3D Printing
A Processing Approach

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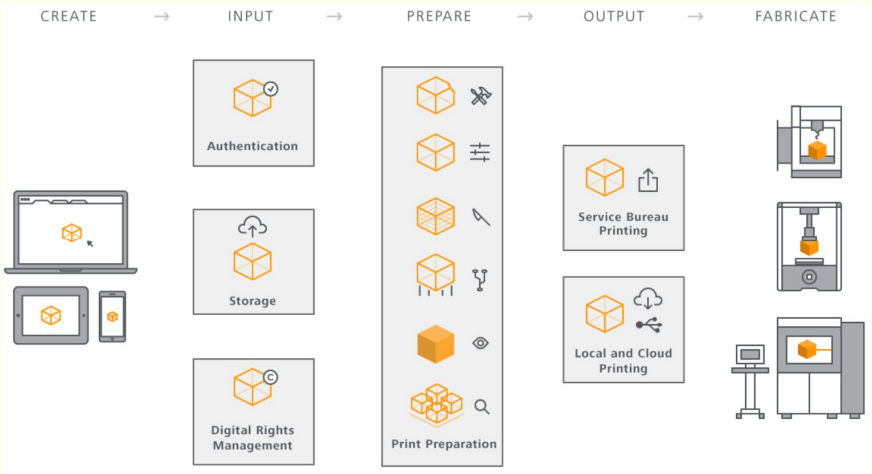
3D Printing Workflow



- General workflow of 3D printing

3D Printing Workflow

- Workflow of 3D printing @ DMSF

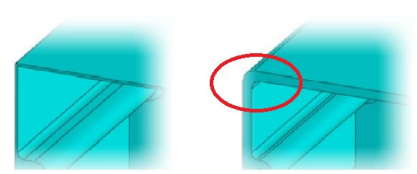
Digital Modeling

- Content to print
  - 3D printers enables product in digital modeling format to be created by laying down successive layers of material.
- Purpose of print
  - Prototype,
  - Engineering models,
  - Obsolete parts for repairing, …
- Materials to print
  - Thermoplastic, Ceramic, Paper, Wax, Metal alloy, …

Simple Rules for Printable Model

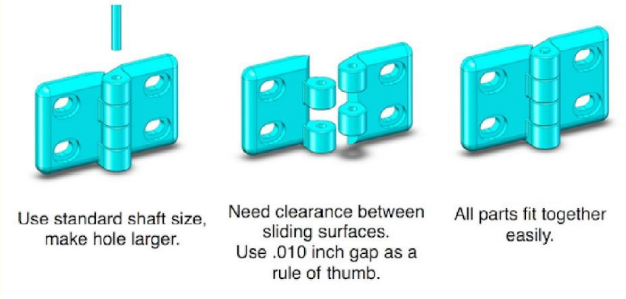
- Add fillets to all thin walls

- Thicken parts for form and fit checking



Simple Rules for Printable Model

- Design clearance into parts and assemblies

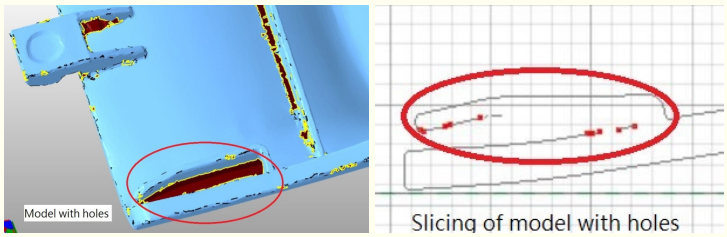


- Use the right process and materials
  - Proof of concept model
    - Lowest cost and fastest (Personal grade FDM, CJP, etc.)
  - Functional testing model
    - Mimic properties of intended objects (Industrial grade FDM, PolyJet, SLA, etc.)

