OpenOak

Preparing, Editing, Milling, and Finishing Guide

Introduction

CNC routing can be a complicated process, and turning milled elements into finely polished pieces can require patience and a keen attention to detail. This project is meant for people who want to explore larger-scale CNC projects in a guided and planned manner, while still offering a certain level of customizability and hand craftsmanship. This instructional document will outline the project specifications, including file formatting, CNC settings, and material details. It will also describe the steps for file editing and set up, much of which is demonstrated in the software Adobe Illustrator or Rhinoceros 3D- both these softwares are only available in full after purchasing but have free trials that will work for the needs of this project.

What skill prerequisites are there for these projects?

These projects were designed with the intention of offering free plots to makers who want customizable, flat-packable, and easily deconstructed furniture. OpenOak does not supply materials or machining. The **ability to access and run a CNC machine**, as well as **the desire to do basic woodworking and construction**, lie at the core foundations of these projects. Familiarity with Adobe Illustrator or Rhinoceros 3D is not required, though they will make file editing easier.

Part 1: Picking materials

Frequently Asked Questions

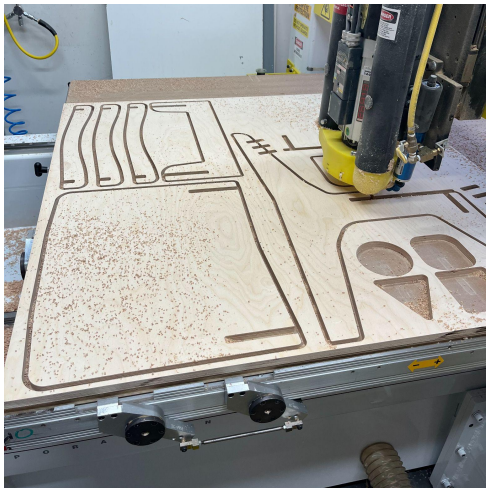
What material is best suited for this project?

Birchwood does not dent or nick easily, and has a hardness comparable to oak or walnut, with a light color and wavy grain. A trusted favorite for CNC routing is Baltic birch plywood, which is naturally stronger and more durable than other types of plywood, and typically runs at a relatively reasonable price. However, at the time of this project (early 2023), the conflict within the Baltic region has impacted the availability of Baltic birch and roughly doubled its price. As a result, as well as for the convenience of this project, **cheaper/lower quality birch plywood can be used instead**, as long as it is chosen according to the quality standards listed below.

What is the difference between high and low-quality materials?

Mainly, **consistency**. Lower-quality hardware store plywood can be used to create really good end results, but the trouble lies in identifying good and bad materials. The wood used for the original run of this project was a slab of prefinished ¾" birch plywood store-bought at a home improvement retail outlet. It came prefinished with a UV clear finish but was graded at C2, which is on the lower end of quality. This piece was chosen because of its cost, and to demonstrate the capabilities of cheaper material. Expensive plywood, like baltic birch, has a hardwood core, meaning the internal ply layers are usually made out of the same hardwood as the exterior. Cheaper plywoods, like what can be bought at Lowe's or Home Depot, tend to have a Fir core, meaning that **it can be more likely to chip** when only partially cut. When using low-quality plywood, it is vital to find a slab that has the best characteristics for CNC milling.

What are the important qualities of material?



It is vital that the plywood slab is **well-laminated** and **as flat as possible**. The CNC machine relies on an even surface, and it is vital for the quality of the finished product that the materials used are stable and flush. If the CNC is not given viable materials, the final result can turn out chipped, jagged, crooked, or warped. The nature of this project is to experiment with the CNC machine's capabilities while minimizing the typical cost of furnishings, and it would be a shame to have to replace or redo any aspect of the milling process when it might have been avoided earlier on.

How reliable are the listed material thicknesses?

It's important to note that, while the plywood will be assigned a thickness by manufacturers, **there are variations in this variable as a result of quality and environment**. In dry places, like Colorado, wood behaves differently than it does in moist places, like New Jersey, due to the way wood interacts and swells in different environments. As a result of this nominal thickness, **it is important to measure the true depth of the plywood**, ideally to a thousandth of an inch, and utilize the test cuts available in the project print files. Utilizing an electronic caliper, ¾ inch plywood can measure anywhere from 0.685 and 0.710 inches, though rarely does it ever truly exceed 0.750 inches.

