# 3D Printing

## (which I consider to be a legitimate form of Computer Graphics display…)


**Mike Bailey**

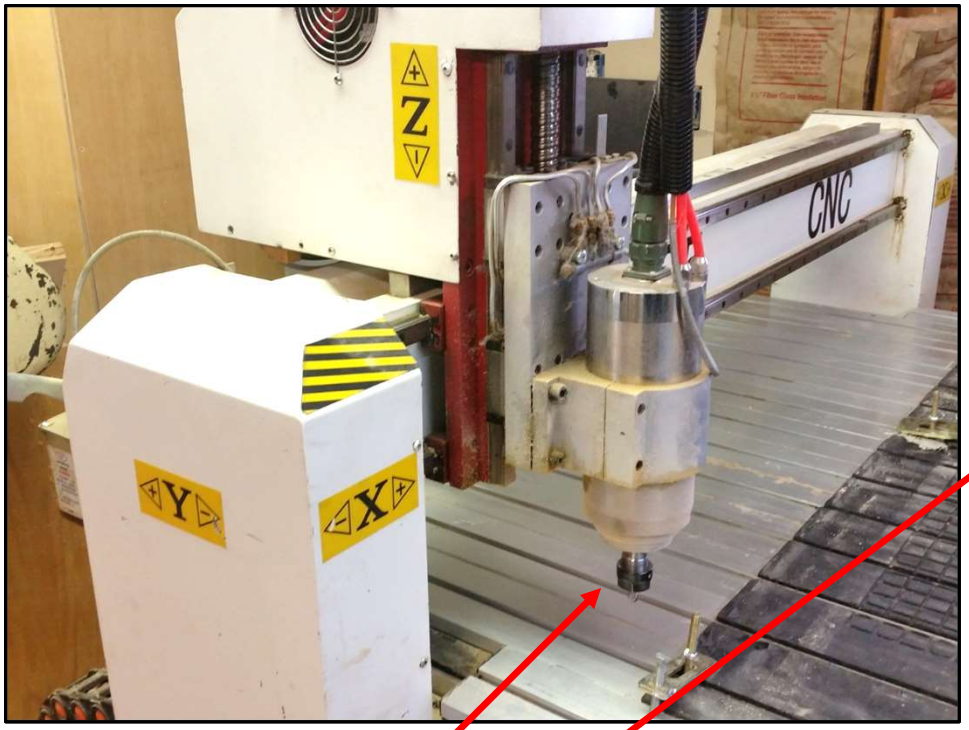
**mjb@cs.oregonstate.edu**



Oregon State University
Computer Graphics

# In the Beginning, All Manufacturing was "Subtractive"



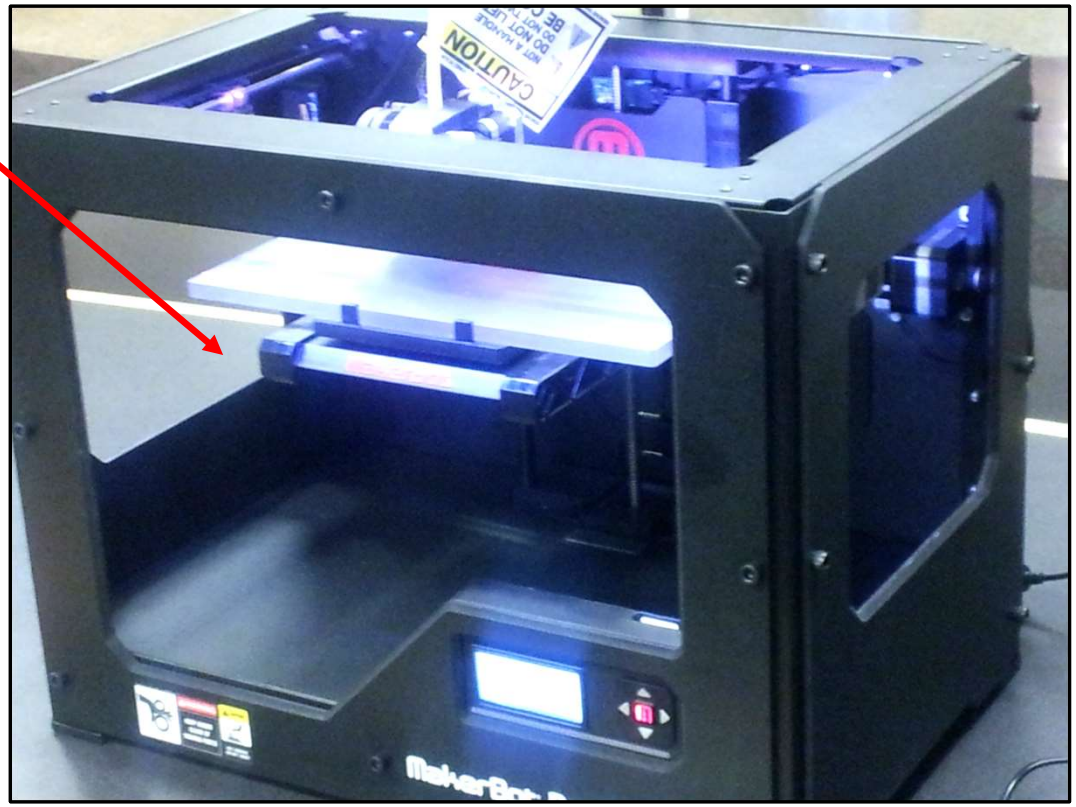



1. The whirling drill bit follows a 3D path around a block of metal, wax, or wood
2. Chips fly
3. A block of metal becomes a part

# Today's 3D Printing Process

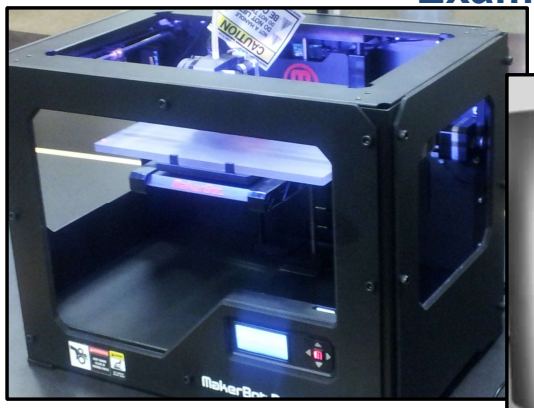
"3D Printing" is generally considered to be some sort of **"Additive**" process in which layers of material get deposited on previous layers. (Additive manufacturing is also sometimes called *Stereolithography*.)

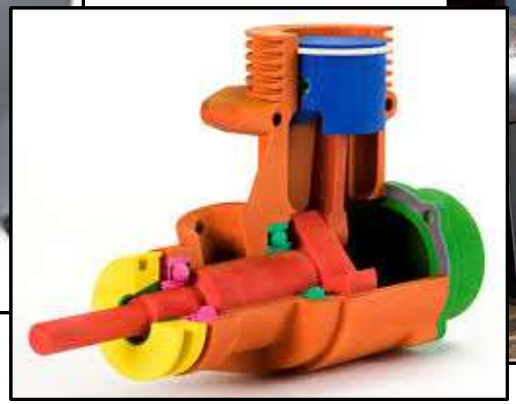
The current frenzy in 3D Printing consists mostly of desktop systems that deposit layers of molten plastic, like this one. But there are many others.



# Examples of 3D Printing using a Variety of Materials





# Portland's Laika uses Color 3D Printing to Make Faces for Stop-motion Movies



From *Kubo and the Two Strings*

# The 3D Printing Geometry File

3D Printers are fed a file called an "STL File", which lists all the triangles in the object. All 3D CAD-ish systems (as well as TinkerCad, Thingiverse, and Blender) can produce this type of file for you.

```
solid

 facet normal   0.00   0.00   -1.00
  outer loop
    vertex   -2.000000   -2.000000   0.250000
    vertex   -1.980000   -1.980000   0.250000
    vertex   -1.980000   -2.000000   0.250000
  endloop
 endfacet

 facet normal   0.00   0.00   -1.00
  outer loop
    vertex   -2.000000   -2.000000   0.250000
    vertex   -2.000000   -1.980000   0.250000
    vertex   -1.980000   -1.980000   0.250000
  endloop
 endfacet

       . . .

endsolid
```

In this particular file, these coordinates were in units of inches.

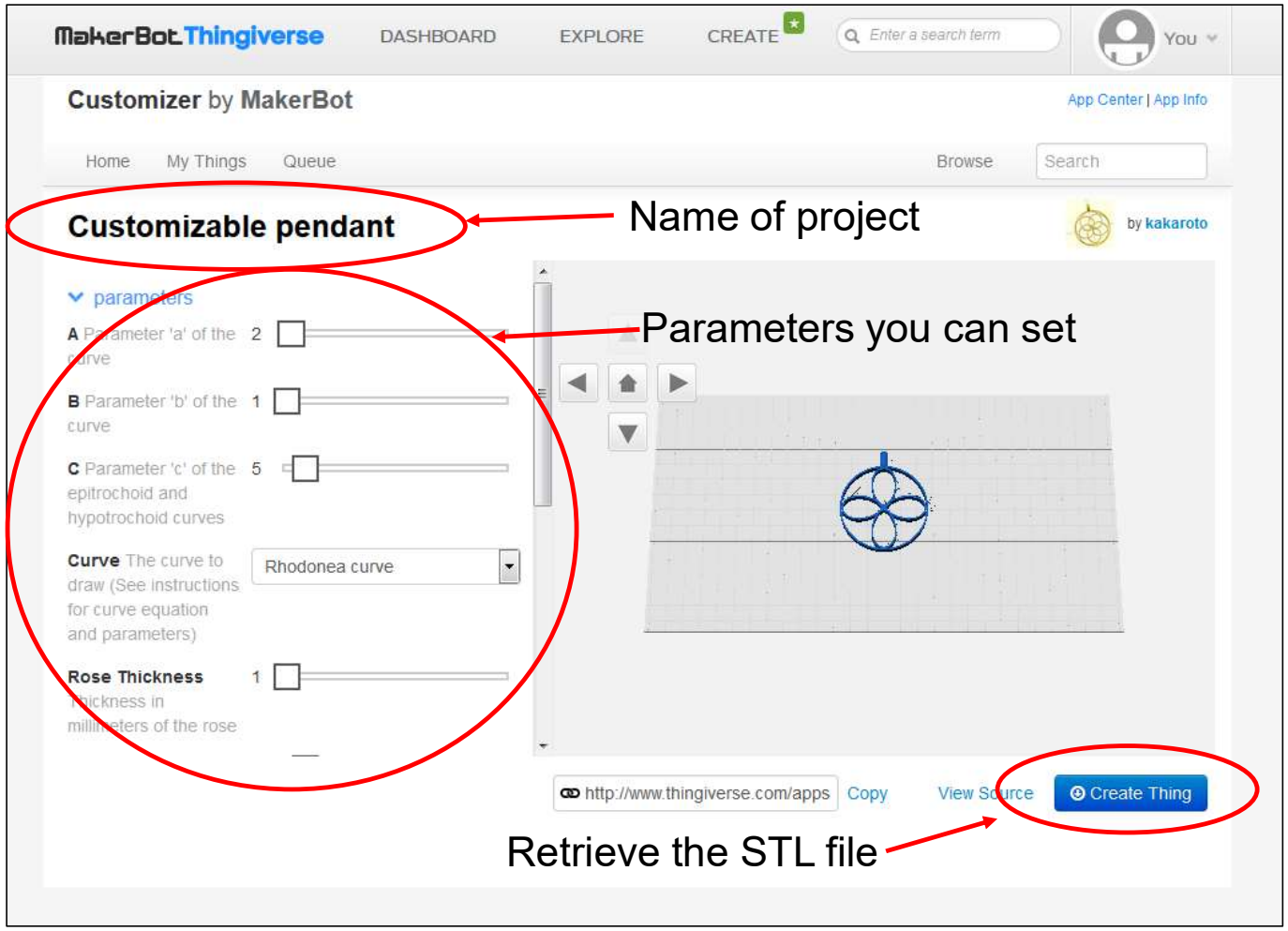
Some 3D Printers still use **inches**, but most now seem to use **millimeters**.

