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"Barriers to Entry" for Large-Format Additive Manufacturing

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About me

Adam Vescuso Day

Adam Day is a Shop Supervisor at the Autodesk Technology Center Boston, where he empowers resident teams to innovate their design and construction processes using additive manufacturing. Adam has 3d printed projects in a range of scales: from the size of a quarter to a full pedestrian bridge. He also is formally trained and has worked as a landscape architect, wildland firefighter, playground designer, and welder.

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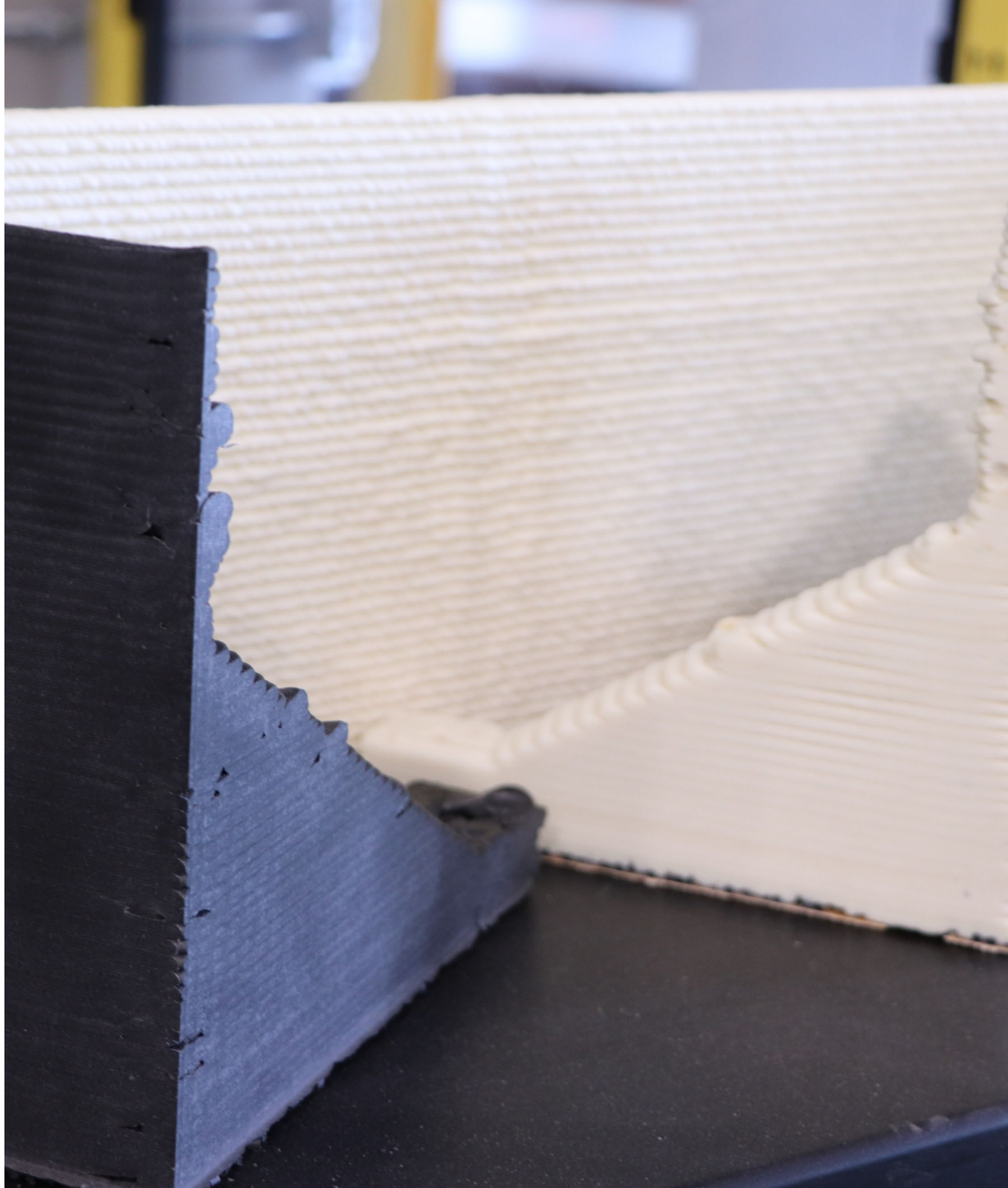
Agenda for today's session

- Intro to LFAM
- Fusion 360 for 3D printing
- Common barriers
- Designing for success
- Required software and equipment

What is not included in todays session.

