# Additive Manufacturing Technology and Trends

***Rapid Software Development for Slow 3D Printers***

4/21/24


Instructors:

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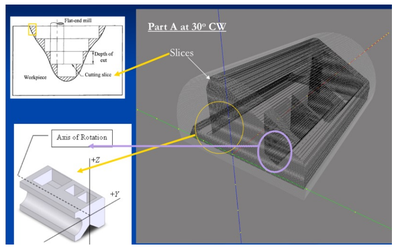
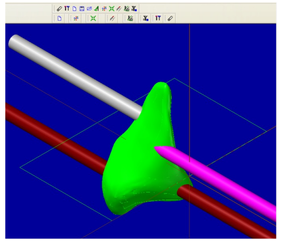
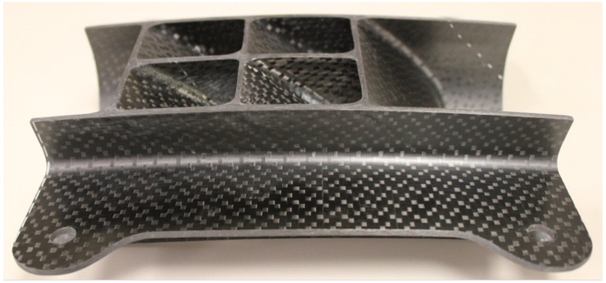
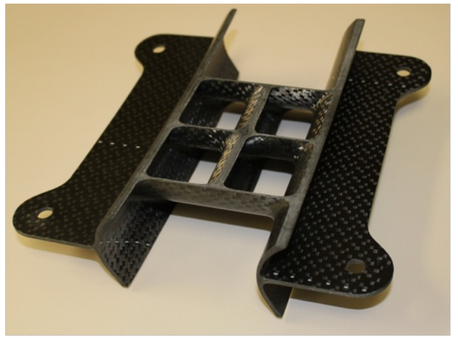
# Alex's Related Previous Work

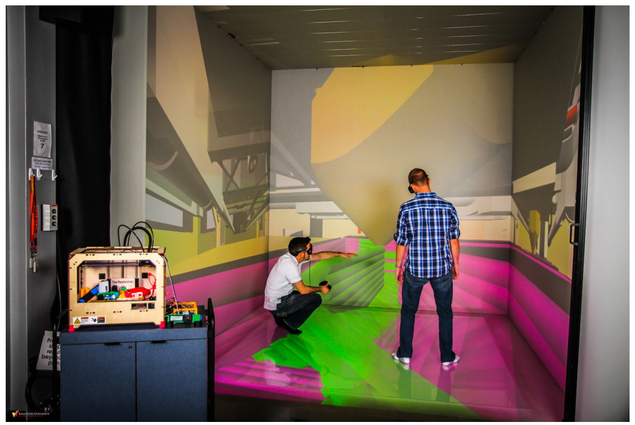
- BS in Mechanical Engineering
- MS in Industrial and Manufacturing Systems Engineering (IMSE)
- Industrial Experience
- PhD Mechanical Engineering, HCI Co-Major
- Dissertation: "A visual process simulation for novice users of desktop 3D printers to reduce part defects"

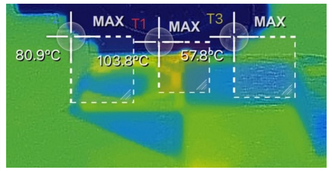


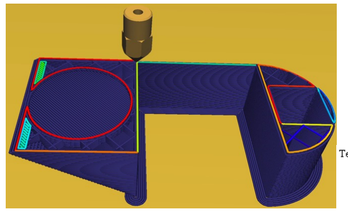



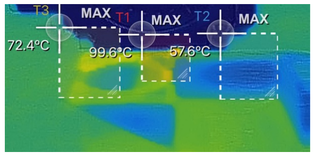


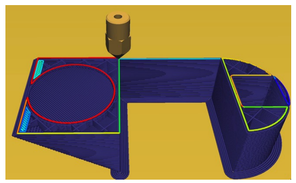


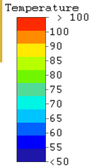








# 3D Printer “expert”

- Someone who rarely knows what they’re 3D printing,
- Someone who can’t wait to take something apart even if it isn’t broken and learns something every time they do so
- Someone who is willing to say “3D Printing is just as much of an art as it is a science”
- Someone who has used and maintained some 3D printers long enough to be asked for advice on how to prepare, print, or improve 3D print quality
- Someone who has spent as many hours running 3D printers as he or she has spent researching them, reading emails forwarded with the subject line “have you seen or heard about this … 3D printing …”, and teaching anyone who will listen to what I think I know about the subject
- ***Not someone who says they’re a 3D printer expert***

# Lecture ~~Attendance~~ Participation Guide

1. What is 3D Printing have to do with the VRAC and HCI Graduate Program?
2. Where can you go to get training and certification to use 3D printers?
3. When should someone use a 3D printer?
4. Why are we doing a “Deep Dive” into 3D printing?
5. How does your degree relate to 3D printing?

# Additive Manufacturing Technology and Trends

***MCA Session Topic: Background***

4/21/24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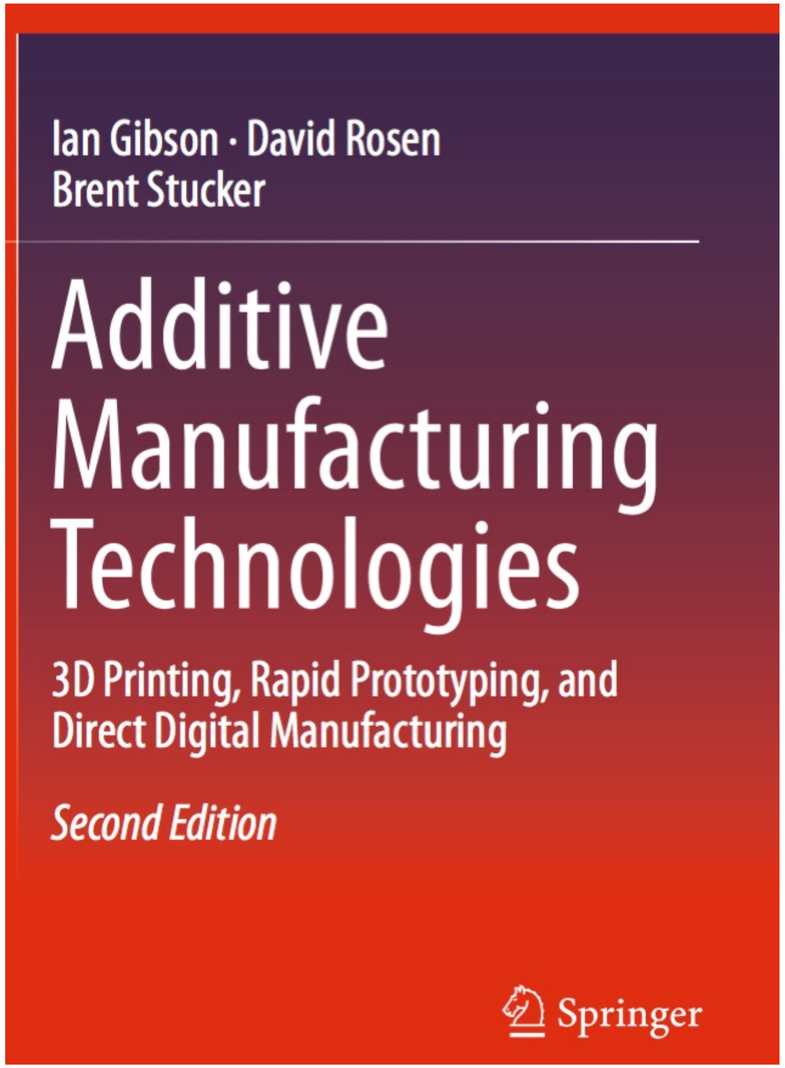
# Background: Terminology