Simple Rules for Printable Model

- Triangulation tolerance
  - Triangulate the CAD model with the targeted print tolerance, such as
    - 0.03 mm for Up Box (with layer thickness = 0.1 mm)
    - 0.01 mm for Connex 350 (resolution = 600 dpi)

- Water-tight model
  - One continuous solid object with clear definition of inside and outside



Digital Modeling Tools

- Computer-aided Design (CAD)
  - From concept to digital model
  - Solid- or Surface-based CAD system
    - SolidWorks, CATIA, Creo, NX, PowerSHAPE, …
  - Mesh-based CAD system
    - SketchUp, 123D Design, Geomagic Freeform / Sculpt, PowerSHAPE, …

Digital Modeling Tools

- Reverse Engineering (RE)
  - From physical parts to digital
  - Non-contact 3D scanning system
    - Structured Light: ATOS Core 200
    - Laser Stripe: Vivid 910
    - Blue LED: iSense
    - CreaForm, Polhemus, …
  - Contact 3D scanning system
    - Renishaw REVO, Faro, …
  - RE CAD software:
    - Creo, Surfacer, PowerSHAPE, …

Digital Modeling Tools

- Non-contact scanning systems @ DMSF

Machine	Scan Volume - Min (mm)	Scan Volume - Max (mm)	Operating Range (m)
iSense	200 x 200 x 200	3000 x 3000 x 3000	0.4 to 3.5
ATOS Core 200	200 x 150 x 250	N/A	N/A
Vivid 910 - TELE	111 x 83 x 40	463 x 347 x 500	0.6 to 2.5
Vivid 910 - MIDDLE	198 x 148 x 70	823 x 618 x 800	0.6 to 2.5
Vivid 910 - WIDE	359 x 269 x 110	1196 x 897 x 750	0.6 to 2
Coord3 Retorfit Machine	700 x 1500 x 600	N/A	N/A
Renishaw REVO - RSP3			

Machine	Accuracy - X	Accuracy - Y	Accuracy - Z	Resolution	Allowable Environment Light (Lux)	Machine weight (kg)	Battery Life (hr of active scanning)
iSense	@0.5m: 0.9mm	@0.5m: 0.9mm	@0.5m: 1mm	640 x 480 (pixel)		0.0992	3 to 4
ATOS Core 200	N/A	N/A	N/A	0.13 (mm)		2.1	N/A
Vivid 910 - TELE	@0.6m: ±0.22mm	@0.6m: ±0.16mm	@0.6m: ±0.10mm	640 x 480 (pixel)	< 500	11	N/A
Vivid 910 - MIDDLE	@0.6m: ±0.38mm	@0.6m: ±0.31mm	@0.6m: ±0.20mm	640 x 480 (pixel)	< 500	11	N/A
Vivid 910 - WIDE	@0.6m: ±1.40mm	@0.6m: ±1.04mm	@0.6m: ±0.40mm	640 x 480 (pixel)	< 500	11	N/A
Coord3 Retorfit Machine					N/A		N/A
Renishaw REVO - RSP3	<0.1 μm	<0.1 μm	<0.1 μm	@100mm: 0.4 μm	N/A		N/A

Digital Modeling Tools

Case 1 – Battery Cover

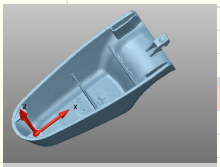
- Replacement part - battery cover

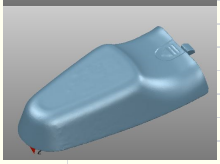
Digital Modeling Tools

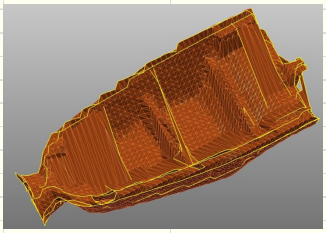
Case 1 – Battery Cover

- Input: non-contact 3D scanning

Brand	GOM	Konica-Minolta	3DSystems
Model	ATOS Core 200	Vivid 910	iSense
Number of multiple scans	40	6	*FAIL*
Time per single scan (second)	30	15	
Total time (minute)	30	10	
Number of Mesh	174,506	9,808	
Number of Point	93,264	5,341	
3D Printing Check:	Up Box		
Quality =	Normal		
Materials =	ABS		
Z Resolution =	0.2 mm		
Part angle <	45 deg		
Part Surface =	4 Layers		
In Fill :	#1 (Least dense)		
Support - Dense =	3 Layers		
Support - Space =	15 Lines		
Support - Area >	3 mm2		
Support Angle <	45 deg		



