



# 3D Printing A Processing Approach

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## 3D Printing Workflow

The diagram illustrates the general workflow of 3D printing, divided into five stages: CREATE, INPUT, PREPARE, OUTPUT, and FABRICATE. 
   
- **CREATE**: Includes icons for a laptop, tablet, and smartphone.
   
- **INPUT**: Includes boxes for Authentication, Storage, and Digital Rights Management.
   
- **PREPARE**: A vertical column of icons representing various preparation steps, with a box labeled 'Print Preparation' at the bottom.
   
- **OUTPUT**: Includes boxes for 'Service Bureau Printing' and 'Local and Cloud Printing'.
   
- **FABRICATE**: Shows three different 3D printing machines.

- General workflow of 3D printing

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## 3D Printing Workflow

The diagram details the workflow at the Design & Manufacturing Services Facility (DMSF), divided into three stages: DIGITAL MODELING, PREPARE, and FABRICATE.
   
- **DIGITAL MODELING**: Includes 'CAD' (with a laptop icon), 'iSense' (with a scanner icon), and 'Renishaw REVO' (with a probe icon).
   
- **PREPARE**: Includes 'ATOS Core 200' (with a scanner icon), 'Vivid 910' (with a scanner icon), and 'Print Preparation' (with a vertical column of icons).
   
- **FABRICATE**: Includes 'Up Plus 2' (with a printer icon), 'Up Box' (with a printer icon), and 'Connex 350' (with a printer icon).

- Workflow of 3D printing @ DMSF

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## 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, ...

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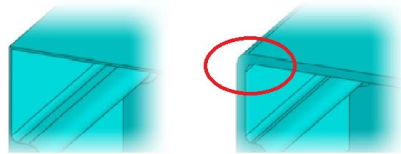


## Simple Rules for Printable Model

- Add fillets to all thin walls



- Thicken parts for form and fit checking



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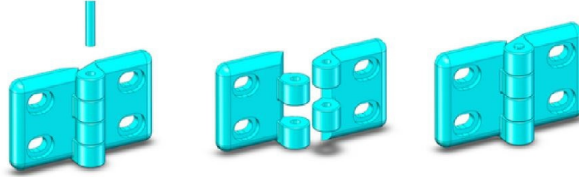
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## Simple Rules for Printable Model

- Design clearance into parts and assemblies



Use standard shaft size, make hole larger.

Need clearance between sliding surfaces. Use .010 inch gap as a rule of thumb.

All parts fit together easily.

- 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.)

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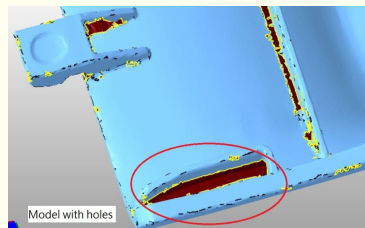
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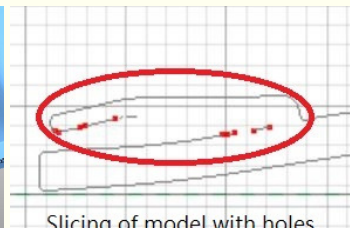


## Simple Rules for Printable Model

- 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



Model with holes



Slicing of model with holes

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## 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](#), ...

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## 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](#), ...

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# 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

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# Digital Modeling Tools

## Case 1 – Battery Cover

- Replacement part - battery cover



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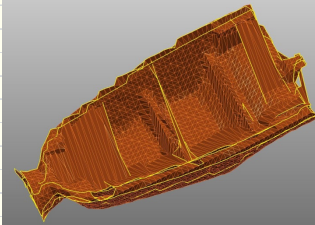
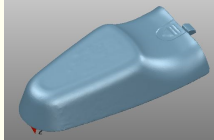
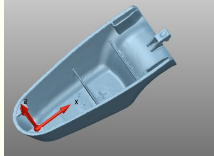


# Digital Modeling Tools

## 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	<b>FAIL</b>
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	
<b>3D Printing Check:</b> 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		



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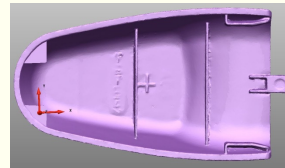
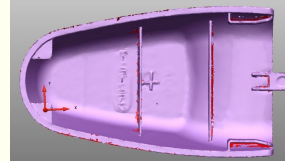
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# Digital Modeling Tools

## 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:



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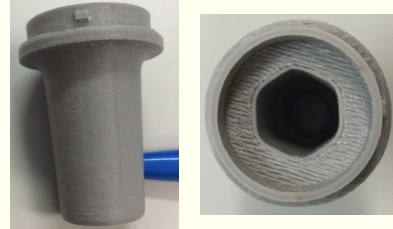




