Manual binder jet 3D printer designed to enable small-scale research, multi-material structures, and interchangeable binder deposition methods

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1. Bill of materials

Table 1. Bil of materials for assembly construction (as of 2023).

Designator	Component	Number	Cost per unit - USD	Total cost - USD	Source of materials	Material type
Stage Assembly Platform	6061 Aluminum 12" x 3" x 3/4"	1	$21.63	$21.63	McMaster-Carr	Aluminum
Base	6061 Aluminum 8" x 8" x 1/4"	1	$18.31	$18.31	McMaster-Carr	Aluminum
80/20 T-slotted Framing Rails	Hollow Single Four Slot Rails - 3 ft.	1	$21.33	$21.33	McMaster-Carr	Aluminum
80/20 Bracket	L Bracket, 1" Long for 1" 80/20 Rails	8	$5.63	$45.04	McMaster-Carr	Aluminum
80/20 Screw - Compact Head	End feed fastener and bolts	18	$0.50	$9.00	McMaster-Carr	Steel
Mitutoyo Micrometer head 150-831	Long flat spindle-type micrometer head (0.001”)	1	$79.45	$79.45	Zoro	Hard chrome plating
Extension Spring	Hook Ends, Min length: .625”, Max length: 1.225” (3-spring package)	2	$16.37	$16.37	McMaster-Carr	Steel
Steel Ball	5.5 mm (0.22”) diameter (50-ball package)	1	$5.22	$5.22	McMaster-Carr	Steel
Build Plate and Spreader Felt	High-Temperature Felt, 0.125” thick	1	$14.23	$14.23	McMaster-Carr	Felt
Brass Insert	Brass Hex Bar - 1/2 ft.	1	$15.61	$15.61	McMaster-Carr	Brass
Heat lamp	240 Vac 10-amp solid state Variable Voltage Control by Payne (18TBP-2-10)	1	$150.00	$150.00	GordoSales	N/A
Heat lamp stand bar	Carbon steel 1/2” width, 1/2” height, 1 ft long	1	$12.77	$12.77	McMaster-Carr	Steel
Heat lamp stand rod	Low-Carbon steel rod 5/16” diameter, 2 ft long	1	$3.95	$3.95	McMaster-Carr	Steel

Designator	Component	Number	Cost per unit - USD	Total cost - USD	Source of materials	Material type
Heat lamp stand screws	Steel Hex Head screw (fully threaded, coarse thread) 1/2” long, 1/4”-20 thread (100-item package)	2	$4.42	$4.42	McMaster-Carr	Zinc-plated Steel
Heat lamp stand nuts	Hex nut 1/4” -20 thread (100-item package)	2	$8.95	$8.95	McMaster-Carr	Zinc-plated Steel
Handheld printer	v4ink BENTSAI BT-HH6105 Series Handheld Ink-Jet Printer	1	$530.00	$530.00	Amazon	N/A
Inkjet Cartridge	BENTSAI v4ink BT-2560N Black Inkjet Cartridge	1	$76.99	$76.99	Amazon	N/A
Spray Template	Clear High-Strength Acrylic – 7/64” thick	1	$8.15	$8.15	McMaster-Carr	Acrylic
Adhesive Back Bumpers	Polyurethane rubber 13/16” x 13/16” x 19/64” (49-item package)	1	$8.89	$8.89	McMaster-Carr	Rubber

2. Build instructions

3.1 Frame

The frame is the printer's foundation; therefore, it is important for it to be sturdy and versatile. The frame assembly process is shown in Fig. 1.

