as well as the energy consumed to produce and transport the necessary materials to make the repair. The disposal of the additional materials would also need to be considered as they too can increase the emissions produced and energy consumed.

Batteries also have a limited lifespan. The lifespan of the lithium-ion battery powering the thermohygrometer may be shorter than the use phase of the dog shelter. If this is the case, the battery would need to be replaced. This action would increase the energy consumption and emissions to extract the base materials, manufacture the product, transport it to the stakeholder's home, and dispose of it at the end of use.

Carbon Reduction Strategies

Since the dog shelter is not carbon neutral, low-carbon and carbon negative actions outside of construction and materials were pursued in order to offset the annual 29.7 pounds of carbon emissions. Through extensive research, several low carbon and carbon negative actions were identified. These options include landscaping, adjusting the dog's lifestyle, and purchasing carbon offsets.

<u>Landscaping Techniques</u>

Carbon negative landscaping can include promoting reforestation, adding soil amendments, increasing biodiversity, and pursuing composting.

- <u>Afforestation</u>: This action consists of adding plants and trees to the property. This action can reduce carbon in the air because plants utilize carbon dioxide to synthesize food during photosynthesis. Plants, especially trees, also have the capability of storing large amounts of carbon as discussed in the Carbon Neutral Components section of this report. Adding trees and other plants to the property not only can reduce the amount of carbon in the air, but can also improve the dog's quality of life while outdoors. As they grow, trees increase the amount of shaded area they provide which can supply the dog with a reprieve from the sun in a cooler area. Bushes, on the other hand, can provide a nice windbreak for the dog, if placed strategically in the yard.

- Soil Amendments: Soil amendments, including biochar and very fine, mineral silicate rocks can be added to the soil of the property in order to increase the rate and capability of carbon sequestration in the soil. This action is less intrusive than afforestation methods as it is constrained to the soil, does not change the available land for other purposes, and is not visible after implementation.
- Increase Biodiversity: A great way to increase the biodiversity of a property is to create a pond. This is also a great way to reduce the amount of carbon in the air since water can naturally sequester and store large amounts of carbon.
- Composting: Both food and dog waste can be composted. By composting organic waste, emissions produced within landfills can be greatly reduced. Food waste is a huge source of methane, a greenhouse gas. According to the US Composting Council, 1 metric ton of dry food in a landfill will generate 25 metric tons of methane within the first 120 days. If the food waste is composted instead, this amount can be reduced by up to 6 metric tons of CO_2.[29]

  A dog can produce large amounts of waste each year. For city residents, this waste is typically placed in a plastic bag, thrown in a garbage, and ends up in a landfill. This action produces significant amounts of methane. In Chicago, 68 million pounds of dog waste ends up in landfills, annually. This waste creates 102,000,000 feet^3 of methane which is 1.5 feet^3.[30] Considering that, on average, a dog will produce 274 pounds of waste per year,[31] this results in 411 feet^3 or 14.22 pounds of methane per year. At first glance, this may seem to be less than half of the annual carbon footprint of the shelter; however, methane's global warming potential (GWP) is 25 times greater than the GWP of carbon dioxide.[32] Every 1 pound of methane will cause 25 times more warming in Earth's atmosphere over the course of 100 years than 1 pound of CO_2. This means that 25 pounds of CO_2 will have the same warming potential as 1 pound of methane. Taking this into account, the 14.22 pounds of methane would be equivalent to 355.5 pounds CO_2. According to the Project Drawdown study, composting organic waste can reduce more than 50% of CO_2 equivalent greenhouse gas emissions produced when disposed of in landfills.[29] Assuming a 50% reduction in emissions, 177.75 pounds of CO_2 equivalent emissions can be reduced by composting all of the dog's waste instead of disposing of it in a landfill. This reduction is approximately 6 times greater than the annual carbon footprint of the dog shelter. This action is more than adequate to offset the emissions of the shelter and will not only achieve carbon neutrality, but become carbon negative.

Dog's Lifestyle

Adjustments to the dog's lifestyle can be made to mitigate carbon emissions over the dog's lifetime. This can include changing the dog's food to a zero carbon dog food brand, such as Only Natural Pet. However, this action can be hard to implement if the dog does not like the taste of the food. Another way to reduce emissions is to repurpose old bags to collect the dog's waste. These bags will likely end up in the landfill anyway, so repurposing them prevents additional bags from being disposed of in the landfills.

Carbon Offsets

Purchasing carbon offsets is a simple way to offset carbon emissions from daily life. Offsets can be purchased in various amounts, and calculators are available to determine the amount of offsets needed to be purchased in order to achieve carbon neutrality. These offsets can be purchased from energy providers, such as for electricity and heat, as well as social enterprises like 8 Billion Trees.

Considering the stakeholder's location and lifestyle, the most effective and practical tactics to reduce greenhouse gas emissions and achieve carbon neutrality are composting and purchasing carbon offsets. Either method, on its own, is capable of achieving carbon neutrality of the dog shelter. On the other hand, a combination of both methods could also be an adequate solution to reduce emissions enough to offset the footprint of the dog shelter.

Environmental Impact Statement

As a single device, the dog shelter will not have a significant impact on the environment. However, if mass produced for worldwide use, the shelter could negatively impact the planet. For this assessment, the individual impact of all five lifecycle phases were considered. These include materials, manufacturing, transport, use, and disposal.

Materials

Whenever possible, sustainable or low-carbon materials were prioritized during the development of the final dog shelter design. As a result, a majority of the shelter consists of cedar and pine that can be locally sourced. Metal fasteners were required to secure the components of the shelter together, so stainless steel was selected as it offers good stability and longevity.

Although sustainable and low-carbon materials were prioritized, material extraction has potential to negatively impact the environment if the dog shelter is mass produced. Obtaining large quantities of wood to create the shelters could increase deforestation. This process can increase the risk of drought and famine in the nearby communities.

Procurement of rare earth materials can result in unsafe and unethical mining practices. These processes permanently scar the earth and can lead to pollution of the surrounding environment.

This includes mining for lithium which requires large amounts of water to extract and purify the material. If not monitored properly, this process can result in drought and famine for the local communities.

Manufacturing

The environmental impact of the manufacturing process is heavily dependent on where the components are produced and the type of energy source used to power the facility. For the initial prototype of the dog shelter, the wood would be locally sourced in the United States. Coal power plants have been diminishing with natural gas plants on the rise. Most likely, natural gas would be used to provide the electricity needed to manufacture the dog shelter components. If the components are being mass produced in other countries, such as China, coal-powered electricity is more likely to be utilized. Using coal plants would create high levels of air pollution and have the potential of polluting the local water supply. The health of local communities would be jeopardized as inhalation of the air pollutants or ingestion of contaminated water could cause several health issues, including asthma, heart and lung ailments, neurological disorders, and various forms of cancer.[33]

Transport

In the case of the initial prototype, the environmental impact from transportation would mainly include land travel by midsize to large trucks. In the case of mass production, the transportation impacts can vary greatly. Some people may be inclined to purchase exotic woulds from other parts of the world which would require greater transportation distances. This long transportation route could also include travel by boat or plane to transport the materials between continents.

Use

The dog shelter has minimal impact on the environment during its use. The only energy required would relate to the thermohygrometer, if implemented. This would include the energy needed to power the device via a lithium-ion battery as well as charging the phones needed to access the data via bluetooth. The phones would most likely be charged within the home which is powered by solar panels, so this wouldn’t increase the carbon footprint.

Another potential impact experienced during the use phase would be repair and maintenance of the shelter. Wood can begin to rot, especially when exposed to outdoor conditions for an extended period of time, and batteries have a lifespan which could be less than the period of use of the shelter. Replacing or repairing components of the shelter would require energy to complete the repairs (i.e. any power tools). It would also increase the energy consumption and emissions needed to extract materials, transport, and manufacture the replacement parts. there would also be additional energy and emissions associated with the disposal of the extra components.

Disposal

The environmental impact of the disposal phase of the dog shelter depends on the method of disposal used. If mass produced for worldwide use, the most common disposal methods would be transporting to a landfill or burning. Transporting to a landfill would increase the amount of waste in landfills and contribute to the need for more landfill areas. Since a majority of the components in the dog shelter are made of wood, burning it at the end of life would release all of the carbon that had been stored within the wood. On a large scale, this would increase the carbon emissions warming the atmosphere. In regards to the lithium-ion battery for the thermohygrometer, improper disposal of the battery would result in environmental pollution. Leakage from the deteriorating battery could seep into the ground and pollute the surrounding water supply.

Material/Cost Analysis

The bill of materials for the final design is shown in Table 4.

Table 4: Bill of materials and estimate of costs.

Bill of Materials	# needed	Cost/Unit	Total Cost
1-in x 4-in x 12-ft Square Unfinished cedar board	4	$14.36	$57.44
2-in x 4-in x 12-ft Cedar lumber	1	$19.71	$19.71
2-in x 4-in x 8-ft Cedar lumber	1	$13.27	$13.27
4-in x 4-in x 8-ft Cedar lumber	3	$26.50	$79.50
3/4-in x 4-ft x 8-ft Southern Yellow Pine Plywood Sheathing	2	$47.67	$95.34
1-1/8 in x 4ftx8ft pine plywood subfloor	2	$63.06	$126.12
Thompson's WaterSeal Clear Exterior Wood Stain and Sealer (1-Gallon)	1	$16.47	$16.47
F4-1/2 White Aluminum Drip Edge	3	$4.44	$13.32
Royal Sovereign Charcoal Algae Resistant 3-tab Roofing Shingles	1	$23.98	$23.98
#11 x 1 in. Electro-Galvanized Steel Roofing Nails (1 lb.-Pack)	1	$2.50	$2.50
#30 216 sq. ft. Felt Roof Deck Protection	1	$16.95	$16.95
thermohygrometer	1	$14.99	$14.99
Stainless Steel Corner bracket	2	$39.50	$79.00
Steel Phillips Flat Head Screws for Wood- #8- 2"	1	$11.23	$11.23
Steel Phillips Flat Head Screws for Wood- #8- 2.5"	1	$9.62	$9.62
Steel Nails - 2"	1	$4.54	$4.54
Steel Nails-2.5"	1	$4.98	$4.98
		Total:	**$588.96**

This gives an outline for the material analysis and cost analysis.. We used cedar for the posts which will be resting on the ground, creating a strong base. The rest of the wood is pine, which is a softwood, which is not as strong as the cedar but is strong enough to create a nice exterior and withstand wind force. Softwood is much cheaper than hardwood and therefore was used to greatly reduce material cost. We also have a non-toxic waterproof sealer to put over the wood. The final price is approximately $90 over budget, largely due to the increase in the price of wood over the past few months. The majority of these prices and materials are from the Home Depot[34] and Lowes[35] in the Ann Arbor area.

Risk Assessment

A qualitative risk assessment of the doghouse was put together to look at areas of concern as we move towards a final design. The risk assessment can be seen below in Table 5.

Table 5: Risk Assessment.

Hazard	Situation	Probability	Impact	Impact Details	Prevention
Overheating	Shelter gets too hot and is harmful for the dog. Overheating is defined as over 80 °F	High	Severe	The shelter overheating would be harmful the dog if she is in it, but not harmful if not being used	Temperature Sensor monitoring from inside the house should control when the dog goes outside. The temperature modeling shows low likelihood for overheating with shading from deck
Collapse	The green roof is too heavy for the frame and collapses.	Low	Severe	This hazard would result in a catastrophic failure of the shelter and would need to be rebuilt.	Stress analysis to be performed on the roof to confirm that the frame is strong enough to hold the roof
Leak	The green roof leaks into the shelter	Low	Medium	The water could damage the interior of the shelter leading to other forms of failure	Use waterproof materials in between the plants and the wood to prevent leaks.
Chewing on Surfaces	Tula chews on the shelter either on the floor or walls and swallows materials	Low	Low	Tula ruins the floor of the shelter by chewing on it rather than using it	Materials are those that Tula does not chew on and selected materials are safe for dogs in case of chewing
Insects	Bugs get inside the shelter or damage the shelter	Low	Low	The bugs can be harmful to Tula and to the structure and longevity of the shelter	The shelter is elevated off the ground 2 inches to prevent flea infestation per engineering standards.

<u>Design's Associated Risks</u>

The risks associated with the doghouse are overheating, collapse, leaking, chewing, and the green roof dying.

- <u>Overheating</u>: The doghouse may reach unsafe temperatures as seen in the temperature analysis. This problem is being combated by adding more airflow in the doghouse and moving completely under shade. A temperature monitor will also be used to determine if the doghouse reaches these unsafe temperatures.

- Collapse: Another concern is the doghouse falling apart from the weight of the roof and collapsing. This risk is being managed by using a stress analysis to make sure the frame is strong enough for the weight of the shelter.
- Leak: The green roof introduces the possibility of leaking into the doghouse. This risk is assessed by using a waterproof membrane between the green roof and the wood shelter.
- Chewing: Tula may end up chewing on and swallowing materials of the doghouse. We chose materials that Tula does not like to chew on and materials that are not harmful to Tula if swallowed.
- Insects: insects getting inside the shelter is a concern because the shelter is open to the outside. To prevent fleas from getting inside, the shelter was elevated off the ground to prevent infestation.

Solution Development

Initial Shelter Design

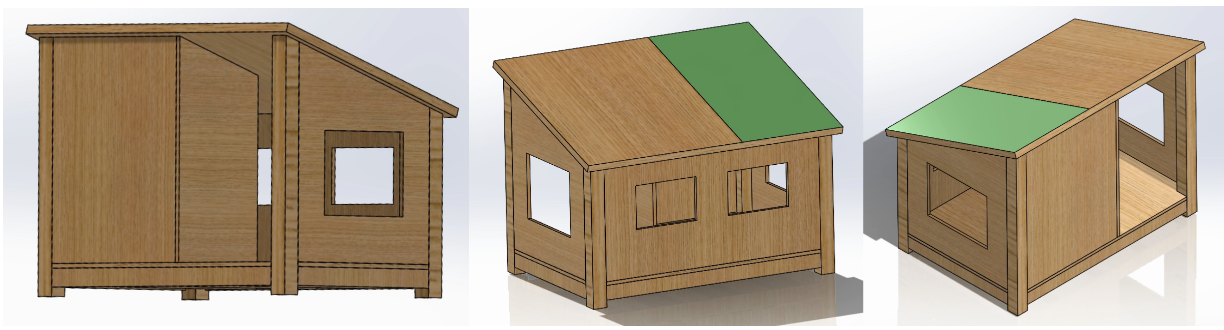

Figure 8: CAD model for the initial shelter design. This model is not finalized and will feature multiple updates before completion.

The CAD model of our initial shelter's design is shown in Figure 8. This design is structured mostly out of oak wood and has a floor area of 6 feet by 4 feet. The taller side is about 56 inches tall and the shorter side is about 40 inches tall. The walls and the top of the base board were designed to be 1 inch thick to comply with most plywood sizes, however many of the thicknesses in the model became dependent on the final material type that is chosen. We based the roof's slope on conventional roof pitches for a house, which range from height:length ratios of 4:12 to 20:12.[36] Our roof is at the low end of that range at a 4:12 ratio with dimensions of 16 inches of rise to 48 inches of run, which makes for a roof angle of about 18.5 degrees. The roof protrudes slightly over the rest of the shelter on each side. This overhang was made to be about 2 inches on each side, which was recommended by Home Depot's website in order to provide better resistance to precipitation and moisture.[37] The shelter is also raised off of the ground by two inches in order to provide better temperature control and to prevent unwanted bugs such as fleas from getting in. As the leftmost picture of Figure 6 shows, there is a vertically halved wall which divides the inside of the shelter into two sections. The half wall is meant to help with insulation during the cold months, and will also allow for increased air flow when the windows are open during hot summer months.

The green-colored section of the roof represents a green roof feature that would have been used to grow vegetation in order to achieve our carbon neutrality requirement. This green roof section will protrude from underneath the deck so that it receives enough sun for the plants to grow. The rest of the shelter without the green roof would be located under the deck and thereby shaded from the sun to help Tula stay cool during the summer.

In terms of functionality, Tula would enter the shelter through the opening on the right side of the taller end of the shelter, shown in the leftmost and rightmost pictures of Figure 6 above. In the shelter's final orientation, all of the windows would face outwards, looking upon the rest of Skerlos's backyard to ensure that Tula does not feel caged in at any location within the shelter.

In terms of maintainability, the side wall underneath the green roof, which is the frontmost wall with a window in the rightmost picture of Figure 6, will be hinged so that it opens to provide easy cleaning access for Dr. Skerlos and his family. This design is also spacious enough for a small child to enter as Tula would enter in order for the child to clean the interior as needed.

Initial Shelter Design Placement

At this point in development, we decided to position the dog shelter behind the deck stairs with the roof only partially underneath the deck. The shelter is also oriented with the roof sloped downwards towards the south. This placement was guided by our carbon neutral requirement; of the potential options for carbon capture, a green roof seemed most constructible, affordable, and applicable to the dog shelter. By angling the roof slope southward (in the Northern Hemisphere), a section of green roof will absorb the most sunlight possible and thereby capture the most carbon. In order to compromise between our requirements of Functional Under All Seasonal Temperatures and of Carbon Neutral, part of the shelter is placed underneath the roof to insulate and cool the interior, whereas the other part of the shelter is exposed to bring sunlight onto the green roof. We had decided that the positioning behind the stairs was the best placement option that satisfied all of these targets. As we developed our idea, we began to realize many changes that we had to make to optimize the design solution.

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Detailed Final Design Solution

Based on initial stakeholder feedback, the shelter design was altered in a few different ways. Half of the shelter was cut and replaced with a deck to allow for an elevated outdoor platform. The green roof was removed because we changed the location of the shelter and few parts were altered to help achieve our project requirements. The shelter is now located fully under the deck due to stakeholder feedback. The placement of the shelter fully under the deck also helps with temperature control as the shade does a better job of cooling than the insulation provided by the green roof. The final design solution can be seen in Figure 9.

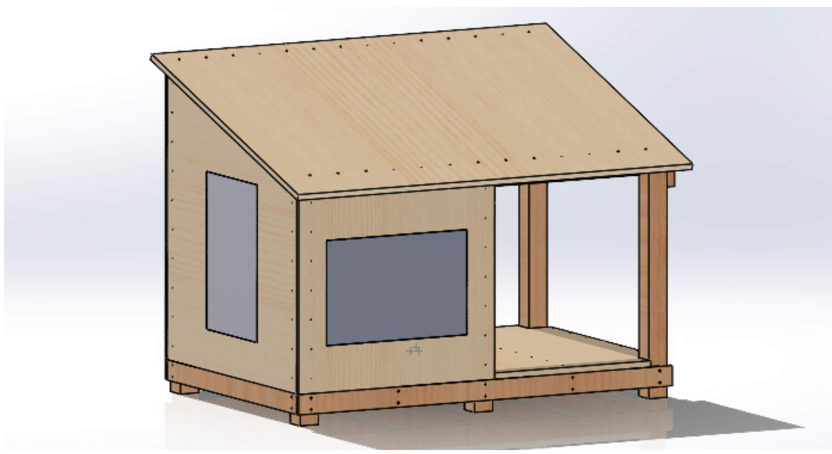

Figure 9: Isometric view of the shelter's front face

The overall dimensions are approximately 6 feet by 4 feet by 5 feet. The shelter is designed to last around 12 years and to handle any of the loads that an 80 pound retriever will induce. Our design is carbon neutral during its use, but the emissions from other lifecycle phases need to be balanced in order to achieve carbon neutrality. We determined that incorporating carbon reduction methods, such as composting dog waste and purchasing carbon offsets, is the best way to offset the carbon emissions.

The removable roof will be conventionally constructed to align with home building standards, and will ensure that the shelter is able to withstand heavy rain and snow conditions.
The open porch and two windows will be beneficial in the summer months to provide better ventilation and more viewpoints for Tula.

The majority of the shelter is made up of cedar and pine treated with stain and sealer.
Stainless steel screws and nails were utilized for better strength and longevity of the shelter.
All materials are considered safe and non-hazardous to the dog in their application.
We have designed the shelter so that the construction and assembly is suitable for one person to build at their own home, at an expense of approximately $500.

Roof Design

The roof is made of a sheet of pine wood and is removable to access the interior of the shelter. The roof is connected to two support planks that run the length of the shelter to hold the roof in place. The supports distribute weight evenly across the poles of the shelter. The roof can be removed with the two supports still connected. A support block of wood is also included to account for the extra width that the walls create. The removable roof can be seen in Figure 10.

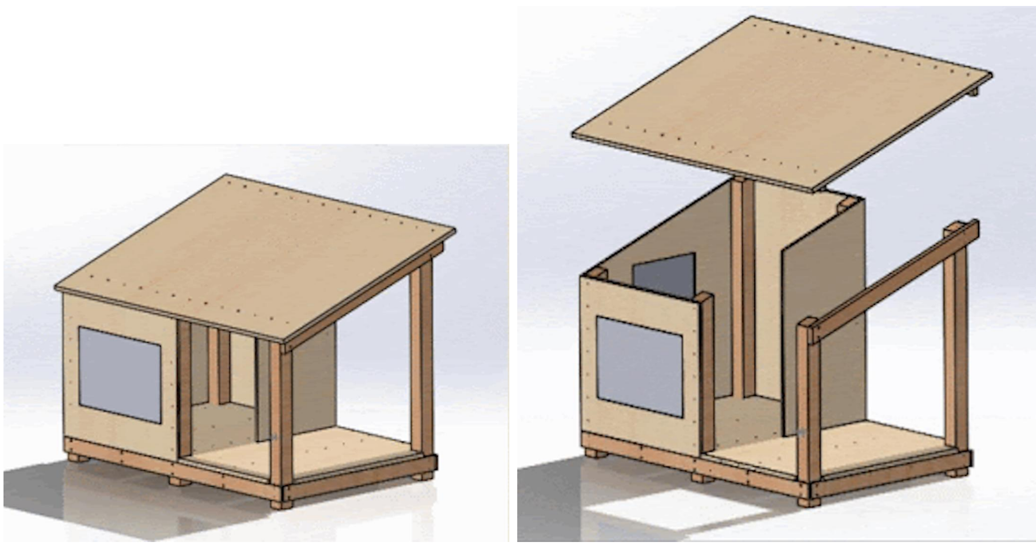

Figure 10: The shelter's roof attached (left) and removed (right)

Shelter Walls

We chose to have all of our walls made out of pine plywood and nailed into our 4x4 posts. The pine plywood along with nails into our posts and base support creates a sturdy exterior for our shelter. Our shelter has 4 walls, 3 exterior walls and 1 half interior wall dividing the deck portion of the dog house from the interior portion. We created a half wall divider to increase airflow in the interior section. We also have 2 windows in the interior section to help the air flow through the system. These windows can be open or closed by the owner. From our temperature modeling we found that the increased airflow had a positive effect on cooling down the shelter, therefore the windows are very important for cooling during the summer months. Along with this, the windows can be closed during the colder months, and therefore the ability to have them open or closed was important. All the walls are flush to the structure of the shelter, leaving zero air holes. This means that when the windows are closed there is air flow in the interior shelter outside of the half wall. Two of the walls are rectangular in shape, and two of the walls are slanted up top to go along with the slant of the roof. The middle wall will also be slotted into the baseboard to increase stability and durability for that wall.

