

3D Printing Clay Wiki

This wiki will gather together all of the resources needed to print on CCA's Potterbots in the Digital Craft Lab.

[Digital Craft Lab - CCA Portal](#)

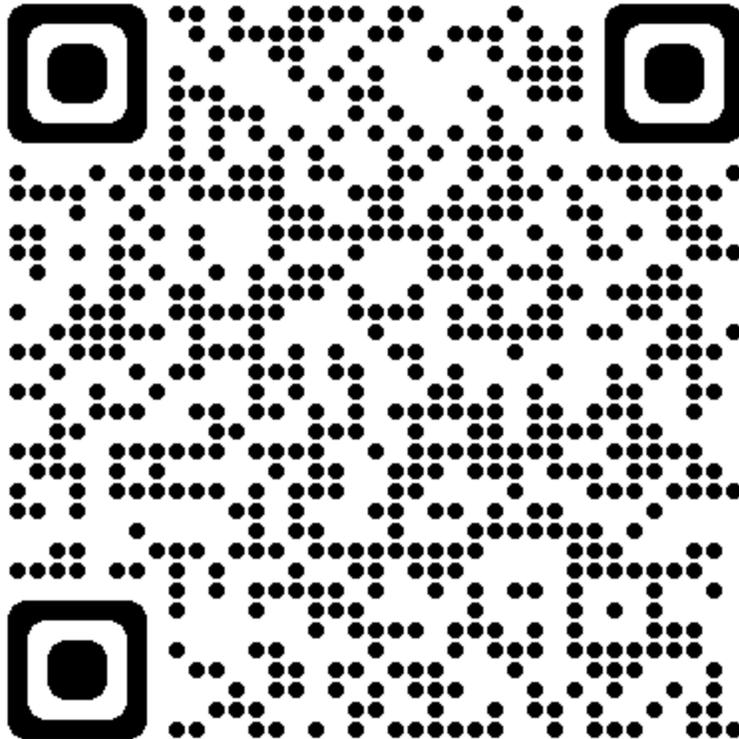


Table of Contents

[Clay Resources](#)

[Preparing Clay for Printing](#)

[Pugmill Operation](#)

[Mixing](#)

[Pugging](#)

[Pugmill Use and Maintenance Protocols](#)

[Hand Loading Operation](#)

[Preparing Tube for Potterbot](#)

[Nozzle Installation](#)

[Piston and Extruder Installation](#)

[Printing](#)

[Fundamental Concepts of FDM 3D Printing](#)

[Terminology](#)

[Creating G-Code](#)

[What is G-Code?](#)

[Common G-Code Commands](#)

[Method 1: Using a Slicing Application](#)

[Method 2: Generative G-Code with Grasshopper](#)

[Operating the Potterbot](#)

[Cleaning](#)

[Training Checklist](#)

[Potterbot Monitor Responsibilities](#)

[3D Printed Clay Examples](#)

[Artists](#)

[Printers](#)

Clay Resources

CCA buys its clay from [Clay People](#) in Richmond, CA. The clay comes in 25 pound bags and significant savings are possible when ordering in bulk. Clay People will deliver to CCA for an added charge. They are located at: [623 S. 32 St., Richmond, California 94804](#)

The clay that we will initially use for the potterbot is called B-Mix clay. We use either B-Mix Cone 5 or B-Mix Cone 10 clay (they are similar, but have different firing temperatures). It is essential to be aware of which clay is being used for when you fire it, so the studio managers know what firing temperature to set.

Besides the B-Mix clay, printing with other clays are possible. Potterbot.com has several [recommendations](#):

- WC-901 Maccabee Mix 5 Clay - stoneware
- WC-902 Axner Mary's Porcelain Clay - porcelain
- EM-700 Vince's Low White Clay - earthenware

Ron Rael has printed with several local clays in projects including:

- [Bad Ombres](#) (mixing two different clays in one print)
- [Four Future Relics](#) (using black Indian clay)

Preparing Clay for Printing

Pugmill Operation

The pugmill is the easiest way to mix the clay to the right consistency and load the potterbot tubes.