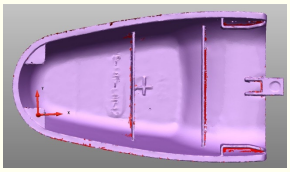


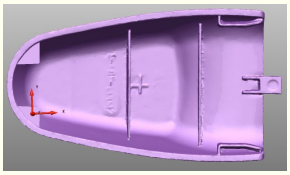


Digital Modeling Tools

Case 1 – Battery Cover

- Only ATOS Core 200 provides good enough scanned mesh model.
- RE CAD system is needed to prepare the STL model for 3d printing.
- Result:

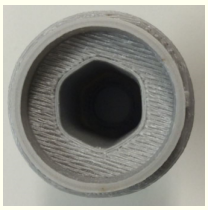




Digital Modeling Tools

Case 2 – Housing

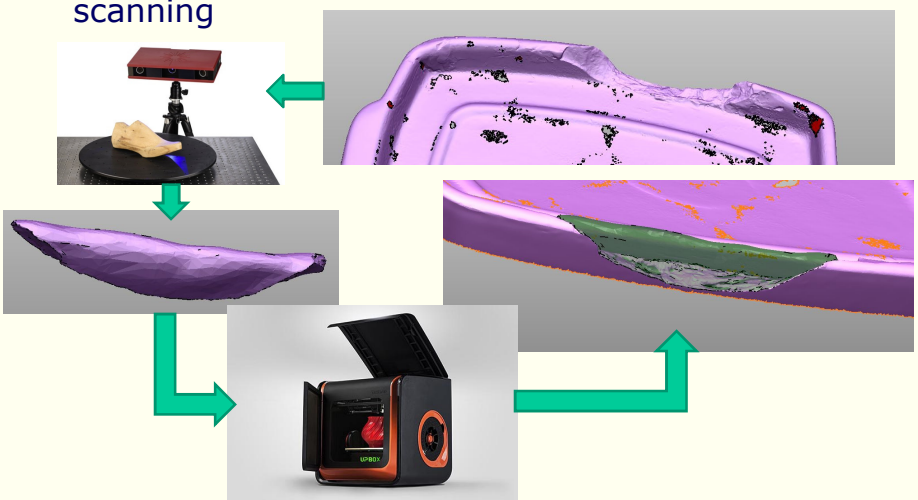
- Input: direct measurement



Digital Modeling Tools

Case 3 – Broken Edge Repair

- Input: repairing dummy & non-contact 3D scanning



Preparation for 3D Printing

Selection of Building Material and Machine

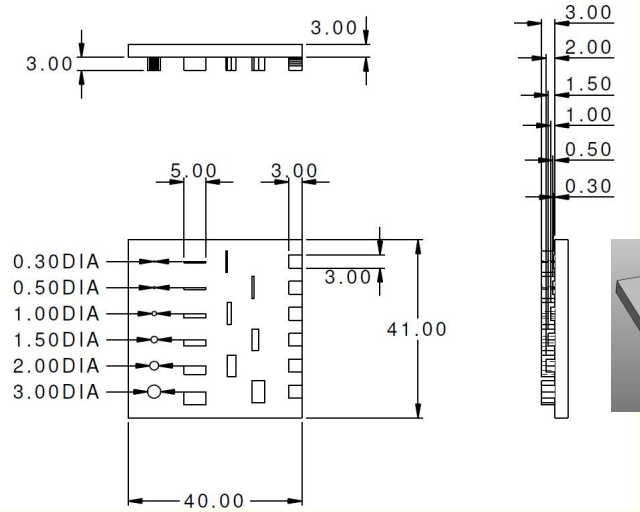
- Strength, flexibility, smoothness, weight, functional vs display, etc.