Floor Space

The floor space of the dog shelter is made out of pine plywood and is divided into two main sections: the interior and the deck section. The interior of the dog shelter is 39.63 inches by 37.06 inches, which is spacious enough to hold a dog bed or food and water bowls. The interior space has three complete walls to make the dog feel secure, and the fourth wall is halved vertically to act as an entrance and exit. The interior has a wide window on its shortest wall and a tall window on its sloped wall; these allow for both the dog to look out from the interior of the dog shelter and also for the dog owners to look into the shelter to view the dog. The thermohygrometer ensures that the owners of the dog know that the temperature and humidity in the interior of the shelter are both safe for the dog.

The deck section of the dog shelter occupies the remaining portion of the floor space, having an area of 34.25 inches by 47.40 inches. Three of the four sides of the deck section are open faced, which allows the dog to have a clear view of the yard and an open region to lay. The vertically halved wall separates the deck section from the interior. The deck section has the roof overhanging it to give the dog a sense of comfort and shelter while the open sides give more immediate access to the outside.

Legs and Elevation

We chose to have our dog shelter elevated to help with temperature control and to help protect against bugs and mud. The shelter is approximately 6 inches off the ground. The 6 posts lay against the ground, and the base supports are 2 inches above the bottom of the posts. The supports are about 3.5 inches thick, and then the baseboard plywood is 0.6875 inches thick. This grand total comes to between 6-6.5 inches, which is high enough to help with temperature control and maintainability, but also low enough where the dog should have no trouble accessing the shelter. Having the dog house elevated slightly increases ventilation under the deck so that the shelter stays slightly warmer in winter months. If the shelter was directly on the ground it would get muddy when it rains and it would also get damaged more easily as it can be sitting in a pool of water. Therefore, elevating the base of our shelter will help with maintainability, durability and affordability as parts will have to be changed less frequently if it all. The elevated floor also helps protect the shelter from bugs, as having the elevated baseboard makes it harder for insects to crawl up the shelter.

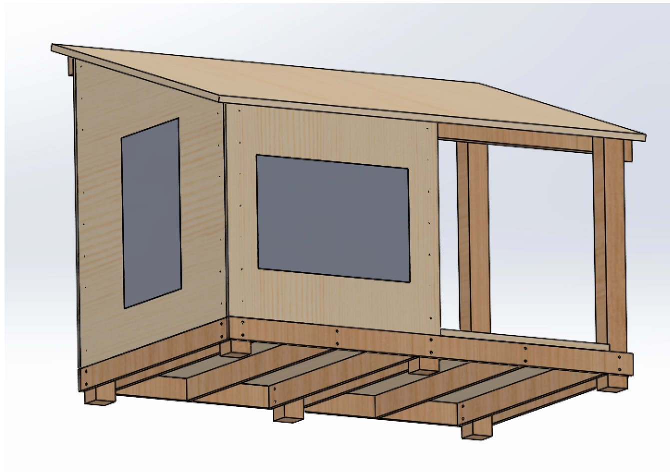

Figure 11: Isometric view of the shelter with base support setup shown

Base Support

The base support is made up of a combination of 1x4 beams, and the material type for these beams is cedar wood. Cedar is a softwood, but it is ultimately one of the strongest softwoods that are available, making it a solid choice of material for the base of the shelter. The 1x4 beams are connected to both the floor plywood and the 4x4 posts via stainless steel screws and nails. Stainless steel fasteners will create long-lasting stability, strong connection holds, and resistance to weather conditions, which makes them a great choice for our design.

There are two different lengths of 1x4 beams used in the base support design, but there are a total of 10 different 1x4 beams included. There are two longer 1x4 beams which are 72 inches in length and then there are eight shorter 1x4 beams that are 46.025 inches in length. As shown in Figure 11 above, six out of eight of the shorter 1x4 beams are screwed directly into the 4x4 posts. There is essentially one support beam on both sides of each of the posts in order to create a stronger base altogether. Each of the shorter support beams are held in place by four screws, which will provide more than enough strength to hold the shelter together and withstand Tula's weight.

The two shorter support beams that are not connected to the 4x4 posts still have ample stability because they are screwed directly into the longer support beams, and they are nailed into the plywood floor from above as well. These two support beams will ensure that any loads Tula places onto the floor's main central areas are easily withstood and balanced out.

The two longer support beams each include ten screws, and are each secured to three 4x4 posts and the middle two short support beams. These 72 inch long supports will be integral to the shelter's stability, they run the entire length of the shelter and are connected to all of the shorter support beams. The 72 inch beams are connected to the shorter beams at the edges at a 90 degree angle, which means that the 72 inch beams extends out and is flushed to the outer edge of the shorter beams. We decided to flush these outer beams, instead of connecting them at a 45 degree angle, so that the wood connections and edges shown were consistent with the shelter's wall setup.

Verification

The final shelter design was evaluated to determine if each of the twelve requirements and the associated specifications were achieved. Each requirement is discussed in detail below.

#1: Durable

We can verify that our design satisfies the requirement of durability. The exterior is made up of cedar and pine wood which will be treated and stained appropriately before the shelter's use, and this adequately satisfies the specification for the exterior to be 100% treated wood, aluminum, stainless steel, brick, or stone. The materials used in our design will also be able to withstand normal wear and tear from a dog and from expected Michigan weather conditions. We have used strong wood materials and stainless steel fasteners to ensure that the shelter can withstand standard wear and tear throughout a golden retriever's average lifetime of 12 years.

Since the design solution will be placed outdoors for the duration of its use, our team focused more heavily on the analysis and durability of the exterior of the design throughout the design process. As a result, the shelter's wood materials are the bulk of our Bill of Materials, which caused some budget problems because wood prices continually rose during the period of our work on this project. Due to budget capabilities and the relevance of particular requirements, the other specification for this requirement was not fully met. The other specification for the durability requirement is that the interior is 100% French linen, jute, or rubber. Although we have not completely verified this specification, we have recommended that the end-user fills the interior with rubber floor padding or mats, as well as blankets and/or pillows for the dog's comfort. Overall, with budget shortages and the limitations of our design, we felt it was best to leave the decisions for the interior's durability and comfort aspects to the discretion of the stakeholder.

#2: Easy access to the outdoors

We can verify that our design satisfies the requirement of easy access to the outdoors. The elevation of the floor is 6.59 inches from the ground, which is within the range of household stair height and therefore accessible for a golden retriever. Passage between the deck area of the shelter and the outdoors is at least 30 inches at all entrance/exit locations, which is greater than our minimum of 11 inches. Additionally, the opening between the interior and the deck area of the shelter is 19.51 inches, which is still greater than the aforementioned 11 inches minimum limit. The lowest height between floor and ceiling including within doorways is 30.5 inches, which is greater than the minimum entrance/exit height of 18 inches parameterized by our specifications.

#3: Suitable for a large dog

We can verify that our design satisfies the requirement of being suitable for a large dog. The first specification for this requirement was for the width and length of the shelter to be between 42 inches and 52.5 inches. Since we decided on a design that has both an inner section and a deck section, this specification is ultimately satisfied if both sections are at least 42 inches in width and length. The width of each section is 46 inches, which falls in the range of the specification. However, since the shelter's overall length is 6 feet, or 72 inches, the length of each section is only about 35 inches. Although this is not within the specified range, the fact that our divider wall between the sections is only a half wall means that there is actually more than 35 inches of length for each section effectively. Overall, though, the width and length dimensions in the shelter's design are easily suitable for a large dog such as a golden retriever. Tula will have plenty of room to move around while inside the shelter, and will have no trouble turning around or being comfortable in the spacious design.

The second specification for this requirement was that the overall height inside the shelter is between 40 and 48 inches. Due to the fact that we have a slanted roof design, the height is variable throughout the inside of the shelter. At the shorter end of the shelter, the height on the inside is about 33 inches, which is still taller than the average retriever standing height, from its head to its toes, of 32 inches. This will provide ample height clearance for the dog even at the smaller side. Nevertheless, though, the height inside the shelter on the taller side is 48 inches, which is the upper bound for our overall height specification. Therefore, the height of the shelter design meets our specification for the necessary height within this requirement, and thus there will be ample vertical clearance for Tula while she is inside of the shelter. With the width, length, and height specifications all met properly, the suitable for a large dog requirement is effectively verified.

#4: Stable

We can verify that our design will reach our stable requirements because of the wood we chose and the fasteners for it. For starters, our base board will easily be able to hold greater than 80 pounds, which was one of our specifications. We know this because of the wood supports we used and the screws we used. The baseboard is supported by eight 1x4 pieces of cedar wood, which is the strongest and most durable softwood. This along with the plywood which is nailed into the base should be more than strong enough to hold 80 pounds. The 1x4s are also screwed into the 4x4 posts, so we know that the floor supports are sturdy and in place.
The ability to withstand > 991 N/m^2 applied to the walls was more difficult to measure. The middle wall being slotted into the floor board should give that wall more than enough stability to withstand this force threshold. Using chat rooms and woodworking forums as reference, we determined that ¾ inch plywood should have no problem withstanding > 991 N/m^2, however it does not say for how long the plywood would be able to withstand this wind force or get an actual value for what pine ¾ inch plywood can withstand. However, the Federal Alliance for Safe Homes recommends that you buy ⅝ inch thick plywood to battle against hurricanes,[38] and our ¾ inch plywood is even thicker than that, however this site does not mention what material the plywood is made out of.

#5: Generally safe

Our specifications for being generally safe are verifiably met in our design. The only electronics used in the design is a wireless BlueTooth thermohygrometer, which means that there are 0 wires exposed to the dog. there are no sharp metal parts protruding and all of our manufactured parts are to be smoothed down with sandpaper, which means that there are 0 exposed sharp surfaces/edges. Furthermore, none of the materials used will have any VOC (Volatile Organic Compound) on their surfaces.

#6: Functional under all seasonal temperatures

The functional under all seasonal temperatures has an associated specification that the shelter should remain operational under outside temperatures of 20-85 °F. The shelter will stay under this threshold, due to shading from the deck, but may overheat on hot summer days. The temperature inside the shelter can be monitored using a thermohygrometer to further ensure that the interior temperatures are safe. A BlueTooth Govee thermohygrometer is included in the design. This device will have a sensor within the dog shelter and transmit a wireless signal to the dog owners' smartphones to easily display if the temperature and humidity are both within a safe range for the dog.

#7: Appealing to dog

The appealing to dog specification is that the dog house should have at least 2 sources of dog motivation. One source used to verify our design is shading. The interior section allows for the dog to be shaded and feel protected inside the shelter. The second source of motivation is the viewpoints and vantage points. The deck allows for the dog to see out into the yard as well as windows allow for her to see out in all directions.

#8: Maintainable

The requirement of maintainability in our design can be verified. The floor space of the shelter has a very open deck section and a partially walled off interior section. The roof can be removed by adults who seek access to the interior for maintenance, and the ceiling is low enough to be accessed by any small children who want to partake in maintaining the interior on their own. All parts of the floor space, including the interior, can be easily accessed by the dog owners. The wooden structure can be cleaned without use of any chemicals which would be harmful to the dog.

#9: Easy to assemble

Our design achieves the easy to assemble requirement. The actual shelter can be completed in 9 steps, and the roof is an additional 8 steps because of the installment of the shingles. Even when combining these two different subassemblies the assembly plans are only 17 steps, which is less than our specification of 20 steps. The assembly plans also require less than 12 tools, which achieves another one of our specifications. Our inability to create an actual physical model makes it hard to determine the time it should take to build our design, however we believe that the building of the structure should be able to be completed in one day.

#10: Affordable

Our design was less than $500 using wood prices from a couple of months ago, but due to the rise of wood prices since then our design is no longer affordable. We are at a final cost of approximately $588, which is 17% over budget. We hope that this will be reduced when wood prices start to decline again. There are also some things in our bill of materials that are not absolute necessities, such as the thermohygrometer, however this was something our stakeholder recommended and we also think it is important to have as you can monitor the temperature the dog is feeling in the shelter.

#11: Carbon neutral

The carbon neutrality requirement had a specification that the shelter has 0 carbon emissions over its life. This requirement was verified using an eco audit to determine the carbon footprint of the shelter. The eco audit concluded that the carbon footprint of the shelter is 29.7 pounds of CO_2 per year for 12 years. The carbon cost is very small compared to the cost of owning a dog, about 5500 pounds of CO_2 a year.[39] This small cost can be offset by many different methods suggested in the engineering analysis section for carbon neutrality.

#12: Aesthetically pleasing

The aesthetically appealing requirement has two specifications: less than or equal to 8 surface faces and greater than or equal to 2 customizable options. The total number of faces on the design is 6, as the design is rectangular with parallel sides. The customizable options are that the roof is removable. The removable roof allows for easy access and a more open feeling. The windows can also be removed as well. The windows can open to allow for more airflow and cooling the inside of the shelter.

Discussion and Recommendations

Our design had many strengths and weaknesses that we would like to discuss. If we were given another semester to work on this project we would like to address many of these weaknesses so that we can have the best possible design for our dog shelter. The strengths of our design is that it is very spacious for Tula. There is both an interior and exterior section to the shelter, both large enough for Tula to be comfortable in. The design is also aesthetically pleasing, both in our eyes and the eyes of our peers and stakeholder. We were also able to use only non-hazardous materials, creating a very safe environment for Tula. Lastly, our design is very stable and durable, two requirements that we valued highly in our concept generation and selection. At this point we have no worries about its ability to last 12 years, which is the average lifespan of a golden retriever.

Our design also had some weaknesses that if we were given more time we would have liked to address. The first one we want to point out is that the design is pretty barren. The interior of the shelter is blank with not much padding or flooring that would be comfortable to lay on. Given more time and budget, this would be the place that we focus on next. We would look to add pillows or a dog bed to provide more comfort. The shelter itself is also not carbon neutral. There are no carbon capture methods implemented into the design to offset the carbon cost of construction. Carbon neutral materials or carbon capture methods should have been studied further to implement into the design. The windows were also hard to implement because of the window sizing. The windows are too thick for the walls and overhang into the shelter. Different windows should have been looked into or different methods to create a viewpoint in the shelter. The manufacturing of the shelter is also a weakness because we do not know how easy the design will be to make. Many parts used specialized tools that we are unsure of the accessibility to. The manufacturing of the design is ambiguous since prototypes were not able to be constricted and the fact that the design is completely digital. The final weakness we want to discuss is the final design itself. The design is a pretty safe design in that it does not do anything innovative. The dog shelter is basically what is on the market now using a different shape for the exterior. Different design techniques should have been considered to create a unique and specialized dog shelter.

We have a few recommendations that another group could do if they were given this project next semester to build on what we have done so far. The first thing we would suggest this group to do is to physically build the design. This will allow them to physically verify many of the requirements and specifications. We recommend this as we can say our design is easy to assemble, but without actually making a prototype we can not verify this fact. Another recommendation we would give is for this group to determine material costs for their design before proceeding with it. We know this is difficult as our design had slight changes right up until our design expo, however this would be important for the group to stay under budget, something we were not successfully able to do. We would also suggest this team to get a better understanding of what tools are available to Dr. Skerlos, as the construction for our design may be tricky if he does not have the proper tools available. Another recommendation for a team who takes over this project is to get better temperature data. Due to time constraints we had trouble getting precise data for temperature modeling and we also were only able to test our final design. If temperature data were to be used throughout the design process they can look at how multiple designs stake up to each other in terms of temperature analysis. The design of our shelter was less analytically driven design and more analysis after the fact. This was due to us not really knowing how to go about these analyses and inadequate data to perform these tasks. We recommend starting analysis of the system as soon as designs are developed to have a better idea of the strengths and weaknesses of each design.

Although our design is generally complete, there are a few recommendations which we have for the end users to optimize their experience with the dog house. One suggestion to become more carbon neutral/negative is to implement a green roof on the dog house in a location where there is enough sunlight for the green roof to flourish and capture carbon. Another suggestion to reduce carbon impact is to partake in methods of reducing carbon emissions, such as afforestation, soil amendments, increasing biodiversity, and composting, as mentioned earlier in the Carbon Reduction Strategies section of this report. A recommendation for constructing the dog shelter is to drill pilot holes for each of the screws going into cedar wood; screws going into pine and nails do not necessarily benefit from pilot holes being drilled, so this recommendation is only for screws going into cedar.

Conclusion

The final design of the dog shelter delivers a carbon neutral luxury dog house. We have analysis to back up many of the decisions we made. We completed temperature modeling analysis, environmental analysis, material analysis, and cost analysis. We also have a risk assessment analysis which will be very important for the stakeholder to read before construction.

In conclusion, our final product is a CAD model of our design with engineering drawings, manufacturing plans, assembly instructions, and an approach to offset carbon output, as well as this report with data which analyzes the temperature and environmental impact of the design.

Authors

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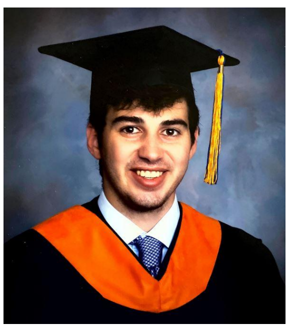
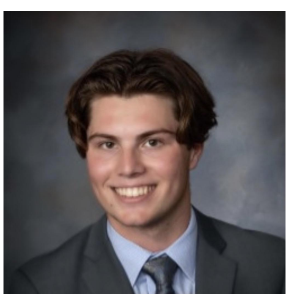
Growing up in the countryside of Ludington, Michigan, Michele was exposed to a wealth of outdoor activities and wildlife. Her love of nature and desire to protect the environment led her to pursue a degree in mechanical engineering. Her passion for sustainability inspired her to declare a designation in sustainable engineering as well as become a member of the 2019-2021 Graham Sustainability Scholars. After graduating with her bachelor's degree this May, Michele will continue her education by pursuing a Master in Engineering in Energy Systems Engineering at the University of Michigan this fall.

Ryan D'Accordo



Ryan D'Accordo is currently a senior in mechanical engineering at the University of Michigan. He is also pursuing a concentration in energy through his mechanical engineering degree. Ryan is from Rockville Centre, New York. Ryan enjoys the sustainability side of engineering along with design. He will be graduating on May 1st and hopes to begin working as a mechanical engineer this summer.

Corbin Gibson



Corbin Gibson is currently a senior in the mechanical engineering program at the University of Michigan. He is also earning a minor through the Entrepreneurship program at UMich. Corbin is from Walled Lake, Michigan; he has lived in Michigan and been a Wolverine fan his entire life. He will be graduating at the end of the fall 2021 term and hopes to be hired by a Detroit-area company as a virtual design engineer.

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We would also like to acknowledge our stakeholders in the rest of the Skerlos household, and especially thank Andrea Skerlos for providing additional perspective into how our dog shelter can best suit the wants and needs of the users.

We additionally thank our peers for providing thoughtful feedback on our project as we progressed, including comments, questions, and concerns about our design.

Lastly, we would like to pay our acknowledgements to Tula, a very good girl.

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Appendices

APPENDIX A: Benchmarking Research

A.i: A-B-C Method

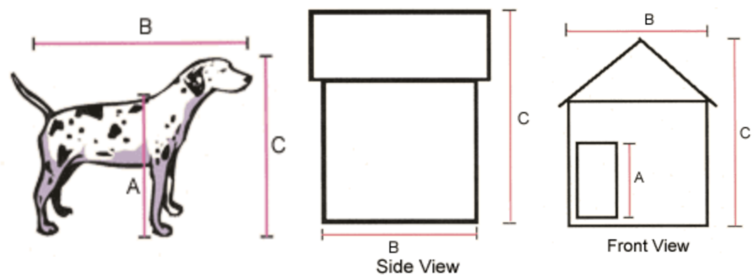

Figure A.1: Pictures demonstrating the measurement process behind A-B-C method

The A-B-C method is the most popular method for deciding on the dimensions of a dog house to be built for a specific dog. The method outlines steps for measuring the dog, and how those measurements attribute to the dimensions of the resultant dog shelter. The A measurement is the dog's shoulder height, B is their full length (head to tail), and C is their full height (top of head to ground). The dog's B and C measurements are to scale in relation to the dog houses shown, but the A measurement must be multiplied by 0.75 to correspond to the shelter's opening height shown on the far right.[15]

A.ii: DIY Dog House Standard Pricing

ITEM	COST
Wooden dog house kit	$80 to $300
Non- insulated plastic dog house	$60 to $150
Insulated plastic dog house	$150 to $250 and more

Figure A.2: Table showing the typical costs for dog house do-it-yourself building kits

Although there is a wide range of costs that any given dog shelter can be, the table above outlines an average do-it-yourself kit cost based on material type. The $500 budget for the project, which is reasonably greater than the costs in the table, will allow for a wide range of solution possibilities.[21]

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APPENDIX B: Concept Generation

B.i: Individual Functional Decomposition

Table B.1: Breakdown of initial concept generation based on defined functions

Entrance/Exit	1. Dog door a. Flap door that perfectly fits the size of the door, exactly like a dog door (rectangular or oval shape) (RD, CG, MA) b. Self-closing 2 panel door design with tiny window (CG) c. Buy a dog door and attach it for the size of our entrance, may need to make entrance a bit bigger depending on the size (RD) 2. Removable vertical slats to customize entrance width (ZW) 3. Motorized flap with sensor that detects dog's collar (ZW) 4. Circular walls so door rotates 90 degrees about center to open: sensor that detects dog's collar (ZW) 5. Plastic flaps - like a commercial cooler (MA, JS) 6. Opening (MA, JS)
Shelter	1. Dog house (RD, MA) 2. Dog door to owner's house (MA) 3. Fenced - 2 area dog shelter (CG) 4. Circular dog house (ZW) 5. Dog dome - hemisphere of see through material that lets the dog have a 360 degree view (MA) 6. Private entrance to personal area of the garage (MA) 7. Burrow (MA) 8. Lean-to to provide windbreak (MA) 9. Indoor shelter w/ exterior access (JS)
Motivations	1. Comfort a. Couch cushions/blanket (RD,JS) b. Temperature control 2. Water a. Water bowl on elevated surface inside the dog house (ZW, RD) b. Spout coming from the outside with water (RD) c. Hamster-type water container (CG) 3. Toys (RD, MA) 4. Treats (MA) - Remote treat dispenser (controlled by owner) (CG)

	5. Food (MA)
	6. Sounds that are appealing or soothing to the dog (MA)
	    a. Treat bag shaking
	    b. dog toy squeaks
	    c. Whistles
	    d. soft music
	7. Vantage point
	    a. Windows
	    b. Raised shelter
	    c. See through dome (MA)