## Digital Modeling Tools

### Case 2 – Housing

- Input: direct measurement



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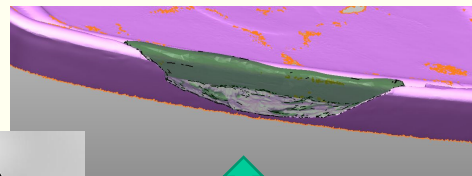
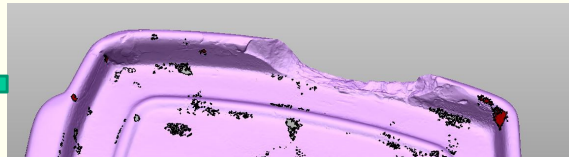
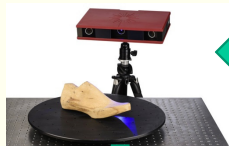
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## Digital Modeling Tools

### Case 3 – Broken Edge Repair

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



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## 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

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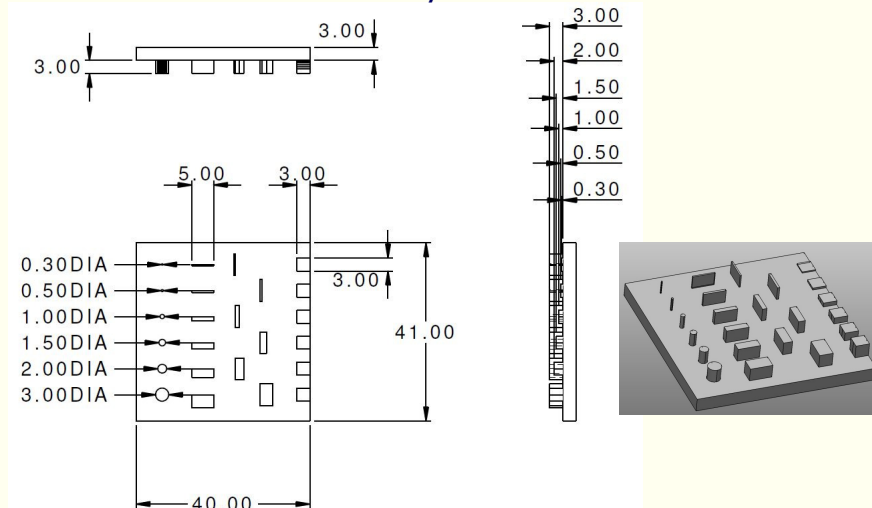
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## Preparation for 3D Printing Selection of Building Material and Machine

- Benchmark for accuracy and smallest feature



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## 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	Tier	Time	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	0.052
Estimated Build Time (min)	28	71		31
Actual Build Time (min)		71	25	35
Modelling Materials - Type	ABS	ABS	ABS	PullCure 835, VeroWhite
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

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## Preparation for 3D Printing Selection of Building Material and Machine

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

	Brand	Tier	Time	MakerBot	Stratasys	3DSystems
	Model	UP Box	UP Plus 2	Replicator 2X	Connex 350	ProJet 3510
<b>Dimension:</b>						
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

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## Preparation for 3D Printing Selection of Building Material and Machine

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

	Brand Model	TierTime UP Box	TierTime UP Plus 2	MakerBot Replicator 2X	Stratasys Connex 350	3DSystems 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
<b>Overall Appearance:</b>						
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

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## 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				√

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# 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

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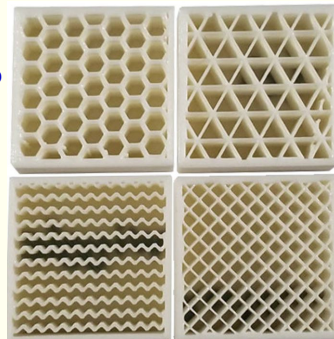
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## Preparation for 3D Printing

### 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



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# Preparation for 3D Printing

## Prepare the FDM Printer

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

Configuration Wizard

### Select your machine

What kind of machine do you have:

- Ultimaker2
- Ultimaker2extended
- Ultimaker2go
- Ultimaker Original
- Ultimaker Original+
- Printrbot
- Lulzbot TAZ
- Lulzbot Mini
- Other (Ex: RepRap, MakerBot, Witbox)

Configuration Wizard

### Other machine information

The following pre-defined machine profiles are available  
 Note that these profiles are not guaranteed to give good results, or work at all. Extra tweaks might be required.  
 If you find issues with the predefined profiles, or want an extra profile, please report it at the github issue tracker.

- BFB
- DeltaBot
- Hephestos
- Hephestos\_XL
- MakerBotReplicator
- Mendel
- Ord
- Prusa Mendel B
- Rigid3D
- RigidBot
- RigidBotBig
- Witbox
- Zone3d Printer
- Julia
- kathal
- punchtec Connect XL
- Custom...