Mixing

In order to print with clay, we need to make the clay softer by adding water to the clay in the mixing chamber of the Pugmill. It is best to add *small amounts of water at a time* and then mixing in order to test the consistency of the clay. It's better to do this than add too much water (although you could add dry clay powder to counteract the water). The clay should be sticky and not too fluid -- aim for the consistency of toothpaste or cottage cheese. Wet clay will make loose, inconsistent prints, and it may be too wet or slippery to mix and extrude successfully out of the pug mill. Dry clay will cause problems with the Potterbot, often overloading the extrusion motor and causing the ACME screw to bend.

- Open the pugmill to determine how much clay is in the chamber. If you can see deep into the pugmill (if there are large gaps), those will need to be filled by adding clay from the various clay buckets or fresh clay from the boxes. Each bucket's clay has a different thickness; feel the clay in the chamber and add the clay whose dampness you think will result in the best consistency for painting after mixing. If the clay in the pugmill feels too damp, add a drier clay from the buckets to balance this out. You can also mix in new clay.



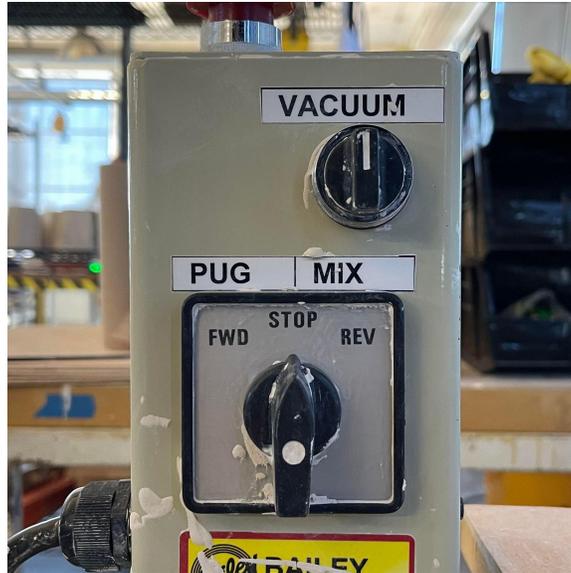
A full pugmill chamber

- Be sure to leave enough room for the lid, which does take up substantial volume. Use the lid to press clay down into the chamber. This may require a LOT of force! If you cannot get the lid to close, remove clay. You can also use a dowel or mixing stick to help push the clay down into the chamber.
- DO NOT put your hands inside the chamber. There are very sharp mixing blades inside.
- Do not bring your own clay to use in the pugmill. Only the approved material (B-Mix) is allowed in this machine. This will ensure consistency in printing results. Consult with your instructor and/or the [Digital Fabrication Studio Manager](#) if you have questions or want to use a different material.



The locking arm should be closed before mixing or pugging. It may not fit completely over the arm, but the pugmill will operate as long as the chamber remains closed

- Once the pugmill is full, close the lid and use the locking arm to hold the lid in place. Ensure that the pugmill is plugged in and that the lid on the pressure chamber is on and sealed tightly. Then turn the operation switch to **REV / MIX**. The pugmill will move clay back towards the rear of the machine and begin mixing it.



- Pay attention to the pressure chamber; clay should come up from the pugmill and may fill the pressure chamber. This is normal, and will create a pressure seal on its own. However, **watch the pressure chamber to ensure that excessive clay does not make its way into the air tube.** If you see this happening, stop the machine and remove the excess clay. Cleaning the air tube is a time-intensive process that we want to avoid; if clay and/or water gets into the air tube and then into the vacuum pump, it can damage the pump.



Pugging

- After the clay has mixed for a few minutes, you are ready to pug. Install the tube adapter flange using the appropriate bolts. Make sure you are using the appropriate adapter depending on the size tube (2000ml vs 3000ml) that you are planning to fill.



