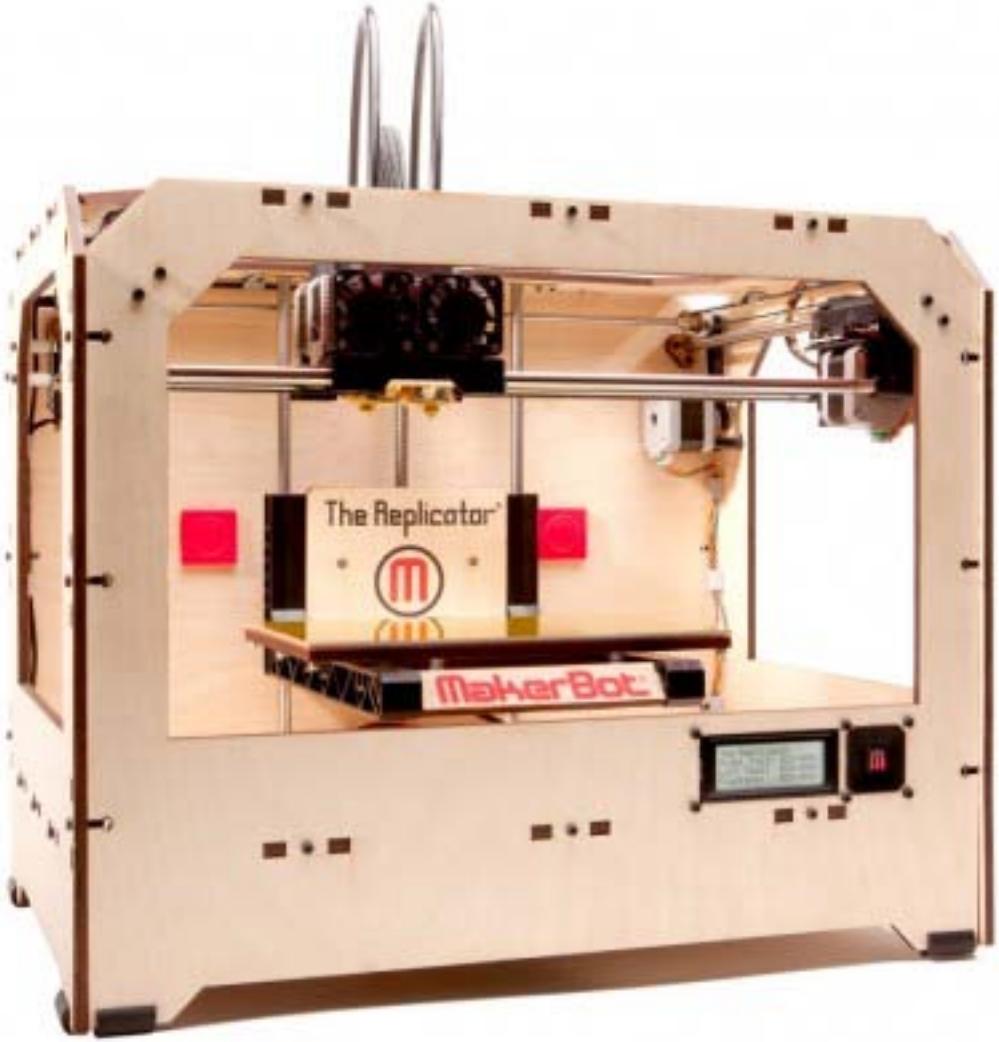
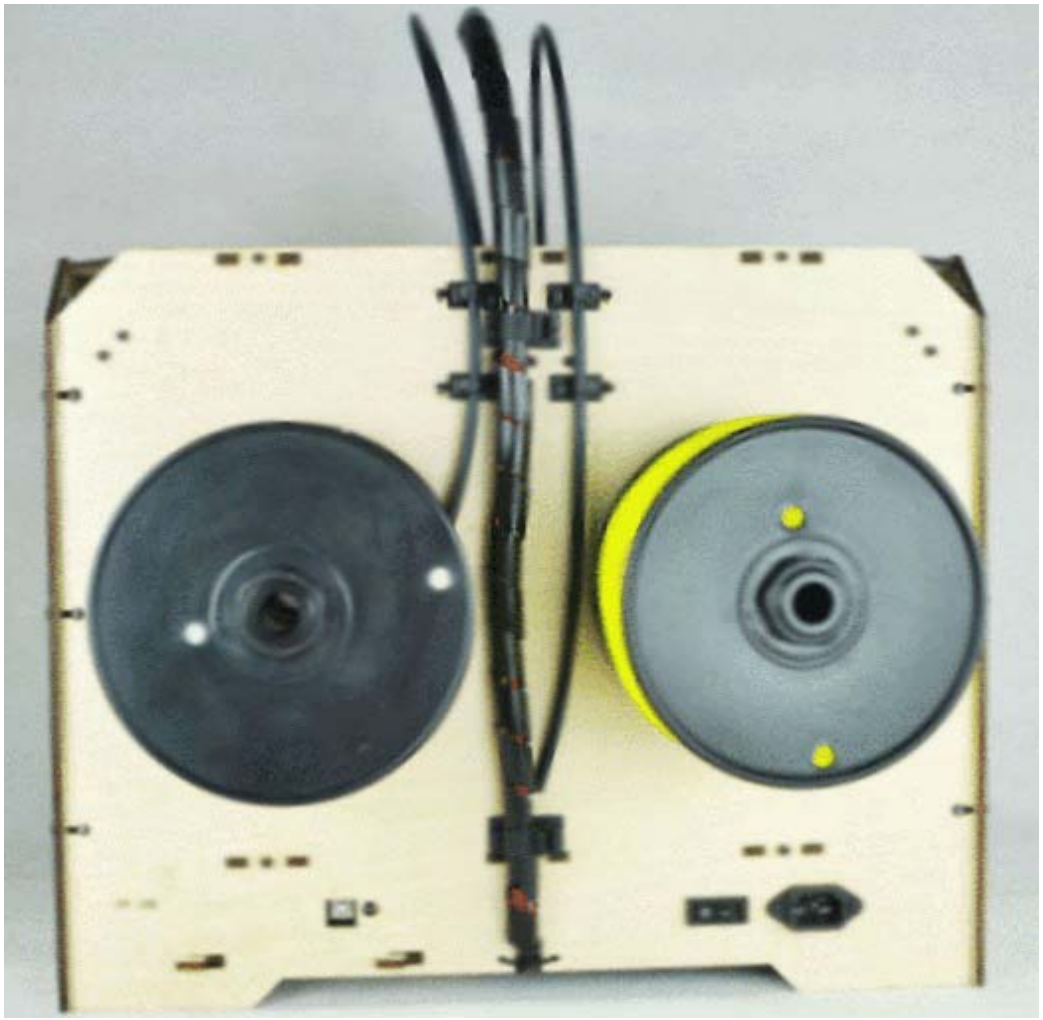
Introduction to 3D Printing

Michael L. Myrick



Makerbot Replicator 1 Dual Extrusion Printer
front view

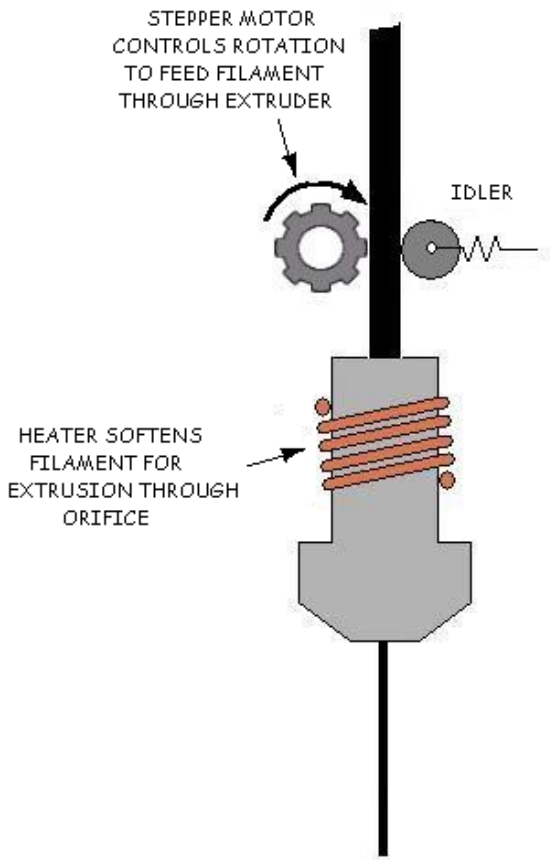


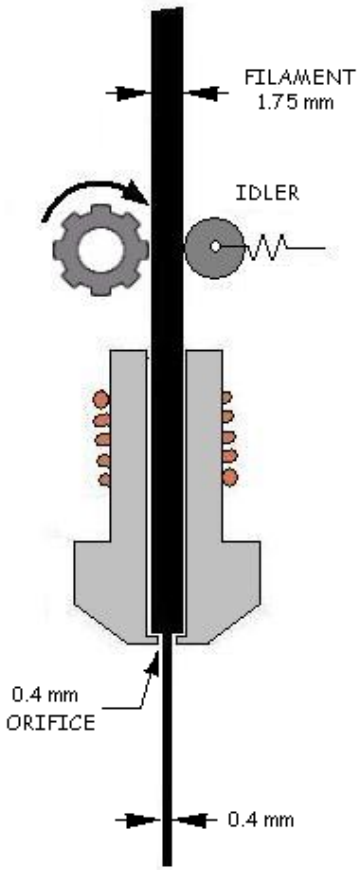
Makerbot Replicator I Dual Extrusion Printer, rear view, showing filament spools and feed arrangement