- Additive Manufacturing (AM): Category
- Rapid Prototyping (RP)
- 3D Printing
- Direct Digital Manufacturing



# What's Additive Manufacturing

- ***Term for machines that bond small "segments" of material together to create a 3D part***
- Term used for both RP and 3D printing
- Industry standard term (ISO/ASTM 52900) used for the technology, processes, academic research, industrial systems
- Technically this term could refer to the Additive Rapid Prototyping and 3D Printing systems
- Textbook definition…

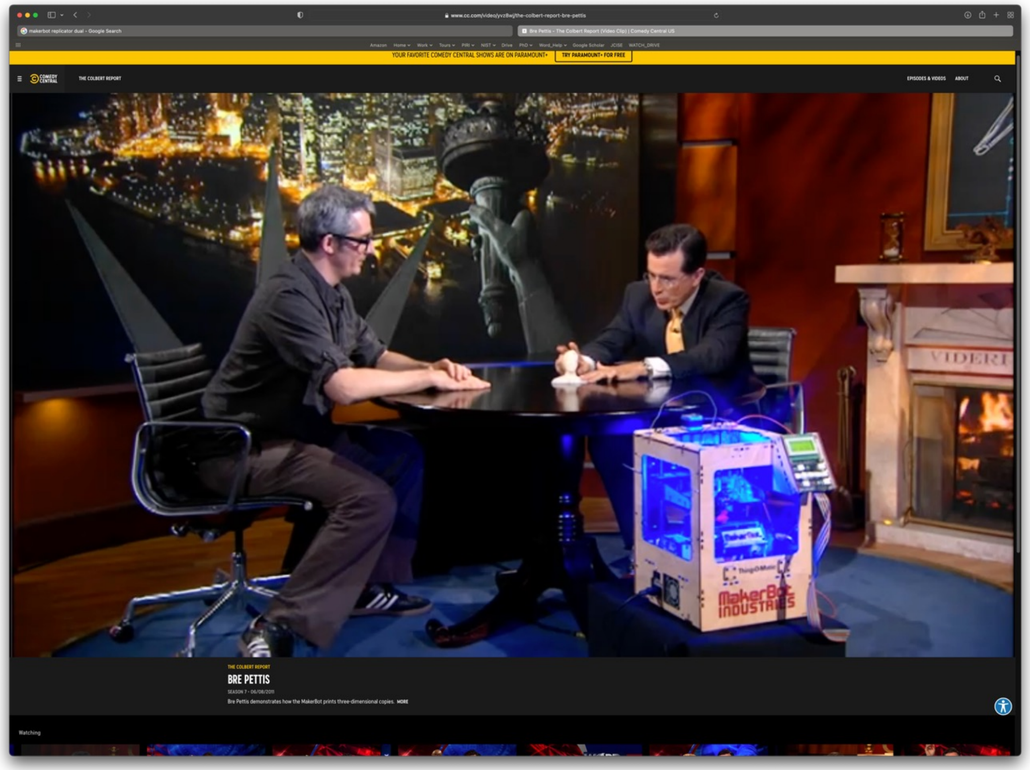
# America Makes

- *Fostering a highly collaborative infrastructure for the open exchange of additive manufacturing information and research.*
- *Facilitating the development, evaluation, and deployment of efficient and flexible additive manufacturing technologies.*
- *Engaging with educational institutions and companies to supply education and training in additive manufacturing technologies to create an adaptive, leading workforce.*
- *Serving as a national Institute with regional and national impact on additive manufacturing capabilities.*
- *Linking and integrating U.S. companies with existing public, private, or not-for-profit industrial and economic development resources, and business incubators, with an emphasis on assisting small- and medium-sized enterprises and early-stage companies (start-ups).*

https://www.americamakes.us/about/overview


# Added Value of 3D Printing Going Mainstream

- Between 2010 and 2011 …“explosion of relatively inexpensive AM devices” (Campbell, Bourell, & Gibson, 2012, p. 257)
- “Desktop 3D printing” sector of the AM industry from rapid increase in sales of low-cost 3D printer kits
- Started with MakerBot Industries LLC 2011



# “Additive Manufacturing”: Textbook Definition

- *Additive Manufacturing is defined by a range of technologies that are capable of translating virtual solid model data into physical models in a quick and easy process.*
- *The data are broken down into a series of 2D cross-sections of a finite thickness.*
- *These cross-sections are fed into AM machines so that they can be combined, adding them together in a layer-by-layer sequence to form the physical part.*
- *The geometry of the part is therefore clearly reproduced in the AM machine without having to adjust for manufacturing processes, like attention to tooling, undercuts, draft angles, or other features.*
- *We can say therefore that the AM machine is a What You See Is What You Build (WYSIWYB) process that is particularly valuable the more complex the geometry is.*
- *This basic principle drives nearly all AM machines, with variations in each technology in terms of the techniques used for creating layers and in bonding them together.*

*Gibson, Ian, David W. Rosen, and Brent Stucker. Additive manufacturing technologies. New York: Springer, 2010.

# “Rapid Prototyping” (RP)

- Rapid – (adjective) marked by a fast rate of motion, activity, succession, or occurrence, synonym: see FAST
- Prototype – (noun) a first full-scale and usually functional form of a new type or design of a construction (as an airplane)
- Textbook for RP :
  - Gibson, Ian, David W. Rosen, and Brent Stucker. Additive manufacturing technologies. New York: Springer, 2010.

