Spring 5-9-2024

Population at Risk: The Design and Production of the Pollinator Plaza

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POPULATION AT RISK:

THE DESIGN AND PRODUCTION OF THE POLLINATOR PLAZA

by

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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford, MS

May, 2024

Approved By

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ACKNOWLEDGEMENTS

First, I would like to thank the rest of my team members who helped bring the vision of the Pollinator Plaza to life: Willow Crosby, Piper Lind, and Desiree Roby. This bug house design was originally Willow's idea, and therefore, she served as our team leader and point of contact for CME faculty. With their backgrounds in engineering, Piper and Desiree proved advantageous during the design and manufacturing phases of this project. Without my team members' contributions, this project would not have been possible.

Next, I would like to thank my mentor and technical advisor, Dr. Denise Theobald and Ethan Lindsay. Dr. Theobald helped the team stay focused on the project's goal and complete necessary checkpoints on time. Ethan helped the team navigate the different types of equipment on the factory floor and advised the team on how the bug house design could effectively be brought to life.

Finally, I would like to thank the entire CME faculty and staff for their support. In addition to Ethan, Andy Gossett and Mark McAnally provided me with additional technical guidance needed to operate various machines on the floor. Rick Hollander and Mike Gill agreed to serve as my readers in addition to Dr. Theobald, and frequent communication with each reader allowed for constant improvement and innovative ideas on how to successfully craft this thesis from my original capstone report. Rochelle Southern helped me procure the raw materials that were essential to the manufacturing

phase of my project. Eddie Carr used his wealth of industry experience to make suggestions and edits regarding the financial section of this report.

ABSTRACT

SHANE HOUSTON STEPHENS: Population at Risk: The Design and Production of the Pollinator Plaza

(Under the direction of Dr. Denise Theobald)

This report focuses on the development and manufacturing of the Pollinator Plaza, a high-quality bug house created to combat pollinator population loss. According to countless studies, pollinator populations have seen a dramatic decrease in recent years, and this product was developed to address these alarming statistics by providing a suitable habitat for pollinators. A market analysis was used to identify our potential clientele and cost point. This research played an integral part in the design of the Pollinator Plaza, which was developed using AutoCAD software. This design became a reality through the construction of a physical prototype.

The Pollinator Plaza's unique features include three separate habitat regions, specifically targeting carpenter bees, monarch butterflies, and a variety of caterpillars and beneficial beetles. These pollinators are common inhabitants of the North Mississippi region and therefore served as the inspiration for this design. Furthermore, the aesthetic appeal of the product was seen as a top priority, and therefore, the bright color, known to attract pollinators, and stencil design were created to enhance the product's marketability. These unique characteristics were carefully integrated into the design to separate this product from its competitors.

The manufacturing process was repeatedly revised to guarantee a high-quality product while incorporating key metrics such as efficiency and economies of scale. This

process involved procuring raw materials, using various types of equipment to transform the materials, and assembling the components into the final product. Following the initial production run, excessive levels of waste as well as elevated labor and material costs were noticed. As a result, the layout for subsequent production runs was edited, which resulted in increased output levels and reduced input costs.

In addition to current manufacturing conditions, this report utilizes multiple sales forecasts and metrics to give the reader a glimpse of potential growth opportunities for the Pollinator Plaza. These projections were formed based on personal conversations with industry experts and extensive market research. With optimistic financial data to go along with a standardized manufacturing process, the Pollinator Plaza has developed an effective business model while accomplishing its intended goal: protecting the world's pollinators.

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MARKET SUMMARY

1.1 INTRODUCTION

Pollinators have played a critical role in the ecosystem since the beginning of time. Although most people think of bees when they hear the word pollinator, this group actually includes a wide variety of insects and birds such as butterflies, hummingbirds, and flies. Pollinators successfully aid in the transportation of pollen from male plants to female plants, inducing fertilization. Plants use certain physical traits such as bright colors and odors to attract specific insects and birds. These pollinators are then able to transfer pollen to neighboring or distant plants. Many plants depend on pollinators for the continuation of their population.

Alarming studies have been published in recent years that highlight the dramatic decrease in pollinators. According to researchers at Penn State, "[s]everal studies show that in the United States alone, beekeepers have lost about 30 percent of their colonies every year since 2006, with total annual losses reaching as high as 40 percent" ("Protecting Honey Bees and Other Pollinators"). Sadly, the decline has not stopped there as reports continue to show a large number of pollinator species facing extinction. The United States Department of Agriculture states that different insect populations in North America have shown a steady decline over the last thirty years with loss of habitat being a major factor (Ramaswamy). Despite these findings, convincing individuals that pollinator extinction is troubling seems to be a difficult task. However, the key to inspiring change can be found in personalizing this data and showing how daily life on Earth will be affected by the absence of pollinators.

Pollinators play a vital role in producing nutrient-rich foods such as fruits, vegetables, and nuts. According to the USDA, “[t]hree-fourths of the world’s flowering plants and about 35 percent of the world’s food crops depend on animal pollinators to reproduce” (Pettis). This statistic alone amplifies the perception of pollinators. Bees, butterflies, flies, and countless others should not be overlooked as each of these species has a direct impact on feeding the world’s population. Furthermore, scientists have even claimed one of every three bites of food consumed exists due to the work of pollinators (Pettis). The world’s agriculture industry clearly depends on the presence of pollinators.

If these statistics are merely informative, more shocking studies about pollinators are being released. Harvard’s School of Public Health released the first study linking human population losses to pollinator population losses. In the groundbreaking report, researchers claim that “Inadequate pollination has led to a 3-5% loss of fruit, vegetable, and nut production and an estimated 427,000 excess deaths annually from lost healthy food consumption and associated diseases, including heart disease, stroke, diabetes, and certain cancers” (Datz). This is one of the first studies to actually quantify the impact pollinators have on humans’ health. This report is merely one example of the undeniable connection between pollinators and the global food supply.

After performing research, the team decided to manufacture a product that could serve as a habitat for pollinators. The original vision was a wooden bug house that could be placed in any garden or flower bed to provide shelter for a variety of insects. The goal was to design a simple yet sleek product that would enhance the aesthetics of a backyard garden while also lending a helping hand to the friendly pollinators and invisible gardeners.

1.2 IDENTIFICATION OF NEED

A marketing survey was used to adequately gauge interest in the Pollinator Plaza. This survey was made available to all students within the Center for Manufacturing Excellence at the University of Mississippi, allowing for a range of answers from students with a variety of experiences in this area of interest. Within this survey, the respondent was asked a multitude of questions relating to bug houses, declining pollinator numbers, and pricing for the product. Out of the 61 responses from current CME students, only 7 individuals indicated they had experience with bug-keeping as shown in Figure 1, and 27 stated that they had never heard of bug houses altogether, as shown in Figure 2.

Along with this, the survey polled students on their awareness and concern about the dramatic decline in pollinator numbers such as bees and butterflies. According to the U.S. Department of Agriculture, a study conducted over 15 years (2007-2022) shows significant declines in the richness (39%) and abundance (62.5%) of bees, as well as the abundance of butterflies (57.6%) documented in three forest locations in the southeastern United States (Ulyshen and Horn). Approximately 75% of the responses indicated that

