Countdown CES and EPICS E-Guide

By: The Countdown CES EPICS Team

Originally Published: April 24, 2024

Revision #: 0

Revision Date: April 24, 2024

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E-Guide’s Purpose and Background

This E-guide serves as a step-by-step manual, detailing the innovative process of crafting desks and chairs from recycled plastics. From shredding and pressing materials into sheets to precision cutting using the ShopBot machine; each stage is elaborated upon to ensure seamless assembly. Additionally, the E-guide provides insights into joint testing methodologies, ensuring the products' structural integrity and ergonomic design. This guide aims to streamline production, enabling the creation of eco-friendly seating solutions for educational institutions in Ghana.

The table and chair designs are targeted towards students in the K-8th grade range, although it could be scaled up in size to cater to older students. The elimination of plastic waste in Ghana waters and the creation of classroom furniture at once shows how our solution solves two problems with one simple solution.

The design and testing process was iterated through for many different prototypes until a final design was settled on. This chair and table design was the ideal solution for this challenge since it fulfilled all the design criteria while also being safe and efficient for classroom use. After testing different thicknesses of plastic, the design progressed from using 0.25" to 0.75" recycled plastic sheets to create the most stable prototype with the least amount of material. The furniture is flat-packed and easy to assemble, while also being able to pass the testing criteria. Without the use of screws and dowels, the assembly and manufacturing process is accelerated, and additional waste is not created. There could be improvements made to these designs; however, with the provided resources and time, this is the most optimal design for durability and comfort. As of March 2024, the project is in a design freeze due to these reasons.

BOM/Capital Needs

These are the capital needs and essential tools required for creating the chair and table. Understanding the investment in both financial resources and necessary equipment is paramount to ensure smooth operation. From machinery to hand tools, each item listed here plays a pivotal role in the building of one chair and table. All prices given are estimates and are subject to change.

Estimated Total: $50,000 USD

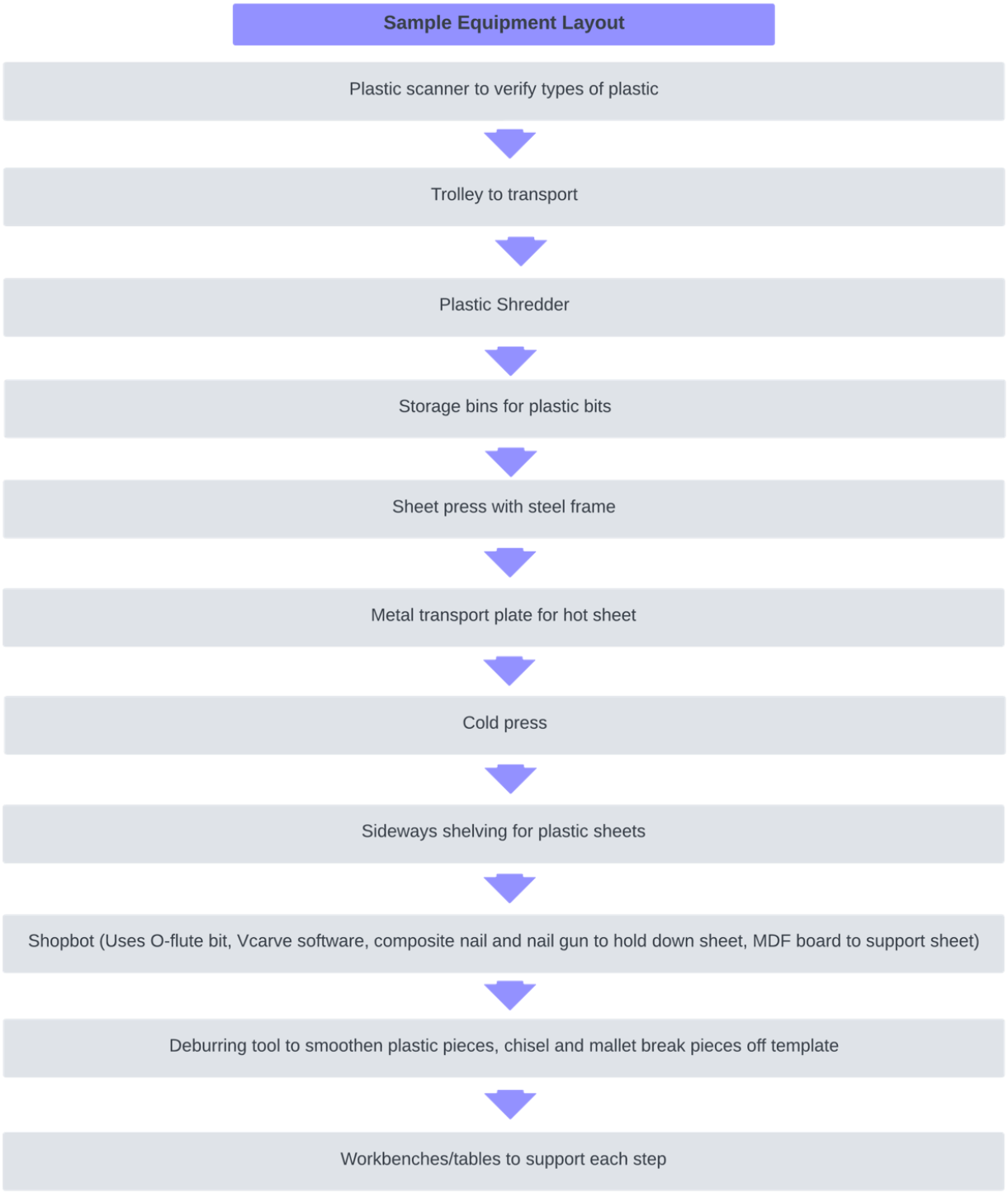
Equipment Name	Use/Description	Cost	Quantity	Link
Transport Trolley	Transport materials between each station	$170	At least 1**	Link
Plastic Scanner	Check if material is HDPE plastic	$2,900	1	Link
Plastic Shredder	Shred HDPE plastic in to small bits	$3,000	1	Link
Storage Bins	Store small bits of HDPE plastic	$99	At least 3**	Link
Sheet Press	Heat and press HDPE	$4,000	1	Link

	plastic bits into sheet			
Cold Press	Cool down hot sheets	$3,600	1	Link
Shelving for Sheets	Store plastic sheets	$315	At least 1**	Link
Shopbot	Machine to cut plastic sheet into furniture pieces	$28,000	1	Link
VCarve Software	Software to instruct cuts	$700	1	Link
¼ inch O-flute Router Bit	Drill bit to cut plastic sheets	$14	1 (more for wear-and-tear)*	Link
Composite Nails	Used to hold down plastic sheet in place while cutting	$37	1*	Link
Nail Gun	Drill nails to hold down plastic sheet	$178	1	Link
MDF Spoil Board	Hold up plastic sheet	$89	1*	Link
Chisel	Separate furniture pieces from plastic sheet	$14	1	Link
Deburring Tool	Smoothen and deburr jagged edges of furniture pieces	$14	1	Link
Workbenches	Table for each station	$330	11 (1 for each step)	Link
HVAC System	Regulate air quality, heating and cooling	$3,000	1	Link
Planer	Sand down sheet thickness	$119	1	Link
Sawzall (Reciprocating Saw)	Cut sheets to be re-shredded	$129	1	Link
Scissors	Manually cut plastic	$16	1	Link
Screwdriver	Clean debris from shredder	$15	1	Link
Shopvac	Clean debris from shredder	$215	1	Link
Temperature Gun	Check temperature of machines and materials	$25	1	Link

Silicon Oil	Machine and mold preparation	$163	1*	Link
Scale	Weighs up to 400 lbs.	$169	1	Link
Sliding Tool	Moving sheets	$20	1	Link
Labeling Device	12 pack of markers for labels	$17	1*	Link
Compressed Air Pump	Used along with nail gun	$172	1	Link
Mallet	Use with chisel to separate furniture pieces from plastic sheet	$11	1	Link
¼ inch ER32 Collet	Secure drill bit to ShopBot	$31	1	Link
Broom	Remove debris from work area	$39	1	Link
Digital Calipers	Measure sheets for Quality Assurance	$20	1	Link
Computer	Must have minimum requirements to operate VCarve, ShopBot. Asus Core I9	$1000	1	Link

***Indicates consumable that will be an ongoing cost**

****Indicates amount will depend on scale of project**



Manufacturing Plan

Purpose and Background

- What is the Manufacturing Plan?

  The manufacturing plan for these products will cover the entire production process, from shredding the plastic, creating sheets, cutting out pieces, and how the designs were tested. Using the same machines and software will result in the closest match to the prototype this team has created. Note that differences in machinery can potentially yield slightly different results.

- What will the Manufacturing Plan Look like?

  The following flow chart (Figure 1) outlines the manufacturing process; from sheet creation, cutting and assembly, to finishing. The process will run smoothest with the use of machines similar to those presented in this document. Experimentation with machinery and machine settings through multiple preliminary trials will need to be utilized to produce results similar to those in this document.

- Rationale Behind Manufacturing Plan:

  Since the use of different machinery will produce different results, multiple trials at the beginning of the manufacturing plan will be needed to ensure the machines are running efficiently and effectively. For example, different ShopBot machines will yield varying errors, which result from a difference in CAD measurements compared to the furniture's real measurements. Since this error is machine specific, a testing plan is needed to ensure the error is within the acceptable tolerance range for the joints. The testing plan is outlined in the Joint Testing portion of the document and must be completed at the beginning of the manufacturing process.