# Rapid Prototyping Machines

Zcorp 3D Printer

Stratasys (FDM)


Stratasys (PolyJet)


EOS (SLS)

# What's Rapid Prototyping (RP): History Lesson

- 1986 Charles Hull (Convex Hull…)
- StereoLithography
- Zcorp "3D Printer"
- Fused Deposition Modeling (FDM) patent (Stratasys)



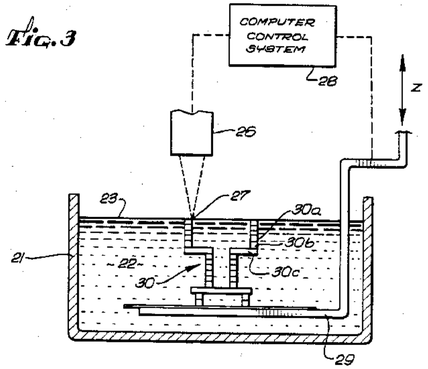



Fig. 3

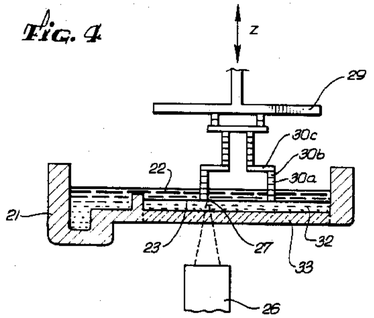



Fig. 4



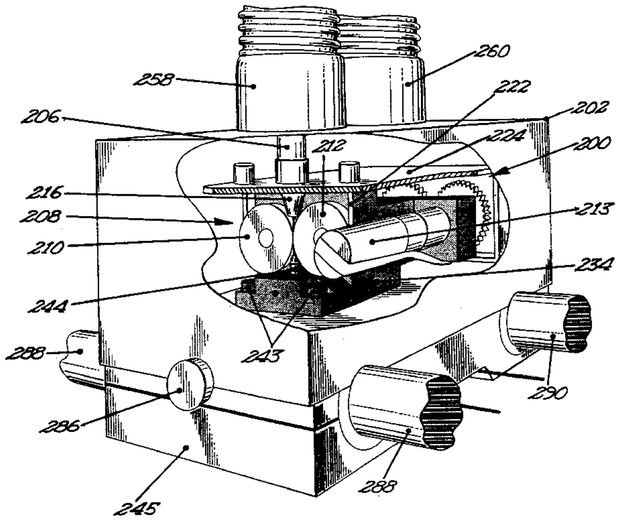
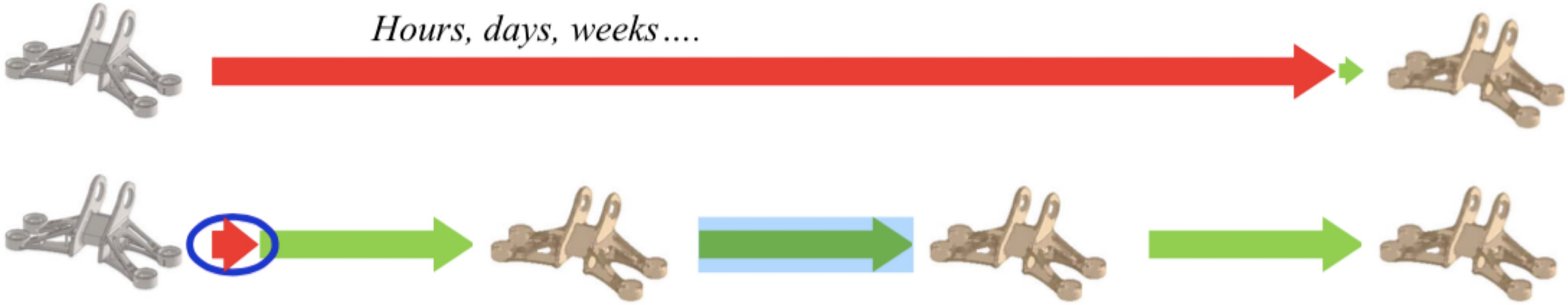



Fig 17

# “Rapid Prototyping”

- Most RP/AM systems make models (but this is slowly changing...)
- RP/AM systems create MODELS that convey form, sometimes fit and less often functional characteristics of a design
- *A Functional model is a Prototype*
- What do we require?
  - Something to look at...
  - Something to assemble with other parts... – Something to test...
  - Something to replace a production part...

# When to Rapid Prototype




Which is “rapid”?  Which is “better”?

How many did you want?

# Form -> Fit -> Function

- Form, as we define it, is the ability of a prototype to convey the design appearance and/or general size and shape of the part.

- – Verification of the design intent – Aesthetics
  – Ergonomics
  – Marketing

- – Promote discussion on Df(x)

# Form -> Fit -> Function

- A prototype that is built for fit will need to more accurately present the size and shapes of the design features.

- – Inspect the general size of the part
  – Verify part and feature dimensions
  – Assemble with other parts (RP or otherwise)

# Form -> Fit -> Function

- A first “part”: that can be tested for performance under the conditions for which it is designed.
- – Thermal, Structural Integrity – Fatigue and Failure testing
  – Cycles to failure
  – Dynamic performance

# 3D Printing Myths - Expert List

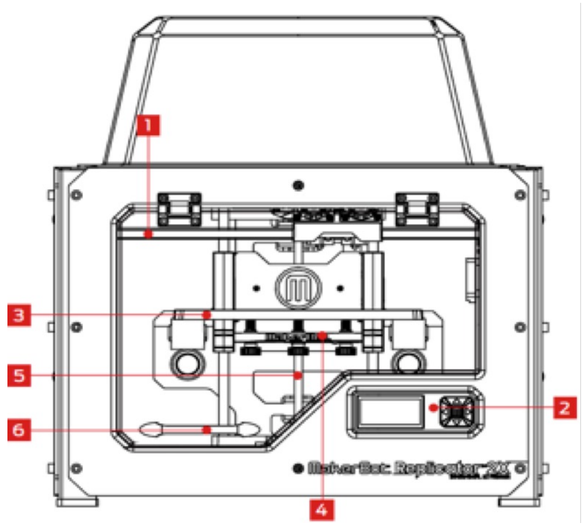
1. AM is a low-labor content, “pushbutton” technology.
2. Additive manufacturing is fast.
3. AM is greener than conventional manufacturing.
4. AM systems can produce anything.
5. With AM, it’s just as efficient to build one part at a time as it is to build many.
6. AM systems and materials are inexpensive.
7. AM will replace conventional manufacturing.
8. AM can print guns.
9. Every household will own a 3D printer.

