

OPERATING MANUAL FOR 3D PRINTER

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Preparing and Loading Molds into Wax Printer

A detailed procedure for creating wax molds with this specific tool is uploaded to the wiki.

Post-Processing Procedure for Wax Molds

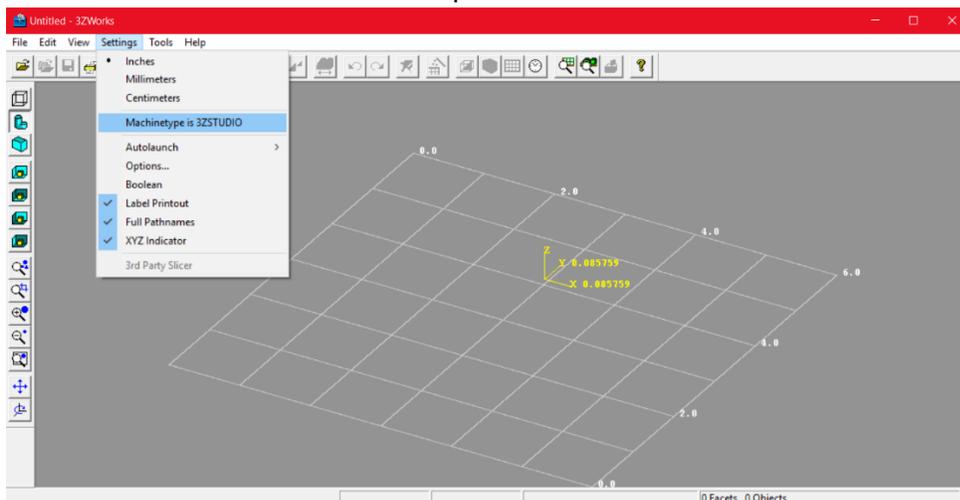
A video is available online showing the wax mold removal process:

<https://youtu.be/6ClhzsoEyZQ>

Creating the File for the Printer

In this section of the guide, we will cover the process of creating functional microfluidic molds from a preexisting STL file. We will also cover commonly seen issues with your molds and how to troubleshoot them.

For the first steps, you will need a USB flash drive and a copy of 3ZWorks on your computer. Upon launching 3ZWorks, go to the “Settings” option on the toolbar, click and scroll down to “Machinetype is” and make sure it is set to “3ZSTUDIO”. If it is not, click on this option and selected “3ZSTUDIO” from the drop down menu.



Notice how right above this option, you can select whether or not you want 3ZWorks to operate in inches, millimeters, or centimeters. In the figure above, we have chosen inches.

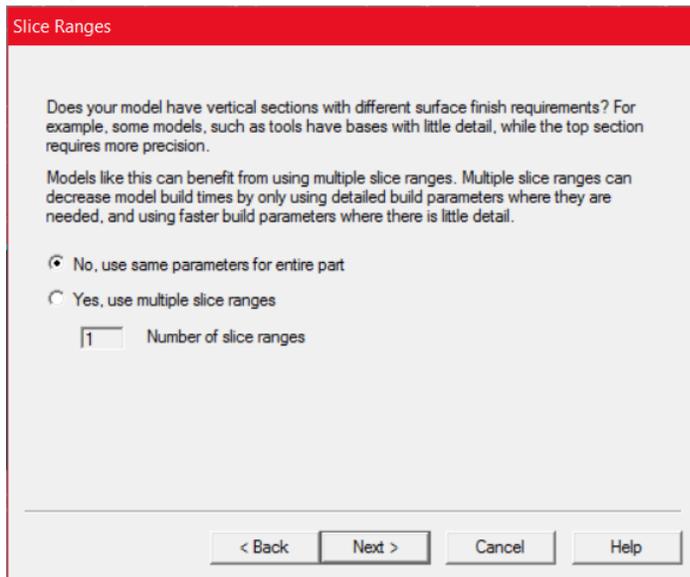
Next, click “File -> Open..” (or press the CTRL and “O” key at the same time) and select the stl file you wish to import into 3ZStudio. If the file is not oriented in the desired direction, click on

the  icon on the toolbar below the file menu. A window will pop up asking you to specify by how many degrees you want your piece rotated in the x, y, and z direction. If you have multiple STL files you want to print, go to “File -> Append” (or press CTRL and D at the same time) and select the desired file. You can edit the position of your pieces on the platform in one of three