Energy	1. Solar panels (RD) (ZW) (CG) (MA)
	    a. Connect to solar panels on owner's house
	    b. Remote
	    c. Attached to shelter
	2. Interior shelter removes need (JS)
	3. Water wheel (in close proximity to rain gutter or drainage from deck when it rains, or stream) (MA)
	4. Biofuel from dog waste in shelter (MA)
	5. Windmill or turbine in secured housing (MA)

Accessibility/ Maintainability	1. Roof that easily opens to one side for convenient access to interior (RD, CG) 2. Removable heating/cooling pads (RD) 3. Roof drilled in on one side, foldable at the middle so the other side opens (RD) 4. Slide-out floor (ZW, CG) 5. Screw on/off floor and roof (threads are part of structure) (ZW) 6. Screw holes to connect walls to floor and walls to roof with screws (ZW) 7. Pins and slots to remove roof/wall (JS) 8. Walls that slide up/out to access (JS) 9. Roof (potentially + 1 side) opens like a delorean (supported by telescoping load lock bars) (MA) 10. Detachable roof (MA, CG) 11. Hinge on bottom of front/back wall (MA) 12. Slight slope for floor to assist with any draining needs (CG)

Temperature Control	1. Removable heating and cooling pad/mat on floor (RD) (CG)
	    a. Heat source in/on walls
	    b. Heated blanket
	2. Insulation
	    a. Use polystyrene insulation in walls (RD, MA)
	    b. Straw (MA)
	    c. Sheep's wool - fire retardant (MA)
	    d. Cotton/denim - cotton is a natural insect repellent, twice as expensive as fiberglass (MA)
	    e. Icynene - spray foam made of castor oil - Seals leaks and drafts but need to add ventilation system - Cancels noise - Reduces energy bill (MA)
	    f. Aerogel - made of 90% air - Difficult for heat to pass through - Ultra lightweight (MA)
	    g. Thermacork - made from outer bark of oak trees - Negative carbon footprint (MA)
	    h. Natural, renewable, recyclable, and biodegradable - Cancels noise - Free of toxins (MA)
	    i. Cellulose (MA)
	    j. Wood (MA)
	3. Blankets and couch cushions (RD)
	    a. Depends on dog
	4. Raised floor (CG)
	5. Windows (with removable screens) (CG)
	6. Shelter placement
	    a. Door/opening faced away from strong winds (CG)
	    b. In shaded area (MA)
	7. Smart dog door that opens w/ temperature control. Dog resides in the house (JS)

Materials	1. Interior
	    a. Synthetic leather (faux leather), can be heated like car interiors, not too expensive ($18 for 54''x36'') (RD)
	    b. French linen (MA)
	    c. Jute (MA)
	    d. Hard rubber (MA)
	    e. Foam rubber floor (ZW)
	        i. Workout mat/tiles
	        ii. Foamy/thicker

	2. Exterior a. Treated wood (MA) b. Stainless steel (MA) c. Aluminum (MA) d. Brick (MA) e. Stone (MA)

B.ii: Group Brainstorming

Table B.2: First session of concept generation and development as a group

Entrance/Exit	1. Magnetic mesh that the dog can push through to get in/out, but will close and be held in place when not in use
Shelter	1. Underground/basement access 2. Tepee
Motivations	1. One wall is opaque for dog to back up against for comfort 2. Water dish in ground or heated to prevent freezing 3. Smells the dog likes/soothing to the dog
Energy	1. Dog on a hamster wheel 2. Remote access to biofuel 3. Nuclear
Accessibility/ Maintainability	1. Liftable roof (supported by telescoping load lock bars) 2. Snap attach/detach assembly
Temperature Control	1. Temperature control sensor in shelter with digital display in house 2. Water dish in ground or heated to prevent freezing
Materials	1. Concrete

B.iii: Design Heuristics

Table B.3: Group development of functional concepts by using design heuristics

Change geometry	1. Quarter sphere of vision so the dog doesn't feel exposed, can put its back against opaque wall 2. Top of roof is a single point to allow snow and rain to not collect too much on the roof a. Conical b. Square pyramid c. Triangle pyramid
Make components attachable/detachable	1. Entrance can be detached for cleaning or switch out for a heavier or lighter material, depending on weather conditions 2. Removable walls/roof/door based on weather conditions 3. Removable screens/solid wall sections 4. Food/water containers can be attached to wall at dog's height for use, then detached for refilling and/or cleaning
Utilize opposite surface	1. Solar charging windows and/or door
Add levels	1. Double decker house
Use multiple components for one function	1. Use door and window for sunlight to heat dog house (dog house on an angle)
Use different energy source	1. Kinetic energy from dog a. Dog playing to produce energy i. Inside tennis ball/fetch toy b. Ampy - user charge on dog walk and plugs in daily 2. Geothermal 3. Hand powered crank a. Inside house and chore for kids to turn b. Out on sidewalk with sign that guilt trips pedestrians into spinning c. Rope toy for pet that spins crank
Offer optional components	1. Optional dog door, can just have entrance with no barrier
Apply existing mechanism in a new way	1. Motorized door flap used as a window

Adjust functions for specific users	1. Motorized dog door opens via sensor on dog - manual button for owner a. Button on dog house and remote button 2. Manual access from roof by lifting or using motorized lift
Change direction of access	1. Ramp/stairs underneath shelter - enter on one side of the floor 2. Opening on top 3. Above-ground tunnel from house to shelter
Allow users to customize	1. Change shape based on how wall segments are connected 2. Speaker that plays sounds/intercom also can play songs that owner chooses (songs that dog likes)

Make multifunctional	1. Cavity somewhere inside for storage
	2. Contains dog “bathroom” where biofuel can be collected
	    a. Dog is trained to go there
	    b. Owner manually puts waste in there

Incorporate user input	1. Adjustable thermostat to set interior temp (available in shelter or owner’s house) 2. Intercom connected to house so that owner can speak to dog while in shelter/use pre-set sounds 3. Connectable webcam so owner can view dog at any time

B.iv: Prioritization of Concepts

Table B.4: Elimination of inadequate concepts based on inability to achieve project requirements, range outside of project scope, and infeasibility to implement.

Entrance/Exit	1. Dog door
	    a. Flap door that perfectly fits the size of the door, exactly like a dog door (rectangular or oval shape)
	    b. Self-closing 2 panel door design with tiny window
	    c. Buy a dog door and attach it for the size of our entrance, may need to make entrance a bit bigger depending on the size
	2. Removable vertical slats to customize entrance width
	3. Motorized flap with sensor that detects dog’s collar
	    a. Motorized dog door opens via sensor on dog - manual

	button for owner i. Button on dog house and remote button ~~4. Circular walls so door rotates 90 degrees about center to open: sensor that detects dog's collar~~ 5. Magnetic mesh that the dog can push through to get in/out, but will close and be held in place when not in use 6. Plastic flaps - like a commercial cooler ~~7. Opening~~ ~~a. Optional dog door, can just have entrance with no barrier~~ 8. Entrance can be detached for cleaning or switch out for a heavier or lighter material, depending on weather conditions 9. Ramp/stairs underneath shelter - enter on one side of the floor 10. ~~Opening on top~~ 11. Above-ground tunnel from house to shelter ~~12. Underground/basement access~~ ~~13. Tepee~~
Shelter	1. Dog house 2. Dog door to owner's house 3. Fenced - 2 area dog shelter 4. ~~Circular dog house~~ 5. Dog dome - hemisphere of see through material that lets the dog have a 360 degree view 6. ~~Private entrance to personal area of the garage~~ 7. ~~Tepee~~ 8. ~~Burrow~~ 9. Lean-to to provide windbreak 10. ~~Indoor shelter w/ exterior access~~ 11. Double decker house ~~12. Change shape based on how wall segments are connected~~
Motivations	1. Comfort a. Couch cushions/blanket b. Temperature control 2. Water a. Water bowl on elevated surface inside the dog house b. Spout coming from the outside with water c. ~~Hamster-type water container~~

	d. Water dish in ground or heated to prevent freezing 3. Toys 4. Treats a. Remote treat dispenser (controlled by owner) 5. Food 6. Sounds that are appealing or soothing to the dog a. Treat bag shaking b. Dog toy squeaks c. Whistles d. Soft music e. Speaker that plays sounds/intercom also can play songs that owner chooses (songs that dog likes) 7. Vantage point a. Windows i. See through dome ii. One wall is opaque for dog to back up against for comfort iii. Quarter sphere of vision so the dog doesn't feel exposed, can put its back against opaque wall b. Raised shelter ~~8. Smells the dog likes/soothing to the dog~~ 9. Intercom connected to house so that owner can speak to dog while in shelter/use pre-set sounds a. Connectable webcam so owner can view dog at any time
Energy	1. Solar panels a. Connect to solar panels on owner's house b. Remote c. Attached to shelter d. Solar charging windows and/or door 2. Interior shelter removes need ~~3. Water wheel~~ ~~a. In close proximity to rain gutter or drainage from deck when it rains~~ ~~b. Near stream~~ 4. Biofuel from dog waste a. Attached to shelter b. Detached from shelter

	~~c. Contains dog "bathroom" where biofuel can be collected~~ ~~i. Dog is trained to go there~~ ~~ii. Owner manually puts waste in there~~ ~~5. Windmill or turbine in secured housing~~ 6. Kinetic energy from dog ~~a. Dog playing to produce energy~~ ~~i. Inside tennis ball/fetch toy~~ ~~ii. On hamster wheel~~ b. Ampy - user charge on dog walk and plugs in daily ~~7. Geothermal~~ ~~8. Nuclear~~ 9. Hand powered crank a. Inside house and chore for kids to turn ~~b. Out on sidewalk with sign that guilt trips pedestrians into spinning~~ ~~c. Rope toy for pet that spins crank~~
Accessibility/Maintainability	1. Roof that easily opens to one side for convenient access to interior 2. Removable heating/cooling pads 3. Roof drilled in on one side, foldable at the middle so the other side opens 4. Slide-out floor ~~5. Screw on/off floor and roof (threads are part of structure)~~ 6. ~~Screw holes to connect walls to floor and walls to roof with screws~~ 7. Pins and slots to remove roof/wall 8. Walls that slide up/out to access 9. Roof (potentially + 1 side) opens like a delorean (supported by telescoping load lock bars) 10. Detachable roof 11. Liftable roof (supported by telescoping load lock bars) 12. Snap attach/detach assembly 13. Hinge on bottom of front/back wall 14. Slight slope for floor to assist with any draining needs 15. Removable screens/solid wall sections 16. Food/water containers can be attached to wall at dog's height for use, then detached for refilling and/or cleaning 17. Manual access from roof by lifting or using motorized lift

	18. Cavity somewhere inside for storage

Temperature Control	1. Removable heating and cooling pad/mat on floor
	    a. Heat source in/on walls
	    b. Heated blanket
	2. Insulation - Use polystyrene insulation in walls
	    a. Straw
	    b. Sheep's wool - fire retardant
	    c. cotton/denim - cotton is a natural insect repellent, twice as expensive as fiberglass
	    d. Icynene - spray foam made of castor oil - Seals leaks and drafts but need to add ventilation system - Cancels noise - Reduces energy bill
	    e. Aerogel - made of 90% air - Difficult for heat to pass through - Ultra lightweight
	    f. Thermacork - made from outer bark of oak trees - Negative carbon footprint
	    g. Natural, renewable, recyclable, and biodegradable - Cancels noise - Free of toxins
	    h. Cellulose
	    i. Wood
	3. Blankets and couch cushions
	4. Raised floor
	5. Windows (with removable screens)
	6. Shelter placement
	    a. Door/opening faced away from strong winds
	    b. In shaded area
	7. Smart dog door that opens w/ temperature control. Dog resides in the house
	8. Top of roof is a single point to allow snow and rain to not collect too much on the roof
	    a. Conical
	    b. Square pyramid
	    c. Triangle pyramid
	9. Removable walls/roof/door based on weather conditions
	10. Use door and window for sunlight to heat dog house (dog house on an angle)
	11. Motorized door flap used as a window
	12. Temperature control sensor in shelter with digital display in

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	house 13. Adjustable thermostat to set interior temp (available in shelter or owner's house)
Materials	1. Interior a. Synthetic leather (faux leather) b. French linen c. Jute d. Hard rubber e. Foam rubber floor i. Workout mat/tiles ii. Foamy/thicker 2. Exterior a. Treated wood b. Stainless steel c. Aluminum d. Brick e. Stone f. Concrete

B.v: Concept Development

Design 1

The first shelter design features a dog house frame with a gable roof and an automatic door. The cover for the door is motorized and opens when the dog approaches due to a sensor that acknowledges the dog's collar. Offsite solar panels provide all of the necessary energy to power the shelter's functions. The width of the shelter's entrance is adjustable to accommodate different dog sizes. This is accomplished by adding or removing vertical slats. This design also features a slide-out floor allowing for easy access to clean without having to enter the shelter. The walls connect independently to the roof and base segments via standard screws.

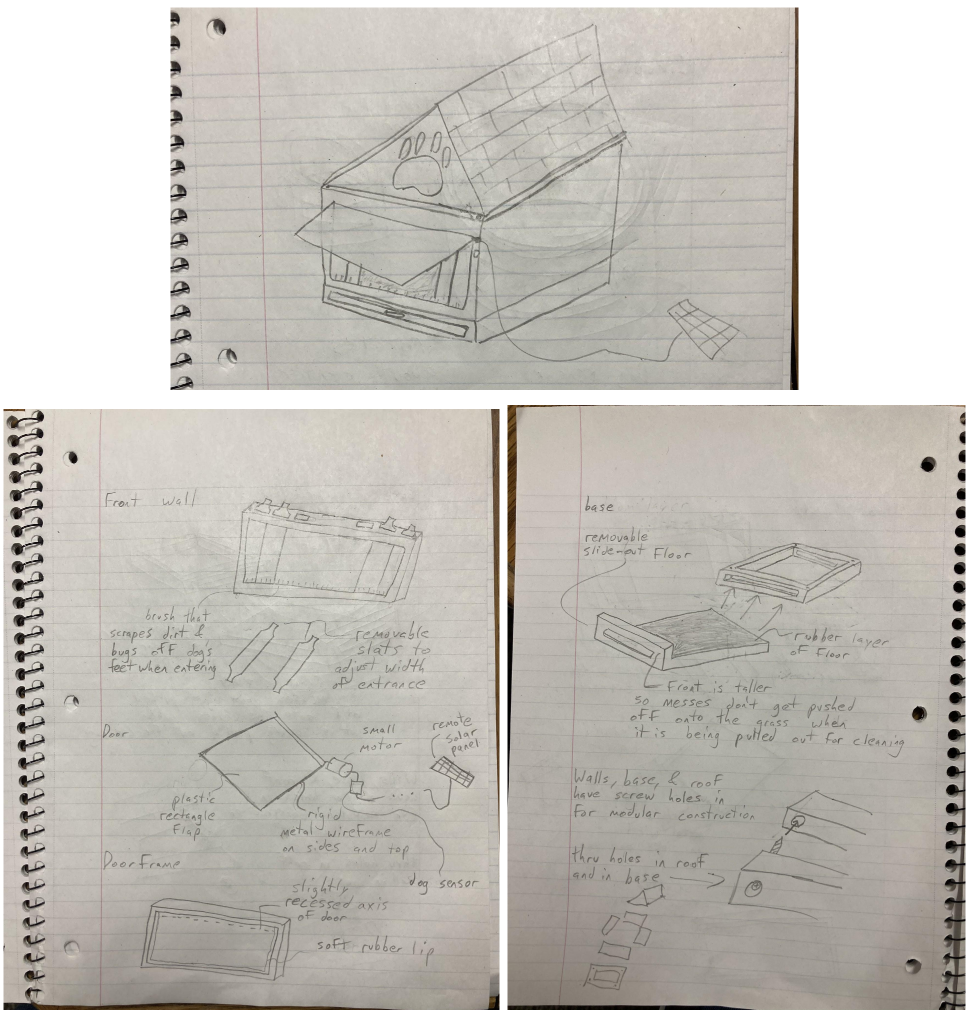

Figure B.1: Design 1 (top) and interior features (bottom two)

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Design 2

Our second design is a circular dog shelter with a conical roof. The entrance to the shelter is a rotating door that slides along a track, allowing it to be sealed or opened through an insert in the wall. The wall section of the dog house is screwed onto a base via threads molded into the circumference of the base. Similar to Design 1, there is a remote solar panel that powers both the door and the sensor that automates the door. The sensor detects the presence of the dog's collar which allows the door to open.

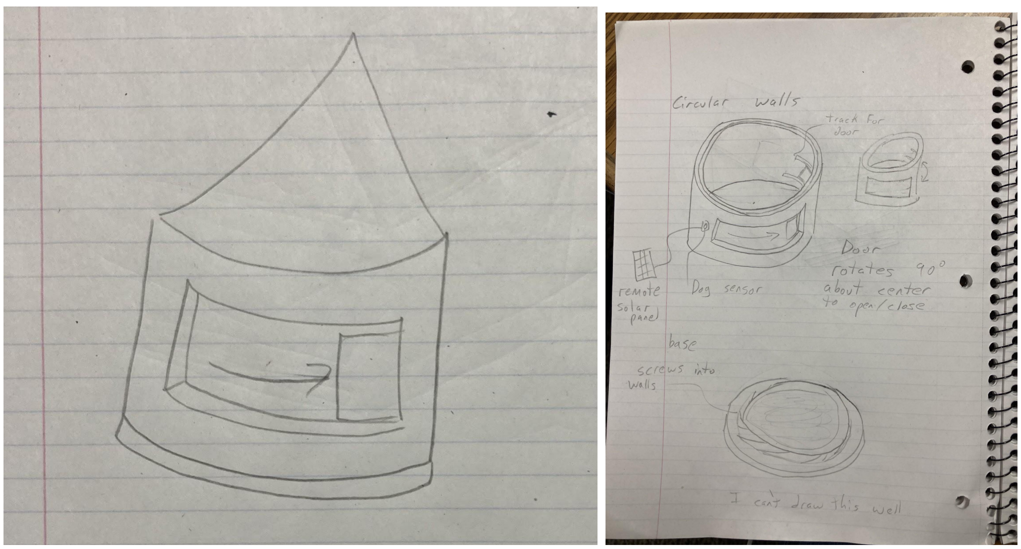

Figure B.2: Design 2 (left) and interior features (right)

Design 3

The third design features an elevated dog house with a gable roof. A ramp on the back left side of the shelter enables the dog to enter from underneath. This design includes two windows for the dog to look out: one in the front and one on the front right of the shelter. The owner has two points of entry to aid in cleaning the shelter. The first is a hatch with load-lock bars on the front right of the shelter. The shelt is a panel that can be unlocked and folded down in the back.

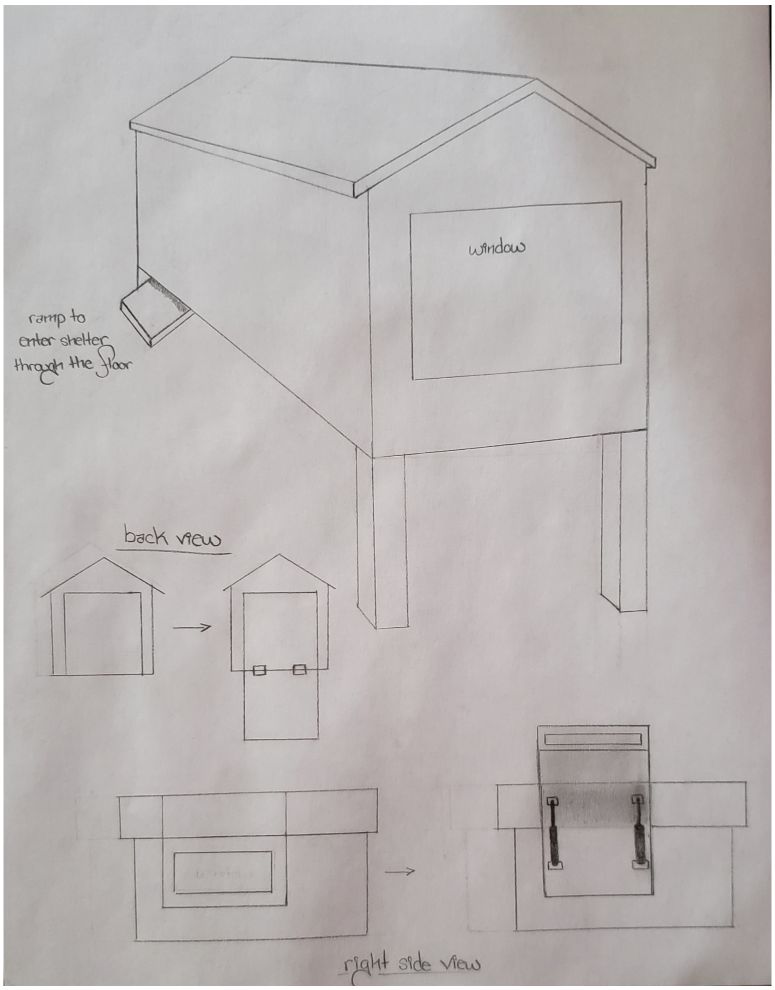

Figure B.3: Design 3

Design 4

This design utilizes a lean-to aesthetic with a shed roof that is designed to reduce the wind load on the shelter. This shelter features both an indoor and outdoor area for the dog that are accessible via a dog door as well as a raised floor to prevent harmful bugs from nesting. A biofuel reactor will convert the dog's waste into energy to provide adequate power as needed. The owner has access to the entire shelter for easy cleaning: the outdoor portion is open and the interior is accessible through a large hatch door on the back of the shelter.

