

Augmented Reality Sandbox

Sandbox Bed and Projector Mount Construction Guide

Compiled for:

Michael Camponovo
University of Tennessee, Knoxville
College of Geography

Compiled By:

Senior Design Students
University of Tennessee,
College of Engineering

PREFACE: Tool Tips

1. Fully read and understand this guide before attempting construction. Steps listed should result in minimal backtracking or partial disassembly during construction.
2. Always adhere to proper shop safety guidelines during construction. All construction should be performed under supervision and while properly utilizing applicable personal protection equipment.
3. Take count of all parts and equipment as they are gathered. Ensure part specifications and dimensions are correct before beginning construction.
4. Verify all equipment integrity prior to use. Inspect equipment for damage. Ensure that the blades are intended for the material to be cut and that they cut straight and level. Always use the right tool for the job.
5. Ensure that all workpieces are well secured. Not only is it safe, but it can ensure greater accuracy of cuts or holes.
6. Finish workpieces by filing, sanding, or otherwise deburring them. Shreds of wood or metal from machining can cause serious injury to handlers or bystanders if not removed and smoothed.
7. Quality of fabrication will result in ease of further construction. Always try to ensure straightness, squareness, or flatness in parts or joints.
8. Step-drill large holes. Start with smaller bits and drill progressively larger holes until the desired diameter is reached.
9. If burrs are present after drilling, plunge a slightly larger drill bit into the surface to remove the burrs and create a countersink.
10. If a hole is found to be slightly misaligned, enlarging it might allow a better fit.
11. Try to use measurements specific to your system during construction. Even a slight deviation from the idealized design presented will need to be accounted for in mated parts. Treat the idealized design as a general guideline.
12. Much of the design presented can be freely modified. Feel free to alter the design to better fit the needs of the user.

STEP 1: Preparing the Sandbox Bed General Dimensions

Once all necessary materials are present and accounted for, construction of the sandbox bed begins with the fabrication of the sheet material used for the bed base. Plywood sheet designated 1/4" but measured as 3/16" thick was used in this particular construction but can be substituted for another material if desired. Figure 1 below shows the basic general dimensions in inches of the bottom of the plywood bed. All corner and midpoint notches are intended to be 1"x1" to fit the vertical 8020 aluminum supports. The hole patterns depicted are explained further on.

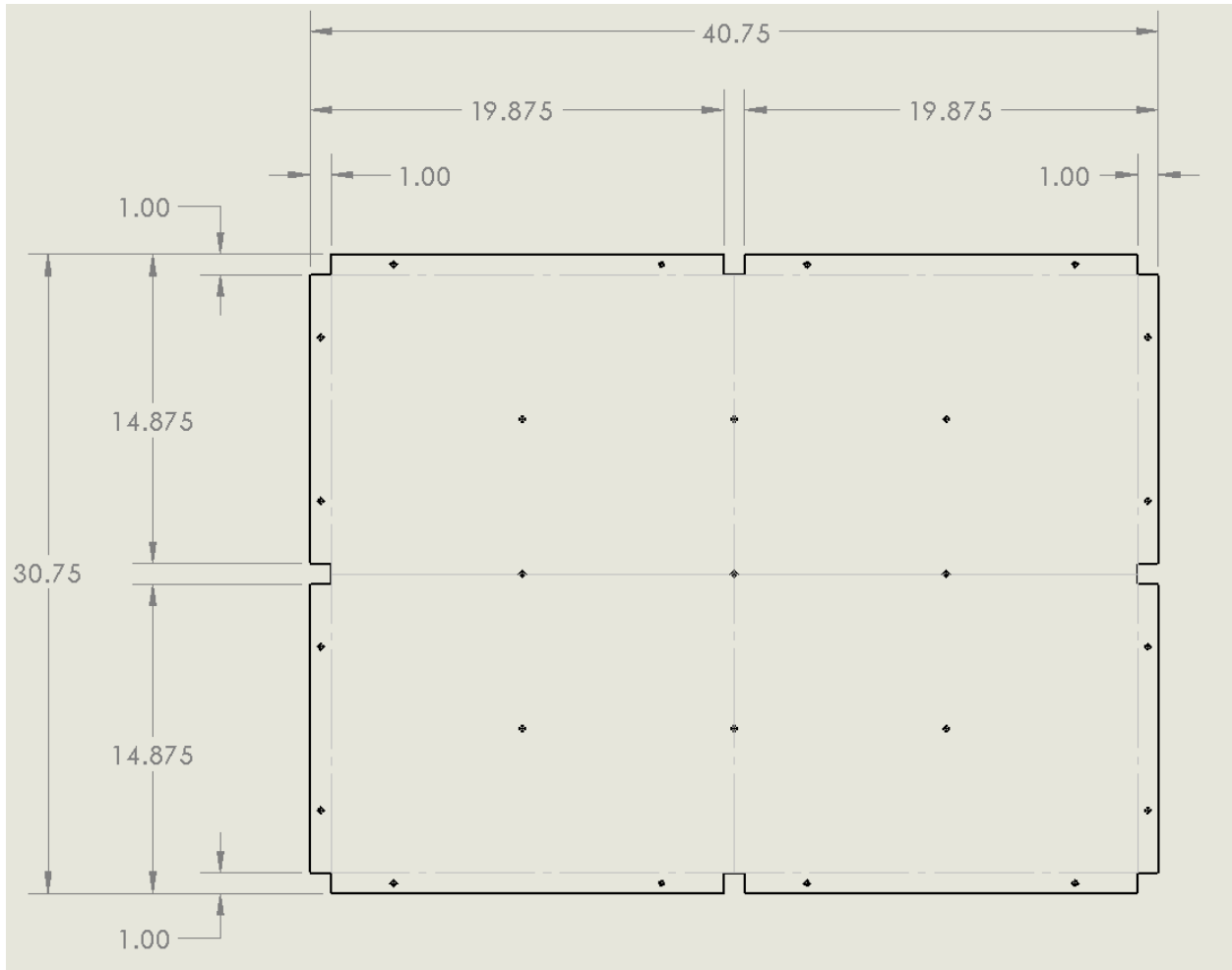


Figure 1. Plywood Base General Dimensions

STEP 2: Sandbox Bed Perimeter Hole Pattern

Once all corner and midpoint notches are cut out, hole positioning measurements can be made. Because the 8020 structure of the bed consists of 1" wide stock, bolts and T-nuts must ride in the central groove. This results in a 1/2" offset of all perimeter holes from the outer perimeter. Figure 2 below shows a suggested bolt pattern, where bolt holes are drilled 3" away from each notch face. Exact hole numbers and positioning can be varied, but a minimum distance of 2" is advised due to the fitting of hidden corner fasteners that will be required later.

For a good fit without precision tools, a bar of 8020 stock can be laid across the edge of the sheet where it would be in the final structure. Trace the edge of this bar along the length of the sheet. Measure half of the distance between that outer line to the edge and mark it on each end. Using the 8020 as a straightedge, connect the marked points and use this new centerline as a guide for your bolt holes.

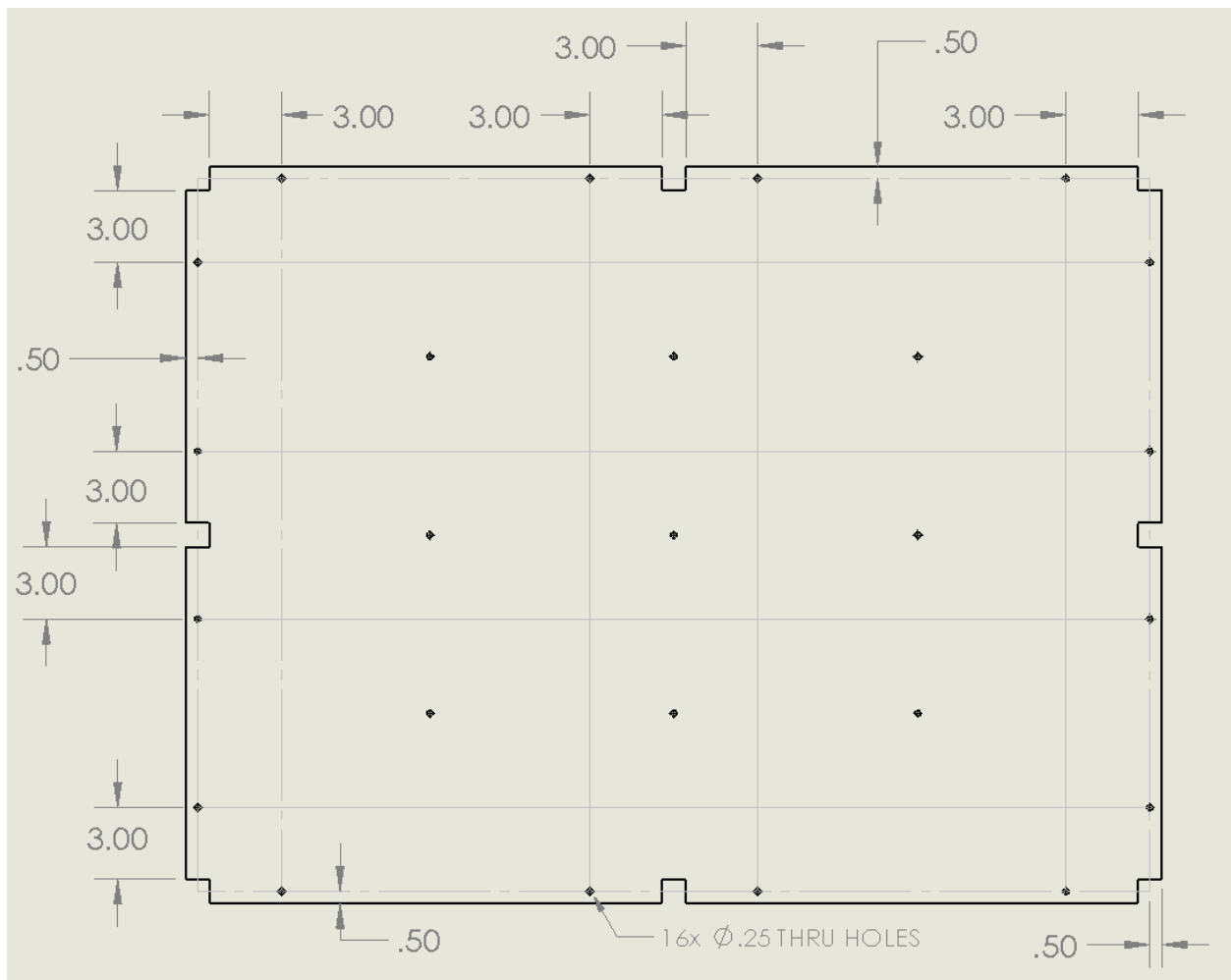


Figure 2. Plywood Base Suggested Perimeter Hole Pattern

STEP 3: Sandbox Bed Interior Hole Pattern

The interior holes to be drilled will determine the patterning of the bars that support the plywood base. Here, five supporting bars are evenly spaced with $7\text{-}7/16''$ between centers. Figure 3 shows a suggested layout with equal spacing of $10\text{-}3/16''$ between three bolts. Guidelines can be drawn as suggested previously to ensure good hole positioning.