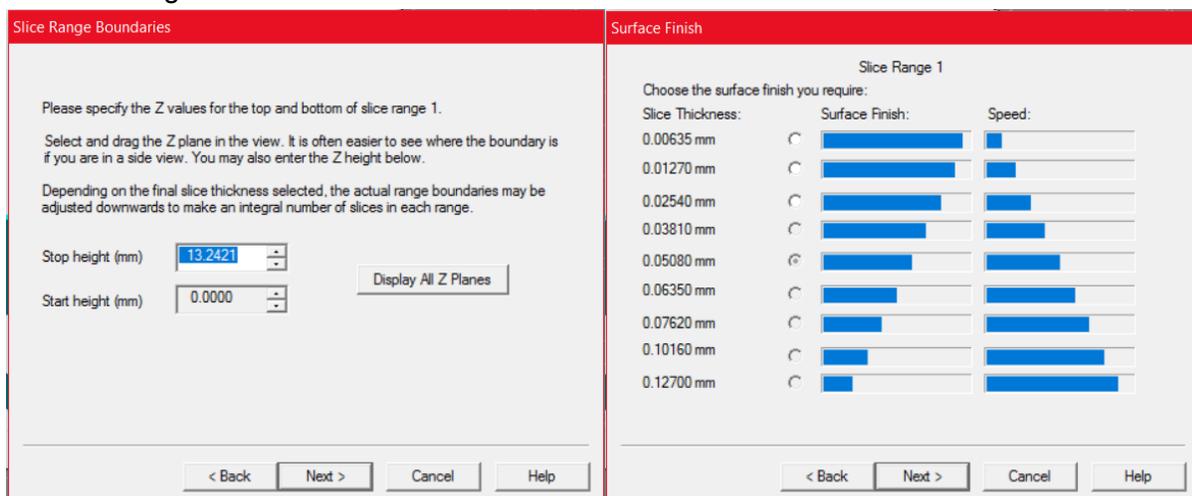
ways. You can move the files manually by clicking the  icon, selecting the piece on the

screen, and dragging it with your mouse. You can also select the  icon and specify the desired position change in the x, y, and z directions. Finally, you can click the  icon, specify the offset and spacing in the x and y direction, and have 3Z works auto arrange the pieces for you.

Once all files have been placed and arranged in their desired locations, it's time to create the file that will be sent to the printer. Make sure your USB flash drive is plugged into the device that is running 3ZWorks. Begin by clicking the  icon. On the pop up screen that results, click "Next". You will then be given a screen asking if you would like to have multiple slice ranges in your print job.



If you select "No, use same parameters for entire part", every section of the printed piece will be built using the same resolution. If you select "Yes, use multiple slice ranges", you will then be prompted to select how many slice ranges you desire. For each slice range, you will be asked to specify the start point for the slice range, the end point for the slice range, and the resolution of the slice range.



The start height for the first slice range should always be 0, which corresponds to the platform floor. The stop height for the first slice range will correspond to the start height for the next slice range. Note that when setting the stop height, the auto generated start height for the next slice range will be slightly less than the previous stop height you set. DO NOT change this parameter. The software generates this value based on known parameters of the machine.

The 3ZStudio wax printer is capable of printing structures using 25.4 um, 12.7 um, or 6.35 um resolution. The lower the resolution of the printer, the more precisely detailed your part can be. However, lower resolution also corresponds to longer print jobs. As an example, if you are printing a 3D microfluidic inverted mold with a base, you might consider printing the base at 25.4 um resolution, since that doesn't involve any fine details. The inverted mold structure resting on the base, however, does have fine details that necessitate the 6.35 um resolution.