- Process physics
- Cost analysis
- Troubleshooting
- Metal, sand, concrete, or clay

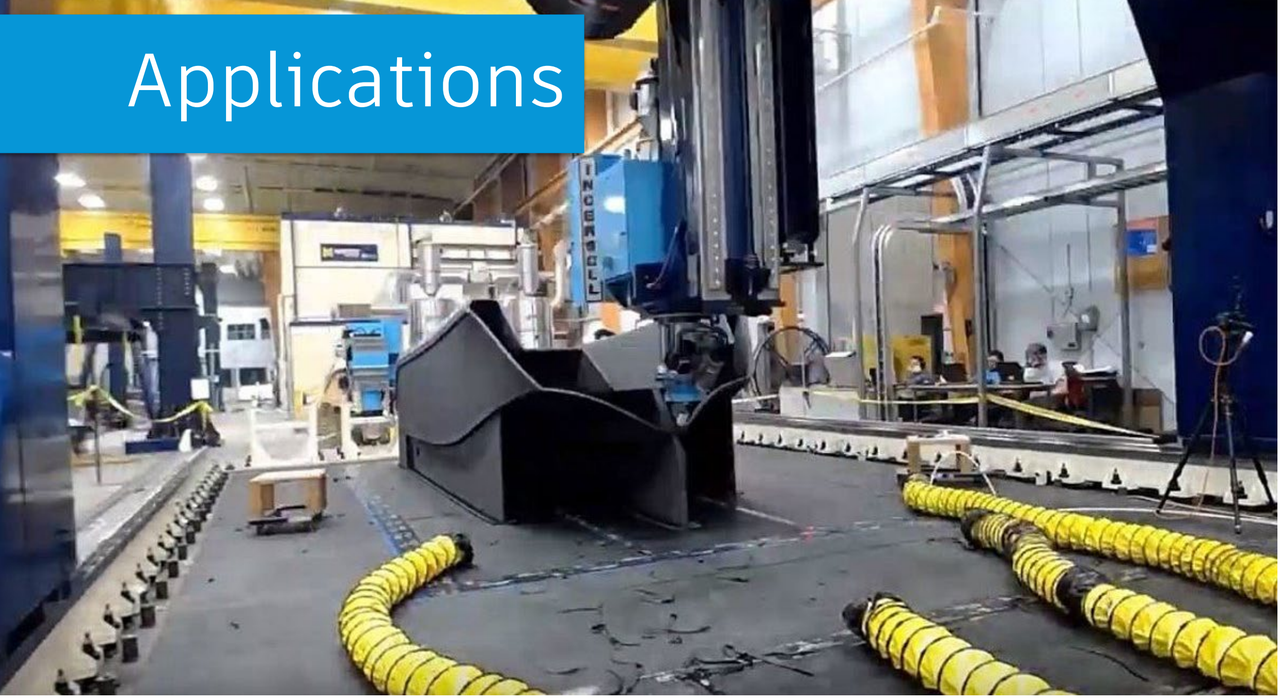


Intro to Large Format Additive Manufacturing (LFAM)

What is LFAM?

Local Motors' Strati – the first 3D-printed car produced by Local Motors – used ORNL's BAAM technology and was unveiled at IMTS in 2014 [Image source]

Applications



University of Maine 3d printed boat [Image source]

Cloud pergola built with the AIBuild system [Image source]

Manufacturing

3Dirigo printed boat- The 5,000 lb boat was 3d printed in 72 hours at the University of Maine and is 25′ (7.62m) long.