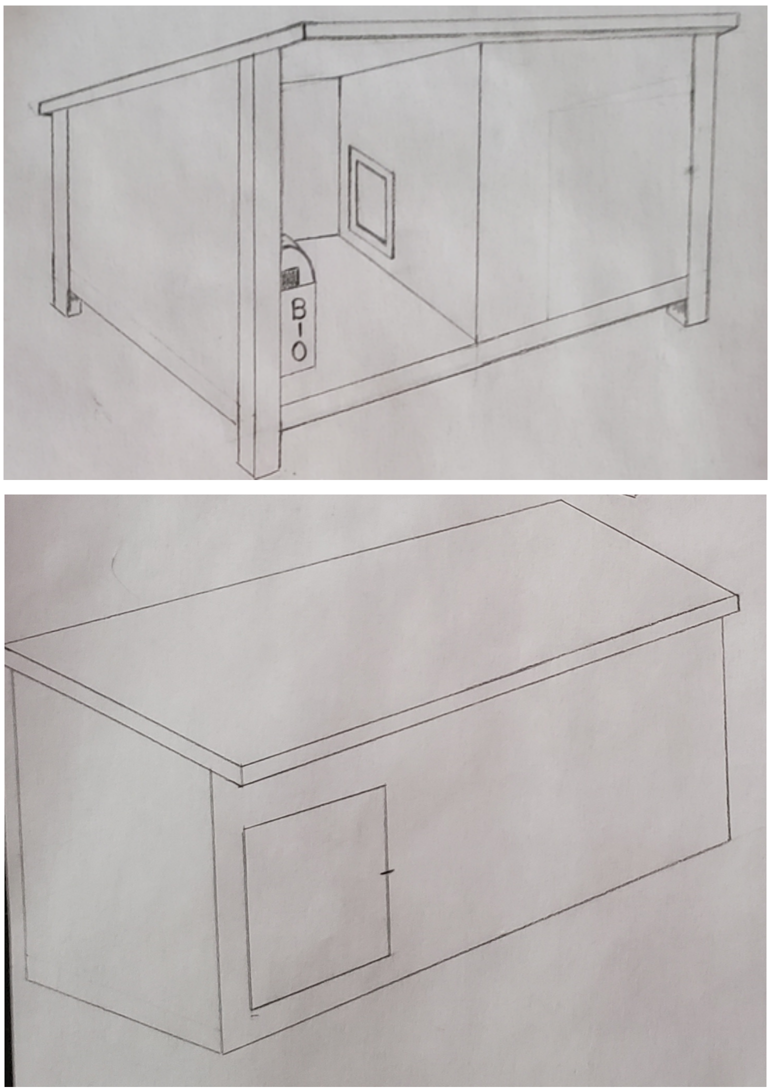

Figure B.4: Design 4

Design 5

Our fifth design is an automated dog door with a built-in sensor and thermometer. Since this design is installed on an exterior door of the owner's residence it allows the dog to access the outdoors directly from the owner's house and removes the need for a standalone structure outside. The dog door has a sliding panel that will move up to let the dog out when it senses the dog's collar, then move down to block the opening when not in use. However, the door will not open if the built-in thermometer registers a temperature that is unsafe for the dog to be outside.

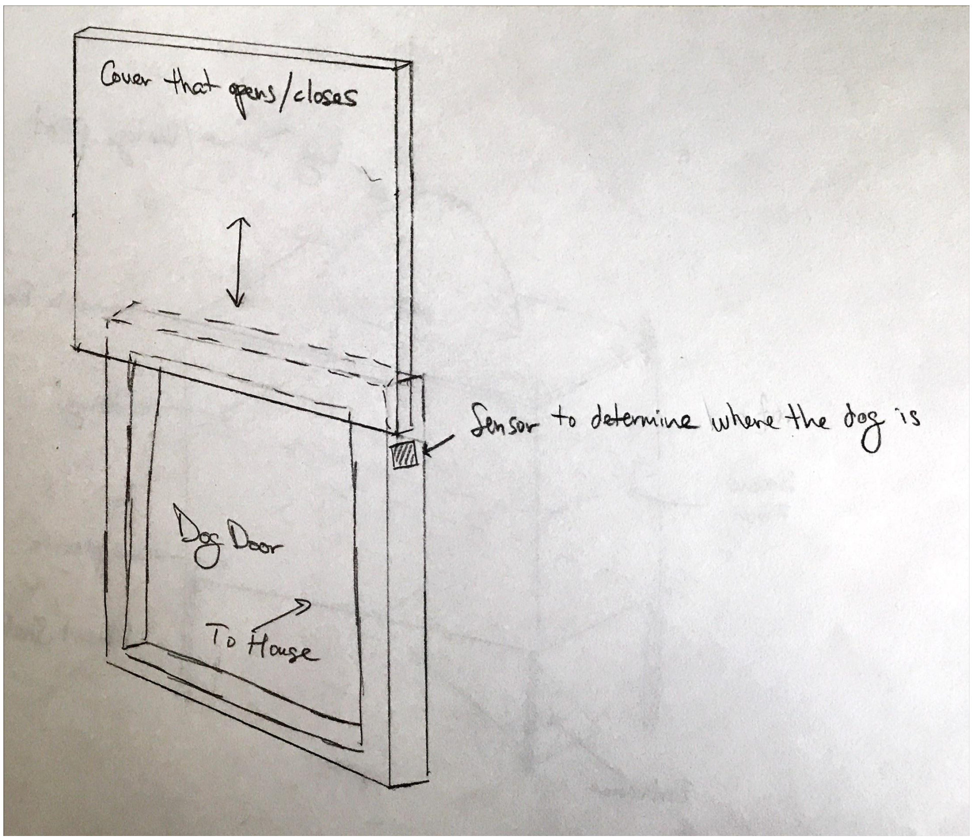

Figure B.5: Design 5

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Design 6

This design is a two story dog shelter with a flat roof and a transparent bubble dome on top. The base of the shelter is elevated off of the ground and utilizes a ramp for the dog to enter from underneath. This two story design allows the dog to climb up and look out of the viewpoint from the top of the shelter. The levels of the shelter can be separated to allow the owner easier access to clean the interior.

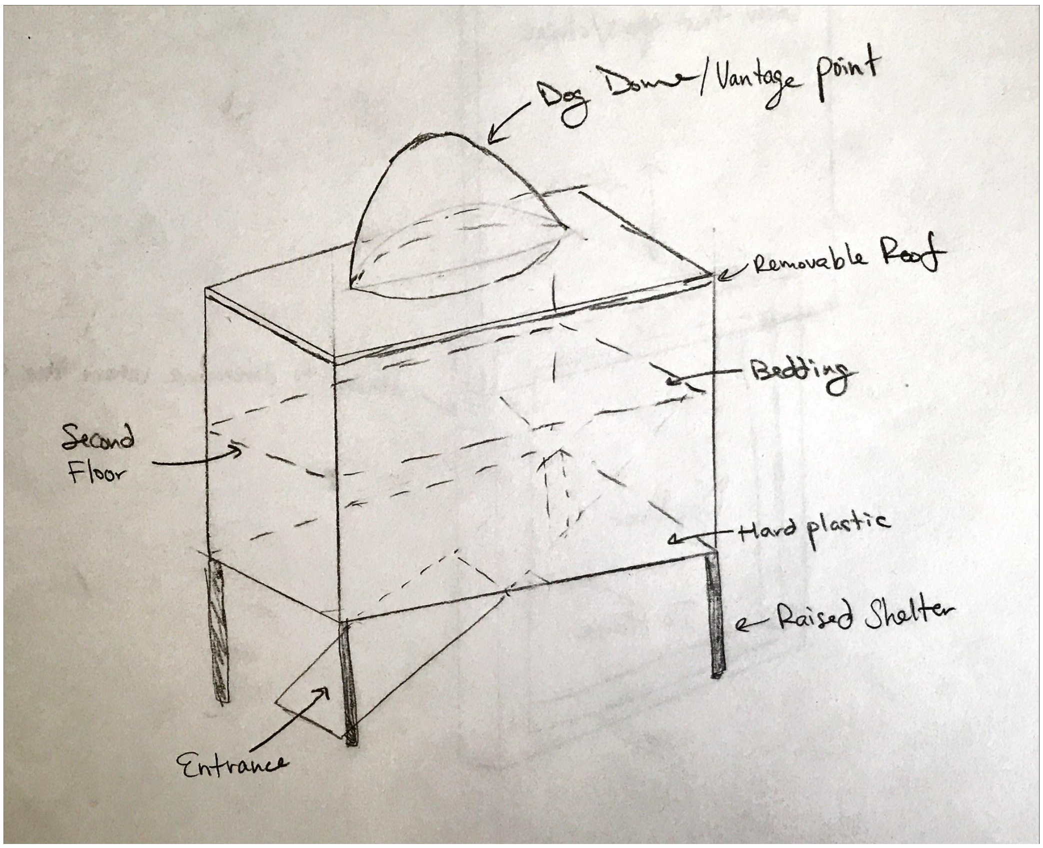

Figure B.6: Design 6

Design 7

Our seventh design is more of a proto-typical dog house. It has a gable roof, a window on the right side, and a door that opens and closes as the dog enters and exits the shelter. It is elevated off the ground by resting on top of a brick base. One side of the roof is hinged at the top, enabling the owner to lift the side and clean the interior of the shelter with ease.

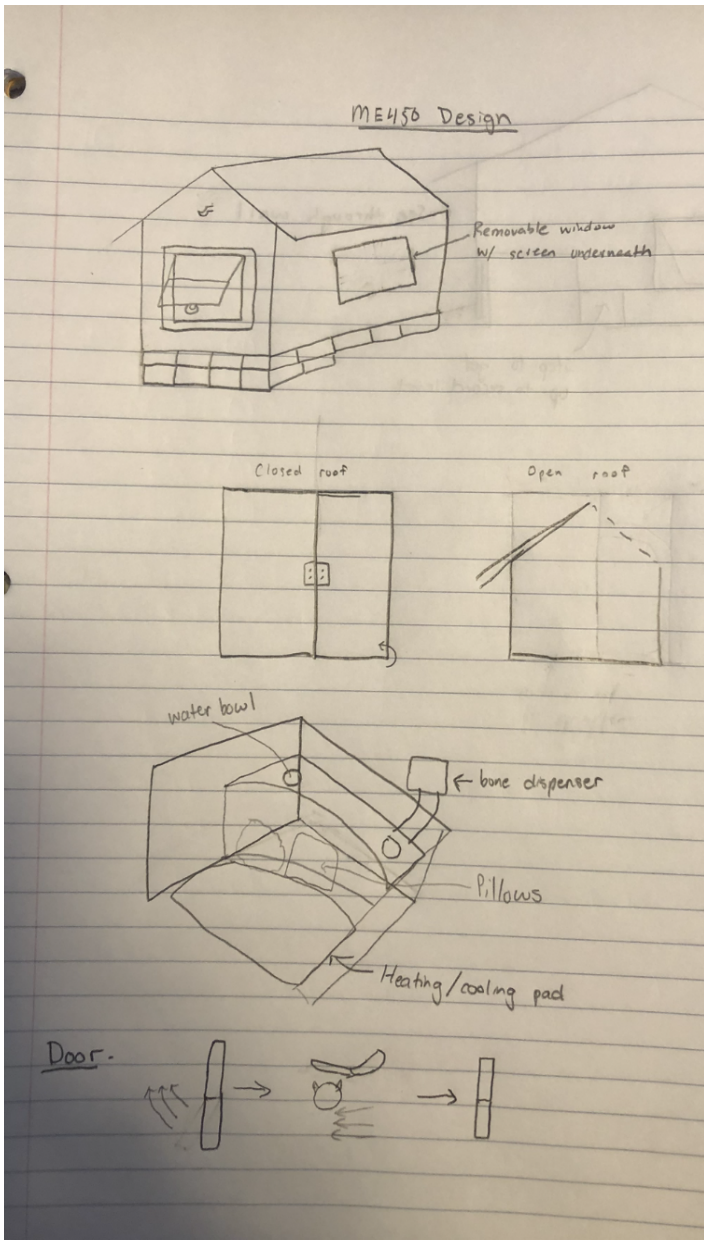

Figure B.7: Design 7

Design 8

The eighth design is a double-decker dog house with a gable roof. The second level of the shelter is elevated by stilts and shifted horizontally from the first level. The first level has a door for the dog as well as interior stairs that lead up to the second level which has a see through wall. To enable easy access for the owner to clean the interior of the shelter, there is a door on the back wall of the first level.

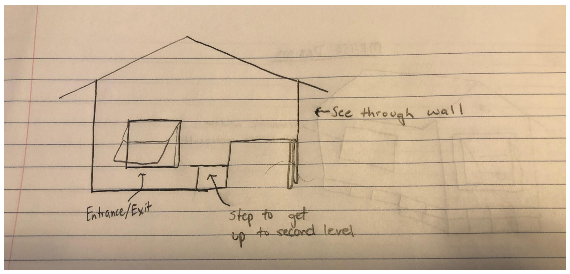

Figure B.8: Design 8

Design 9

This design is a rectangular shelter with a flat roof. The shelter is divided into an indoor area and an outdoor area. The left side of the shelter is an indoor area where the dog can rest on a removable heating or cooling pad. An interior temperature sensor will help monitor the indoor temperature, so the dog is comfortable regardless of the outside weather conditions. The floor is also raised to help prevent harmful bugs from nesting in the interior of the shelter. The right side of the shelter is a fenced-in outdoor area where the dog can get fresh air and relax. A flap door connects the indoor section to the outdoors as well as the indoor section to the fenced-in area. Both sections of the roof are hinged and able to be lifted and folded back to allow the owner to clean the interior of the shelter. Remote solar panels provide the necessary energy to power the shelter's functions.

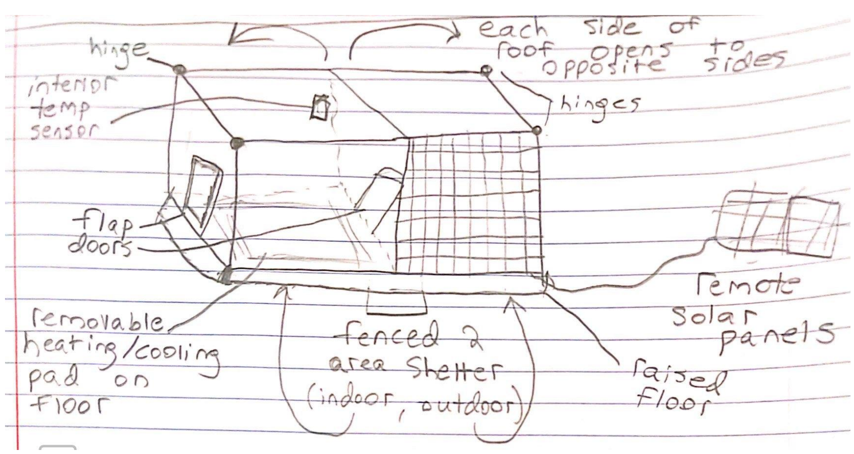

Figure B.9: Design 9

Design 10

The final design has a semi-elliptical top profile with a flat roof which is hinged for easy access. It has one opaque flat wall whereas the rest of the sides are curved and transparent. This shelter has a raised floor as well as a magnetic mesh door for the dog to enter and exit to help prevent harmful bugs from nesting in the dog's area. This design features a concave hill in the interior that the dog can lay against to relax. It also includes a dog bowl on top of the concave hill from which the dog can drink. The opaque wall also features an openable window for additional airflow during hot summer days.

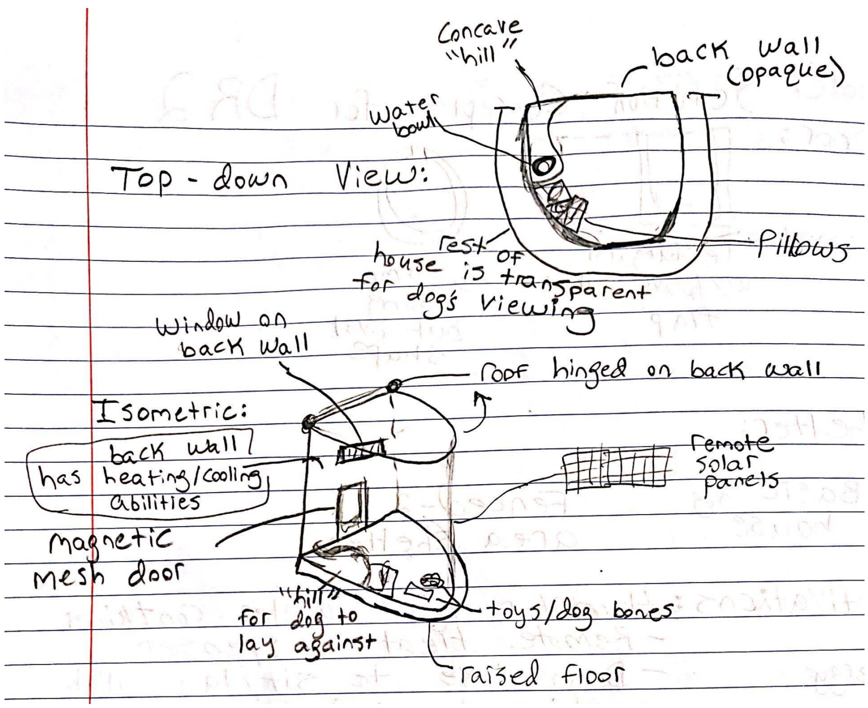

Figure B.10: Design 10

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APPENDIX C: Supplemental Information

C.i: Engineering Standards

The final shelter was designed so that it followed engineering standards for dog houses and for adequate shelter. Although there are not many official standards that correspond to the development of dog houses, our team was able to find and employ multiple other standards and rules that were found through benchmarking online.

One of the main standards utilized was the A-B-C method,[15] which contains dimensional information for sizing the dog house properly. Following this method ensures that the shelter will be of adequate size for the dog in which it is being built. The A-B-C method requires an owner to take measurements of their dog, and then convert those measurements to minimal and maximum dimensional requirements for the dog house. The A-B-C method, if used correctly, guarantees that a dog will be comfortable and safe in its dog house. We dimensioned the shelter using the A-B-C method based on an average golden retriever's full grown size.[10]

An additional standard that we utilized during design was that the floor of a dog house should be raised at least two inches off of the ground to provide better safety.[21] More specifically, though, this technique will help prevent harmful bugs such as fleas from easily entering the shelter. Following this technique will also provide better temperature control and resistance to wet weather conditions. This standard was outlined in multiple different websites that detail dog house building guidelines.

The dog house's roof was also built to follow conventional roof sizing for houses.[27] The roof's pitch was designed to be a ratio of 4:12 in rise over run, which creates an 18.5 degree roof angle. That angle is the lower bound for conventional roof slopes, which means that the roof is built to handle heavy rain and snow if necessary, just like a regular home. The roof was also designed to have at least two inches of overhang on all four sides of the shelter in order to prevent excess rain or snow from accumulating inside or on the walls of the shelter.[28] The two inch overhang standard was found on Home Depot's website.

The outlined procedure for installing the shelter's roof shingles follows basic shingling guidelines. Properly utilizing these guidelines to shingle the roof will guarantee that the shelter is amply protected from harsh weather conditions, and that the roof will be strong and durable throughout the shelter's lifetime.

While many standards and guidelines that we used were found from official sources, we also utilized some self-imposed standards to make some design decisions. One of the standards we implemented was that there must be 0 VOC (volatile organic compounds) present on the shelter's surfaces.[18] The 0 VOC standard will ensure that the shelter's parts and infrastructure are not toxic to Tula. Another standard that we imposed was that there should be zero sharp edges or exposed wires within the shelter's interior. Without exposed wires we can be sure that Tula will not ever shock herself while using the shelter. No sharp edges will simply create a safer environment for Tula. These self-imposed standards were created in response to our generally safe requirement for the dog house.

C.ii: Engineering Inclusivity

Upon starting this project, we realized that there exists a large variety of conditions that affect the needs of potential end users of dog shelters; for this reason, as well as our disinterest in transforming the design as a business venture, we decided to define our end user stakeholders to be only the Skerlos household. As our design was made for only this specific household, the design was only parameterized to identify these stakeholders as the only end users with a focus on what would work for them. Our initial definition of the problem essentially drew several adjectives from the initial project description and required that a dog house must be designed which would vaguely satisfy these requirements. With feedback from our class peers and from our stakeholder, this idea became the basis of more clearly and objectively defining our requirements and specifications of the problem.

By the nature of one of our stakeholders also being our professor, the decision making process was structured according to the Claimed Space of the curriculum. The original premise for the project as presented to us was also a Claimed Space, written and parameterized by our end users to fit the wants and needs of only those specific stakeholders. From this, we engaged with weekly virtual meetings with one of our stakeholders to create an Invited Space of cooperative and involved decision making, and we also met virtually with another stakeholder to receive additional information. One of our stakeholders was not able to engage in these virtual Invited Space meetings due to the fact that she is a dog, so other stakeholders spoke on her behalf. Between our Invited Space meetings, we worked on our own in our group as a Closed Space to decide how to implement and actualize the input previously received from our stakeholders without them being presently engaged. The virtual and remote nature of our stakeholder interactions may have limited our ability to fully evaluate and assess their input pertaining to the solution space.

Due to our end users all being of the same household family, the variety of social identities mostly did not significantly impact the design. The social identities which were most impactful on our design were Age and Physical (Dis)Ability. First, the dependency of physical ability on the age of the human end users affected our decision making regarding maintainability and access to the dog shelter. We needed the shelter to not

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only be fully accessible by a dog, but by both adults and children for maintenance. Based on feedback from an adult stakeholder and a child stakeholder, we decided to make two different access methods to the interior: removing the roof for taller and stronger end users (generally adults), and a wider and taller doorway for shorter and smaller end users (generally children).

With a small number of end users who each are all of the same family household, our team was limited in how much we needed to practice inclusivity in designing. Though we could have expanded our scope of the problem to include the general public and therein have a greater variety of stakeholders to include, we ultimately decided not to due to the lack of information and our disinterest in creating a business enterprise.

C.iii: Environmental Context Assessment

The final shelter design was evaluated using two necessary conditions for a sustainable technology: 1) Does the system make significant progress towards an unmet and important environmental or social challenge?, and 2) Is there potential for the system to lead to undesirable consequences in its lifecycle that overshadow the environmental/social benefits?

In regards to the first condition, the carbon neutral luxury dog house does not make significant progress towards an unmet challenge as it does not fully achieve carbon neutrality. Throughout our research as well as concept exploration and development, we developed an understanding of a comfortable and desirable environment for a dog as well as the motivations to lead a dog to utilize a shelter. We achieved this understanding by focusing on the comfort of the dog and temperature analysis within the shelter to ensure a comfortable environment during warm and cold weather. Another important aspect of our shelter is addressing the climate crisis by mitigating carbon emissions through lifecycle analysis and incorporating actions that can reduce or even offset the shelter’s carbon footprint. According to the eco-audit completed for this design, the shelter will produce an average of 29.7 pounds of CO_2 per year over a lifespan of 12 years. This is a very small amount of emissions especially when compared to the average American’s carbon footprint of 16 tons per year, or the global average of about 4 tons.

Regarding the second condition, if our design was mass produced for worldwide use, the dog shelter would have potential to lead to undesirable consequences in its lifecycle. This is mainly due to the current, typical business practices such as material extraction, manufacturing processes, and methods of disposal. However, it is unlikely that the shelter will achieve the level of success necessary to be utilized worldwide.

Obtaining materials to produce the dog shelters could be detrimental to local communities. Mass production of the shelters worldwide could result in mass deforestation in order to procure enough materials to construct the dog shelters. Due to historical trends in material collection, especially rare earth materials, motivation for unsafe and unethical mining practices could harm impoverished communities. The process of mining lithium for batteries is highly water intensive. An estimated 500,000 gallons of water is used per ton of lithium being extracted. This practice not only permanently scars the land, but also impacts the quality and quantity of the local water supply and drastically increases the risk of drought or famine is not monitored properly.[40]

Residents located near the factories manufacturing the components for the dog shelter could be exposed to various pollutants degrading their health and the surrounding environment. This is especially true for areas utilizing coal-powered plants. The environmental hazards can include air and water pollution sources which can negatively impact residents' health if inhaled or ingested. Common health problems associated with these types of pollution include asthma, heart and lung ailments, neurological disorders, and various forms of cancer.[33] These forms of pollution also degrade the surrounding environment, impacting local wildlife.