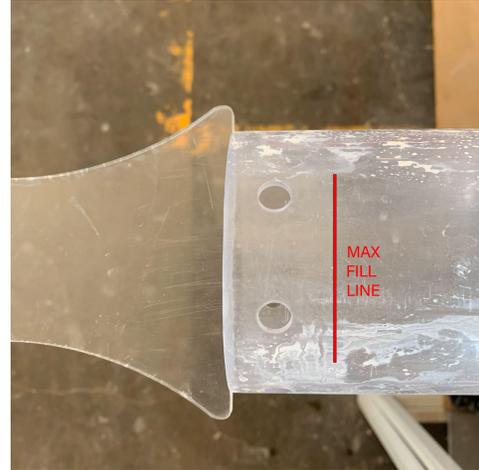
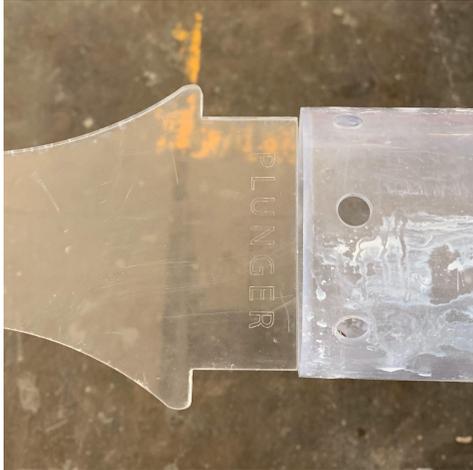
- With the tube adapter installed, you may now attach a clean tube to the adapter using the metal dowels.



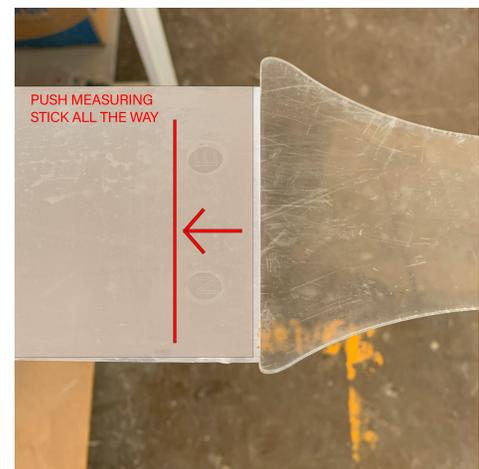
- Turn the vacuum switch to the right, then turn the operation switch to **FWD / PUG**. You should see the clay begin to move forward towards and into the tube slowly but steadily. If you don't see any movement, you may need to add more clay. If the pressure chamber seal is not tight, you will not have enough pressure to pug clay. The needle on the pressure gauge should jump when the vacuum is on. (You may need to apply pressure or press down on the vacuum chamber seal).



- There is an acrylic measuring stick that helps determine how much clay fits into the tube with consideration for the end cap and nozzle. Insert the side labeled B (?) into the end of the clay tube furthest from the machine. This will be the top side of the tube, which will hold the threaded extrusion arm that pushes clay towards the nozzle. Note how far the measuring tool goes into this end of the tube, and turn off the machine just before the clay reaches this line (clay will continue to move forward even after the machine is powered down, so account for that residual push).



- Once the tube is full of clay per the limit indicated above, remove it from the pugmill by loosening the attachment hardware. Use the side labeled A (or “NOZZLE”)) on the measuring stick and carve out excess clay from the side of the tube that was closest to the pugmill. This will be the nozzle side of the tube.



Pugmill Use and Maintenance Protocols

1. Keep the Pugmill chamber full of clay. We do this for a number of reasons:
 - a. If the pugmill chamber is full, it is less likely to dry out
 - b. It saves time for the next person if they arrive at a full pugmill so they can immediately start working.
 - c. It's fair. You are benefiting from the use of someone else's clay when you come in and it is full. Pay it forward and replace the clay that you used with your own clay.
2. **Clean the pugmill before you leave.** Wipe off all clay off of the outside and clean all of the handles and knobs on the machine (but avoid getting water into the electronics).
3. Place a wet sponge in the vacuum chamber.

4. Take the tube adaptor off and replace the end lid. Place a wet sponge and wet paper towels in the lid to keep the clay wet.

Hand Loading Operation

If you are using another clay body than the one inside the pugmill, you will need to load the tubes by hand. The problem with loading by hand is that it will be difficult to eliminate air pockets which may cause problems while printing.