Art/Design

Cloud Pergola- part of the 16th International Architecture Exhibition La Biennale di Venezia, is one of the world's largest 3D printed structures.

How is it different from FFF?

- Feedstock
- Throughput
- Extruder design/Material heating
- Support structures/overhangs
- Feature resolution
- Multi axis/hybrid process
- Printing equipment

Feedstock

Pellets not Filament

- Cheaper
- More options
- Easier feeding and drying
- Industrial suppliers like Techmer and Sabic

Throughput

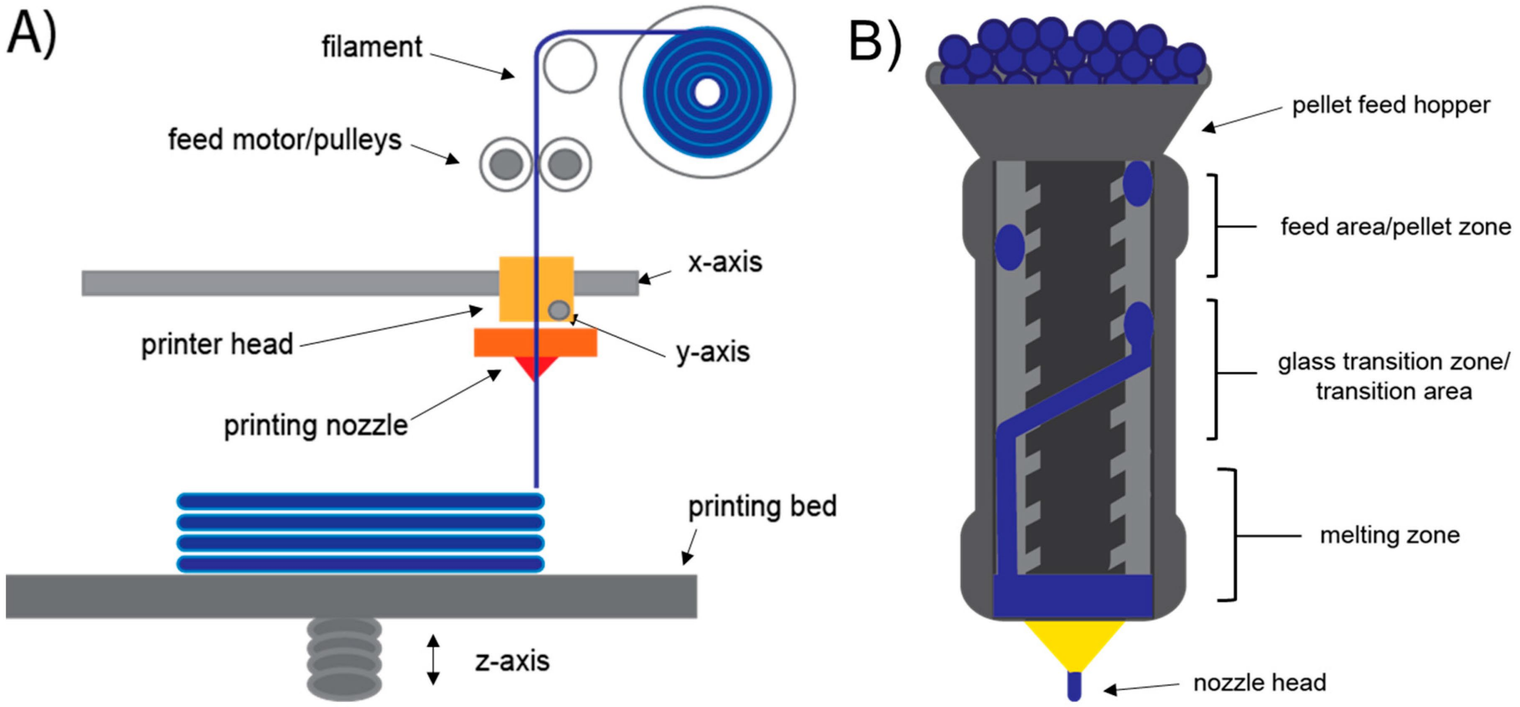
Bigger parts = More material

- Feed rates up to 227kg (500lbs) per hour
- Continuously feeds and dries
- Ability to print parts over 2270kg (5000lbs) without stops to refill material