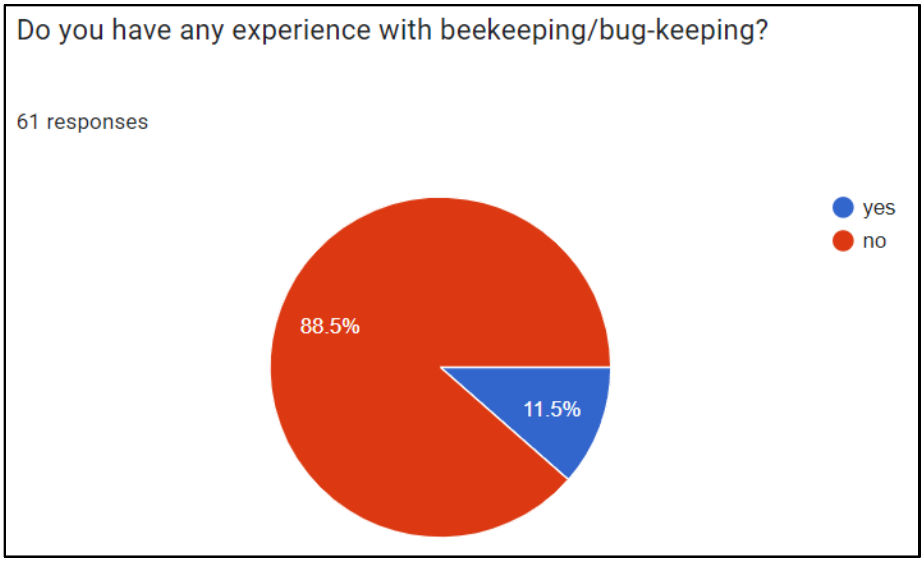

Figure 1: Bug/Beekeeping Experience

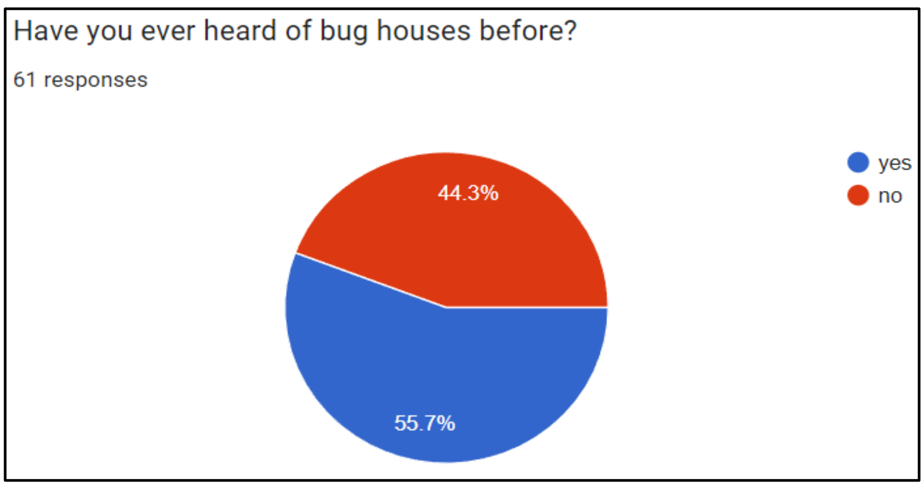

Figure 2: Bug-House Knowledge

they were unaware of this statistic as shown in Figure 3. Next, the students were asked if this statistic was alarming; to this question, approximately 95% of the respondents stated they were concerned, indicating that people become concerned when they are made aware of the decrease in the pollinator population, as shown in Figure 4. If this data is generalized, despite the lack of knowledge about bug-keeping and reduction in pollinator numbers, it reveals that many members of the population are worried about the rapid decline in the most common pollinator species.

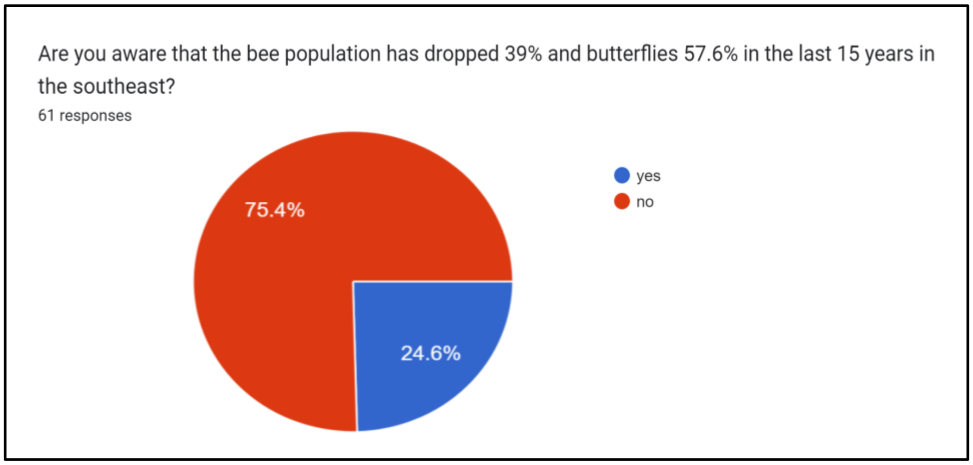

Figure 3: Population Decline Awareness

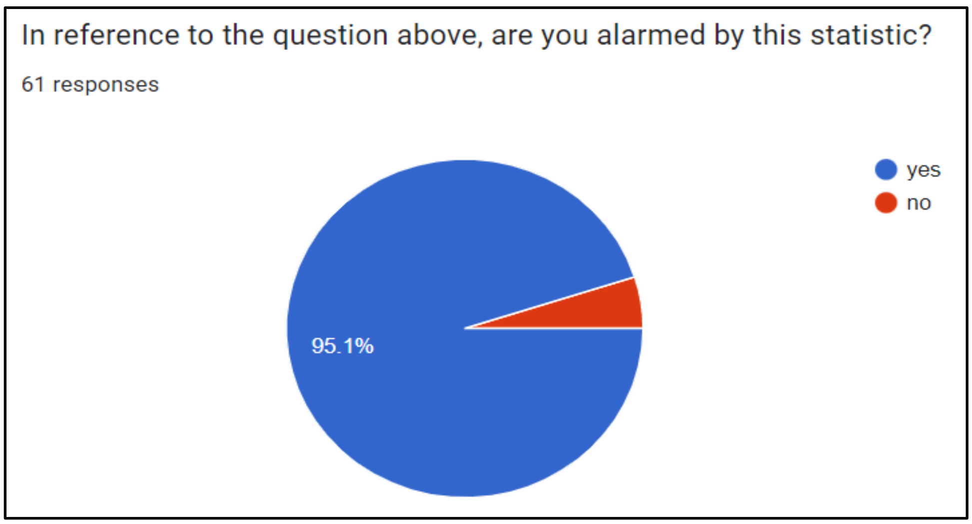

Figure 4: Alarm Regarding Population Decline

Using this information, the team polled the participants on how much they were willing to pay for a product such as the Pollinator Plaza. An analysis of these responses shows a wide array of interest in this product. One-third of participants stated that twenty-five dollars would be a reasonable price for this product. On the other hand, 30%

of respondents emphasized their desire for the Pollinator Plaza by saying they were willing to pay fifty dollars or more for the chance to protect local pollinators. These results are shown in Figure 5.

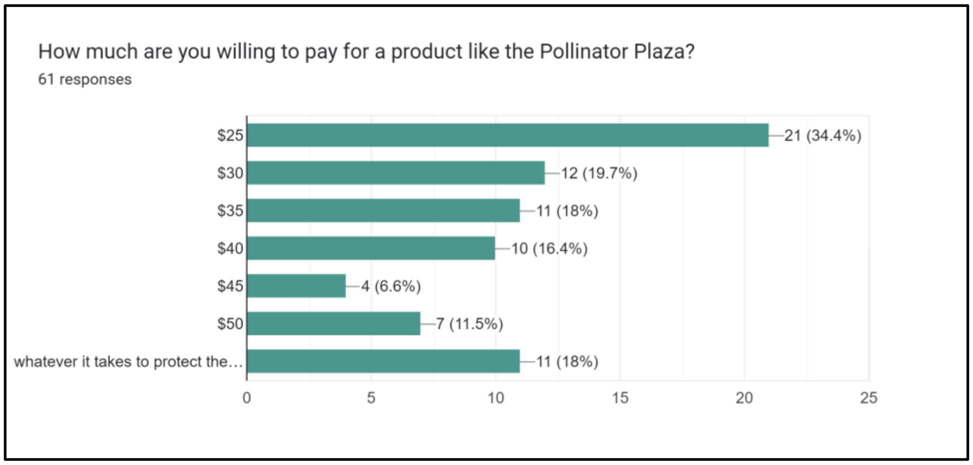

Figure 5: Price Willingness

Following the market research regarding interest in bug houses, optimistic levels of consumer demand for the Pollinator Plaza were noted. Currently, several types of bug-houses and bee-houses are available for purchase. However, very few of these products specifically target pollinators. The Pollinator Plaza design is directly marketed to individuals interested in bee, butterfly, and caterpillar habitats. With several different habitats combined into one product, the Pollinator Plaza can target a variety of species at the same time, differentiating itself from its competitors. Ultimately, the marketing survey suggests that a capital investment in this idea would be successful.

PRODUCT DESIGN

2.1 SPECIFICATIONS

Since this product is specifically designed for flower beds and gardens, local pollinators in Oxford served as inspiration. With the intent of creating a proper habitat for different insect species of the North Mississippi region, several components were necessary to provide shelter for carpenter bees, monarch butterflies, and various beetles and caterpillars. The final product can be seen in Figure 6.