Here are the instructions from the Potterbot.com website on loading by hand:

The simple answer is add 15 ounces of water to standard 25 pound bag of clay. I cut the square bag of clay into 4 long pieces and I usually put microfiber towel in between the clay pieces before I add the water. Now roll up the bag again and make it airtight. Wait until the water has penetrated the clay, usually one to two days. Now take out the clay that has the proper moisture content, roll it into a cylinder a little bit smaller than the diameter of inside of the tube. Put the nozzle on the tube with tape over the end and gently tap the long piece of clay into the tube. Tap the tube and nozzle on soft piece of carpet so not to damage it. That's it, this is your best method to load your tubes without a pug mill. ([link](#))

[Video link](#)

The Potterbot website also notes that you can load the machine using a trowel and that it may be possible to eliminate more air pockets through this method:

This is done with a trowel or a spatula on a flat table. As you force clay you can tap the tube to move the clay further down as you continue to load the tube. If the consistency of the clay is correct, you can eliminate the air at the same time. ([link](#))

Preparing Tube for Potterbot

Nozzle Installation

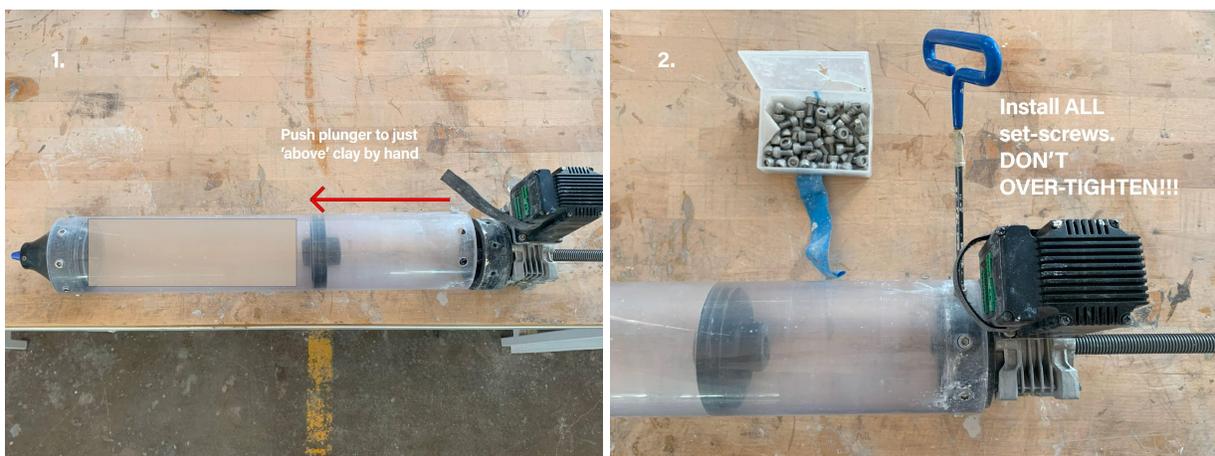
- If there is any extra clay from the tube after using the acrylic measuring tool, you can manually stuff some of this into the nozzle adapter using your fingers. Try to pack it as tight as possible, mindful that any air bubbles will cause issues during printing.
- Insert the nozzle adapter into the clay tube, then fix into place using the threaded screws and the appropriate allen keys. Although these are threaded, they will really only hold the adapter in place with friction. Some may fall out as you rotate the tube; keep track of them so you don't lose any.

- With the adapter in place, you may now install the nozzle into the adapter by pressing it into place. Be careful not to push it too far; it will be very difficult to remove. Note the groove on the nozzle, which will give you an idea of how far it rests into the adapter.
 - Note that there are different nozzle sizes whose diameters will directly influence clay extrusion. Make sure the nozzle that you are installing is coordinated with your nozzle size settings in your design files.
- Insert a set screw into the nozzle adapter and tighten to hold the nozzle in place.