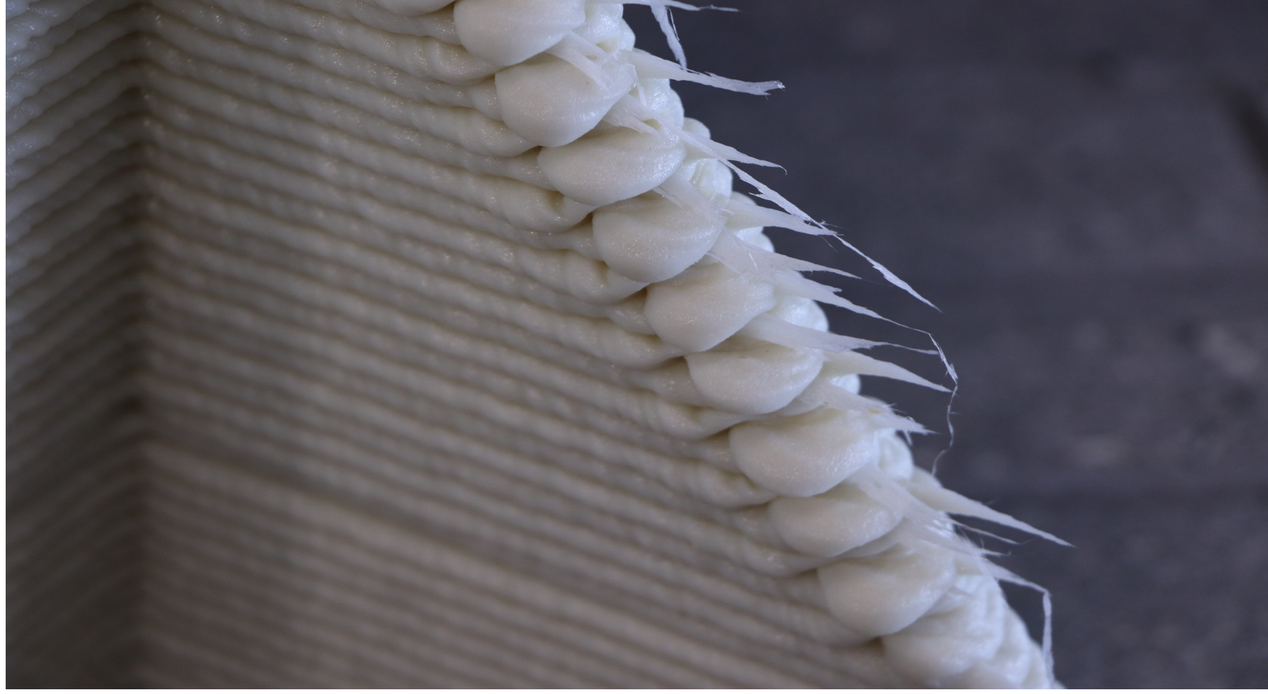
Extruder design/ Material heating

- Heats material faster for higher throughput
- Can process most materials used in injection molding
- Can utilize composite materials with high fiber loads >30%
- Higher thermal mass of bigger layers = slower cooling of layers then desktop prints
- More susceptible to slumping and heat related issues
- Increased stress from the cooling and shrinking can cause warping and delamination between layers.
- More difficult to reheats previous layers do to increased thermal mass
- Multiple heat zones
- Material is under pressure in extruder due to screw design

FFF vs Pellet



Lamm, M.E.; Wang, L.; Kishore, V.; Tekinalp, H.; Kunc, V.; Wang, J.; Gardner, D.J.; Ozcan, S. Material Extrusion Additive Manufacturing of Wood and Lignocellulosic Filled Composites. *Polymers* **2020**, *12*, 2115.