Flow Chart

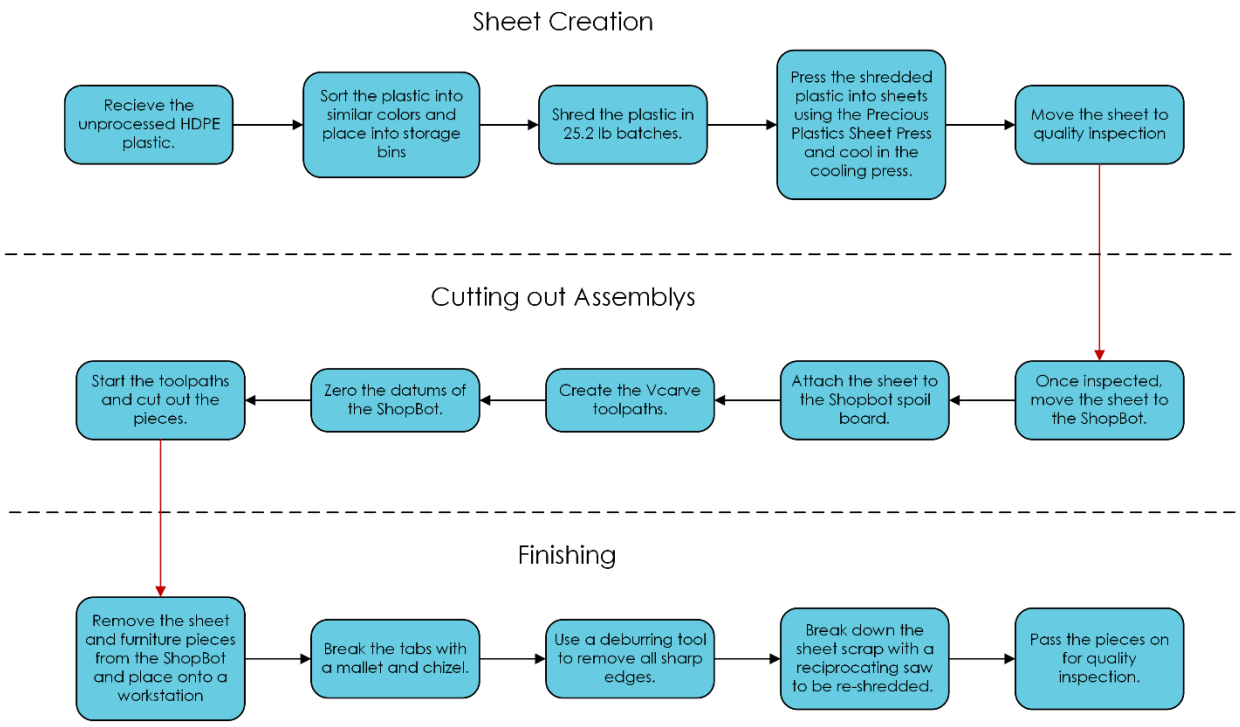


Figure 1: Manufacturing Flow Chart

Step by Step Instructions and Pictures

Shredding

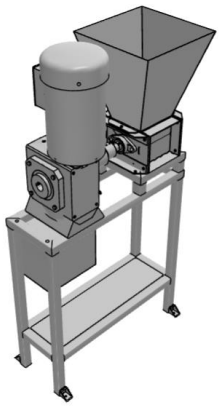


Figure 2: 3D model of the shredder

Required Materials

- Precious Plastics Shedder
- Plastic Scanner
- Scissors

- Reciprocating saw
- Shopvac (vacuum for debris)
- Screwdriver
- Temperature Gun
- Storage bin

1. Remove contaminants and non-shreddable items from the sorted HDPE plastic. This can include paper labels, metal pieces, bottle caps, etc.
   Note: Check a few pieces of plastic from the batch with the plastic scanner to make sure the batch is HDPE.
2. According to Precious Plastics, the max thickness of the input plastic is 4mm. Any thicker plastic cannot be shredded.
3. For larger pieces that do not fit in the hopper (400 x 200 mm), cut them down to size with scissors or the reciprocating saw.
4. Adjust shredder settings and blades accordingly to the Precious Plastics user guide. Ensure the feed hopper is clean and free of debris with a shopvac and screwdriver.

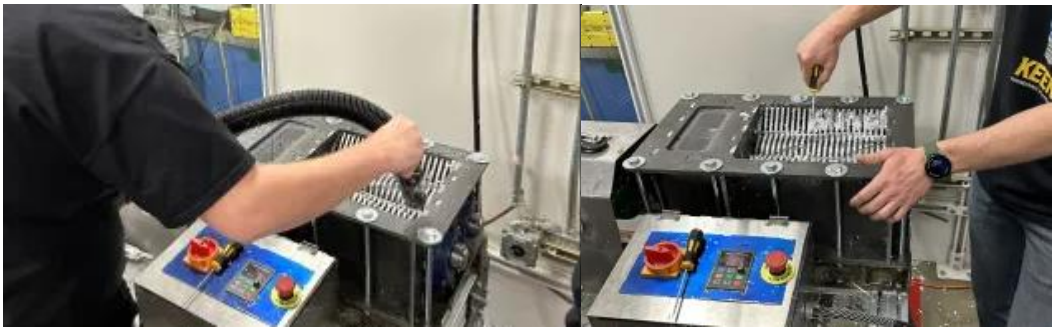


Figure 3: Cleaning the Shredder with a Shopvac and screwdriver

5. Gather the un-shredded plastic in an organized manner to facilitate a smooth feeding process.
6. Power on the shredder following Precious Plastics guidelines.
7. Allow the machine to reach operating temperature and RPM.
8. Place a storage bin under the shredder output funnel.
9. Feed materials into the shredder in a controlled manner. Plastic should be poured in a way that the shredder can grab it, and hands are removed once the plastic is caught in the teeth. For the second shred, just fill the hopper with the shredded plastic.

Figure 4: Shredder hopper and feed system

10. Add the plastic steadily and keep a constant eye on the shredding process. Address any issues promptly, such as jams or abnormal sounds.
    Note: When shredding, make sure that you always run your motor under its rated amperage on average. Allow break time so that the amperage does not overload power. Keep an eye on the temperature of the blades of the shredder blades, bearings, box, and motor with a temperature gun. The blade should not exceed 90 degrees Celsius, or your plastic will start to melt.
11. Periodically inspect the shredded output for consistency. Adjust settings if necessary to achieve the desired output.
12. Collected plastic should be about 0-30mm (about 1.18 in) in size.
13. Re-shred the output plastic once more until it reaches 0-10mm (about 0.39 in) in size as seen in Figure 5.

Figure 5: Shredded Plastic

Figure 6: Re-shredding the plastic

14. Follow proper shutdown procedures to power off the shredder.
15. Clean the machine and surrounding area.
16. Store the shredded plastic material in appropriate containers or proceed with further processing, such as melting and molding into new products.

    Note: Implement proper waste management practices to dispose of any leftover materials responsibly.

Preventative maintenance will need to be scheduled and performed on the machine, for direction visit: https://community.preciousplastic.com/academy/build/shredderprorun

Sheet Press

Figure 7: 3D Model of Sheet Press

Required Materials

- Precious Plastics Sheet Press
- Two Aluminum pressing plates (1220x1220mm)
- Mold (1040mm x 1040mm x 19.05mm)
- Workbench
- Silicon oil
- Scale
- Sliding tool
- Transport trolly

1. Plug in the sheet press, check the emergency stop is released and switch on the main power switch.
2. Set the PID controller to 220°C.
   Note: This is the required melting temperature for HDPE plastic.
3. Close the pressing plates using the bottle jack and wait for them to heat up.
4. While waiting for the heating plates to warm up. Place the bottom sheet of the mold on the prep table and apply a layer of silicone oil. Make sure to remove any remnants of the previous sheet.
5. Place the mold frame in the center of the sheet and apply a layer of silicone oil to the top of the frame.
6. Weigh 25.2 kg of plastic and load it into the mold.

Figure 8: Pouring plastic into the mold

7. Spread the plastic evenly across the area inside the mold frame, ensure to leave less material around the borders. .
8. Oil the top sheet of the mold and place the oiled side face down on the bottom two sections of the mold.

9. When the sheet press is at 220°C. Open the pressing plates of the sheet press by releasing pressure from the bottle jack.
10. Position the prep table next to the open side of the sheet press.
11. Use the sliding tool, push the mold from the prep table to the sheet press.
12. Close the pressing plates using the bottle jack until the spring is fully compressed. Let plastic melt for 60 minutes (the required time for 25.2 kg of HDPE).
13. Whilst waiting for the plastic to melt. Prepare the next mold and sheet on the prep table. (Steps 4-8).
14. 2 mins before the recommended melting time (60 mins). Close the pressing plates using the bottle jack until the jack starts to give strong resistance.
15. Continue to the cooling press instructions.

Preventative maintenance will need to be scheduled and performed on the machine, for direction visit: https://community.preciousplastic.com/academy/build/sheetpressrun

Cooling Press

Required Materials

- Precious Plastics Cooling Press
- Sliding tool
- Transport Trolly

Instructions

16. When the mold has been in the sheet press for required melting time (60 mins). Open the pressing plates of the cooling press by releasing pressure from the bottle jack.
17. Open the pressing plates of the sheet press by releasing pressure from the bottle jack.
18. Use the sliding tool, push the mold from the sheet press to the transport trolly.
19. Move the transport trolly to the cooling press and slide the hot sheet and mold onto the colling press.
20. Close the pressing plates of the cooling press using the bottle jack.
21. Load and press the next sheet into the sheet press (Steps 10-13). This time stack it on top of the previous sheet.
22. Repeat steps 13-20 until all the required sheets are complete. Switch off and close the sheet press.
23. Clean and apply a layer of silicone oil to the mold sheets to protect them from moisture between use.

Preventative maintenance will need to be scheduled and performed on the machine, for direction visit: https://community.preciousplastic.com/academy/build/sheetpressrun

Storage

Required Materials:

- Vertical Sheet Rack
- Storage Bins
- Labeling Device

Plastic HDPE sheets should be stored vertically or in racks where the sheet can lean at an angle of approximately 10º. Similar to plywood, a system depicted in Figure 9 would work well and allow for specific sheets to be grabbed easily.

Figure 9: Vertical sheet rack

Choose appropriate containers for storing the shredded plastic. These containers should be clean, dry, and made of any common plastic types. Common options include plastic bins, barrels, or bags. An example of these bins in provided in Figure 10.

Figure 10: Clear plastic storage bin

Clearly label each container with information: The date of shredding and any other relevant details. This helps with organization and ensures proper identification of the material during later processing stages. Store the shredded plastic in a controlled environment to minimize degradation and maintain quality. Factors such as temperature and exposure to sunlight can affect the properties of the HDPE. Ideally, the storage area should be cool and away from direct sunlight.

Arrange the containers of shredded plastic in a way that maximizes space utilization and facilitates easy access. Stack them neatly, ensuring that containers are stable and not at risk of toppling over. Depending on the location and value of the shredded plastic, consider implementing security measures to prevent theft or unauthorized access.

Periodically check the stored shredded plastic to ensure that it remains in good condition. Look for signs of degradation, contamination, or any other issues that may arise during storage. Address any problems promptly to prevent further deterioration. Maintain detailed records of the stored shredded plastic, including inventory levels, storage conditions, and any relevant observations or maintenance activities. This documentation can help track the material's history and ensure compliance with re-shredding standards.

Sheet Setup

Required material:

- HDPE plastic sheet

- Nail Gun
- Composite Nails
- Compressed Air Pump

1. Place the HDPE plastic sheet on the ShopBot medium-density fiberboard (MDF) spoil board. This can be seen in Figure 11. Verify that all corners of the HDPE sheet are properly lined up with a corner of the spoil board.

   Note: While handling the plastic sheet, beware of sharp edges. Wearing gloves will reduce the chance of an injury.

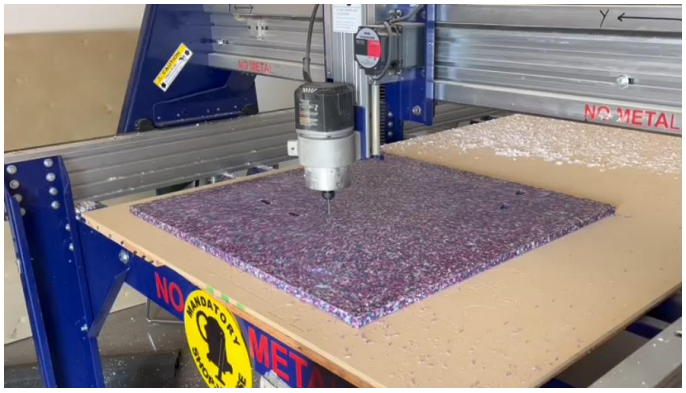


Figure 11: Sheet on the ShopBot MDF spoil board

2. Staple in all four corners of the sheet to the spoil board with the nail gun. The nail gun contains composite nails which are safe for the endmill to pass through. The nail gun is hooked up to compressed air at 100psi or follow the manufacturing guidelines for a different nail gun.
   a. Note: If the sheet is still not secure, staple between corners as needed in the scrap areas. Do **not** staple on the faces of the furniture parts. The composite nail will end up in the final piece of furniture.