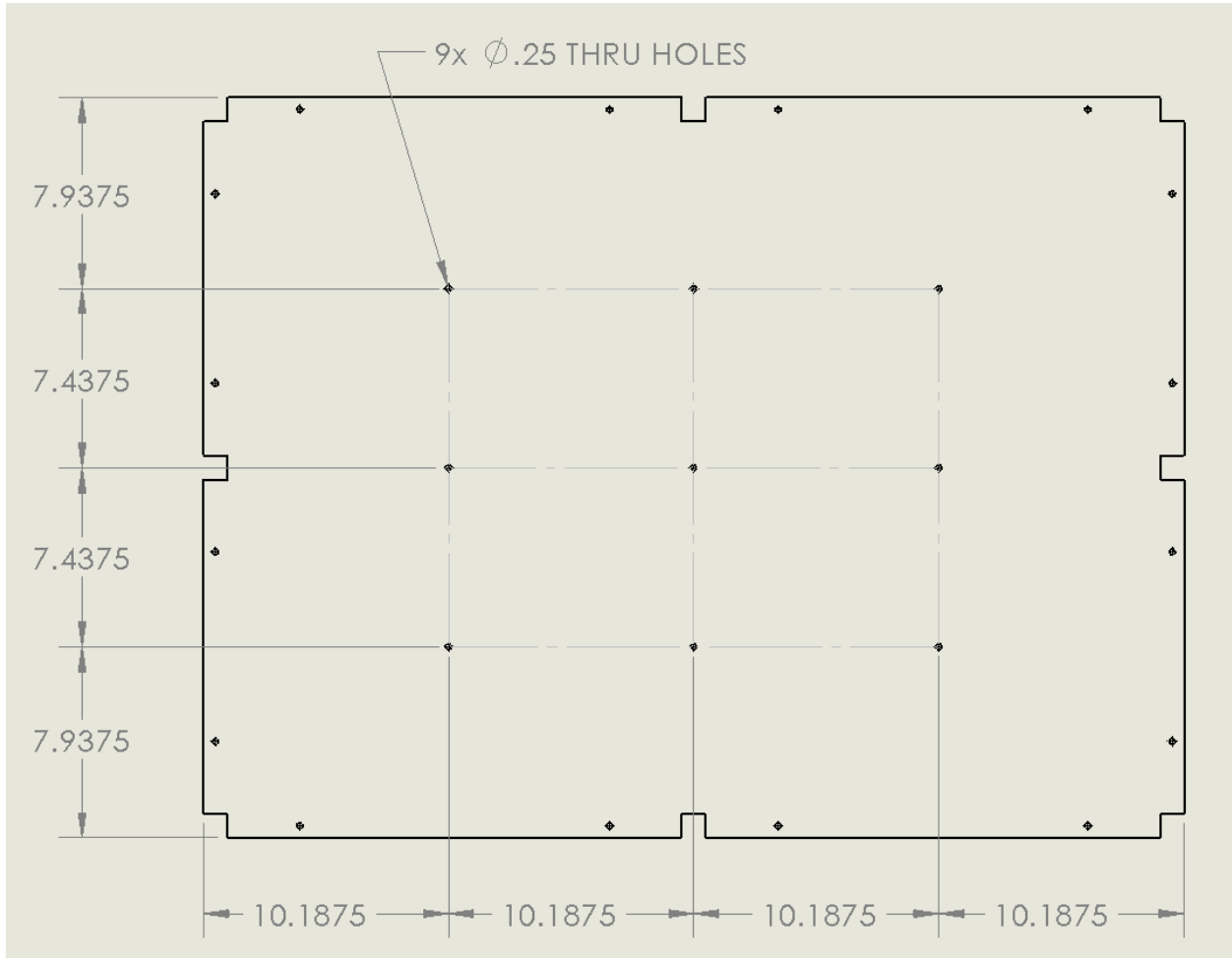


Figure 3. Plywood Base Suggested Interior Hole Pattern

STEP 4: Sandbox Bed Long Wall Preparation

Two identical walls of this type will be required to be made. The height of the walls is determined by the thickness of the base. The thickness of the base and the height of the walls should sum to 6-5/8" in total. Here, a measured 3/16" base thickness results in a 6-7/16" wall height. Top corner square notches must be 1"x1" minimum for the upper ring of the 8020 to fit properly. The channel notch width cut into this piece is determined by the thickness of the adjoining plates. In Figure 4, these are shown to be 3/16" wide, but should be cut slightly wider than anticipated for ease of fitting. For good fitting, extra channel widening can be done on the outer sides of the channel.

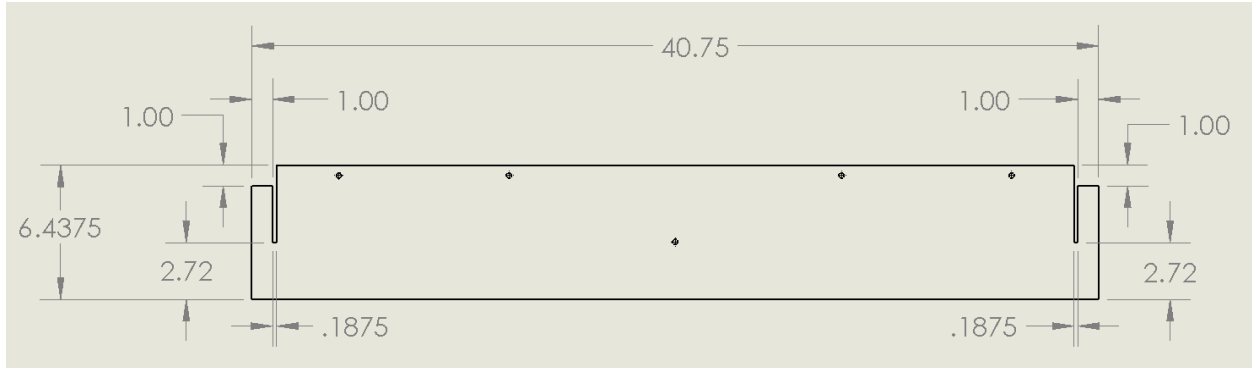


Figure 4. Sandbox Bed Long Wall General Dimensions

STEP 5. Sandbox Bed Long Wall Preparation

The suggested bolt hole pattern is shown below in Figure 5. The exact positioning of these holes is less critical than many other holes, but at least 4 bolts with minimum 3" clearance to edges is suggested to hold the bed wall to the 8020 frame. The four bolts across the top of the wall are ideally 1/2" below the top edge, and a guideline can be traced as described in Step 2. The vertical positioning of the central hole is ideally in the center of the wall or near the height of the notches.

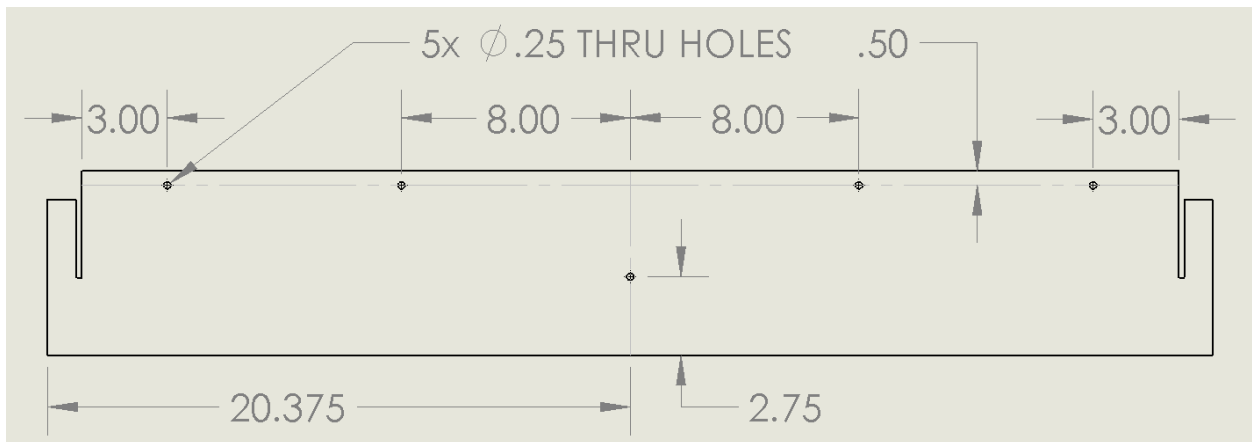


Figure 5. Sandbox Bed Long Wall Suggested Bolt Hole Pattern

STEP 6: Sandbox Bed Short Wall Preparation

Two pieces of this type will be required for the bed. Upper corners have 1"x1" notches for the fitting of the 8020 frame. Again, channel width is determined by the thickness of the joining long wall segments, which is 3/16" as shown here. Bolt holes along the top perimeter are again offset by 1/2" from the top edge. Exact number is variable, but 3 is suggested. Vertical positioning of the center hole is also somewhat variable, but is suggested at 2-3/4" in Figure 6.

Once completed, check the fitting between the long and short wall pieces by slotting them together. If fitting is not vertically correct, extra depth may need to be cut into the channel notches. If one sheet warps or deflects, then the positioning of the channel notches might need checked. Once fitting is as desired, the lining of the bed should be ready for assembly. Painting, priming, staining, or other wood finishing can be performed on the wood now.

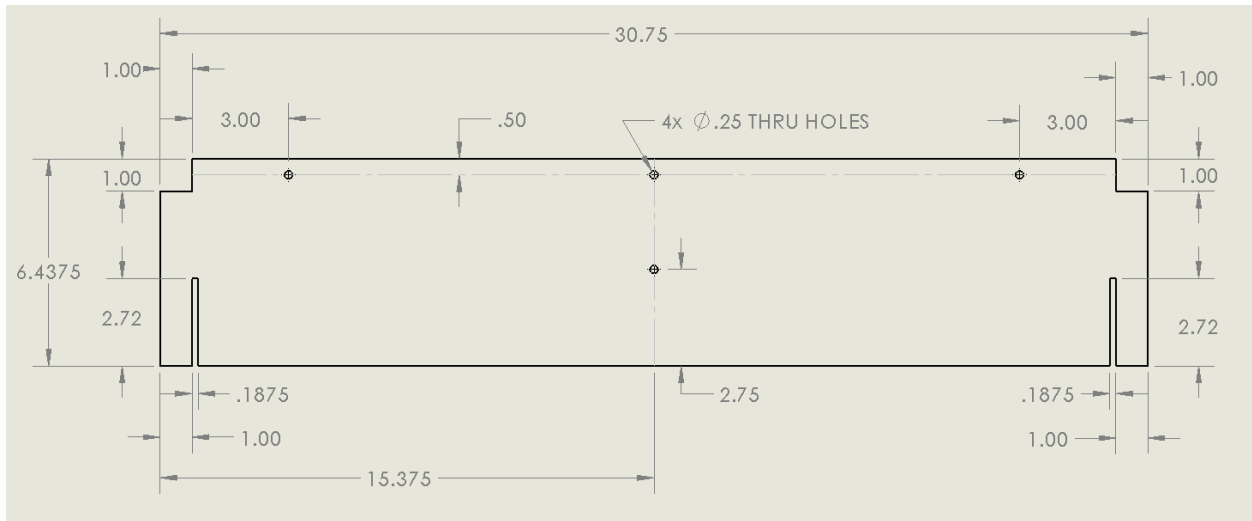


Figure 6. Sandbox Bed Short Wall Schematic

STEP 7: Barstock Preparation

With the bulk of the woodwork completed, the metal 8020 barstock will now require preparation. Table 1 below contains a list of all necessary lengths and quantities of those lengths of barstock that will need to be cut from the raw stock. During this cutting process, it is important to be aware of the width of the cutting blade and how each cut will subtract from the length of the stock. Even more important, all cuts must be well executed. Ensuring clean, 90° cuts during this operation will make assembly much easier.

Table 1. List of Required Stock Lengths

Length (in)	Quantity	Description
50.125	1	Projector Mounting Post
44.50	1	Projector Mounting Post Reinforcement
40.75	4	Long Side Members
38.75	3	Bed Underside Ribs
28.75	4	Short Side Members
18.75	1	Kinect Distance Adjustment Member
9.75	1	Kinect Attachment Member
7.75	1	Kinect Assembly Vertical Post
5.625	8	Bed Upright Member

Raw barstock was found to be cheaper per unit length as the purchased bar size increased. Using the five bars of 10'x1"x1" 8020 barstock specified in the bill of materials, cuts were performed as mentioned in Table 2. In Table 2, the reported excess stock does not include consider kerf of the saw blade. The actual reported excess stock will be shorter than values listed.

Table 2. Suggested Cuts for 10 Foot Raw Stock

Bar #	Lengths of Cuts (in)				Excess (in)
1	40.75	(2x) 38.75	-	-	1.75
2	(2x) 40.75	28.75	7.75	-	2
3	40.75	38.75	28.75	9.75	2
4	(2x) 28.75	52.125	5.625	-	4.75
5	(7x) 5.625	18.75	44.5	-	17.375

STEP 8. Attach Rib Members to Underside of Plywood Base

Insert 1/4"-20 bolts of 1/2" length into the interior bolt pattern as shown in Figure 7. Unless explicitly mentioned, all bolts in this assembly will be of this dimension. Every bolt should be loosely mated with a T-nut as shown in Figure 8. It is very important that the lip of the nut face away from the bolt head as shown. Leave a relatively wide gap between the nut and the plywood, as the 38.75" segments of 8020 stock will need to slide through this gap, as shown in Figure 9. Snug the bolts to prevent them from coming loose but ensure the newly attached bars can still move.

