The 3D Printing Process: Concept to Reality

NIH Center for Engineering Complex Tissues (CECT)
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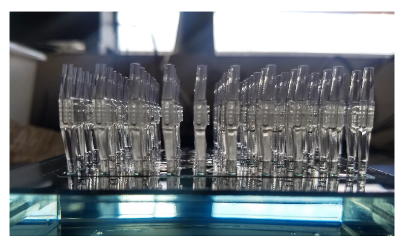
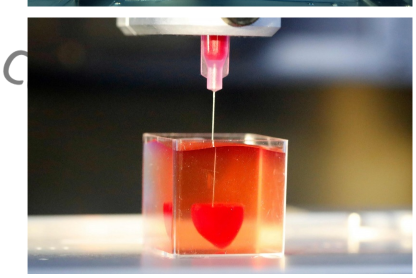
Slide information courtesy Dr. Max Lerman and Dr. Bhushan Mahadik

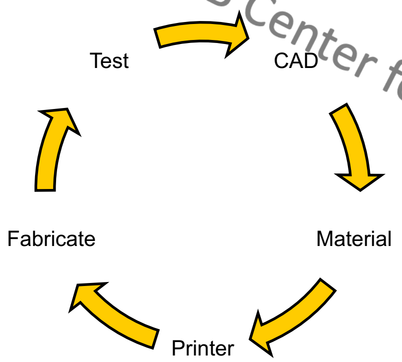
When to use 3D printing

- **Rapid prototyping**
  - Quick turn around time (hours)
  - Small volumes (dozens)
  - Highly customizable (Soft design)
- **Minimizing Waste and Cost**
- **Print on Demand**





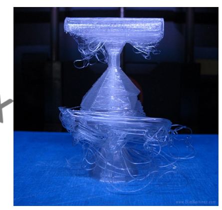
Iterative process with optimization



Planning, planning, planning!

Paper → *CAD* → *Print*

- **Considerations**
  - Cost
  - Time
  - Frustration



3D Printing Considerations

Early Design Decisions
- Internal features
- Overhangs
- Indents
- Texture

Printing Orientation
- Mechanical strength
- Structural stability
- Print accuracy

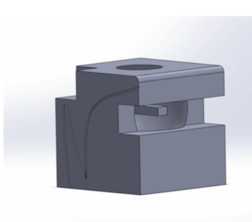
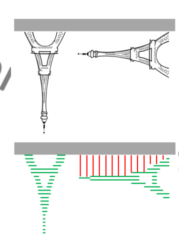
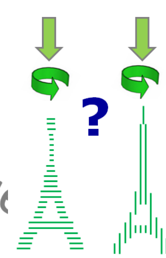
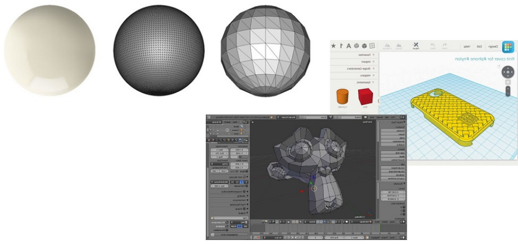