Figure 12: Nail gun and composite nails

3. Confirm that sheet is secure to spoil board by pushing the edges to see if the sheet moves.

VCarve

Required Materials:

- Computer
- VCarve Software

1. Start up the VCarve application on your device.
    a. Note: Make sure to have the cutout files (.dxf files) for the pieces uploaded to your device.

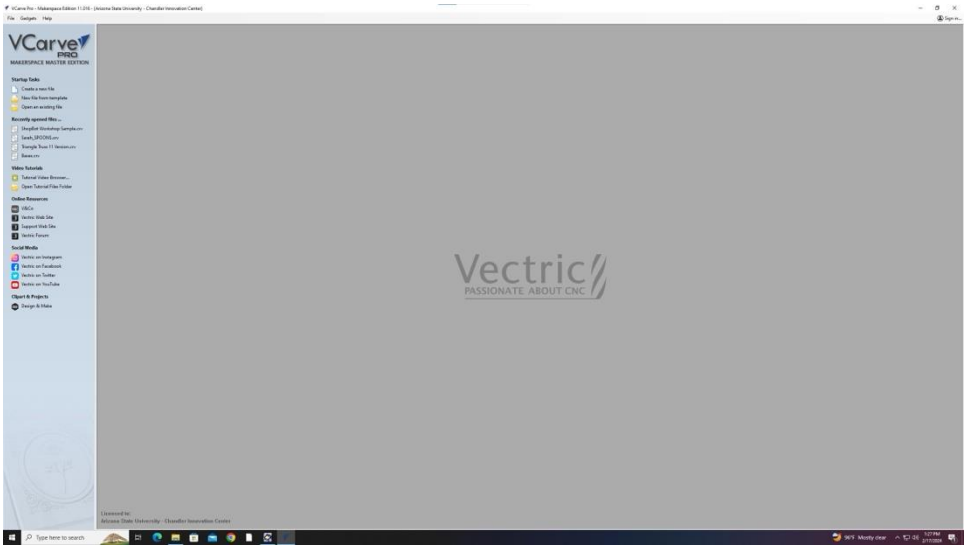


Figure 13: Starting up VCarve Application

2. Open up a blank board on the application(Figure 13):

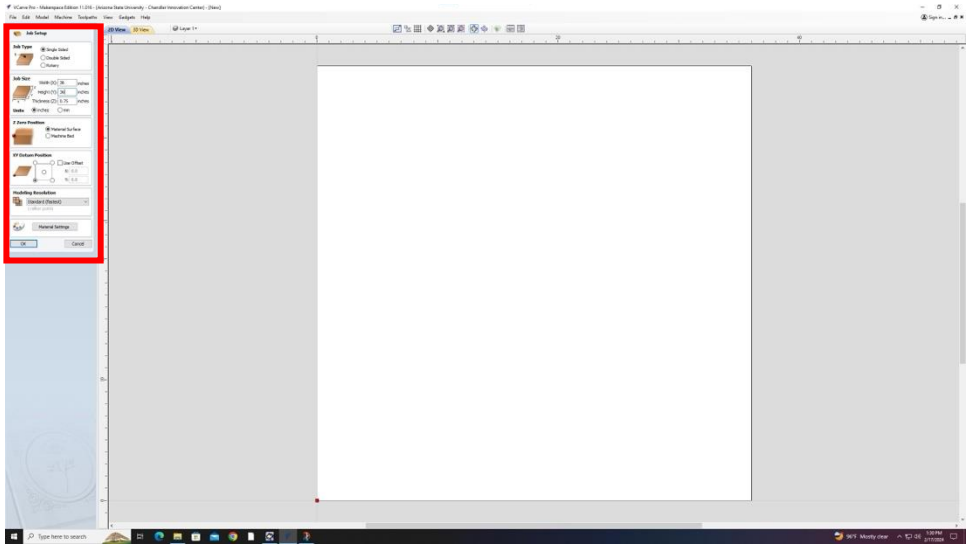


Figure 14: Job Setup settings(in red box)

3. For the Job Setup, set the “Job Size” dimensions to the length, width, and depth of the sheet, which is 36” by 36” by 0.75” respectively(Figure 14).
    a. Set the “Job Type” to “Single Sided”

b. Set the Z Zero Position to the “Material Surface” option in order to zero the z axis to the top of the sheet.
c. Set the “XY Datum Position”, or the point of origin, to the bottom left corner of the board setup.
d. Note: ENSURE THAT OFFSET IS NOT SELECTED FOR.

4. After clicking the “OK” button, click on the “Drawing” tab on the left side and import the drawing from the dxf file saved to the device(Figure 15). (To edit job setup click job dimensions).

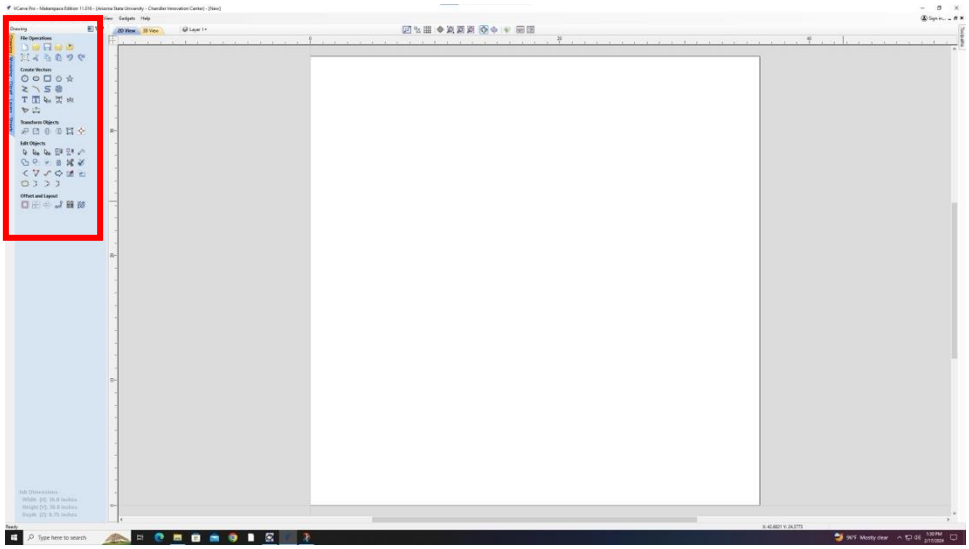


Figure 15: “Drawing” tab on the left side

a. Move the pieces on the board to make sure none of the parts are placed off the sheet(Figure 16).

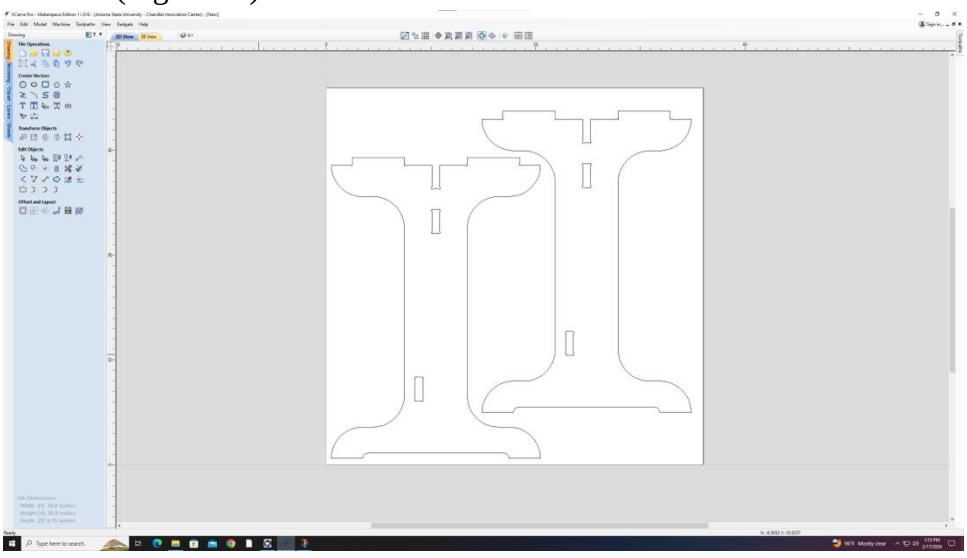


Figure 16: Placement of cutouts on the sheet(make sure cuts do not go outside of the sheet)

5. Select the entire outer region of the pieces(not the internal pockets) and select the button “Profile Toolpath”(Figure 17). The part that should be selected is shown in pink. The rectangle cuts on the inside should be black.

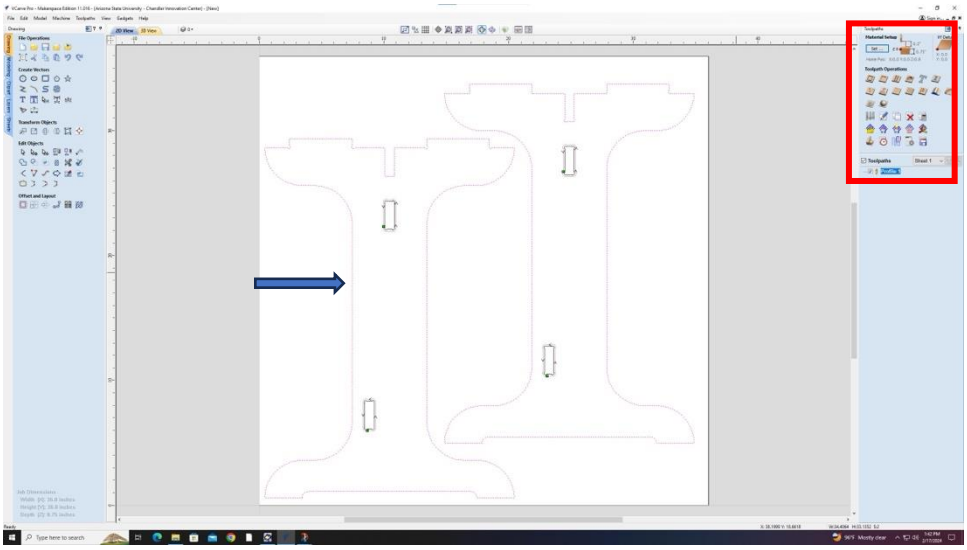
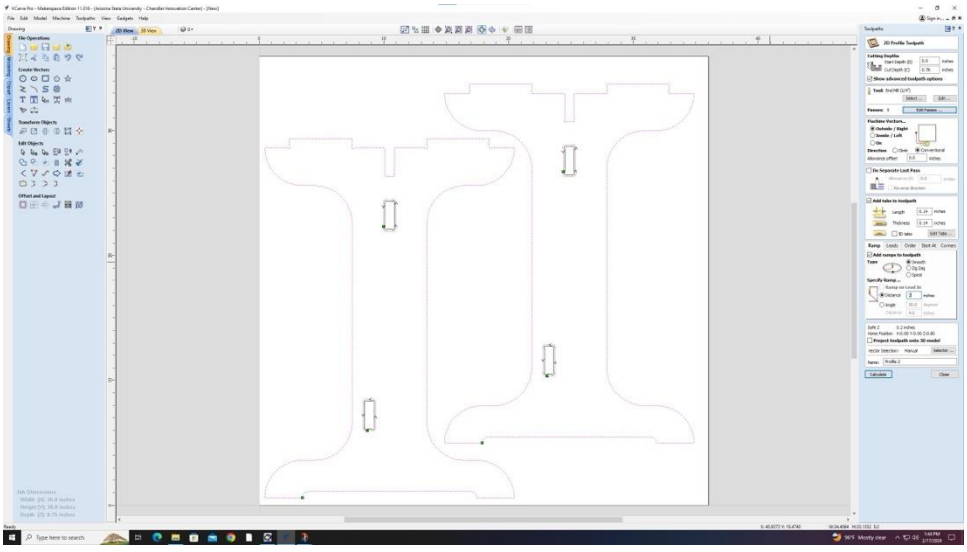