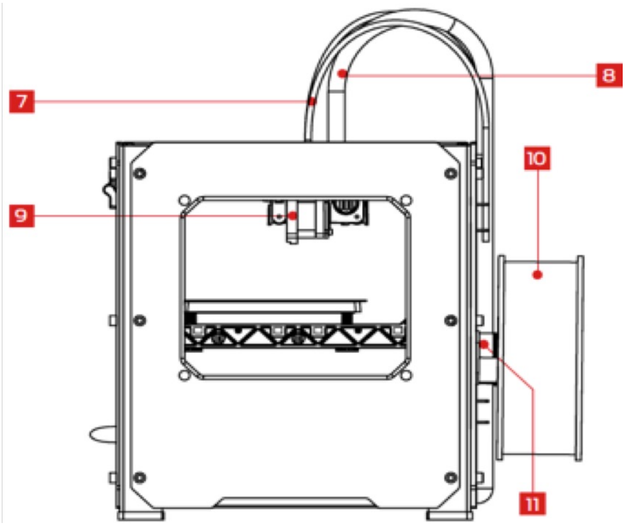
*Wohlers, Terry, and Tim Caffrey. "Additive manufacturing: going mainstream." Manufacturing Eng 151.6 (2013): 67-73.*

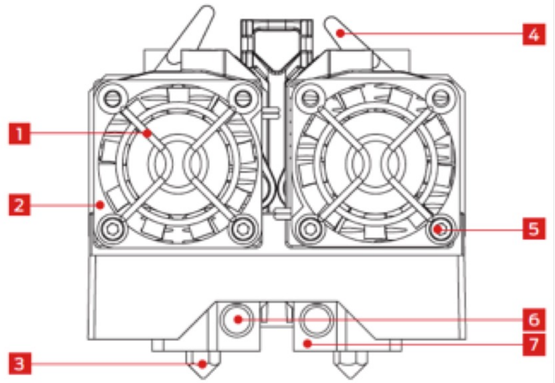
# In-Class Activity

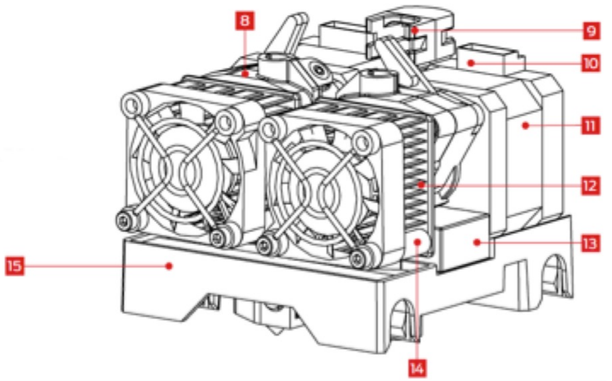
- Theme: Hands-On machine component investigation
- Use the provided explanation and hands-on investigation of machine components to answer these questions:

1. For a machine component that is heated and a second that moves, where/when in the G-code do the components get the info they need?
2. What type of data conversion occurs for the motor(s) used in the following G-code commands:
   - G1 X9.202 Y15.578 Z0.600 F9000; Travel Move
   - G1 X8.962 Y15.888 Z0.600 F5400 A47.05344; Inset
3. If you never saw the CAD file, but had the slice files, could you print the part?



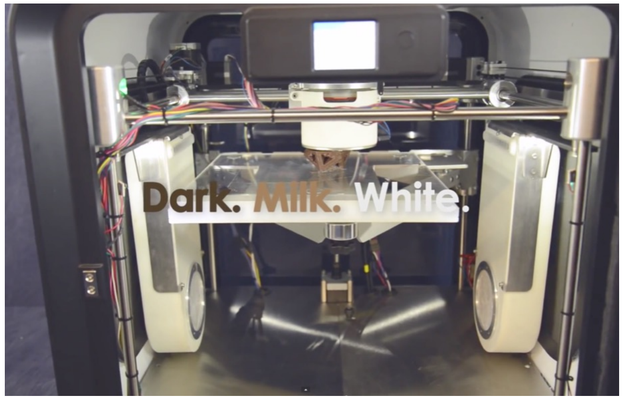
# 10 Minute Break

# 3D Printing Myths

- Confirmed, Plausible, or Busted?
- You can make Additive Manufactured substitutes for:
  - Human Organs?
  - Prosthetics?
  - Cars and other large products?
  - AeroSpace Parts?
  - Guns?
  - Jewelry?
  - Candy?

BAAM BIG AREA ADDITIVE MANUFACTURING at IMTS 2014



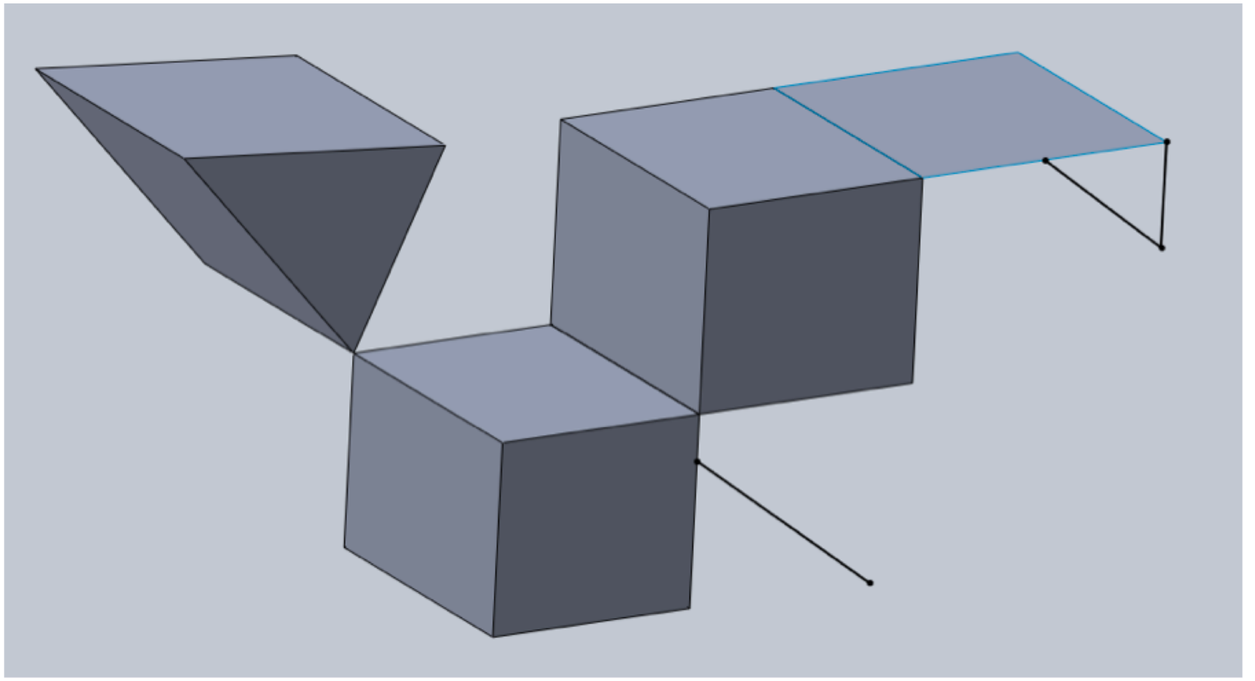


# Transition from CAD to Machine

- Often involves two people, causing potential issues:
  - Designer's intent may conflict with Additive Manufacturing (AM) requirements
  - AM Machine operator often does not know designer intent
- *"AM language"* barriers
  - Lack of verbal communication between two people quality is not a function of quantity
  - Digital data elements, transfer method(s), and unique accept/reject criteria