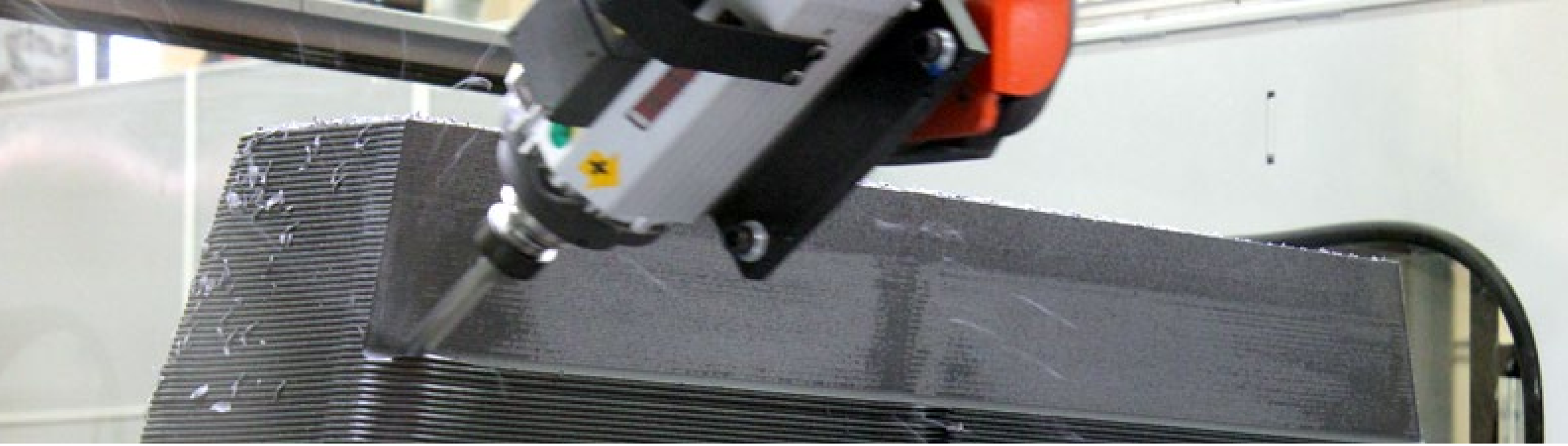
Multihull boat with many overhangs. Courtesy of Moi Composites.

Support structures/overhangs

- Supports are difficult to remove
- Supports use a lot of material
- Small overhang failures can ruin the entire print
- Testing required to determine acceptable overhang
- Dependent on material, geometry, print parameters and re-coat temperature

Feature resolution

- Larger bead width and height
- Cannot create small features
- Choose a nozzle size which will give you a good balance between minimum resolution and print speed
- max height:width ratio is lower than standard FFF
- Tall layers = decreased surface finish



Thermwood LSAM printer trim head. This printer is able to both print and cut in 5 axis [Image source]