Summary

To summarize the ideal materials for this project, the priority are:

1. a 4'x4' flat, ¾" slab of birch plywood, with minimal surface or laminate defects (per milling project).
2. An electronic caliper capable of measuring to the thousandth of an inch.
3. A CNC router with a 4'x4' bed or bigger.

Part 2: File Editing

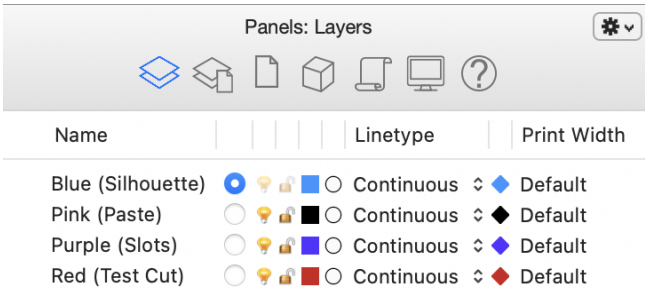
Notice: There are four layers to each .ai file.

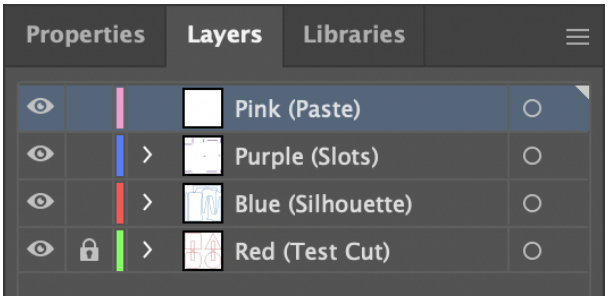
a. The Blue (Silhouettes) Layer consists of **the outer silhouettes** of each piece of furniture. These shapes will be referred to as “silhouettes” from here on.

b. The Purple (Slots) Layer consists of **the rectangle that will become the slots** for the furniture to key together once cut. These shapes will be referred to as “slots” from here on.

c. The Pink (Paste) Layer consists of nothing, as it is **a place to paste offset slots**.

d. The Red (Test Cuts) Layer consists of **a piece to test cut**, to test slot thicknesses before milling the final pieces.





Why use .ai files?

Adobe Illustrator files, denoted by their .ai file type, are vector files, so the visual images within them are created directly from geometric shapes defined by mathematical formulas defined on a Cartesian plane. This means that the graphics held within them can be made infinitely large without losing quality, so these files can be repurposed on smaller, 3’x3’ plywood to create smaller or child-sized furniture as well. This specific format can be utilized in many vector editing softwares, due to the popularity of Adobe Illustrator as a program- this practice is demonstrated here, where OpenOak’s free .ai files can be edited either directly in Adobe Illustrator or uploaded into Rhinoceros 3D (Rhino 7). However, for those not using Illustrator or Rhino, .dxf, .svg, and .png formats are also available for download.

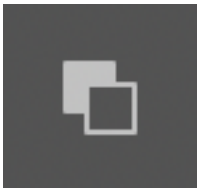
Editing via Adobe Illustrator:

To make the editing process easier, ensure now that the Blue (Silhouettes) and Red (Test Cuts) layers are both locked (Denoted by a small 🔒 to the left of the layer name in the tab titled “Layers”). This means any elements on these layers will not be clickable on the file itself.

Test Cuts

There are 4 test cut samples in the corner of each document. These test cuts reside on the Red (Test Cuts) layer and are meant to hold different slot thicknesses to test which measurement is most compatible with the plywood material. Each of the four test cuts has a different silhouette to ensure the user can differentiate between the thicknesses of the slots.