Figure 6: Final Product

The top triangular portion of the bug house is packed with bamboo that is similar in diameter to carpenter bees. Research indicated that these insects prefer to burrow themselves in the bamboo, and therefore, it felt necessary to include several stalks in the project due to the bees' decline. In the rectangular center of the plaza, there is a hollow area that is covered by a wooden piece with three oval slits, serving as ideal butterfly habitat. These thin openings allow for butterflies to enter and leave the area. This provides a safe shelter for an already dwindling population. Finally, the bottom triangular portion contains a hollow center covered by a detachable door. A metallic mesh overlay allows for smaller species to enter the hollow portion. By making the door removable, the consumer can fill the hollow portion with native foliage or similar material conducive to native species. For example, the portion may be filled with newspaper clippings, pine straw, or other similar materials that have been shown to provide good housing for smaller species. The flat back side of the house allows for a stake to be attached. This lets the customer have freedom in deciding how to display the bug-house, depending on their particular landscape. Although several slight alterations in design have been made throughout the process, the team felt that it was important to remain loyal to the original intent of the design – creating a habitable home for declining species based on their natural preferences.

2.2 PROTOTYPE DESIGN

For the prototype, much research and modification was done to ensure the best fit for the product and the pollinators. Scrap wood from the Center for Manufacturing Excellence (CME) factory floor was used to create the first prototype, which served as a gauge of what thickness and type of wood would be best. Brackets were ordered to see if they would hold the inside panels, but it was ultimately decided they would not be needed for the final product. The original bamboo order worked well; however, the finances suggested going with a more economical option for the final product. Along with the bamboo and brackets, hardware cloth, yellow spray paint, white spray paint, wood screws, and magnets were purchased. Many of the materials ordered worked well, to the point where some leftovers could be used for later productions. This excess material was used to make adjustments quickly, which resulted in increased budget flexibility.

2.3 FINAL DESIGN

The final design of the product remained extremely similar to the prototype. As previously mentioned, it was necessary to keep the three main components of the bug-house to maintain the integrity of the project's goals. After much analysis, it was decided to reduce the overall width of the design from 7.5" to 7" to maximize materials and create easier cuts. The original bamboo was switched for bamboo sticks with a wider diameter, giving the product a more natural look. Moreover, a stencil was created to personalize the Pollinator Plaza with the addition of a flower on one side of the unit. Despite these changes, the appearance was left relatively the same but the subtle improvements created a more elegant finish. One of the biggest changes was the decision to mill a small hole for the placement of the magnets, allowing for a flush magnetic door. This not only upgraded the product's appearance but also provided more protection for the magnets from natural elements. The change also altered the location of the screws as an effort was made to prevent the heads from sticking out of the sides. Because of the flimsy material of the original flower stencil, the paint did not appear crisp on the edges of the flower and leaves. To create a clearer image on the side of the bug houses, a Cricut machine was used to laminate the cardstock cut for the final design in order to improve the stencil's durability and longevity. Since the laminated version can be reused for a long period of time, a Cricut machine is not essential to everyday production and has been neglected from total cost. Ultimately, this stencil is a value-added activity as it enhances the aesthetic appeal of the product.

2.4 CAD DRAWINGS

All CAD drawings have been made according to project specifications as defined from time spent on the factory floor. In Figure 7, the overall structure can be seen containing the top, middle, and bottom portions surrounded by side and back pieces. The side and back pieces are specified in Figure 8, along with the front piece with slits for the monarch butterflies. Figure 9 shows measurements for the top and bottom triangular pieces, with one overlapping the other, eliminating the need for a 45-degree angle joint. The shelves behind the front butterfly piece can also be found in Figure 9. They add extra support to the structure as well as distinguish the three habitats. Finally, Figure 10 illustrates the wooden component of the magnetic door piece attached to the bottom triangle. Figures 7-10 were all made using SolidWorks software, with all measurements in the Imperial System. Each component pictured is made of cedarwood. With each joint in the prototype, there is a combination of wood glue and nails or screws to hold the pieces together. The magnetic piece contains a piece of hardware cloth in the middle to enclose the hollow bottom triangle as a habitat for its respective species. The team created different poka-yokes for several portions of the assembly process to more accurately cut, attach, and assemble parts, as needed when in production. The CAD drawings allowed for continuous improvement in the design and visualization of the product as well as assistance in creating specific fixtures.