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# Preparation for 3D Printing

## Prepare the FDM Printer

- Cura
  - Settings provided:

Basic | Advanced | Plugins | Start/End-GCode

**Quality**

Layer height (mm)

Shell thickness (mm)

Enable retraction

**Fill**

Bottom/Top thickness (mm)

Fill Density (%)

**Speed and Temperature**

Print speed (mm/s)

Printing temperature (C)

Bed temperature (C)

**Support**

Support type

Platform adhesion type

**Filament**

Diameter (mm)

Flow (%)

Basic | Advanced | Plugins | Start/End-GCode

**Machine**

Nozzle size (mm)

**Retraction**

Speed (mm/s)

Distance (mm)

**Quality**

Initial layer thickness (mm)

Initial layer line width (%)

Cut off object bottom (mm)

Dual extrusion overlap (mm)

**Speed**

Travel speed (mm/s)

Bottom layer speed (mm/s)

Infill speed (mm/s)

Top/bottom speed (mm/s)

Outer shell speed (mm/s)

Inner shell speed (mm/s)

**Cool**

Minimal layer time (sec)

Enable cooling fan

```

; -- START CODE --
M136 (enable build)
M73 P0
G162 X Y Z2000(home XX axis maximum)
G161 Z F300(home Z axis minimum)
G92 X0 Y0 Z-5 Z0 B0 (set Z to -5)
G1 Z0.0 F(travel_speed)(move Z to Z)
G161 Z F100(home Z axis minimum)
M132 X Y Z A B (recall stored home)
G92 X152 Y72 Z0 A0 B0
G1 X-141 Y-74 Z40 F(travel_speed)
G130 X20 Y20 A20 B20 (lower axes)
M135 T0
M104 S220 T0
M133 T0
G130 X127 Y127 A127 B127 (Set Start)
; Sliced [filename] at: [day] [date]
; Basic settings: Layer height: [la]
; Print time: [print_time]
; Filament used: [filament_amount]
; Filament cost: [filament_cost]
M73 P0;
; -- end of START CODE --
  
```

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# Preparation for 3D Printing

## Prepare the FDM Printer

### - Cura: Expert setting

<b>Retraction</b>		<b>Support</b>	
Minimum travel (mm)	1.5	Structure type	Lines
Enable combing	All	Overhang angle for support (deg)	45
Minimal extrusion before retracting (mm)	0.02	Fill amount (%)	5
Z hop when retracting (mm)	0.0	Distance X/Y (mm)	0.7
<b>Skirt</b>		Distance Z (mm)	0.15
Line count	1	<b>Black Magic</b>	
Start distance (mm)	3.0	Spiralize the outer contour	<input type="checkbox"/>
Minimal length (mm)	150.0	Only follow mesh surface	<input type="checkbox"/>
<b>Cool</b>		<b>Brim</b>	
Fan full on at height (mm)	0.5	Brim line amount	20
Fan speed min (%)	100	<b>Raft</b>	
Fan speed max (%)	100	Extra margin (mm)	6
Minimum speed (mm/s)	10	Line spacing (mm)	1
Cool head lift	<input type="checkbox"/>	Base thickness (mm)	0.4
<b>Infill</b>		Base line width (mm)	0.8
Solid infill top	<input checked="" type="checkbox"/>	Interface thickness (mm)	0.27
Solid infill bottom	<input checked="" type="checkbox"/>	Interface line width (mm)	0.4
Infill overlap (%)	10	Airgap	0.0
Infill prints after perimeters	<input checked="" type="checkbox"/>	First Layer Airgap	0.22
		Surface layers	4
		Surface layer thickness (mm)	0.2
		Surface layer line width (mm)	0.8

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# Preparation for 3D Printing

## Prepare the FDM Printer

### - Cura: Bed Leveling Wizard

Bed leveling wizard

### Bed leveling wizard

This wizard will help you in leveling your printer bed

It will do the following steps

- \* Move the printer head to each corner and let you adjust the height of the bed to the nozzle
- \* Print a line around the bed to check if it is level

Connect to printer

---

Resume

Up 0.2mm    Down 0.2mm

Up 10mm    Down 10mm

---

< Back    Finish    Cancel

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# 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.

	Layer 1	Layer 2	Layer 3+
Heater Temp. (°C)	250	245	240
Preheat Timer (Min)	0		

	Set 1	Set 2	Set 3	Set 4
Nozzle Diameter	0.300000			
Scan Width	0.470000			
Hatch Width	0.500000			
Hatch Layer	3.000000			
Support Space	5.000000			
Scan Speed	35.000000			
Support Speed	45.000000			
Scan Scale	1.000000			
Support Scale	0.900000			
Layer Thickness		0.100000		
Scan Times		1.000000		
Hatch Space		3.000000		
Support Width		0.500000		
Support Layer		3.000000		
Hatch Speed		40.000000		
Jump Speed		150.000000		
Hatch Scale		1.050000		
Feed Scale		0.450000		



# 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.



Door stopper treated with Acetone



- Sanding

- Sand the areas that will be painted
  - Start with a rough grit 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 grit sandpaper to smooth out striations

- Paint



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