Image: http://www.3ders.org/articles/20131210





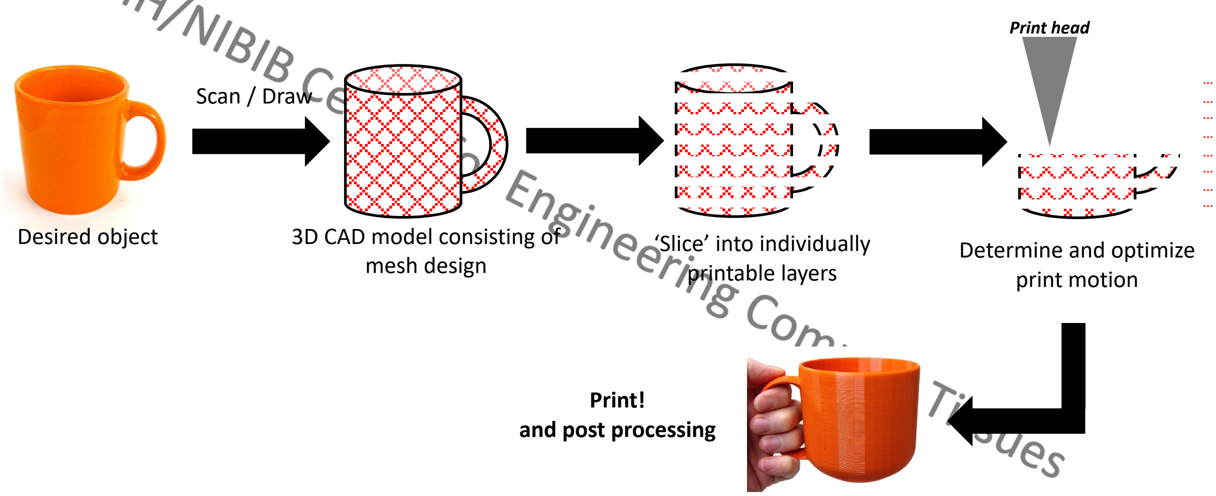
3D Printing Considerations



Print file optimization
- Variations in .stl file origins
- Resolution
- Autocorrection of shells, mesh size, etc.

Material Selection
- Dependent on printer selection
- What is the **function** of the part?
- What are the downstream applications?
- Cost
- Available materials

Basic 3D printing process



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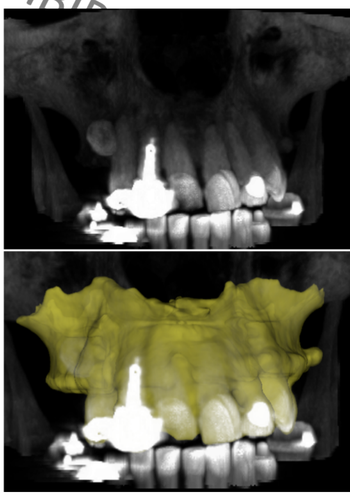
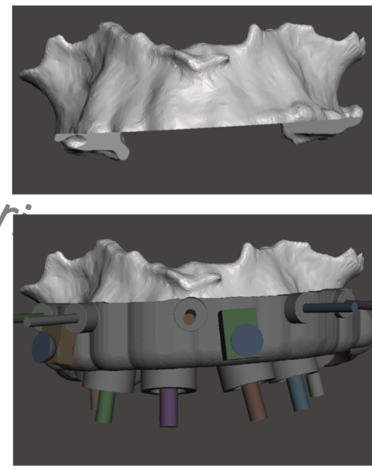
3D Printing Process Applied

1. Medical Image (CBCT)

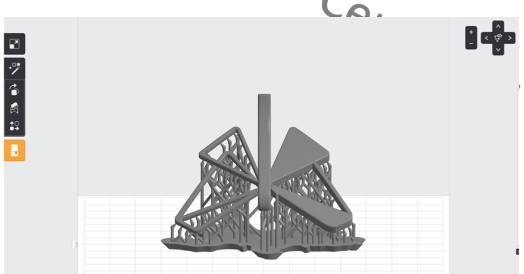


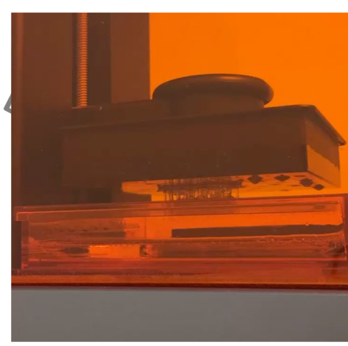
2. CAD



3D Printing Process Applied

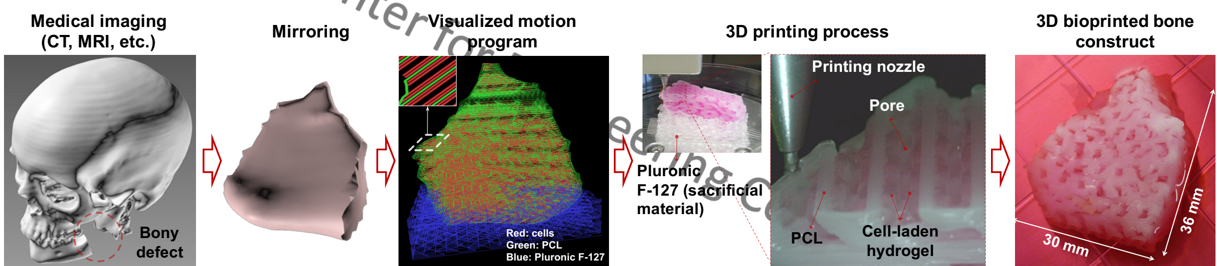
3. 3D Printing (SLA)