# CAD to CAM

- Iterative Process
- Consult 3D printer operator as early as possible
- Not just designing to meet customer requirements
  - Non-manifold geometry
  - 3D Printer considerations (how good can the machine make it)

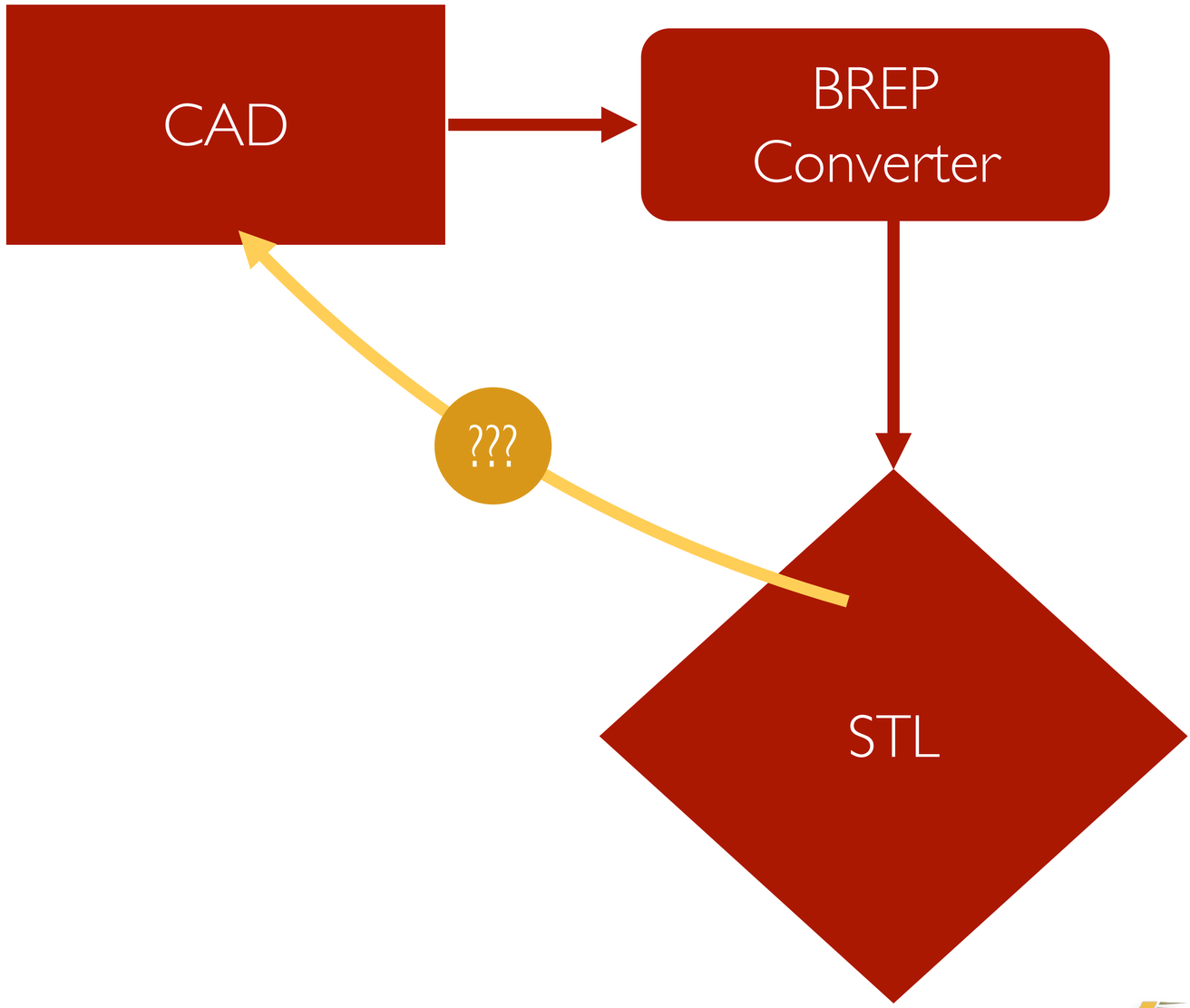


# Designer to AM User Discussion

| Designer | AM User |
| --- | --- |
| "Is my STL ok?" | "I'm sure your design is great!" |
| "No, I mean is it going to print?" | "That's hard to say" |
| "WHAT! I was told you were the expert?" | "Well I have lots of experience, just not with your design." |
| "AHAH, so you DON'T like my design, I knew it!!!" | "[***mumbling***] apparently I need a PhD in Engineering and be a magician" |