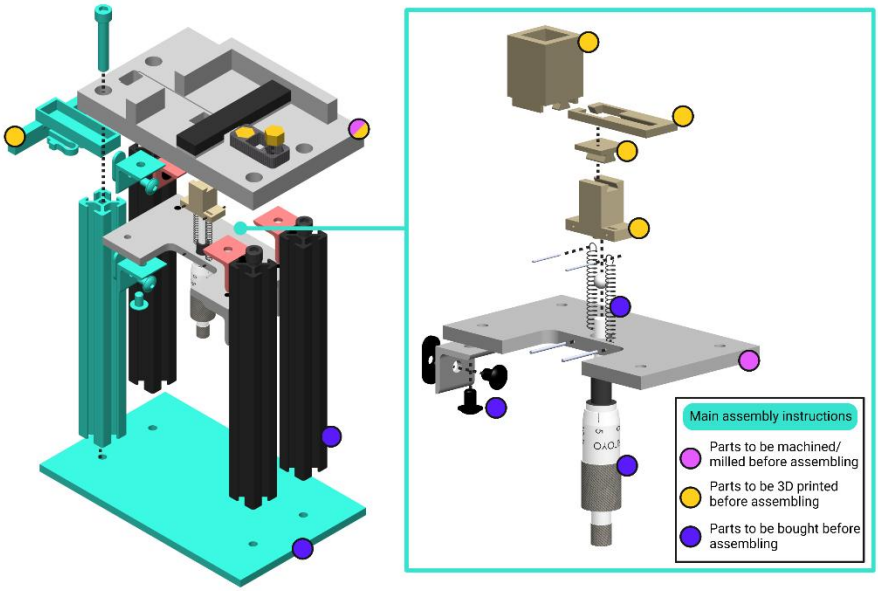

Figure 1. Frame and stage assembly process, showing exploded view of the stage assembly. Parts recommended to be printed or machined are indicated. Though only the Ink-Cartridge Top Plate is shown, the concept is consistent for corresponding parts on the Spray Top Plate.

Start by cutting four lengths of 1" (25.4 mm) T-slotted 80/20 aluminum framing rails to serve as posts for the printer. These posts will connect the base, the top plate, and the stage assembly that rests between them. Use a bandsaw to cut the posts slightly longer than needed and then use an endmill to finish the cutting operation to achieve a precise finish to equal lengths. Each post must have a tap at both ends to accept the appropriate hardware for attaching the base and top platform.

Fabricate the base and stage assembly platform using a manual mill or CNC machine. Once milled to the correct dimensions, drill four threaded holes into the base; this is where the posts attach. Use 80/20 L-brackets through the threaded holes to attach the posts to the stage assembly platform. The nature of the T-slot allows for adjustability in the position of the entire stage assembly and therefore the micrometer. For accurate measurement of the layer heights and ease of use, ensure that the stage assembly and top plate (instructions below) are parallel. Then, stick adhesive feet to the bottom of the base, raising it off the surface it sits on. Adding feet to the base of the printer prevents sliding on smooth surfaces.

3D-print the build bed support from high temperature resin using a FormsLab Form 3+ printer (see Table 2). Construct the stage assembly from the build bed support, build plate, micrometer, springs, pins, and bearing ball. Attach the micrometer and the build bed support through the hole in the stage assembly platform. Place the bearing ball on top of the micrometer and lock it by placing the build bed support on top. Align the hook end of one retention spring in a stage assembly platform slot and insert a locking pin to hold the spring in place. Affix the other end of the same spring in the spring slot on the build bed support. Repeat this process with the second spring. To stabilize the entire stage assembly, insert the build bed support into the top plate through-hole and turn the micrometer to raise the assembly and tension the springs.

Use another set of four 80/20 L-brackets on top of the stage assembly and secure them to the posts as before. These brackets support the powder catchers. Their height should be adjusted after the top plate has been added, to properly secure the powder catchers in place.

Table 2. Material and printing specifications for 3D-printed parts.

Part	Printed material	3D printer	Printing parameters	Comments
Ink-Cartridge Top Plate	Generic PETG	Prusa i3 MK3S	20 % infill, 0.2 mm (0.01”) layer height, 2 perimeters (contours)	Part could also be printed with Onyx or machined
Powder catchers	Onyx	Markforged X7	100 µm layer thickness, closed cell fill	N/A
Powder carriage				
Powder spreader				
Heat lamp stand				
Build bed support	High temperature resin V2	FormsLab Form 3+	50 µm layer thickness, 25 µm XY resolution, 85 µm laser spot size	Cured at 80 °C for 120 min
Build plate				
Transfer box				
Transfer box stabilizer				

Create the top plate by 3D printing from PETG or Onyx. In the case of printing (for which a Prusa MK3 i+ or Markforged X7 could be used, with suggested printing parameters in Table 1), the printed material must have a softening temperature above the temperature of the heat lamp. For this reason, PLA is not recommended.

The Spray Top Plate could be machined instead of printed. In the case of machining, use a manual mill or CNC machine to create the recessed build area in the top of the platform where the powder carriages interact. Mill (or cut using wire electrical discharge machining (EDM)) the through-holes for powder to exit the build area into the powder catchers, along with the counterbored holes to attach the posts. Lastly, cut the squared center through-hole to fit the build bed, e.g., using wire EDM. Screw the top plate in position on top of the four posts.

3D-print the build plate and transfer assembly (transfer box and transfer box stabilizer) with the same high-temperature resin used for the build plate (Table 1), to allow them to be placed in an oven for curing. Use high-temperature glue to attach a square of felt that fits on the bottom of the build plate surrounding the dove tail. This felt allows the plate to slide off the build bed support in a smooth motion into the transfer assembly, preventing disturbances to the printed part.