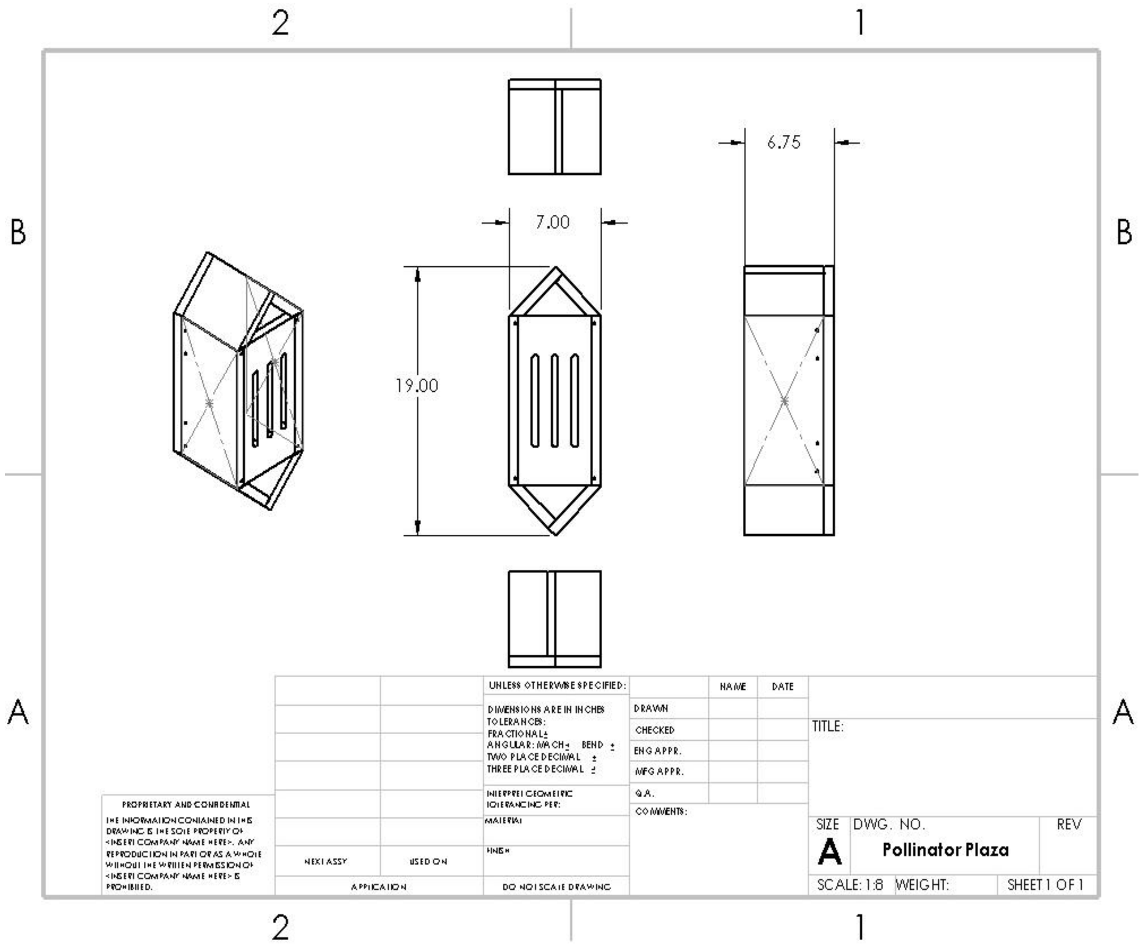

Figure 7: Overall Structure of Pollinator Plaza

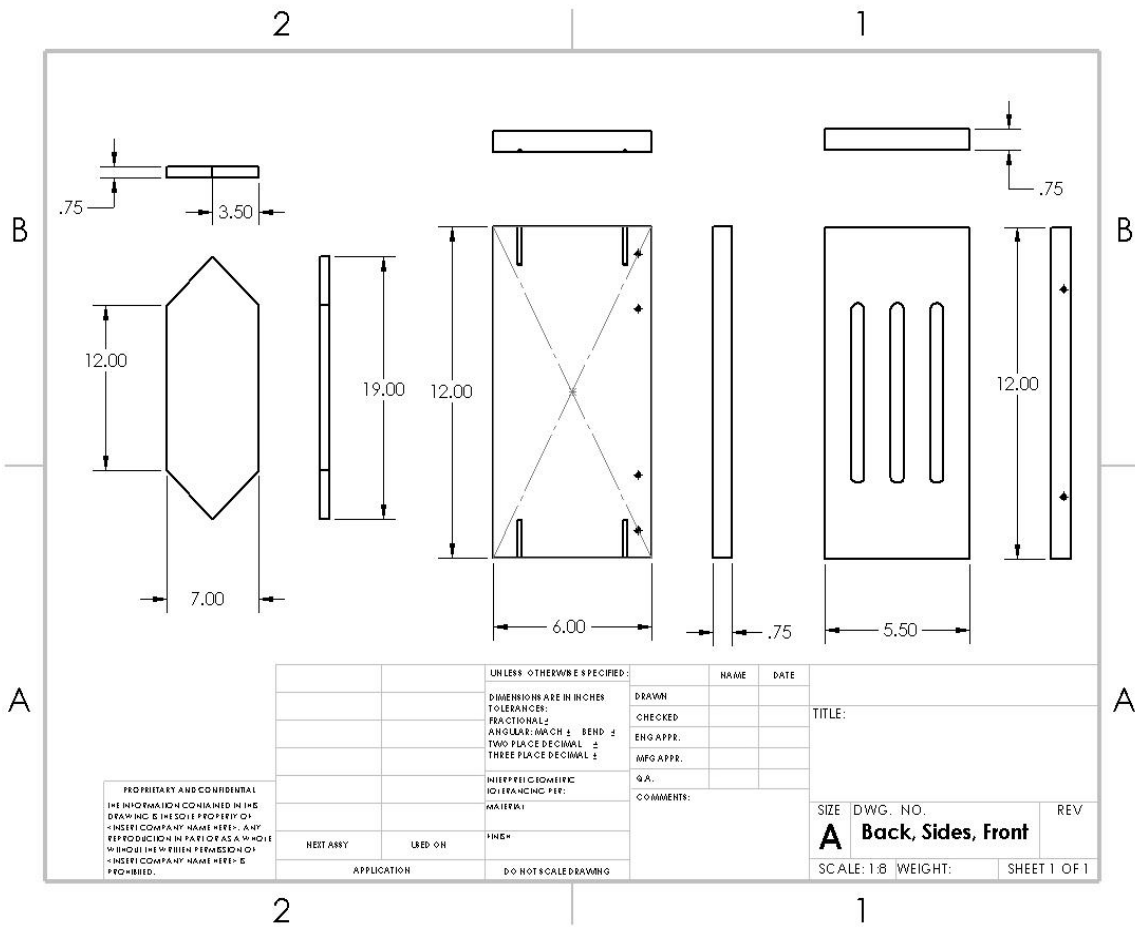

Figure 8: Back, Sides, and Front Pieces

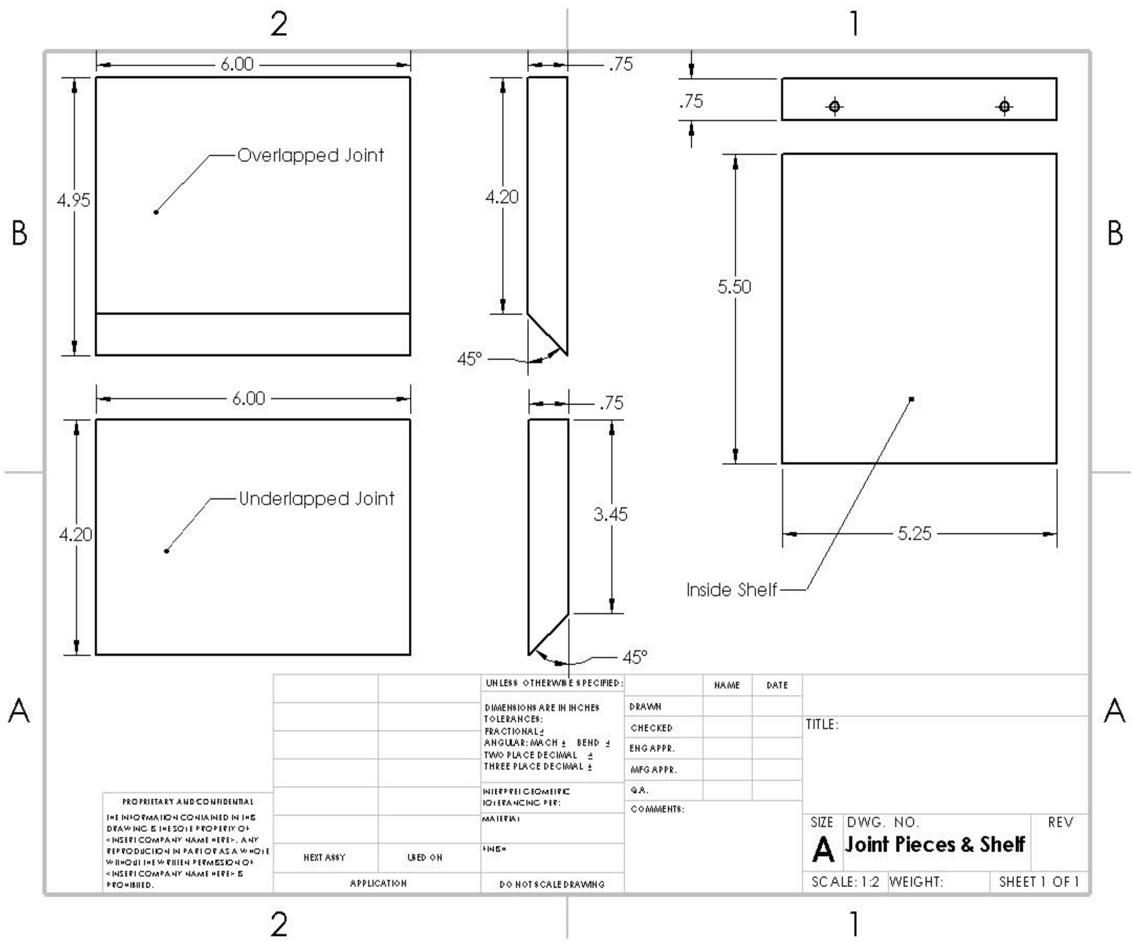

Figure 9: Shelves and Over/Underlapped Pieces for Triangular Ends

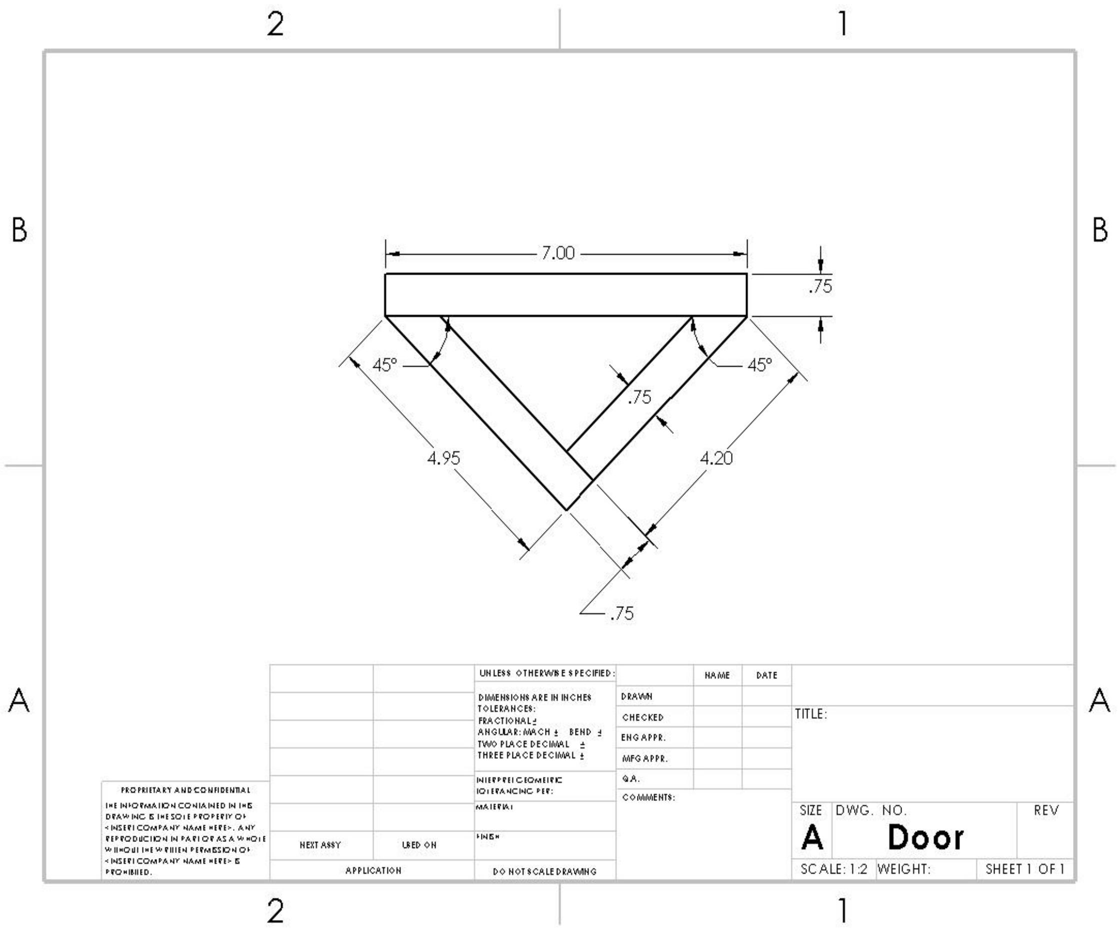

Figure 10: Magnetic Door

MANUFACTURING

3.1 PROTOTYPE PROCESS

In the creation of the prototype, minor adjustments were made to create a product that best fit the original needs. Scrap wood from the factory floor as well as screws from storage were used to create the wooden body of the house, shelves, front butterfly piece, and frame of the bottom door. Scrap hardware cloth was used for covering the door frame, and magnets were purchased for attaching the door to the house. The door allows the customer to place any material inside this hollow area to best attract species in their area. Bamboo was purchased and inserted into the habitat as shown in Figure 6. The bamboo acted as a place for bees to burrow into, and the magnets helped to attach a removable door. The spray paint was purchased to act as an added layer of protection from environmental elements. A stencil used for the outside design was hand-made using a Cricut machine and poster board which was then laminated. Several tools were used on the factory floor to cut, drill, and attach pieces together. All scrap wood was cut using the table saw, drilled using a hand drill, and secured using wood glue and screws.

When creating the prototype, it became apparent that specific wood, paint, screws, and wire would need to be ordered to create a quality product. Given that the Pollinator Plaza will be placed in outdoor conditions, cedarwood was chosen for its sustainable properties and rust-free magnets were ordered for attaching the door. All spray paint would also need to be weatherproof to add an extra layer of sealant to the cedar. The team also opted for thinner screws to create cleaner lines on the body of the house. With these changes, the Pollinator Plaza will be more durable long term.

3.2 PRODUCTION PROCESS

Based on the expected annual sales projection of 7,200 units, the team decided two operators can complete cutting all cedarwood and bamboo to length. Operator 1 cuts the 6-inch bamboo strips, places them in the fixture, and moves the fixture to the assembly area. At the same time, Operator 2 cuts the cedar planks to the correct dimensions. Because the bamboo takes only one minute to cut, Operator 1 will take the cut cedar planks and run them through the sander. After being sanded, some pieces will be taken to the miter saw where Operator 3 will cut a 45-degree angle. The remaining cedarwood will be delivered to Operator 4 at the final assembly table. Once all the sanded cedarwood is taken to the appropriate stations, Operator 1 places the last cut piece of cedarwood into the CNC machine to create the door and front panel. Operator 1 now places the hardware cloth in the CNC laser, waits 31 seconds for the process to complete, removes the hardware cloth, and delivers it to assembly. After this step, Operator 1 balances their time between cutting bamboo and sanding, until the CNC process is complete. Once this process is complete, Operator 1 will remove the finished door and front panel from the CNC and deliver them to Operator 4 at the assembly area.