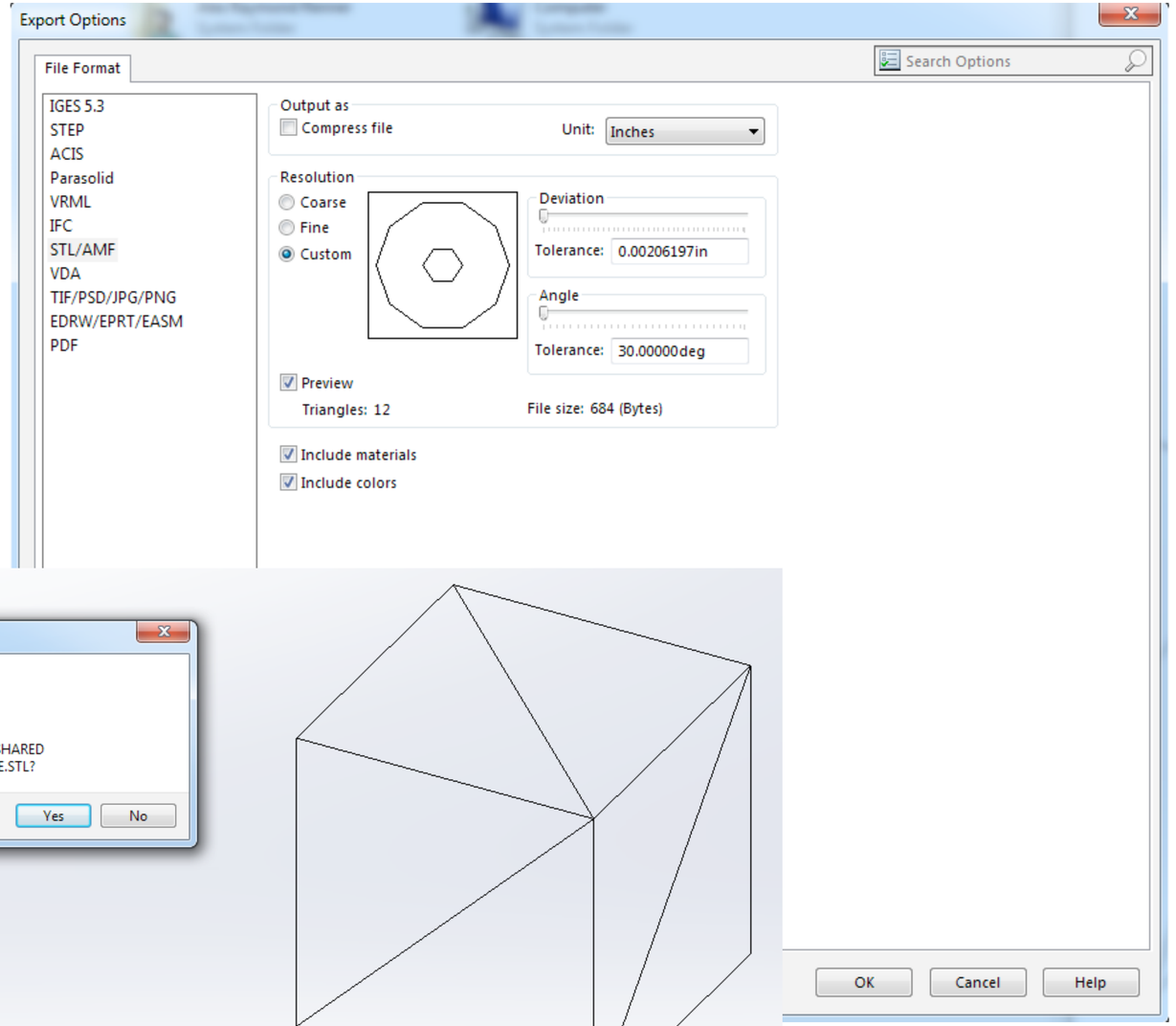
# BREP to STL

- Good converters use BREP surface connections when converting to STL.
- Once exported to STL can you go back to “perfect CAD”?



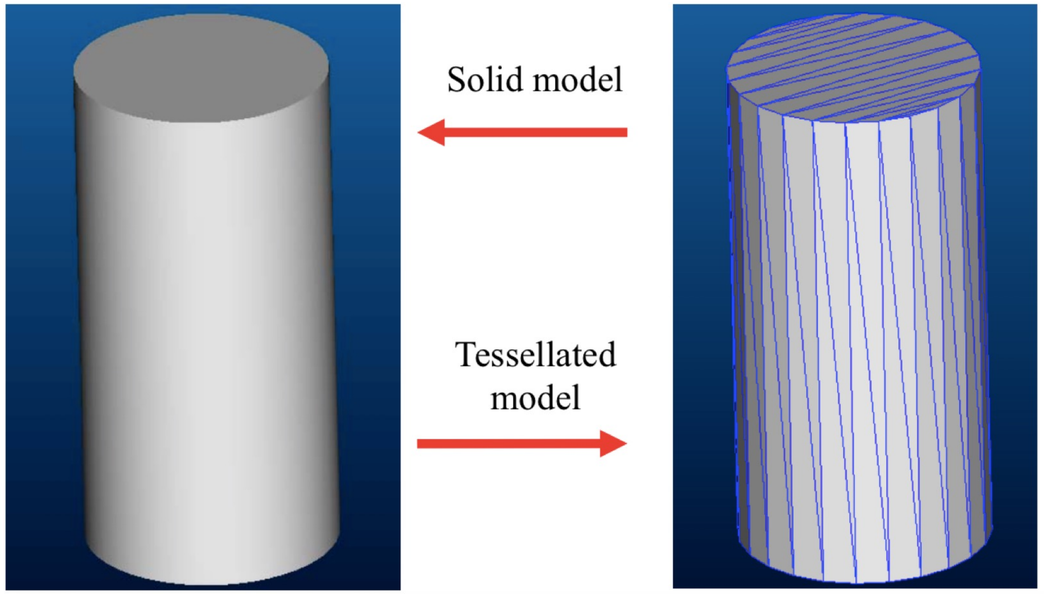
# CAD Export Options

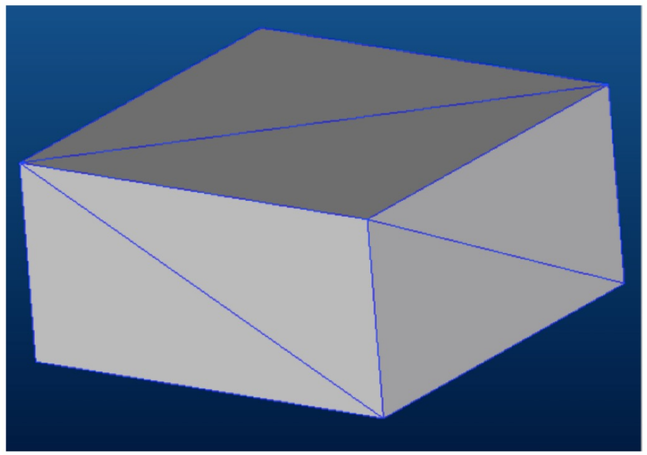
- STL/AMF
  - Mesh 3D model format ISO/ASTM 52900
  - What's do they have in common?
- Export Resolution = CAD Approximation Tolerance
  - Chordal Deviation?
  - Angle Tolerance?