Multi axis/hybrid process

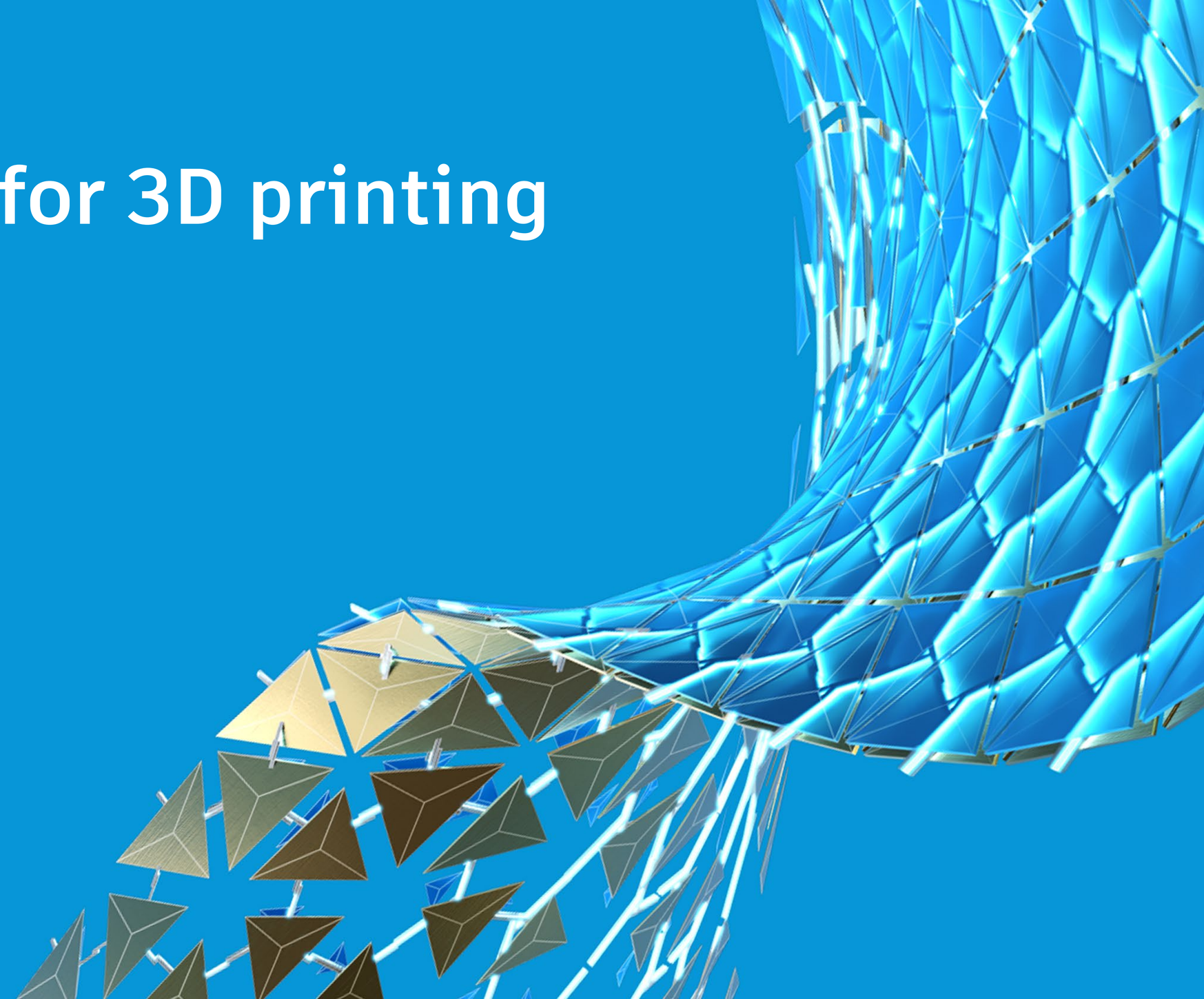
- LFAM machines, especially gantry-based machines are stiff enough for subtractive processes
- Printers based on 6-Axis industrial robot arms already have the capability to do non-planar printing.
- Specialized slicing software is the only thing required to do non-planar or 5 axis printing with a robot arm.