Piston and Extruder Installation

- Prepare to install a piston and extrusion rod on the other end (what will be the top) of the tube. The flat piston goes into the tube first. Try to position this plunger as flat as possible relative to the clay.
 - Note that if the tube is only partially filled with clay, you will need to push the plunger all the way down to be flush with the clay. You can use a spare rod or PVC tube to help orient it properly.

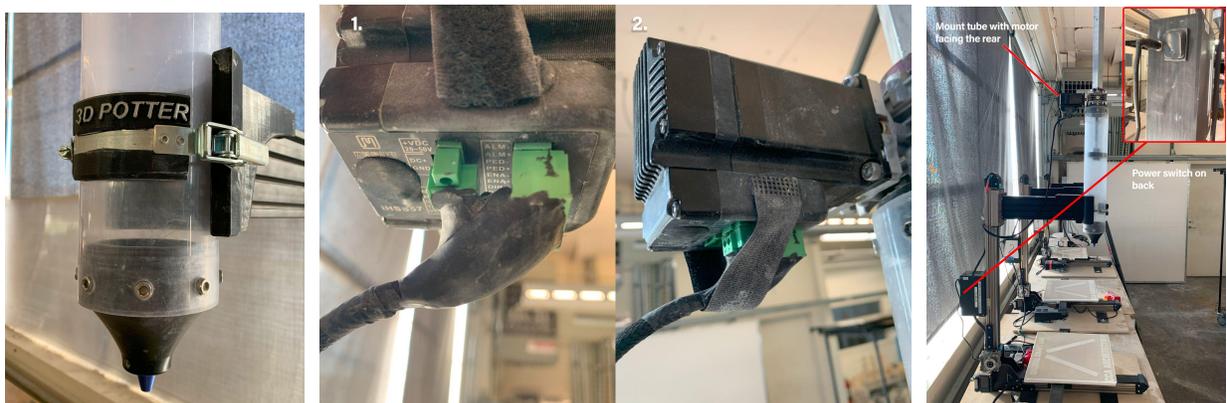


- Next, you will attach the extruder motor, which will start by inserting the ACME screw into the tube to align with the pocket at the top of the piston. If the tube is full of clay, it is very

important that the screw is completely or almost completely recessed in the gearbox adapter (the black ring connected to the extrusion motor) before attaching it to the clay tube. To adjust the screw, you can use the square key on the drill and **SLOWLY** and turn the bolt until the ACME screw is properly positioned. If it backs all the way out of the extruder, simply screw it back in.



- Use hex screws to secure the extruder to the tube, then use the square key and drill to and begin to turn the bolt - **very slowly**. This will begin to push clay towards the nozzle. *****If the ACME screw is too far forward, you will be unable to make the adapter align with the screw holes, and turning the key will simply continue to extend this distance.**
- Continue turning the ACME screw until clay reaches the nozzle; watch for clay to come out of the nozzle and stop at or just before that point. You should back up the ACME screw if the pressure is too tight and excessive clay is spilling out. **Please be careful not to push the piston too far or too tight if there is strong resistance, as this will overstress the screws connecting the extruder to the tube, and may also bend the ACME screw.**
- With both the nozzle and the ACME screw now in place, the clay tube can be attached to one of the Potterbots. Clay tubes are held in place via pressure using the locking arms. Keep the clay tubes high to begin with; you can lower them as necessary when printing begins.



Printing

Fundamental Concepts of FDM 3D Printing

Before we get into specific methods we will use for 3D printing with clay, it's useful to review some fundamental concepts related to 3D printing. The first is that there are many different types of 3D printing and even more different types of printers. We will be focusing on what is called Fused Deposition Modeling or FDM ([wikipedia entry](#) on FDM printing). In this style of printing, a filament of material, in our case clay, is deposited onto the bed and previous clay layers to build up a model in space. Most consumer-grade printers such as FlashForge and Makerbot printers use FDM but with plastic filaments such as PLA or ABS. Although we will be using clay, the idea is essentially the same. A material is pushed through a nozzle and layers are built up, one tube of material after another.

Terminology

Layer Height: The height of each layer. Also known as the contour height.