# Tessellation

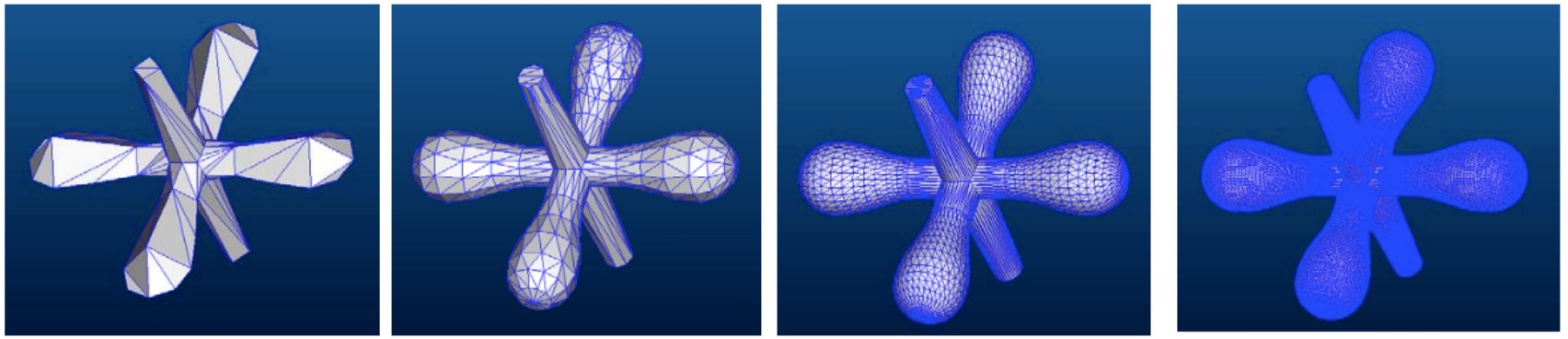
- OBJ, VRML, STL?
- Engineering CAD Settings
- Exporting an approximation
  - Coarse or Fine?
  - Binary or ASCII?
  - Chordal Deviation?
  - Angle Tolerance?



*What is the error for a prismatic part?

# Approximation Error



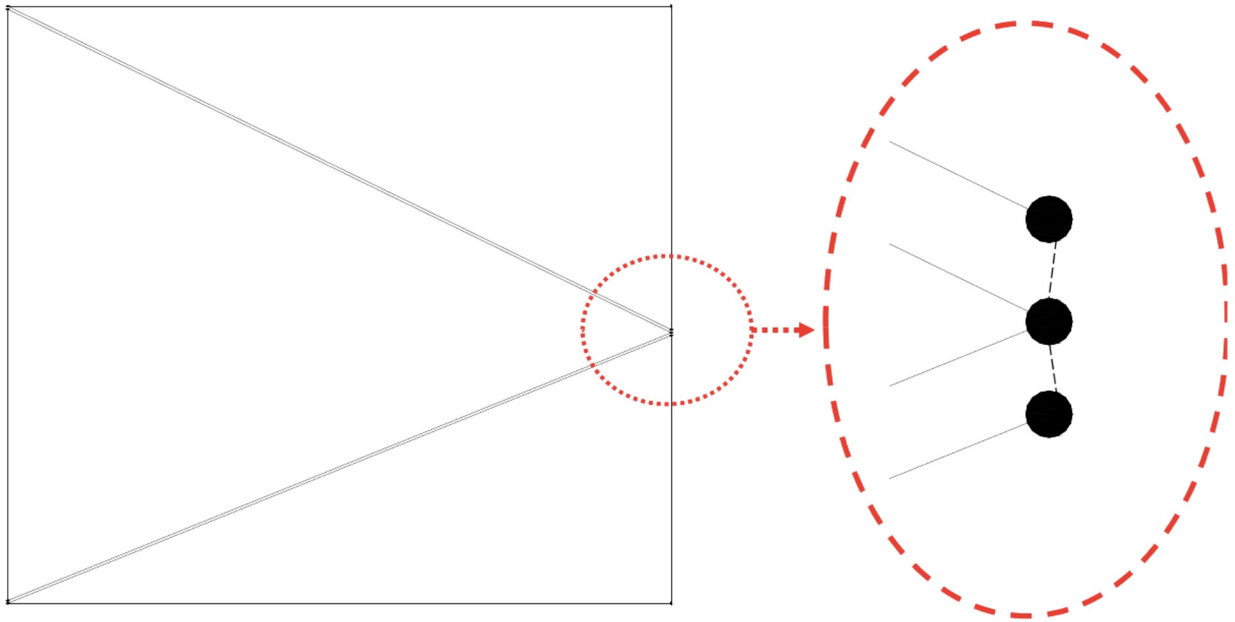
188 facets 728 facets 4,232 facets 35,804 facets

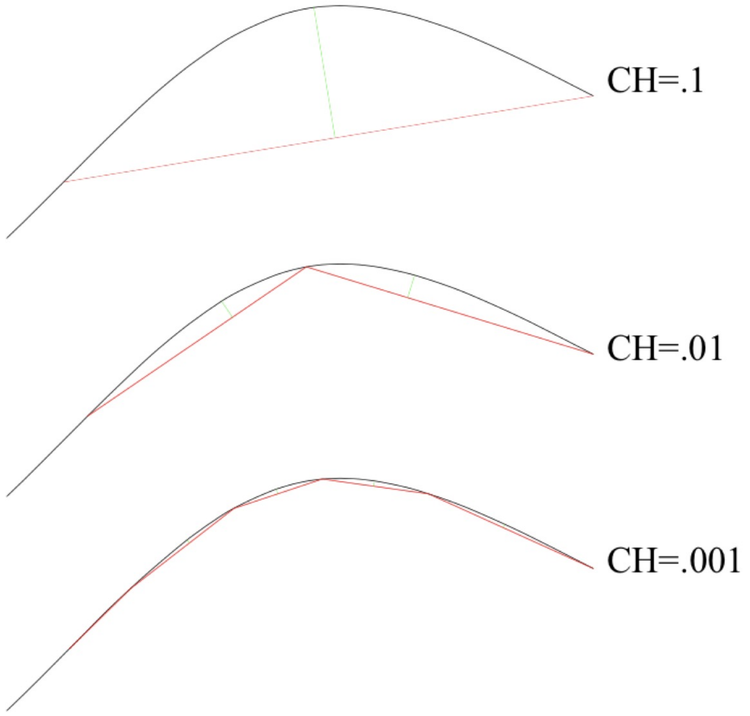
Error

File size (#of facets)

Trade off of error versus file size (number of facets)