Figure 17: Profile Toolpath, where profiles are created for different cuts; arrow shows which cuts should be selected for the toolpath in pink.

   a. For the “Cutting Depths”, change the “Cut Depth” to 0.76-0.79. This can vary slightly from each run of the machine due to the differences in sheet thickness and the drill bit.
   b. For “Passes” select 5.
   c. Since this is the outer region, select “Outside/Right” for the Machine Vectors. Click on “Conventional” for “Direction” options



   d. For the “Ramp” option, edit the “Distance” to 0.5
   e. Save this profile
   f. Add a minimum of 1 tab to each of the pieces and click “OK” when all the settings and the toolpath are shown as expected(Figure 19).

Note: Tabs hold pieces in place while being cut, so that material does not shift out of place.

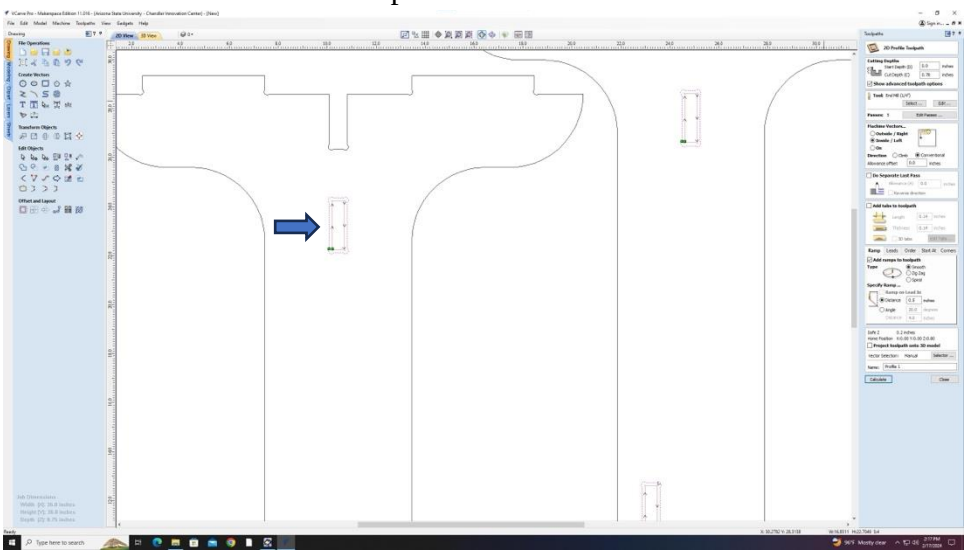


Figure 19: The tabs on the inside cuts are in green, with the arrow pointing to the inside cuts in green.

6. Select the inside cuts of the pieces and save as a profile. The inside cuts should be in pink.

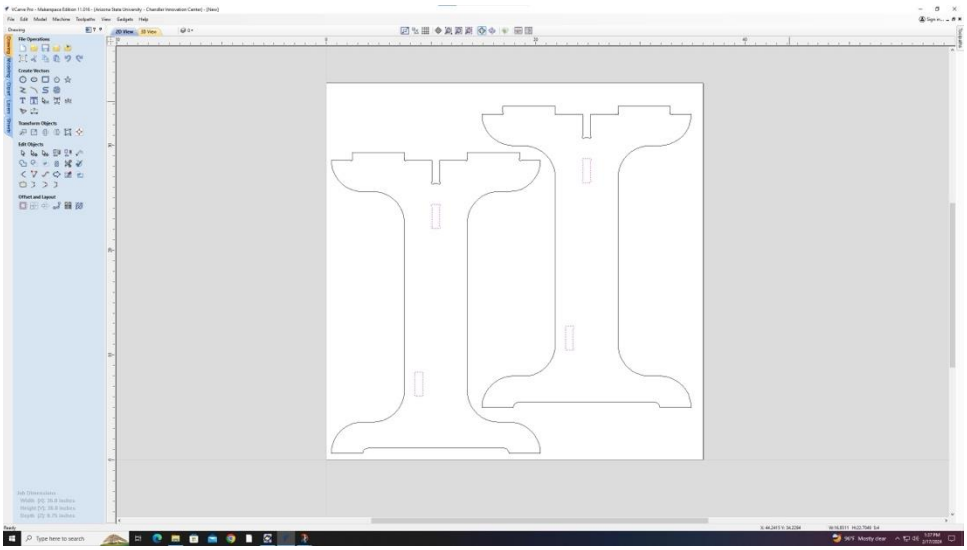


Figure 20: Inside cuts are in pink, they should be saved to a new profile.

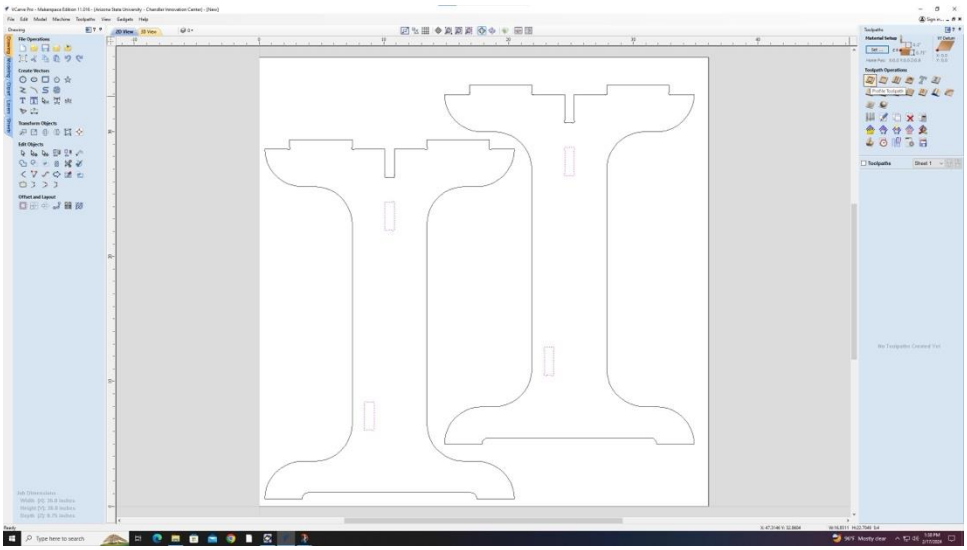


Figure 21: Another example of inside cuts in pink.

7. Create another profile, under a different name, and use the same settings as above, except for the “Machine Vectors”, select “Inside/Left” and for the “Ramp” option, select “Smooth” for the “Ramp Type”

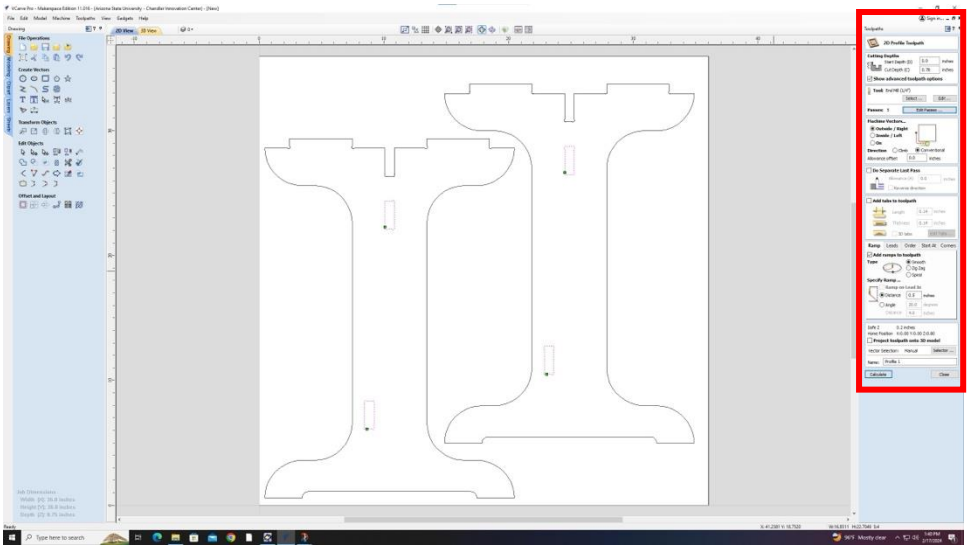


Figure 22: Selecting options for the profile for inside cuts

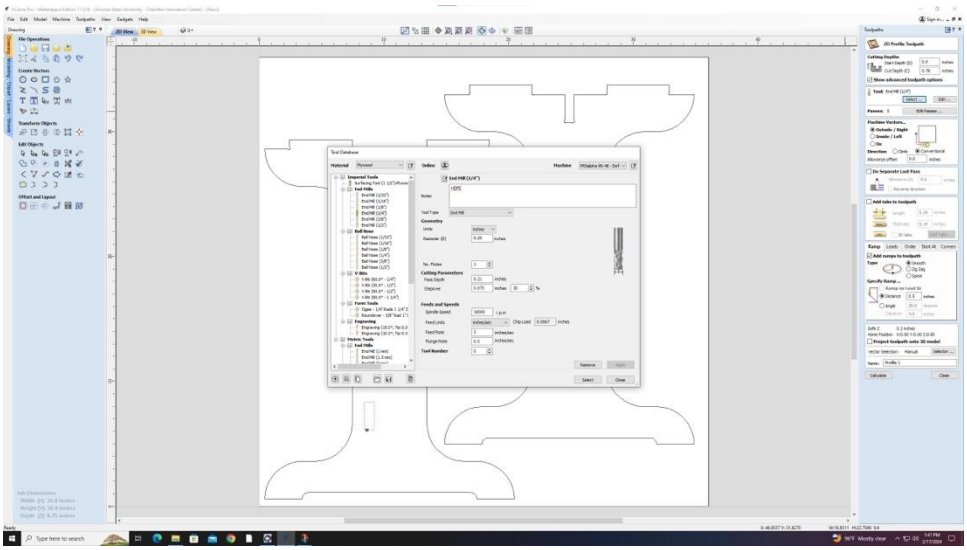


Figure 23: Edit the “Feeds and Speeds” and “Cutting Parameters”

Figure 23:

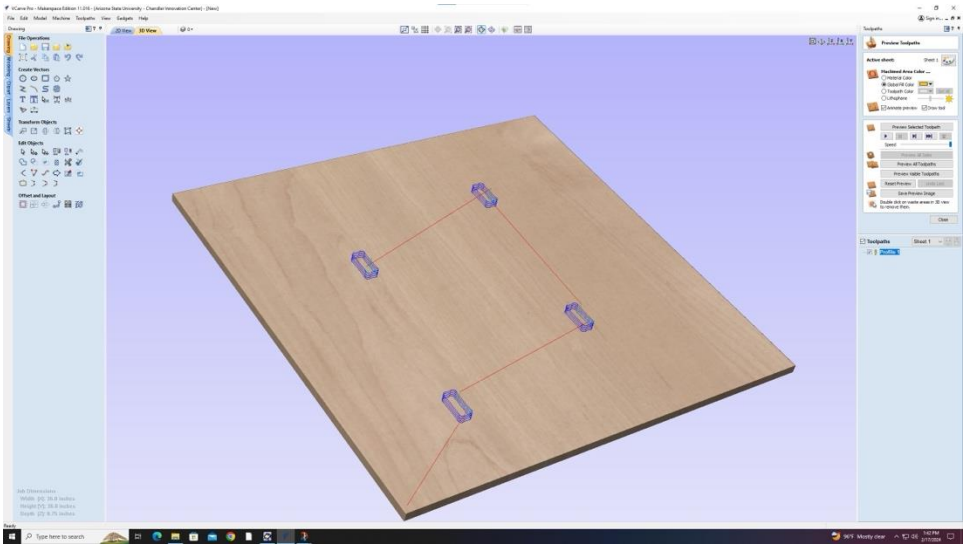


Figure 24: After saving the toolpath, preview it to see how it will be cut and in which order

8. Save and export this toolpath to your device. Make sure to save each under a different name so that toolpaths don’t get deleted or overwritten.
9. Open both Toolpaths under the “Preview Toolpath” tab(Figure 24).

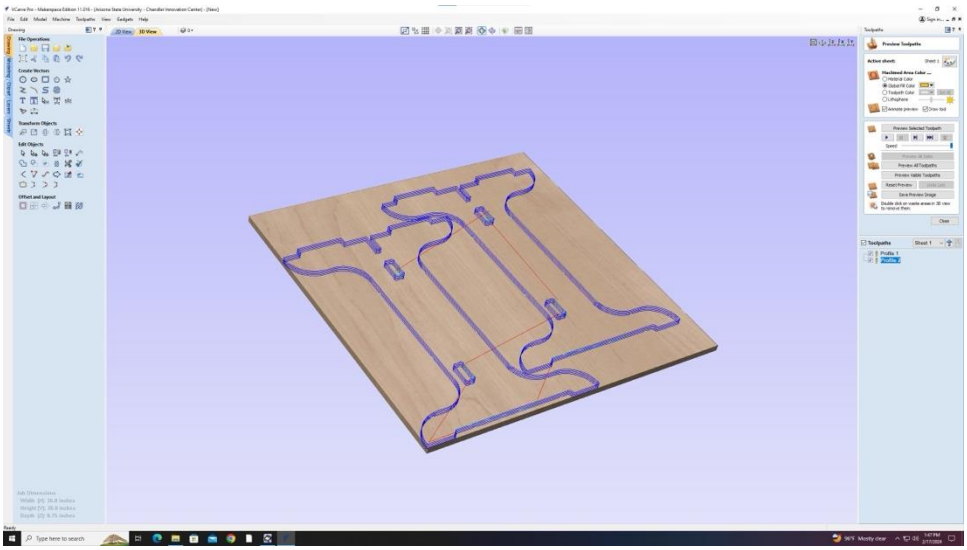


Figure 25: Preview the other Profile's toolpath as well

10. Save this whole setup as a new toolpath.

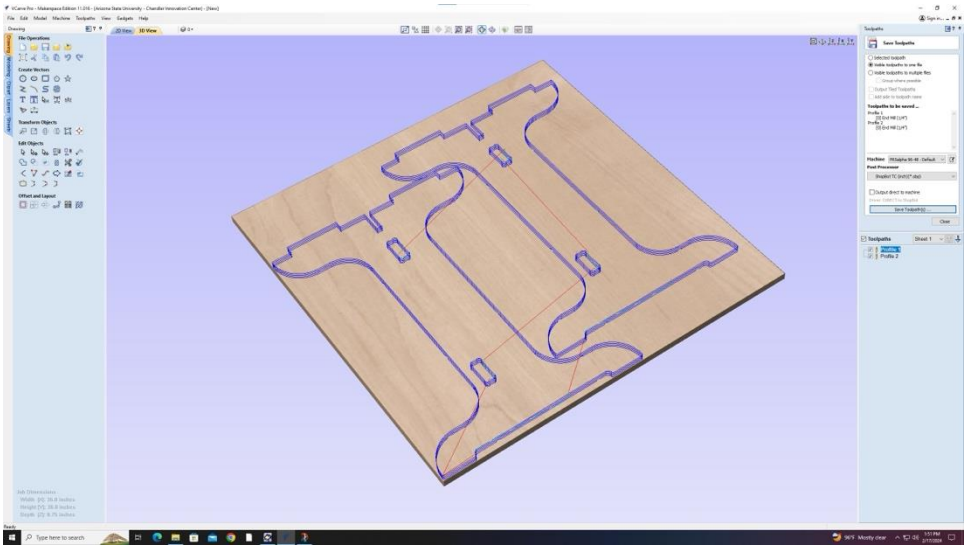


Figure 26: Toolpath of

11. Connect to the ShopBot, hit Print, and cut out the pieces. In between each sheet being cut, make sure to vacuum excess plastic chips in order to prevent interference.

ShopBot Setup

Required Materials:

- ShopBot
- ¼'' O-flute Endmill
- ¼'' ER32 Collet
- ShopBot Controller Software (included with ShopBot)
- Aluminum Plate (Included with ShopBot)

- Grounding Cable (Included with ShopBot)
  1. Insert the drill bit into the collet and ensure that it is secured to the machine so that it will not be loosened when the machine is run.
     Note: The drill bit should be compatible with the sheet being cut. The team used a ¼" single flute bit, as it was found to be compatible with the pieces being cut and the thickness of the sheets.

  2. Move the center of the bit, to the aligned corner of the plastic sheet. Move the center of the bit, to the corner of the plastic sheet.

(Example of a corner)

3. Zero the z-axis using the plate and bringing the drill bit down to the zeroing plate (metal plate with wire connected to router).
4. Set the origin to the bottom corner of the board. Make sure when right above the corner X,Y and Z are approximately 0.
5. Hit 'Cut Part' when ready to cut pieces.
   - If cutting starts in wrong direction or wrong place immediately press the emergency red button
6. Re-zero the axes each time a new sheet is cut.

Finishing

Required Materials:

- Deburring Tool
- Broom
- Vacuum
- Mallet and Chisel

Before deburring, carefully examine the plastic pieces for any burrs, rough/sharp edges, or imperfections that need to be removed.

1. Remove tabs using a chisel and mallet.
2. Hold the deburring tool at a slight angle against the edge of the plastic piece, applying gentle pressure. Pull toward you.

3. Rotate the plastic piece as needed to access different areas and ensure edges are smoothed.

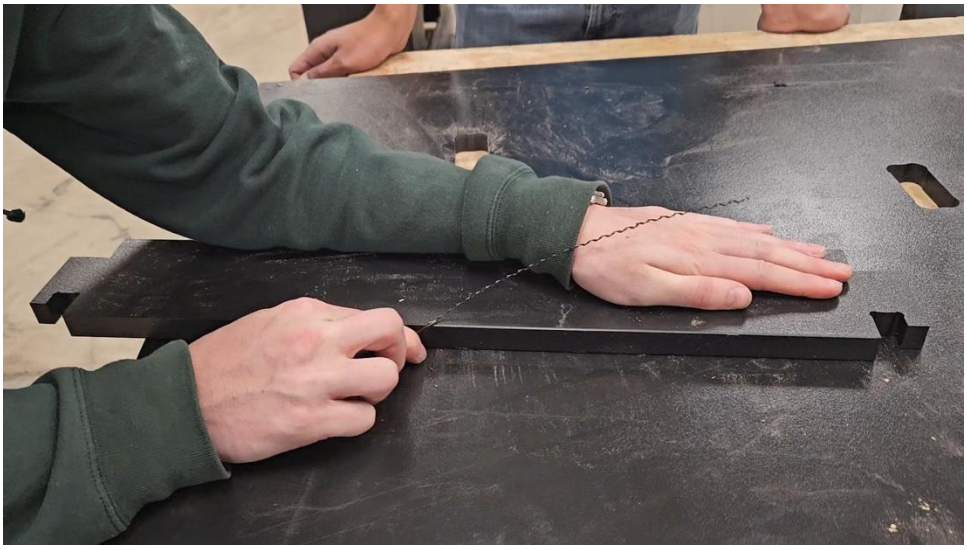


Figure 13: Deburring of a piece

4. Periodically stop to inspect the edge for smoothness and remove any remaining burrs or rough spots.
5. Once deburring is complete, carefully remove any debris or shavings from the work area with a broom.
6. After deburring, inspect the plastic piece to ensure that all edges are smooth and free from jaggedness.

Testing

Purpose

Implementing a joint testing plan ensures the accuracy and reliability of furniture joints, addressing key objectives, such as identifying errors during cutting processes and establishing acceptable ranges of interference between joint components.

Joint Testing

To ensure a quality and repeatable fit of the joints in the furniture, a joint testing plan was created. The goals of the plan are to:

- Determine the error introduced by the machine used to cut the furniture pieces.
- Determine the acceptable range of interference between the two different pieces of a joint.

The first goal was to determine the error introduced by the shop equipment used to manufacture the design. As the design is cut out, the ShopBot cannot exactly cut the dimensions given in the computer-aided-design (CAD) and computer-aided-manufacturing (CAM) program. The difference between the CAD measurements and physical manufactured model is the machine offset. This testing plan determined the specific error present in the Innovation Hub's Shop bot and whether this error is within the acceptable tolerance range of the joints. This machine error will differ between different models of the ShopBot and is machine specific. This part of the testing will need to be repeated at the beginning of the manufacturing process and the CAD designs adjusted accordingly to the new offset for the machine in Ghana.

The second goal of the joint testing plan was to determine the range of joint geometry that comprises an acceptable fit. This is the acceptable tolerance range that the manufactured joint can have. The tolerance range will be determined for both the *x* and *y* dimensions of the two different types of joints in the current designs: the puncture and slot joint. These geometries are shown in Figure 14.