At the same time as the above processes, Operator 4 begins assembling the delivered parts. Operator 3 assists Operator 4 in the final assembly area by stapling the hardware cloth to the door and placing the magnets. Operator 4 places and fastens all the parts together, as well as glues the magnets and bamboo into the body of the product. Once the Pollinator Plaza is finished, Operator 3 takes the assembled product to the spray paint booth and paints the Pollinator Plaza with a primer coat followed by a yellow coat. The stencil is then added to the side of the product.

3.3 PROCESS FLOW

To build the Pollinator Plaza, the team used a relatively small space to eliminate movement as much as possible. It is important to note, however, that several machines on the factory floor were not able to be moved, such as the spray paint booth, table saw, sander machine, and CNC machine. The process begins with cutting all the cedarwood down to size at the cutting station and then passing it to the sanding station. From this station, parts flow to the final assembly table, the miter saw for additional cuts, and to CNC routing for the front panel only. While these parts were being passed to the assembly table, the bamboo was being cut and the front door was being created. The goal is to have each part moving to the assembly table in the order that it needs to be pieced together. Outer pieces are made first, followed by the inside shelves, and finished with the front butterfly piece and magnetic door. A station for spray painting (see Figure 11) follows the assembly table.

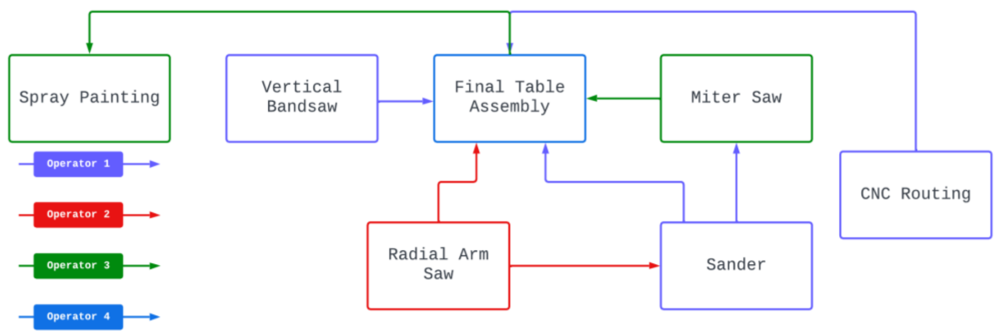

Figure 11: Initial Process Flow Diagram

3.4 LINE BALANCING

During the initial production run, a large issue noticed was that the line was heavily unbalanced. The assembly station served as the limiting process, creating a bottleneck. To alleviate this in the future, the team reallocated tasks as seen in Table 1. During the first production run, Operator 4 took 25 minutes to complete the task. Adding another operator to this station cut the time down to 12 minutes. As a result, it became possible to make five units an hour rather than two, signaling a maximum production of 10,000 units annually.

Although assembly as a whole remains a longer step in the manufacturing process, making this major change would create a more balanced line. It is also important to note that the person assembling the outside and back of the Pollinator Plaza does not move around the factory floor; this eliminates any wasted time traveling to another station. Moving one person from cutting bamboo and sanding to assisting with assembly would reduce assembly stress, increase work productivity, and balance the line. All amendments to the process flow for each operator are noted in Figure 12 with color coding to match Table 1.