4. Surgical Guide and Surgery

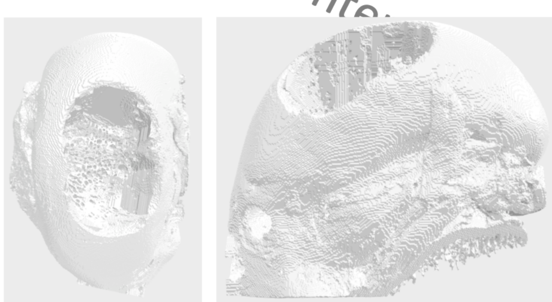
Bioprinting Process



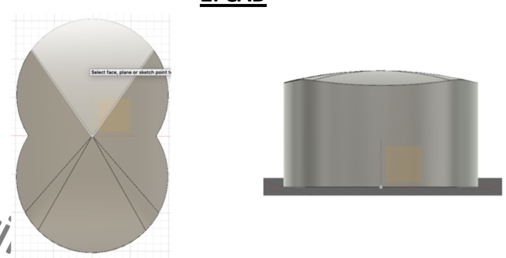
Kang H-W, Lee SJ et al. Nat Biotechnol. 2016

3D Printing Osteochondral Scaffolds

1. Medical Image

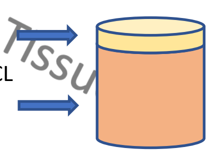


2. CAD

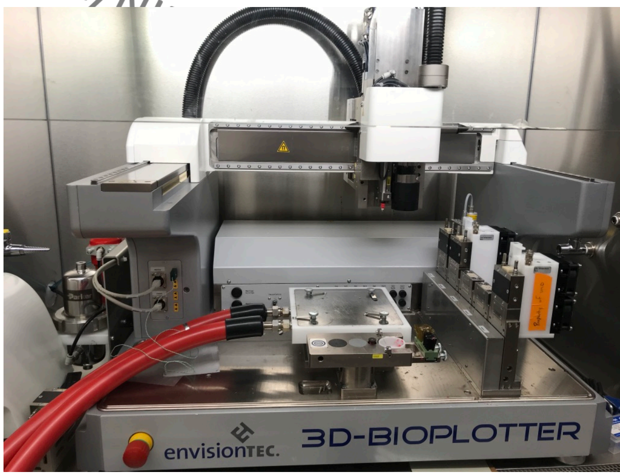


Printing Plan and Material Selection

Cartilage Layer
1.5 mm Thickness
Material- aPLGA/PLCL
Bone Layer
4.5 mm Thickness
Material - PCL



Microextrusion: 3D Bioplotter



- 4 bioinks at a time
  - 2 high temp (RT-160°C)
  - 2 low temp (4°C – RT)
- UV crosslinking
- Controlling internal architecture
- Extrudable materials
  - PCL, PLA, PLGA, etc.
  - Alginate, gelatin, pluronic, etc.

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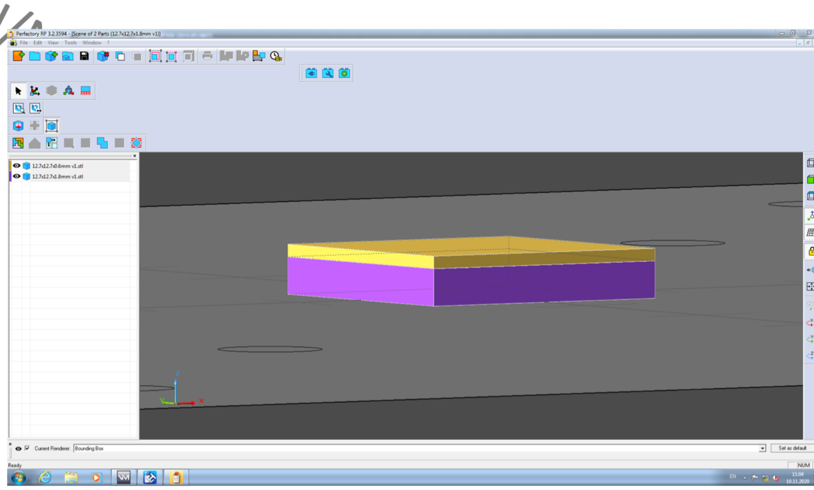
Setting up the Print Job