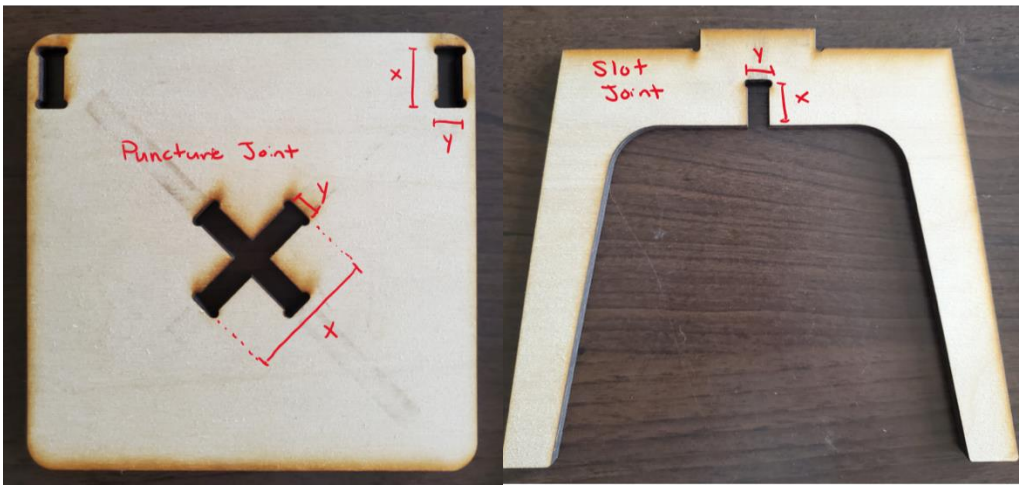


Figure 14: The different joint types present in the furniture designs

This testing will not need to be repeated since this tolerance range is design specific, not manufacturing specific. For more specific information on how to conduct the joint testing, the spreadsheets and data, and how the data was analyzed, refer to the documents below:
JointTestingPlan_Final.docx
JointTestingSpreadsheet.xlsx
Joint Testing Takeaways.pptx

From our completed testing, it was found:

- The Innovation Space ShopBot consistently cut away 0.002 inches extra from our desired dimensions. To compensate, each joint dimension in the CAD model was offset to account for the extra material taken away. This offset will be different for the machine in Ghana, follow the joint testing plan to determine the new offset.

- The acceptable interference range is 0 inches to 0.0158 inches. Any interference outside of this range would result in a loose or overly tight fit.
- The ShopBot and sheets are not consistent enough to grantee a joint fit when producing large quantities of chairs. More precise manufacturing methods will be needed in the future.

BIFMA Testing

Introduction

BIFMA **(**Business and Institutional Furniture Manufacturers Association) is a global standards and certification organization for a variety of furniture products to ensure safety, quality, durability and comfort. Countdown CES utilized these standards as a reference for testing protocols to validate our furniture prototype designs. The type of test performed and the results are shared below.

Table 1: Chair BIFMA testing

Test Done	**Result (Pass/Fail)**
Strength Test –Functional Load	Pass
Strength Test –Proof Load	Pass
Drop Test	Pass
Stability Test - Backward	Pass
Stability Test- Forward	Pass

Table 2: Table BIFMA testing

Test Done	**Result (Pass/Fail)**
Strength Test –Functional Load –Concentrated	Pass
Strength Test –Proof Load –Concentrated	Pass
Strength Test- Functional Load- Distributed	Pass
Strength Test –Proof Load –Distributed	Pass

Quality Assurance Plan

Purpose and Background

- Why is Quality Assurance Important?

  Quality Assurance (QA) is a systematic process that ensures the end user will receive a product that meets standards. Ensuring the quality of a product is integral to maintaining

the safety and satisfaction of customers. Receiving a faulty product could endanger and harm people who have placed trust in the products of Countdown CES. These are more than just legal obligations to the people who use the products but an ethical obligation as a company to produce quality products that help people.

- What will QA look like for this project?

  The following section will outline a process for inspecting the pressed plastic, checking the furniture joinery, and reclamation of scrap material. This QA process works best for small-scale production and must be reevaluated for larger-scale production. An overview is depicted in *Figure* 15.

Flow Chart

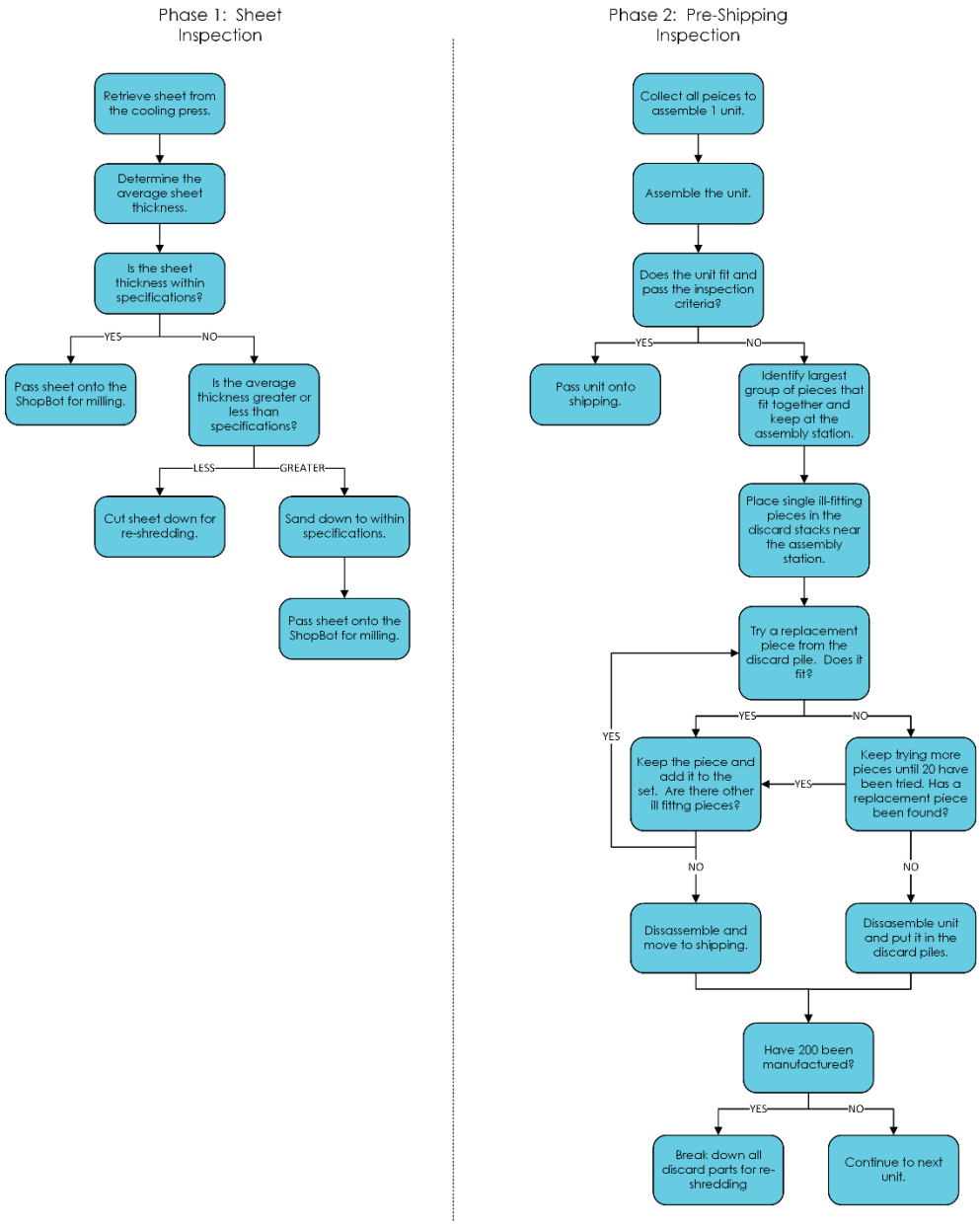


Figure 15: Quality assurance flow chart

Step by Step Instructions and Pictures

The following set of instructions further explains the different components of the flow chart depicted above in *Figure* 15.

Sheet Inspection Instructions

Required Materials:

- Fully cooled sheet
- Digital Calipers

- Calculator
- Hand Planar
- Reciprocating Saw

Inspecting the sheets before any pieces are cut is the first part of the QA process. Catching quality errors in this stage will save time, money, and effort.

1. Pull a sheet off the cooling press once cooled to room temperature and place it onto a workstation or table.
2. Measure 5 locations along each edge with digital calipers and take average of each edge. See Figure 16 and Figure 17.

Figure 16: Example of a sheet thickness measurement

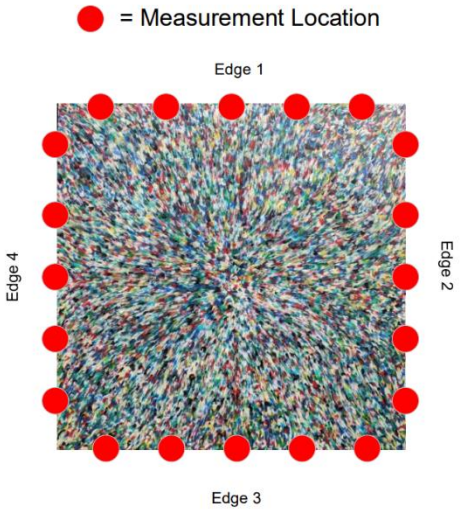


Figure 17: Measurement locations for each sheet edge

a. If any average measurement is greater than 0.770 inches, sand down the sheet to 0.755 inches with a hand planar.

Figure 18: Hand planar

i. Remeasure the sheet and if within the above-specified limits, pass it onto the ShopBot for milling.

3. If any average measurement is less than 0.740 inches, then cut the sheet with a reciprocating saw into pieces and re-shred for a new sheet.

Figure 19: Example of a reciprocating saw (Sawzall)

4. If the sheet is within the specifications, pass onto the ShopBot for milling.

Pre-Shipping Inspection Instructions

Once a piece of furniture has all the necessary pieces cut out and deburred, the chair or table will be completely assembled to verify the product is ready for shipping. Ideally, each unit could be packaged right after the finishing process, however the chosen CNC mill is not accurate enough to have a qualified process and ensure a working product each time. The joint testing section covers this in more detail. A complete assembly is therefore required to ensure a working and safe product reaches the customer.

In the future, more accurate manufacturing methods can be implemented. Statistical process control can then monitor the manufacturing process and ensure an acceptable percentage of failures.

Required Materials:

- 1 Chair or Table Assembly
- Mallet
- Workbench
- Reciprocating Saw

1. Collect all the required pieces to build one unit of either the chair or table. In this example, the chair is used. A picture of the required table pieces is also included below.

Figure 20: Required pieces for one chair assembly

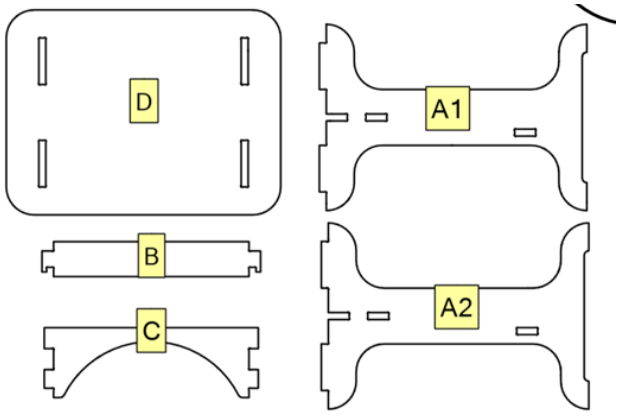


Figure 21: Required pieces for one table assembly

2. Once all the pieces have been gathered, a worker will attempt to assemble the unit.

Figure 22: An example of a fully assembled chair that passes the criteria

a. If the unit passes the three below criteria, it can be moved to the shipping bay after disassembly:
    i. Fits and passes a visual inspection (shown above).
    ii. Fits with the use of a mallet.
    iii. Does not pull apart under its weight.
b. If a joint fails one of the criteria described above, then proceed to step 3.