Table 1: Estimated Run Times

Process	Time (minutes)		
Bamboo cuts	1:05		
Cut wood	6:50		
Sander	4:00		Operator 1
Operator 1 Total Time	11:55		Operator 2
Cut 45 degree angles	4:31		Operator 3
Cut metal door	0:31		Operator 4
CNC machine	4:06		
Operator 2 Total Time	9:08		
Assemble inside (shelves & face)	4:00		
Painting (no dry time)	5:30		
Operator 3 Total Time	9:30		
Assemble outside and back	8:30		
Operator 4 Total TIme	8:30		
Limiting Process	**11:55**		

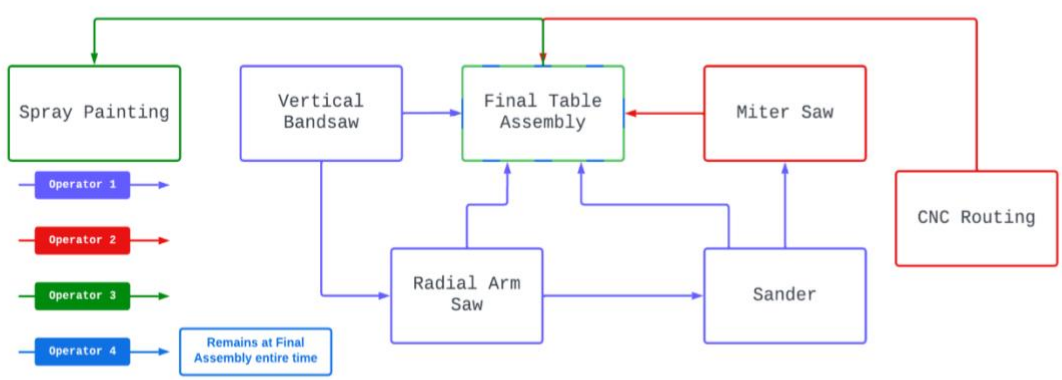

Figure 12: Final Process Flow Diagram

3.5 EQUIPMENT

The prototype was completed using minimal machinery. The table saw was used for all straight cuts and a miter saw for all angled cuts. A mill was used to drill the holes in the front piece of the bug house for magnet placement. For the assembly of the bug house, wood glue was used to hold the pieces while screwing them together. For safety and aesthetic purposes, each piece was sanded before assembly. Once constructed, corners and screw holes were sanded again. For the finished project to look as seamless as possible, all gaps were filled with wood putty.

Following the completion of the prototype, however, the need for more tools was quickly realized. To produce multiple units in one production run, several automatic machines were used to decrease variance and increase the speed of creating individual parts. The Haas SR-100 Gantry Sheet Router was used to CNC the front piece containing the three magnet holes, as well as the triangular door with pre-drilled holes for the mating magnets. The IPG Photonics laser cutting machine was utilized to cut the mesh wire into small triangles to be connected to the rear of the door. To cut most of the cedarwood pieces for the outer frame on the table saw, 90-degree angled jigs were created to produce consistent cuts with the desired length for each measurement. The jigs could easily be clamped to the table saw for each corresponding measurement to reduce time at that station. The Original Saw Company radial arm saw was used for cutting each piece to size. The Laguna sander was used to smooth the wood that was being cut at the table saw while the miter saw was utilized to cut the 45-degree angles. Finally, the Vectrax vertical bandsaw was used to cut the bamboo sticks to the proper length.

In product assembly, a Milwaukee Tools drill was utilized to pre-drill holes into the unit. In addition, a nail gun was used to connect and stabilize different pieces throughout assembly while being supplemented by the use of wood glue. The staple gun was used to ensure that the wire on the magnetized door remained attached. Sandpaper was used to smooth any areas cut post-sander or post-CNC.

The first production run offered more insight into whether additional machinery should be used. It was determined that the pieces required for the door were too small to safely cut by hand and were difficult to maneuver. Because of this issue, CNC routers could be utilized to reduce any potential for injury, while allowing for a smoother finish. Producing the detachable door via CNC router instead of hand cutting, as well as using the laser cutter for the mesh, increased safety and decreased variance among products.

3.6 FIXTURES

To quickly cut and assemble the bug-house, fixtures became an integral part of the production process. One of the most important fixtures was built to hold the assembly steady as the individual pieces were being added. The fixture was assembled using scrap wood from the CME factory floor, so it added no extra costs to the final product. In addition to this main fixture, several simple fixtures were utilized to make quick and accurate cuts. An L-shaped block of wood was clamped onto the table saw for each unique cut. Most of these fixtures were implemented on the table saw to cut the panels of cedarwood to the correct dimensions; however, one of these measurement fixtures was created for the vertical bandsaw specifically to cut the bamboo to the proper length.

These fixtures eliminate the need to measure each piece individually, which reduces time and potential human error for the overall production.

Due to bamboo's varying diameter, each bug house required a different amount of bamboo. An additional fixture was created to accurately measure the amount of bamboo needed for placement into the habitat. This triangular fixture's dimensions match those of the triangular opening on the unit. A final fixture was created via a 3D printer for consistent placement of the magnets.

FINANCIALS

4.1 EXPENSE TRACKING

For the prototype, one unit of each item seen in Table 2 was purchased. These items, with the exception of the brackets kit, were used in the construction of the prototype. The prototype was constructed with scrap wood from the factory floor, but cedarwood boards were purchased for the final production. After building the prototype, excess materials such as the spray paint, hardware cloth, and wood screws kit were saved to make multiple units. In total, $60.90 was spent to complete the prototype of the Pollinator Plaza.

Table 2: Prototype Orders

Material	Total Cost
Hardware cloth	$13.98
Bamboo	$15.98
Yellow spray paint	$5.98
White spray paint	$5.98
Wood screws kit	$7.95
Brackets kit	$8.99
Magnets	$2.04
Total	**$60.90**

For the actual production, more materials needed to be purchased to create a maximum of ten bug houses. It was decided to order cedarwood for the final product, as it has a natural ability to resist the elements and thus saved us from having to put a finisher on the final product. All of the material orders for the Fall 2023 semester can be seen in Table 3. In total, for the Fall semester, $385.62 of materials were purchased. In a true manufacturing environment, the team is confident that these materials could be obtained for less by utilizing bulk orders. Under the current methodology, the team believes this product can be produced at a price that is competitive with others in the industry.

Table 3: Total Material Cost for Production Runs

Material	Cost per unit	Units to order	Total Cost
Hardware cloth	$13.98	1	$13.98
Bamboo	$39.99	2	$79.98
Yellow spray paint	$5.98	4	$23.92
White spray paint	$5.98	1	$5.98
35 mm screws	$7.95	3	$23.85
Magnets	$2.04	2	$4.08
Cedar Wood (3/4"x6"x12')	$32.98	5	$164.90
Cedar Wood (3/4"x8"x8')	$31.98	2	$63.96
Wood glue 8 oz	$4.97	1	$4.97
Total spent			**$385.62**

4.2 MATERIAL, LABOR, AND MACHINE COST CALCULATIONS

In order to calculate the cost per unit, the team had to calculate the dollar value of the direct raw materials that were needed to produce a single unit. As seen in Table 4, the manufacturing process obviously does not use whole quantities of materials for each product. As a result, leftover materials such as spray paint and wood can be used to build other units. After the team mapped out the most efficient way to utilize the material quantities, a direct material cost of $26.78 per unit was calculated.

Table 4: Direct Materials Budget per Unit

Direct Materials Budget	Cost per unit of material	Quantity needed per unit	Total Cost
Hardware cloth	$0.93	1	$0.93
Bamboo (120 pieces)	$0.37	24	$8.98
Yellow spray paint	$1.99	1	$1.99
White spray paint	$0.60	1	$0.60
Magnets	$0.08	3	$0.24
Cedar Wood (3/4"x6"x12')	$9.00	1	$9.00
Cedar Wood (3/4"x8"x8')	$3.20	1	$3.20
Scrap Factor (15%)			$1.83
Total DM per unit			**$26.78**

The direct materials budget does not contain all the materials needed to complete a unit in a normal manufacturing facility. Materials that are not easily traceable are considered indirect materials. Indirect materials include high-use yet small items such as brad nails. As seen in Table 5, the individual cost of a staple is nonessential to the final cost calculation. These materials are therefore separated from the direct materials.

Table 5: Indirect Materials Budget per Unit

Indirect Materials Budget	Cost per unit of material	Quantity needed per unit	Total Cost
35 mm screws	$0.15	8	$1.20
Wood glue	$0.25	1	$0.25
Staples	$0.004	3	$0.01
3/4" brads	$0.01	12	$0.09
Total IM per unit			**$1.55**

Before the team's first production run, roles and layouts were established. The ideal production rate was five units per hour as this rate would yield a satisfactory starting profit margin. In the current layout, two individuals were tasked with making the appropriate straight cuts and sanding the wood. One person was responsible for making the 45-degree angled cuts while the other individual was tasked with assembling all of the pieces. Under this layout, the rate of production was approximately half of the goal. The cutting/sanding and miter saw operator both work at a much faster pace than the assembly operator. Therefore, the assembly position seemed to be the bottleneck for the production process, and all line balancing efforts will be focused on this position to hopefully reduce the direct labor cost per unit as seen in Table 6.