Nozzle Diameter: This is the diameter of the opening at the tip of the nozzle. Typically we use standard round/circular nozzles (4mm, 5mm, etc.) but you can also 3d print your own nozzle shapes out of ABS.

Extrusion Multiplier: This is a multiplier typically set within the Grasshopper script to control how fast the extruder motor runs relative to the X, Y, Z move speed. It is recommended to start with this at 1.0 and then increase/decrease slightly as needed if the extrusion rate seems off. Note that you can also do this manually while printing using the speed and extrusion overrides on the Potterbot.

Move Speed: The speed at which the print is moving in X, Y, or Z. Sometimes known as the "print speed". Typically measured in mm/min.

Extruder Speed: The speed at which the nozzle is extruding material. Sometimes known as "Feedrate" or "Flowrate". Typically measured in mm/min. The extruder rate is usually a calculation performed by the slicing application based on the user input layer height, nozzle diameter, and extrusion multiplier.

Nozzle Diameter vs. Layer Height:

<https://rigid.ink/blogs/news/what-3d-printer-nozzle-size-should-i-use-the-pros-and-cons>

Creating G-Code

What is G-Code?

G-Code is the code read by the 3D printer (or many types of CNC machines) and we need to convert the geometry of your model into a series of commands that the printer understands. G-Code was created in the late 1950s so it is a very established coding language. It is also fairly simple compared to most programming languages. Although it is possible to manually write G-Code, it is often generated programmatically by an application. At times you may need to insert specific commands at the beginning or ending of the code. To learn more about G-Code, see its [wikipedia page](#), specifically the list of all [G commands](#). Most 3D printing applications use a flavor of G-Code that was built for the [RepRap](#) firmware (the software that runs on the Potterbot). Review the list of [G commands in the RepRap version](#). The commands are very similar, but the RepRap version of the commands are more specific to 3D printing rather than general CNC machining.

Common G-Code Commands

All G-Codes are preceded by the letter “G” and then a number and then a list of parameters or arguments. Not all parameters need to be used. Here are a list of common G-Code commands used in 3D printing followed by an example and an explanation. In order to make comments (test that the printer will ignore) in G-Code, use the semicolon character (;) .

G0: Rapid linear Move

This is a move that you would do when not printing (or milling or whatever).

Format: G0 Xnnn Ynnn Znnn Fnnn

X = The position to move to on the X axis

Y = The position to move to on the Y axis

Z = The position to move to on the Z axis

F = The feedrate (speed of the move) per minute of the move between the starting point and ending point (if supplied).

Example: G0 X100.00

Explanation: Rapidly move the print head to 100.00mm on the X-axis.

G1: Normal Move

Use this move when you are moving and printing (or milling or whatever). 99.9% of all of your G-code will probably be G1 commands.

Format: G1 Xnnn Ynnn Znnn Ennn Fnnn

X = The position to move to on the X axis

Y = The position to move to on the Y axis

Z = The position to move to on the Z axis

E = The amount to extrude between the starting point and ending point

F = The feedrate (speed of the move) per minute of the move between the starting point and ending point (if supplied).

Example: G1 X100.00 Y100.00 E20 F3000

Explanation: Move to 100,100 at a speed of 3000mm/min while extruding 20mm of material.

G2 & G3: Controlled Arc Moves

These two commands are similar to G0 and G1 but are used to move the printhead in a controlled arc rather than in a straight line. If you want to make a arc-shaped move, it may make more sense to use G2 or G3 as it will result in a smoother movement.

Format:

G2 Xnnn Ynnn Innn Jnnn Ennn Fnnn (Clockwise Arc)

G3 Xnnn Ynnn Innn Jnnn Ennn Fnnn (Counter-Clockwise Arc)

X = The position to move to on the X axis

Y = The position to move to on the Y axis

I = Arc Centerpoint X

J = Arc Centerpoint Y

Ennn The amount to extrude between the starting point and ending point

Fnnn The feedrate per minute of the move between the starting point and ending point (if supplied)

Example: G2 X100.00 Y100.00 I50.00 J50.00 E20 F3000

Explanation: Move in a clockwise arc to 100,100 with a centerpoint of the arc at 50,50 at a speed of 3000mm/min while extruding 20mm of material.