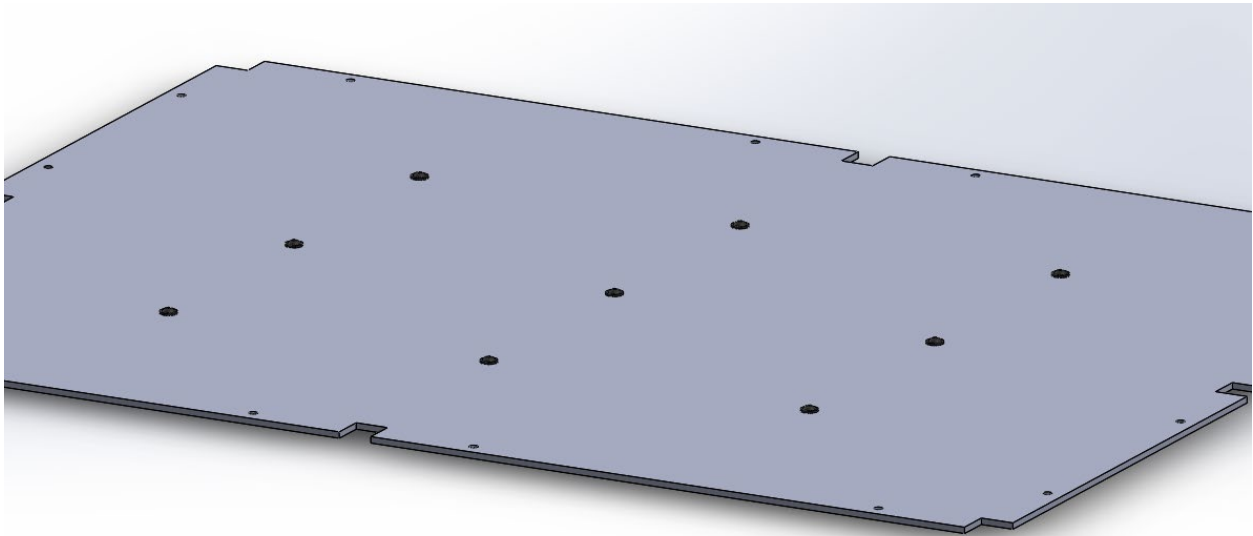


Figure 7. Bolts Filling Configuration

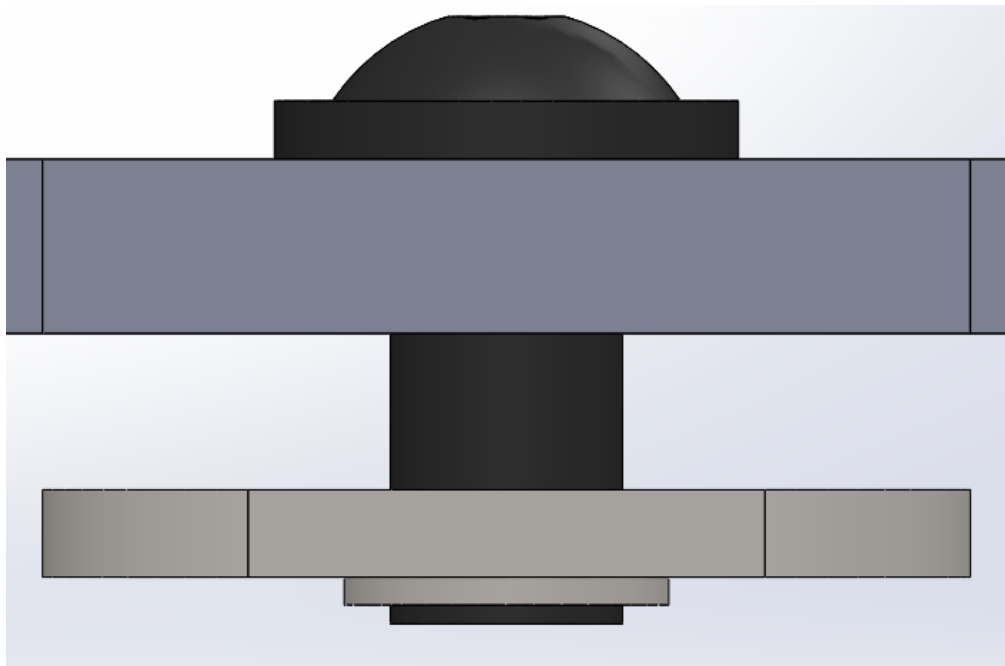


Figure 8. T-Nut Application

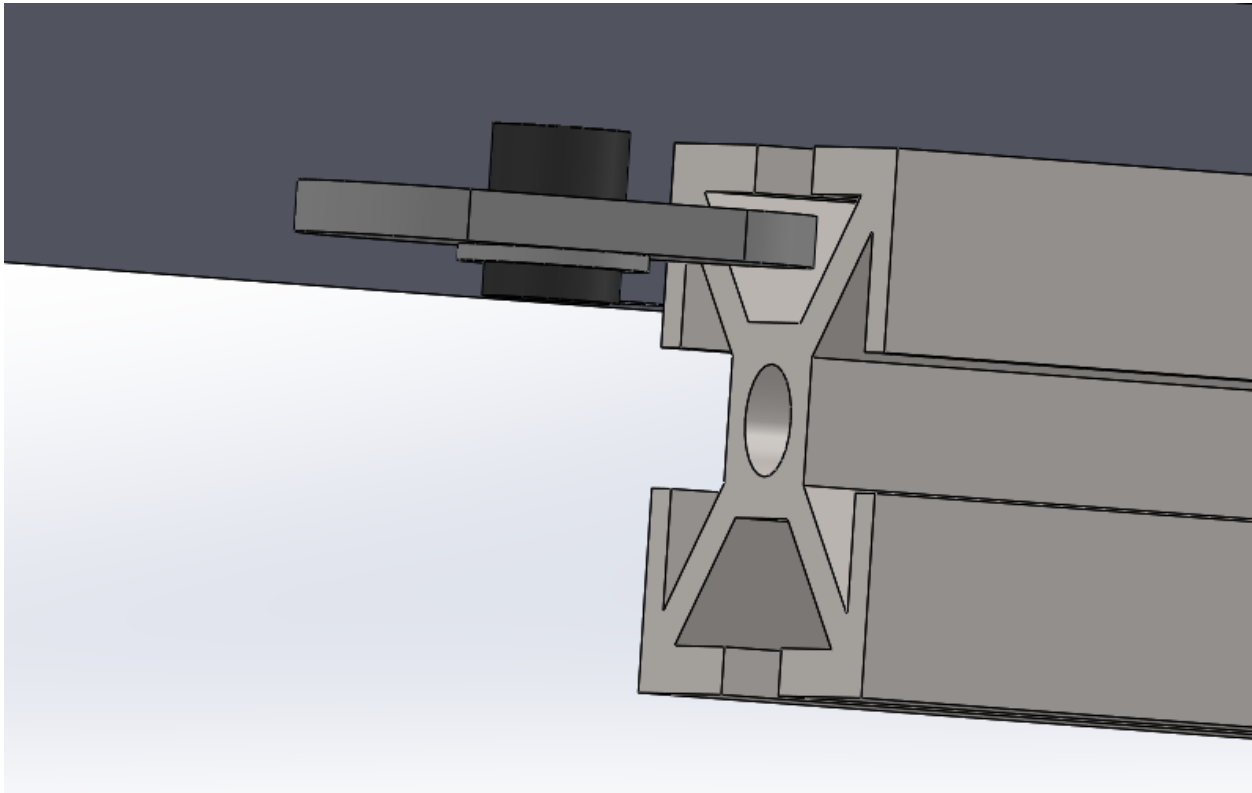


Figure 9. Sliding Barstock Through T-Nut Gap

STEP 9: Attach Side Members to Rib Members

Similarly to Step 8, attach more bolts and T-nuts through the perimeter bolt holes on the short sides of the plywood base as shown in Figure 10. Once completed, two hidden corner fasteners should be inserted into each end of the 38.75" rib members as shown in Figure 11. Gently slide the 28.75" side bar across the base, taking care to ensure the T-nuts and hidden corners slot correctly. At the halfway point, insert two more hidden corner fasteners into the top channel of the 28.75" piece. These will be used later to fasten the midpoint vertical uprights. Once fully the side member is fully slotted, place one additional hidden corner fastener into each of the short members as shown in Figure 13. Finally, snug the bolts while allowing the side member to continue moving.