Current waste produced around the world is not properly disposed of, leading to significant sources of environmental pollution, including water. Specifically, if not properly disposed, the lithium ion battery could pollute the surrounding environment, including the local water supply. This is mainly due to the fact that it is less costly to throw components in the landfill rather than recycle, and there are no governmental restrictions to incentives proper disposal and recycling of components. This common practice could result in a large increase of waste in landfills. Also, if wood is disposed of or burned, the carbon being stored within could be released back into the atmosphere.On a large scale, worldwide, this could result in an increase of carbon emissions.

With large scale use of the dog shelter around the world, environmental pollution would persist with this common practice. If the world could change its traditional business practices to reflect an ability to follow proper recycling and disposal practices as well as ethical procurement of resources through practices such as mining, the dog shelter could be a sustainable solution for the future.

C.iv: Social Context Assessment

The final shelter design was evaluated to define the social impact of the proposed design. The system is not likely to be adopted and be self sustaining in the market. The dog shelter design is specialized to one specific user. The shelter does not do anything new or game changing that will make it more valuable than alternative dog shelters.

The system is not likely to be so successful that planetary or social systems will be thrown off. The environmental impact of the dog shelter has been a focus throughout development. The carbon footprint of the shelter was kept to a minimum and uses mostly natural materials in the form of wood. The social impact is also minimal. The product was developed for a single use and not intended to be mass produced. The implementation will not be detrimental to any dog shelter business or to the economy.

The dog shelter does not make significant progress towards an unmet and important challenge and will not disrupt business as usual. The goal of the project was to create a carbon neutral shelter via any means. The methods in which we achieved this were not revolutionary in terms of carbon neutrality. The methods are simplistic and will not create a large social disruption.

C.v: Ethical Decision Making

We reviewed the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers and made sure that our design and the processes we used to get to this final design abided by the code. Our design process and final solution upheld the code, and we did everything the way we should have according to the code of ethics. We also abided by the Honor Code for the University of Michigan’s College of Engineering throughout the project.

We faced a few ethical dilemmas during our design process. One example of an ethical dilemma we faced during this semester was that we had to decide which type of wood to use for our shelter. We could have used softer wood and come in under budget, or we could have used a stronger wood and come in over budget. We decided to use cedar, which is a strong and sturdy type of wood, but our dog shelter was now over budget. We decided to use the stronger wood because we owe it to our stakeholder to have a stable, safe design first and foremost. By using the softer wood, we could be putting his dog in harm's way, and we have a moral obligation to not do this and be as safe as possible.

APPENDIX D: Engineering Drawings

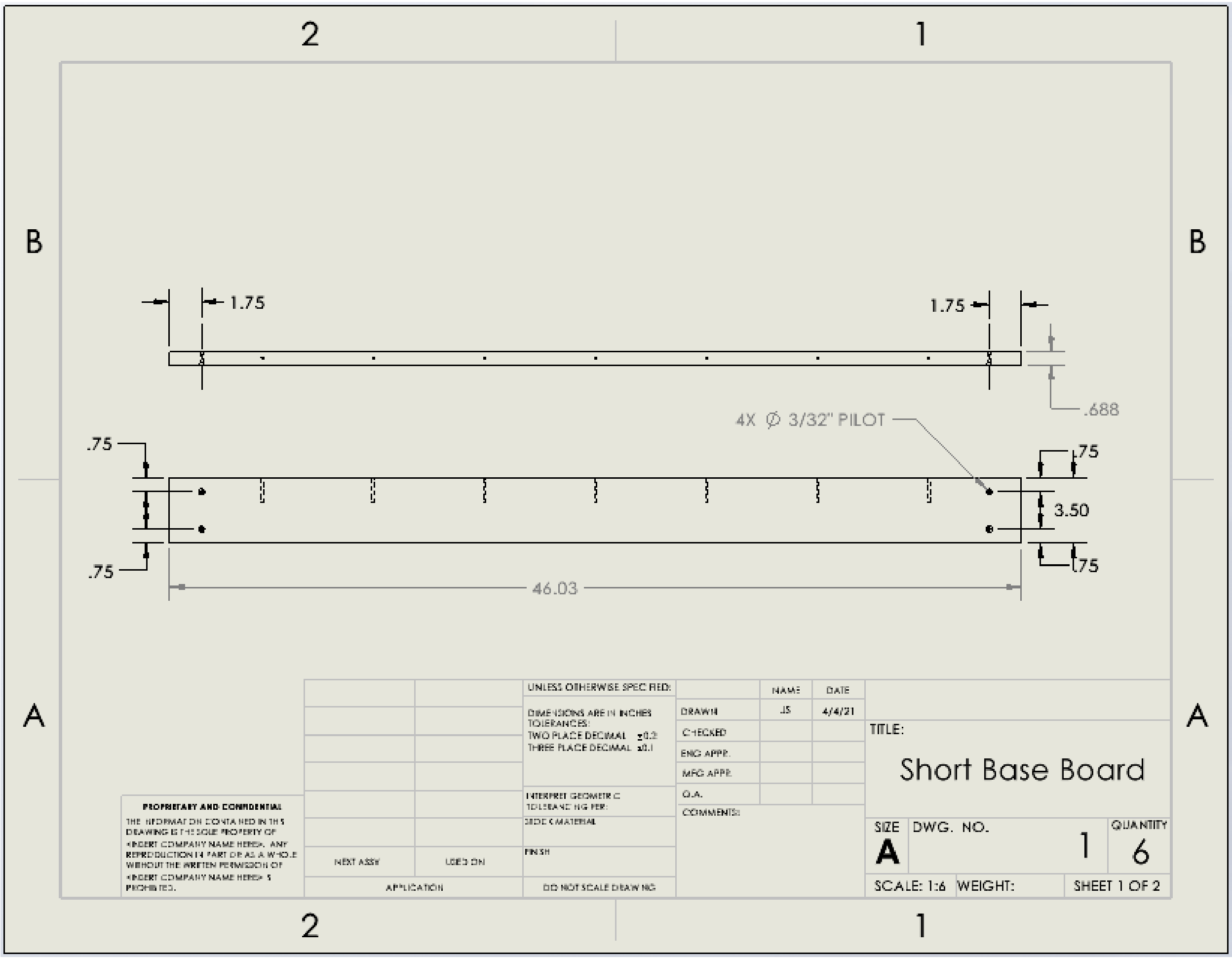


Figure D.1: Engineering Drawing of the Short Base Board.

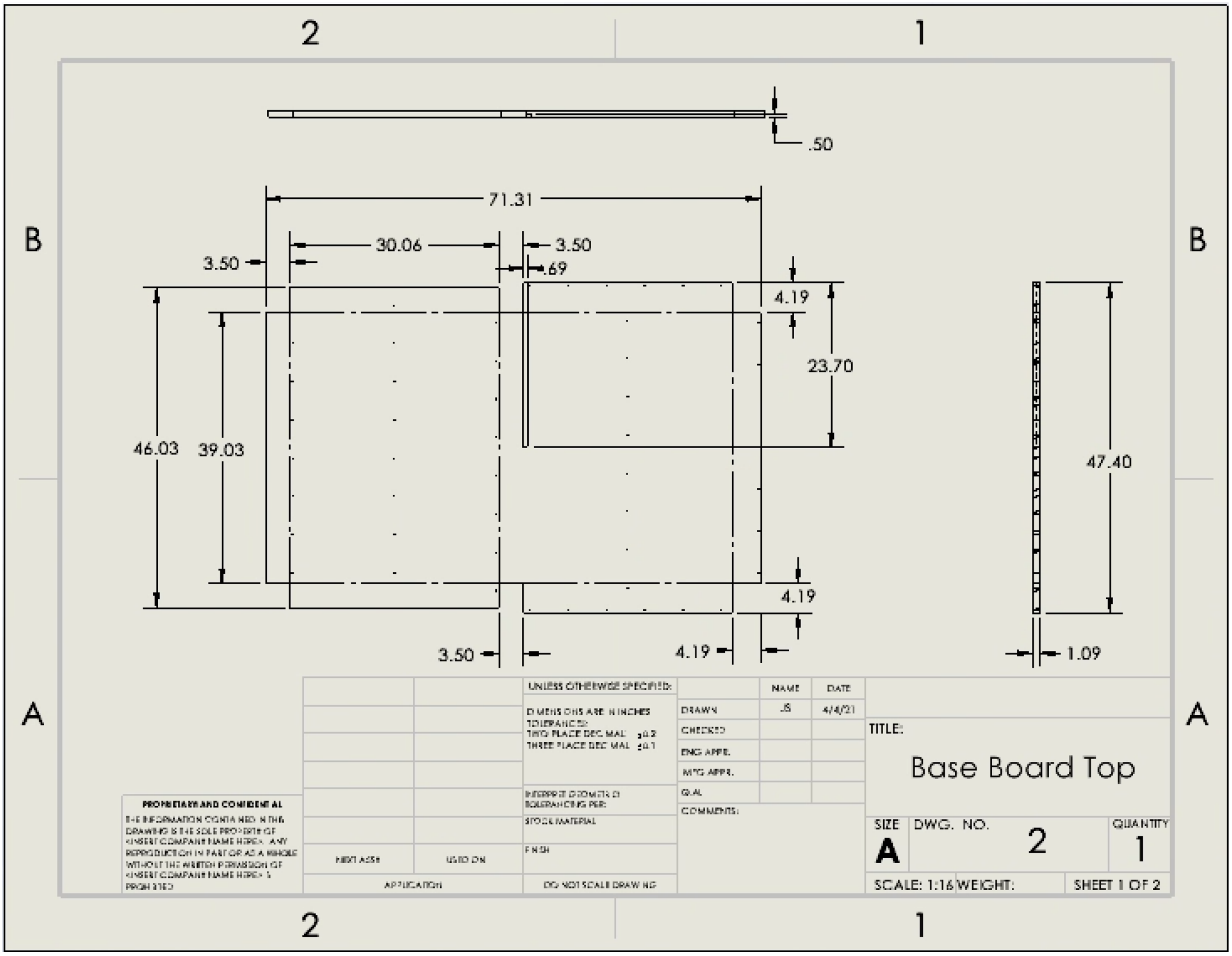


Figure D.2: Engineering Drawing of the Base Board Top.

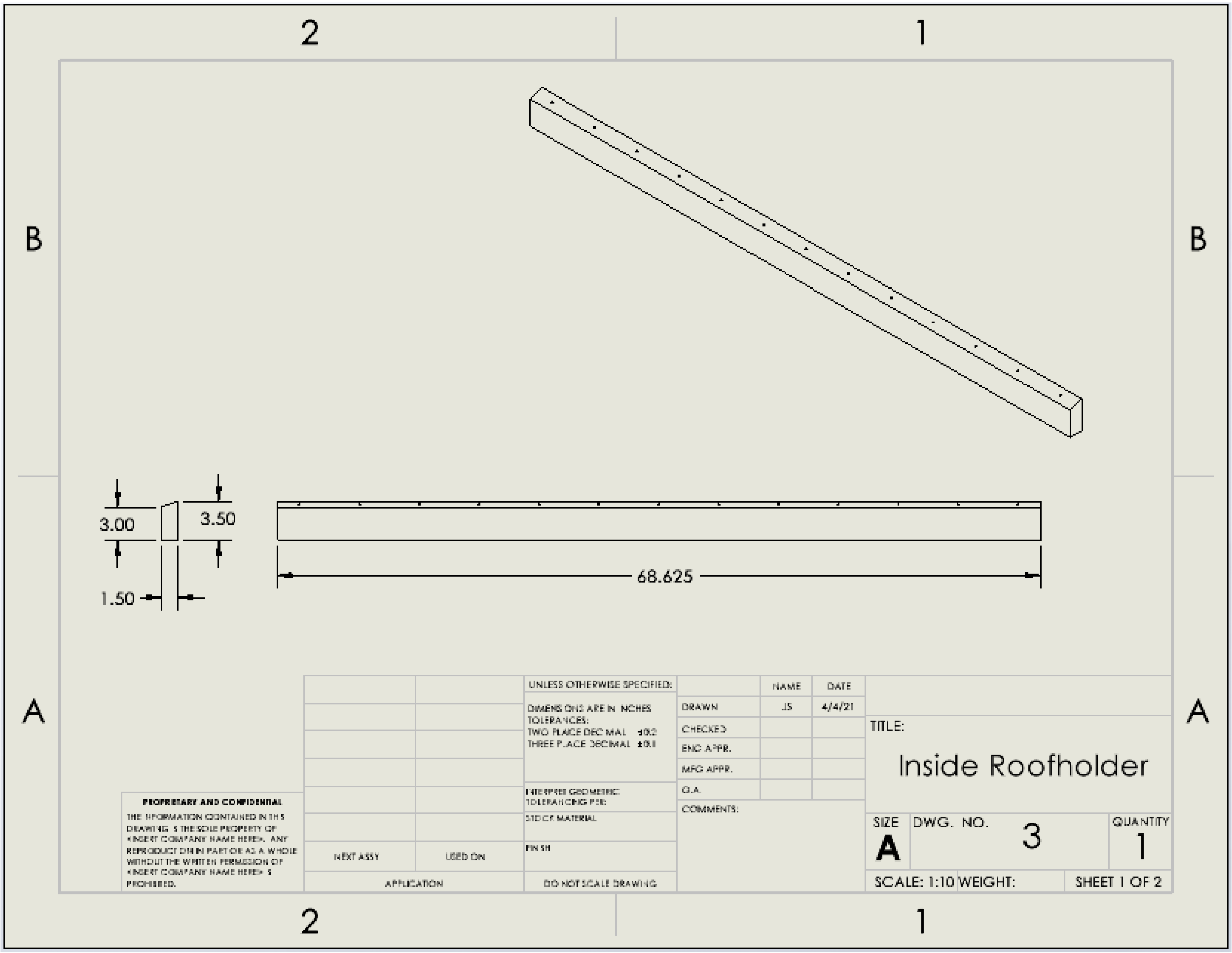


Figure D.3: Engineering Drawing of the Inside Roofholder.

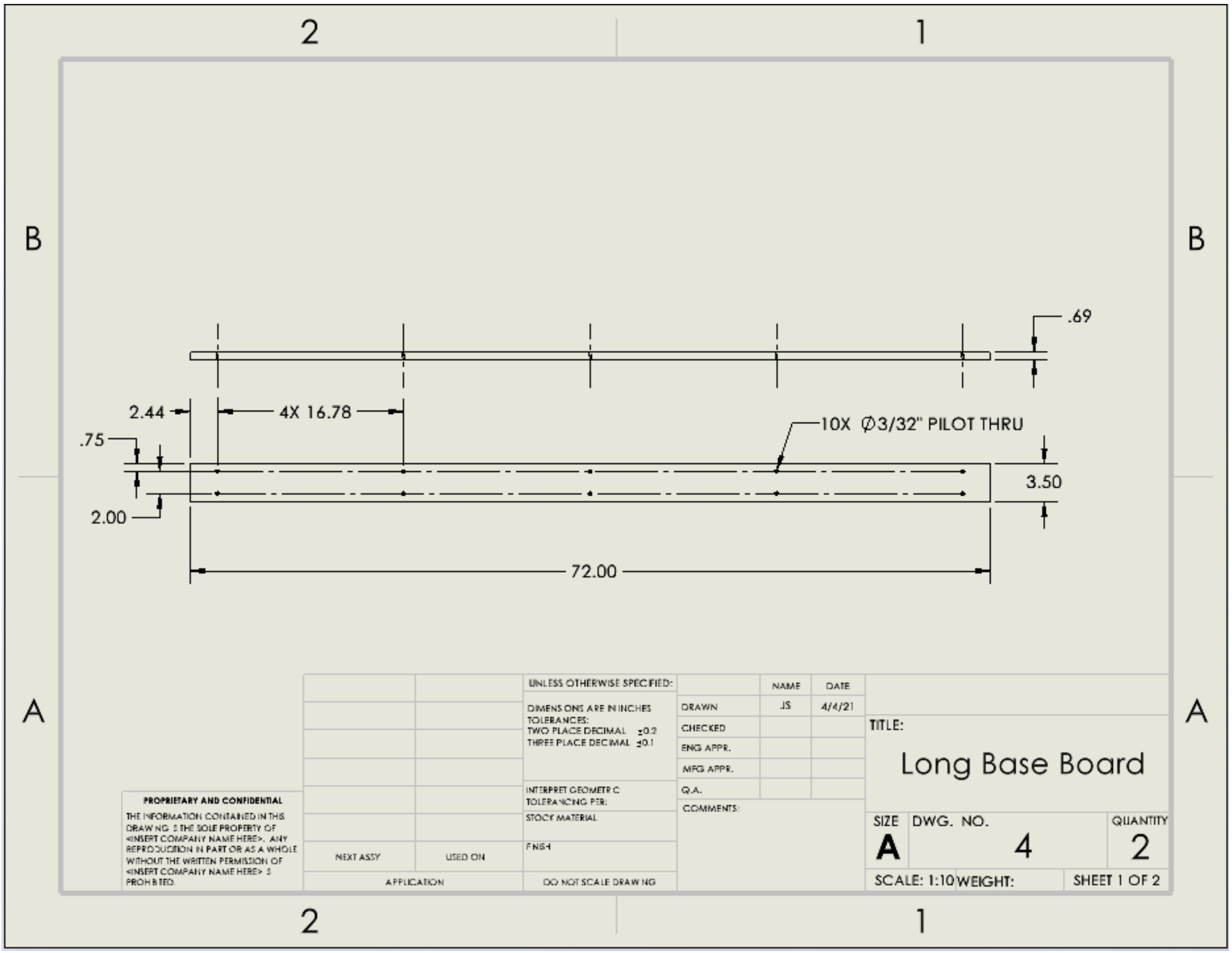


Figure D.4: Engineering Drawing of the Long Base Board.