***Check! It matters!***

Note: there are 25.4 mm/inch

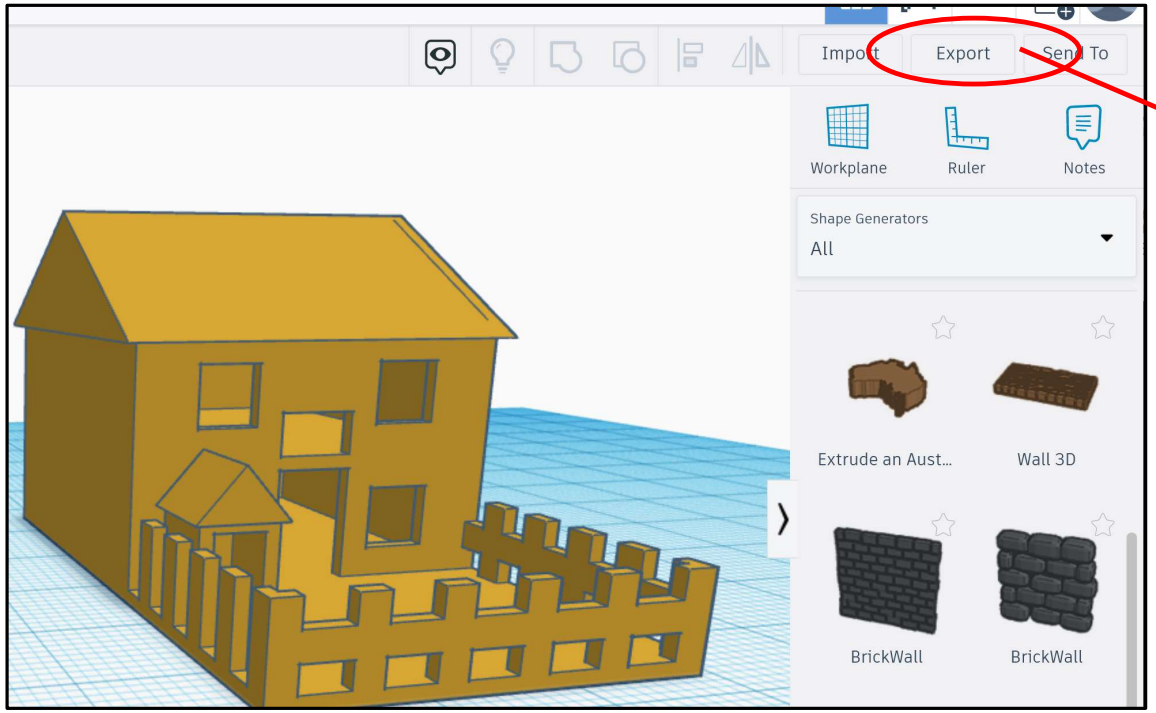
If you sent this file to a millimeter-based 3D printer, the part would come out very, very tiny! ☺

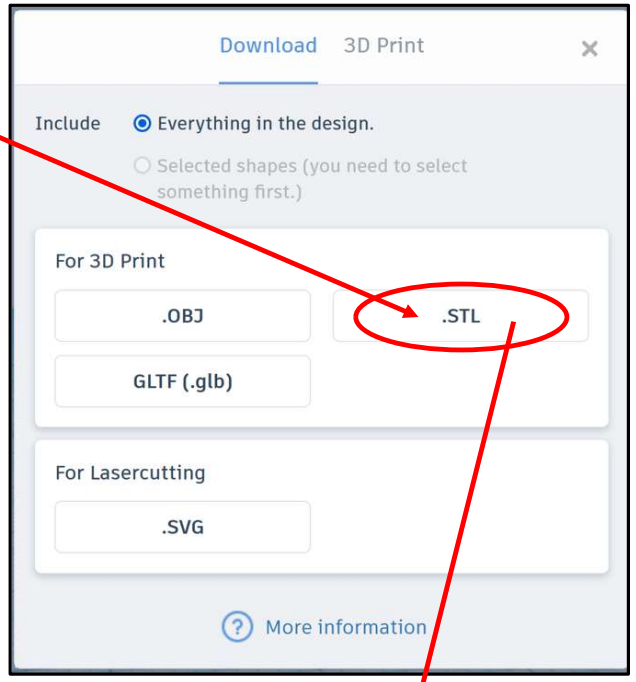
# thingiverse.com

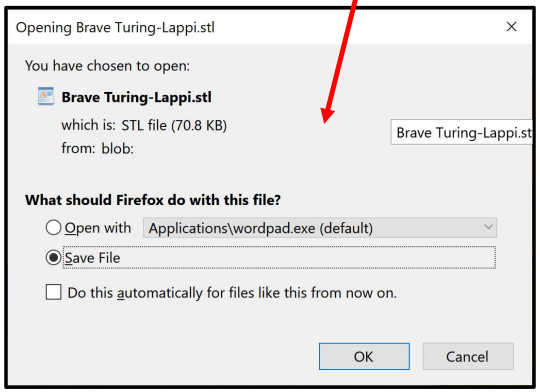


# TinkerCad





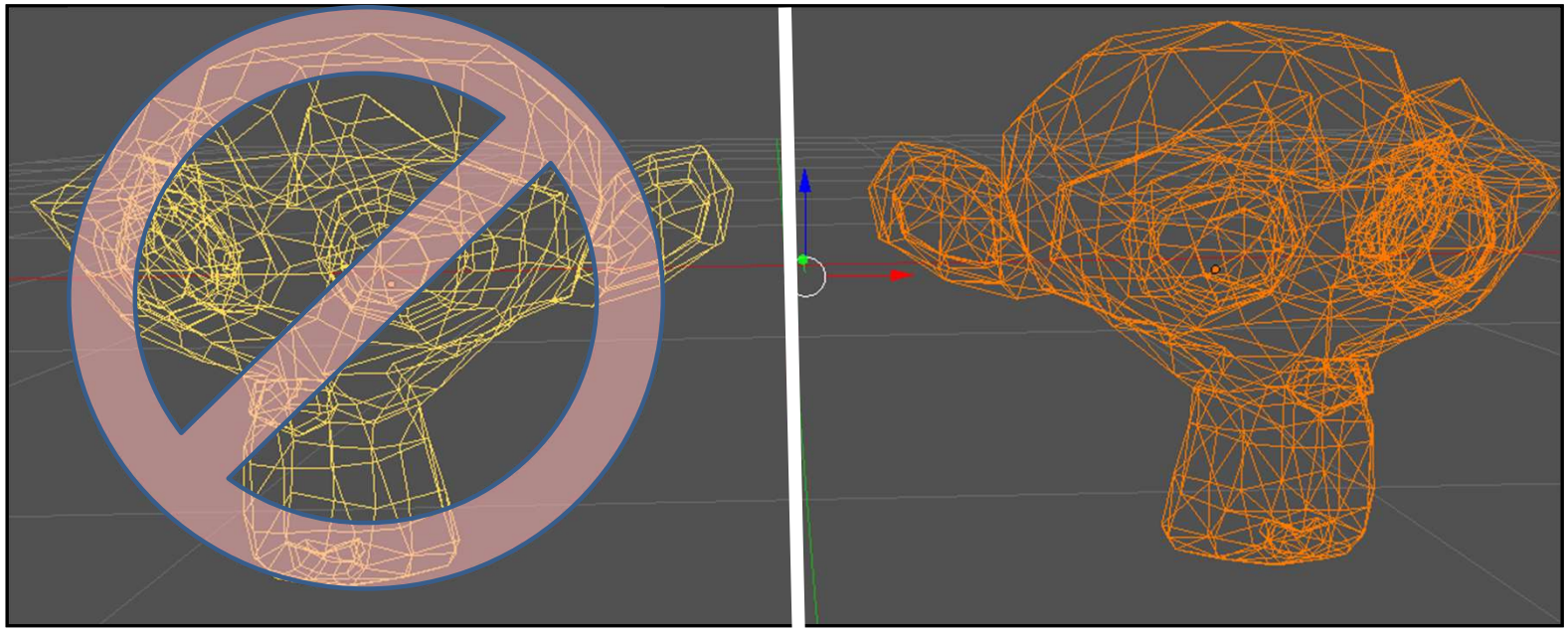




Click on **Import→STL**

# Object Rules for 3D Printing

**1.** The object must be a mesh and ***consist only of triangles***.

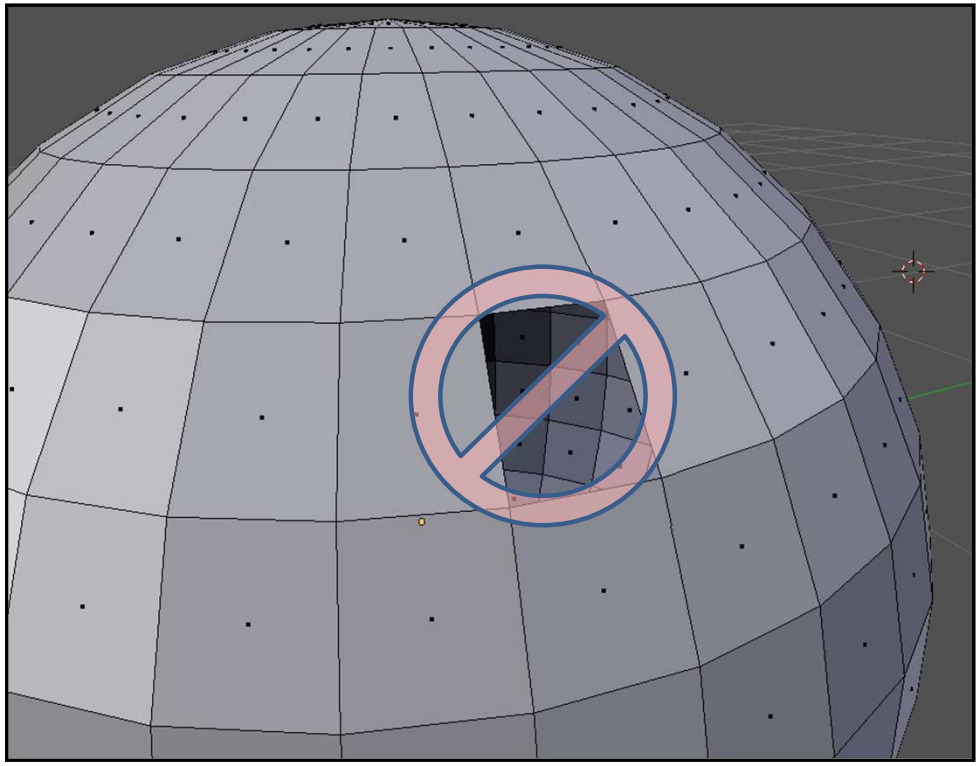


**Quads and triangles** **Triangles only**

**In Blender:** Modifiers → Add Modifier → Triangulate

# Object Rules for 3D Printing

**2.** The object *must* be a legal solid. It *must* have a definite inside and a definite outside. It can't have any missing face pieces.