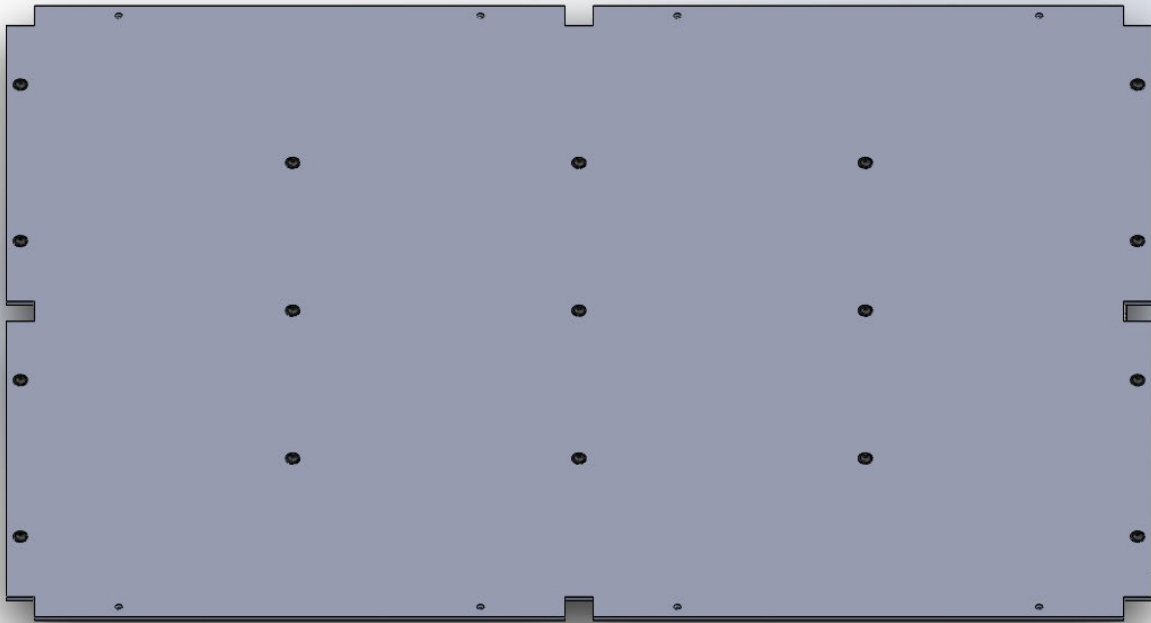


Figure 10. Perimeter Side Holes Filled

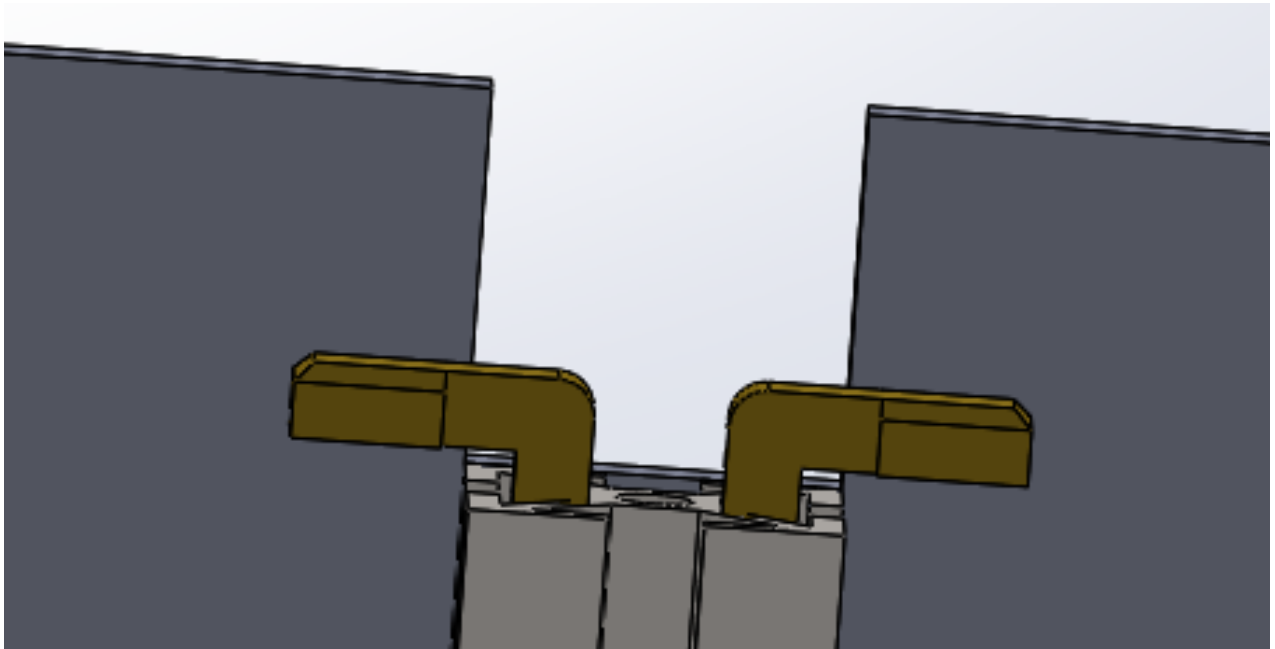


Figure 11. Hidden Corner Placement

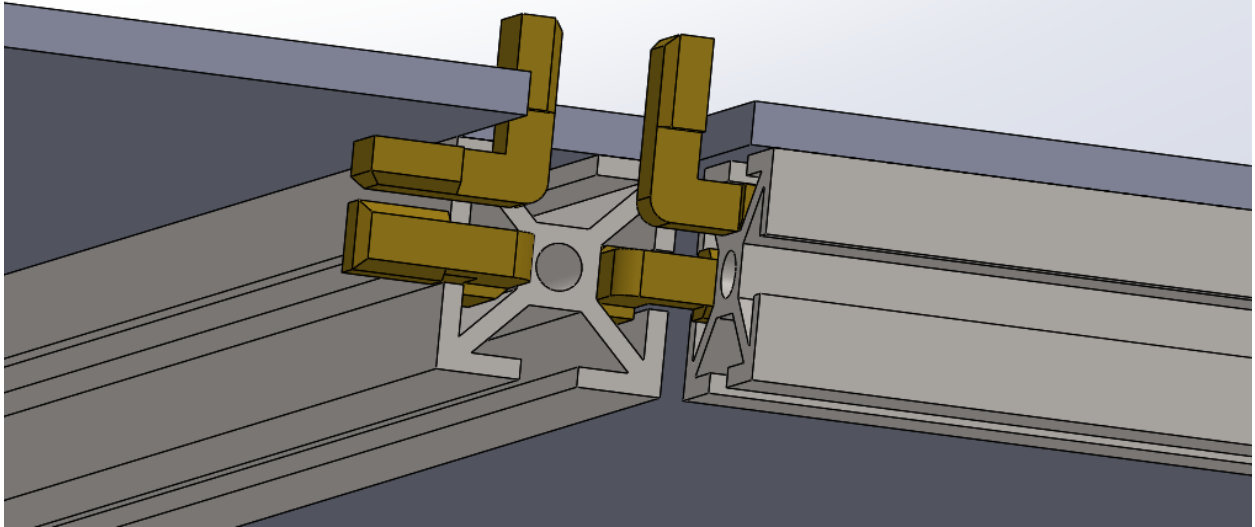


Figure 12. Hidden Corners at the Midpoint

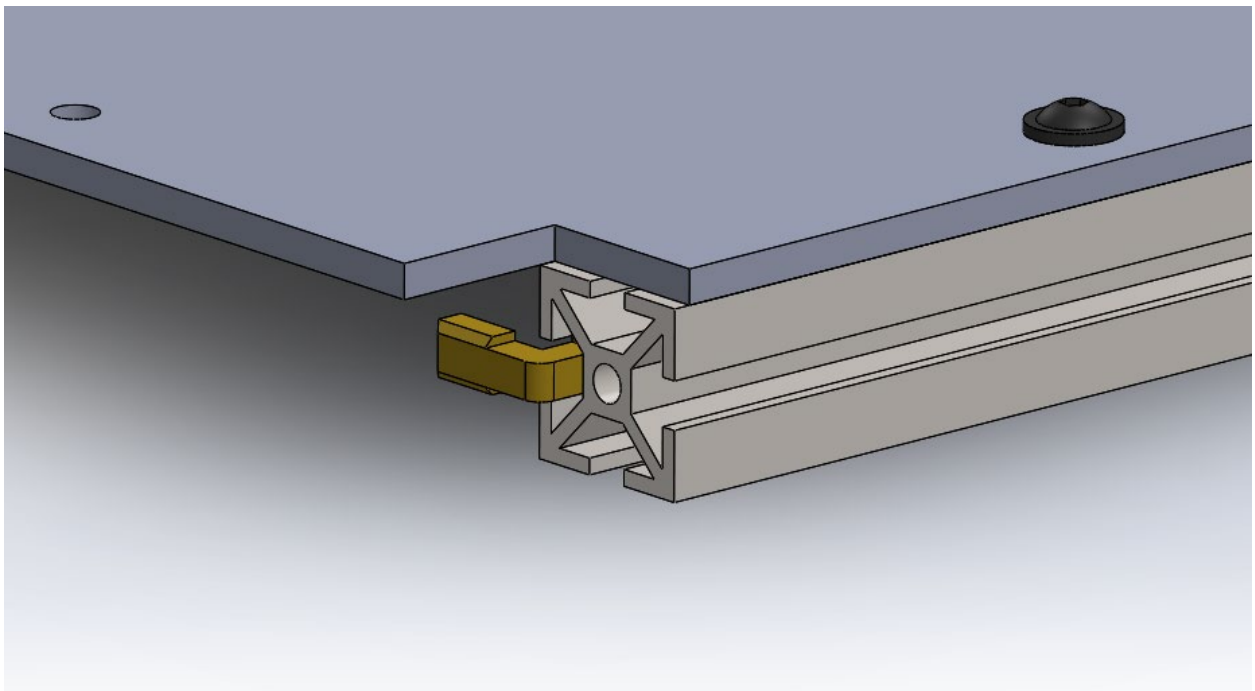


Figure 13. Side Member End Corner

STEP 10: Attach Long Members to Side Members

Once the side members are slotted, place more of the same bolts and T-nuts in the same configuration in all of remaining holes in the bed base. Slot the hidden corner fasteners from Figure 13 through the 40.75" long members as they are fed through the bolt and nut assemblies. At the midpoint of this feeding process, pause to insert additional hidden corner fasteners, (refer to Figure 12). The underside of the final product of this process is shown in Figure 14. In this figure, each of the corners containing hidden corner fasteners is marked red. The top side of the reinforced bed base is shown in Figure 15.

Once this step is completed, use a square or level to check all member alignments. Shift and adjust members as necessary to compensate for uneven cuts or defects. Once alignment is corrected, fully tighten all fasteners and connections.

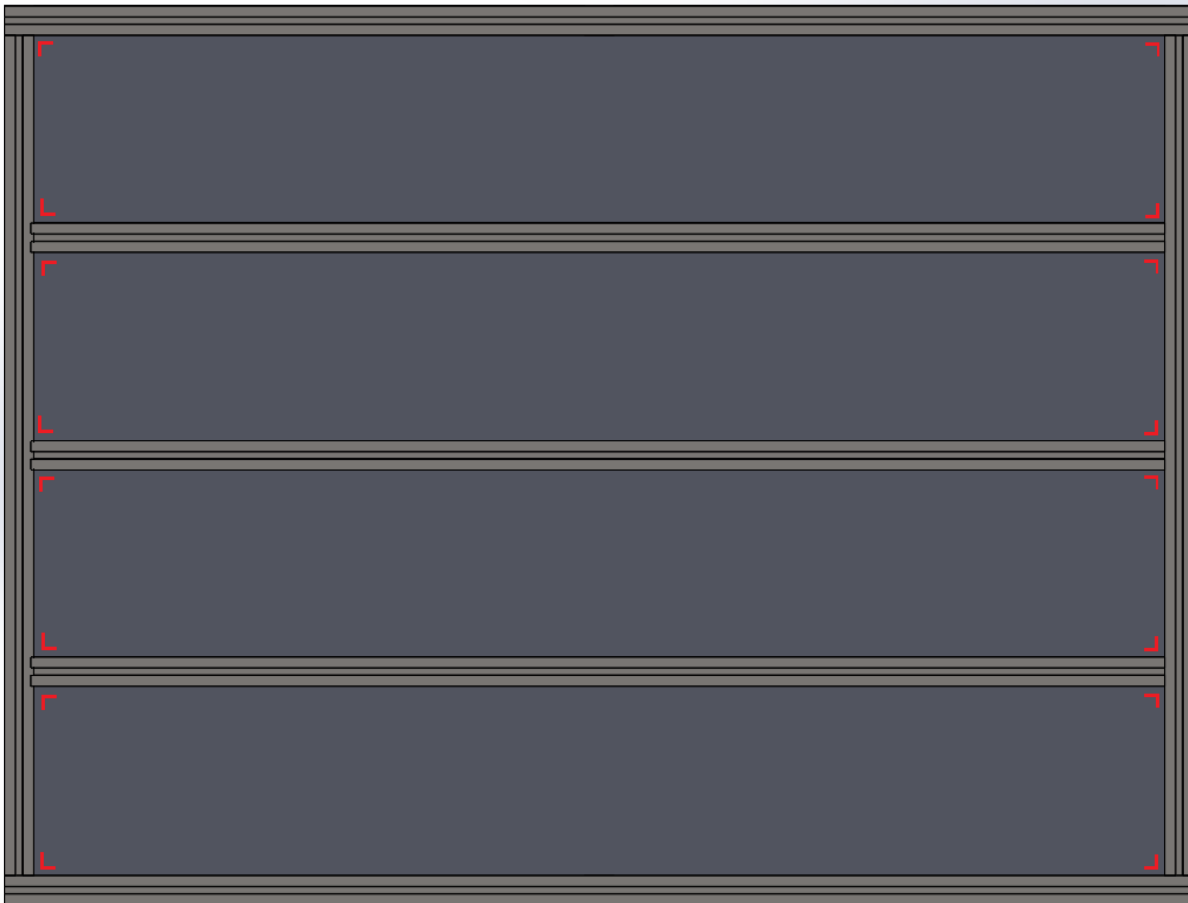


Figure 14. Reinforced Bed Base Bottom

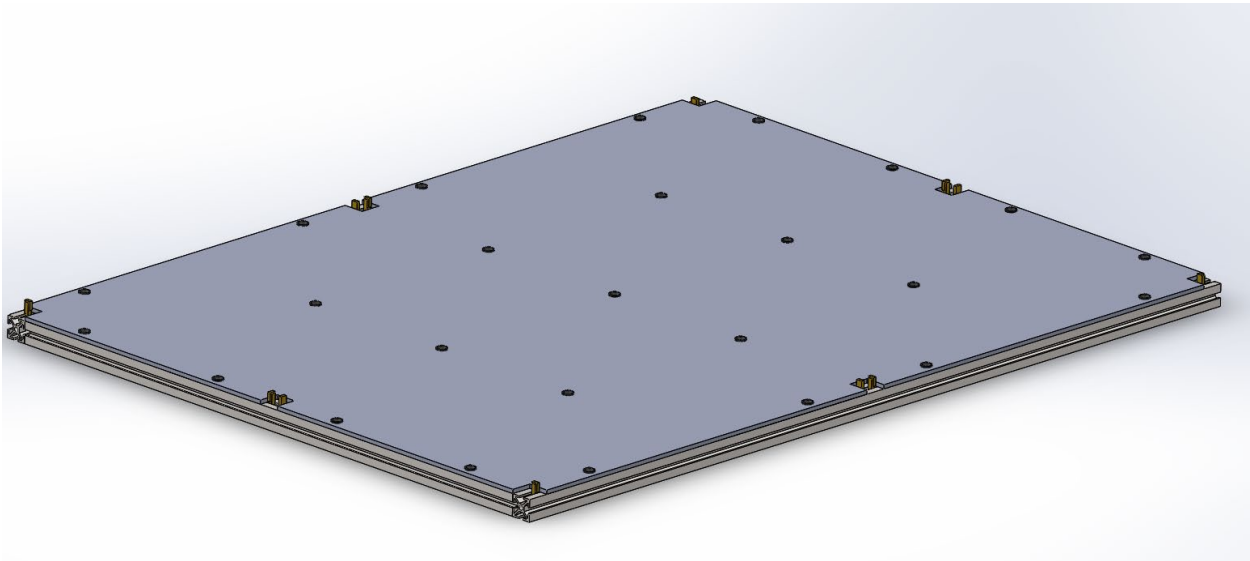


Figure 15. Reinforced Bed Base Top

STEP 12: Exterior Fasteners Part 1

Prepare eight 3"x3" triangular brackets by inserting bolts and attaching T-nuts appropriately. Four of these will be of type A, and four will be of type B, which are pictured below in Figure 16. Gently slide the 40.75" long members back and forth to allow slotting of the B-type brackets onto the 28.75" side members of the bed frame.