On the next screen, you will be asked if you want to add an extra support cell. Select "No, don't add an extra support cell". Adding an extra support cell causes more support material to be printed on the wax mold. This serves no purpose and leads to longer print jobs and longer post processing since more extraneous material needs to be removed.

Clicking "Next" yields the final screen in the wizard. Clicking the "Change File Name..." button allows you to change the name and directory that the output file should be sent to. Make sure that the output directory is the USB drive you have plugged in, and make sure that the output file type is .3zs. If the output type is something else, such as ".3zp", then you have not configured the machine as 3ZSTUDIO in the "Settings" menu. Go back, change the machine type, and start over from the beginning.

Once the proper destination and file name is specified, click "Next" and then click "Finish". The screen that pops up will be entitled "Build Time Estimate", and will include information such as the total hours that the print job will require. Note that this time measure tends to be an underestimate. Leave the "Jet Check" option as "Smart". Click "Ok".

Build Time Estimate

Time Estimator Version 9.3.4.0 June 18, 2014

C:\Users\Jonah
Kohen\Documents\BackupThisFolder\ENGR241\Square_cytometer_piece_Dr

Number of Copies = 1
Number of Layers: 600
Slicing time (min.): 0.05

Volume estimates:

Model	1115.4594 cubic mm
Build	2700.8549 cubic mm
Support	1937.8651 cubic mm

Time estimates:

Build	2.60
Support	2.50
Jet Check	0.00
Cutting	3.00
Cooling	5.70
Total (Hours)	13.80
+/-	1.38

0.09 bld crayons 0.07 spt crayons

Jetcheck
 Smart Standard

Configuration Parameters
Configuration ID = 1100
Rev 06 - EZS Z25

Slice thickness: 0.0254 mm

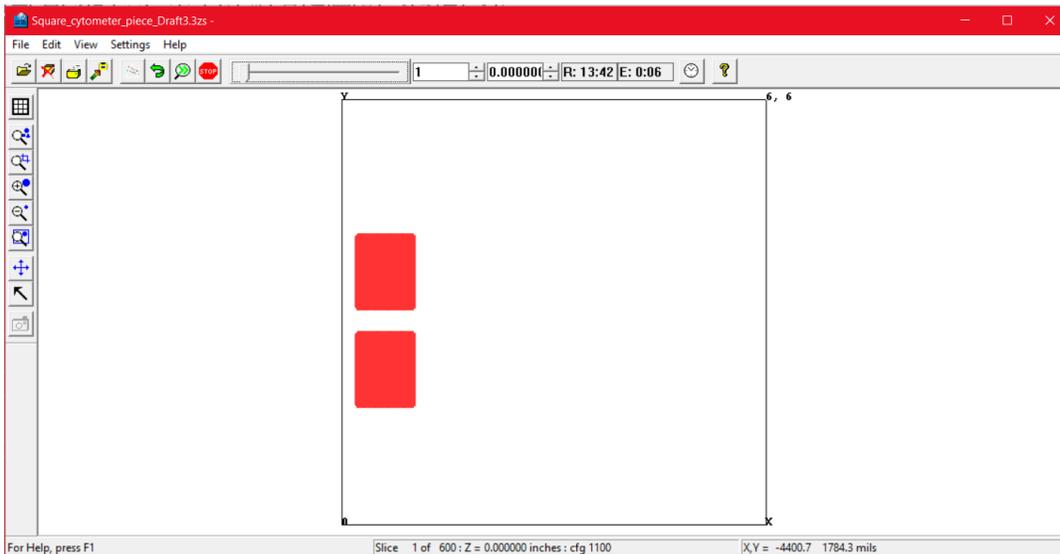
Platform Layers : 2
Mill Platform : 0
Perimeter Support: 0

Show All Slice Ranges Costing Print... Help OK

The next screen will depict a layer by layer simulation of the build. The support material is represented with orange pixels, while the build material is represented by green or blue material.