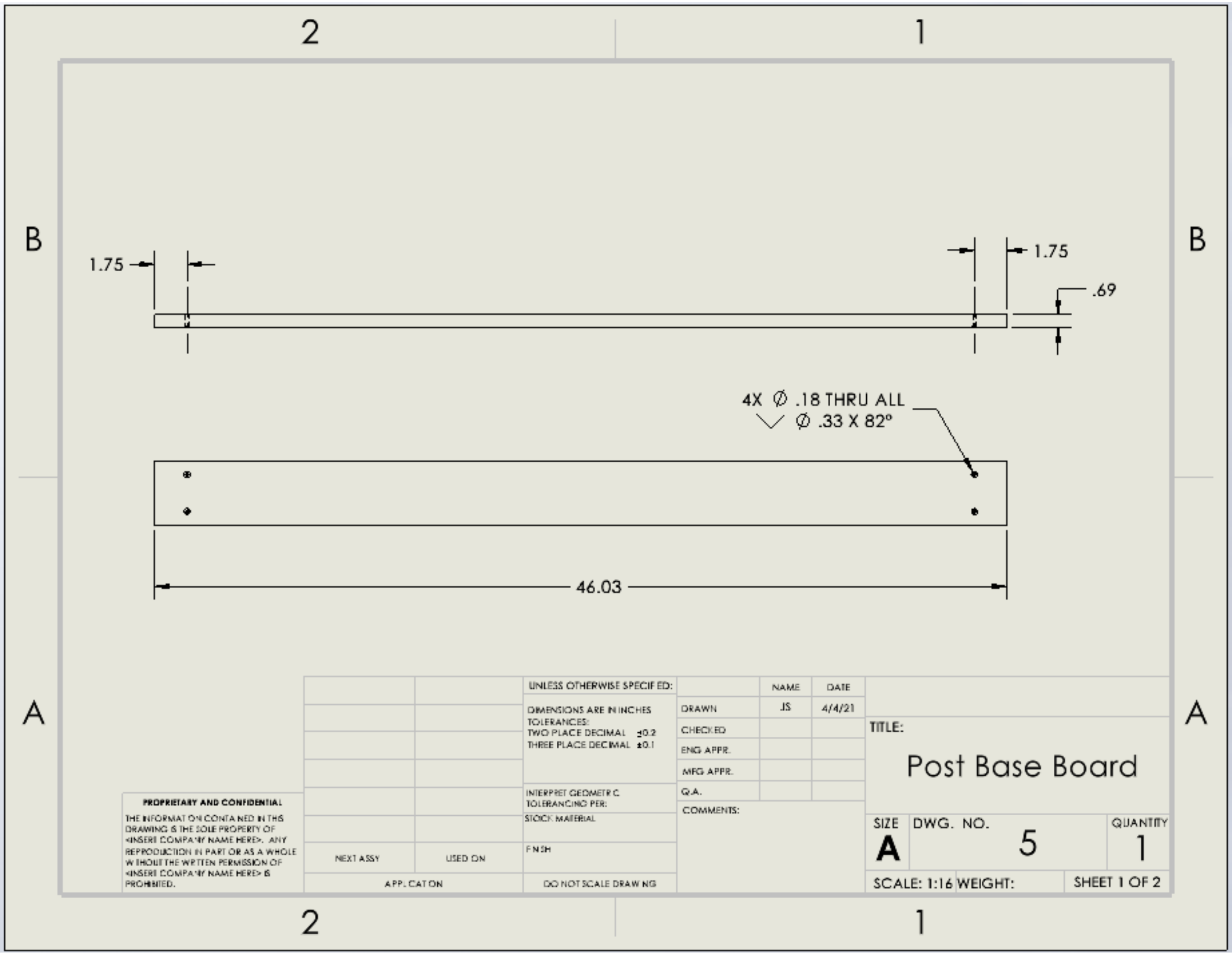
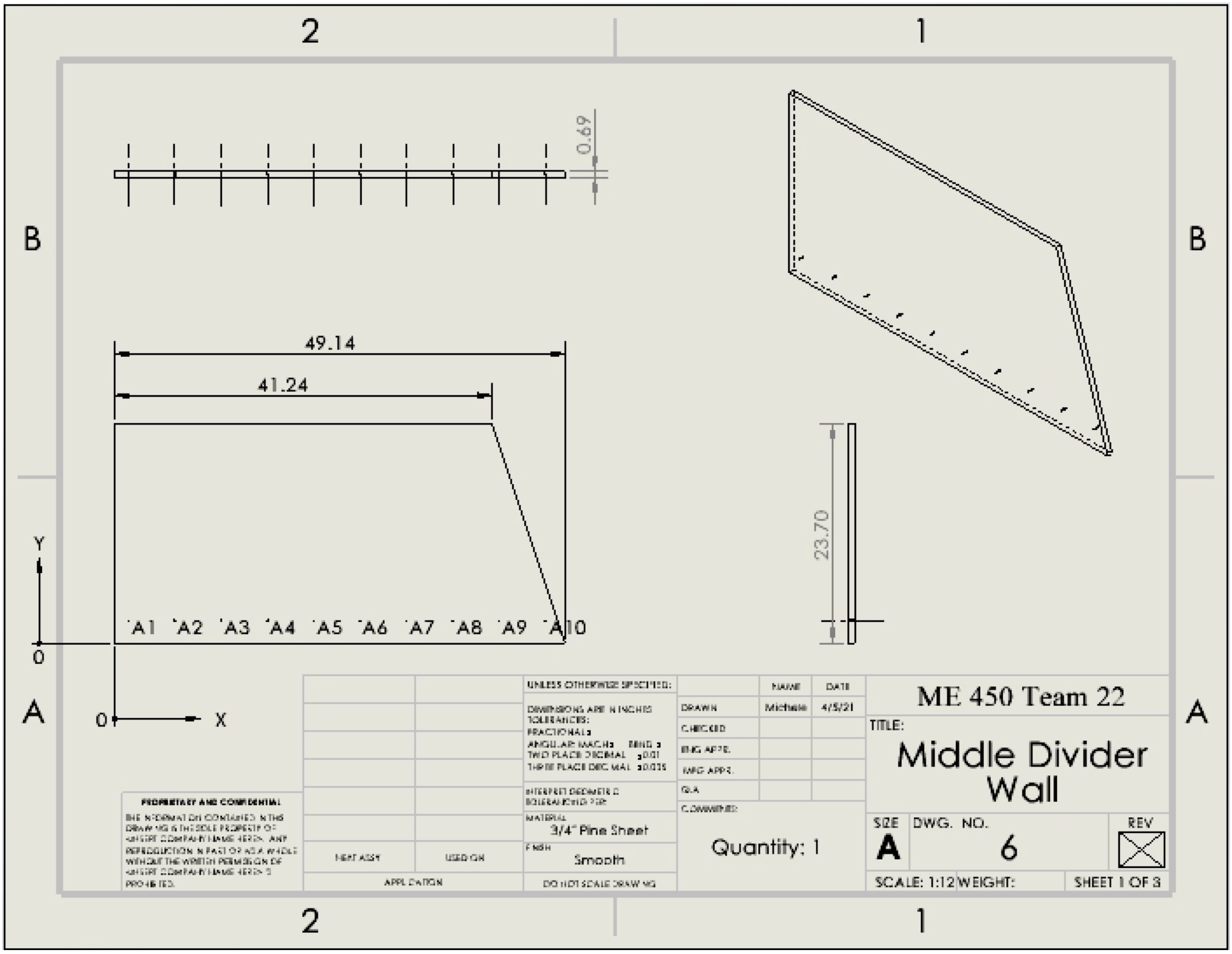
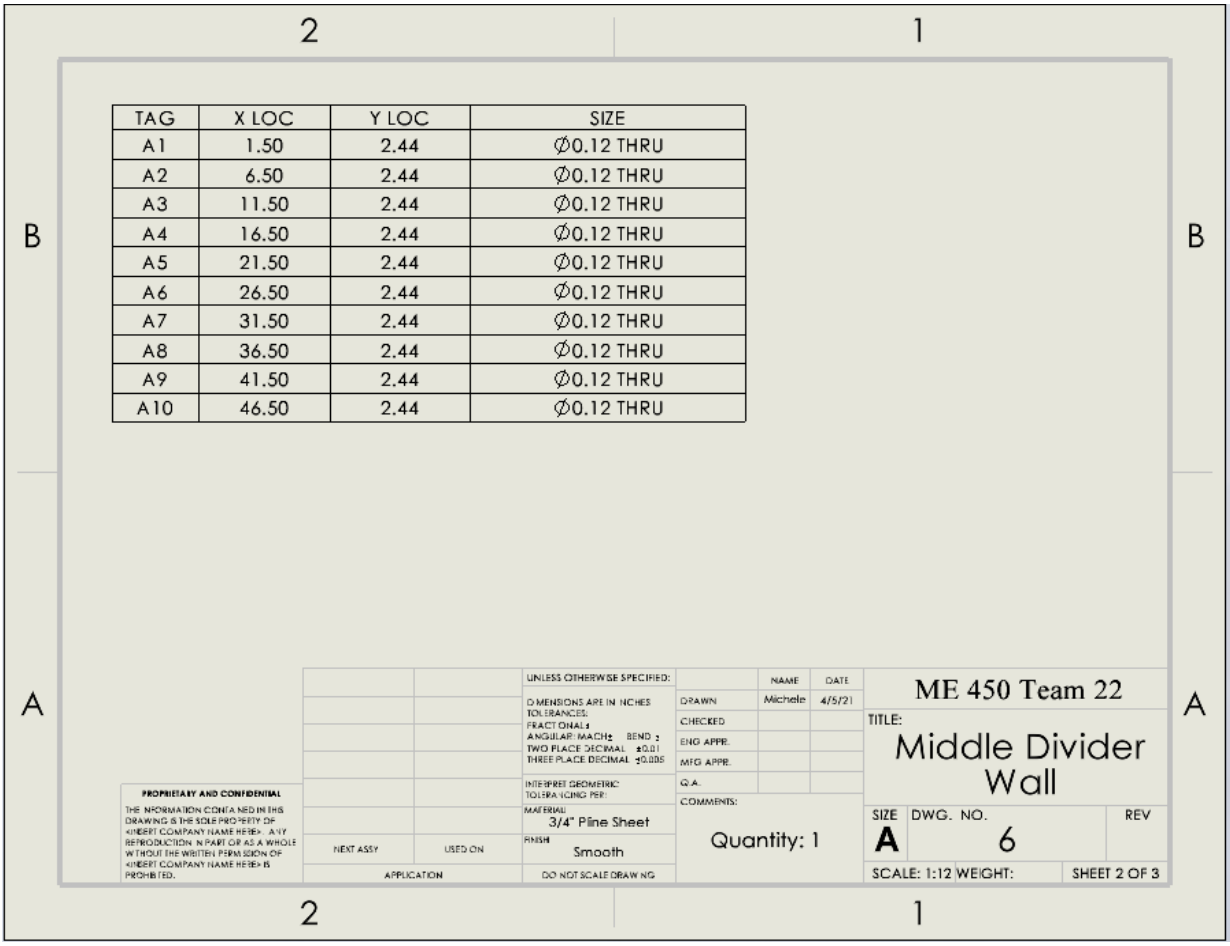


Figure D.5: Engineering Drawing of the Post Base Board.


2
1
B
A
0.69
49.14
41.24
23.70
Y
0
X
A1 A2 A3 A4 A5 A6 A7 A8 A9 A10
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
Michaela
4/5/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
3/4" Pine Sheet
FINISH
Smooth
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
Quantity: 1
ME 450 Team 22
TITLE:
Middle Divider Wall
SIZE
A
DWG. NO.
6
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 3



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A2	6.50	2.44	∅0.12 THRU
A3	11.50	2.44	∅0.12 THRU
A4	16.50	2.44	∅0.12 THRU
A5	21.50	2.44	∅0.12 THRU
A6	26.50	2.44	∅0.12 THRU
A7	31.50	2.44	∅0.12 THRU
A8	36.50	2.44	∅0.12 THRU
A9	41.50	2.44	∅0.12 THRU
A10	46.50	2.44	∅0.12 THRU

Figure D.6: Engineering Drawing of the Middle Divider Wall.

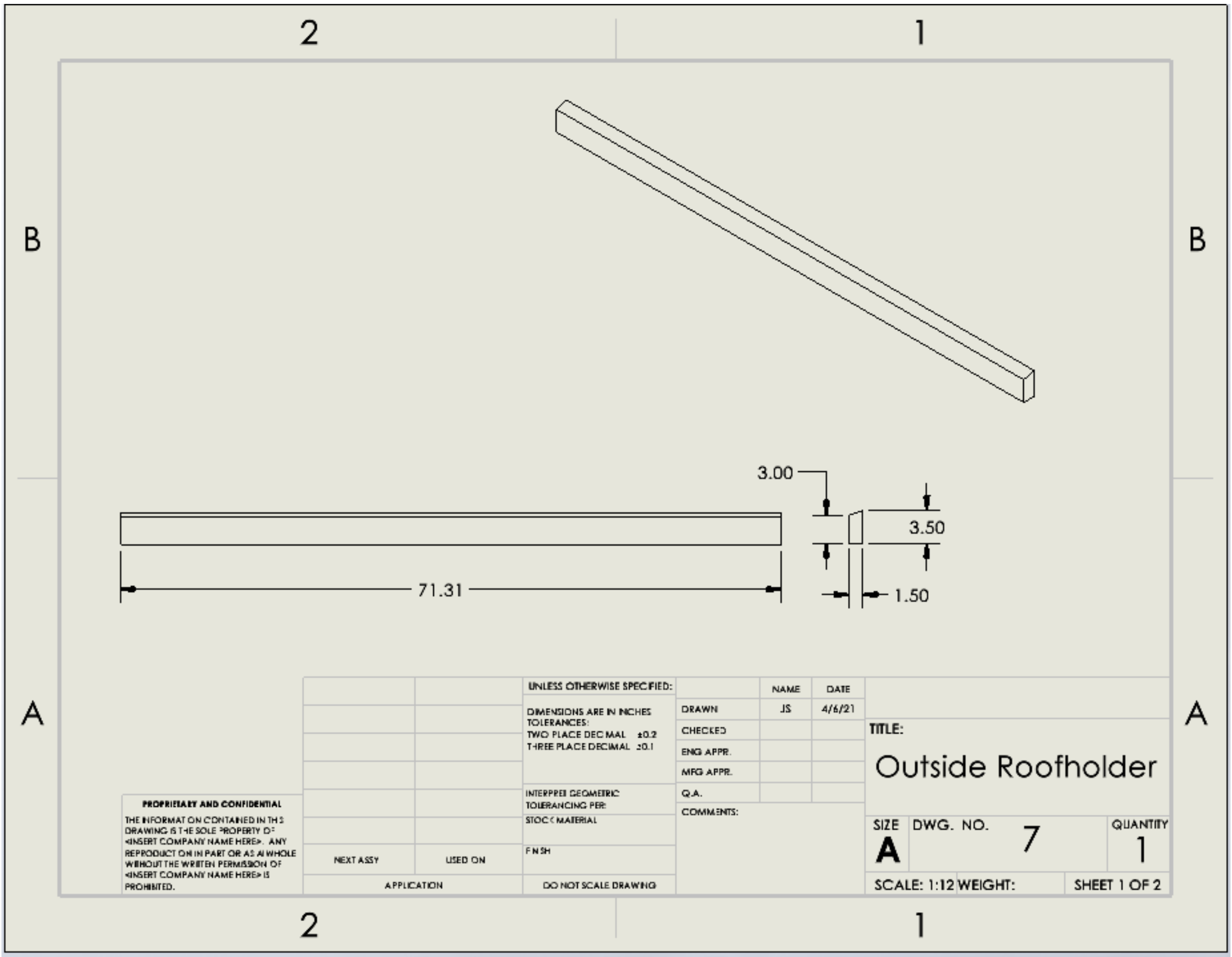
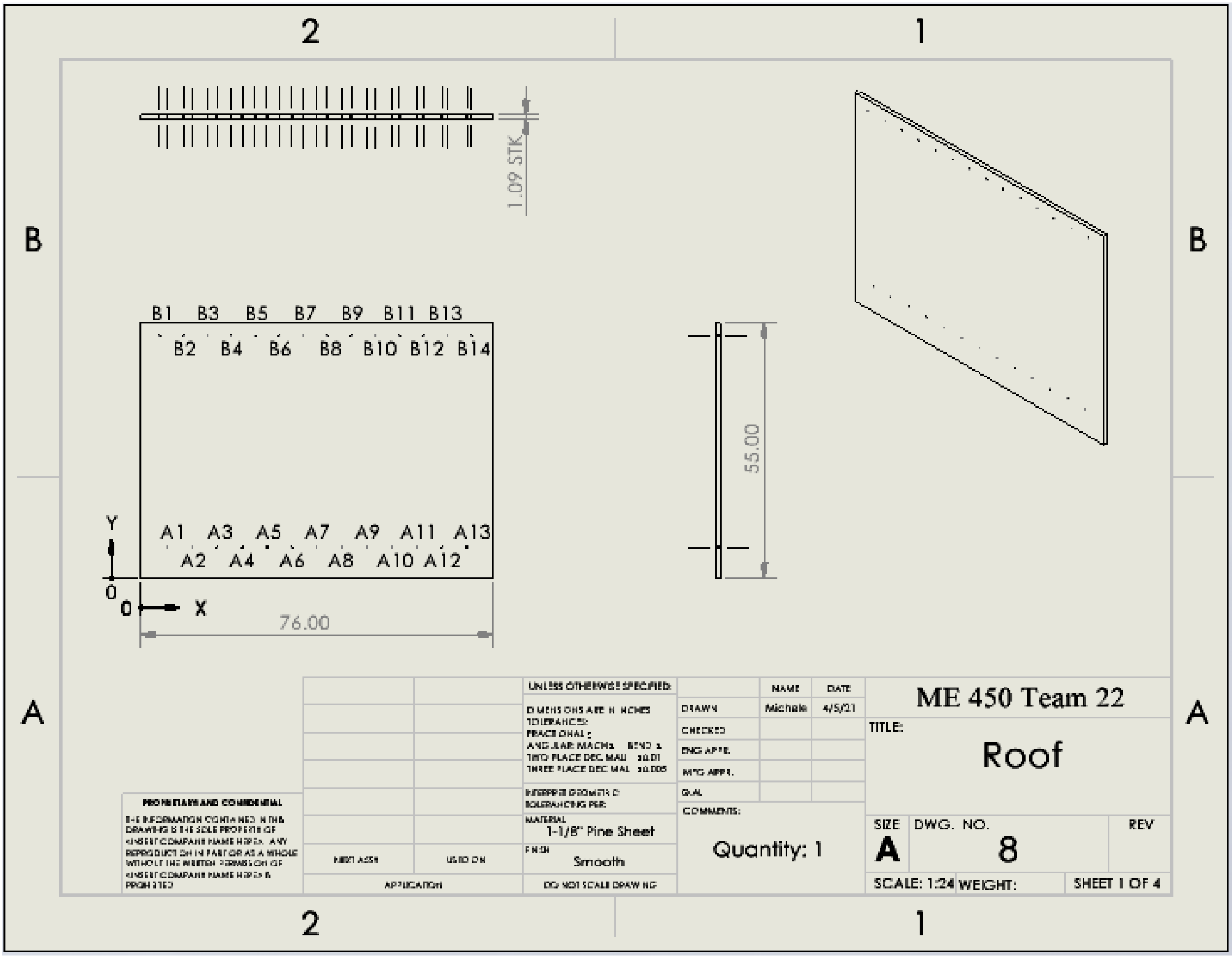


Figure D.7: Engineering Drawing of the Outside Roofholder.



1.09 STK
B1 B3 B5 B7 B9 B11 B13
B2 B4 B6 B8 B10 B12 B14
A1 A3 A5 A7 A9 A11 A13
A2 A4 A6 A8 A10 A12
Y
X
0
76.00
55.00
ME 450 Team 22
TITLE:
Roof
DRAWN Michale 4/5/21
MATERIAL 1-1/8" Pine Sheet
FINISH Smooth
Quantity: 1
SIZE A
DWG. NO. 8
SCALE: 1:24
SHEET 1 OF 4

TAG	X LOC	Y LOC	SIZE
A1	5.69	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A2	11.08	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A3	16.47	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A4	21.86	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A5	27.25	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A6	32.64	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A7	38.03	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A8	43.42	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A9	48.81	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A10	54.20	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A11	59.59	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A12	64.98	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°
A13	70.37	6.66	⌀ .18 THRU ALL ⌵ ⌀ .33 X 82°

SHEET 2 OF 4

TAG	X LOC	Y LOC	SIZE
B1	4.00	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B2	9.18	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B3	14.36	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B4	19.54	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B5	24.72	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B6	29.90	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B7	35.08	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B8	40.26	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B9	45.44	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B10	50.62	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B11	55.80	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B12	60.98	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B13	66.16	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°
B14	71.34	52.25	Ø .18 THRU ALL ⌵ Ø .33 X 82°

SHEET 3 OF 4

Figure D.8: Engineering Drawing of the Roof.

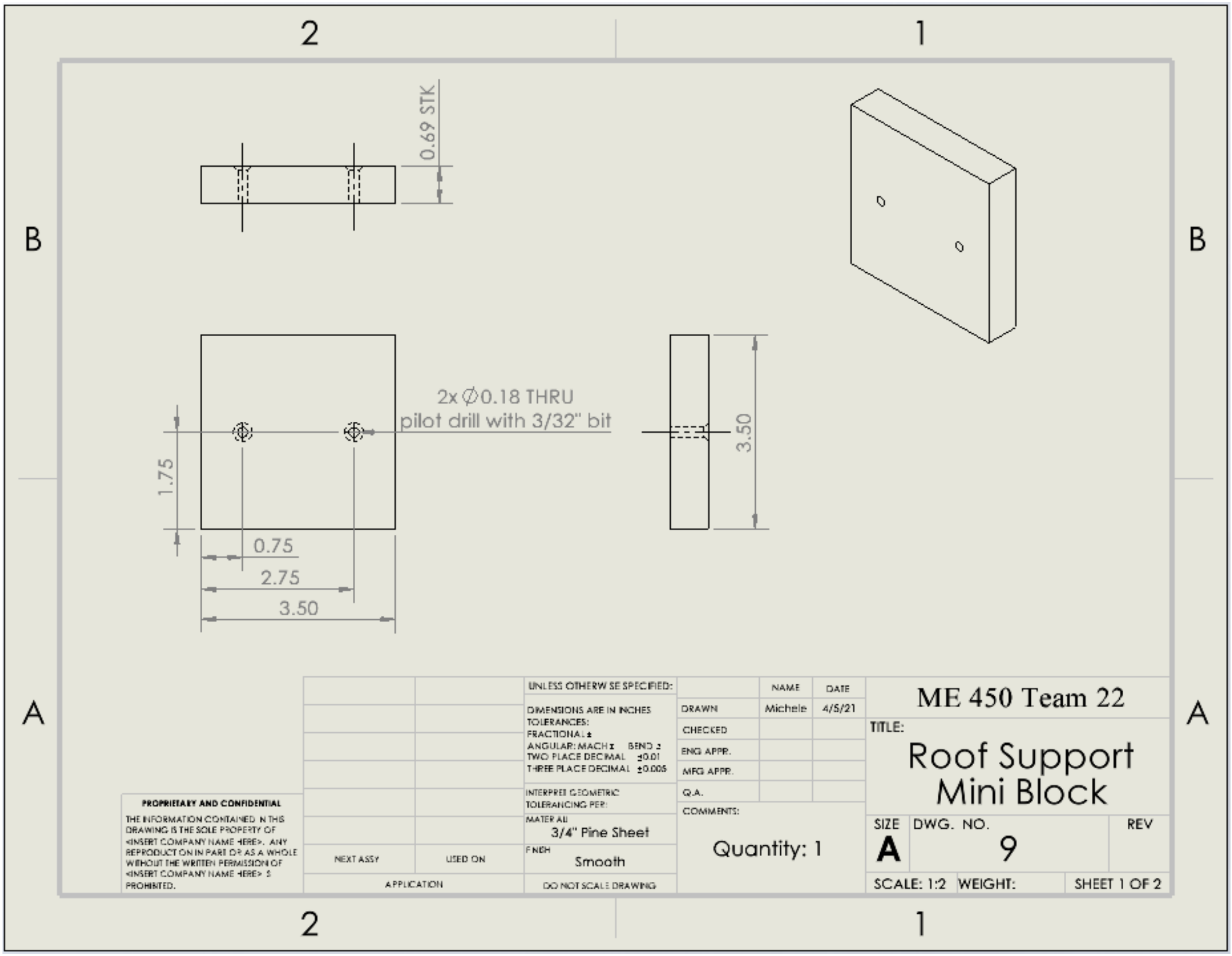


Figure D.9: Engineering Drawing of the Roof Support Mini Block.