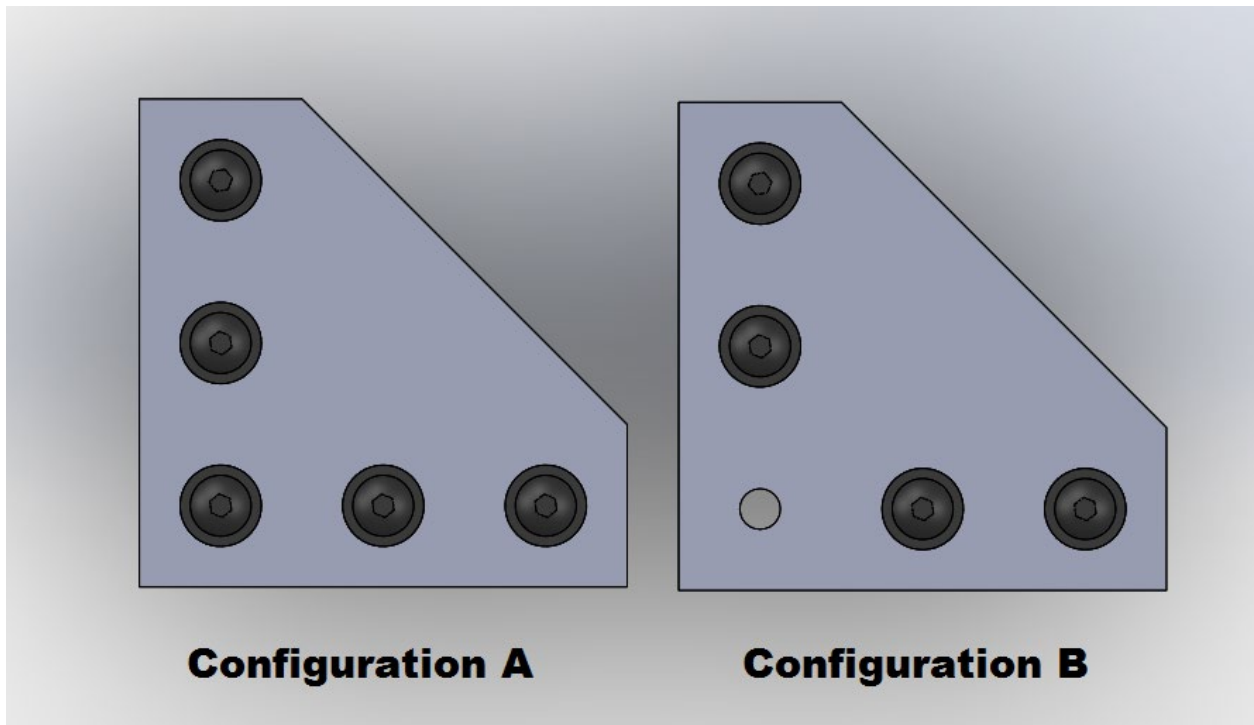


Figure 16. 3"x3" Bracket Configurations

Prepare two 1"x1" L-brackets by inserting 1/4"-20 bolts of 0.375" length and T-nuts. These bolts should be exclusively used in the L-brackets. Slot both bolts with T-nuts into the open face of just one of the 40.75" long members. These brackets are a permanent fixture and will be used to slot the projector mount into during setup. Slide these brackets to the center of the bar and slot all four A-type brackets into the open channels of the 40.75" long members. All eight 3"x3" brackets should be seated and loosely snugged now.

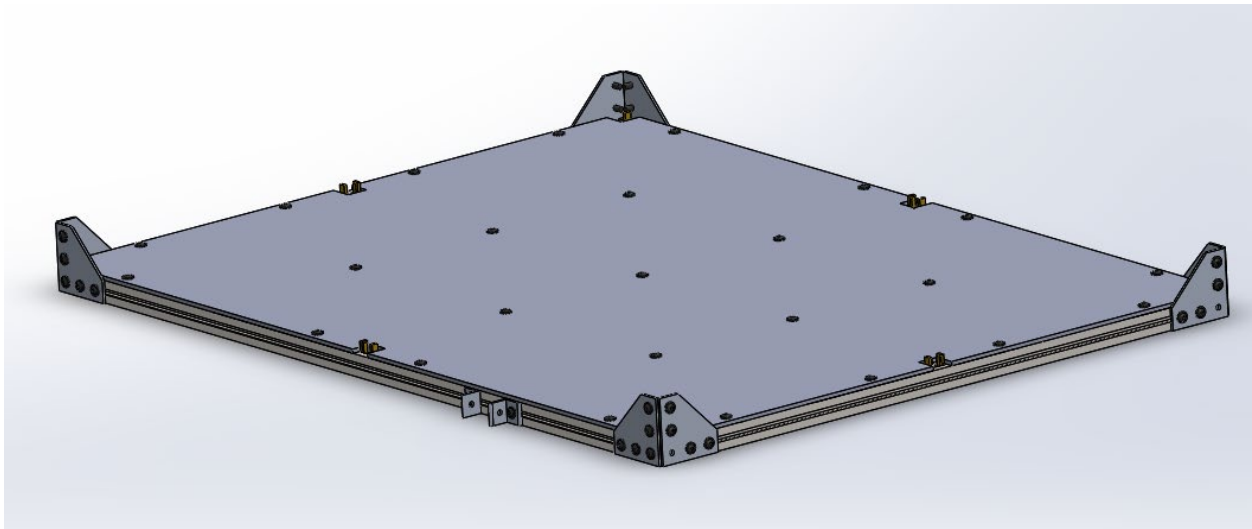


Figure 17. Corner View with Projector Mounting Brackets

STEP 13: Positioning Vertical Uprights

Place all eight 5.625" uprights in the notched-out positions, making sure to slot each hidden corner fastener into the bars. Carefully measure out the expected position of the threaded portion and drill small holes in the plywood base to allow fastening. The uprights and brackets can be temporarily moved during drilling. Once the fastening holes are drilled, replace any moved components and fully tighten the portions of the hidden corners embedded underneath the plywood. The assembly should look similar to Figure 18 below.

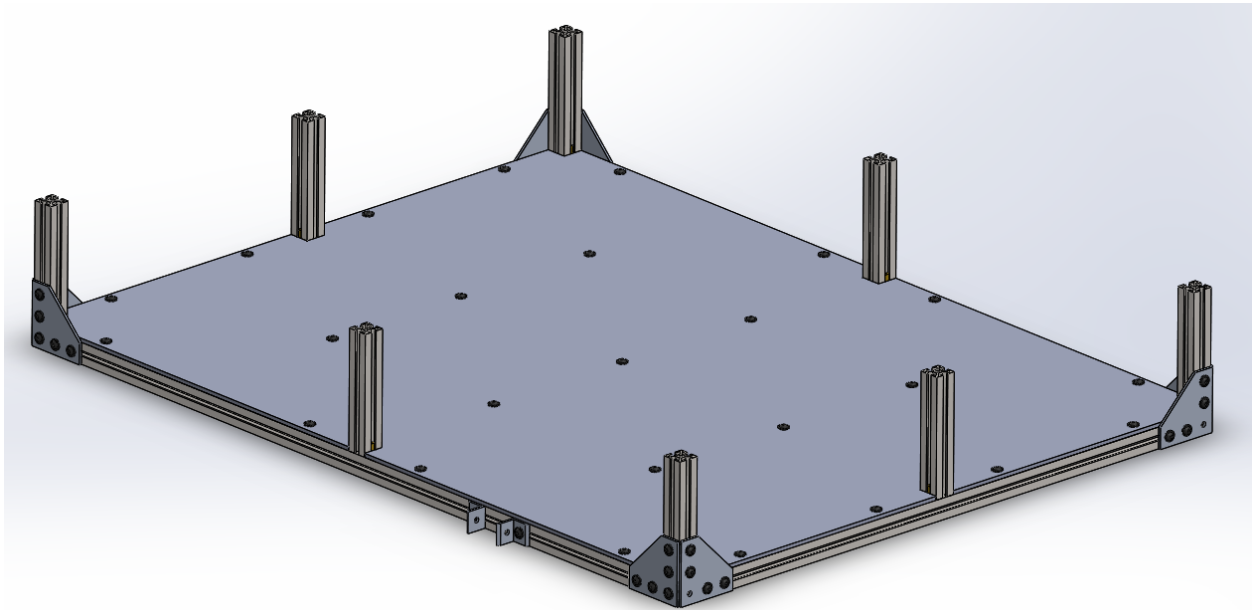


Figure 18. Assembly with Uprights

STEP 14: Add Bed Walls

Fill all holes of the bed walls with pairs of bolts and T-nuts. The bolt heads will determine which face of the walls will become the bed interior. Slot the long walls onto the matching vertical supports through the central bolt and T-nut. Similarly, slip the short wall channels into those of the long walls while slotting the central bolt and T-nut. Snug the vertical bolts loosely. The assembly should look close to Figure 19 below.

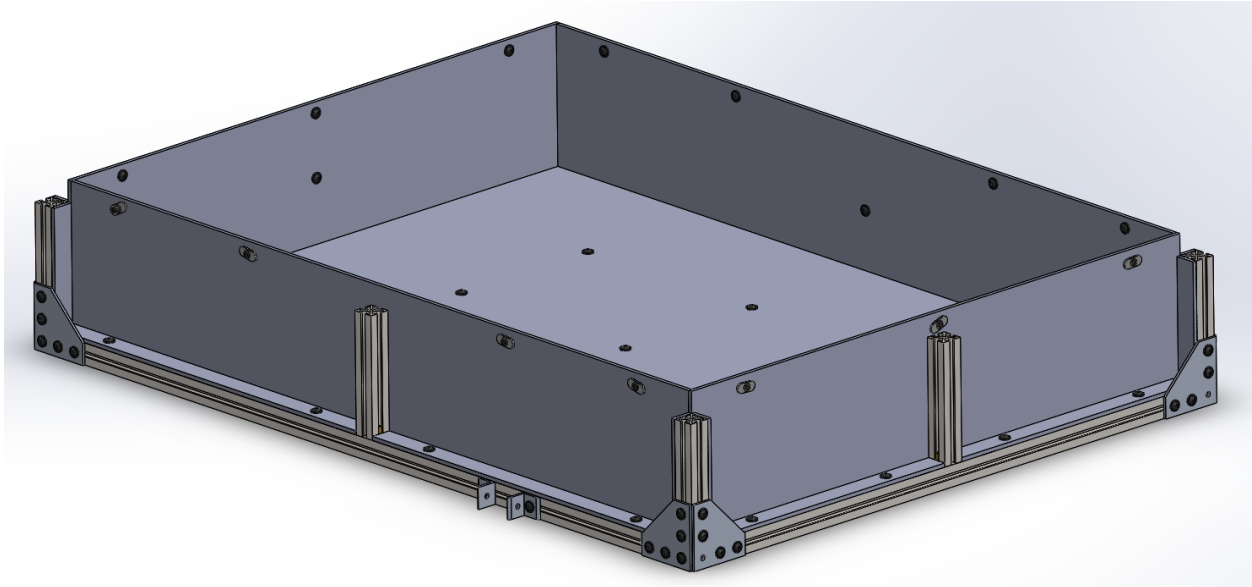


Figure 19. Assembly with Walls

STEP 15: Add Upper Side Bars

Prepare eight additional 3"x3" corner brackets with bolts and T-nuts. Again, this will require 4 A-type and 4 B-type brackets. Refer to Figure 16 for bracket configurations if necessary. Slot the B-type brackets into their matched uprights accordingly. Begin sliding the 28.75" upper side bars into position while slotting the B-type brackets. Pause briefly to slot hidden corner fasteners into the center upright. The process is shown in Figure 20 below.