Material	ABS	PLA	High Detail Resin	Metal Alloy
Short Description	Strong and tough, good dimensional accuracy, higher temperature resistance than PLA	Strong, more rigid and brittle than ABS, less warping and dimensional accuracy than ABS, better fine details than ABS	Nice and smooth, rigid, opaque plastic	Building materials can be essentially the final materials. Surface roughness of 4.5 to 6.3 Ra.
Typical Use	Full functional models for engineers and professional applications with mechanical users in mind.	For display or small household applications.	Small detailed parts	Functional prototypes for engineering, tooling and medical.
Technology	Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF); Need a heated print bed	Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF), Need cooling fan blow directly	UV Curing / Material Jetting (Stratasys: PolyJet Matrix)	DMLS, SLM, SLS
Minimum Wall Thickness / (for Nozzle Dia. = 0.4 mm)	1.25 NDU / 0.5 mm (NDU: Nozzle Dia. Unit)	1.25 NDU / 0.5 mm (NDU: Nozzle Dia. Unit)	0.5	0.1
Minimum Wall Thickness (Strong) (mm)	1	1	2	
Print Tolerance	1.25 NDU	1.25 NDU	0.2 to 0.3 mm	0.2 to 0.3 mm
Minimum Corner Radius	1.25 NDU	1.25 NDU	N/A	N/A
Minimum angle of overhang (deg)	45	45	N/A	N/A for SLS, and 45 deg for SLM / DMLS
Maximum Size (mm)	255 x 205 x 205	255 x 205 x 205	350 x 350 x 200	~ 250 x 250 x 350
Accuracy	±0.1% (min ±0.2 mm)	±0.1% (min ±0.2 mm)	0.02 to 0.08 mm (< 50 mm) 0.2 mm (full model size)	±0.05 mm
Heat Resistance (deg C)	76	50	43	400 deg for metal

Preparation for 3D Printing

Selection of Building Material and Machine

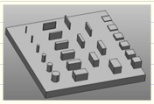
- Benchmark for accuracy and smallest feature



Preparation for 3D Printing

Selection of Building Material and Machine

- Benchmark for accuracy and smallest feature
  - Build time and cost (ABS)



Theme:	3D Printers - Specification and Benchmark Results			
Updated on:	14-Oct-15			
Brand	Tiertime	Tiertime	MakerBot	Stratasys
Model	UP Box	UP Plus 2	Replicator 2X	Connex 350
Quality Setting	Normal	Fine	Standard	Digital Materials
Layer Thickness Setting (mm)	0.2	0.15	0.2	0.032
Estimated Build Time (min)	28	71		31
Actual Build Time (min)		71	25	35
Modelling Materials - Type	ABS	ABS	ABS	FullCure 835, VeroWhit
Modelling Materials (g)	5.8	6.5	7.52	10
Supporting Materials (g)	N/A	N/A	N/A	5
Cost of Benchmark Printing (HKD)	$ 2.53	$ 2.83	$ 2.48	$ 29.56

Preparation for 3D Printing

Selection of Building Material and Machine

- Benchmark for accuracy and smallest feature
  - Accuracy and smallest feature (ABS)

	Brand	Tiertime	Tiertime	MakerBot	Stratasys	3DSystems
	Model	UP Box	UP Plus 2	Replicator 2X	Connex 350	ProJet 3510
	Dimension:					
Round Rods:	Rod 1 - Deviation in Dia (mm)	N/A	N/A	N/A	0.044	-0.02
	Rod 2 - Deviation in Dia (mm)	N/A	N/A	0.18	-0.003	0
	Rod 3 - Deviation in Dia (mm)	0.385	0.18	-0.07	-0.01	-0.02
	Rod 4 - Deviation in Dia (mm)	0.08	-0.01	-0.19	-0.01	-0.01
	Rod 5 - Deviation in Dia (mm)	-0.05	-0.055	-0.13	0.01	-0.01
	Rod 6 - Deviation in Dia (mm)	-0.095	-0.13	-0.17	0.01	0.025
X-dir Slabs:	X-dir Slab 1 - Deviation in Thickness (mm)	N/A	N/A	0.16	0.1	0.01
	X-dir Slab 2 - Deviation in Thickness (mm)	0.37	0.4	-0.04	0.08	0.02
	X-dir Slab 3 - Deviation in Thickness (mm)	0.11	0.05	0.035	0.08	-0.02
	X-dir Slab 4 - Deviation in Thickness (mm)	0.08	0.15	0.13	0.08	-0.01
	X-dir Slab 5 - Deviation in Thickness (mm)	0.08	0.09	0.12	0.09	-0.01
	X-dir Slab 6 - Deviation in Thickness (mm)	0.02	0.05	0.07	0.1	0.01
Y-dir Slabs:	Y-dir Slab 1 - Deviation in Thickness (mm)	N/A	N/A	0.1	0.08	0.04
	Y-dir Slab 2 - Deviation in Thickness (mm)	N/A	0.25	0	0.05	0.02
	Y-dir Slab 3 - Deviation in Thickness (mm)	0.26	0.11	0.12	0.04	0.03
	Y-dir Slab 4 - Deviation in Thickness (mm)	0.03	0.1	0.07	0.03	0
	Y-dir Slab 5 - Deviation in Thickness (mm)	-0.01	0.1	0.12	0	0.02
	Y-dir Slab 6 - Deviation in Thickness (mm)	0.04	0.05	0.13	0.01	0