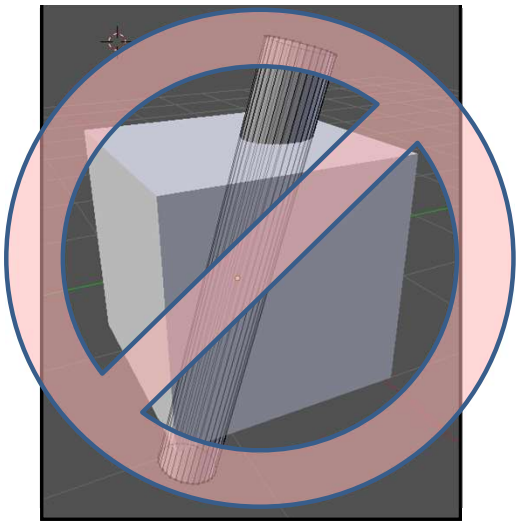


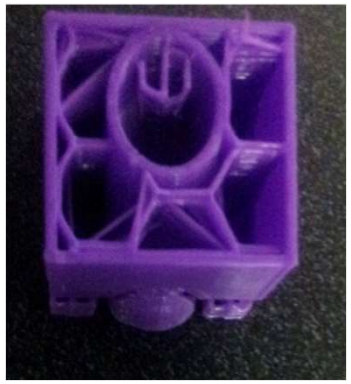
"Definite inside and outside" is sometimes called "Two-manifold" or "Watertight"

# Object Modeling Rules for 3D Printing

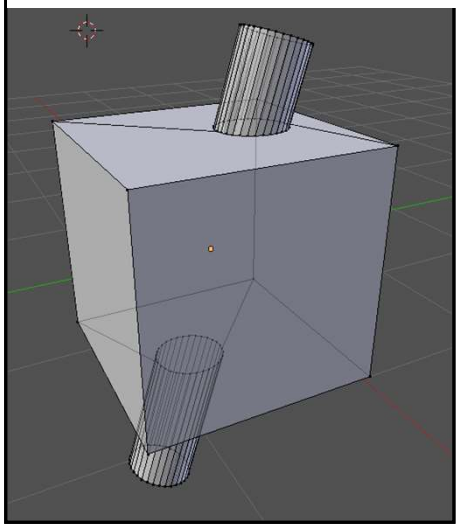
**3.** You can't make a compound object by simply overlapping two objects in 3D. If you want both shapes together, do a Boolean union on them so that they become one complete, legal object.

**Overlapped in 3D -- bad**



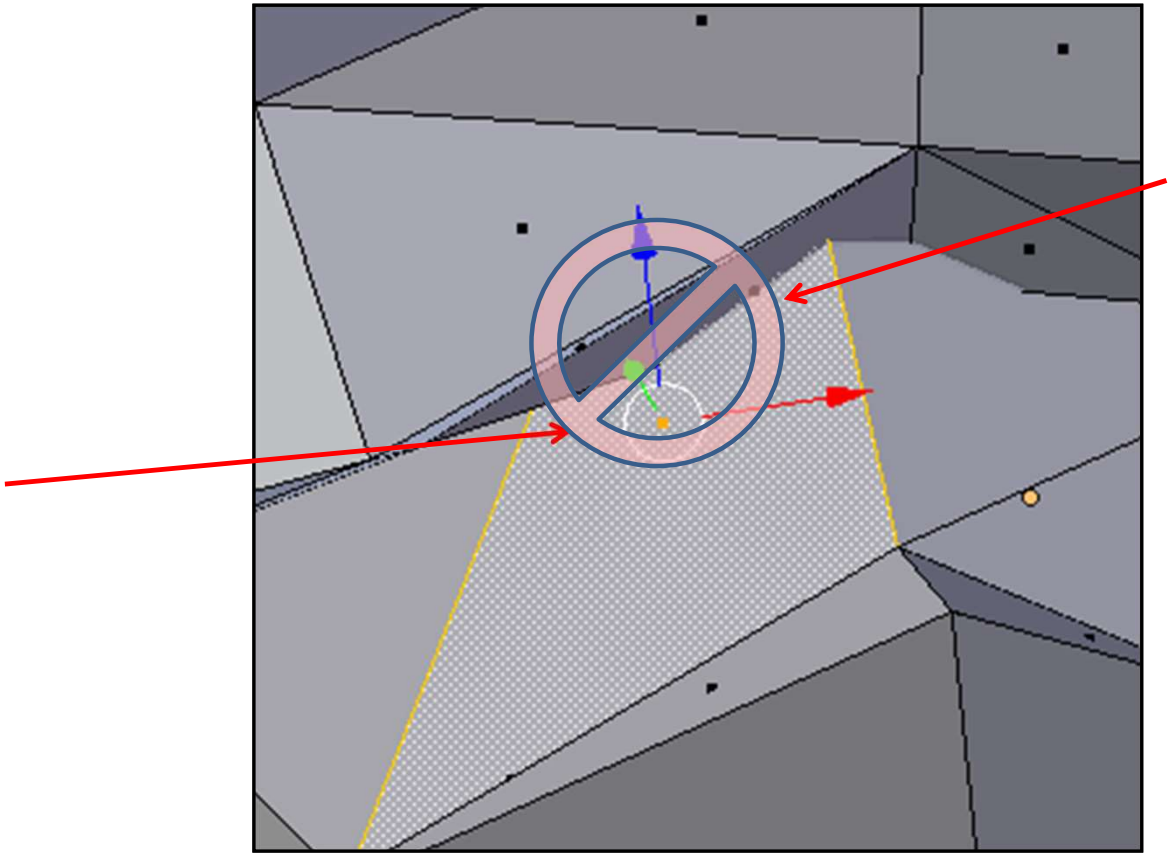


**Boolean union -- good**



# Object Rules for 3D Printing

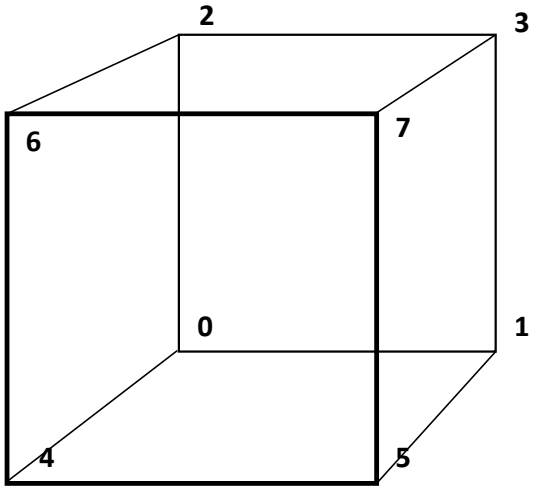
**4.** Each edge in the mesh must bound 2 and only 2 triangles (this is known as the **Vertex-to-Vertex Rule**)



# The Simplified Euler's Formula* for Legal Solids

$$F - E + V = 2$$

| | |
|---|---|
| F | Faces |
| E | Edges |
| V | Vertices |

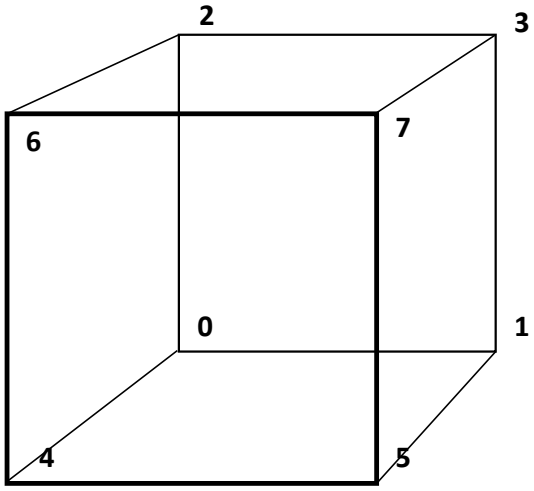



**For a cube: 6 – 12 + 8 = 2**

*sometimes called the Euler-Poincaré formula

# The Full Euler's Formula* for Legal Solids

$$F - E + V - L = 2( B - G )$$




| | |
|---|---|
| F | Faces |
| E | Edges |
| V | Vertices |
| L | Inner Edge Loops (within faces) |
| B | Bodies |
| G | Genus (number of through-holes) |

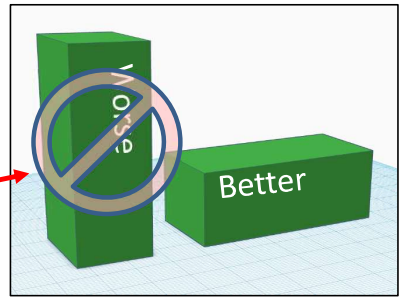
**For a cube: 6 – 12 + 8 – 0 = 2( 1 – 0 )**

*sometimes called the Euler-Poincaré formula

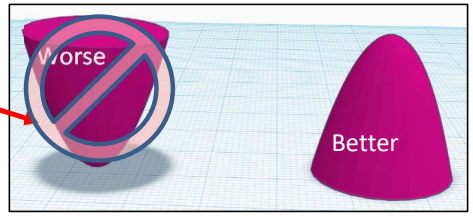
# Advice on 3D Printing

Don’t make the part too big to start – it will take a long time to 3D print. It's nice if you can fit several models in a single run.

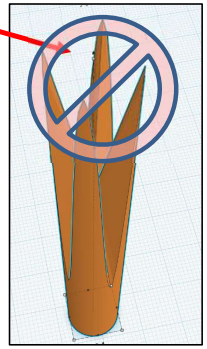
Try to rotate the part so the smallest dimension is vertical. It’s stronger that way, and it builds faster.



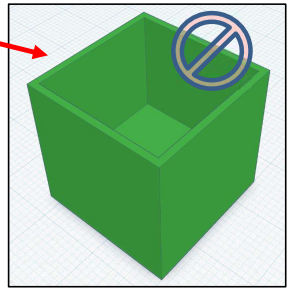

The 3D Printer will like it better if the part gets smaller as it goes up, not the other way around.