MakerBot Replicator 1 Specifications

Mechanical Dimensions	320 x 467 x 381 mm (12.6 x 18.4 x 15 in)
Weight	32 lbs
Printing Build envelope	225 x 145 x 150 mm (8.9 x 5.7 x 5.9 in)
Build volume	5 liters
Layer thickness	0.2-0.3 mm (w/stock nozzle)
Stock nozzle diameter	0.4 mm
Speed	40 mm/s
Approximate Flow Rate	24 cc/hr
Maximum Extruder Temperature	230^{o}C
Maximum Heated Build Platform Temperature	120^{o}C
Positioning precision	2.5 microns on z-axis 11 on x and y-axes
Print media	ABS, PLA, and other materials
Filament diameter	1.75 mm

Dual Extruders, Makerbot Replicator I





Extruder detail

TYPICAL 1 KG (2.2 LB) REEL OF 1.75mm DIAMETER FILAMENT

AVAILABLE MATERIALS INCLUDE: ABS PLA PVA HIPS

ACRYLONITRILE BUTADIENE STYRENE (ABS)

ABS is a common petroleum based thermoplastic (Note: LEGO blocks are made of ABS.)

ABS is more prone to producing ultra fine particles when heated, compared to PLA. Good ventilation is recommended. (ABS produces a slight 'burnt plastic' smell when extruding.)

Parts printed using ABS have greater flexibility and are less brittle than PLA.

In general, parts printed using ABS have a glossier finish than PLA parts.

ABS has a lower coefficient of friction than PLA and requires slightly less force to be extruded than PLA.

ABS can be considered the "legacy" type of filament since it was used for 3D printing before PLA.

POLYLACTIC ACID (PLA)

PLA is a plastic made of renewable starches such as corn and sugarcane.

It is biodegradable and does not emit a lot of ultra fines particles.

It produces a barely noticeable, but quite pleasant, sugary smell when extruding.

Parts printed using PLA are more rigid than ABS parts (ABS is more flexible).

In general, parts printed using PLA have a slightly glossy finish.

PLA is less prone to warping during print and is much more ‘stickier’ than ABS.

PLA requires a bit more force to be extruded as it has a higher coefficient of friction than ABS.

PLA is a bit more recent in the history of FDM 3D printers and has a promising future.

POLYVINYL ALCOHOL (PVA)

PVA is a water-soluble synthetic polymer hydrolysed from polyvinyl acetate.

PVA is fully degradable and dissolves in water, hence its utility as scaffolding for 3D prints.

PVA has a glass transition temperature of around 85°C (185F), but this temperature depends on the polymer's degree of hydrolysation (ratio of alcohol groups to acetate groups).

It decomposes rapidly above 200°C as it can undergo pyrolysis at high temperatures.

ACRYLONITRILE BUTADIENE STYRENE (ABS)

Principle use: usable parts

Melt flow index (220^{o}C, 10kg): 5.5 g/ 10min

Melting point: 105^{o}C

Glass Transition Temperature: 90^{o}C

Extrusion Temperature: 180^{o}C[(1)]
230-240^{o}C[(2)]

Platform Temperature: 80^{o}C

Specific Heat: 0.3 cal/ g^{o}C

Density: 1.05 g/cm^{3}

Solubility: soluble in acetone

Note: somewhat hygroscopic

[1]Minimum temperature for extrusion through orifice
[2]Recommended extrusion temperature for layer bonding

POLYLACTIC ACID (PLA)

Principle use: usable parts

Melt flow index (210^{o}C, 2.16kg): 7.5 g/ 10min

Melting point: 60^{o}C

Glass Transition Temperature: 50^{o}C

Extrusion Temperature: 160^{o}C[1]
180-190^{o}C[2]

Platform Temperature: 50^{o}C

Specific Heat: 0.36 cal/^{o}C

Density: 1.25 g/cm^{3}

Solubility: soluble in sodium hydroxide

Note: somewhat hygroscopic (more than ABS)

[1]Minimum temperature for extrusion through orifice
[2]Recommended extrusion temperature for layer bonding

POLYVINYL ALCOHOL (PVA)

Principle use: dissolvable scaffolding

Melt flow index (190°C, 2.16kg): 1.5 – 3.5 g/ 10min

Melting point: 104°C

Glass Transition Temperature: 85°C

Extrusion Temperature: 180°C[1]
180-190°C[2]

Platform Temperature: 60-80°C[3]

Specific Heat: 0.25 cal/ g°C

Density: 1.19 – 1.31 g/cm^3

Solubility: soluble in water

Note: very hygroscopic!

[1]Minimum temperature for extrusion through orifice
[2]Recommended extrusion temperature for layer bonding
[3]For PVA-only prints, recommended platform temperature is 60°C

HIGH IMPACT POLYSTYRENE (HIPS)

Principle use: usable parts, dissolvable scaffolding

Melt flow index (200^{o}C/5kg) 7.5 g/ 10min

Melting point: 104^{o}C

Glass Transition Temperature: 85^{o}C

Extrusion Temperature: 180^{o}C(1)
230-240^{o}C(2)

Platform Temperature: 80^{o}C

Specific Heat: 0.31 cal/ g^{o}C

Density: 1.04 g/cm^{3}

Solubility: soluble in d-Limonene

[1]Minimum temperature for extrusion through orifice
[2]Recommended extrusion temperature for layer bonding

3D Printing Workflow

The process:

Compose Create Check Slice Print Evaluate

3D Printing Workflow:

Compose Create Check Slice Print Evaluate

COMPOSE

PLANNING AHEAD BEFORE GENERATING A 3D MODEL WILL HELP MAKE THE TASK EASIER

- DIMENSIONS
- GEOMETRY
- ORIENTATION

WILL THE PRINTED PART FIT ACCURATELY?

WILL THE PRINTED PART FIT THE AVAILABLE BUILD VOLUME?

WILL THE FINAL PRINT MAKE EFFICIENT USE OF RESOURCES?

DON'T BE AFRAID TO DRAW A SKETCH !

3D Printing Workflow:

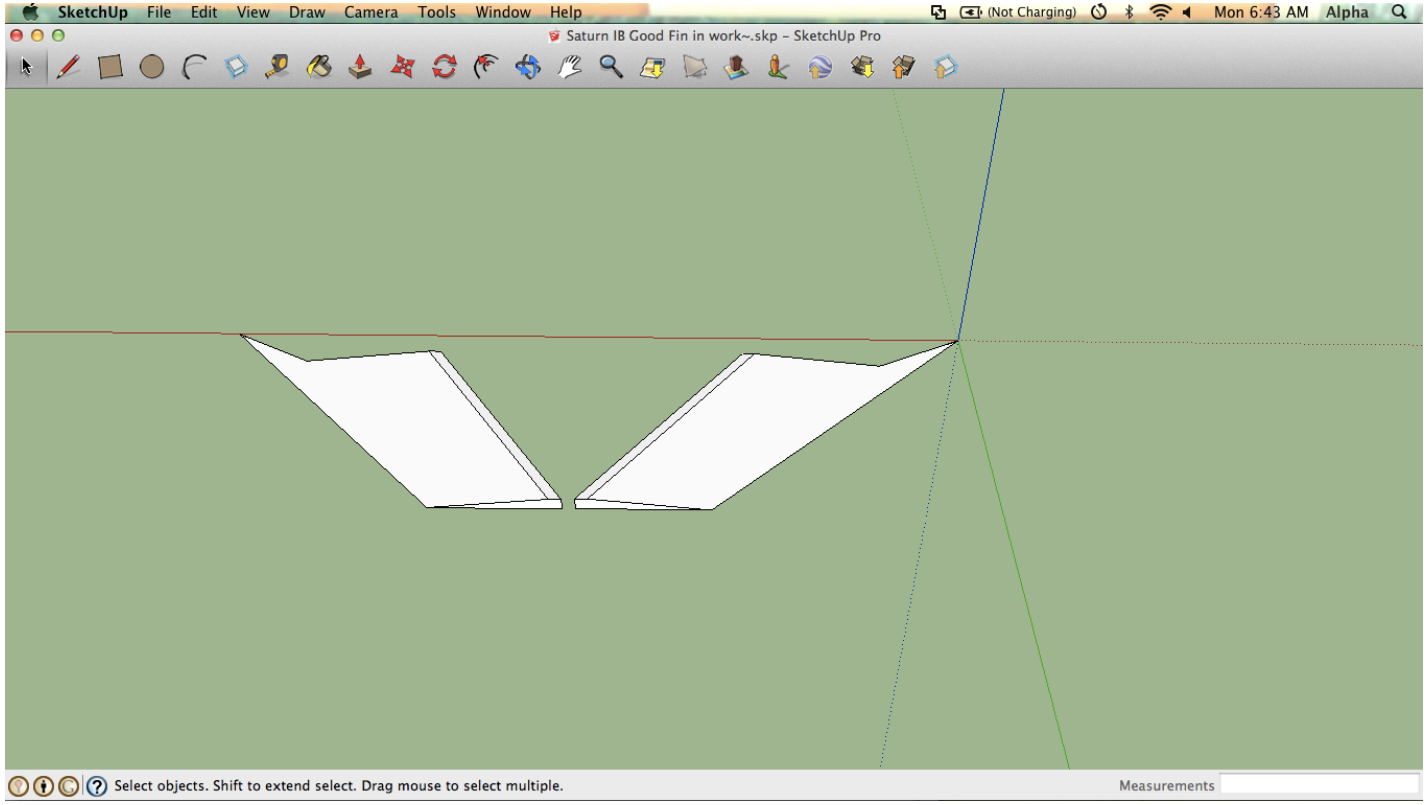
Compose Create Check Slice Print Evaluate