Raise the stage assembly using the micrometer, until the build bed support emerges from the squared center hole of the top plate and the entire dove tail is exposed. Slide the build plate into position (centered in the build bed) and lower the build bed again until the surface of the build plate is leveled with the surface of the top plate.

3.2 Powder Manipulation

The powder is deposited during printing by the powder carriages that travel within the recessed build area on the top plate. Print the powder carriages, spreader, and catchers from Onyx filament with a Markforged

printer (Table 1). Insert the powder catchers into their respective positions underneath the top plate to catch excess powder during printing.

Note: These parts were 3D printed because they must slide around the aluminum surface of the build area with minimal friction and without scoring or gouging it. Often the user applies pressure to the sliders while operating it, and more abrasive materials would accelerate the wear of the build area. Additionally, Onyx provides a lower surface roughness than other printed materials, allowing for a smoother sliding process.

Glue square pieces of felt to the bottom of the powder spreader on both sides of the blade to help the spreader sweep excess powder into the powder catchers. During operation, the spreader is moved from one side of the printer to the other to level the print bed and, in the case of the Spray Top Plate, push powder to exit through the slots in the top plate. The small surface area of the spreader blade levels the powder in the build bed.

The powder carriages should fit with high tolerance into the narrow sections of the build area depression. The square hole in the center of each carriage contains the powder during printing. This hole is sized to be slightly greater than the print bed so that as it is slid over, it empties powder over the entire bed. Glue a small piece of felt to the outer bottom surface of the carriage, so that powder is cleaned from the top plate as the carriage is returned to its starting location. To weigh the powder carriages, cut the brass hexagonal bar on a lathe to the height on the powder carriages and glue the brass inserts into place.

Note: The shape and material of the weights are flexible, and you should decide what is best for your application, but this may change the characteristics of the powder carriage (brass offers a higher density than steel and aluminum).

3.3 Binder Application

I. Spray method

For the dosed spray bottle, thoroughly clean a store-bought nasal spray bottle and fill with water-based binder. Since inhaling binder vapors can be hazardous, the entire assembly should be contained in a fume hood. However, since the small droplets are interrupted by the air moving within the fume hood, secondary containment is necessary for this top plate. For the setup presented here, a glass aquarium was used as secondary containment, ensuring that the air flow within the fume hood was not restricted by its placement. Glass also helps with easy cleanup, wiping excess binder with a wet cloth after each print. Note that for the spray method, water-based binder is highly recommended to enable simpler cleanup of stray binder.

With any desired and available method (e.g., laser cutting, saw, etc.) cut a spray template to fit the large rectangular depression of the printer top plate (2.95” x 2.32”, or 75 mm x 59 mm), with desired opening(s) centered above the build bed opening (maximum size equal to the build bed opening, 0.59” x 0.59”, or 15 mm x 15 mm). Shields should also be fabricated to protect the top plate and front of the entire printer during binder application, but the size, shape, and material of these larger shields is not important; they just must cover everything that is not the desired build bed opening. Acrylic sheet is recommended for easy cleaning.

II. Ink-cartridge method

Though the choice of handheld printer is up to the user, the design of the top plate may need to be modified for any other models, and the jetting instructions here are model-specific.

For the handheld printer, a BENTSAI BT-HH6105 Series handheld ink-jet printer was used with a BT-2560 N BENTSAI inkjet cartridge. Empty the ink cartridge by removing the top rubber stopper, discharging the ink, and washing thoroughly with water. Then, refill the cartridge with the binder desired for printing. Clean the nozzles using a damp Kimwipe. Connect a USB drive to the handheld printer with the desired printing

shape, select that shape from the file menu, and align it to the left-hand side of the screen. After pressing the print button in the touch screen, align the handheld printer with the guides provided by the Ink-Cartridge Top Plate design. Press the printing button in the handle and swipe the handheld printer to the right to create the binder layer on the powder bed.

3.4 Heat lamp stand

3D-print two heat lamp stand holders from Onyx. Cut the steel rod into two 7.8” (or 198 mm) sections. Connect the heat lamp stands with the two rod sections. Cut the square cross-section steel bar to a length of about 3.2” (or 81 mm). Machine through-holes (slightly larger than 0.25”, or 6.4 mm) near each end of the steel bar. Insert one of the screws through one steel bar hole and between the two connecting rods and secure it from the bottom with a nut. Insert a second screw in the other steel bar hole and screw it into the heat lamp voltage regulator. Make sure the wire connecting the heat lamp voltage regulator to the power outlet is sufficiently long to move the heat lamp on and off the printer during drying, and that it does not go underneath the heat lamp while drying the binder. Additionally, make sure to place the heat lamp on a safe surface while it is still hot (Fig. 2).