1. Click on the slot on top of one of the test-cut silhouettes. It should be highlighted in red.
2. In the Transform section of the Properties tab, change the W: value from 0.7 to the desired thickness. If the “**Properties**” tab is not visible: Click on the “**Window**” tab at the very top of the screen. Click on “**Properties**” as it appears beneath the top bar.
    a. Recommendation: Based on research and product testing at OpenOak, the ideal thickness for test slots is steps of 0.002” above the measured thickness of the plywood milling material. Example: If the plywood measures as 0.696” thick, then the test slots would be 0.698” 0.700” 0.072” and 0.074” for the best results.
3. Repeat this process 4 times, to experiment with which thicknesses reap the best fit.
4. Individually highlight the tabs and borders of **only one silhouette** at a time.
    a. Note: Highlighting everything at once will remove pieces from the document. If this happens, click CMD+Z on Mac and CTRL+Z on Windows to undo.
5. Once each silhouette and its respective slots have been highlighted, look to the “**Properties**” tab and find the section titled “**Pathfinder**.” Beneath “**Pathfinder**” are 4 pairs of squares. Click the second pair to the left, which should feature **a dark square atop a light square**. This will cut rectangular tabs into silhouettes in the size and shape of the slots.



6. In the layers tab, click the eye icon (👁️) next to the Blue (Silhouettes) and Purple (Slots) layers. This will turn each layer invisible.
    a. Ensure the red layer is visible and unlocked.
7. The base file is now ready to format for milling. Continue to mill **only** these 4 blocks.

How to decide which thickness to use based on the test cuts?

The best thickness will be one that can fit another piece tightly within it, while not splintering or scratching too severely. These slots should be as tight as possible since CNC-routed or slot-based furniture can loosen up over time due to variables in environmental or material quality. If the set will be stained, it should be noted that those materials will add thickness to the pieces, but the difference is negligible enough to be ignored during test cuts. If the final set is cut too tightly, hand tools, sandpaper, or the test of time can all be utilized to fix these errors- while it will make the furniture harder to take apart in the beginning, it is recommended that the slots fit very tightly right at the beginning, to prevent or delay any possible wobbling.

In the event that test cuts are not possible, become corrupted, or do not help decide the right thickness, the rule of thumb at OpenOak is **+0.006 inches** from the measured thickness of the material. So, if the measured thickness of the material is 0.697 inches, a thickness of 0.703 inches would be given to each slot.

Manually change the tab widths

The first way to edit files in Illustrator is to manually highlight the furniture slots and change their thicknesses to match the material. This is the easiest way to reliably change all the slot measurements, but it can be time-consuming.

1. In the layers tab, click the far left box next to the Blue (Silhouettes) and Purple (Slots) layers, ensuring an eye icon (👁) reappears. This will turn each layer visible.
2. Click on the tab titled **Properties** located to the left of the **Layers** tab. Note: If the **Properties** tab is not visible, click on the **Window** tab at the very top of the screen, then click on **Properties** as it appears beneath the top bar.
3. Highlight a slot by clicking on its border. A slot is highlighted if its borders turn blue and features white squares at each of its corners.
4. Under the **Properties** tab on the right of the screen, there is a section titled **Transform**. Beneath that, there are four boxes filled with values- focus only on the values in the boxes **W:** and **H:**
    a. One of these boxes will be filled with a value of “0.7 in.”
        i. This is the only size value that the user will be editing. **Do not change any other value in these boxes**, unless specifically advised.

ii. If ***none*** of the boxes are filled with the value "0.7 in:" either:

1. There is more than one slot highlighted on the page. To fix this, highlight only one slot at a time.

2. The slot highlighted on the page is angled at "190" or "10" degrees. To fix this, change the angle value to 0, input the desired width, and re-input the original angle of the slot.

b. Highlight the value "0.7 in" and type in the measured width of the material.

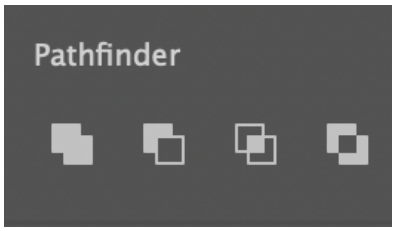
i. This should be the **only** value being changed in the four boxes directly beneath "Transform."

c. Repeat this process for all slots in the document.

5. Once all slots have been modified to the correct thickness, return to the **Layers** tab, and unlock the layer by clicking the lock (🔒) icon next to the layer name.

6. Individually highlight the tabs and borders of ***only one silhouette*** at a time. Note: Highlighting everything at once will remove pieces from the document. If this happens, click CMD+Z on Mac and CTRL+Z on Windows to undo the error.

7. Once each silhouette and its respective slots have been highlighted, look to the **Properties** tab and find the section titled **Pathfinder**.



8. Click the second pair of squares to the left, which should feature a dark square atop a light square. Note: This will cut rectangular tabs into silhouettes in the size and shape of the slots.