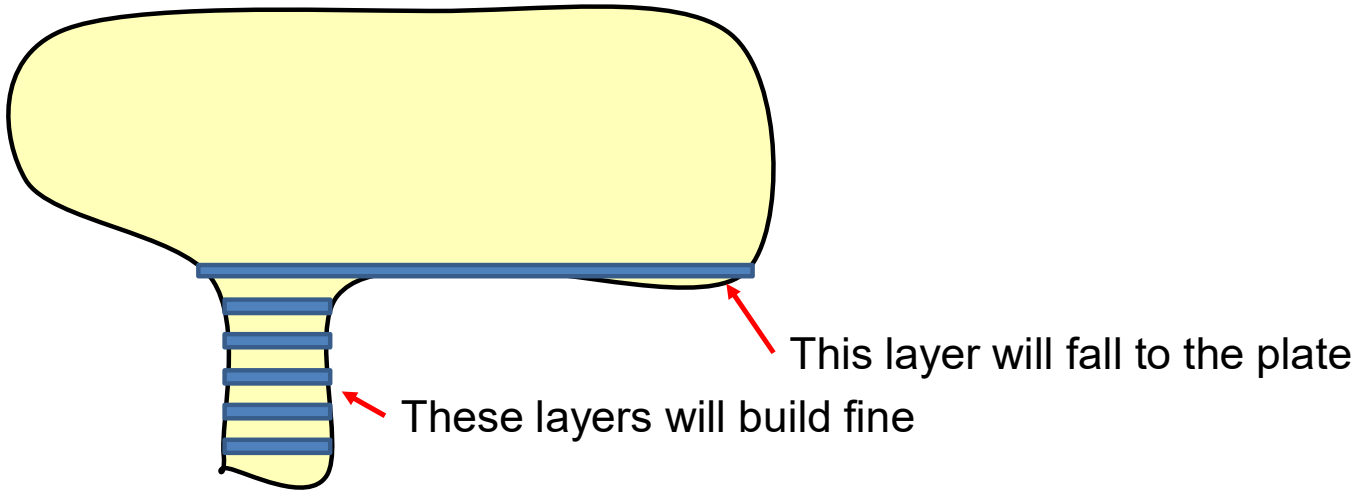

Don’t design the part with long, thin edges. They will snap right off.



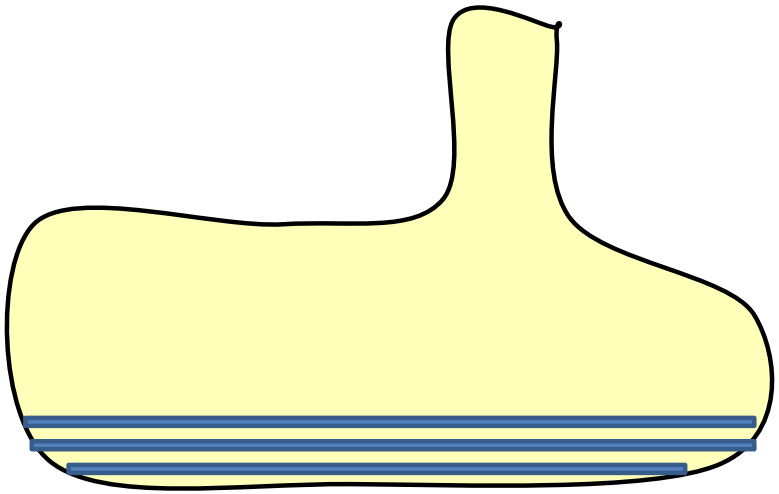
Don’t make walls too thin – they will break.



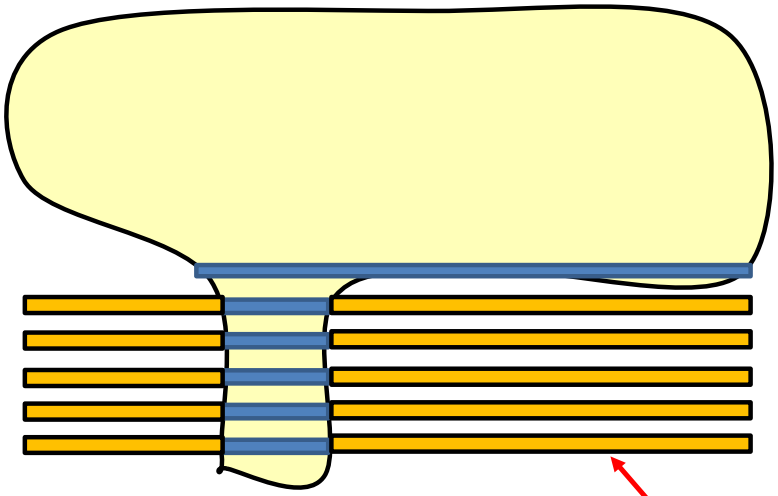
# Watch Out for Overhangs!



## Note that, if you build this object upside-down, it will probably be fine

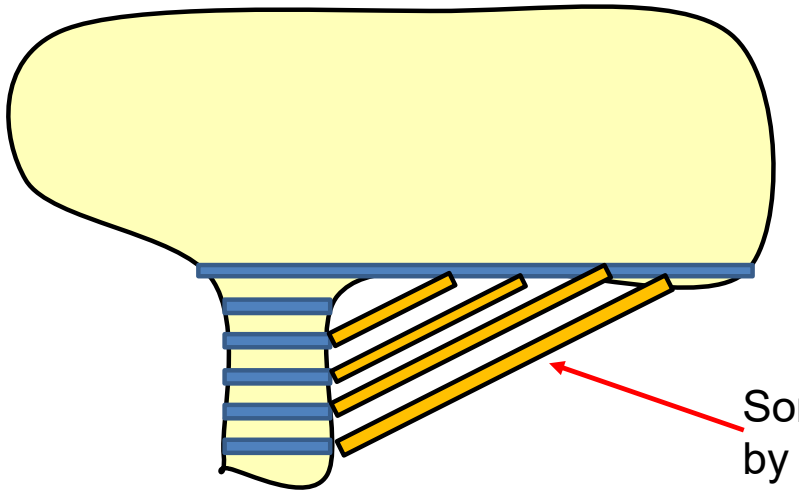


# Watch Out for Overhangs!



Some 3D printers handle overhangs by leaving unused material in place to support the overhangs

# Watch Out for Overhangs!



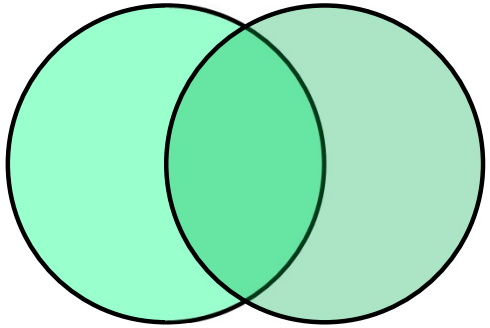
Some 3D printers handle overhangs by using software to add “support structures” to the overhangs

Some 3D printers handle this better than others…

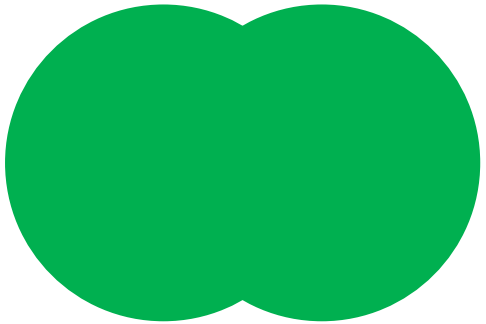
# What Happens if You Don't Follow the Rules?

Check here:
**http://twistedsifter.com/2013/08/when-3d-printing-goes-wrong/**

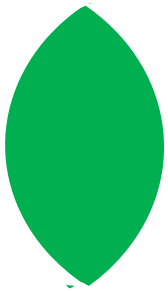
# How Can You Guarantee That You Are Modeling With Legal Solids?
# Remember the "3D Venn Diagrams"



Two Overlapping Shapes



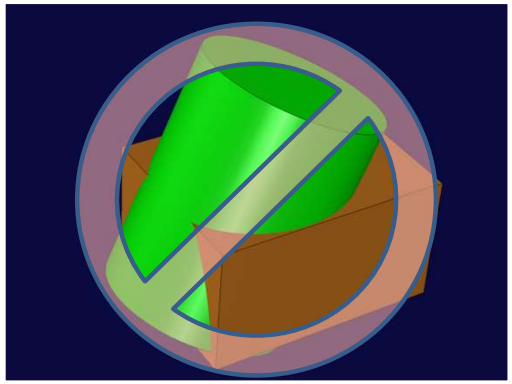
Union



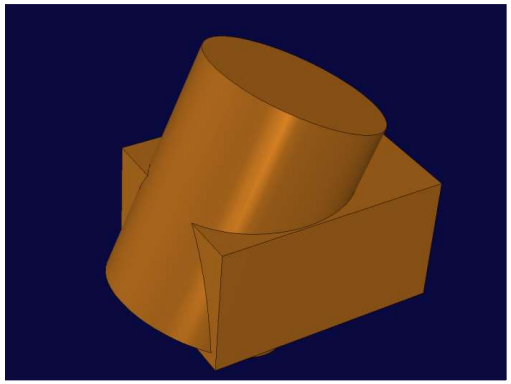
Intersection

Difference

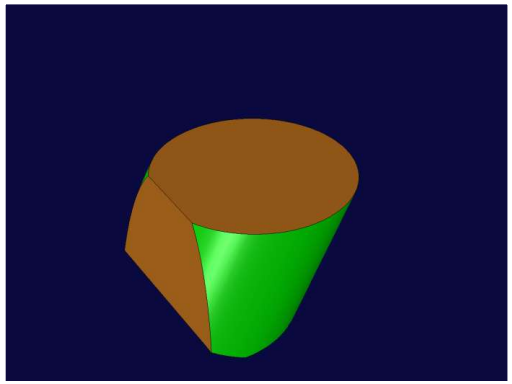
# How Can You Guarantee That You Are Modeling With Legal Solids? Remember the "3D Venn Diagrams"