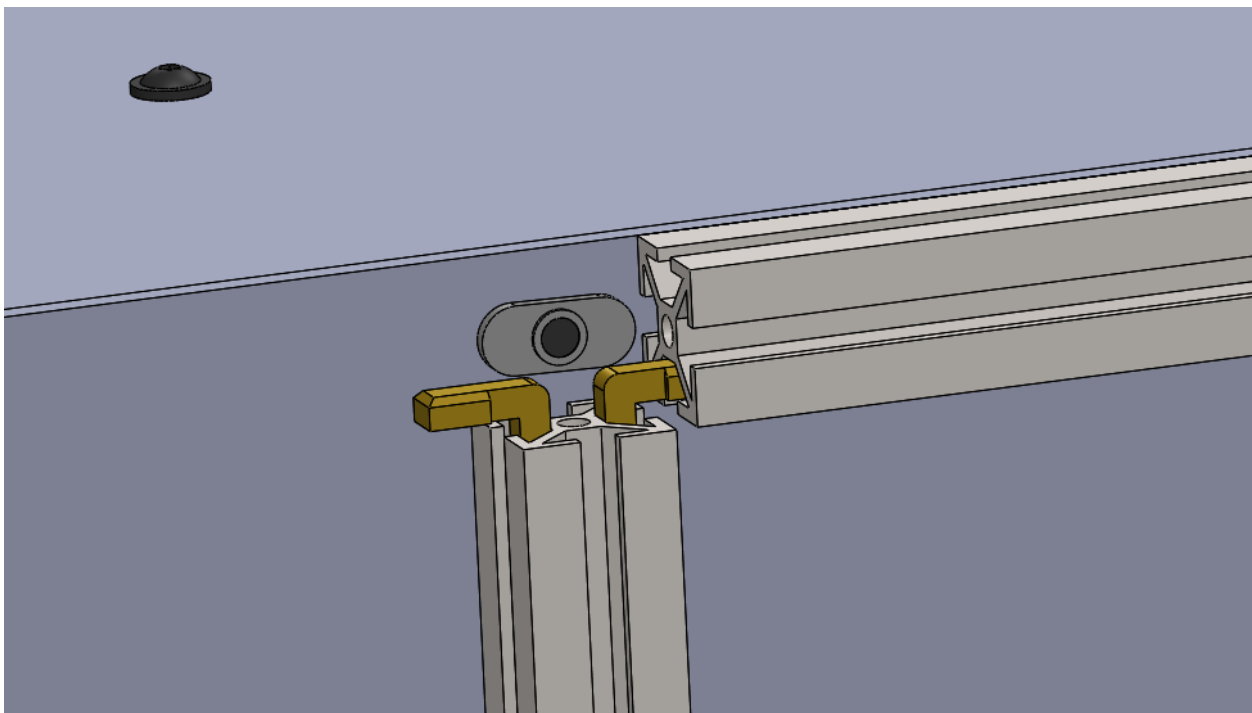


Figure 20. Slotting Hidden Corners of Upper Side Bars

STEP 16: Finalize Box Assembly

Prepare another two 1"x1" corner brackets with bolts and T-nuts. As before, the L-brackets should be attached with 1/4"-20 by 0.375" bolts. Slot these into the 40.75" long member on the same side as the other set. Slot the A-type brackets into the uprights as shown in Figure 21. Finally, slot the 40.75" long members into the assembly. Pause halfway through the slotting process to place two hidden corner fasteners in the upright member. Use a level or square to ensure proper alignment of all members before fully tightening all fasteners.

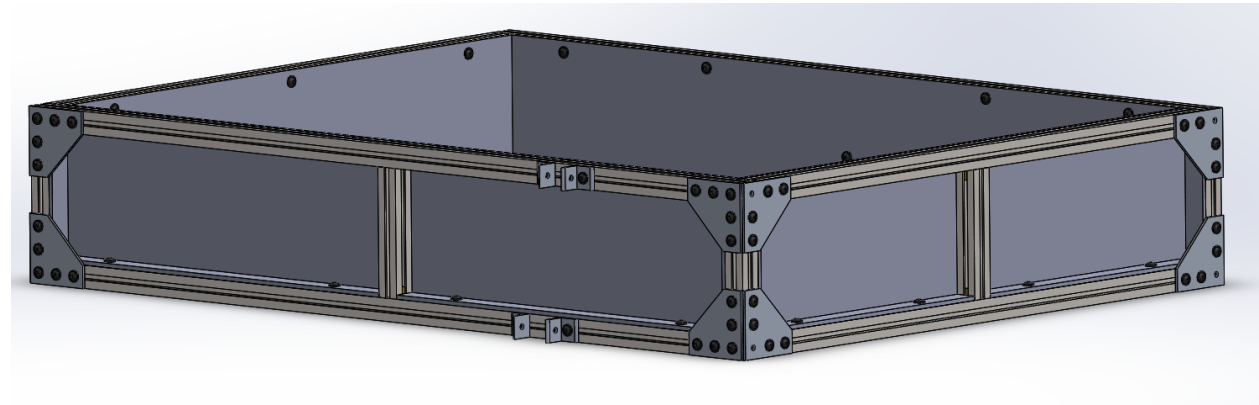


Figure 21. Completed Box Assembly

STEP 17: Prepare Projector Mounting Post

Lay the 50.125" projector post next to the 44.5" projector reinforcement post, adjusting them until the ends are flush. Fill 4-6 2"x2" brackets with bolts and T-nuts before using them to secure the two posts together. Figure 22 shows the subassembly in this state.

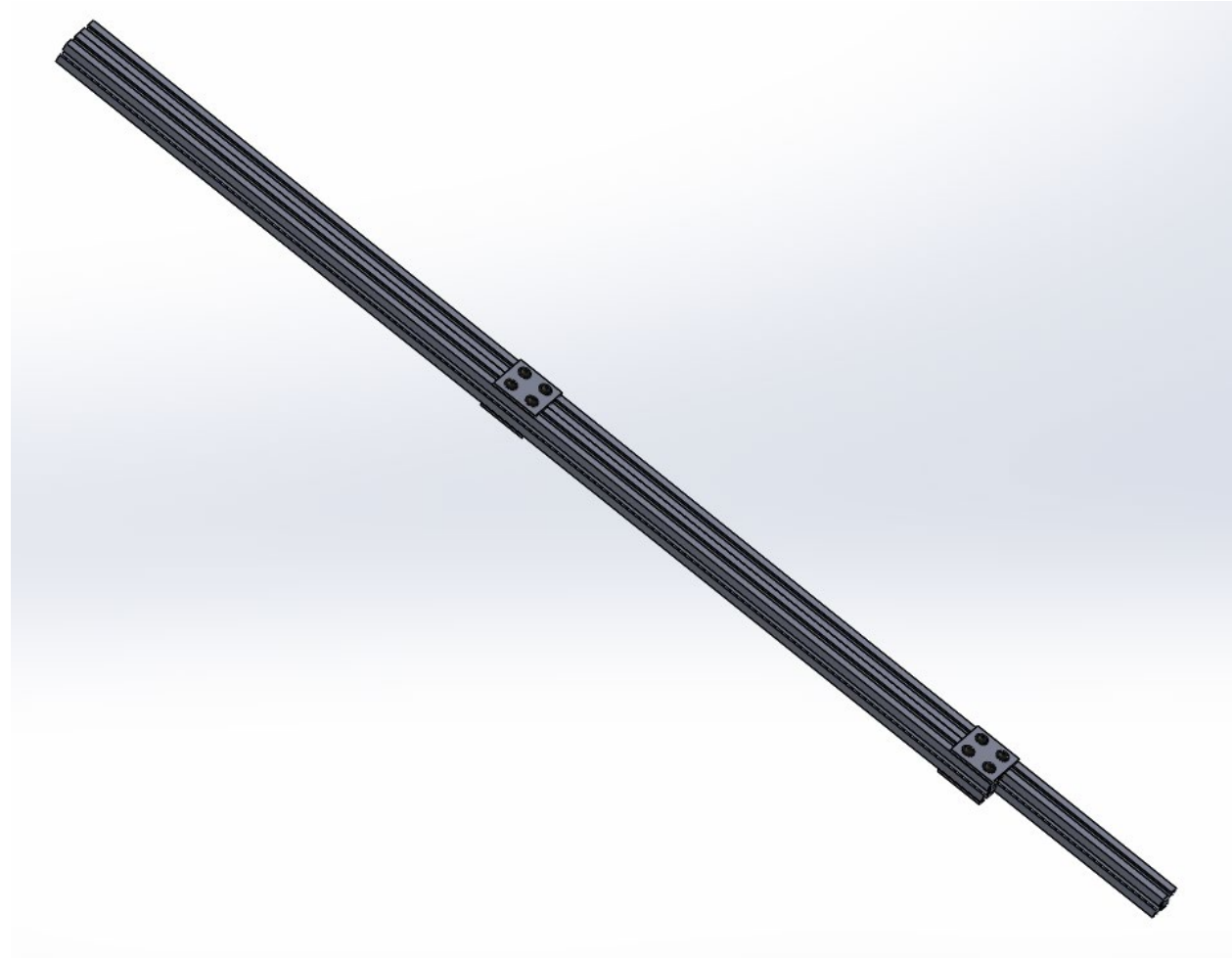


Figure 22. Projector Post Assembly

STEP 18: Connecting the Distance Adjustment Member

Once the posts are firmly attached, prepare two 6-hole 2"x4" corner brackets with bolts and T-nuts. Ensure that the 2" side of each bracket runs vertically along the length of the projector mounting posts. The 18.75" distance adjustment member should slide through 4 sets of bolts and T-nuts per side. The projector mounting posts will each seat one bolt per side. A hidden corner fastener can be used to reinforce this joint if desired. Prepare two 4-hole 3"x2" corner brackets and attach it as shown in Figure 23. Use a square or level to ensure that the assembly is straight before fully tightening the bolts of the 6-hole 2"x4" brackets. Leave bolts in the 4-hole 2"x3" brackets loose enough to enable sliding.

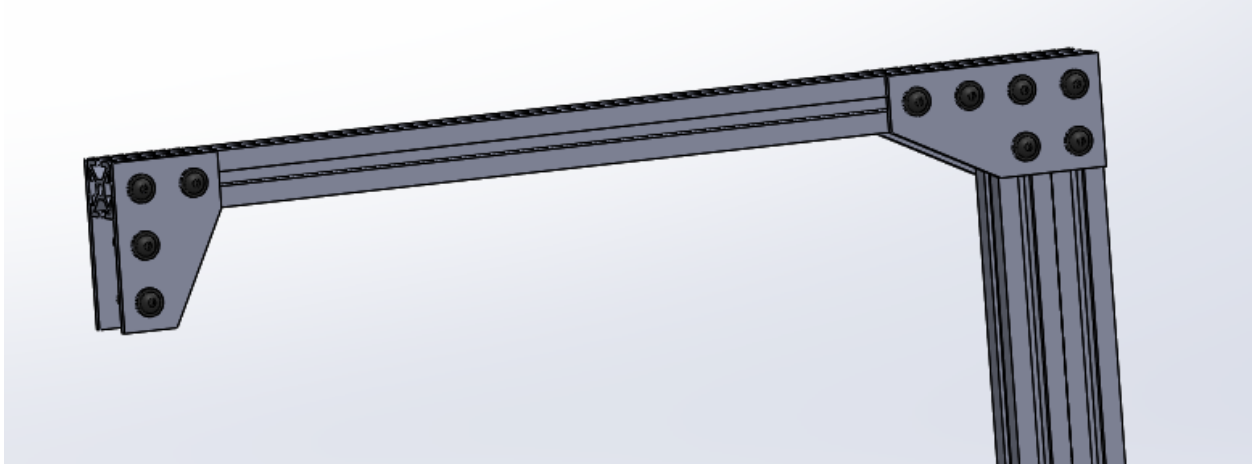


Figure 23. Mounting Configuration for Distance Adjustment Member

STEP 19: Attach Kinect Mounting Members and Kinect

Slip a hidden corner fastener into the underside of the 18.75" distance adjustment member and attach the 7.75" member vertically. Fasten the hidden corner and the bolts into the 7.75" member. Snug, but do not fully tighten the bolts in the 4-hole 2"x3" brackets. Slip two hidden corner fasteners into the ends of the 7.75" vertical member and mount the 9.75" Kinect mounting member through them as shown in Figure 24. Fully fasten the hidden corner connections into the 7.75" member and snug the connections in the 9.75" member. Attach the Kinect horizontally to the underside of the 9.75" member with zip-ties.