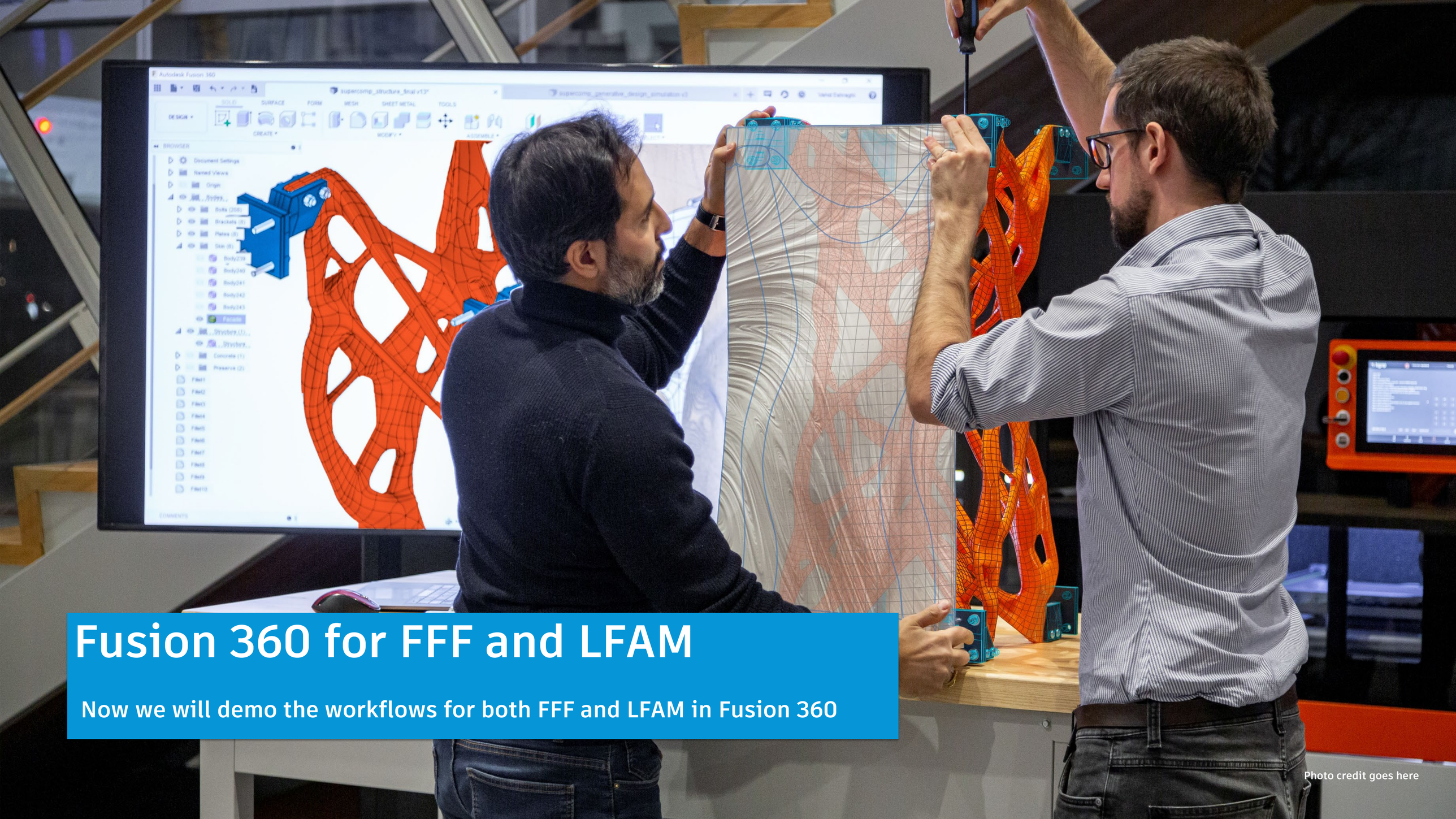
Printing equipment

Major equipment differences between LFAM and Desktop polymer printing:

- Size!
- Desktop scale machines cost $1000 - $50,000
- LFAM machines average cost $50,000 - $2,000,000
- Fully integrated = Higher cost
- Piece build systems = Lower cost
- Lots of separate systems must be combined and integrated to produce LFAM parts.