# Chordal Deviation and Angle Tolerance





# STL vs. STL 2.0 (AMF)

- Additive Manufacturing Format (AMF) has been called STL 2.0
- May contain additional information such as color, volume, units that some AM machines need
- Fundamental concepts of the STL format are incorporated
- Still under development, could but does not need to replace the STL format

```
<?xml version="1.0" encoding="UTF-8"?>
<amf unit="millimeter" version="1.1" xml:lang="en"><constellation id="0">
    <instance objectid="2922"/></constellation><object id="2922" type="model">
        <mesh>
            <vertices>
                <vertex><coordinates><x>-12.7</x><y>-12.7</y><z>-12.7</z></coordinates></vertex>
                <vertex><coordinates><x>12.7</x><y>-12.7</y><z>-12.7</z></coordinates></vertex>
                <vertex><coordinates><x>-12.7</x><y>-12.7</y><z>12.7</z></coordinates></vertex>
                <vertex><coordinates><x>12.7</x><y>-12.7</y><z>12.7</z></coordinates></vertex>
                <vertex><coordinates><x>-12.7</x><y>12.7</y><z>-12.7</z></coordinates></vertex>
                <vertex><coordinates><x>12.7</x><y>12.7</y><z>-12.7</z></coordinates></vertex>
                <vertex><coordinates><x>-12.7</x><y>12.7</y><z>12.7</z></coordinates></vertex>
                <vertex><coordinates><x>12.7</x><y>12.7</y><z>12.7</z></coordinates></vertex>
            </vertices>

            <volume>
                <triangle><v1>2</v1><v2>6</v2><v3>0</v3></triangle>
                <triangle><v1>6</v1><v2>4</v2><v3>0</v3></triangle>
                <triangle><v1>1</v1><v2>2</v2><v3>0</v3></triangle>
                <triangle><v1>4</v1><v2>1</v2><v3>0</v3></triangle>
                <triangle><v1>5</v1><v2>3</v2><v3>1</v3></triangle>
                <triangle><v1>3</v1><v2>2</v2><v3>1</v3></triangle>
                <triangle><v1>4</v1><v2>5</v2><v3>1</v3></triangle>
                <triangle><v1>7</v1><v2>6</v2><v3>2</v3></triangle>
                <triangle><v1>3</v1><v2>7</v2><v3>2</v3></triangle>
                <triangle><v1>5</v1><v2>7</v2><v3>3</v3></triangle>
                <triangle><v1>6</v1><v2>7</v2><v3>4</v3></triangle>
                <triangle><v1>7</v1><v2>5</v2><v3>4</v3></triangle>
            </volume>
        </mesh>
    </object>
</amf>
```

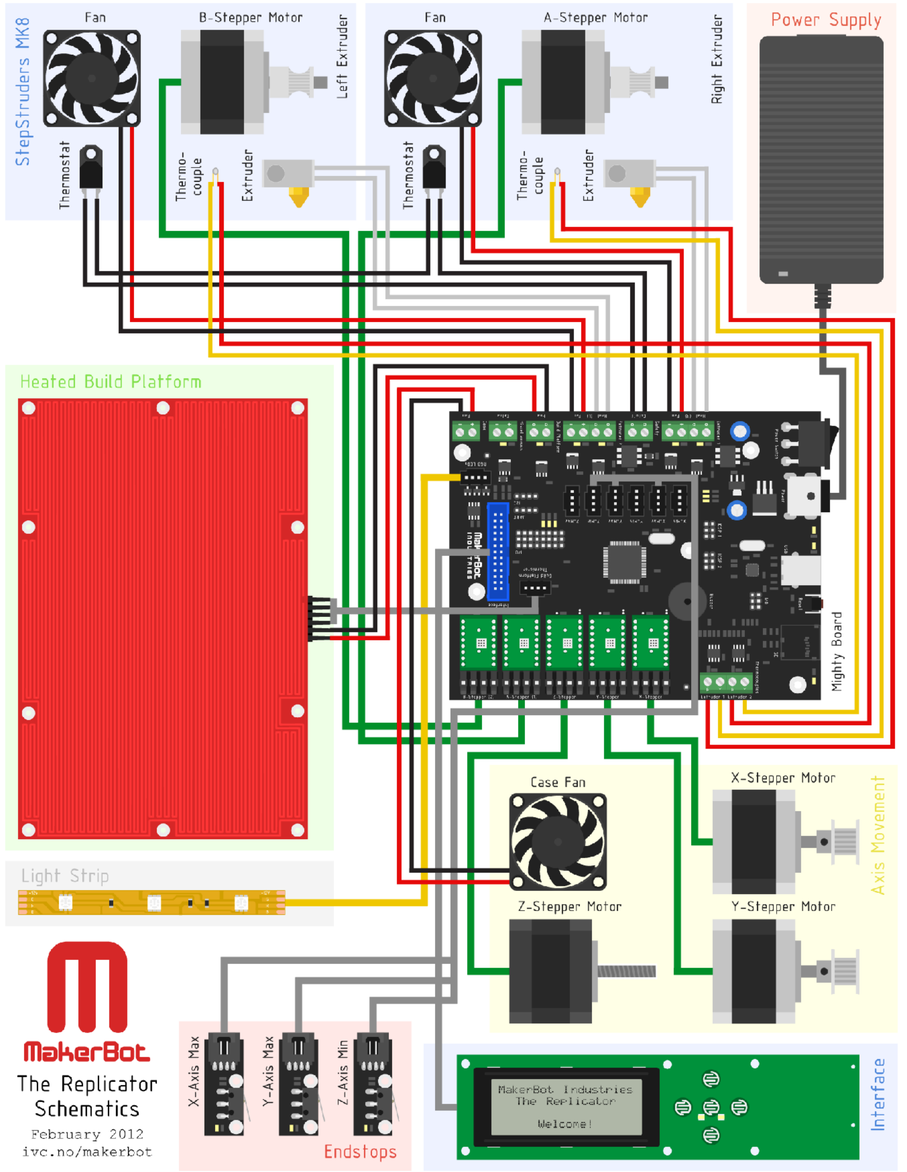
```
solid cube
   facet normal 1.000000e+000 1.365924e-016 0.000000e+000
      outer loop
         vertex 1.000000e+000 1.000000e+000 1.000000e+000
         vertex 1.000000e+000 0.000000e+000 1.000000e+000
         vertex 1.000000e+000 1.000000e+000 0.000000e+000
      endloop
   endfacet
   facet normal 1.000000e+000 1.365924e-016 0.000000e+000
      outer loop
         vertex 1.000000e+000 1.000000e+000 0.000000e+000
         vertex 1.000000e+000 0.000000e+000 1.000000e+000
         vertex 1.000000e+000 0.000000e+000 0.000000e+000
      endloop
   endfacet
   facet normal 0.000000e+000 1.000000e+000 0.000000e+000
      outer loop
         vertex 0.000000e+000 1.000000e+000 1.000000e+000
         vertex 1.000000e+000 1.000000e+000 1.000000e+000
         vertex 0.000000e+000 1.000000e+000 0.000000e+000
      endloop
   endfacet
```

# STL Files: Made for 3D printing

- De-Facto” standard file for RP
- A faceted representation of the boundary of a part, where each facet is a triangle
- Process of creating this representation is called “Tessellation”
- The STL file is an approximation of the surfaces of the part

# Activity/Discussion

- 3D Printer Hardware
  - What type of info might be sent to the machine?
  - What components in the schematic on the right can be removed and why?
  - What's the difference between firmware and software?
  - If you never saw the CAD file, but had the slice files, could you print the part?
  - What type of info might be sent from the machine to the STL file in the software?



# Homework

- Blog post about
  - Why was 3D printing called Rapid Prototyping
  - Why is converting from STL to CAD not possible