Import all the .stl files associated with your print job

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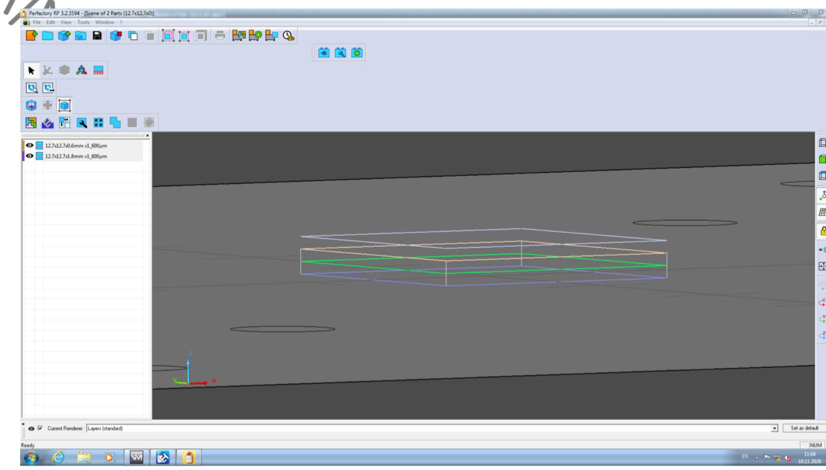
Setting up the Print Job



Slice each component of your print job

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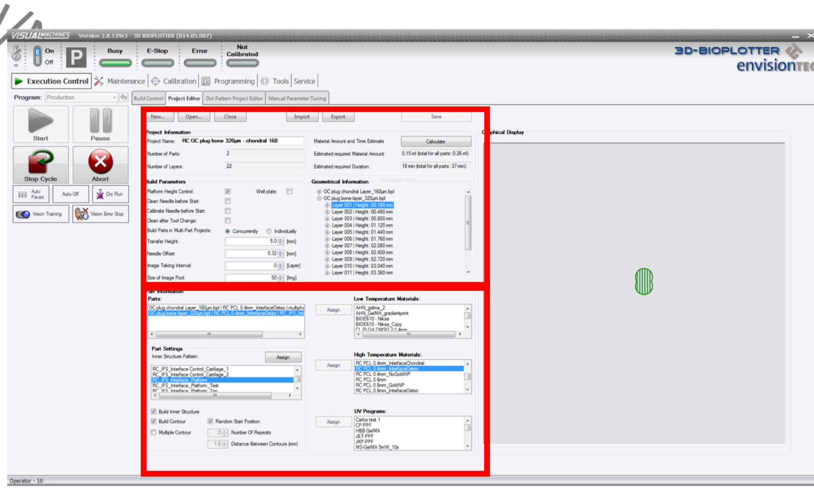
Setting Up the Print Job



2. Finalize the file:
   1. Check the number of layers
   2. Check needle offset
   3. If you have multiple parts, determine whether you can build together or separately
1. Set the material and pattern preferences at each layer

Setting up the G-Code – Material and Pattern Selection

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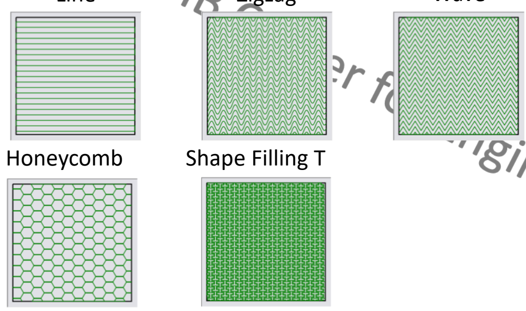
Other Considerations When Planning Layers

Patterns



Pore Dimensions

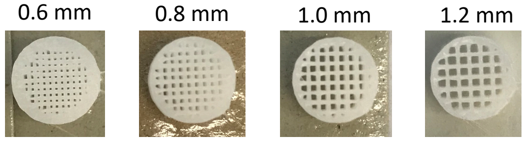


Table 1. Pore Sizes and Porosity of Various Scaffold Types Required for Different Cellular Activities