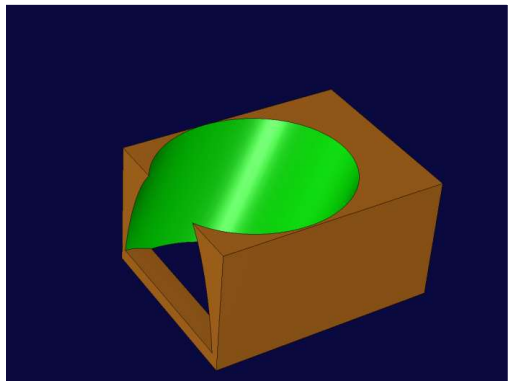
Two Overlapping Solids



Union



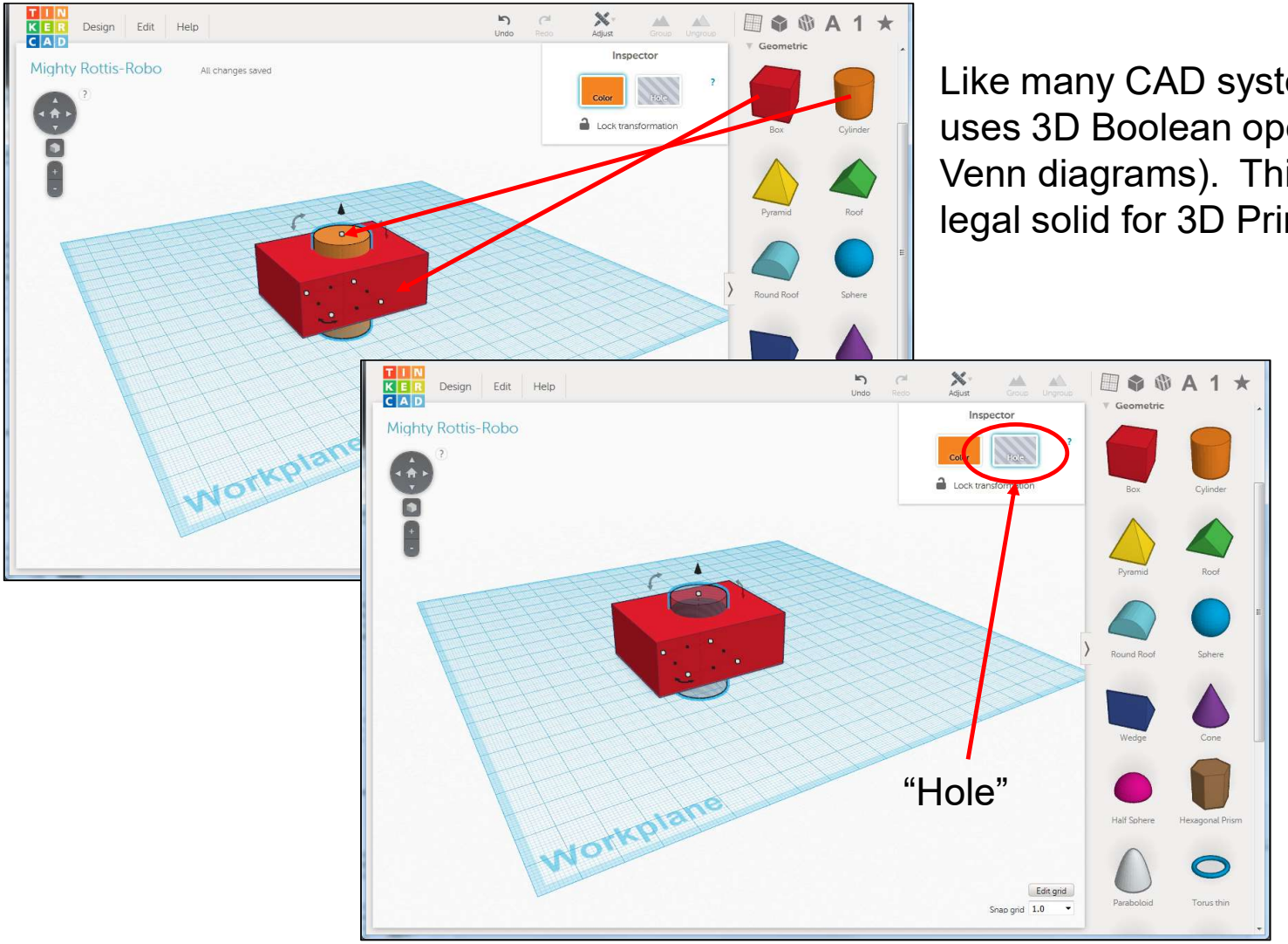
Intersection



Difference

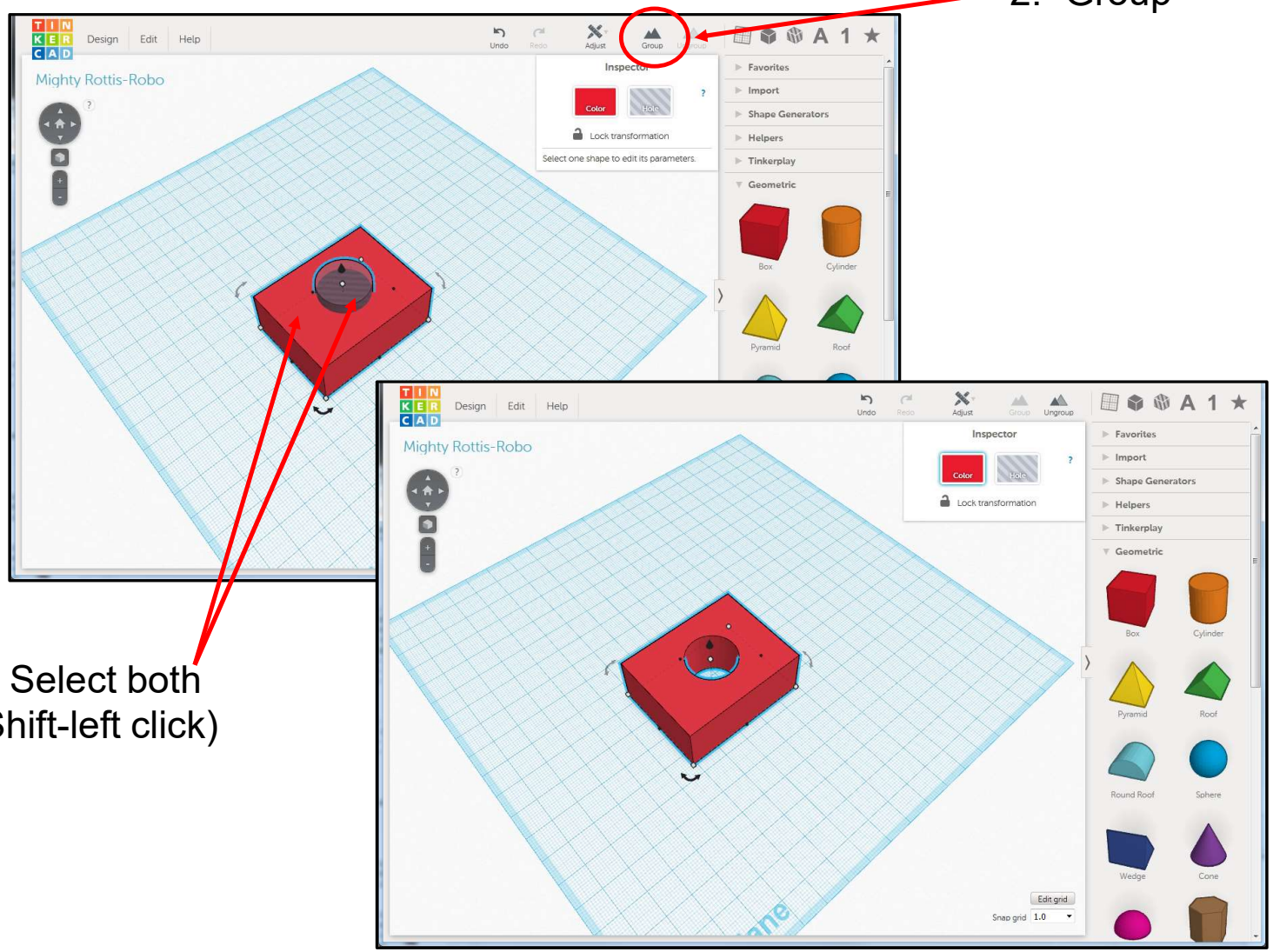
**This is often called Constructive Solid Geometry (CSG)**

# TinkerCad: http://www.tinkercad.com



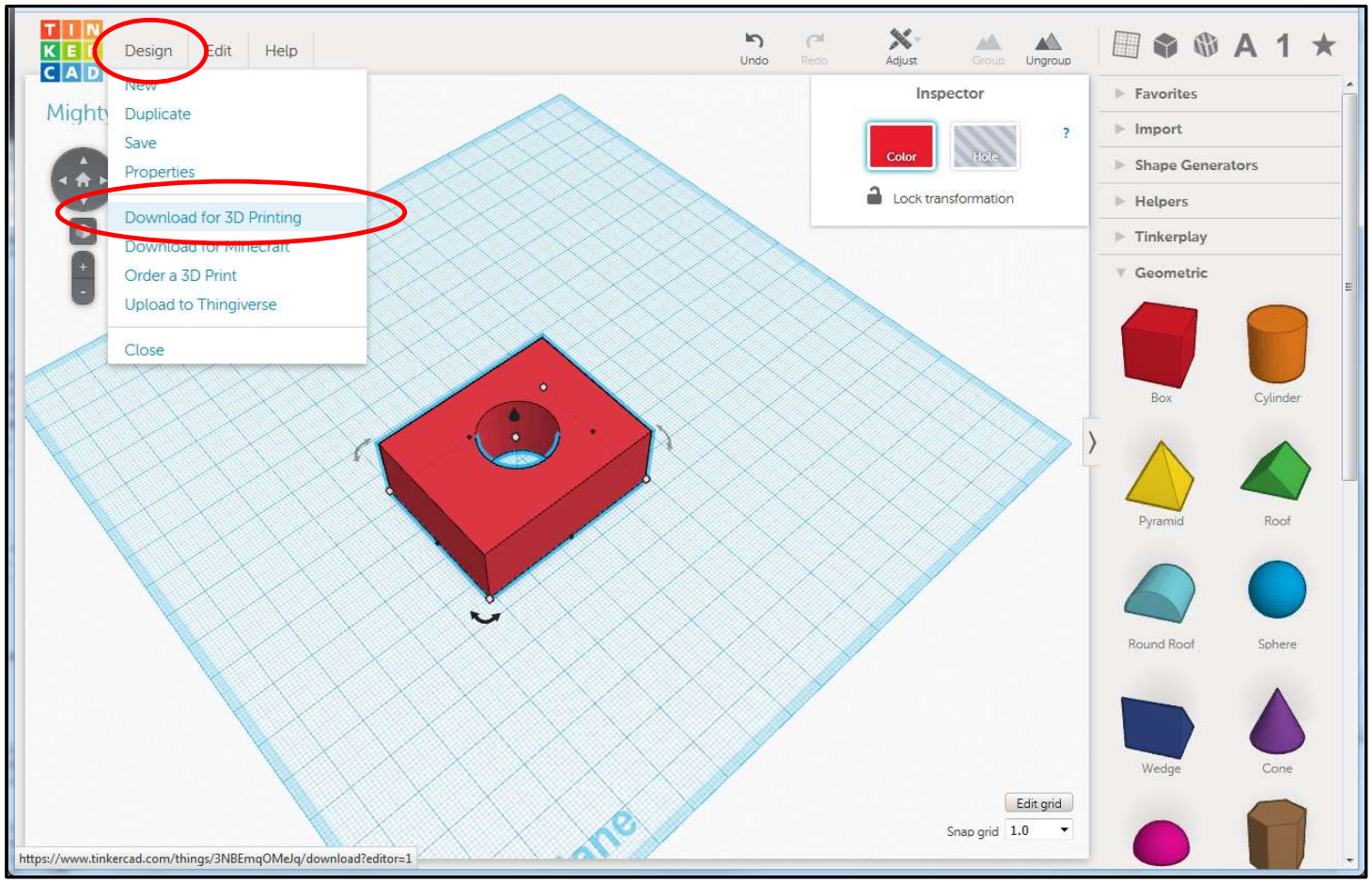

Like many CAD systems, TinkerCad uses 3D Boolean operators (3D Venn diagrams). This guarantees a legal solid for 3D Printing.