You can press the  button to rapidly go through all the build layers to see how the device will be built in the printer. Using the scroll bar, arrow buttons, or numerical field

, you can select the layer you would like to view.



Feel free to exit out of the simulation screen and the pop up window entitled “remote monitor”. Close 3ZWorks.

Printing the Molds

Enable the 3ZStudio wax printer on badger. Tap on the blue circular icon if there is a green check mark next to it. On the next pop up screen tap the “clear job” button, and close the popup screen. Eject the flash drive from your device and place it into the USB port located on the wax printer. Once the file has been successfully uploaded, you will see a green check mark next to the blue circular icon located at the top of the touch screen. Below this, the name of the .3zs file is displayed. The wax printer will choose the most recent .3zs file on the USB drive. Click the “Start Job” button. Before building the actual wax molds, the printer will first run some calibrations. Unless the printer explicitly stops in the middle of the job and requests user interference, there is no need to worry.

On rare occasions, the job will get stuck in calibration mode. If the screen depicts that the printer is on a certain step such as “Calibration: Support Low Volume” and remains stagnant for an hour or so, then the software has crashed. Turning the printer off and then on again will restart the job and fix the problem.

A very common issue that can occur is a tape jam. When this occurs, the job will pause and the user will be required to open up the printer and fix the issue. Looking at the paper tape, the user will observe that the tape has been ripped and flung off to the left of the conveyor belt, as shown in the figure below:



Print jam error screen Pop up when error icon is clicked Physical paper jam

This tends to occur if the paper tape roll currently inside the printer is very old. Old paper is wrinkly, causing the edges of the paper to rise slightly. This is unsuitable for the wax printer environment, which requires all instruments to be very finely calibrated. If the paper edge is high enough, it may get caught on the extruder tip as the print head moves from the tape conveyor belt to the build plate. The head will drag the tape along with it and eventually cause a tear. The severed tape will no longer be able to move forward along the conveyor belt, and a jam will be detected.

To remedy this problem, press the tape icon with the red "X" on the 3ZStudio touch screen. On the resulting popup window, tap the move button until all excess tape has been removed from the feeder. Thread the remaining tape across the conveyor belt and down through the tape feeder, and press the "move" button again. If the tape doesn't move, push it even more into the feeder and try pressing "move" again. Do so until the tape is being pulled mechanically through the feeder. Once this is done, close the lid of the wax printer and click the "test" button. Once a green checkmark appears on the screen, close the popup window and click "Resume Job". If the problem occurs again, your tape roll is too wrinkled and needs to be replaced.

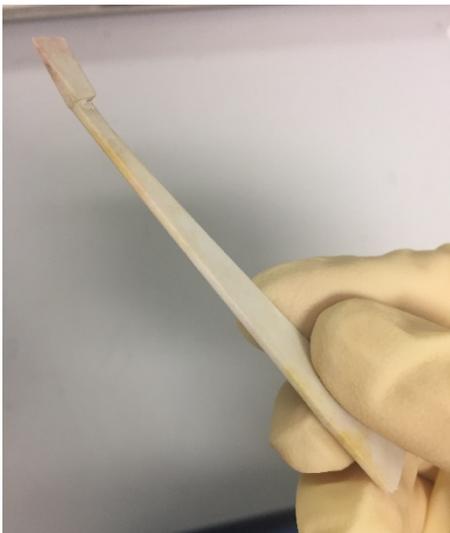
Once the print job is done, open the printer. The actual structure will be modeled out of blue wax, while the surrounding support material will be brownish red wax. An example completed job is shown below:



A completed print job (the beige platform is a section of the build plate)

Mold Post-Processing

Remove the build plate from the printer by sliding the two latches on the top and bottom of the plate to the left, as shown in the user manual. The molds will be stuck to the build plate and can only be removed by melting the bottom layer of wax. Don't worry. The bottom layer is made of support material, not build material. So long as the structures on the bottom layer are sturdy enough, no harm will come to your structures through this process. Place the build plate on a hot plate heated to 110 degrees Celsius. It will take roughly 20 to 30 minutes for the build plate to be heated sufficiently. To remove the molds, you can use a small, tool with a thin, flat, and fine edge, such as the one depicted below:



The tool the author used to remove the molds from the build plate

You will need to wait for the plate to be heated to a suitable temperature. To test if the plate is hot enough, slide your tool along one of the edges of a mold. If the support material along the edge slides off as one single long, thin piece without much resistance, you know that the molds are ready to be removed. Start by scraping away all support material from the edges of the structure. Slide the removal tool slightly under one edge of the mold. If the structure is released from the build plate then and there, congratulations. Otherwise, do not attempt to forcefully remove it. Pull the removal tool away from the structure, and repeat the process for a different edge, sliding it just slightly under the mold. Do so for all distinct edges. Once this is done, go back to the first edge you processed and gingerly slide the removal tool even further into the underside of the structure. Continue this process once again for all edges, iteratively sliding deeper under the mold each time, until it breaks away from the build plate. Usually, removing a mold from the build plate does not require the removal tool to be slid under each edge more than twice.

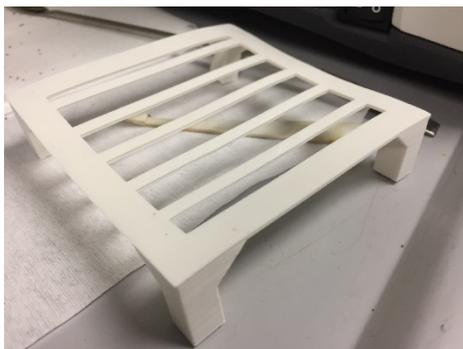
Once the molds have been successfully removed from the build plate, it's time to remove the rest of the support material. Fill a large glass beaker about half full with VSO mineral oil, which is a special type of mineral oil mixture sold by SolidScape. The mineral oil should be replaced every 10 or so jobs. This mineral oil needs to be heated to between 50 and 55 degrees Celsius and can UNDER NO CIRCUMSTANCES exceed 55 degrees Celsius. You should monitor the temperature of the bath with a thermometer. Make sure that the tip of the thermometer is not touching the beaker, as this could lead to inaccurate measurements. Hot plate temperatures that achieve the desired thermometer readings will vary. At the time of writing this document, a half full beaker filled with ~1 L of VSO mineral oil could be set to roughly 53 degrees Celsius if the hot plate was set to about 80 degrees Celsius (see picture below). Place a magnetic stirrer inside the mineral oil. Do not begin stirring yet.

Placing the molds on the bottom of the beaker will be harmful for two reasons. The higher temperature of the beaker relative to the bath will cause temperature gradients across the mold, which will lead to warping (see figure below). If the bath is set to too high a temperature, this may also cause warping or simply cause the molds to melt. The support material will also be removed much more quickly from the molds if the bath is stirred. However, if the wax pieces and stirrer are both on the bottom of the beaker, the stirrer might toss them around, causing the pieces to break.



An example of warping in the molds

To solve this, we have printed a simple plastic table that can be placed in the mineral oil. It is tall enough to not disturb the stirrer and wide enough to fit many wax pieces at once. A picture of this table is shown below.



The 3D printed table



The completed apparatus

Once the thermometer temperature reads the desired temperature, place the molds in the bath and turn on the stirrer. The stirring speed will vary based on the size of the molds. You want to be able to stir the bath such that the molds do not move around within the bath. As a point of reference, for molds roughly 3 cm wide and 3 cm long, a stirring speed of 150 rpm was used, while molds .5 cm wide by .5 cm long could only be stirred at a maximum of roughly 85 rpm. The time the molds should be in the bath varies with size and the number of fine features your structures have. As a general rule of thumb, the molds should remain in the bath between 1 and 1.5 hours at the temperatures prescribed above. Leaving them in the bath for longer than that may cause warping or distortion of features. The molds should be gently extracted from the liquid with tweezers and placed on a napkin to dry. Drying can take as long as a full day if the molds are left untouched. The process can be sped up by lightly dabbing the surfaces with a napkin to absorb excess mineral oil. Take care when applying the napkin, as excessive force can damage delicate features. Moreover, wiping the surface with the napkin too aggressively can lead to scratches and small paper flakes.