G4: Dwell

This command just pauses the printer for a specified number of milliseconds.

Format:

G4 Pnnn

Example:

G4 P1000

Explanation: Pause for 1000 milliseconds (1 second)

G28: Home

This command is commonly used at the beginning and ending of a print in order to tell the extruder to go to the "Home" position. Home is usually where X, Y, and Z are all zero.

Format:

G28 X Y Z

Examples:

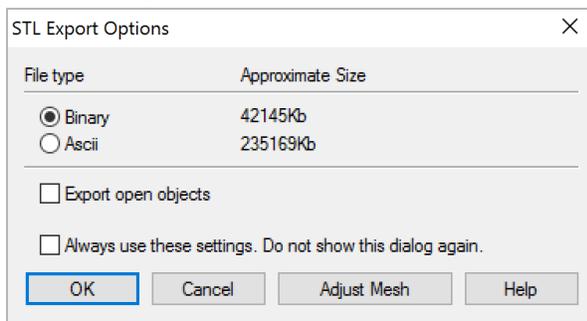
G28 ; Home all axes

G28 Z ; Home Z axis only

Method 1: Using a Slicing Application

Cura, Simplify3D, etc are all applications that take in a 3D model in STL format and output a gcode file that can be read by the Potterbot. Please note that almost all things in the world of 3D Printing are measured in metric.

Step 1: Create a solid object in Rhino (or any other software) and export an .STL file (a [stereolithography](#) file). While exporting in Rhino, it gives you the option to save the .STL as either binary or ASCII formats. Choose binary.



Step 2: Import the .STL file into your choice of slicing application. Here are a few options to consider:

- [Cura](#) (free)
- [Repetier](#) (free)
- [Slic3r](#) (free)
- [KISSlicer](#) (free)

Method 2: Generative G-Code with Grasshopper

This is the method we will typically use at CCA in association with research seminars and courses using the Potterbots. Using custom-developed scripts in Grasshopper, one can generate the G-Code directly in Grasshopper (from a series of lines, or toolpaths), rather than going through a slicing program. This workflow allows the designer to customize and design the toolpaths to create features such as bumps, loops, and other anomalies that might produce unexpected yet interesting results on the Potterbot. It also allows for parametric iteration -- for example, using sliders to test upper and lower limits of specific parameters, such as bump size.

For more information on these workflows, it is best to connect with CCA faculty leading the relevant courses.

Operating the Potterbot

- Storage & organization protocol - photos of tools etc.
- Access wifi, include URL & password - include note about shutting off anti-virus

- Upload gcode
- WARNING: Quick drop on Z Axis
 - Reset tube manually before every print
- Interface
 - Uploading
 - Printing / Pausing / Emergency Stop
 - Increase speed / Extrusion Rate

TO CONNECT TO NEW POTTERBOT:

<http://192.168.42.14>

Potterbot Wifi password: 12345678

Troubleshooting

- Tips for troubleshooting Gcode issues with a working Gcode (having a base one that you know works so you can figure out if the problem is with the machine or with the Gcode) - demonstrate successful simulation in GH, ability to troubleshoot
- Tips for identifying problems with potterbot ex. Grinding sound= stop print

Cleaning

- **Cleaning up after printing takes time! Always budget yourself time to clean up before your next courses or other obligations begin; Failure to do so will result in disciplinary action such as temporarily revoked access. This is not any studio monitor's responsibility and nobody else is going to clean up after you.**
- Water Protocols
 - Since we do not have a sink in the DCL, we must
- Empty Clay Tubes
 - Remove any remaining clay from the empty tube and put it back into one of the clay buckets. You may need to use tools to reach the innermost part of the tubes. We want to waste as little as possible!
 - Pro tip: keep the plunger arm in the back of the tube and use a long piece of wood or PVC pipe to push it through the length of the tube. This will force out the last of the clay pretty cleanly.
 - Once the majority of clay has been removed, you can now use water to clean the inside of the tube. Start with the outermost bucket of water and dunk the tube,

ensuring water gets everywhere. You will need to agitate the water and use your hands or other tools to ensure that the clay residue is washing off.