3. Separate the fitting and non-fitting pieces into different locations on the workstation.
4. Identify the largest group of fitting pieces and keep them at the workstation, example shown below, and return the other pieces to the discard piles.

Figure 23: Example of a large group of fitting pieces. Not all large groups will contain this combination of pieces.

5. Take additional pieces from the discard piles to replace the ill-fitting pieces from the original set.

   a. Repeat step 4 for a total of around 20 times or until a suitable replacement is found.
   b. If a replacement is not found, proceed to step 6.
6. Disassemble the product completely and place the pieces in their corresponding discard piles.
7. After 200 units have been produced, any parts not in a complete set will be cut with a Sawzall and re-shredded for new sheets.
   a. Note: The 20 times and 200 units is an over-approximation to avoid re-shredding the pieces.

Disclaimer:

This is an example QA plan with room for improvement. This is meant to serve as a guide and example of what needs to be checked and studied as the furniture is being produced. Changes may be needed depending on machinery and results.

Testing in EPICS

Testing, within the limited time and resources of EPICS, has shown that assembly and disassembly do not negatively impact the sturdiness of the furniture. This was accomplished by:

- Once a week for a total of 15 weeks the chair and table were assembled and dissembled 1 time.
- At the end of this durability test the furniture showed no negative impact of the joint fit.

From this test, we can confidently say the furniture will not experience a negative effect from prior assembly before shipping.

In addition, we also performed a variety of strength and usability testing to ensure the designs were safe, work well in a classroom, and fit the target student population. It was found that the chair and table passed the project's approximation of BIFMA testing standards.

Re-Shredding Sheets

Included in the QA plan is a process for reclaiming waste and scrap plastic. HDPE has a limited number of times it can be re-melted before it starts to degrade. Further testing is required to prove the efficacy of re-shredding the plastic. This testing can include:

- Single batch recycling where one sheet is continuously re-shredded and melted until the final product is no longer within standards. This will help determine if re-melting will have a discernable impact.

- Percentages of shredded scrap will be mixed in with fresh shredded and tested to see if the mix impacts the sheet and product quality.

Both are important future testing areas and out of the scope of this E-guide.

Shipping Plan Recommendations

Purpose and Background

This section of the E-guide will cover an estimated size and weight of shipping for each unit of the furniture. Since the furniture was designed with easy and low-cost shipping in mind, all the designs are shipped disassembled in uniform boxes.

A fully developed shipping plan is beyond the scope of this project. This section will provide possible examples of what a shipped package could look like and will discuss further areas of research that will be needed for a comprehensive plan.

Since the chair and table are flat-pack design, more of them can be packed together to be shipped out. Use foam padding or another form of biodegradable padding(such as biodegradable packing peanuts) in order to protect the furniture until it is opened and assembled. Cardboard and bubble wrap can be used, but it would not be as sustainable, which is elemental to this project. It is required by FedEx that the package be no more 150 lbs for the packaging suggestions mentioned above. If the package exceeds 150 lbs, then additional cushioning and moving blankets will be needed.

Ensure that all parts of the furniture are covered by the packaging, and use extra boxes to separate individual chairs if needed.

Packaging Materials

To establish an efficient shipping plan, inspiration from IKEA's shipment model can be utilized. Similar to IKEA, flat packing techniques should be implemented to maximize package space, reduce shipment costs, and reduce environmental impact. Shipping the furniture by their components in flat packing will optimize transportation efficiency.

To ensure the packaging plan is sustainable, more environmentally friendly packaging alternatives should be considered. For example, biodegradable packaging such as cornstarch-based plastic alternatives can be implemented when shipment requires use of plastic. For shipment containers, recycled cardboard should be implemented to promote the circular economy. Water based inks and adhesives should be implemented for labeling and sealing to reduce the release of harmful chemicals into the environment.

Shipping Weight and Size

- Total Weight of Chair:
- Total Weight of Table:
- Approximate dimension sof the chair and table once assembled:
    - Chair:
    - Table:
-

Future Areas of Research

- Costs of shipping
    - Shipping will depend on weight of the package, number of units being transported at a time, distance from site to destination, and more,.
- Sourcing packing materials
    - There are many sustainable options for packaging the furniture.
    - Some options for creating custom packaging include:
        - https://www.ecoenclose.com/
        - More information regarding things to look out for can be found here: https://www.cruzfoam.com/post/eco-friendly-furniture-packaging-exploring-the-future-of-sustainable-living
- Transportation (trucks, etc.): OUT OF SCOPE
- Infrastructure available at the manufacturing site:
    - Ensure that machinery and equipment needed to operate it are available at the site, packaging and shipping should also be included in the machinery in order to properly transport the furniture and do it in an efficient manner
    - Potentially look into sustainable power sources in order to power the site and the machinery (can use hydropower, wind turbines, solar panels, etc).

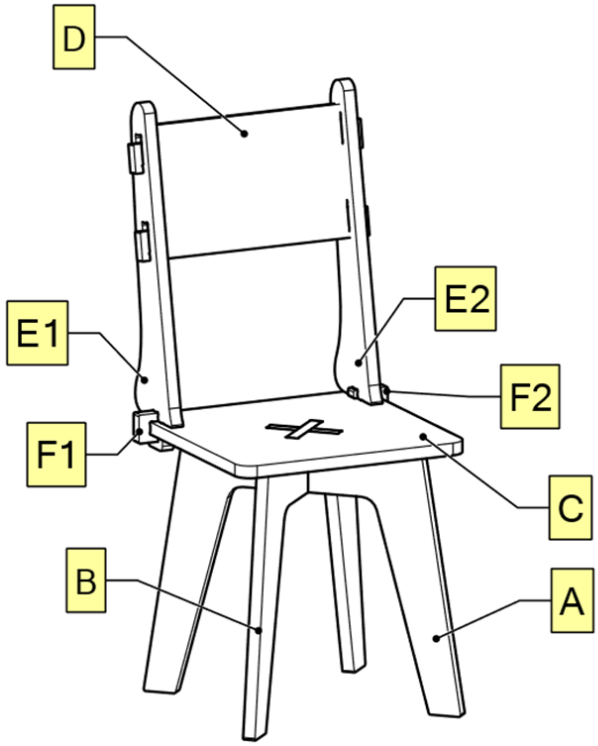
Instruction Manuals

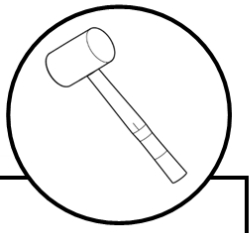
Purpose and Background

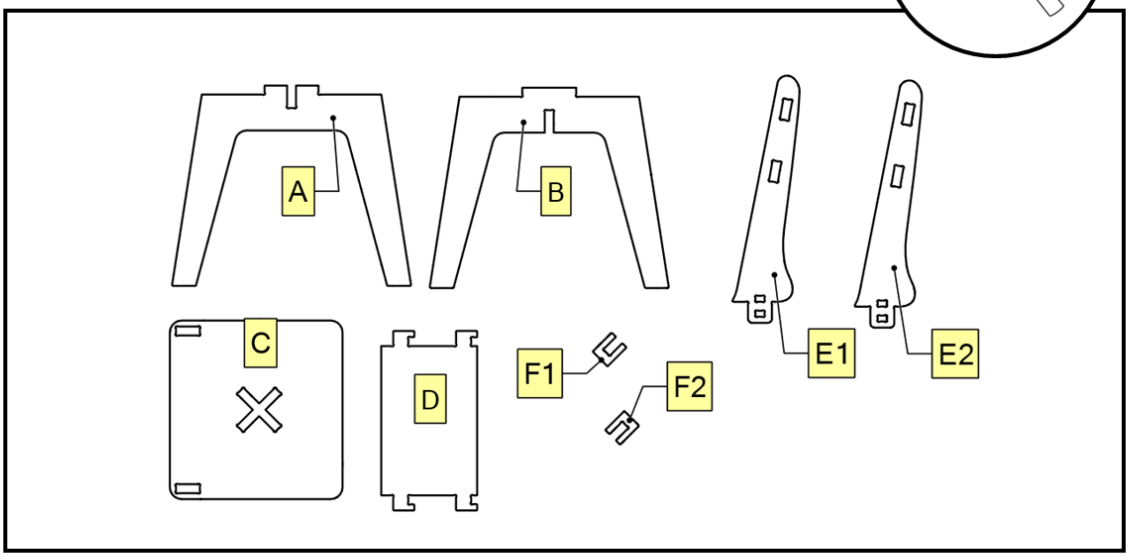
This instruction manual will help you to assemble the table and chair. It has been created without the use of any words so that it can be understood and interpreted by people who speak any language. Each of the pieces is lettered and the steps are numbered. The manual has a simple picture layout which is followed vertically and walks the user through the basic assembly. The manual is made for users in Ghana and created to make the implementation of the furniture in school seamless. The instruction manual is specifically designed to be versatile and easy to follow for people of all backgrounds. Copies are available in ".pdf" for in the project package.