In order to alleviate this bottleneck, the team decided to task another operator at the assembly station with one operator constructing the outside of the unit before passing it down the line for the interior to be completed. After several production runs, the team observed that the cutting/sanding process only needs one operator to work smoothly. Ultimately, by shifting the layout and manpower, the team was able to map out a reasonable production process that can meet the desired production rate.

Table 6: Direct Labor Budget per Unit

Direct Labor Budget	Total # of Operators	Hourly Rate	Total units per hour	Total
Cutting/Sanding	1	$17	5	$3.40
Miter Saw	1	$17	5	$3.40
Assembly Team	2	$17	5	$6.80
Total DL per unit				**$13.60**

In addition to the direct labor costs, construction of the Pollinator Plaza requires a variety of machines. The three different saws and sander listed in Table 7 are integral pieces to the process. Under current assumptions, these machines will need to operate continuously throughout an eight-hour shift to meet customer demand. After obtaining the equipment costs from the CME faculty, these machines can be purchased instead of rented to create a more profitable business model. Common industry rental rates for these machines are $10/hour. With this metric in mind, increased profit margins would quickly make up for this relatively minor investment. Furthermore, the acquisition of these capital assets would allow for management to use the equipment on their own terms. The generally accepted useful life for these machines is five years. Therefore, the financial statements will recognize these assets by recording depreciation expense at the end of each fiscal year.

Table 7: Capital Expenditures

Machine	Cost of Machine
Table Saw	$4,349
Miter Saw	$500
Vertical Bandsaw	$2,899
Sander	$1,555
Total Capital Investment	**$9,303**

The CNC router is utilized for producing the face and door of the product, and the CNC laser cutter cuts out the hardware cloth that is attached to the door. Remarkably, the CNC router can produce one face and two doors every four minutes. After researching and talking with experienced professionals, the team determined the manufacturing facility would be more profitable if the CNC machines were rented due to their high price tag. With both costing well over $1,000,000, the machines would have a significant impact on the bottom line as depreciation expense is recognized.

Table 8: Machine Rentals Budget per Unit

Machine Rentals	Timed Used (minutes)	Rental Price	Cost per Unit
CNC Router	4	$100	$6.67
CNC Laser Cutter	0.5	$100	$0.83
Machine Rental Costs			$7.50

After careful analysis, these estimates have been deemed the most appropriate for the manufacturing process. All of these estimates would ultimately impact the cost per unit. After totaling the variable and fixed costs and dividing by the number of expected sales, the Pollinator Plaza can be realistically built for $76 per unit as shown in Table 9.

Table 9: Cost per Unit

Cost per Unit	
Total Costs	$545,349
Total Units	7,200
Standard Cost	$76

Although the team is confident that the Pollinator Plaza can be competitive in this market right away, the manufacturing process will certainly experience a normal learning curve. First, the operators will need time to be properly trained and equipped to perform their jobs at the desired rate. Next, the sales and marketing team has to grow the product's following and brand recognition. With a passionate and dedicated consumer base, the product is much more likely to turn a profit. Moreover, the team sees multiple avenues of continuous improvement and firmly believes steps can be taken to improve both the rate of production and sales metrics.

After calculating the total cost of the product, the team decided to assign a 15% profit margin to each unit which is equivalent to a selling price of $89.99. Based on the marketing survey, this selling price is expected by a large number of respondents. This amount is out of the price range for the cheaper, low-end bug houses but is competitive with some of the higher-quality bug houses with some selling for more than $100. The quality of the materials and machines as well as a dedication to excellence signals that this product will only continue to improve and thrive in this industry.

When calculating the selling price, it was useful to determine the contribution margin per unit. The contribution margin shows how much revenue is left to cover the fixed costs after subtracting out the variable costs. For overhead calculations, variable overhead is allocated as 100% of direct labor. The variable cost of $53.96 per unit is calculated by totaling direct material, direct labor, and variable overhead per unit. As seen in Table 10, the contribution margin per unit is $36.03, which is equivalent to a contribution margin percentage of 40%.

Table 10: Contribution Margin per Unit

Contribution Margin		
Sales	$	89.99
Variable Cost	$	(53.96)
CM	$	36.03

In order to get a better understanding of the break-even point, a pro-forma income statement was constructed. This financial document includes the estimated sales projections for the first full year in business. A steady increase in sales is expected as the product develops name recognition within the industry. As seen in Tables 11 and 12, the monthly sales target is expected to be reached around September of the first full operating year. With the production facility estimated to break even in August, as seen in Figure 13, stakeholders can feel confident that this product is capitalizing on its potential.

Table 11: Pro-Forma Income Statement January-June

	January	Feburary	March	April	May	June
Sales	100	150	200	250	300	375
Sales Revenue	$ 8,999	$ 13,499	$ 17,998	$ 22,498	$ 26,997	$ 33,746
Cost of Goods Sold	$ (5,396)	$ (8,093)	$ (10,791)	$ (13,489)	$ (16,187)	$ (20,234)
Fixed Costs	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)
SG&A Expense	$ (720)	$ (1,080)	$ (1,440)	$ (1,800)	$ (2,160)	$ (2,700)
EBIT	$ (10,188)	$ (8,747)	$ (7,305)	$ (5,863)	$ (4,421)	$ (2,259)

Table 12: Pro-Forma Income Statement July-December

	July	August	September	October	November	December
Sales	450	550	600	600	600	600
Sales Revenue	$ 40,496	$ 49,495	$ 53,994	$ 53,994	$ 53,994	$ 53,994
Cost of Goods Sold	$ (24,280)	$ (29,676)	$ (32,374)	$ (32,374)	$ (32,374)	$ (32,374)
Fixed Costs	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)	$ (13,072)
SG&A Expense	$ (3,240)	$ (3,960)	$ (4,320)	$ (4,320)	$ (4,320)	$ (4,320)
EBIT	$ (96)	$ 2,787	$ 4,229	$ 4,229	$ 4,229	$ 4,229

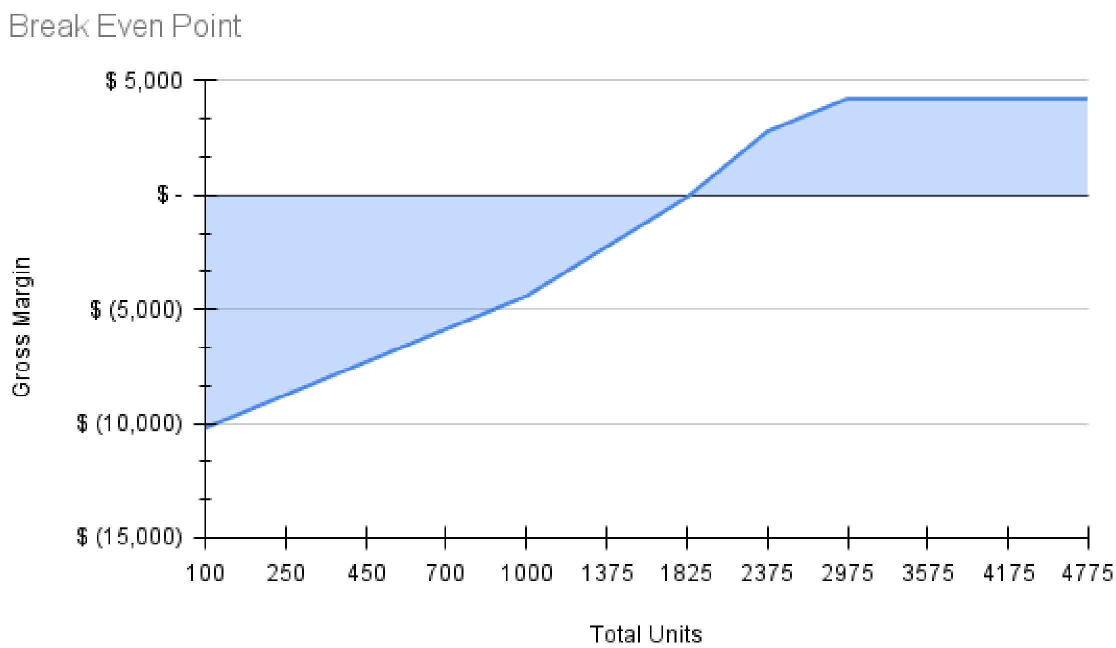

Figure 13: Break Even Point

When projecting sales, it was decided to use a sensitivity analysis to determine how different levels of sales will affect future earnings. For variable costs, the previously calculated direct materials, direct labor, and variable overhead costs were used to determine the total variable costs. In terms of fixed costs, discussions with industry experts suggest these estimates of common fixed costs are appropriate for manufacturing facilities of this caliber. Industry standards suggest that for every $1 of direct labor cost incurred, the facility must also prepare for $3 of fixed and variable overhead (Carr). Furthermore, selling, general, and administrative costs were allocated as 8% of total sales. After calculating the fixed and variable costs, the Pollinator Plaza is realistically positioned as costs align with industry standards.