<u>CREATE</u>

DEVELOP THE 3D MODEL USING CAD OR COMPUTER GRAPHICS SOFTWARE

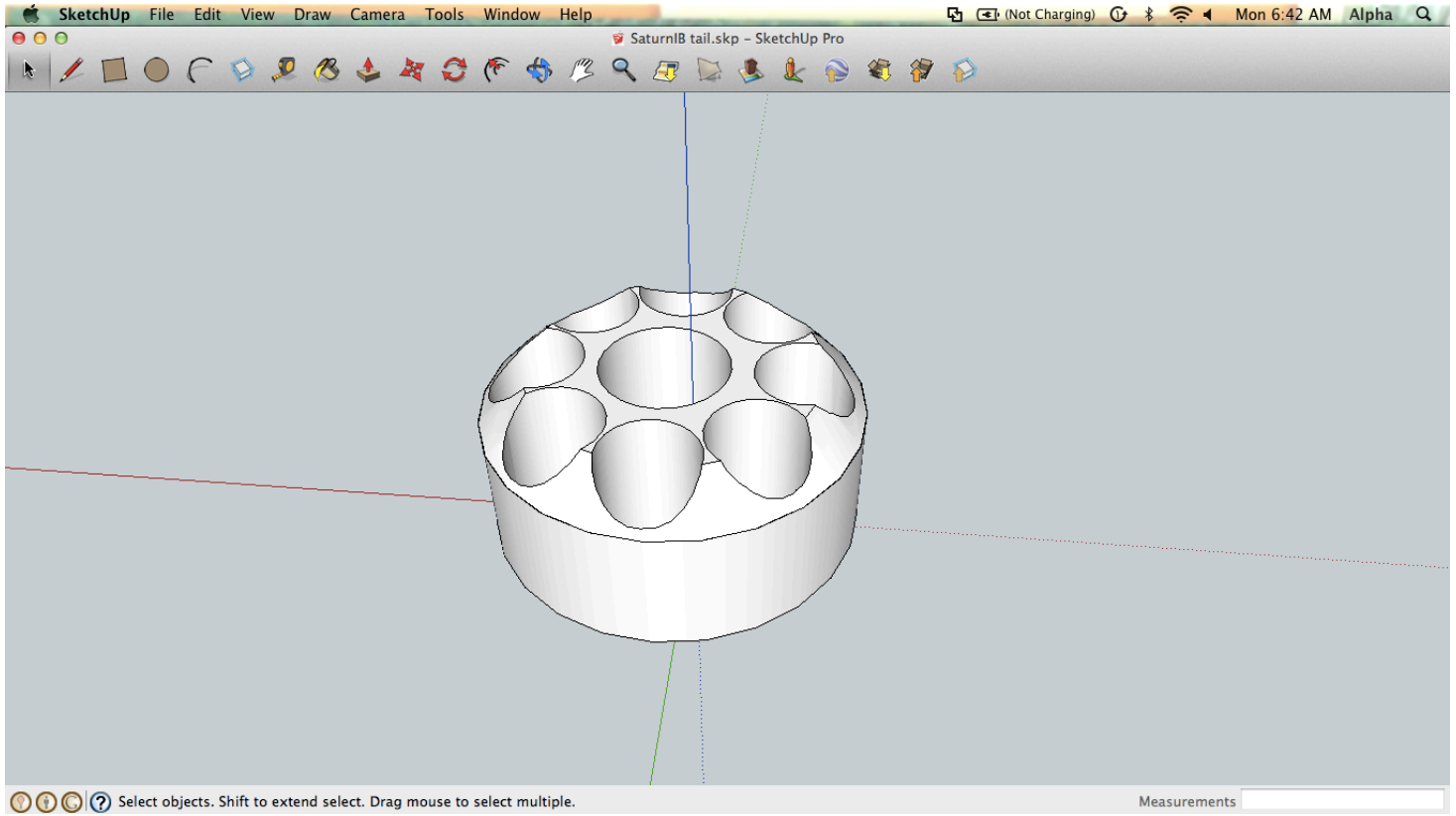
3D Printing Workflow:

Compose **Create** Check Slice Print Evaluate



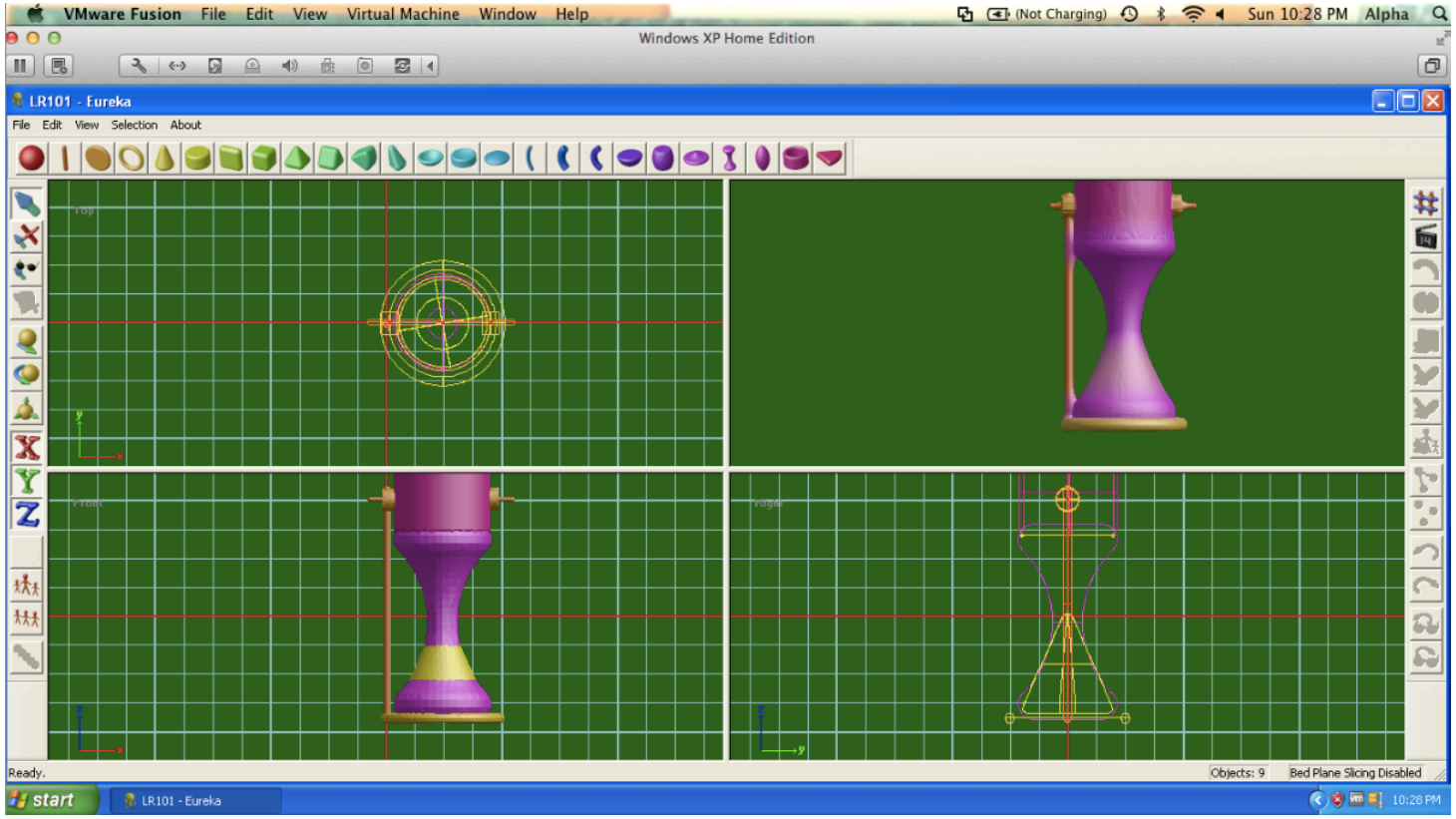
3D Printing Workflow:

Compose **Create** Check Slice Print Evaluate



3D Printing Workflow:

Compose **Create** Check Slice Print Evaluate



NARCON 2014
FLORIDA'S SPACE COAST

3D Printing Workflow:

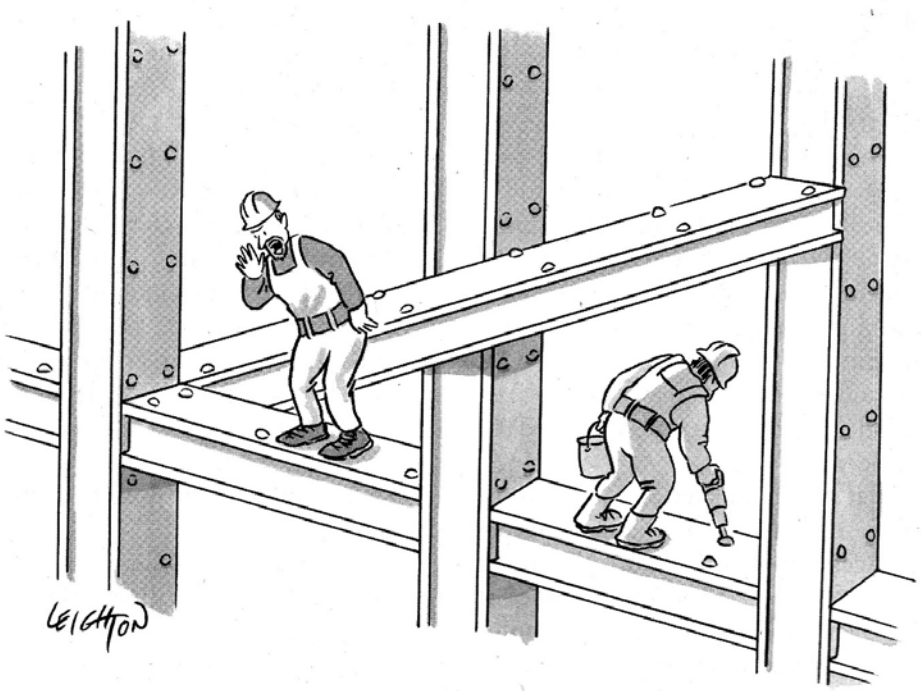
Compose Create **Check** Slice Print Evaluate

<u>CHECK</u>

THE MODEL MUST BE “WATERTIGHT”, THAT IS, HAVING NO GEOMETRIC ERRORS THAT WILL PREVENT A SUCCESSFUL PRINT. SOFTWARE SUCH AS MESHLAB PROVIDE A WAY TO CHECK (AND TO REPAIR) A 3D MODEL.

3D Printing Workflow:

Compose Create **Check** Slice Print Evaluate



"Escher! Get your ass up here."

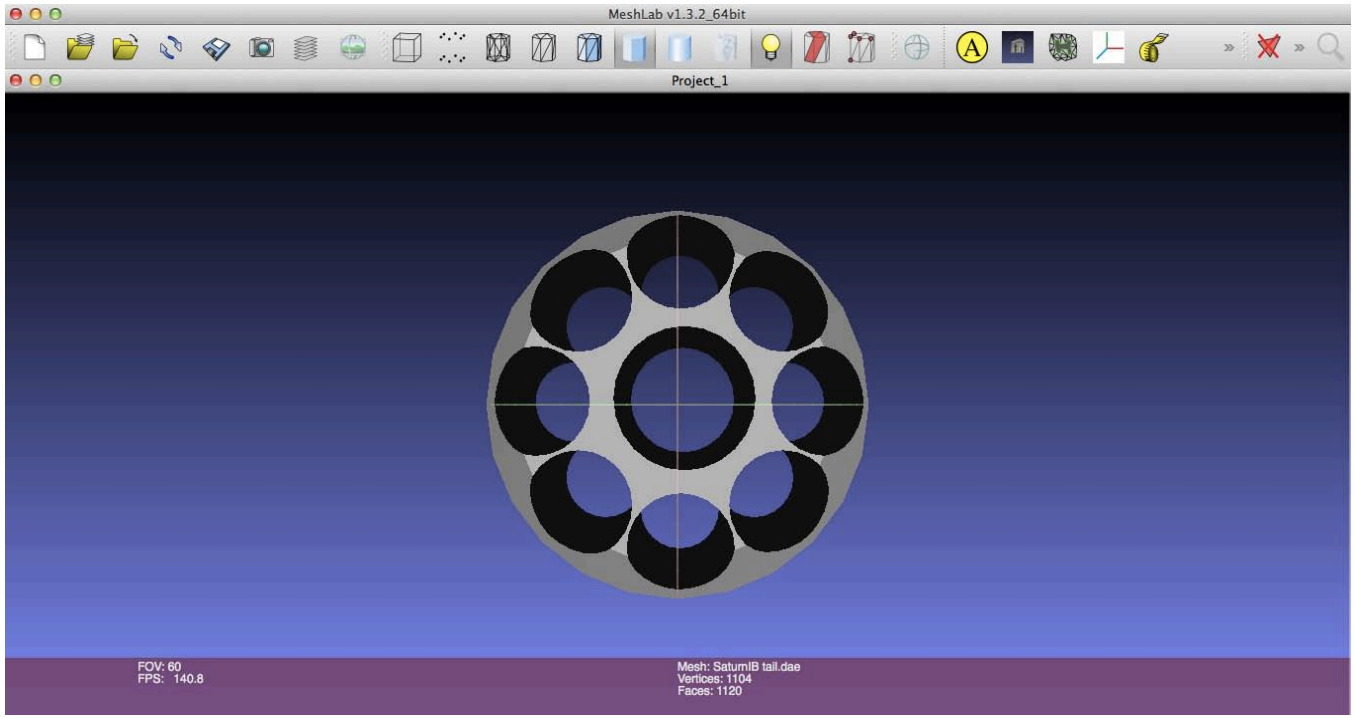
3D Printing Workflow:

Compose Create **Check** Slice Print Evaluate

	Input	Output	Comments
Blender http://www.blender.org/ Windows, OS-X, Linux	.3ds, .dae, .fbx, .dxf, .obj, .x, .lwo, .bvn, .svg, .ply, .stl, x3d, .vrml	.3ds, .dae, .fbx, .dxf, .obj, .x, .lwo, .bvn, .svg, .ply, .stl, x3d, .vrml	Free
Meshlab http://Meshlab.sourceforge.net Windows, OS-X, Linux iOS, Android	.ply, .stl, .off, .obj, .3ds, .dae, .ptx, .v3d, .pts .apts, .xyz, .gts, .tri, .asc, .x3d .x3dv, .vrml, .aln	.ply, .stl, .off, .obj, .3ds, .dae, .vrml, .dxf, .gts, .u3d, .idtf, .x3d	Free

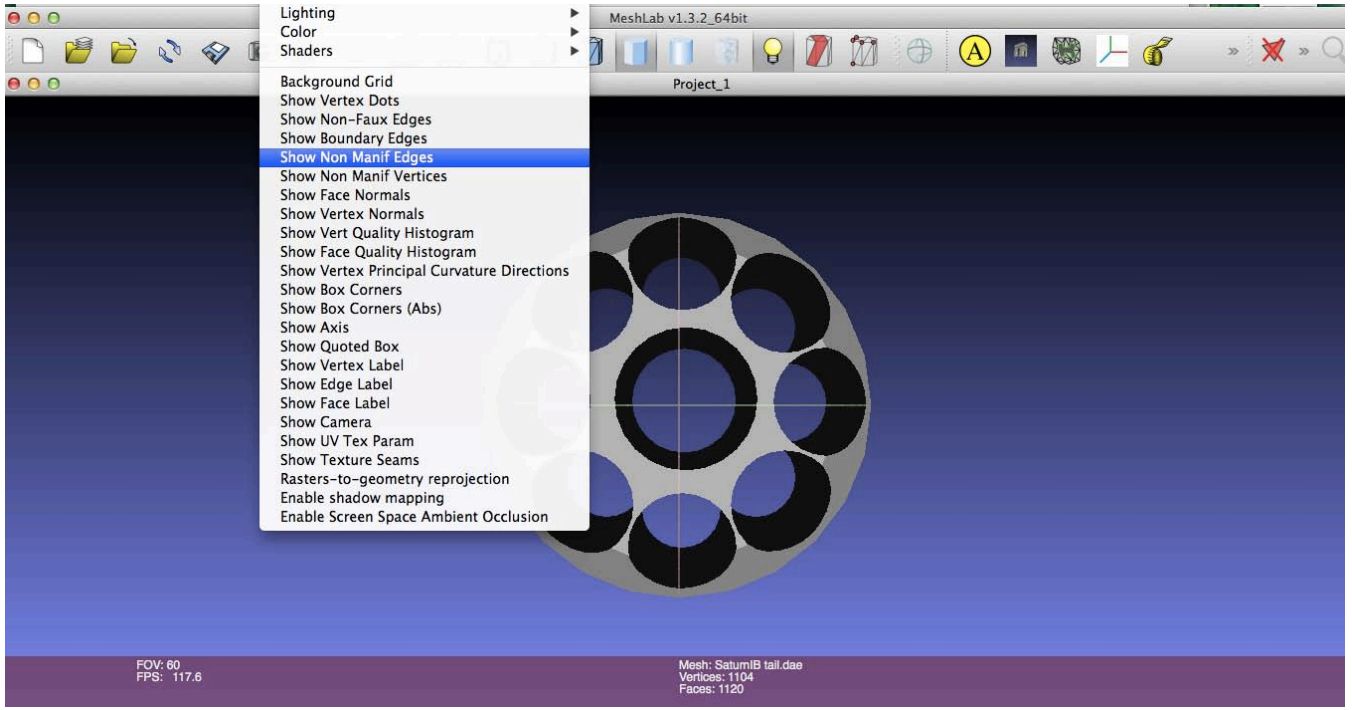
3D Printing Workflow:

Compose Create **Check** Slice Print Evaluate



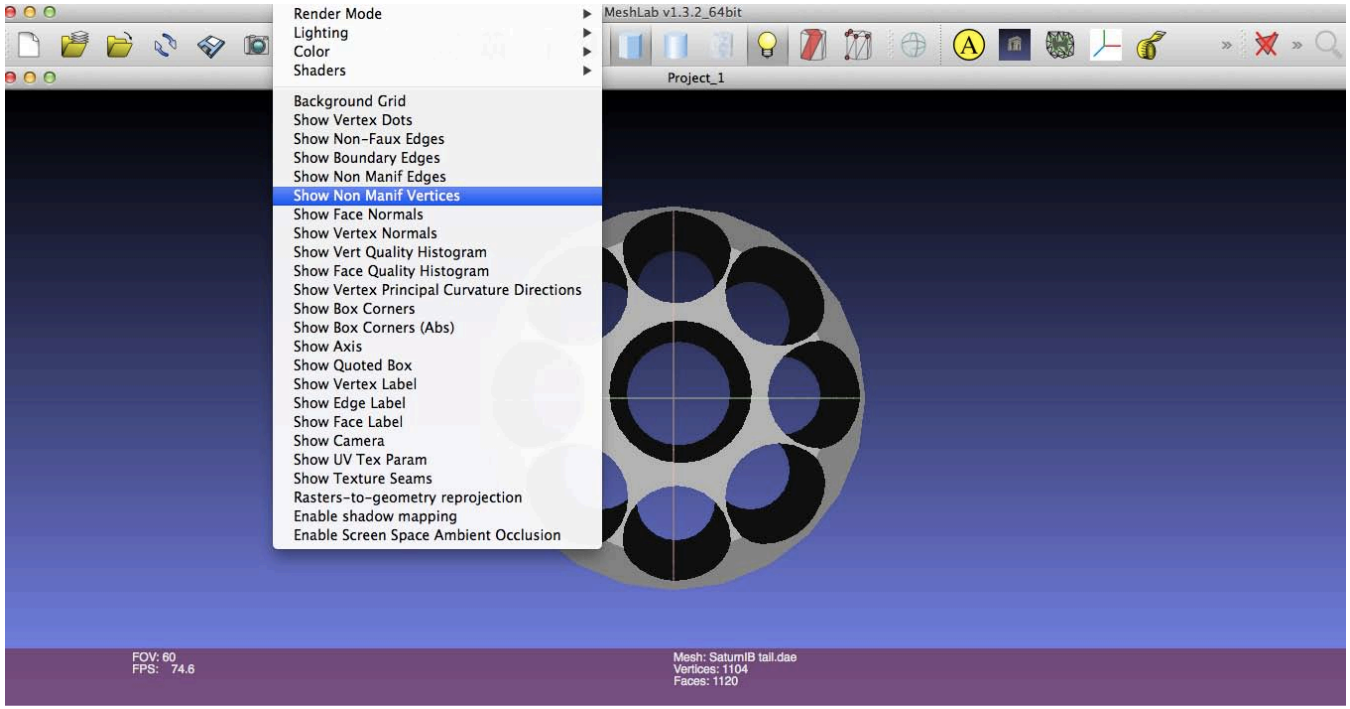
3D Printing Workflow:

Compose Create **Check** Slice Print Evaluate

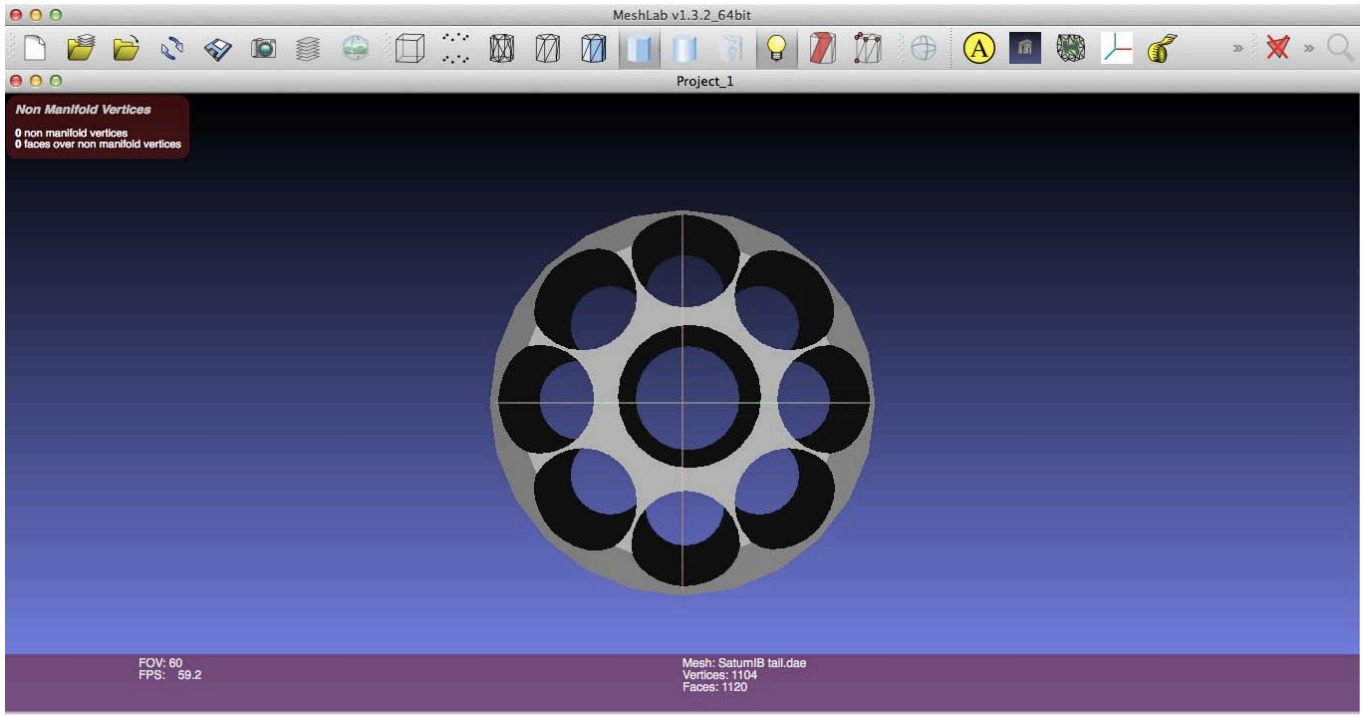


3D Printing Workflow:

Compose Create **Check** Slice Print Evaluate



Compose Create **Check** Slice Print Evaluate



3D Printing Workflow:

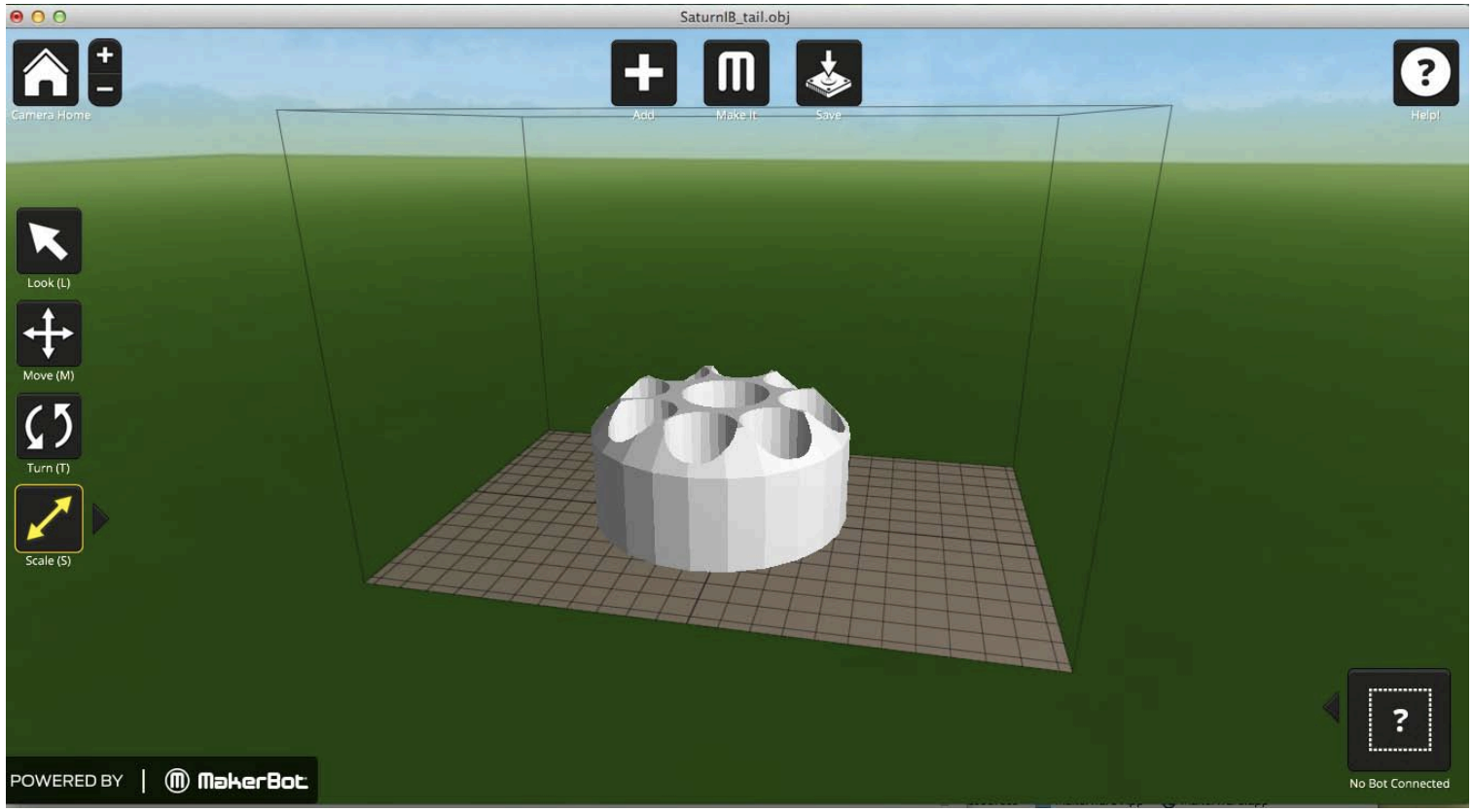
Compose Create Check **Slice** Print Evaluate

SLICE

SLICING IS THE PROCESS OF BREAKING A 3D MODEL INTO LAYERS AND GENERATING THE NECESSARY TOOL PATHS FOR PRINTING AN OBJECT, LAYER BY LAYER

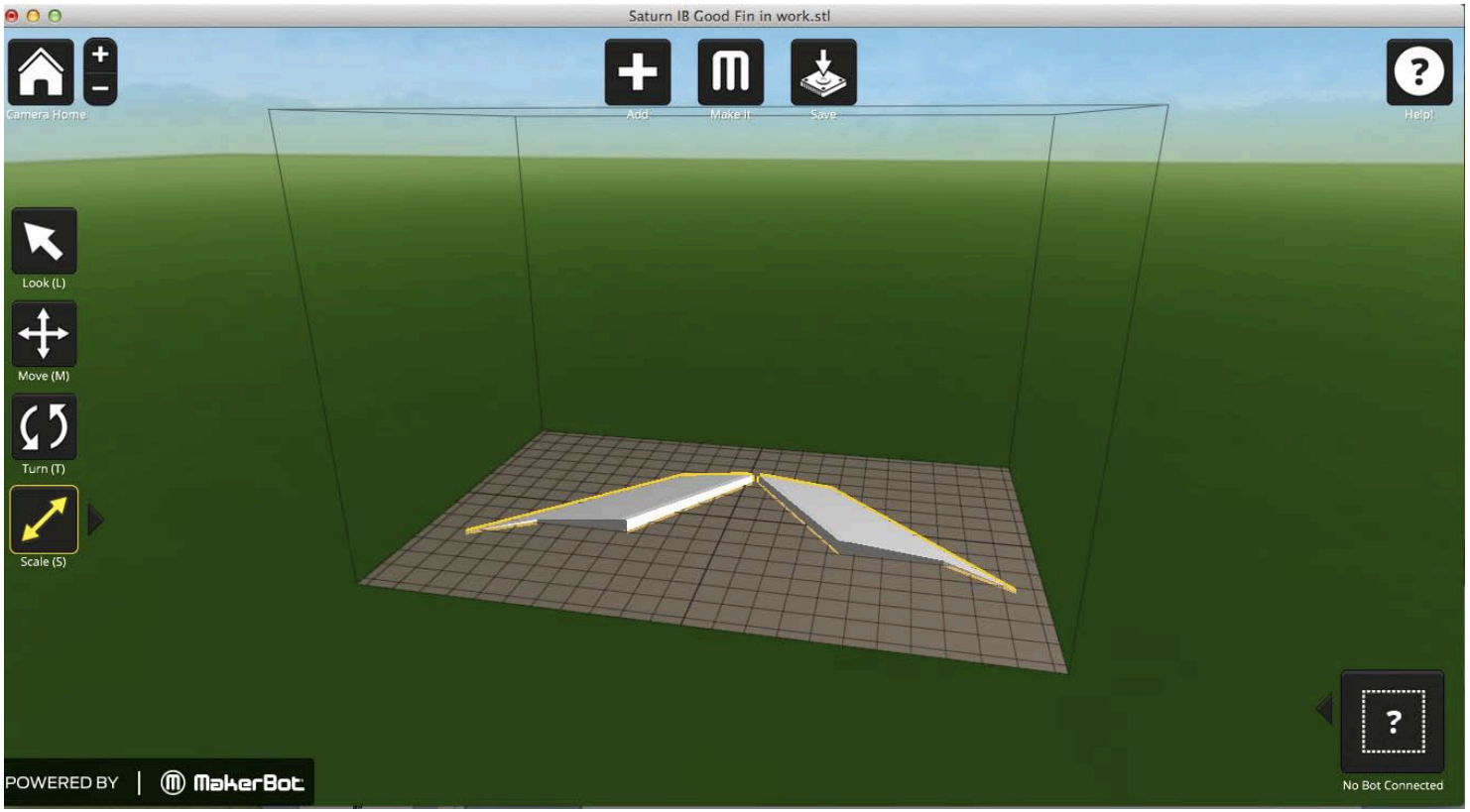
3D Printing Workflow:

Compose Create Check **Slice** Print Evaluate



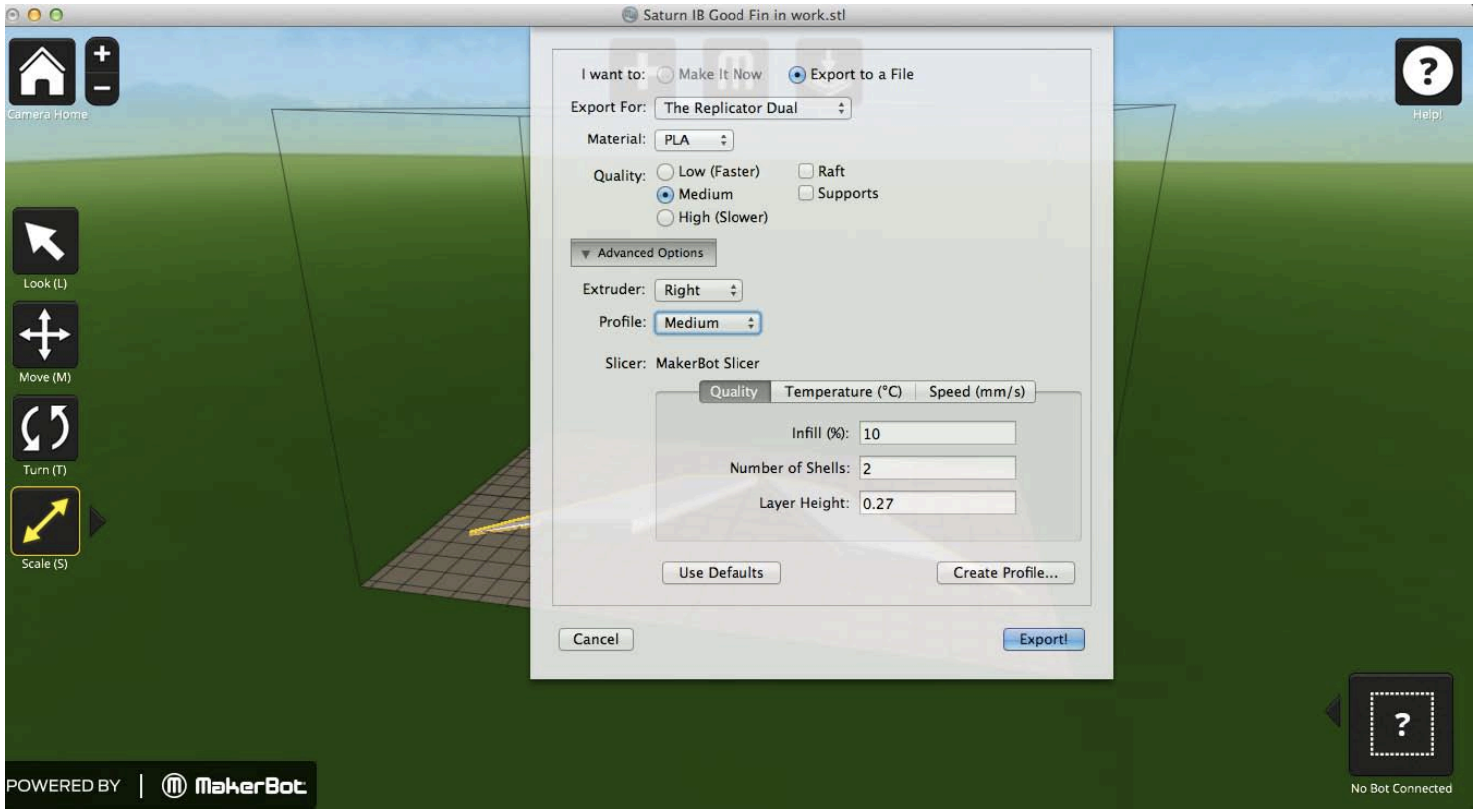
3D Printing Workflow:

Compose Create Check **Slice** Print Evaluate



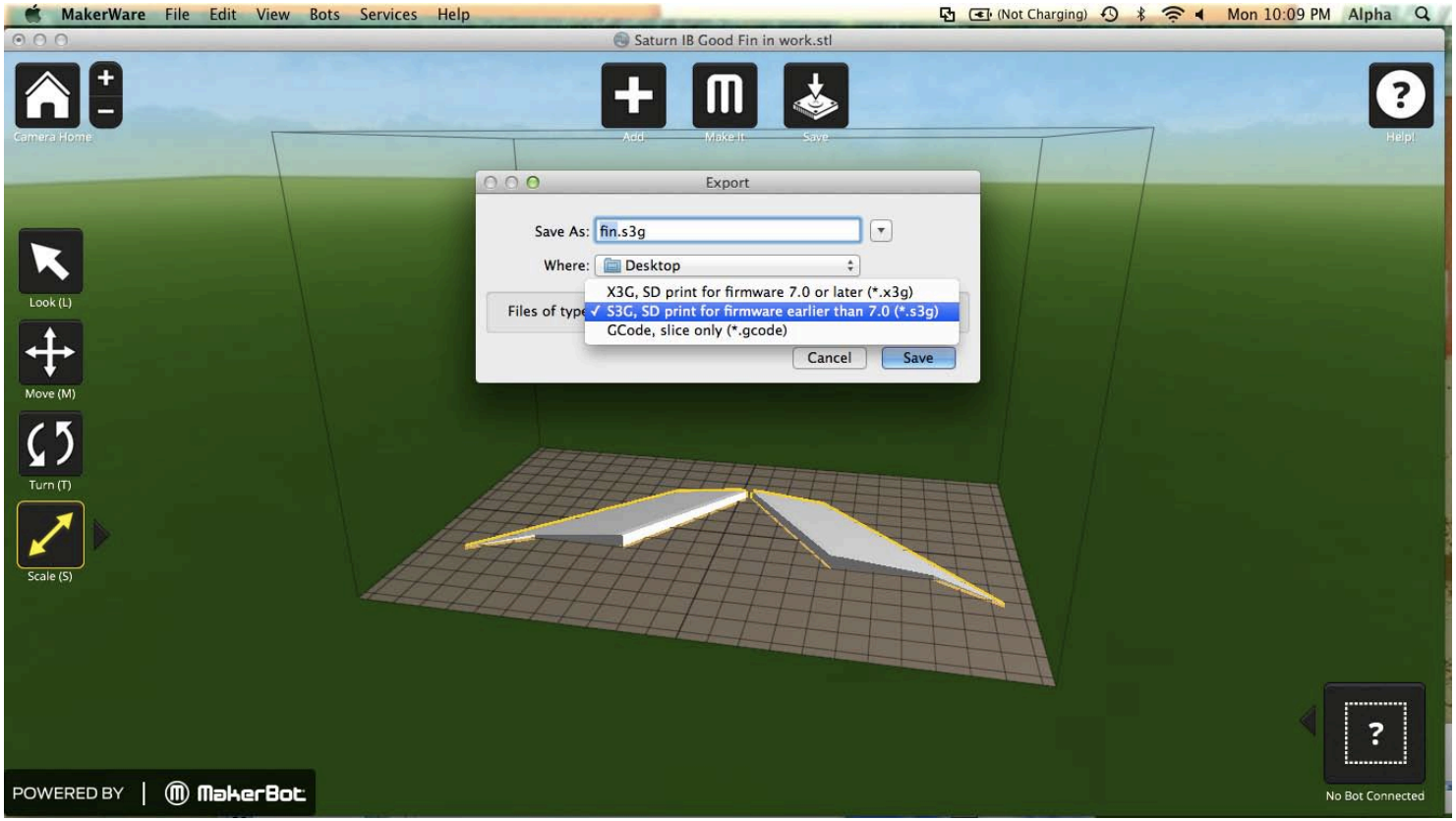
3D Printing Workflow:

Compose Create Check **Slice** Print Evaluate



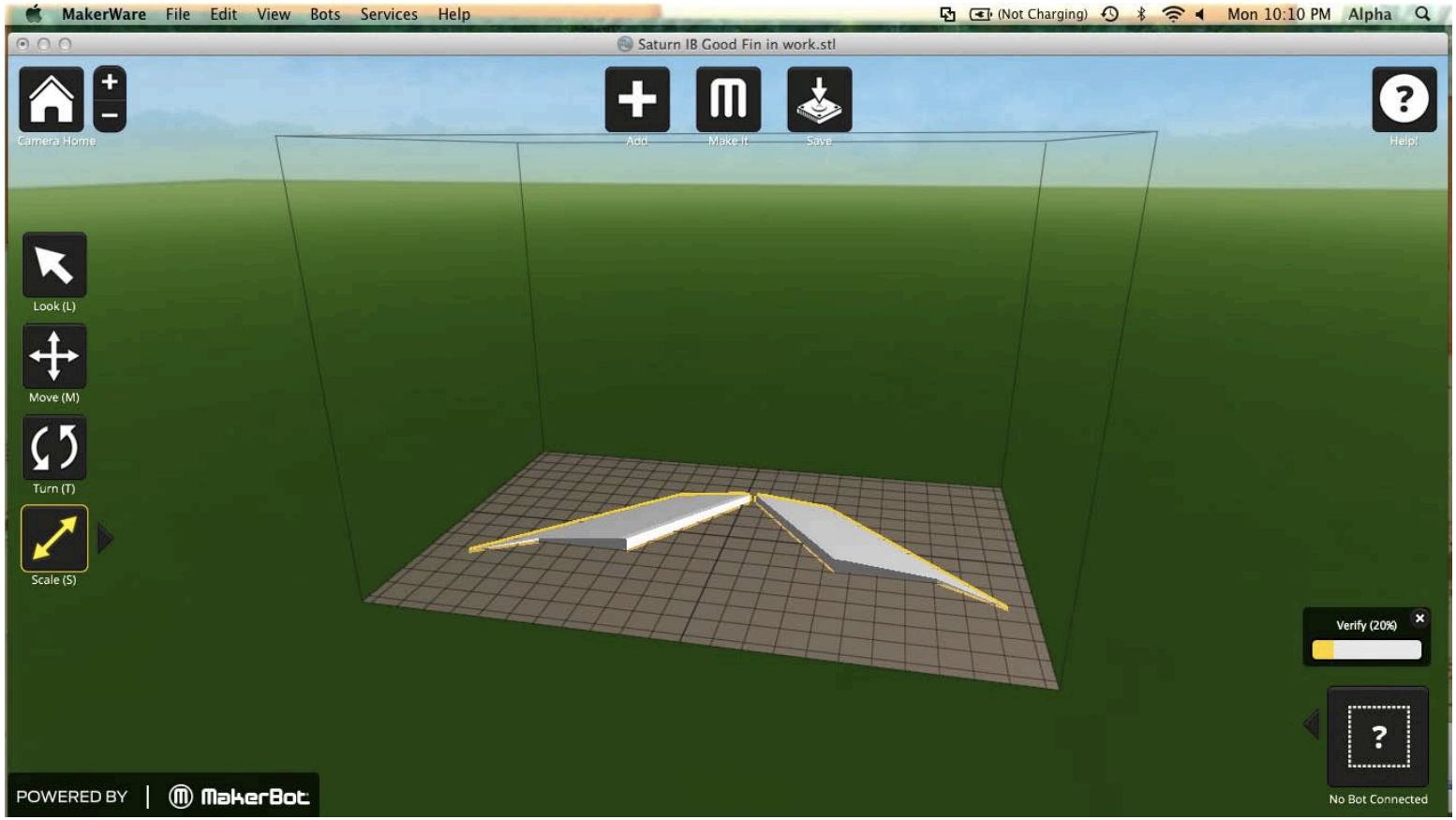
3D Printing Workflow:

Compose Create Check **Slice** Print Evaluate



3D Printing Workflow:

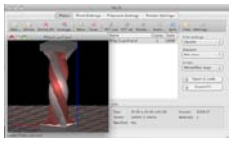
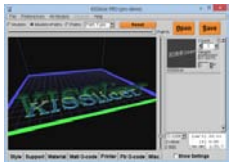
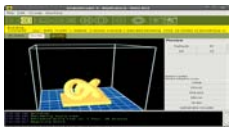
Compose Create Check **Slice** Print Evaluate



NARCON 2014 FLORIDA'S SPACE COAST

3D Printing Workflow:

Compose Create Check **Slice** Print Evaluate

	Input	Output	Comments
 Slic3r http://slic3r.org/ Windows, OS-X, Linux	.stl , .amf , .obj	G-code, .svg	Free (Donations accepted)
 KISSlicer http://kisslicer.com/ Windows, OS-X, Linux RaspberryPi, FreeBSD	.stl	G-code	Basic version free Pro version $42
 ReplicatorG http://replicat.org/ Windows, OS-X, Linux	.stl	G-code, .s3g, .x3g	Free
 Makerware http://www.makerbot.com/ Windows, OS-X, Linux	.stl	G-code, .s3g, .x3g	Free

3D Printing Workflow:

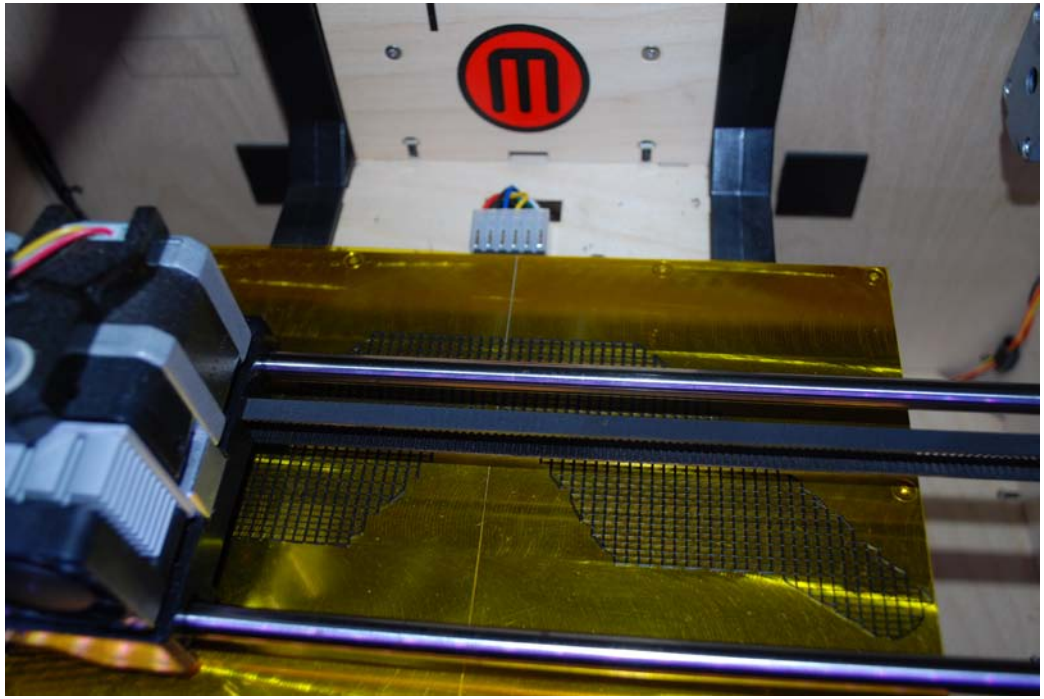
Compose Create Check Slice **Print** Evaluate

PRINT

PRINTING IS THE PROCESS OF ACTUALLY APPLYING MATERIAL LAYER BY LAYER UNTIL THE FINAL 3D PART IS COMPLETE.

3D Printing Workflow:

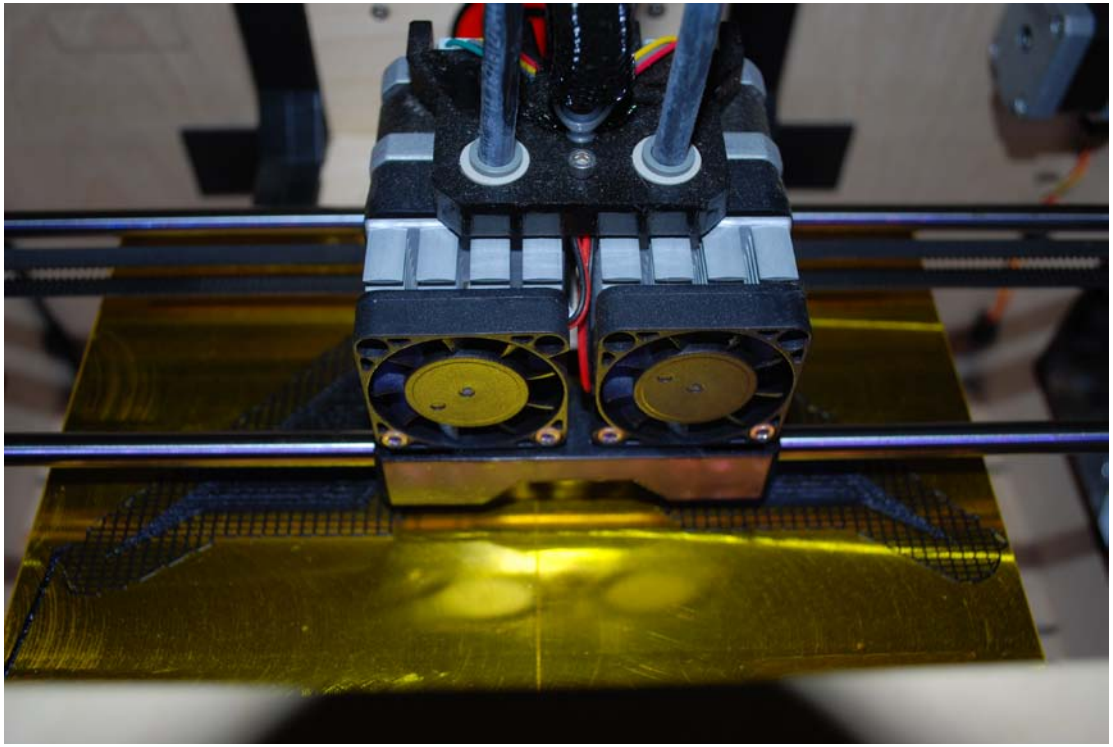
Compose Create Check Slice **Print** Evaluate



RAFT

3D Printing Workflow:

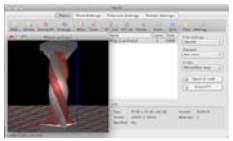
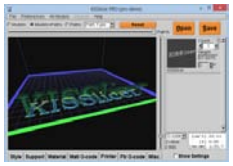
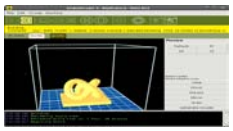
Compose Create Check Slice **Print** Evaluate



PART BEING PRINTED ON RAFT

3D Printing Workflow:

Compose Create Check Slice **Print** Evaluate

	Input	Output	Comments
 Slic3r http://slic3r.org/ Windows, OS-X, Linux	.stl , .amf , .obj	G-code, .svg	Free (Donations accepted)
 KISSlicer http://kisslicer.com/ Windows, OS-X, Linux RaspberryPi, FreeBSD	.stl	G-code	Basic version free Pro version $42
 ReplicatorG http://replicat.org/ Windows, OS-X, Linux	.stl	G-code, .s3g, .x3g	Free
 Makerware http://www.makerbot.com/ Windows, OS-X, Linux	.stl	G-code, .s3g, .x3g	Free

3D Printing Workflow:

Compose Create Check Slice Print Evaluate

EVALUATE

EXAMINATION OF THE PRINTED PART CAN REVEAL CLUES TO ADJUSTMENTS (OR OTHER CHANGES) THAT, IF PER- FORMED, WILL YIELD A PART WITH IMPROVED QUALITIES ON A SUBSEQUENT PRINT ATTEMPT.