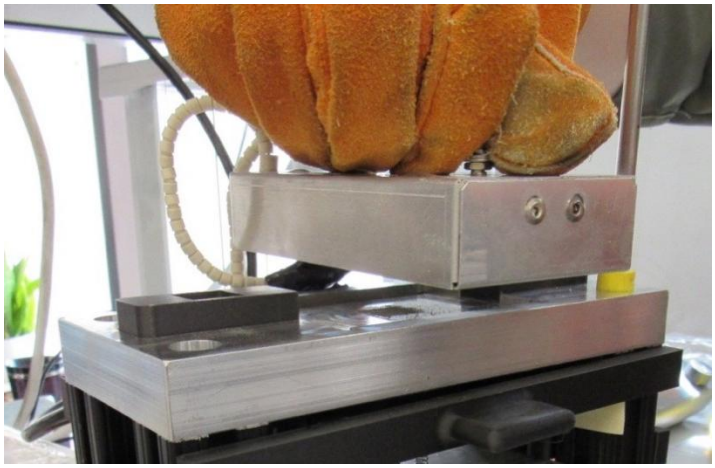

Figure 2. Demonstration of the proper PPE required to handle the heat lamp without a heat lamp stand.

3. Operation instructions

I. Spray Top Plate

The printing process using the Spray Top Plate is shown in Fig. 3 and described below.

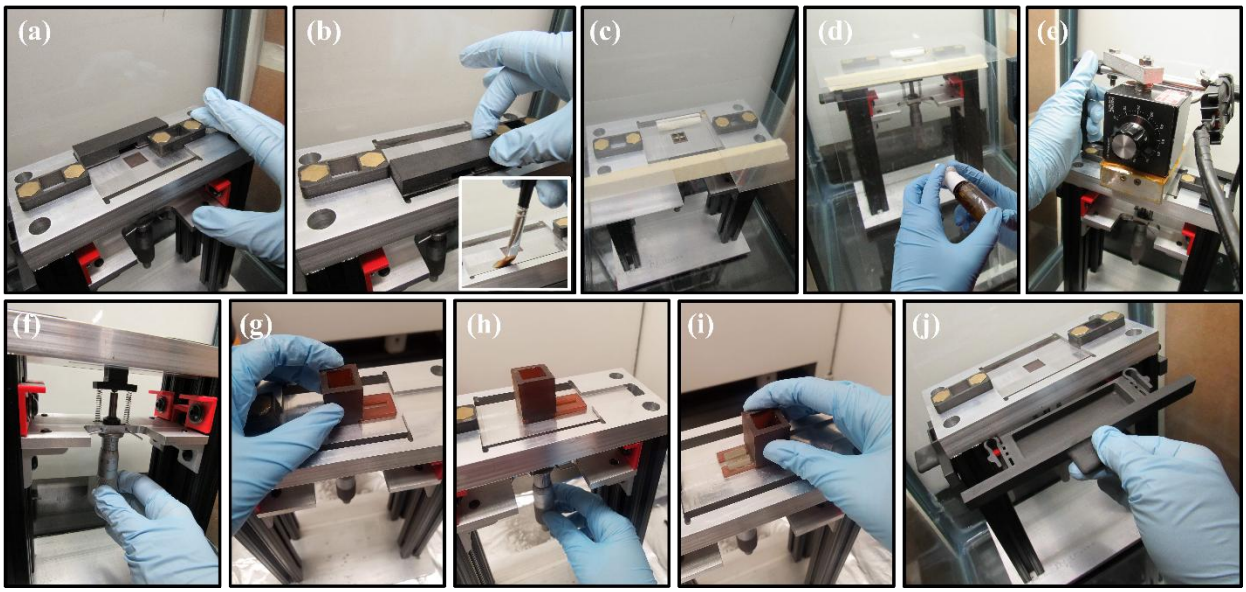

Figure 3. Visual steps of the operation instructions for printing with the Spray Top Plate and sprayed binder deposition.

(a) Deposit powder by swiping the powder carriage over the build plate (without pushing past the build bed and allowing the felt to touch the new loose powder layer). Return the powder carriage to its slot.

(b) Flatten the bed with the spreader and use a small brush to sweep any excess powder into a powder catcher.

(c) Use spray template and shield covers to protect the printer from excess binder spray.