Preparation for 3D Printing

Selection of Building Material and Machine

- Benchmark for accuracy and smallest feature
  - Accuracy and smallest feature (ABS)

	Brand	Tiertime	Tiertime	MakerBot	Stratasys	3DSystems
	Model	UP Box	UP Plus 2	Replicator 2X	Connex 350	ProJet 3510
Z-dir Bosses:	Z-dir Boss 1 - Deviation in Height (mm)	0.05	0	0.05	-0.01	-0.03
	Z-dir Boss 2 - Deviation in Height (mm)	0.1	0.1	0.15	-0.01	0.01
	Z-dir Boss 3 - Deviation in Height (mm)	-0.01	0.08	0	0.01	0.01
	Z-dir Boss 4 - Deviation in Height (mm)	0.04	0.02	0.08	-0.02	0
	Z-dir Boss 5 - Deviation in Height (mm)	-0.02	0.12	-0.07	-0.07	-0.01
	Z-dir Boss 6 - Deviation in Height (mm)	0.02	-0.01	-0.01	-0.03	0.01
	Overall Appearance:					
Round Rods:	Roundness	Fair	Fair	Good	Good	Excellent
	Straightness	Good	Fair	Fair	Excellent	Excellent
	Height of smallest printed rod = Designed Height	N/A	N/A	N/A	No	Yes
X-, Y-dir Slabs:	Rectangularity	Fair	Fair	Good	Excellent	Excellent
	Straightness	Fair	Fair	Good	Good	Excellent
	Height of smallest printed slab = Designed Height	N/A	N/A	Yes	No	Yes
Z-dir Bosses:	Squareness	Good	Fair	Good	Excellent	Excellent
	Straightness	Good	Fair	Good	Good	Excellent
Geometrical Feature:	Corner Sharpness	Fair	Fair	Fair	Fair	Excellent
	Flatness of Base Plate	Good	Good	Fair	Good	Good
	Surface Finish of Base Plate	Good	Fair	Poor	Good	Excellent

Preparation for 3D Printing

Selection of Building Material and Machine

- Benchmark for accuracy and smallest feature
  - Observations

3D Printer	Up Box	UP Plus	Makerbot Replicator 2X	Connex 350
Build Volume (WxDxH in mm)	255 x 205 x 205	140 x 140 x 135	246 x 163 x 155	342 x 342 x 200
Layer Thickness - Min (mm)	0.1	0.15	0.1	0.016
Layer Thickness - Max (mm)	0.4	0.4	0.3	0.03
Triangulation Tolerance / (for Minimum Layer Thickness, LThk)	0.3 LThk / 0.03 mm	0.3 LThk / 0.045 mm	0.3 LThk / 0.03 mm	0.01 mm (for resolution = 600 dpi)
Lowest machine cost		√		
Lowest materials cost	√	√	√	
Printing parameters - less control	√	√		
Printing parameters - full control			√	
ABS / PLA and feature size > 1.5 mm	√			
ABS / PLA and better surface finish	√			
ABS / PLA and minimum feature size > 0.5 mm			√	
ABS / PLA and better shape precision			√	
Able to print feature of 0.3 mm				√
Best shape precision				√
Best surface finish				√