9. Repeat this process for each silhouette, until there are no slots left in the file.

10. Before milling, delete the 4 test cuts, and their related slots.

a. If a test cut is desired before milling the full piece, follow the above directions for the Red (Test Cuts) layer.

b. Ensure the Blue (Silhouettes) layer is visible, and the Purple layer is empty.

11. ***Check that all slots are of the right thickness.***

12. The base file is now ready to format for milling. Continue to mill the entire file.

Change tab widths based on offsets

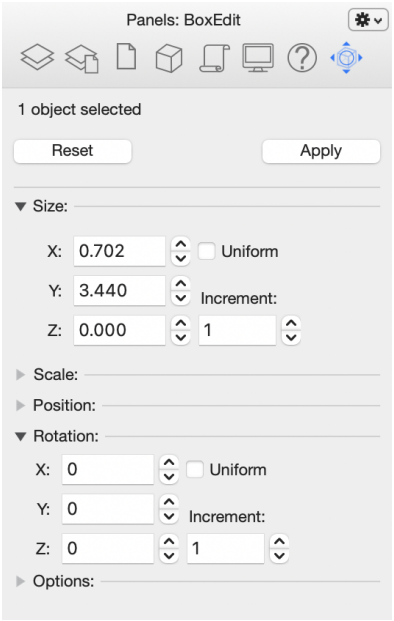
The second way to edit files in Illustrator is to utilize the Offset feature built into Adobe Illustrator. This is the best way to ensure all the slots are edited the same amount, but it may be confusing or overwhelming to people new to Adobe Illustrator or unfamiliar with offsets.

1. Ensure the Blue (Silhouettes) and Red (Test Cuts) layers are both locked (denoted by the lock icon (🔒) on the left of each layer.)
2. Highlight everything.
    a. Either click CMD+A on Mac or CTRL+A on Windows or highlight via click+drag over the whole canvas.
3. In the top bar, click **Object**. Scroll down and hover over **Path**, and click **Offset Path**.
4. Type in the desired offset value. Click OK.
    a. Since offsets work by expanding or shrinking a distance equal to the offset value ***on all sides***, the offset value will be half the difference between 0.7 and the desired thickness. Example: If the desired thickness is 0.695", then the offset value will be -0.0025". The difference between 0.695 and 0.7 is 0.005, and half of 0.005 is 0.0025.
    b. If the desired thickness is ***smaller*** than 0.7 inches then this value must be ***negative*** because negative values shrink the offset, while positive values expand it.
5. ***Do not click anywhere on the canvas.*** The program has automatically highlighted the correct slots, and clicking away will require manually selecting the correct slots.
    a. In the event that the automatic selections have been undone, click CMD-Z on Mac or CTRL+Z on Windows and repeat steps 3 and 4.
6. Without clicking the canvas, select the Pink (Paste) layer, ensuring that it is unlocked (denoted by the unlocked lock icon (🔓) to the left of the layer.)
7. On the canvas, ***right-click*** anywhere, hover over **Arrange**, and click **Send to Current Layer.**
    a. This action has moved all the correct slots to the Pink (Paste) layer and left all the default slots on the Purple (Slots) layer.
8. Click the eye icon (👁️) to the left of the Purple (Slots) layer to turn this layer invisible.
9. ***Check that all slots are of the correct thickness.***
10. The base file is now ready to format for milling. Continue to mill the entire file.

Editing via Rhinoceros 3D:

The version of Rhinoceros 3D utilized in this demo is Rhino 7, and older versions of the program may have features placed in different sections of the portal. To prevent any later confusion, the main feature to look for in any older versions is the "BoxEdit" panel. The Rhinoceros 3D user portal can be overwhelming to newcomers, so it is important to take advantage of these instructions or any available online resources when editing.