If the molds have been handled properly, then they should be ready to use upon drying. The molds will either look solid dark blue, or they will have a frosty finish to them, as shown in the figure below. This frosty finish is nothing to be afraid of. The mold is still smooth and completely usable.

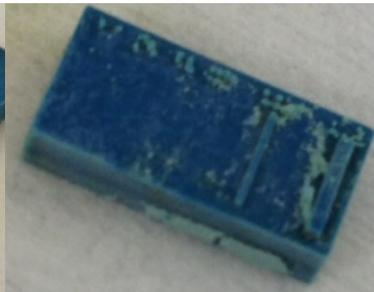


Frost residue

However, all too often this is not the case. Improper post processing of the structures can lead to undesirable residues remaining on the mold surfaces after drying. Three of the most common types of residue are shown below:



Thermal Residue



Dust Residue



Leftover Red Wax

The leftmost figure depicts thermal residue. If the temperature of the bath is too low, then it will take a very long time (sometimes longer than a day) before the support material appears to be mostly removed. After drying, brown residue may accumulate on the mold. We are not sure what causes this residue, nor what it is made out of. Leaving the mold in the bath for longer does not remove it. Unfortunately, there is no known way to remove the thermal residue.

The next type of residue to be aware of is the flaky blue residue depicted in the figure above in the center. This results from dust created during printing. While the structures are being built, a vacuum attached to the wax printer occasionally sucks away dust being generated during the build. If the vacuum bag is full, this suction ability is reduced. If this occurs, a prominent pile of blue dust (made out of build material) will accumulate on each structure. Once the material is submerged in the bath, this dust doesn't float away. Instead, the mineral oil clumps the dust together, which sticks to the surface of the mold. Once the mold dries, the clumps remain, forming the blue residue. If the structure is stable enough, this residue can be gently scraped away using a napkin or some sort of sharp edge. There is no other way to remove this residue. Making sure to replace the vacuum bag every 5 to 7 prints will prevent the dust from accumulating. Brushing away any small dust particles before submerging the molds in the bath is another good preventive measure.

The figure on the right depicts leftover support material. This can occur with larger molds that have long, narrow channels. It is possible that the 1.5 hour submerging in the bath is not enough for the heated mineral oil to dissolve all of the support material. In such an event, DO NOT leave the mold in for longer. This can cause warping, as described above. Instead, take the molds out of the bath and let them cool for about an hour. Once the molds have cooled, submerge them in the bath again for another 1 to 1.5 hours. This should remove any remaining red wax.

Assuming no residue has built up and the mineral oil has dried completely, your molds are now ready to use. Congratulations.

3d Model Automation Scripts

In order to automate the creation of 3d stl files for printing characterization tests, supporting Python scripts were developed for developing and scaling stl files. Automatic scripts for iterating multiple aspect ratio dimensions, for example, saved a lot of time. Also, the CAD software used often could not support the creation of basic shapes at the desired dimension, requiring the user to create the desired geometries at a larger scale. Scaling the files was useful for taking existing complicated models (e.g. designed in Google SketchUp or Solidworks) and scaling them down to the desired dimension. See <https://github.com/rexgarland/stl-utilities> for this code and its documentation.

References

- [1] Hofmann, Oliver, Philippe Niedermann, and Andreas Manz. "Modular Approach to Fabrication of Three-Dimensional Microchannel Systems in PDMS—application to Sheath Flow Microchips." *Lab Chip* 1, no. 2 (2001): 108–14. doi:10.1039/B105110P
- [2] Rekštytė, Sima, Mangirdas Malinauskas, and Saulius Juodkazis. "Three-Dimensional Laser Micro-Sculpturing of Silicone: Towards Bio-Compatible Scaffolds." *Optics Express* 21, no. 14 (July 15, 2013): 17028. doi:10.1364/OE.21.017028.