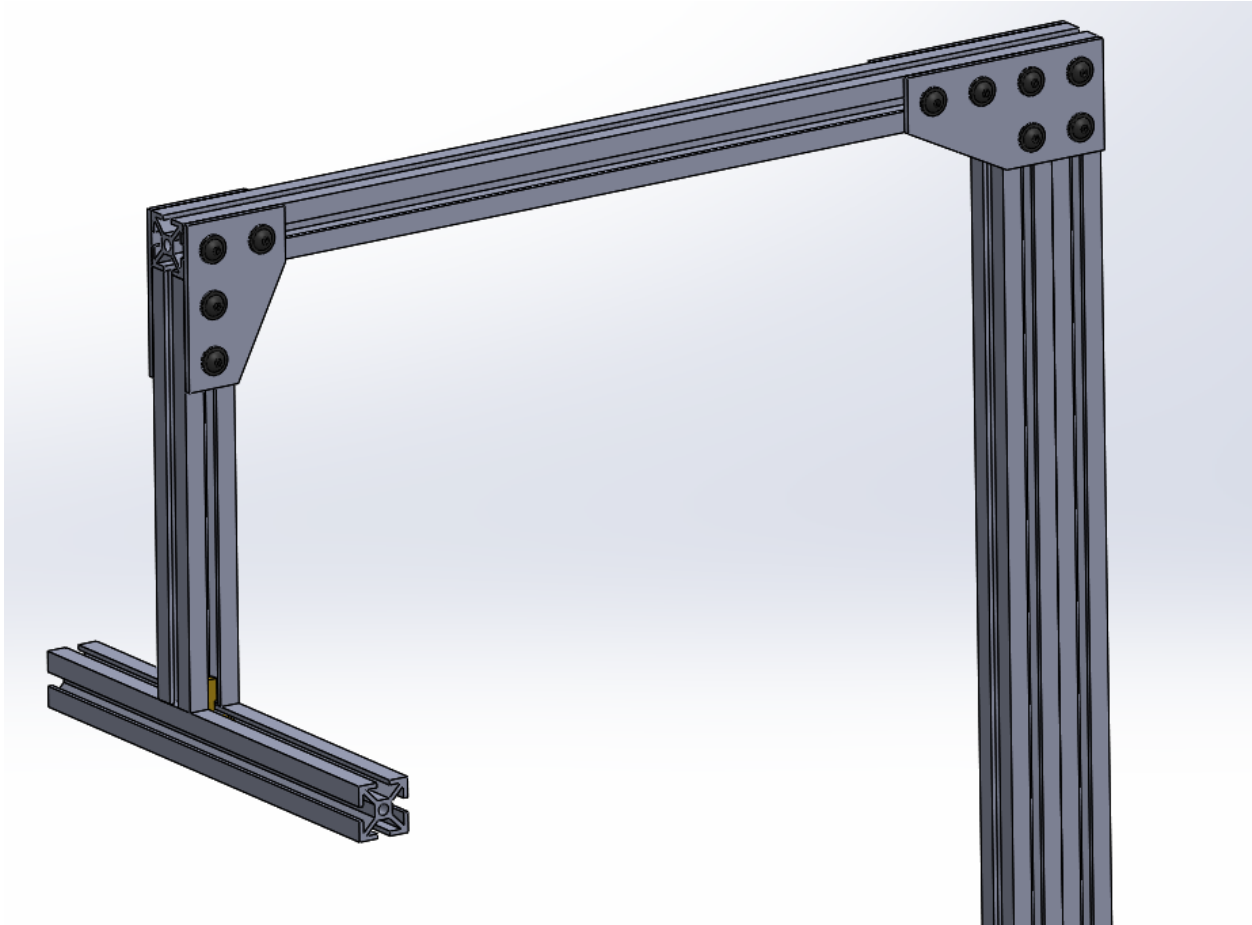


Figure 24. Kinect Mounting Subassembly

STEP 20: Prepare Projector Mounting Plate

Figure 25 shows the general schematic of the of the 1/8" aluminum plate. The dimensions shown are approximate. For more precise measurements, lay a piece of paper across your projector bottom. Cut a straight edged notch from the paper to lay across the flat foot of the bottom of the projector. Ensure that the paper does not move during this step. Poke in the bolt holes with a pencil, widening them fully. Trace out the location of the notch, as well as the position and shape of the speaker hole pattern. Transfer these measurements to the 1/8" aluminum plate with a marker. Notches can be cut out with a metal-bladed jigsaw. Jigsaw entry points can be made with a drill.

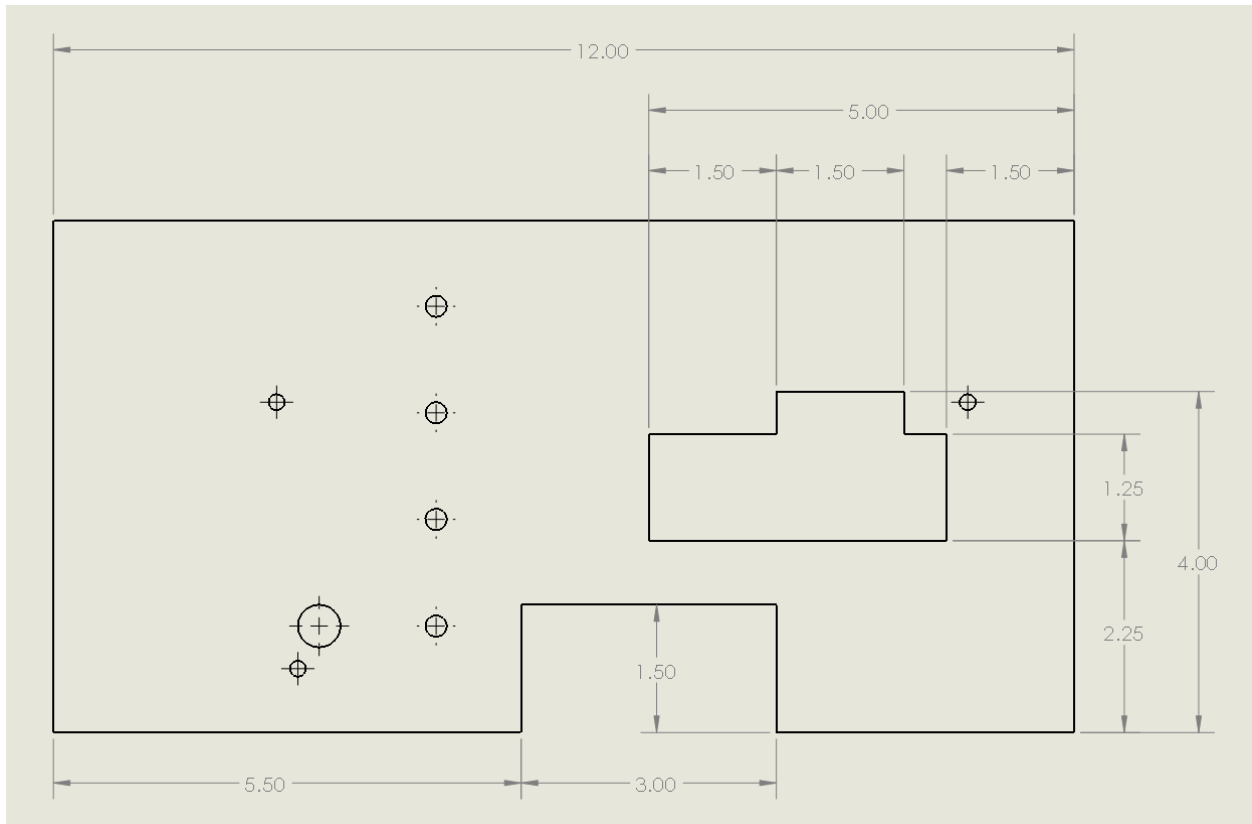


Figure 25. Mounting Plate Schematic

Figure 26 shows the approximate hole dimensions and sizes required. Holes should be step drilled starting from 1/8" diameter until the bolts fit smoothly through the holes. The largest hole should be step drilled until properly fitting the protrusion from the projector underside. Horizontal alignment of the 4 0.25" holes will determine the offset of the projector lens and subsequently the offset of the projector post assembly from the table's center.

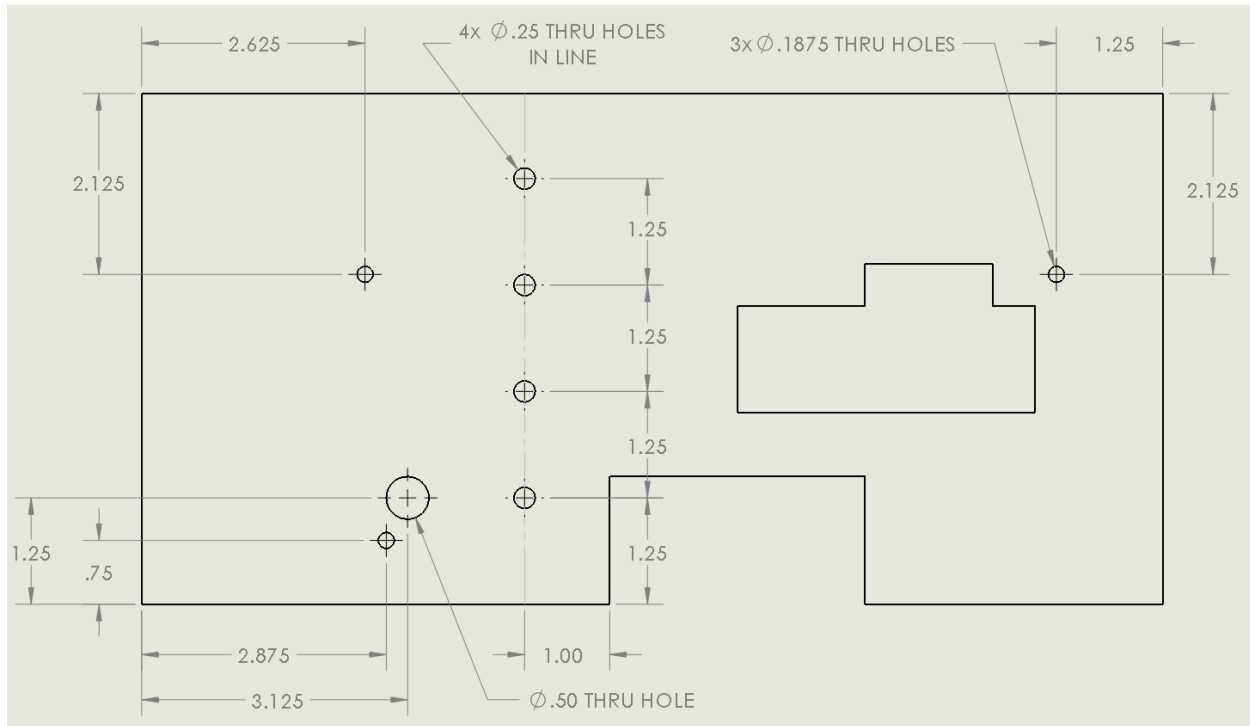


Figure 26. Approximate Mounting Plate Holes

STEP 21: Mount the Projector

Once the projector mounting plate has been prepared and the fitting checked, ensure that the orientation of the plate is correct and use four 1/4"-20 by 1/2" bolts and T-nuts to loosely attach it to the 44.5" post. With the help of an assistant or two, slip the projector mounting posts and loose projector mounting plate onto the constructed bed frame. Place the remaining 4 1/4"-20 by 0.375" bolts and T-nuts into the 1"x1" L-brackets. Slot the exterior post through the four 1"x1" corner brackets. Attach the projector to the mounting plate using two 20mm M4 screws in the top holes and one 16mm M4 screw in the bottom hole. Plug in the projector power cord and HDMI. The projector and mounting plate connection will not be tight and should contain a fair amount of exposed threading. Do not overly tighten the projector mounting screws, they should be hand tightened and the projector is expected to be able to rock and pivot. The assembly should now resemble Figure 27.