1. On the top edge of the frame, make sure the **Standard** tab is selected. Find the file icon (📂) and open the .ai file from downloads. **Be sure to preserve units while importing.**
2. On the side, there will be a panel titled **Panels: Layers.** Visible there are 4 layers in the document. Note: The colors of each layer may be different as seen on the canvas, but their titles and roles remain the same.
3. Underneath **Panels: Layers** Will be a series of icons. One will be a 3d box with arrows pointing in the 4 cardinal directions. Click this icon. It will be called **Panels: BoxEdit.**
4. There will be a series of sections in this tab- ignore all of them except **Size** and **Rotation**.
5. Highlight a slot by clicking on its border. A slot is highlighted if its borders turn yellow and features white circles at each of its corners.
6. Under the **Size** tab on the right of the screen, there are four boxes filled with values- focus only on the values in the boxes **X:** and **Y:**
    a. One of these boxes will be filled with a value of "0.7 in."
        i. This is the only size value that the user will be editing. ***Do not change any other value in these boxes***, unless specifically advised.
        ii. If ***none*** of the boxes are filled with the value "0.7 in:" either:
            1. There is more than one slot highlighted on the page. To fix this, highlight only one slot at a time.
            2. The slot highlighted on the page is angled at "190" or "10" degrees. To fix this, change the angle value to 0 under the **Rotation** section, input



the desired width in the **Size** section, and re-input the original angle of the slot.

b. Highlight the value “0.7 in” and type in the measured width of the material.

   i. This should be the ***only*** value being changed in the four boxes directly beneath “Size.”

c. ***Make sure to click* Apply *in the top right corner***, or the new value will not hold.

d. Repeat for all slots in the document.

7. ***Check that all slots are of the right thickness.***

8. Before milling, delete the 4 test cuts, and their related slots.

   a. If a test cut is desired before milling the full piece, follow the above directions for the Red (Test Cuts) layer.

9. The base file is now ready to format for milling. Continue to mill the entire file.

Alternative Options:

There are many different vector editing software available. The reason Adobe Illustrator and Rhino 7 are referenced here is that they are industry-standard programs, and will likely be available for a while to come. Alternatives exist both as downloadable software and browser-based editors, and will almost certainly accept .ai files as options to upload and formats to download, but, for those that don’t, OpenOak also offers .dxf, .svg, and .png file formats. Some options for free or cheap alternatives include:

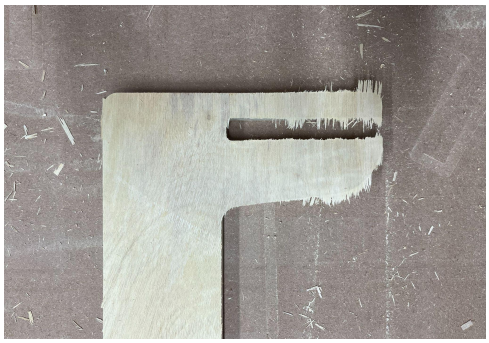
1. Inkscape
2. SketchUp
3. Boxy-SVG
4. Vectornator
5. TinkerCAD
6. FreeCAD

Since these programs are not industry standard, and it is harder to predict what future versions, updates, or iterations might look like, there will not be detailed instructions written here for any of them. However, OpenOak highly encourages experimentation with any one of these options before committing to Adobe Illustrator or Rhinoceros 3D and always recommends utilizing free trials before paying full price for software that will rarely be used.

Part 3: The CNC

Because there is so much variation between machines, this guide will outline the main specifications and universal directives for the milling section of the project.

1. Milling Bit: **a sharp ⅜" straight flute cutter**.
2. Milling depth: Set to either **+0.004 inches or +0.006 inches** more than the measured thickness of the material.
    a. It is likely that a very thin layer of veneer will remain on the edges of the cut pieces. This remnant is easily removed with a piece of sandpaper held at an angle.



3. Toolpaths: there are two possibilities for setting up 2D toolpaths, based on the end result of the edited files.
    a. The slots have all been used to cut out sections of the silhouettes. This would result in having only the Blue (Silhouette) Layer active while milling. If only the silhouettes exist, **the toolpaths will exist only as exterior profiles for everything.**
    b. The slots are still visible in the document and reside on a layer other than the Blue (Silhouette) layer. This would result in having two layers active while milling. If the slots and silhouettes reside on different layers, **the toolpaths for the slots would exist as interior profiles**, and **the toolpaths for the silhouettes would exist as exterior profiles.**
4. Property safety measures: CNC machines can be dangerous when not operated correctly. Be sure to:
    a. **Wear safety goggles and proper footwear** at all times while operating.
    b. Check **the machine is off when changing or replacing tools**. Never use blunt, cracked, or chipped tools.
    c. Check there is **no hardware in the way** of the milling bit.
    d. **Never operate heavy machinery without full mental faculties.** This includes drug use, alcohol, and any illness that would impede concentration.
    e. **Always observe the CNC machine as it is milling**. There is always the possibility of error or malfunction, so be sure there is always someone present when the machine is on.