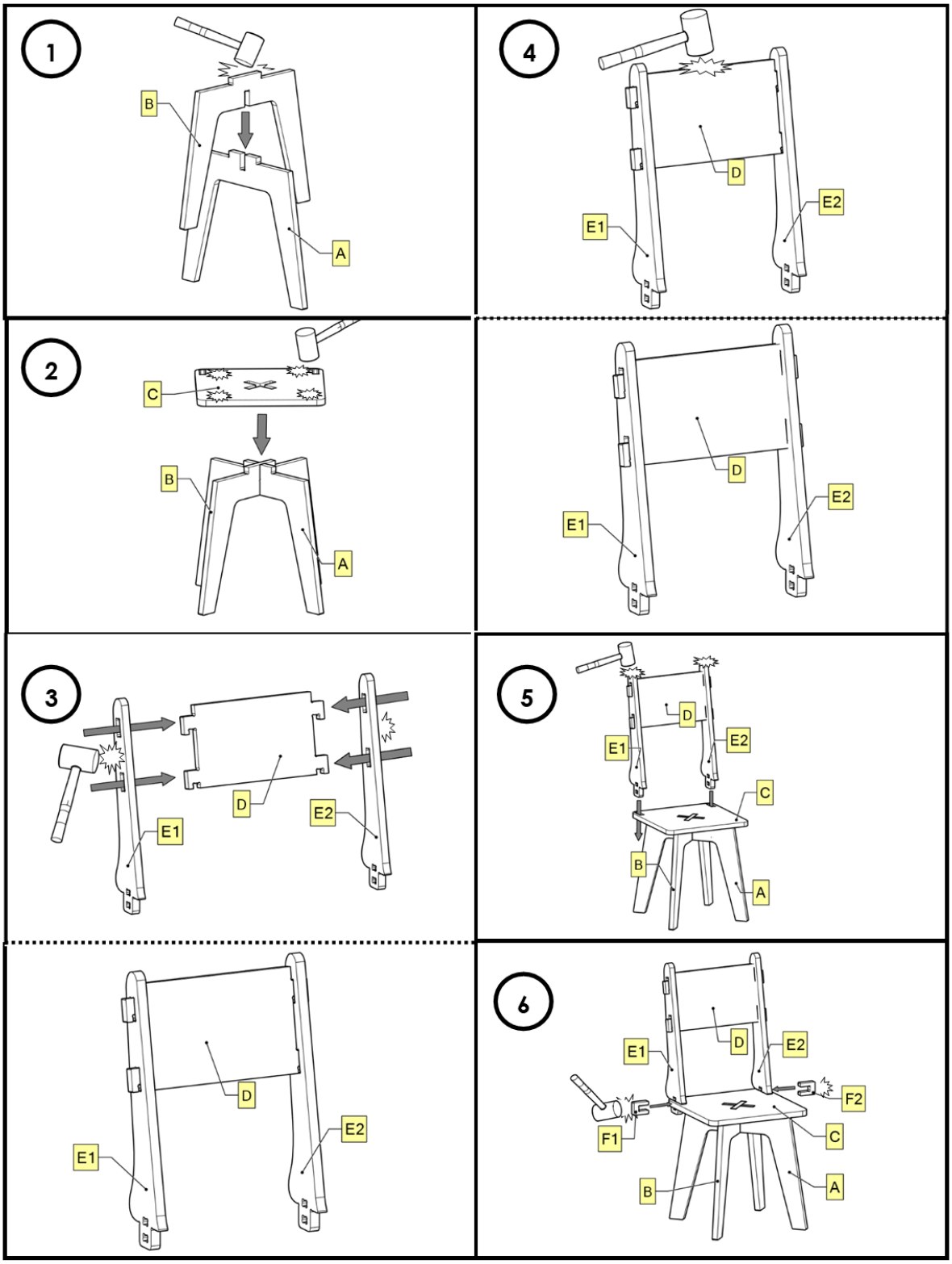
"Chair Name" Instruction Manual

Countdown CES, 2024





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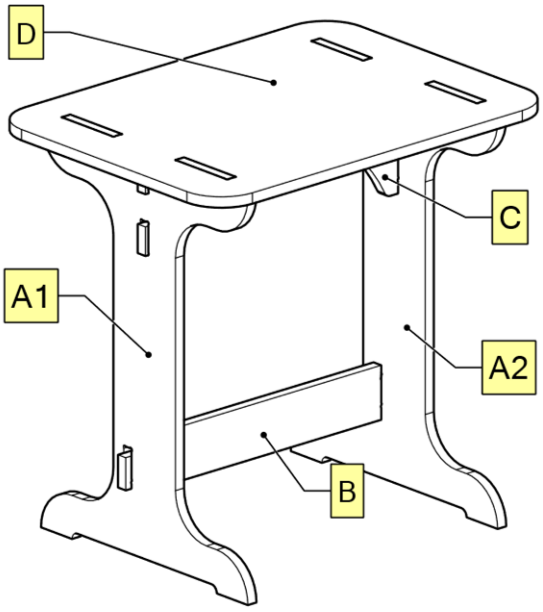
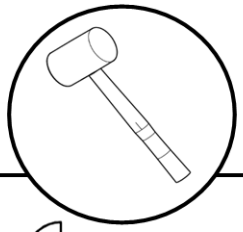
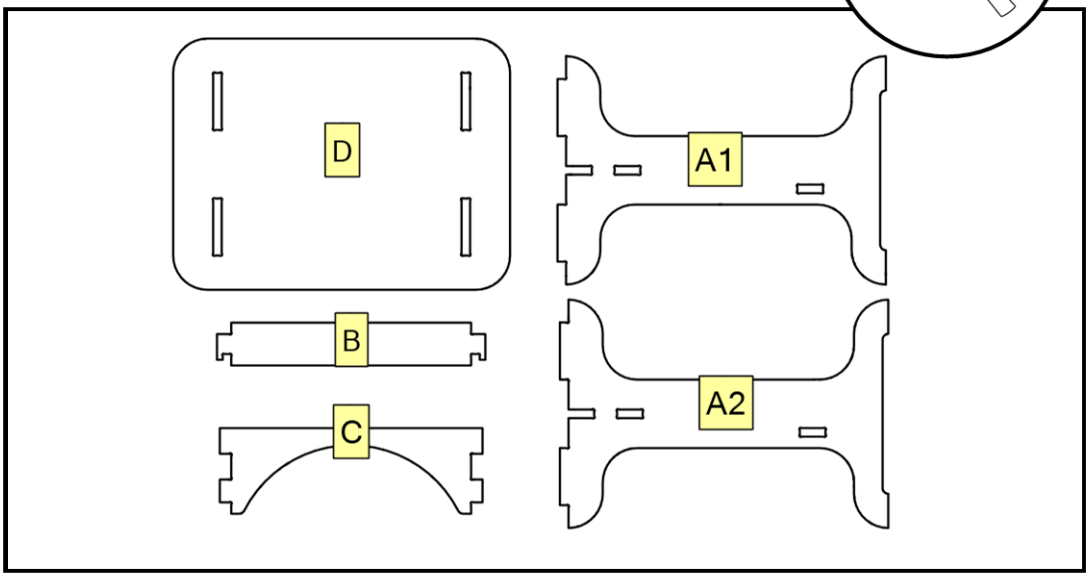
A

"Table Name" Instruction Manual

Countdown CES, 2024







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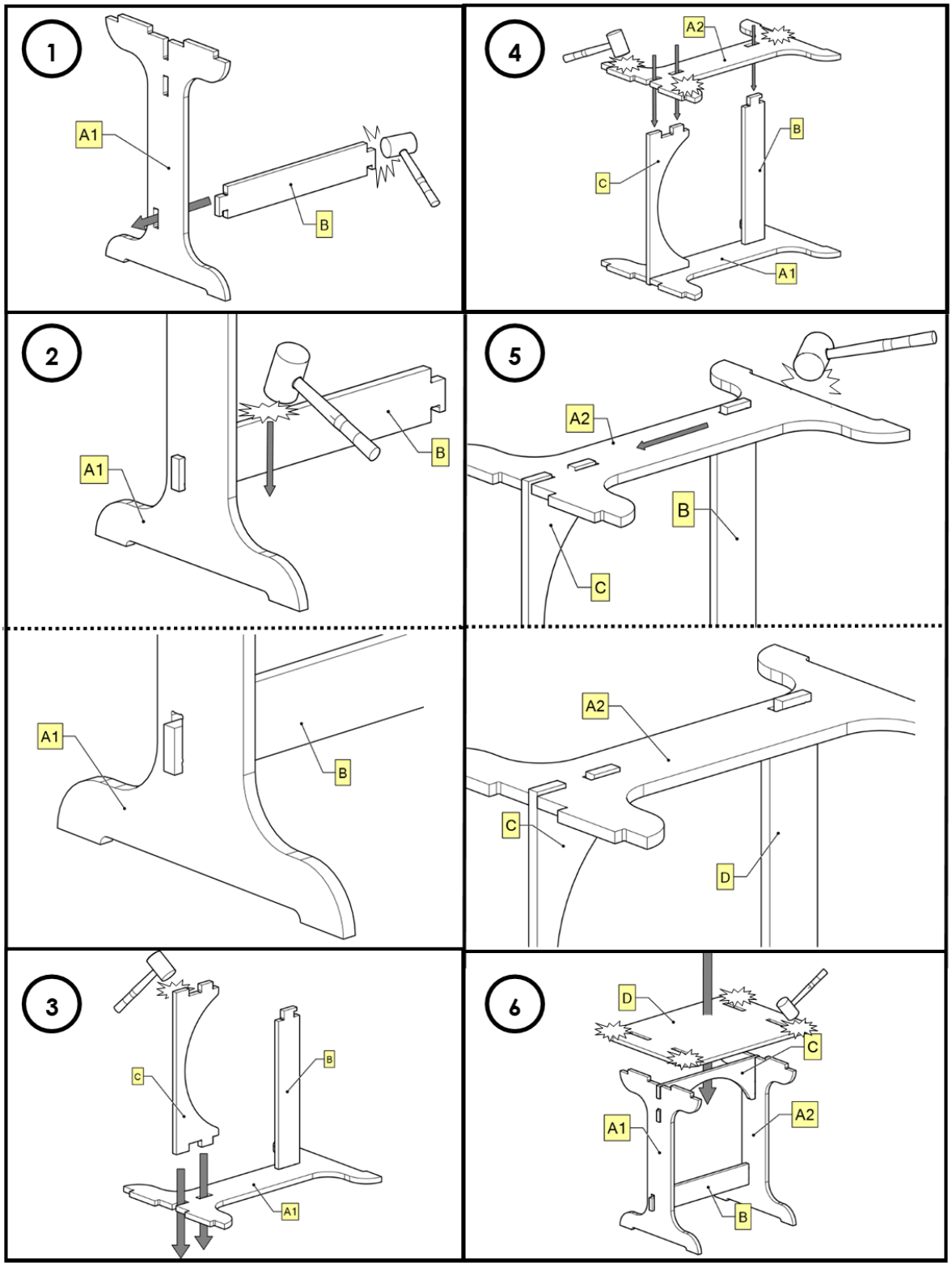
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Appendix

Appendix will provide the checklist to finish the E-guide and start a micro factory. In addition, a revision table is also included.

Requirements Table

User Need #	Need Description	Requirement #	Requirement Description
1	Uses the Precious Plastic (PP) sheet processing tools	1.1	The unprocessed plastic shall be shredded with the PP shredder.
		1.2	The sheets shall be made using the PP sheet press.
		1.3	The pressed sheets shall be cooled in the PP cooling press.
2	Must be designed flatpack	2.1	The chair and table shall be assembled on site and a 2D part design.
3	Created using recycled plastics	3.1	The table and chair shall be made from recycled HDPE plastic.
4	Manual/documentation on creating project	4.1	An E-guide detailing manufacturing, quality checks, detailed BOM, and an instruction manual shall be provided to the community partner.
5	Durable furniture	5.1	The chair and table shall follow the restrictions of BIFMAX6.1-2012.
		5.2	The chair shall hold a minimum 150 lb and the table 225 lb.
6	Usable in a classroom setting	6.1	The chair and table shall be easy to handle and able to be moved around

			while assembled.
		6.2	The chair seat height shall be 16" to 19".
		6.3	The chair backrest height shall be 12"-16" from the top of the seat.
		6.4	The chair backrest shall have an angle of 11-12 degrees for comfort.
		6.5	The table shall have a tabletop height of 28"-30".

Startup Check List

- Perform machine error testing to determine the CAD offset.
    - Adjust CAD and VCarve file.
- Finalize the QA plan.
- Finalize the shipping plan.
- Acquire training for each piece of equipment.
- Determine the scheduled maintenance of each piece of equipment.
- Determine if the manufacturing and assembly process create viable products.
- Determine the viability of re-shredding.

Revision Table

Revisor Name	Revision Date	Revision Number	Reason for Revision
Emma Mickelsen		0	Initial Release/ E. Mickelsen