# TinkerCad


2. “Group”
1. Select both
(Shift-left click)
Design
Edit
Help
Undo
Redo
Adjust
Group
Ungroup
Mighty Rottis-Robo
Inspector
Color
Hole
Lock transformation
Select one shape to edit its parameters.
Favorites
Import
Shape Generators
Helpers
Tinkerplay
Geometric
Box
Cylinder
Pyramid
Roof
Round Roof
Sphere
Wedge
Cone
Edit grid
Snap grid
1.0

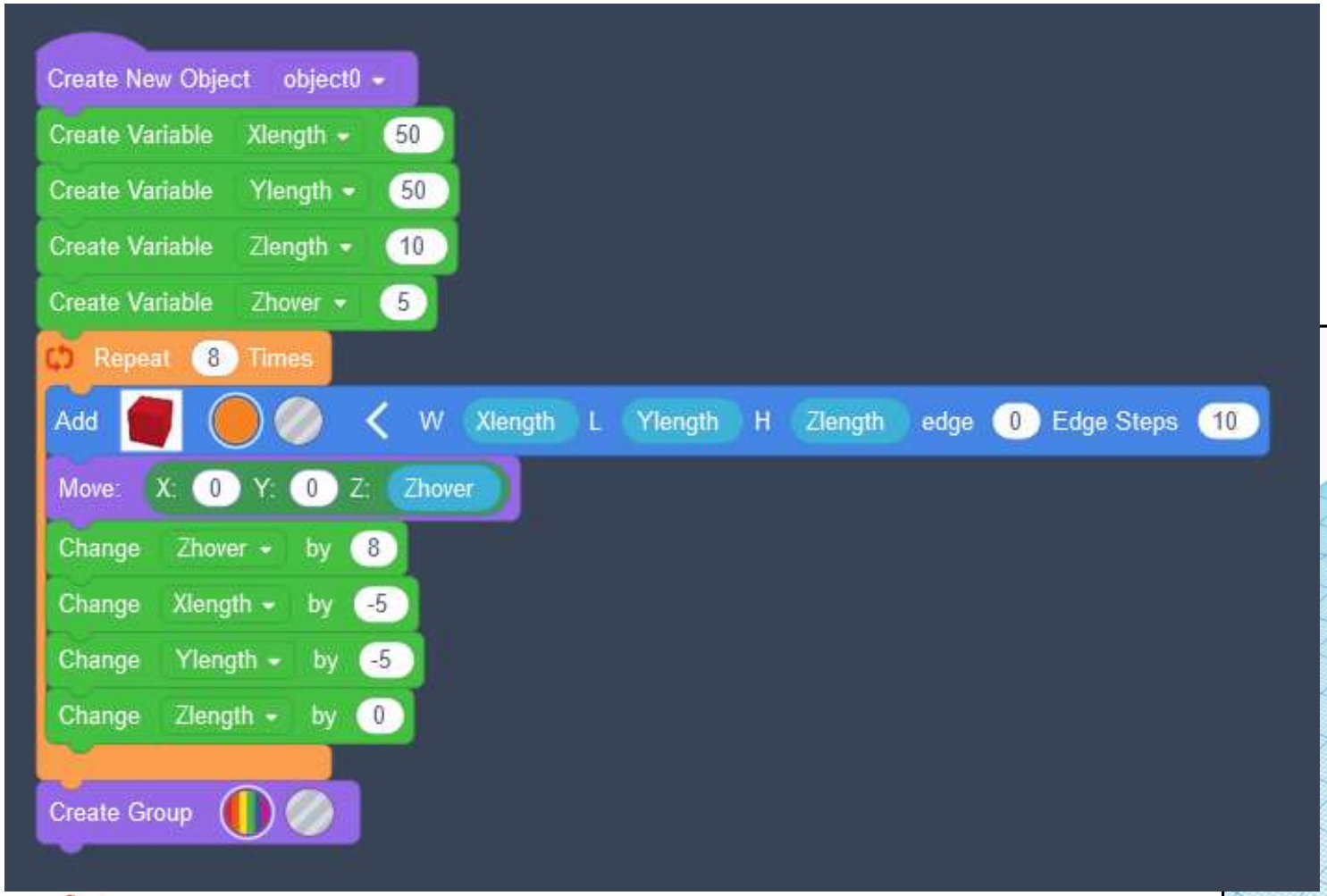
# TinkerCad

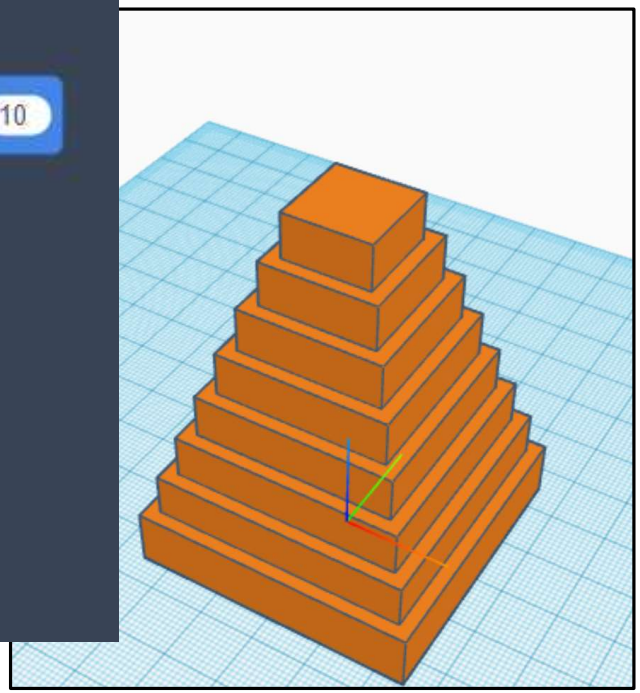



Design
Edit
Help
Undo
Redo
Adjust
Group
Ungroup
New
Duplicate
Save
Properties
Download for 3D Printing
Download for Minecraft
Order a 3D Print
Upload to Thingiverse
Close
Inspector
Color
Hole
Lock transformation
Favorites
Import
Shape Generators
Helpers
Tinkerplay
Geometric
Box
Cylinder
Pyramid
Roof
Round Roof
Sphere
Wedge
Cone
Edit grid
Snap grid
1.0
https://www.tinkercad.com/things/3NBEmqOMeJq/download?editor=1

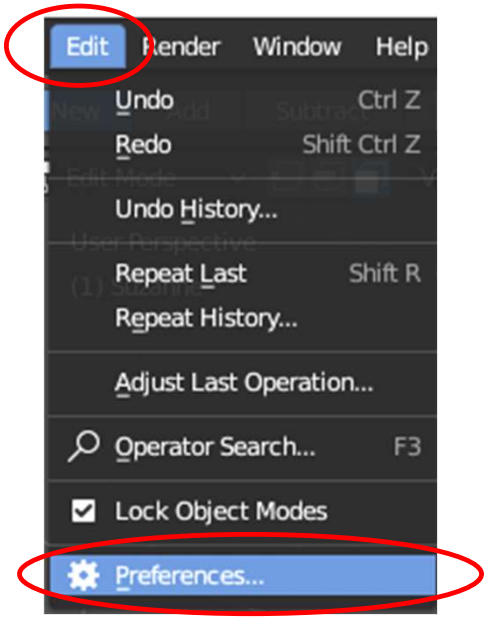
# Procedural CSG Using TinkerCad/Codeblocks





# Blender's 3D Printing Utility isn't there by Default

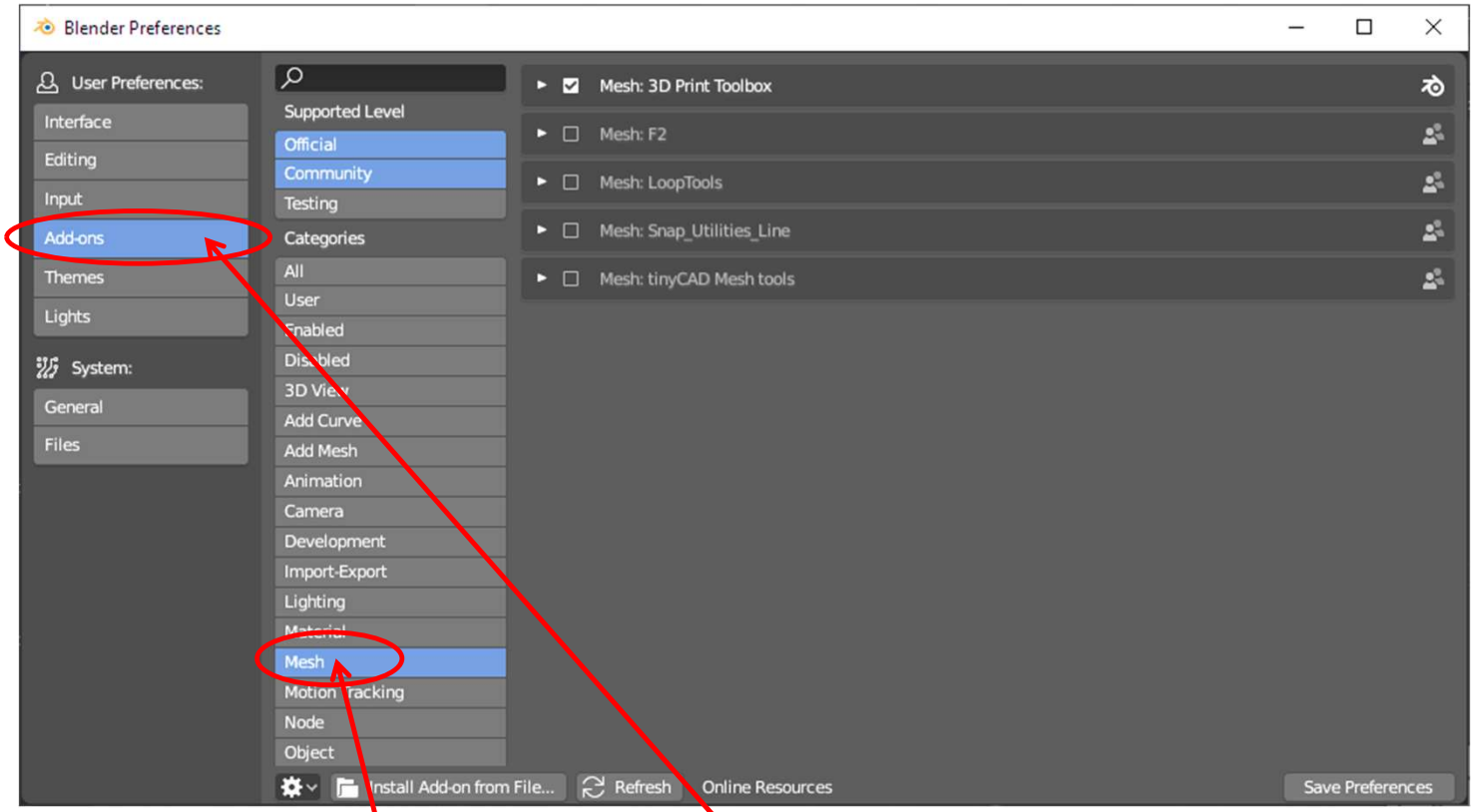



By default, Blender doesn't let you see its 3D Printing utility. You need to tell Blender to turn it on.