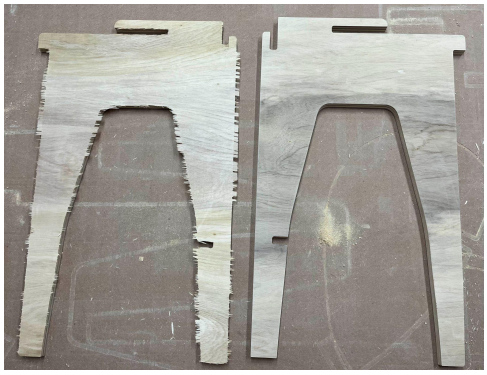
Part 4: Finishing

Filling

Plywood can often have air pockets hidden within its lamination, which some people can find unsightly.

1. To fix air pockets, mix a paste made roughly 50/50 out of wood glue and sawdust, or buy wood filler and patch these holes.
2. It's important to remember to **never sand wet glue** and to cure any filling materials for over 24 hours before sanding, staining, or painting.
3. Filled patches may also **react differently than the wood to stains**, so act accordingly when treating them later.
    a. Not filling gaps in laminate would mean any stain applied later would show up equally across the grain, whereas the filled areas would remain the same color. Note: not filling gaps won't impact the structural integrity of the piece.

Sanding



A key part of a comfortable piece of furniture is the way it feels when it's touched, and that mostly boils down to sanding. While the easiest way to achieve the ideal surface would be to use an orbital sander, which can be bought for as cheap as $30 US, hand sanding can work in a pinch.

1. The best way to sand is to **use ascending grits of sandpaper**, starting at roughly 80 grit and working up to at least 150 grit to remove any splintering and prevent snagging.
    a. Sanding edges and corners is also a good idea, as sharp rims can cut or scratch.
2. Surfaces should be wiped with a dry rag once sanded, then a cloth wet with mineral spirits or water, and make sure all surfaces are completely free of sawdust.
3. **Be careful not to sand below the surface veneer of the plywood**, as this can make for an unsightly grain on the final product
4. Always sand in a well-ventilated area with appropriate PPE.

Staining

Staining furniture can give it a professional appearance, and really highlight the material's quality. However, once a piece of wood has been stained, it can be very difficult to remove.

1. **Stains should always be tested on scrap wood** before being applied to the final product, so break down the scrap from the CNC and practice staining that before deciding to move on.
    a. A great option for experimenting with stains is to practice on any test cuts made during the milling process.
2. Birchwood can also be rather temperamental when it comes to absorbing stains, so explore using pre-stain conditioners with scrap tests.
3. Be sure to follow the directions of the manufacturer on the stain itself.
4. Always stain in a well-ventilated area with appropriate PPE.

Painting

Painting is one of the best ways to really customize furniture and can brighten up an otherwise drab area. There are a lot of options for paint for plywood projects, so do research to find out what will best result in the goal design.

1. Prime first with roughly 2 coats of primer before painting, to give the surface a neutral white tone before adding color.
2. While painting, add as many coats as necessary to achieve the desired effect.
    a. Between each layer, it is also optional to sand the paint with very fine grit sandpaper to give it a smoother finish.
3. Sealing paint is important, as it can chip and flake away over time without proper protection.
4. A great option for experimenting with painting is to **practice on any test cuts made during the milling process**.
5. Every layer of paint added to each piece will thicken it, and may change the way the set fits together. Note: This can be a possible solution to wobbliness as the set settles over time.

Conclusion:

As times change, the way humanity interacts with its surroundings will be ever affected by the evolution of technology. The CNC machine is a widely useful tool, and its many applications can be taken advantage of to assist day to day life. OpenOak wants all their users to enjoy their free, open source, guided projects, and highly encourages customization and innovation when following along. The most important part of these projects, other than safety, is to **have fun!** Be sure to share any final projects with the team at OpenOak.

Contact:

OpenOak@gmail.com
https://www.open-oak.com/

University of Colorado Boulder
320 UCB, 1125 18th St,
Boulder, CO 80309