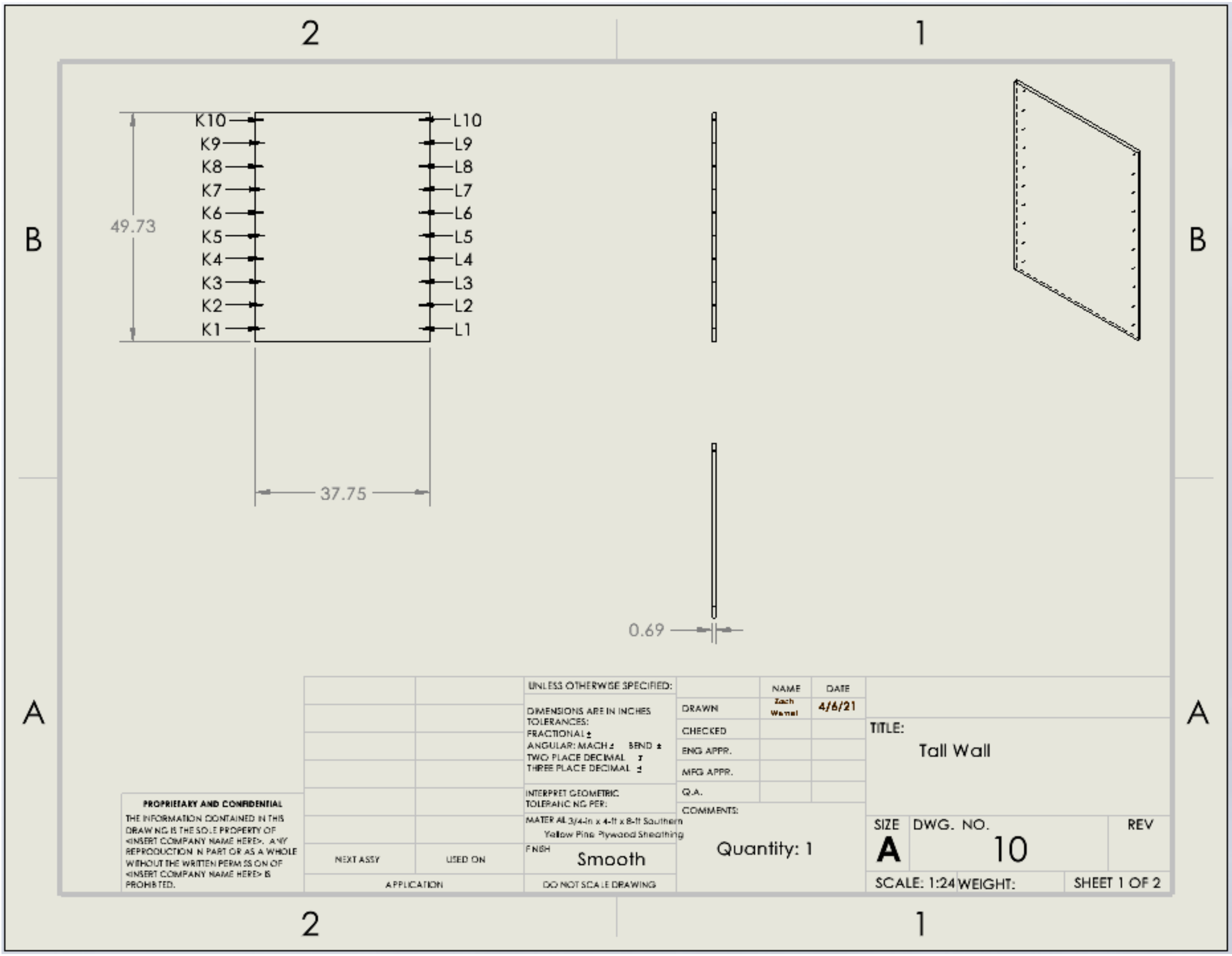
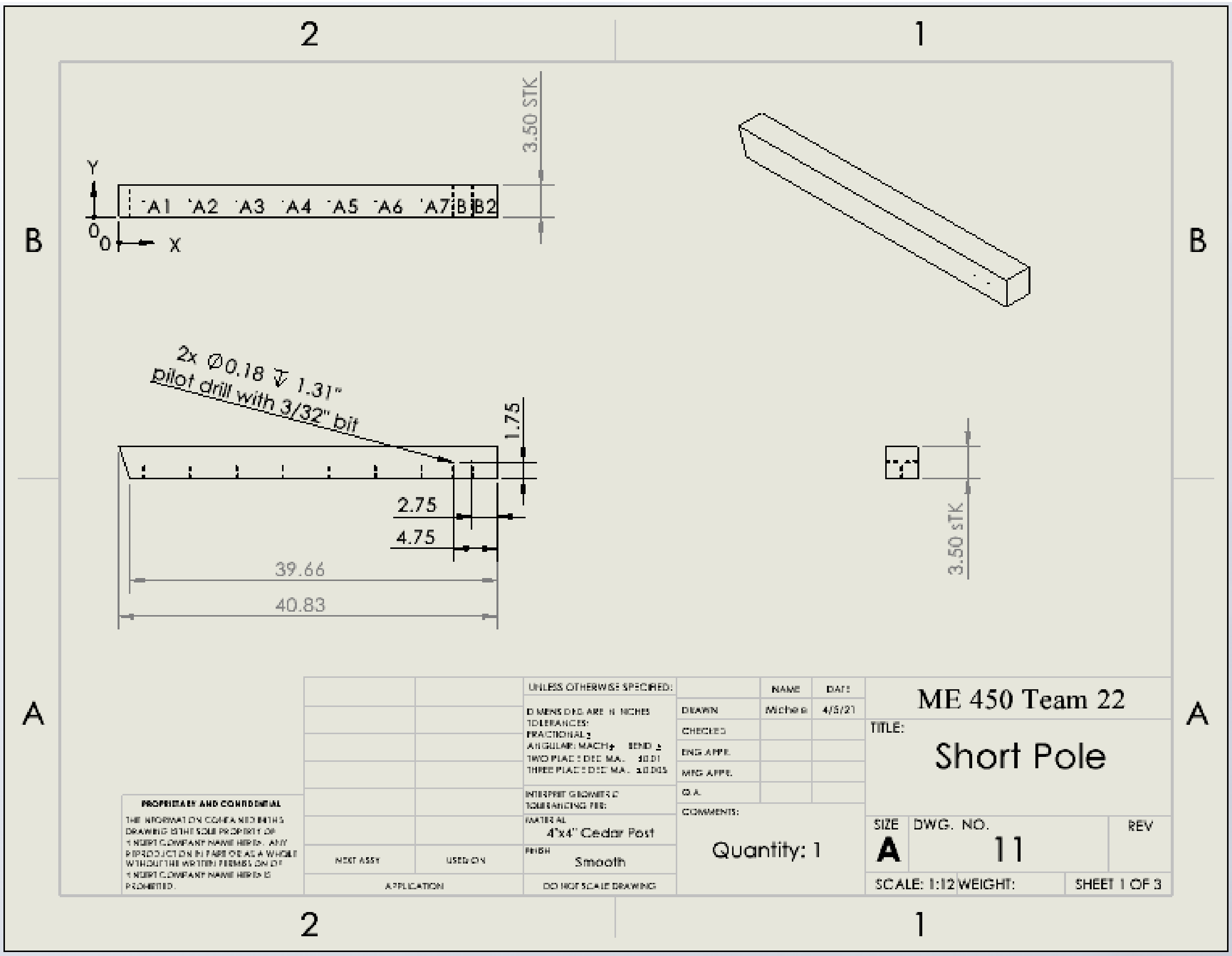
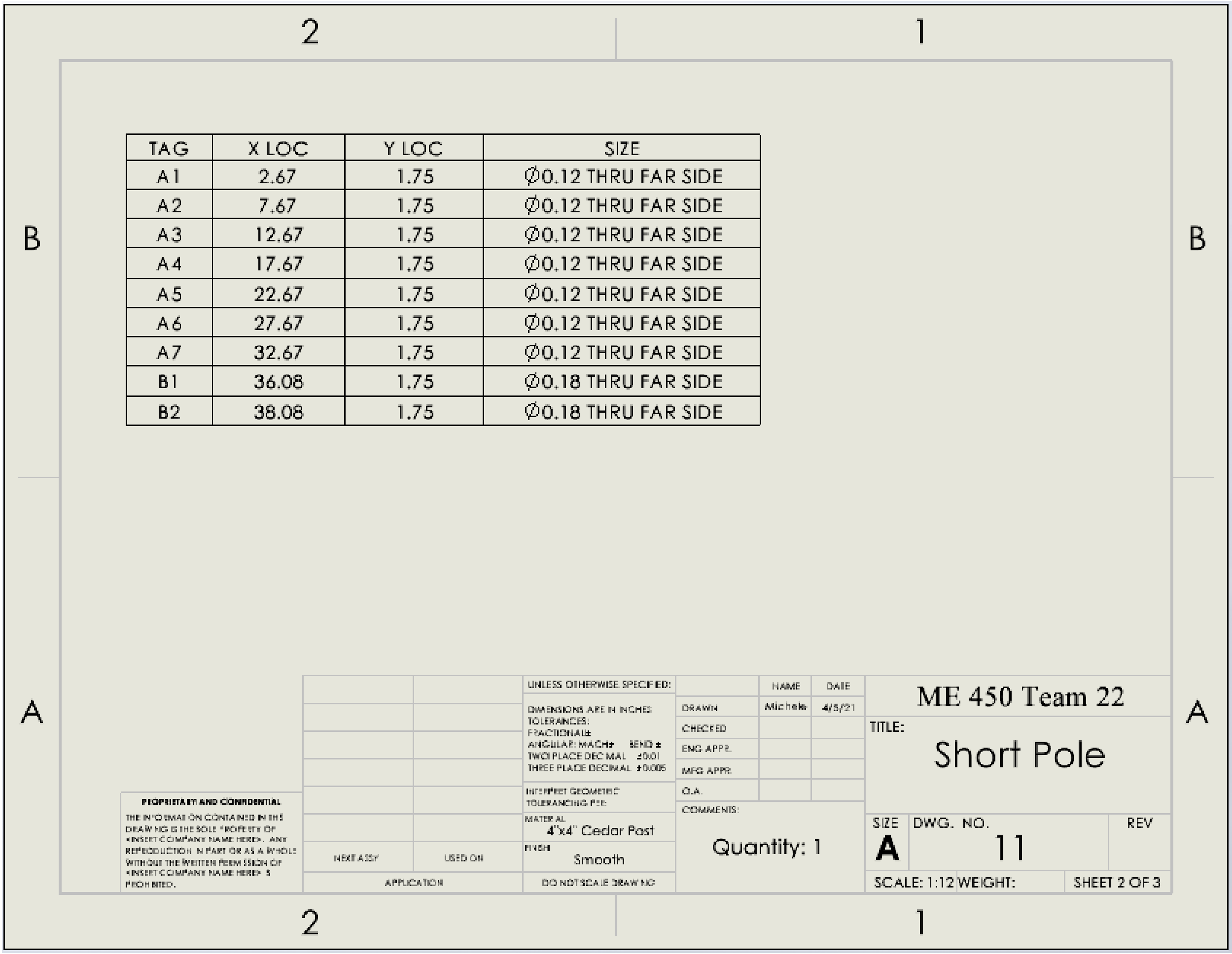


Figure D.10: Engineering Drawing of the Tall Wall.



2
1
B
A
3.50 STK
Y
X
A1
A2
A3
A4
A5
A6
A7
B1
B2
2x ∅0.18 ↧ 1.31"
pilot drill with 3/32" bit
1.75
2.75
4.75
39.66
40.83
3.50 STK
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
4/5/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 1
MATERIAL
4"x4" Cedar Post
FINISH
Smooth
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
ME 450 Team 22
TITLE:
Short Pole
SIZE
A
DWG. NO.
11
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 3



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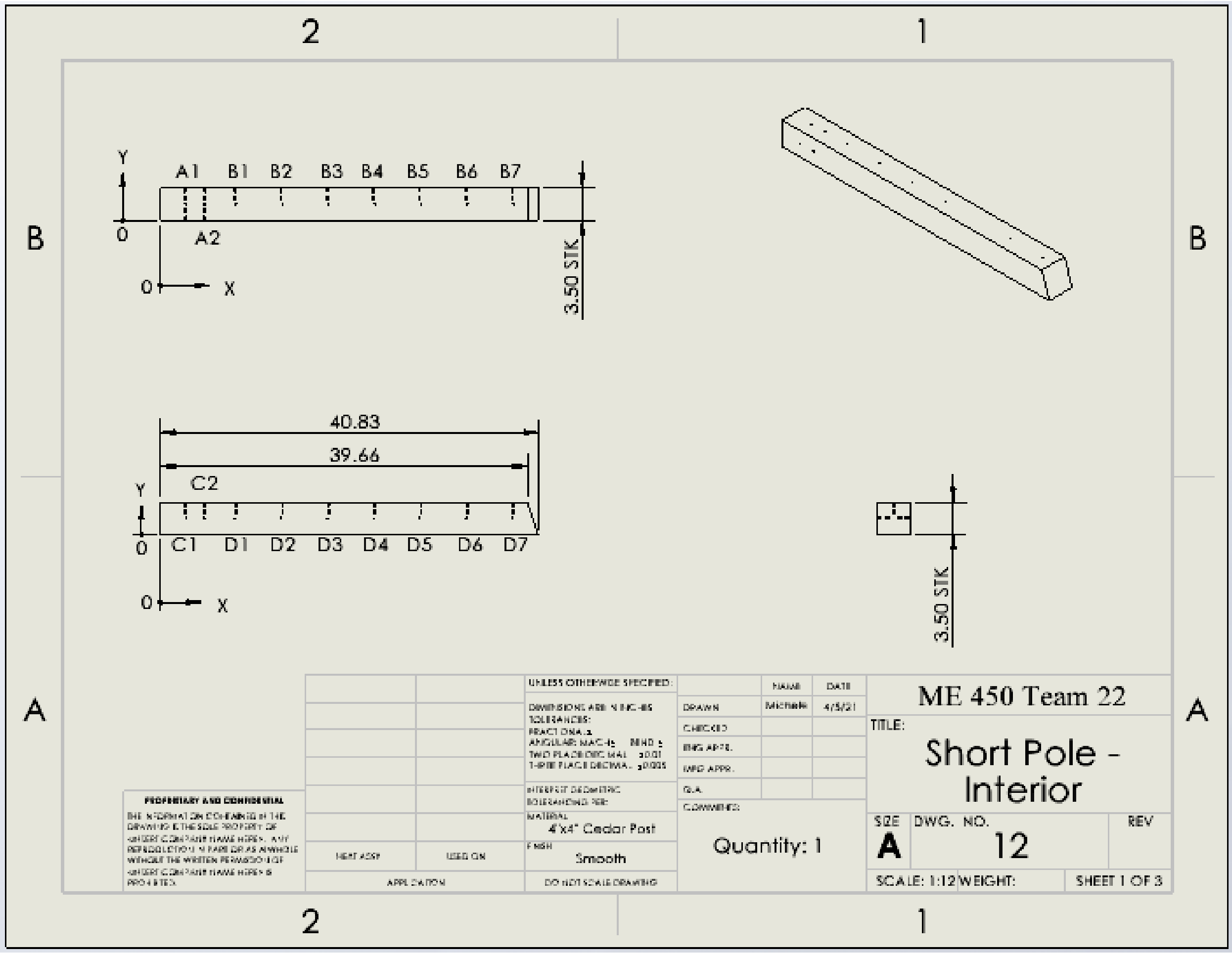
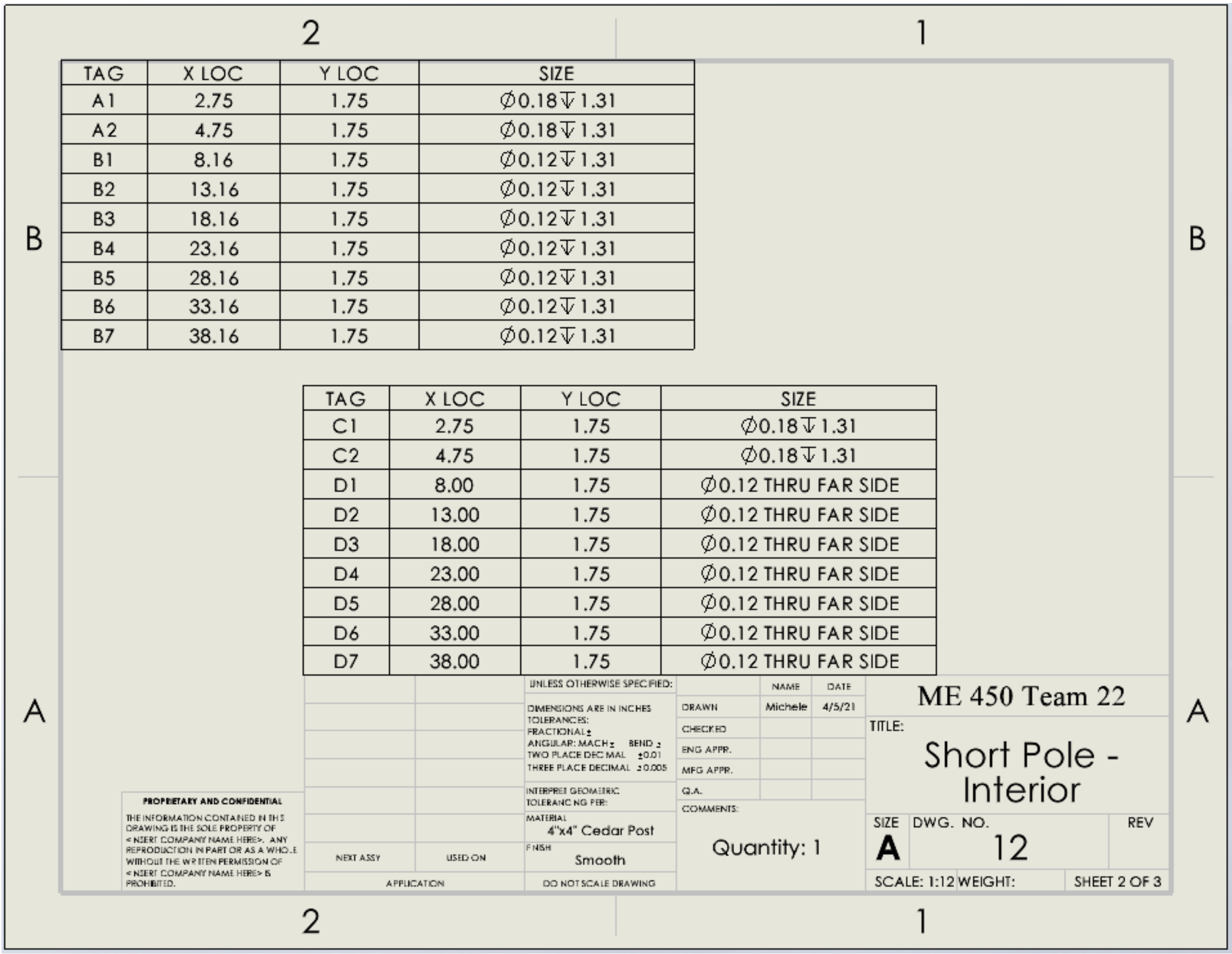
A2	7.67	1.75	∅0.12 THRU FAR SIDE
A3	12.67	1.75	∅0.12 THRU FAR SIDE
A4	17.67	1.75	∅0.12 THRU FAR SIDE
A5	22.67	1.75	∅0.12 THRU FAR SIDE
A6	27.67	1.75	∅0.12 THRU FAR SIDE
A7	32.67	1.75	∅0.12 THRU FAR SIDE
B1	36.08	1.75	∅0.18 THRU FAR SIDE
B2	38.08	1.75	∅0.18 THRU FAR SIDE

Figure D.11: Engineering Drawing of the Short Pole.



2
1
B
A
Y
A1 B1 B2 B3 B4 B5 B6 B7
0
A2
0
X
3.50 STK
40.83
39.66
C2
Y
0
C1 D1 D2 D3 D4 D5 D6 D7
0
X
3.50 STK
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
Michele
4/5/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
ME 450 Team 22
TITLE:
Short Pole - Interior
MATERIAL
4'x4" Cedar Post
FINISH
Smooth
Quantity: 1
SIZE
A
DWG. NO.
12
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 3
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL



TAG	X LOC	Y LOC	SIZE
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A2	4.75	1.75	∅0.18↧1.31
B1	8.16	1.75	∅0.12↧1.31
B2	13.16	1.75	∅0.12↧1.31
B3	18.16	1.75	∅0.12↧1.31
B4	23.16	1.75	∅0.12↧1.31
B5	28.16	1.75	∅0.12↧1.31
B6	33.16	1.75	∅0.12↧1.31
B7	38.16	1.75	∅0.12↧1.31

TAG	X LOC	Y LOC	SIZE
C1	2.75	1.75	∅0.18↧1.31
C2	4.75	1.75	∅0.18↧1.31
D1	8.00	1.75	∅0.12 THRU FAR SIDE
D2	13.00	1.75	∅0.12 THRU FAR SIDE
D3	18.00	1.75	∅0.12 THRU FAR SIDE
D4	23.00	1.75	∅0.12 THRU FAR SIDE
D5	28.00	1.75	∅0.12 THRU FAR SIDE
D6	33.00	1.75	∅0.12 THRU FAR SIDE
D7	38.00	1.75	∅0.12 THRU FAR SIDE

Figure D.12: Engineering Drawing of the Short Pole - Interior.

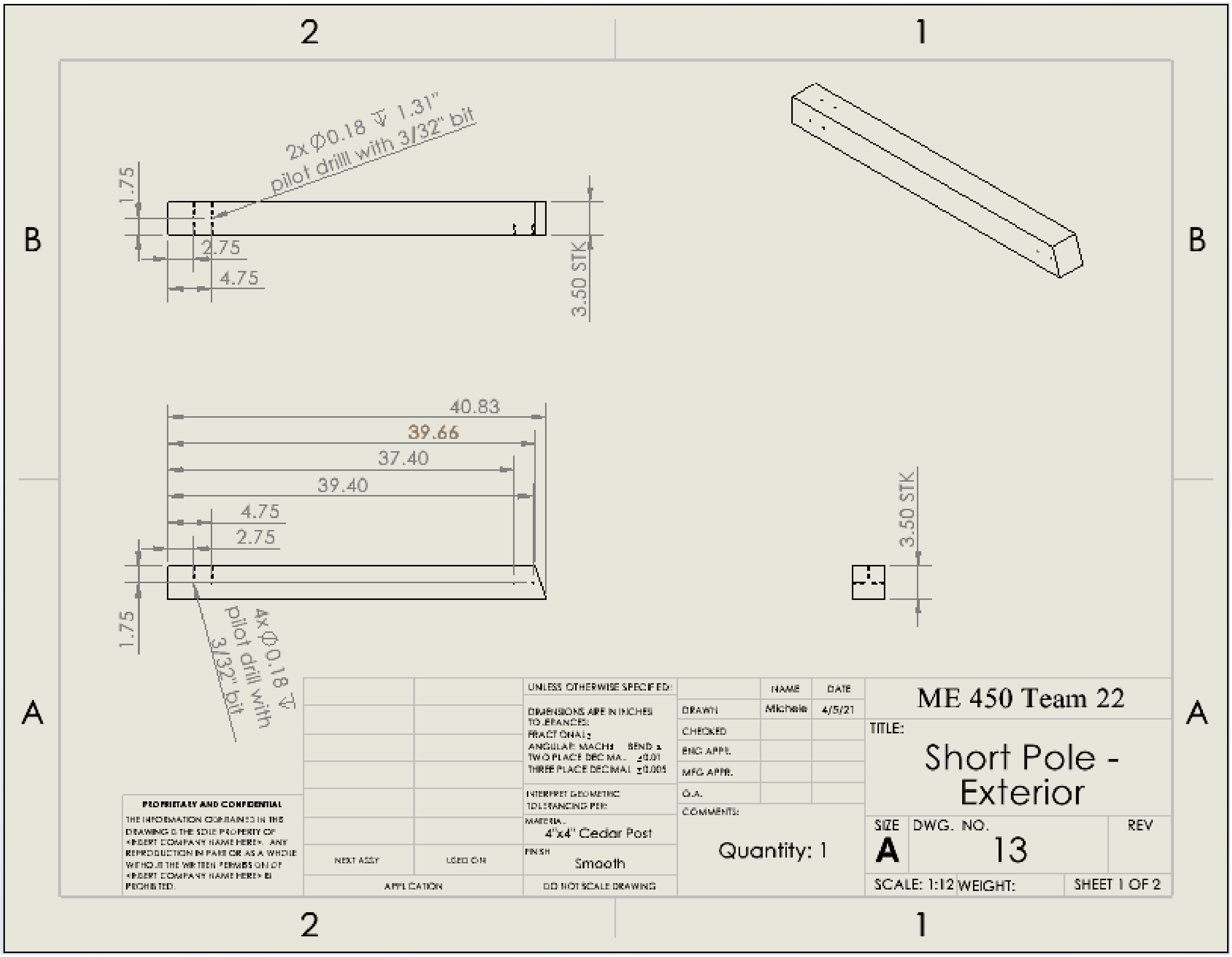

Figure D.13: Engineering Drawing of the Short Pole - Exterior.