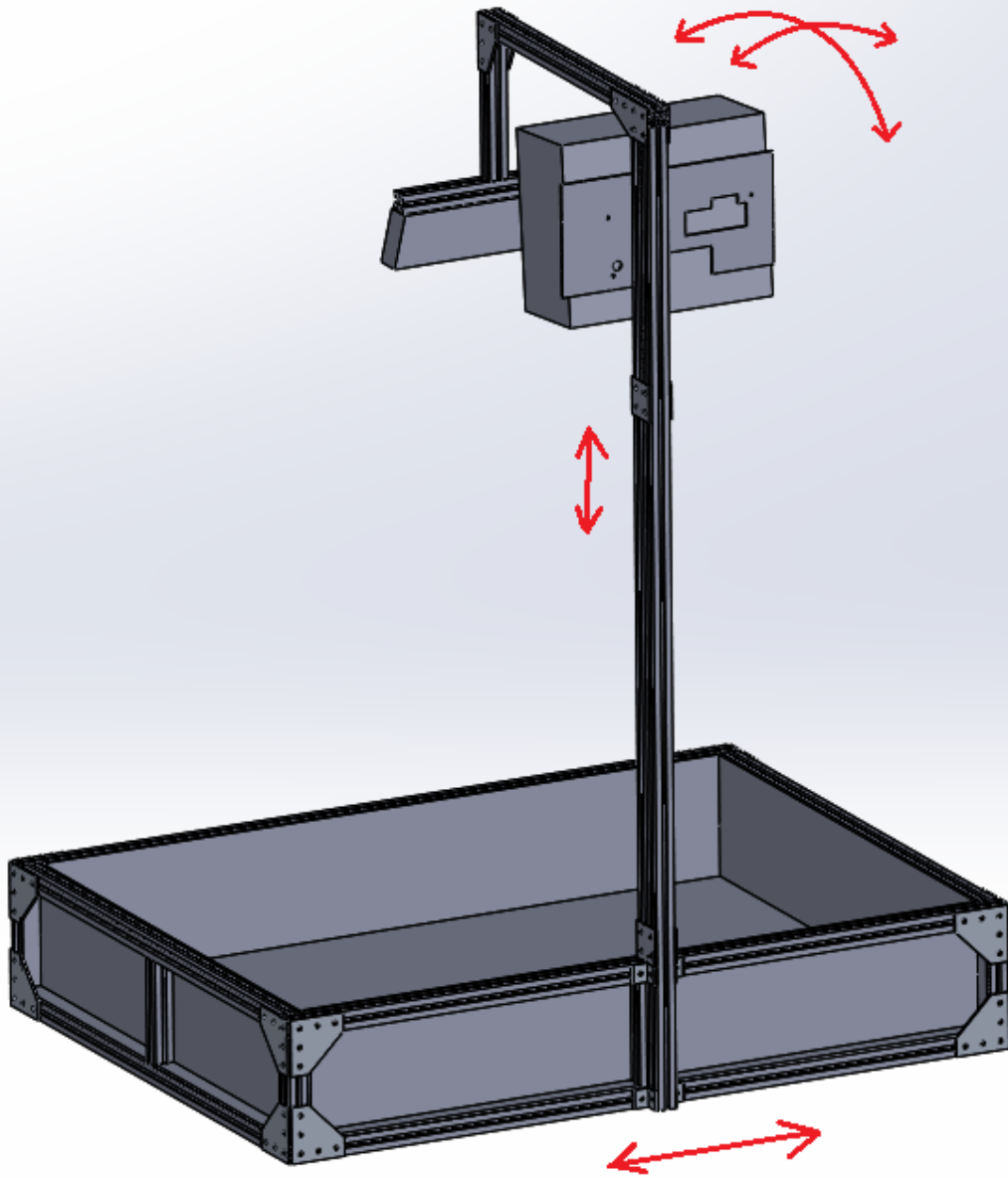


Figure 27. Assembly with Mounted Projector Post and Axes of Motion

STEP 22: Projector Aiming

With the aid of your assistant(s), the projector must be manipulated in 4 axes at once. First, the vertical height of the projector must be determined. The expected height of the projector lens from the upper surface of the bed is 40.5". Be sure to leave room for the projector cords on the back of the projector. A good projector height can also be determined from the light shining on the table surface. (If this is done, ensure that projection size is minimum or near minimum and that the projector resolution has been set.) Once a suitable height is determined, mark the position of the projector mounting plate, remove the projector, and firmly tighten the bolts interfacing the mounting plate to the projector posts. Place the projector back onto the mounting plate when done.

The second axis to be manipulated is the horizontal slide of the entire projector/Kinect mounting assembly. Use a square or level to ensure that the post remains upright, then slide it and the connecting 1"x1" L-brackets until light distribution is even between sides. Fully tighten all bolts in the 1"x1" L-brackets when the projector is in position.

Finally, the projector must be aimed angularly forwards or backwards in the bed. The extra threading in the projector mounting screws that interface the projector to the mounting plate will be used to adjust the angle of projection. Fully push the projector to the mounting plate and allow the top screws to feed back through, tilting the projector back. The projection angle will now be as far inwardly facing as possible. Drop washers between the bolt head and the back of the projector mounting plate on each side to angle the projector forwards until desired. Refer to Figure 28 for a visual explanation of this process. Similarly, creating uneven stacks of washers between projector sides will result in a light rotation around the mounting post, if desired. Once complete, ensure all bolts and fasteners relating to the projector posts and mounts are fully tightened.

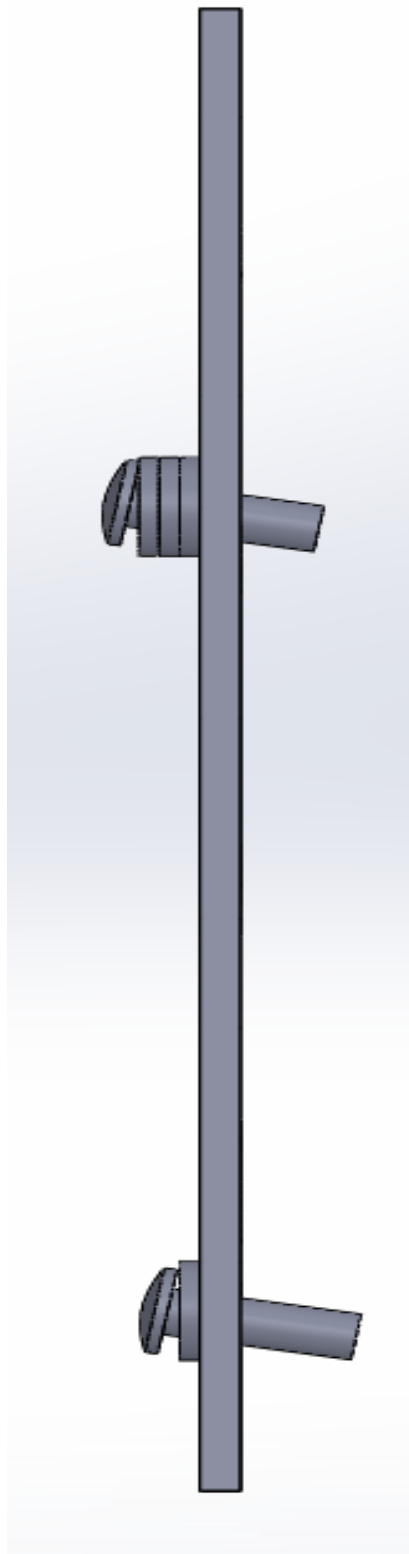


Figure 28. Using Spacers to Aim the Projector

STEP 23: Kinect Aiming

With the projector light illuminating the bed, the Kinect must be aimed. Use the accompanying software to read the recorded images of the Kinect. The Kinect field of vision should be able to record the entirety of the table. Slide the two Kinect mounting members along the distance adjustment member to adjust one dimension and adjust the sliding position of the 9.75" member that the Kinect is tied to for the other dimension. Continue adjustments until the Kinect reads as necessary. Refer to Figure 29 for visual aid. Fully tighten all fasteners relating to the Kinect mounting assembly.

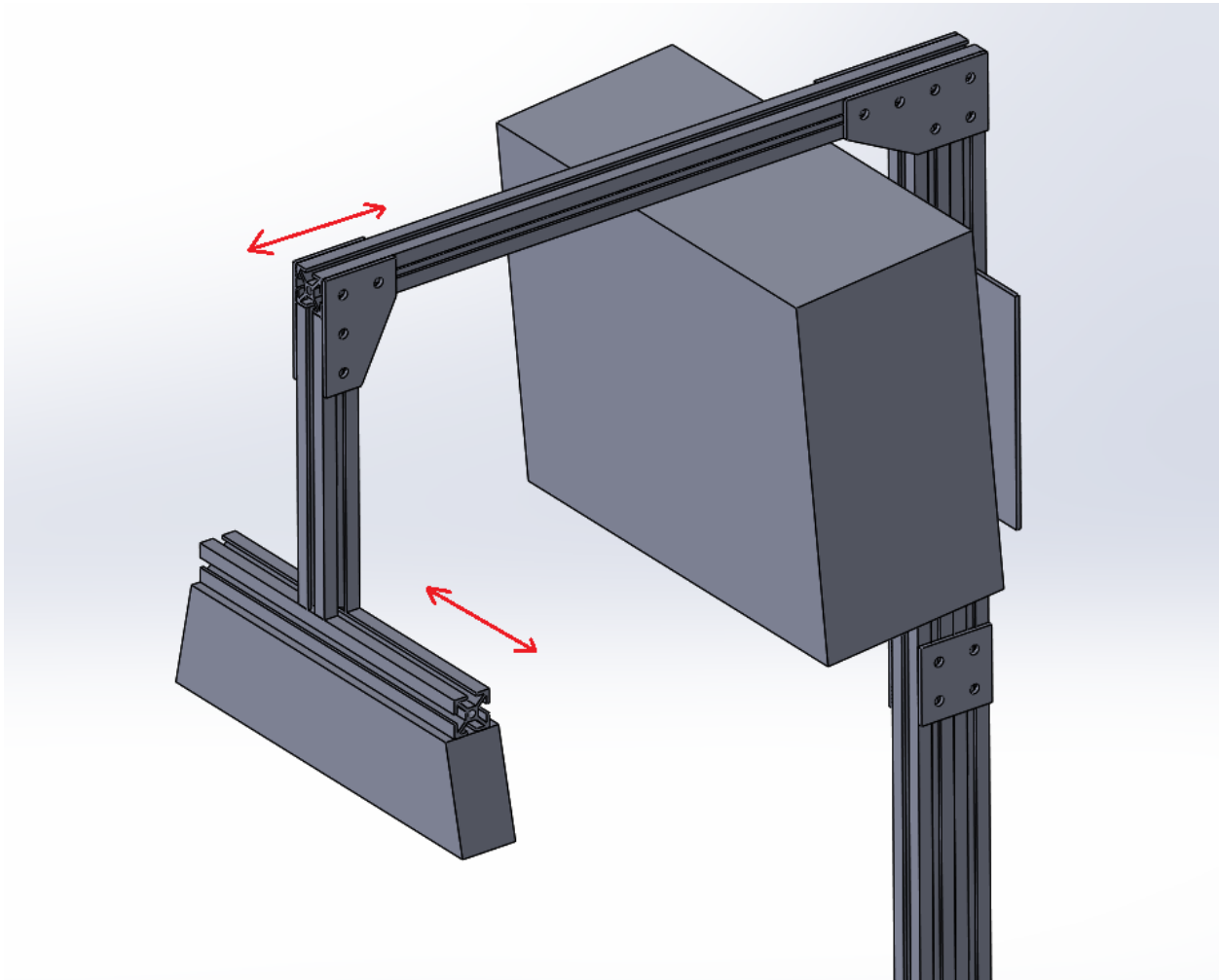


Figure 29. Kinect Aiming and Axes of Motion

STEP 24: Caulking

The major construction of the bed and projection system should now be complete. Clean the bed interior with a damp cloth and allow to dry. Using suitable caulk, fill all creases in the wooden frame of the bed. Avoid contact between the bed frame and the caulk in case of any future maintenance. Allow the caulk ample time to dry before attempting to fill the table.

STEP 25: Quality of Life and Other Improvements

With construction complete, non-critical additions can be made to the system. These can include modifications for visual purposes as well as useful modifications that make the system easier to set up, transport, or use. For example:

- Additional painting, graphics, decals, or visual features
- Routing and securing projector and Kinect cables
- A mounted multi-socketed power outlet/surge protector
- Corner modifications to reduce hard edges
- Replacement of projector mounting pole to bed frame bolts with wingnut headed bolts
- Openings or holes to drain sand

STORAGE AND TRANSPORTATION

To pack the system for travel, loosen bolts between the projector mount post and the L-brackets that hold it to the bed. Vertically slide the projector post out of position. Place the projector post assembly in a safe position that does not stress it. Further disassembly of the projector post assembly should not be necessary but can be done to compact it further. Remove the media from the interior of the bed. Alternatively, a plastic or plywood sheet can be secured over it to prevent spilling.

APPENDIX A: Equipment List

Cutting Tools	Purpose
Band Saw / Circular Saw	General stock cutting
Jig Saw w/ Metal Blade	Cutting notches in plate

Drilling Tools	Purpose
Battery / Power Drill	Drilling holes where necessary
Fractional Drill Bit Set (1/16"-1/2")	Drilling / countersinking holes
Drill press	(Optional) Powerful, more precise drilling

Fastening Tools	Purpose
2.5mm Allen Wrench	Fastening 1/4"-20 bolts
5/32" Allen Wrench	Fastening hidden corners
Ratchet and Sockets w/ Hex Head Sets	(Optional) Quicker fastening
Caulk Applicator	Securing / leakproofing wooden panels
Screwdriver	(Optional) Fastening of projector screws

Finishing Tools	Purpose
Primer / Paint / Sealant / Stain	(Optional) Decoration of the assembly

Safety Tools	Purpose
Safety Glasses	Eye protection
Gloves	Hand protection
Files / Deburring tools / Sandpaper	Remove sharp edges from wood/metal
Angle Grinder / Sanding Disks	(Optional) Quicker Deburring