Preparation for 3D Printing

Mesh Review and Fixing

- Reverse engineering, mesh reduction:
  - Creo, Surfacer, PowerSHAPE, …
- Mesh review and fixing:
  - netfabb Basic
    - Mesh quality and repair (water-tight, reverse, …)
    - Printability checking (wall thickness, feature size, …)
    - Slicing preview
- Mesh sculpt, fixing, hollowing:
  - Autodesk Meshmixer
- Model slicing, gcode generation, printing control:
  - Cura, …

Preparation for 3D Printing

Prepare the FDM Printer

- Operating temperature of hot end and heat bed, and print speed
  - Match used materials

Material	ABS	PLA	TPE	Nylon
Extruder temperature (deg C)	230 - 240	200 - 220	210 - 225	245 - 280
Heat bed temperature (deg C)	80 - 100	40 - 60	20 - 50	45 - 55
Print speed (mm/s)	50	50	30	40

- Build tray
  - Flat and clean
- Cooling fan
  - ABS: small amount of active cooling can improve corner
  - PLA: active cooling leads to sharper details

Preparation for 3D Printing

Prepare the FDM Printer

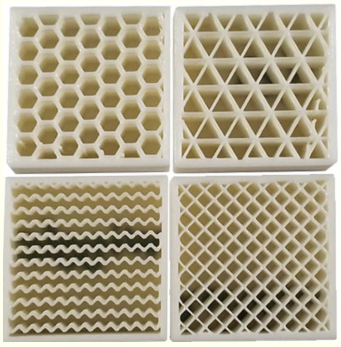
- Brim and/or Raft - Helps to reduce warping and tall print
  - Brim: A base flange around the base geometry

  - Raft: Multiple sparse layers under printed object

Preparation for 3D Printing

Prepare the FDM Printer

- Infill
  - Mainly for support and mechanical properties
  - Prefer to be 20-25%
  - Pattern
    - Rectangular, Triangular, Honey comb
    - Wiggle

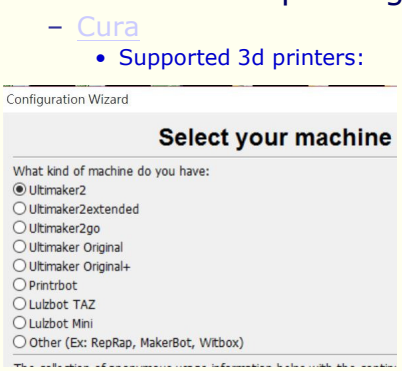


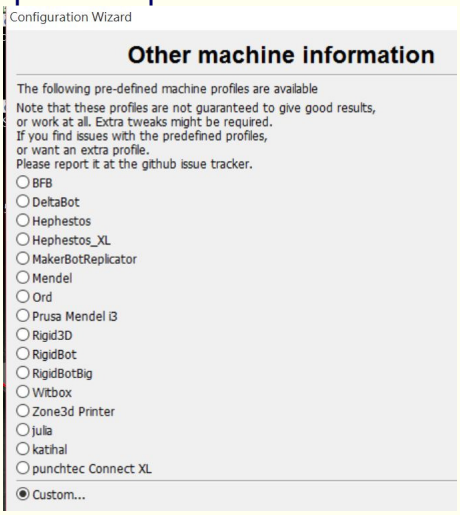
- Support
  - Overhang > 45 deg
- Space between moving parts
  - ~ 0.4 mm
- Printing speed of first layer
  - ~ 30mm/s

Preparation for 3D Printing

Prepare the FDM Printer

- Modification of printing process parameters
  - Cura
    - Supported 3d printers:

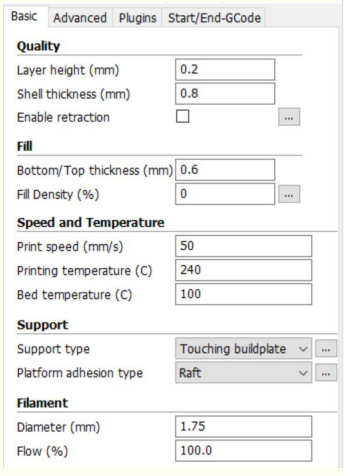


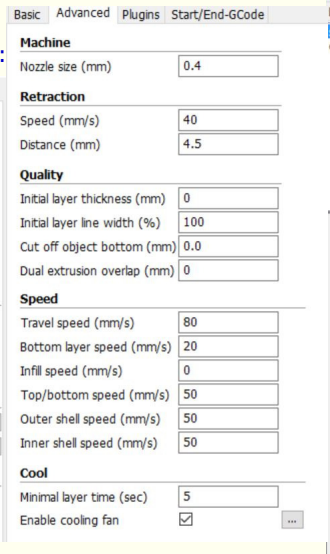


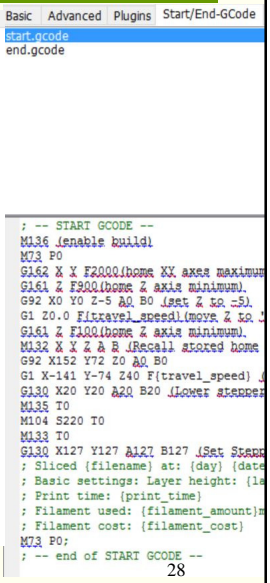
Preparation for 3D Printing

Prepare the FDM Printer

- Cura
  - Settings provided:



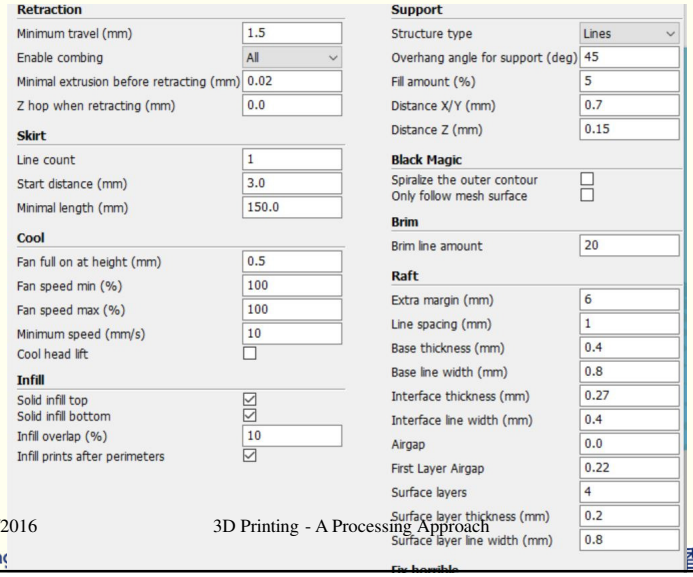




Preparation for 3D Printing

Prepare the FDM Printer

- Cura: Expert setting



Preparation for 3D Printing

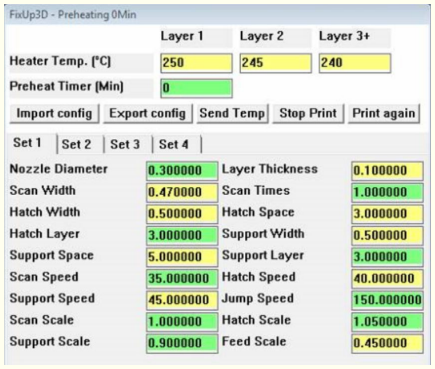
Prepare the FDM Printer

- Cura: Bed Leveling Wizard

Preparation for 3D Printing

Prepare the FDM Printer

- Modification of printing process parameters - FixUp 3D
  - For Up! and Up Box
  - Green: default value
  - Yellow: custom value
  - Delete input field contents to restore default.



Post Processing

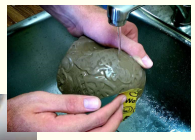
- Preparation
  - Deburring, remove support materials
    - ABS - breaking, cutting.
    - PLA - breaking, cutting, dissolving.

  - Bring back color to spots, remove tiny strings, and/or bending
    - ABS - Hot air gun, small torch, acetone.
    - PLA - Hot air gun, small torch.

- Sanding
  - Sand the areas that will be painted
    - Start with a rough girt like 150 or 200 grit sandpaper
    - After all layer lines are smoothed, then moves to a 300 or 400 grit sandpaper
  - Wash in warm water, and allows to completely dry

Post Processing

- Prime
  - "High-fill" sandable prime
  - Uses a 800 girt sandpaper to smooth out striations



- Paint