- Pro tip: Squeeze the large sponge into the tube and push it through with a PVC pipe. Twist/rotate the sponge within the tube and repeat.
- As the tube gets cleaner, you can move on to the next bucket in line and repeat the process.
- Use a wet paper towel or wet rag to wipe down the exterior and interior of the tube and remove the last of the remaining clay. Then set the tube out to dry.
- Nozzles
 - Nozzles must be thoroughly cleaned to avoid clogging. You will need to use your fingers and various tools to dig out any clay that is stuck in the nozzle.
 - Try to save as much clay as possible before resorting to water.
 - With most of the clay removed, you can now rinse the nozzle in the water buckets. Dunk and agitate to get as much clay off as possible.
 - Finish by using a wet paper towel or rag to remove the last remaining clay residue, then set the nozzle out to dry.
- Measuring Sticks and Printing Bases
 - Clay should first be scraped off of the measuring sticks and printing bases, then returned to the clay buckets.
 - The acrylic bases and measuring sticks can be cleaned in the water buckets. Wood bases should be wiped down with a wet paper towel or rag.
- Pugmill
 - Remove excess clay from around the pugmill lid as well as the pressure chamber.
 - The clear lid of the pressure chamber should also be wiped down so that the next user can see clearly into the chamber. Insert a wet sponge or wet paper towel into the pressure chamber - this helps prevent the clay in the pugmill from drying out.
 - Use metal wire to scrape excess clay off of the front of the extrusion area. Return this clay to the buckets.
 - A wet paper towel needs to be installed into the extrusion area to prevent the remaining clay from drying.
 - Cover the extrusion opening with the black plastic cap.
 - Ensure that the pugmill is unplugged before leaving the area.
- DCL Space
 - Sweeping
 - Sweep up dust around the potterbots and pugmill; this space is shared and dust will build up over time and travel into different parts of the studio.
 - Mopping
 - After sweeping, lightly mop the floor to get rid of as much clay residue as possible. Do not leave the floor soaking wet; use a dry mop to absorb excess water to avoid slipping hazards.

Training Checklist

In order for a student to be able to use the Potterbots individually outside of scheduled monitor time, they need to demonstrate the following capacities:

- Can correctly assemble and disassemble/clean potter bot
- Can calibrate nozzle head height
- Demonstrate ability to operate pugmill properly.
- Demonstrate ability to operate potterbot properly.
- Demonstrate ability to clean machine and all parts and workspace properly.
- Knowledge of where tools and parts are to be stored after printing.

Potterbot Monitor Responsibilities

- Work with Architecture faculty to coordinate schedule, expectations,
- Schedule a regular weekly printing time at which the Monitor supervises and assists students who are printing on the Potterbots.
- Supplies
- Cleaning
- Water

3D Printed Clay Examples

Artists

- [Emerging Objects](#): Ron Rael (UC Berkeley) and Virginia San Fratello (UC San Jose). They use various printers to print clay including several models of Potterbots but also Zcorp printers (inkjet + powder printer).
- [Olivier van Herpt](#): Dutch pioneer in Ceramic 3D printing.
- Jonathan Keep: In addition time being a great artist, Jonathan has also produced an excellent series of wiki posts on ceramic 3D printing:
<https://wikifactory.com/@jonathankeep>

Printers

Machine Supplies

- Lithium Grease for ACME screws:
https://www.amazon.com/Lucas-Oil-10533-Lithium-Grease/dp/B06XY6QKS7/ref=sr_1_4?crd=2OB5UYKR81V51&keywords=lithium+grease&qid=1666201331&qu=eyJxc2MiOil0LjcyliwicXNhIjoiMy45NyIsInFzcCI6IjMuOTAifQ%3D%3D&srefix=lithium+greas%2Caps%2C223&sr=8-4
- Screws for attaching clay tubes (Potterbot v10): <https://www.mcmaster.com/91292A441/>
- Set screws for attaching nozzle to nozzle adapter (Potterbot v10):
<https://www.mcmaster.com/92015A127/>