**1.** Click **Edit → Preferences**

# Blender's 3D Printing Options aren't there by Default

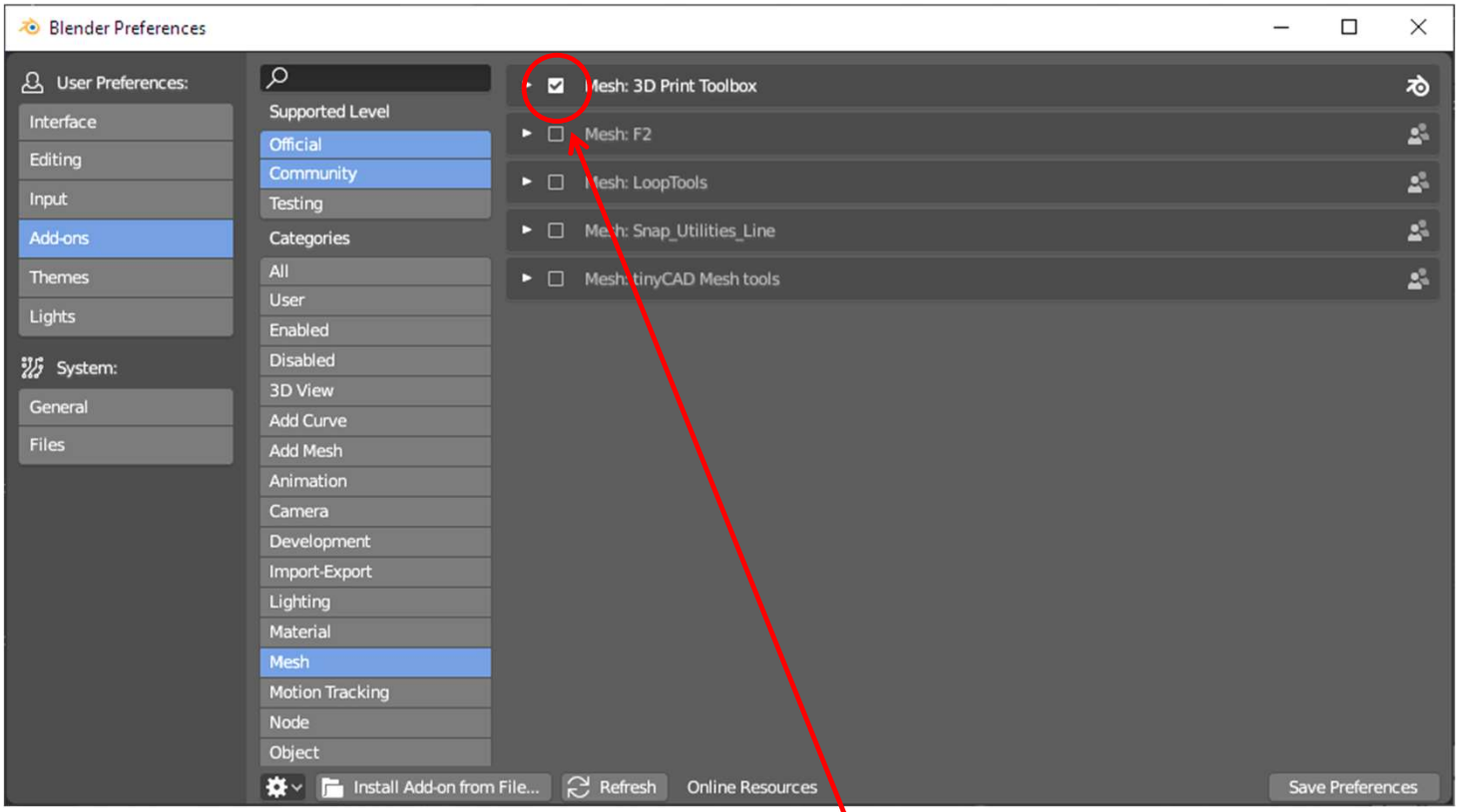





**2.** Click on the **Addons** tab
**3.** Click on **Mesh**

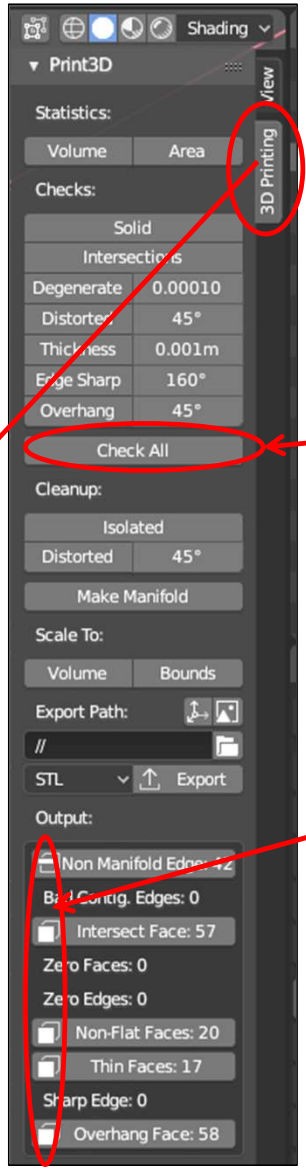
# Blender's 3D Printing Options aren't there by Default






**4.** Click the **Mesh: 3D Print Toolbox**

# Blender Options for 3D Printing

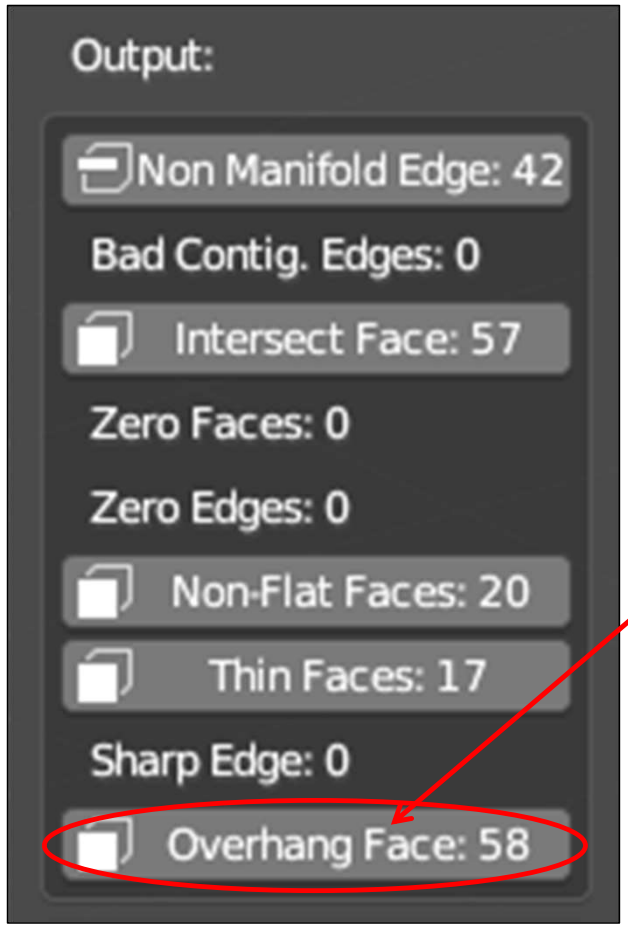



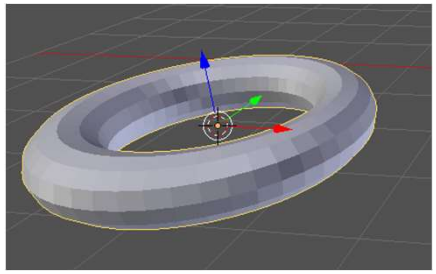

**3D Printing** now shows up in your Properties Region (hit the ‘n’ key if you’re not seeing it)

Objects destined for 3D Printing must be “legal solids”. Clicking on object and then on **Check All** will try to determine that

Tab over to Edit Mode. Clicking on any of these will highlight where they are on your object.

# Blender Options for 3D Printing



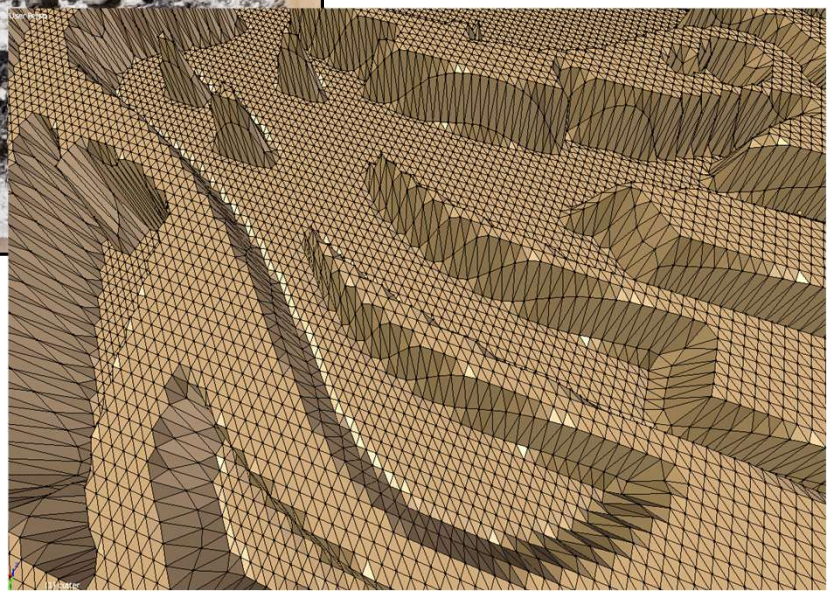



An overhang face is not necessarily a bad thing. The entire bottom of the part will consist of, by necessity, overhang faces.

However, overhang faces that are not the bottom of the part could be a problem.