(d) Position the spray bottle horizontally and spray the binder towards the powder bed (suggested spray bottle location and spray amount are detailed in *Validation and Characterization*).

(e) Remove the covers, wipe them with a cotton cloth (most importantly, the spray template), and dry the binder with the heat lamp.

(f) Lower the stage by the layer thickness amount.

Repeat steps (a)-(f) until the part is complete.

(g) Place the transfer assembly on the top plate, with the transfer box aligned with the build plate hole.

(h) Raise the powder bed to transfer position (with the build plate and its dovetail just above the top plate).

(i) Slide the transfer box with attached build stage over to the removal position. Remove the transfer box with the stage attached and place it in an oven to cure.

(j) Empty the powder catchers.

II. Ink-Cartridge Top Plate

The printing process using the Ink-Cartridge Top Plate is shown in Fig. 4 and described below.

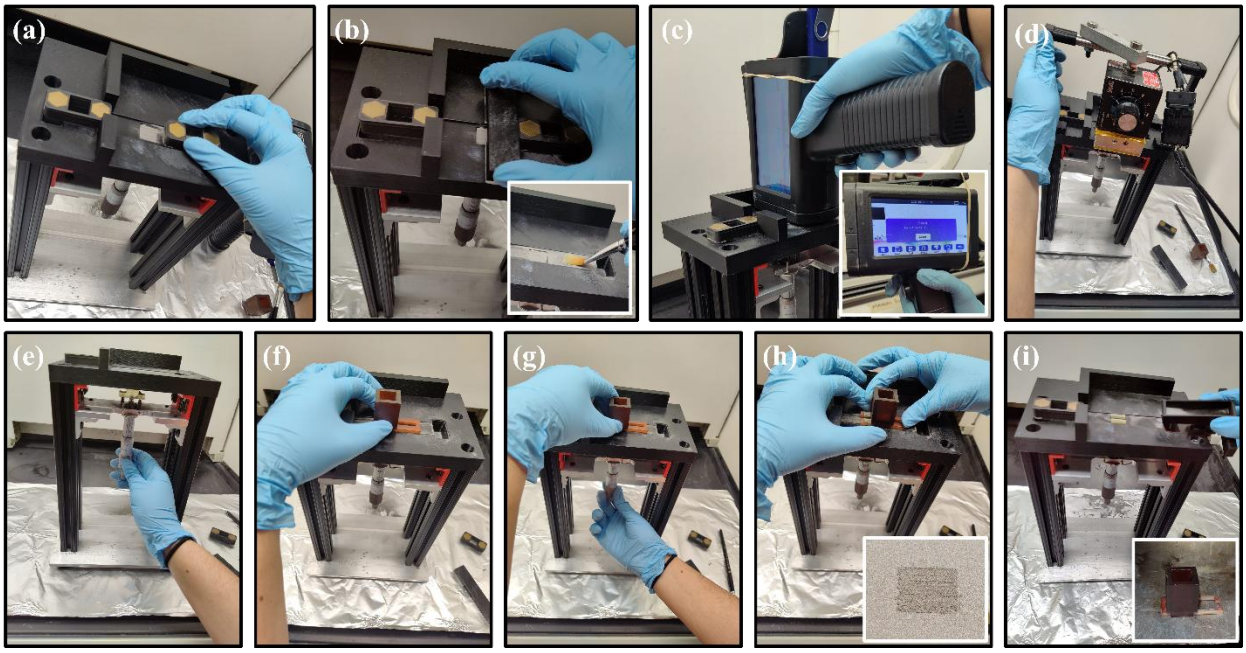

Figure 4. Visual steps of the operation instructions for the manual binder jet 3D printer with the Ink-cartridge top plate.

(a) Deposit powder by swiping the powder carriage over the build plate (without pushing past the build bed and allowing the felt to touch the new loose powder layer). Return the powder carriage to its slot.

(b) Flatten the bed with the spreader and use a small brush to sweep any excess powder into a powder catcher.

(c) Align the inkjet printer with the top-left corner, press the button on the handle to begin printing, and swipe to the right to spread binder. In the inkjet printer, a shape should have been selected (e.g., from a USB drive).

(d) Dry the binder with the heat lamp.

(e) Lower the stage by the layer thickness amount.

Repeat steps (a)-(e) until the part is complete.

(f) Place the transfer assembly on the top plate, with the transfer box aligned with the build plate hole.

(g) Raise the powder bed to transfer position (with the build plate and its dovetail just above the top plate).

(h) Slide the transfer box with attached build stage over to the removal position. Remove the transfer box with the stage attached and place it in an oven to cure.

(i) Empty the powder catchers.