Function	*Cell type used/*in vivo *tests*	*Scaffold material*	*Pore size (μm)*	*Porosity (%)*	*Reference*
Angiogenesis	Multilayered agent-based model simulation/*in vivo* rat implantation	Porous PEG	160–270	—	154
Adipogenesis	Murine embryonic stem cells	PCL	6–70	88	156
	Rat BMCs	Silk gland fibroin from nonmulberry	90–110	97	157
	Mice ASCs	Porcine type 1 collagen	70–110	—	158
Cell infiltration	Dermal fibroblasts	Synthetic human elastin	11	34.4	139
	Primary rat osteoblasts	PHP	100	—	144
Chondrogenesis	Human ASCs	PCL	370–400	95	146
	Porcine chondrocytes	Chitosan	70–120	80	159
	Rabbit MSCs	PLGA-GCH	200	74	160
	Rabbit MSCs	PLGA	200–500	—	161
	Porcine chondrocytes	PCL	750	30	162
	Porcine BMSCs	PCL	860	59	162
Hepatogenesis	Human ASCs	PLGA	120–200	—	163
	Rat bone marrow stem cells	c-PLGA	150–350	94	164
Osteogenesis	*In vivo* rat implantation	Hydroxyapatite-BMPs	300–400	—	145
	hMSCs	Coralline hydroxyapatite	200	75	136
	In vivo mice implantation	β-tricalcium phosphate	2–100	75	165
	In vivo mice implantation	Natural coral	150–200	35	166
	RBMSCs	Sintered titanium	250	86	167
	Fetal bovine osteoblasts	PCL	350	65	168
Proliferation	hMSCs	Coralline hydroxyapatite	500	88	136
	Human trophoblast ED27	PET	30	84.9	132
	Rat MSCs	PET	> 12	96.7	133
	Human foreskin fibroblasts	Silk fibroin	200–250	86	134
	Human foreskin fibroblasts	Silk fibroin	100–150	91	134
	Rat chondrocytes	Type A gelatin	250–500	—	138
	MC3T3-E1 cells	CG	325	99	140
	Primary rat osteoblasts	PHP	40	—	144
Skin regeneration	Guinea pig dermal and epidermal cells	CG	20–125	—	169
Smooth muscle cell differentitation	Dog BMSCs	PLGA	50–200	—	170

Loh QL *et al.* Tissue Engineering: Part B. *2013*

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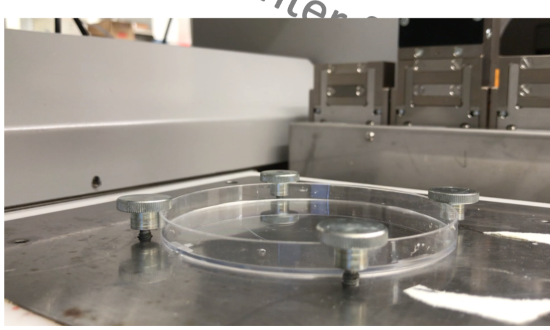
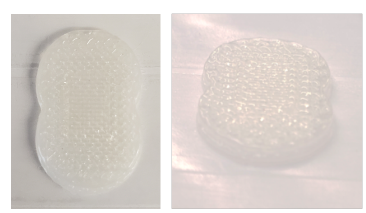
3D Printing Osteochondral Scaffolds

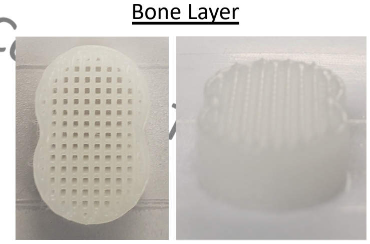
Printing the Scaffold



Cartilage Layer



Bone Layer



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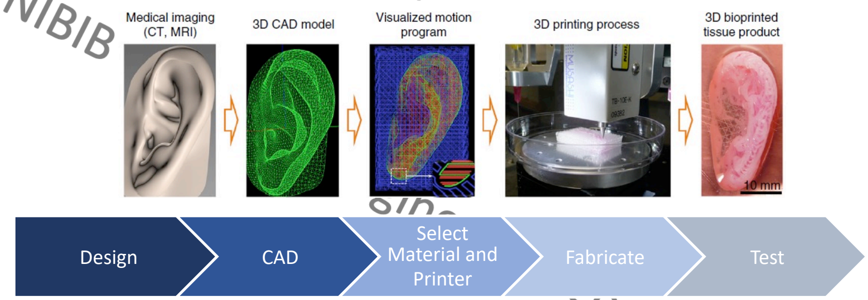
Takeaways

3D Printing Workflow



- Prepare to optimize your workflow
- Trial and Error
- Print your Project!

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Thank you for listening!

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