After adding these numbers to the sensitivity analysis, three separate scenarios emerged, as seen in Table 12. Under the pessimistic assumption, the factory will not be profitable by a wide margin. However, under the expected sales assumption, the break-even point should be reached by the month of August. Finally, the optimistic sales projection shows the ideal profitability of the Pollinator Plaza.

Table 13: Sensitivity Analysis

Sales	Pessimistic	Expected	Optimistic
Units	5000	7200	10000
Price per Unit	$89.99	$89.99	$89.99
Total Sales	**$449,950**	**$647,928**	**$899,900**
Variable Costs			
-Materials	$133,783	$192,648	$267,567
-Labor	$68,000	$97,920	$136,000
-Variable OH	$68,000	$97,920	$136,000
Total Variable Costs	$269,783	$388,488	$539,567
Contribution Margin	**$180,167**	**$259,440**	**$360,333**
Fixed Costs			
-Dep Exp	$1,861	$1,861	$1,861
-Salary Exp	$90,000	$90,000	$90,000
-Factory Rent Exp	$25,000	$25,000	$25,000
-Insurance Exp	$25,000	$25,000	$25,000
-Utilities Exp	$15,000	$15,000	$15,000
Total Fixed Costs	$156,861	$156,861	$156,861
Gross Margin	**$23,306**	**$102,579**	**$203,473**
-SG&A Exp	$35,996	$51,834	$71,992
EBIT	**-$12,690**	**$50,745**	**$131,481**

IMPROVEMENTS

5.1 DESIGN UPDATES

Many of the design updates after the creation of the prototype were successful. After building the prototype, an innovative way to give the product an aesthetically-pleasing finish needed to be developed. This was eventually accomplished by sanding the wood after sawing. It was also found that many fixtures/jigs were needed to cut the cedarwood and bamboo, along with a fixture to hold the exterior in place so only one operator would have to be in the final assembly process. All of these fixtures were created, with the addition of a fixture to help measure the amount of bamboo needed per unit. Adding two shadow boards, one at the cutting station and one at the final assembly, was a great improvement in workplace organization. They lessened confusion regarding which piece went where and decreased time spent figuring out piece placement. For example, the left-hand side is designated for the L-shaped fixtures while the right side was reserved for tools. An example of this shadow board can be seen in Figure 14.

During the most recent production run, two additional opportunities for improvement were identified. The first area would involve implementing an additional fixture to consistently measure the halfway point on the back-unit piece. This step is

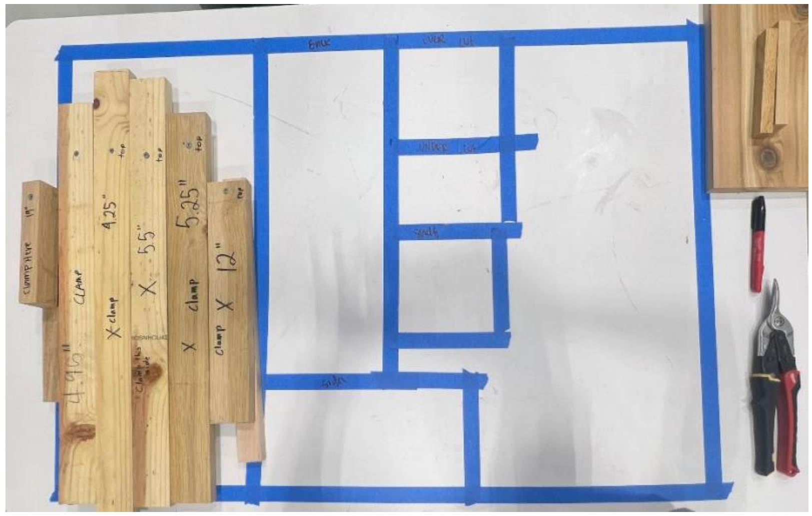

Figure 14: Shadow Board

crucial to the next area of improvement. While this mid-point reference is useful, the next challenge comes with cutting at 45 degrees to create a triangle. Despite the presence and use of a guiding light on the saw, slight margins of error on the back piece were observed during the assembly of the unit. In fact, in the practice runs and production runs, the angled cut on the back piece deviated by approximately 1/8” to 1/4”. This error can be eliminated by adding another stencil or fixture that could consistently show where to draw the line for cuts.

Although the design updates have been successful, there is one more design update that is planned for implementation in the future. Currently, it would be beneficial to add a small wooden stake and screws to allow the customer to decide how they want to place their Pollinator Plaza in their garden. This way, the customer could decide if they want to place the bug house on the ground, hang it up, or attach it on the stake.

5.2 FUTURE WORK

Although the Pollinator Plaza has the potential to be an astounding success for households, parks, and school campuses around the country, the team has bigger aspirations for pollinator habitat. In order to provide a large-scale effect, the team would like to produce the Pollinator Plaza in a variety of sizes, including houses much larger than our current product. Although the product was created for specific local species, the Pollinator Plaza contains habitats that can be occupied by a variety of pollinators across the country. With specific crops benefiting from the presence of certain pollinators, it would be ideal to introduce this product to farmers across the country. For example, bees play an important role in pollinating fruit trees such as apple trees. These orchards could benefit greatly from an increase in pollinator habitat. Similar to crop rotation and sustainable farming practices, the implementation of pollinator habitat would not only make farmers more efficient and profitable in the long run, but they would also help reverse the population decline among pollinators.

CONCLUSION

Upon reflection, one of the most blatant issues that needed to be addressed was the placement of magnets. Although it was initially presumed that the magnets placed on the bottom of the bug house could hold the door closed, gravity thwarted this idea. In response, different ways to attach the door, such as milled holes for the magnets or a hinge, were debated. Eventually, it was decided that countersinking the magnets would be the best solution to this problem.

Another issue became apparent after analyzing the bamboo order. The first set of bamboo that was placed into the bug house was too small in diameter to host carpenter bees like originally intended; however, it was still large enough to host a few species of caterpillars. To resolve this issue, bamboo with a larger diameter was ordered. This addition allows the bug house to host a wider variety of pollinators.

Overall, completion of the Pollinator Plaza provided many opportunities and lessons in both manufacturing and teamwork. From calculating the profitability to adjusting dimensions in AutoCAD, a holistic perspective of manufacturing was used to complete this project. Regardless of the product's market success, the unit's creation has served as a platform to advocate for increased pollinator habitat across Mississippi and the United States.

REFERENCES

Carr, Eddie. Interview. By Shane Houston Stephens, 3 April 2024.

Datz, Todd. "Pollination Loss Removes Healthy Foods from Global Diets, Increases Chronic Diseases Causing Excess Deaths." *Harvard T.H. Chan School of Public Health*, 14 Dec. 2022, www.hsph.harvard.edu/news/press-releases/pollination-loss-removes-healthy-foods-from-global-diets-increases-chronic-diseases-causing-excess-deaths/, Accessed on 10 Apr. 2024.

Pettis, Jeff. "The Importance of Pollinators." *USDA*, www.usda.gov/peoples-garden/pollinators, Accessed on 13 Apr. 2024.

"Protecting Honey Bees and Other Pollinators." *Penn State*, www.psu.edu/impact/story/protecting-pollinators/, Accessed on 13 Apr. 2024.

Ramaswamy, Dr. Sonny. "Reversing Pollinator Decline Is Key to Feeding the Future." *USDA*, 24 June 2016, www.usda.gov/media/blog/2016/06/24/reversing-pollinator-decline-key-feeding-future, Accessed on 9 Apr. 2024.

Ulyshen, Michael, and Scott Horn. "Declines of Bees and Butterflies over 15 Years in a Forested Landscape." *National Institutes of Health (NIH)*, 10 Apr. 2023, www.srs.fs.usda.gov/pubs/ja/2023/ja_2023_ulyshen_001.pdf, Accessed on 28 Mar. 2024.