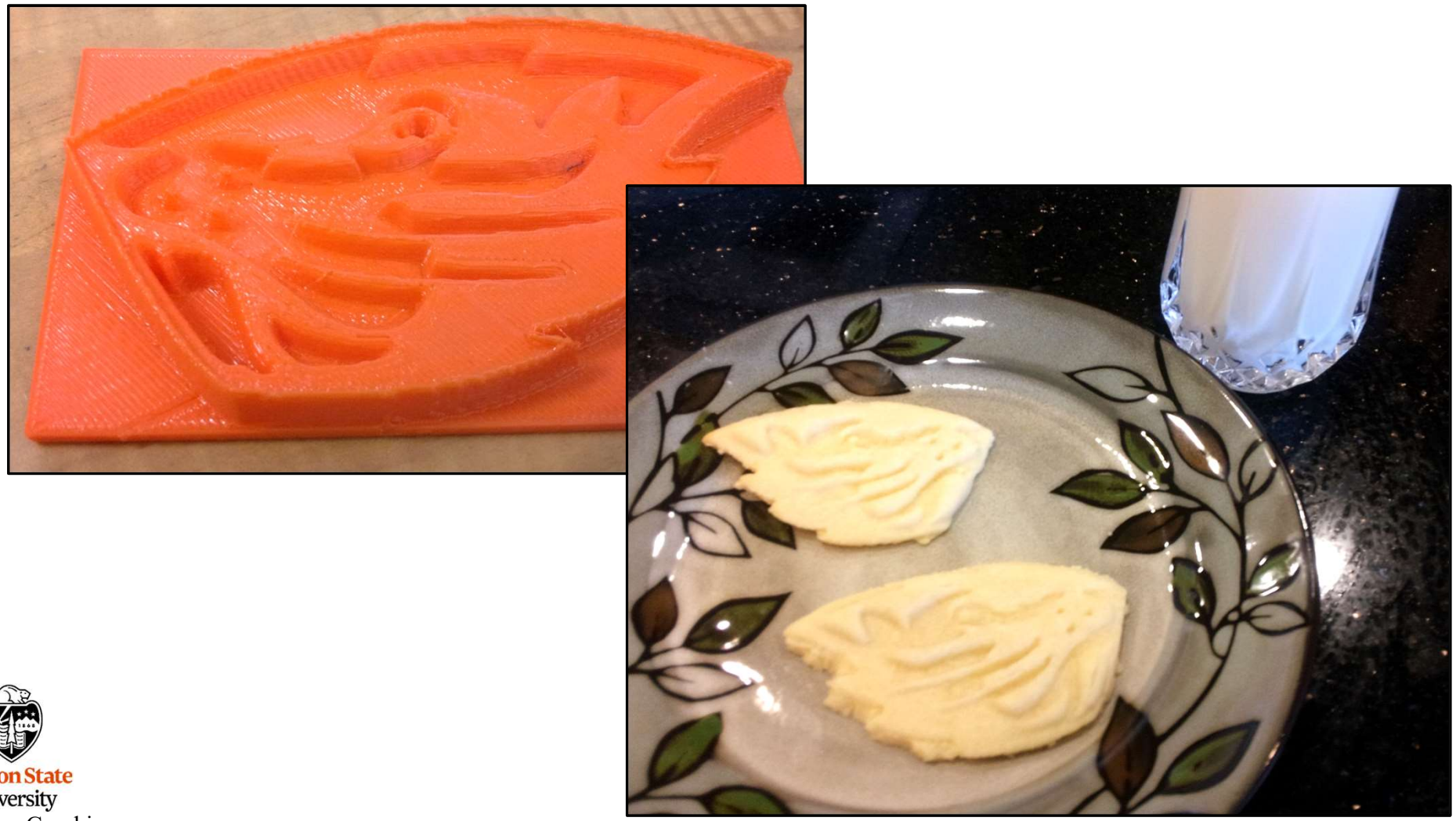
# Heightmap Files are Straightforward to use with 3D Printing





# A Very Special Heightmap 3D Printing Model (mmm…)



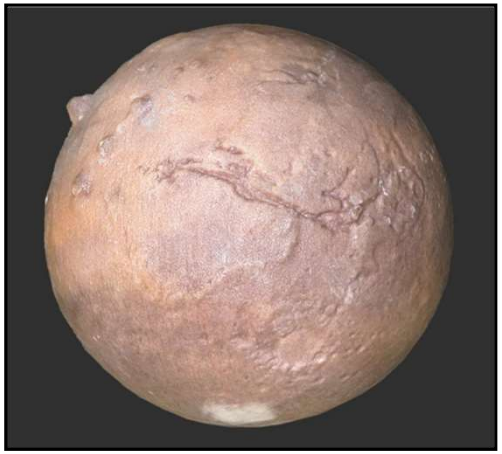


# A Very Special Heightmap 3D Printing Model (mmm…)

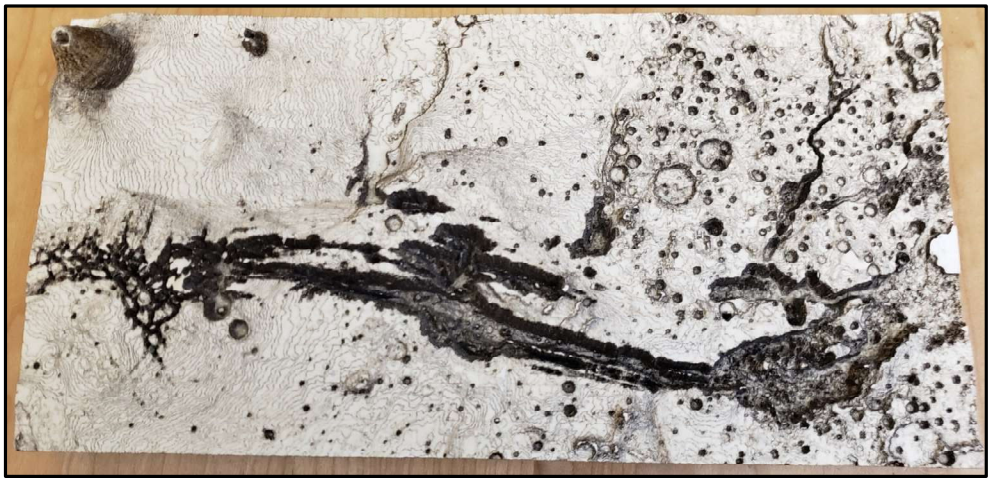


# Most Any *Data* Can be Turned into a 3D-Printable Model





Mars



Mars

3D Ultrasound

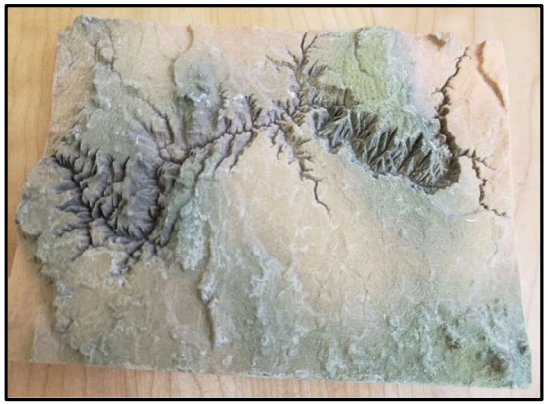
3D Ultrasound

Molecular Modeling

# Most Any *Data* Can be Turned into a 3D-Printable Model



Oregon



Grand Canyon

Dinosaur Egg

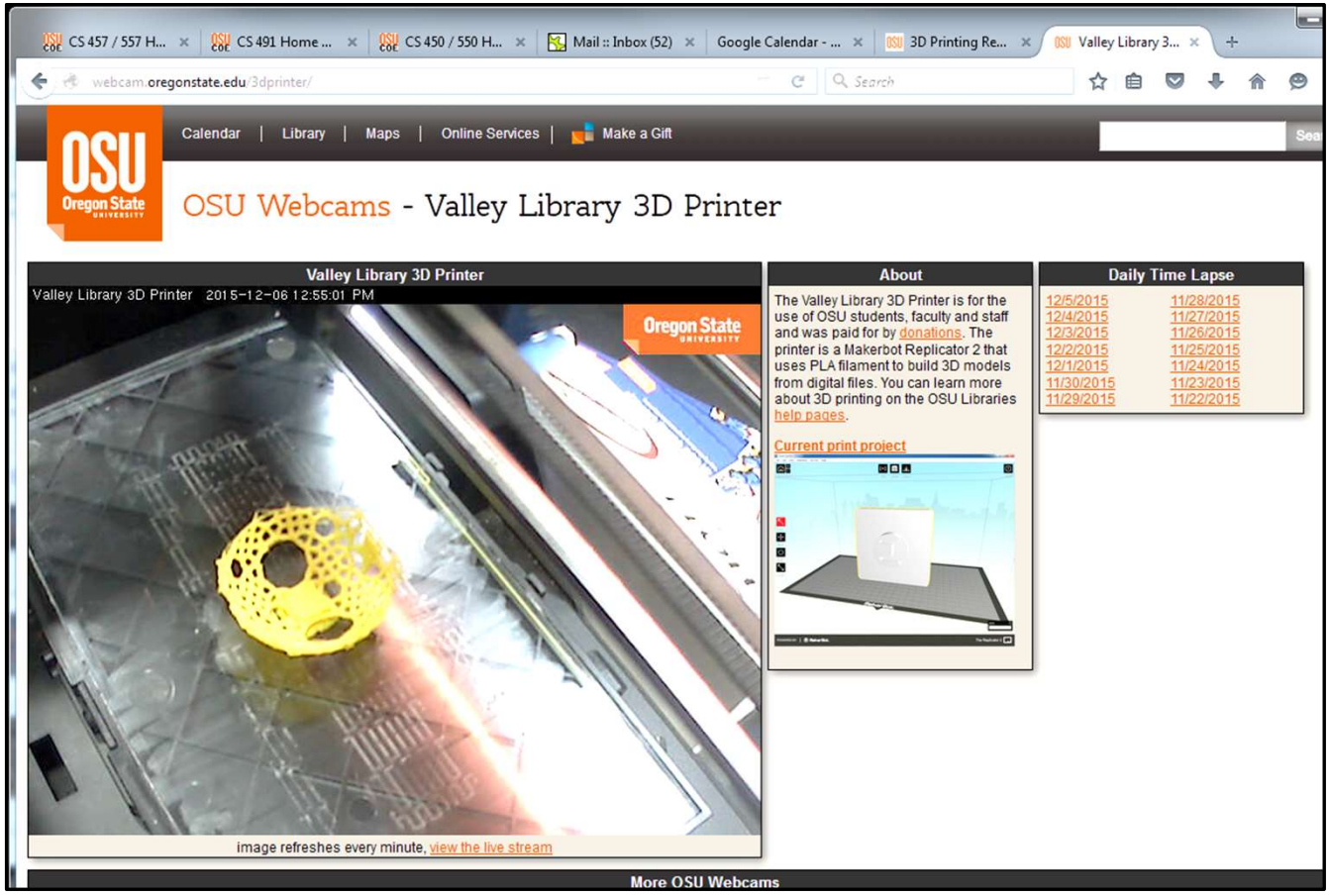
MRI Scan

Earth

# The OSU Library Has Four 3D Printers for Student Use

To watch the OSU Library's 3D Printers, go to:

**http://webcam.oregonstate.edu/3dprinter/**



# The OSU Library Has Four 3D Printers for Student Use

To send an STL model to the OSU Library's 3D Printers, go to:

## http://guides.library.oregonstate.edu/3Dprinting/3Dprintform