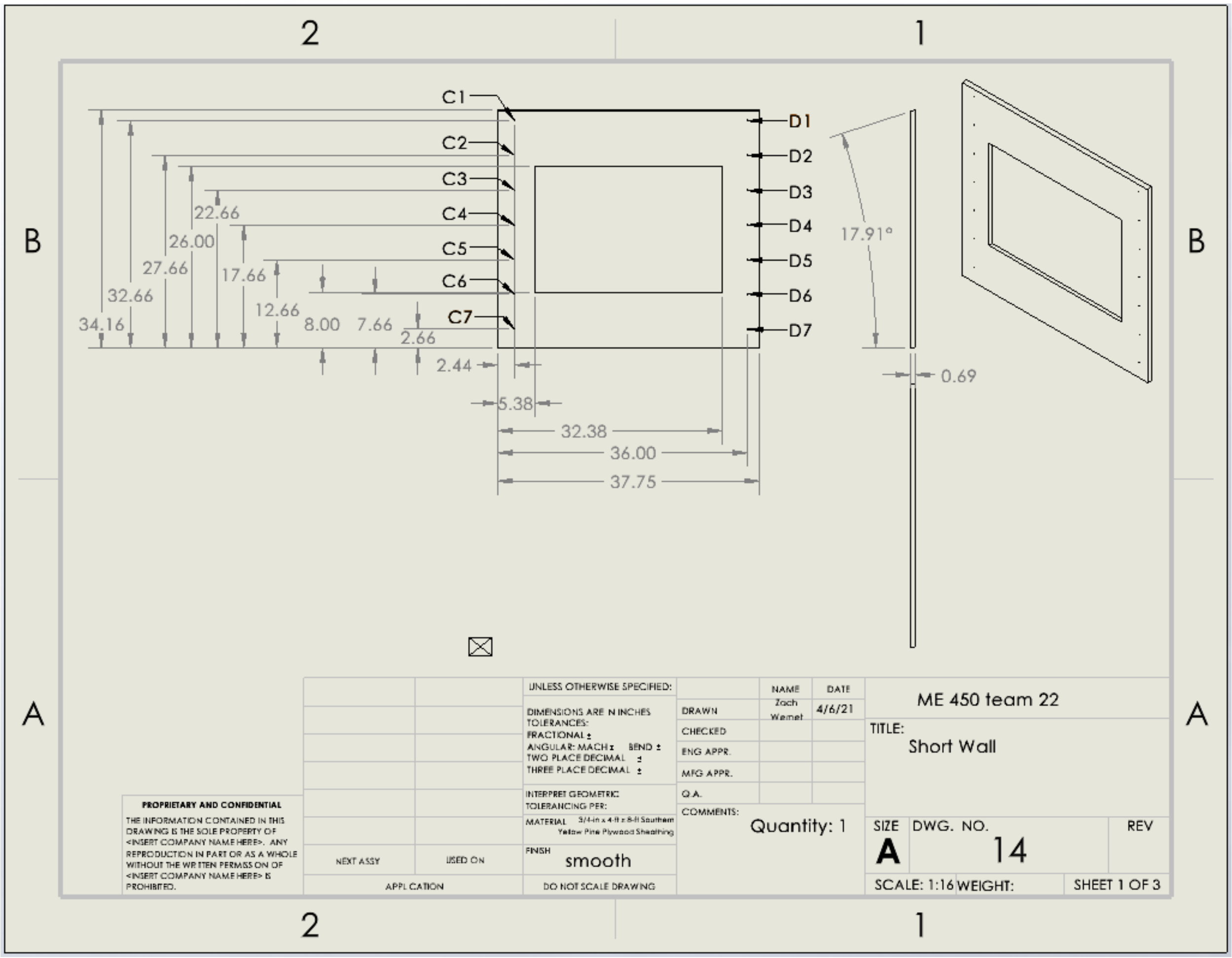

Figure D.14: Engineering Drawing of the Short Wall.

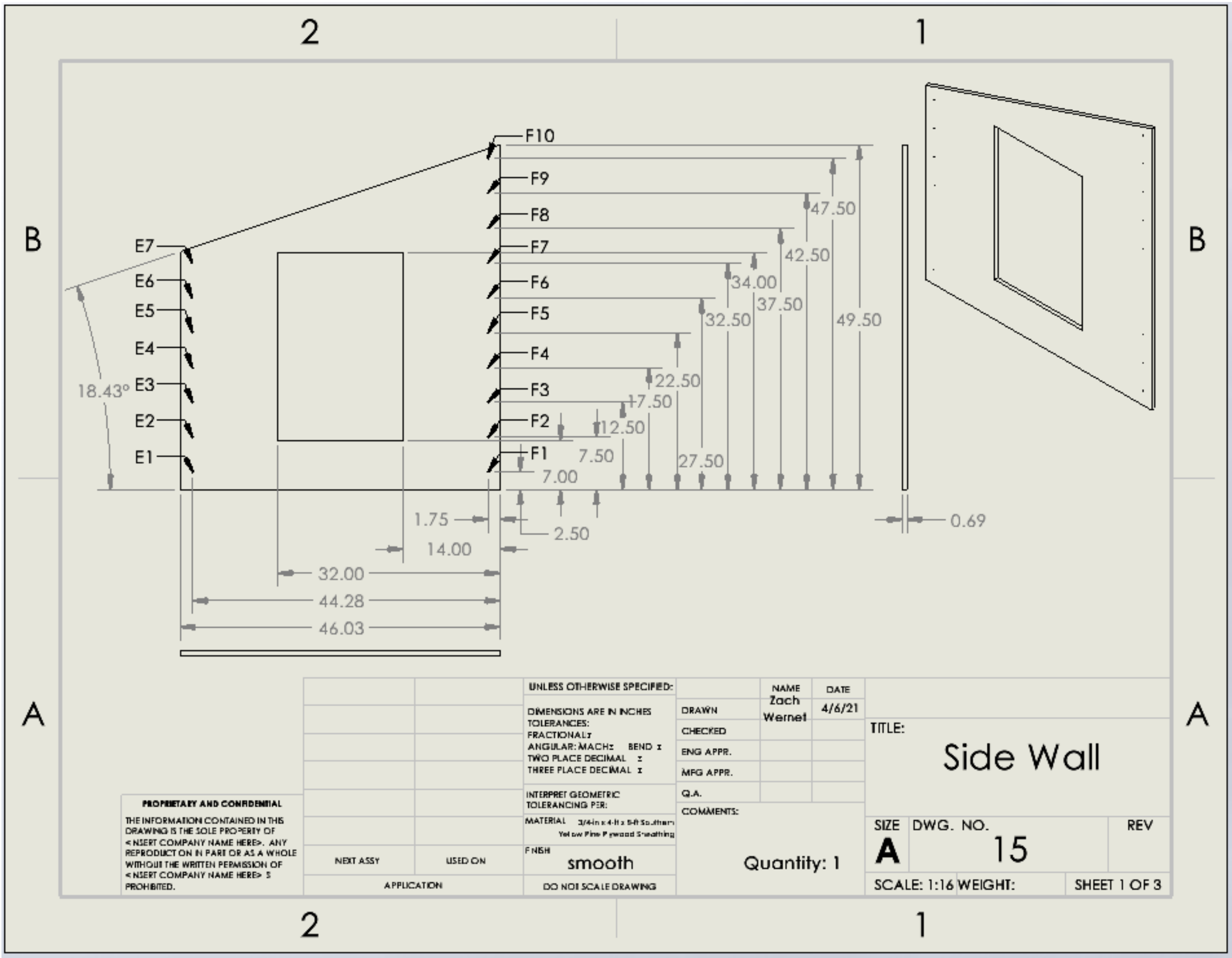

Figure D.15: Engineering Drawing of the Side Wall.

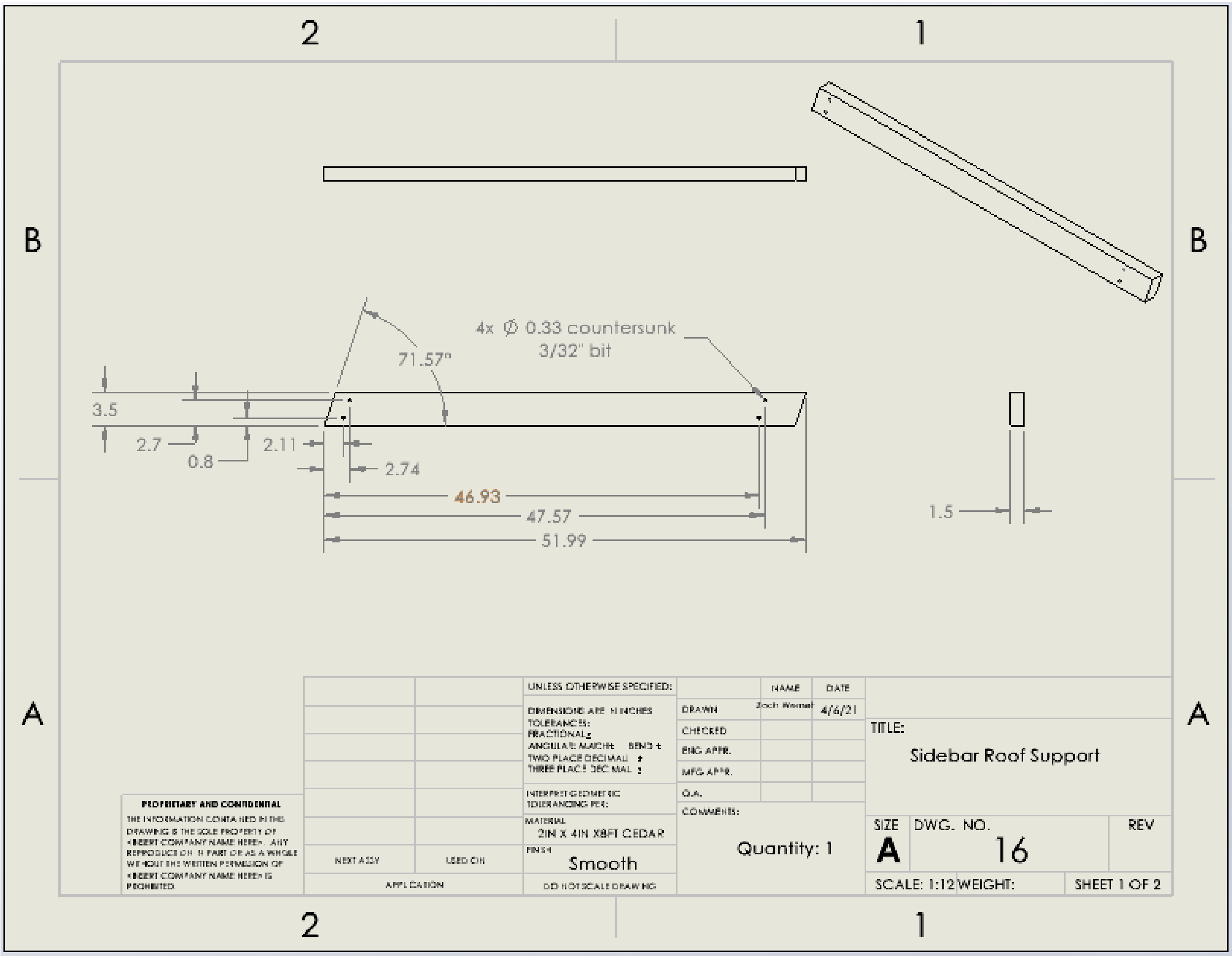

Figure D.16: Engineering Drawing of the Sidebar Roof Support.

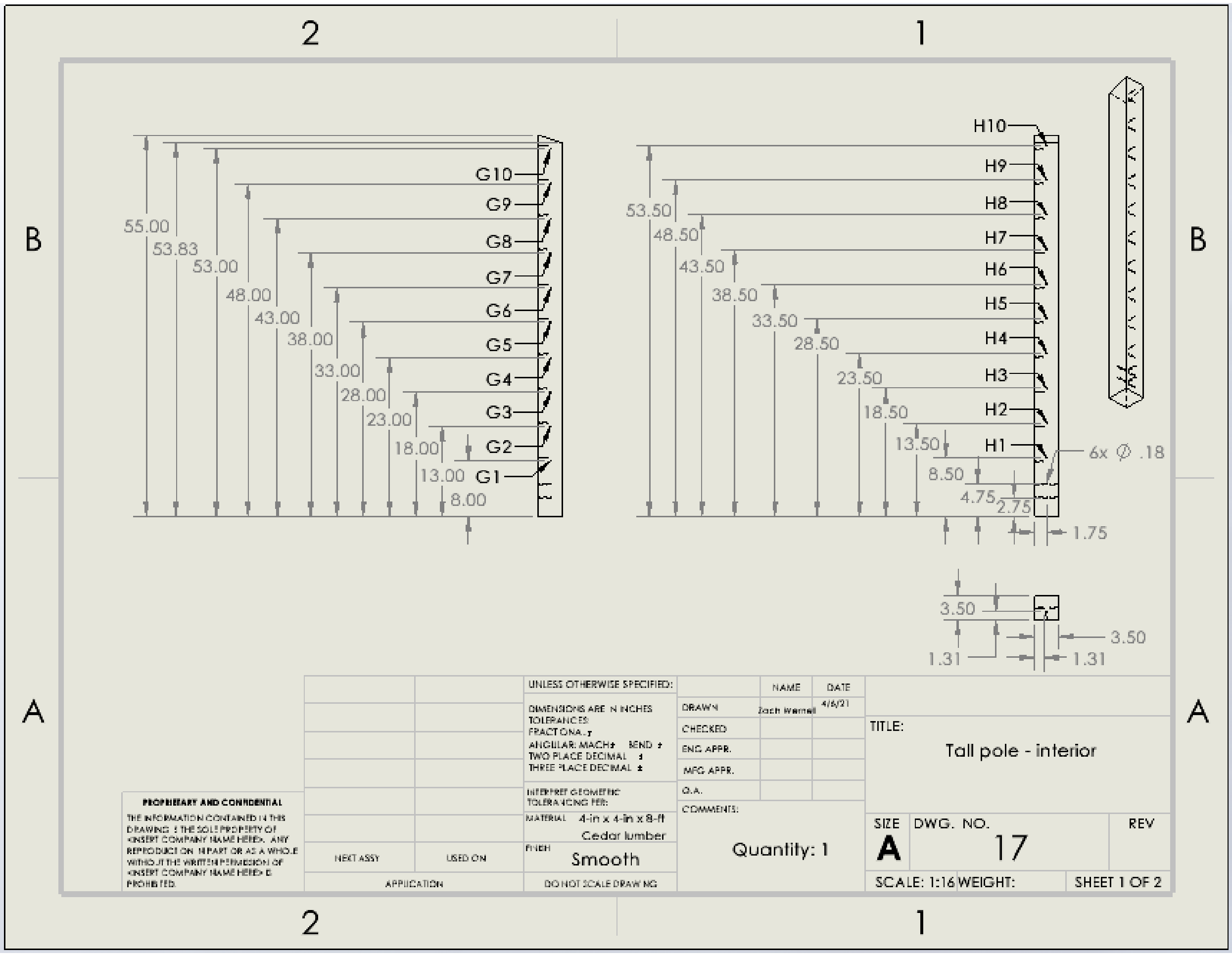

Figure D.17: Engineering Drawing of the Tall Pole - Interior.

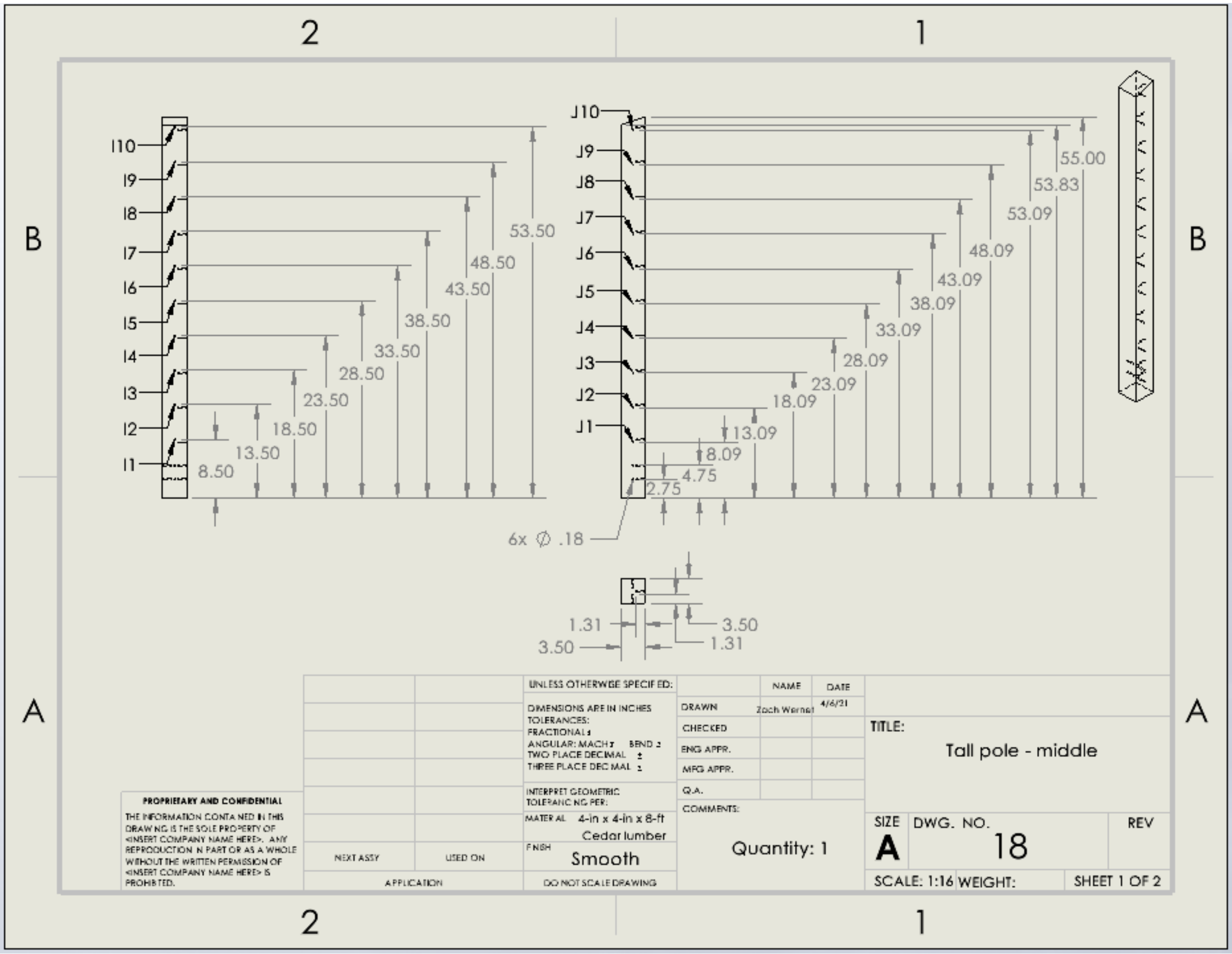

Figure D.18: Engineering Drawing of the Tall Pole - Middle.

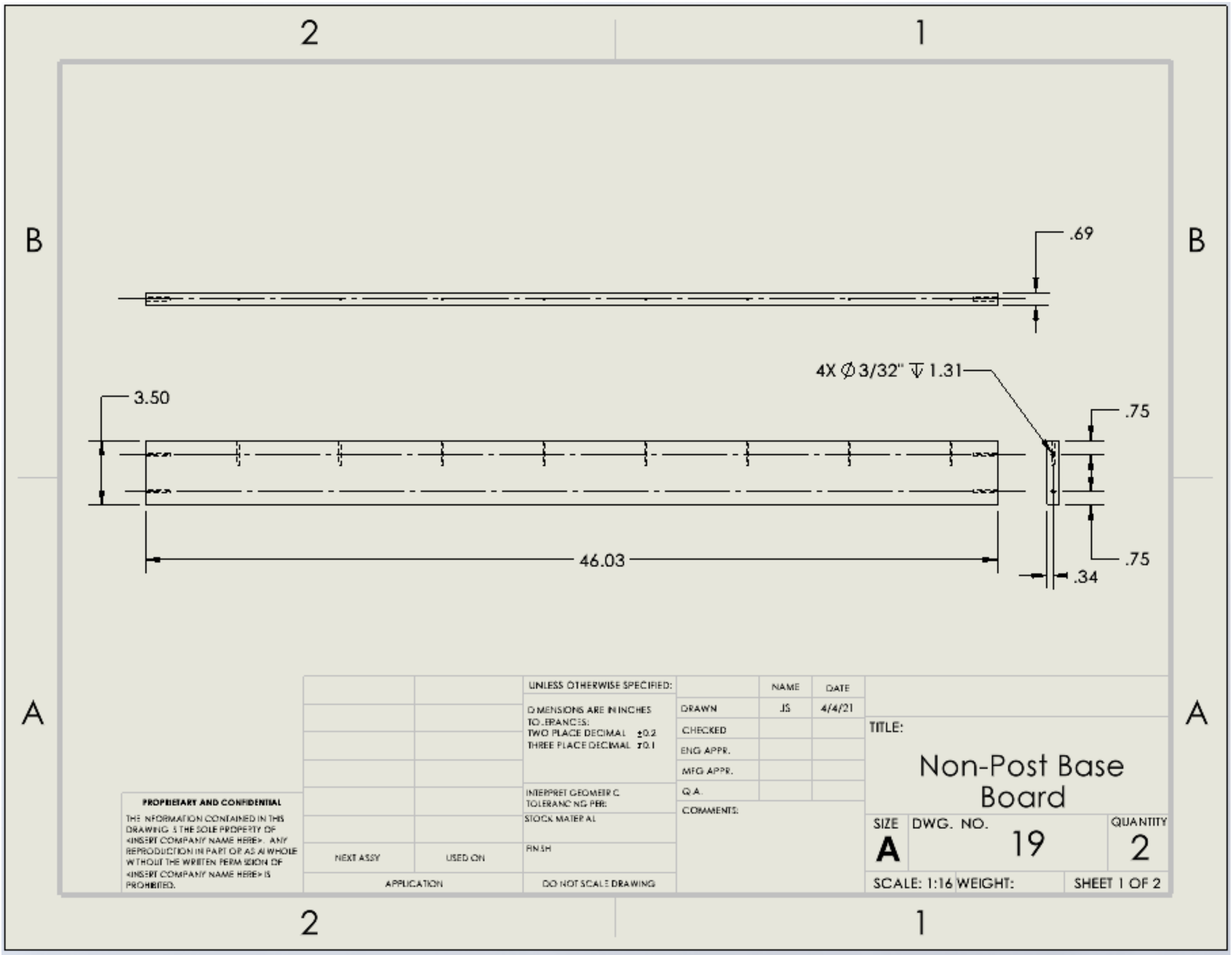

Figure D.19: Engineering Drawing of the Non-Post Base Board.