Fusion 360 for 3D printing



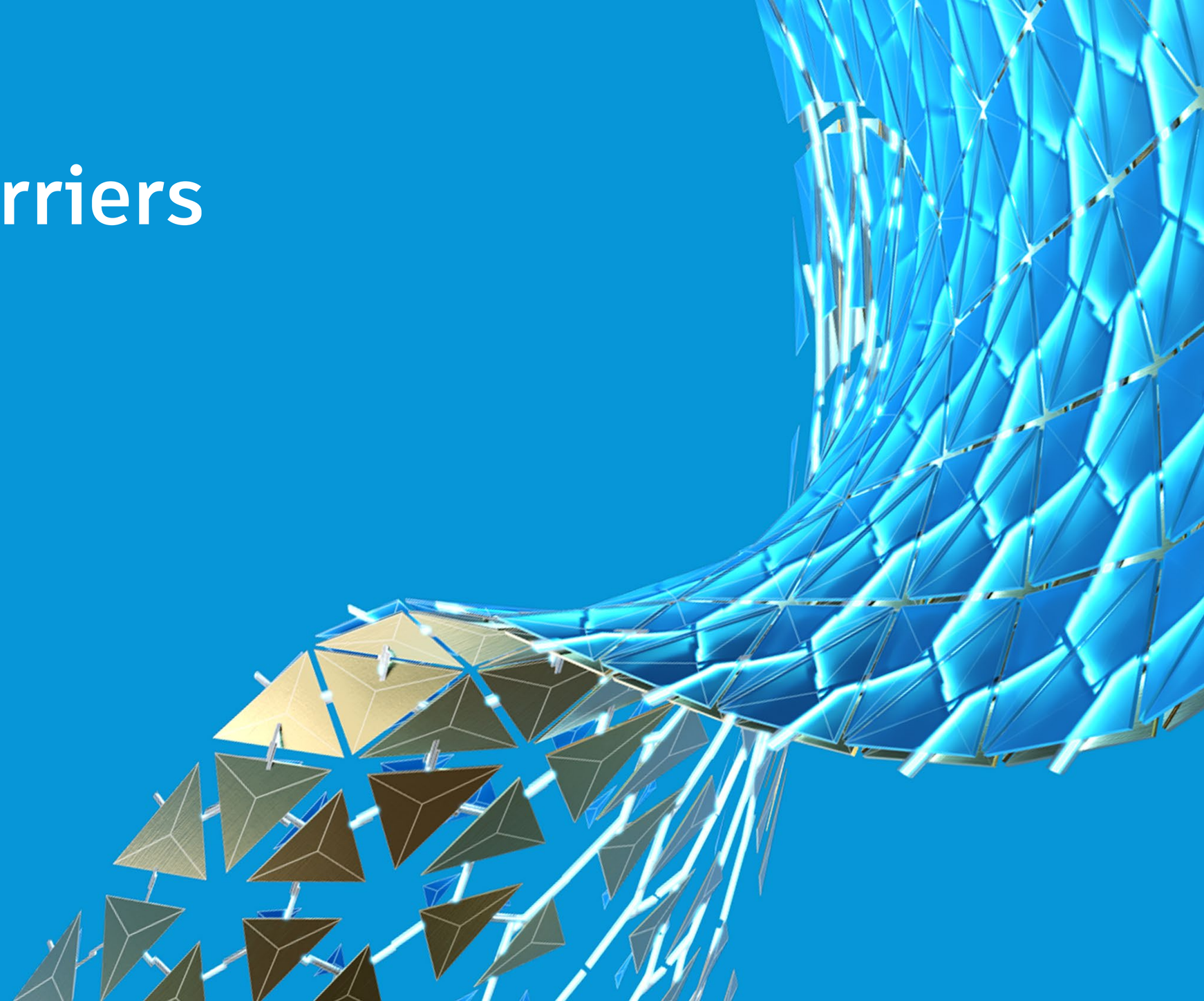


Fusion 360 for FFF and LFAM

Now we will demo the workflows for both FFF and LFAM in Fusion 360

Photo credit goes here

Common barriers



Common barriers

- Warping
- Temperature control
- Layer adhesion/Delamination
- Oozing/Stop and starts
- Poorly dried material

Designing for success

Designing for Polymer LFAM

- Designing for the process you use to build your part is the single best strategy for success for every manufacturing process
- vital when dealing with new processes such as LFAM where designers may not be able to use intuition gathered from previous work

Designing for Polymer LFAM

PART SIZE

The largest factor in determining:

- Extruder size
- Build plate size & type
- Nozzle size & flow rate
- Print time

WALL THICKNESS AND FEATURE RESOLUTION

- Avoid thin walls and small features
- Minimize starts and stops
- Wall thickness should be a multiple of bead width

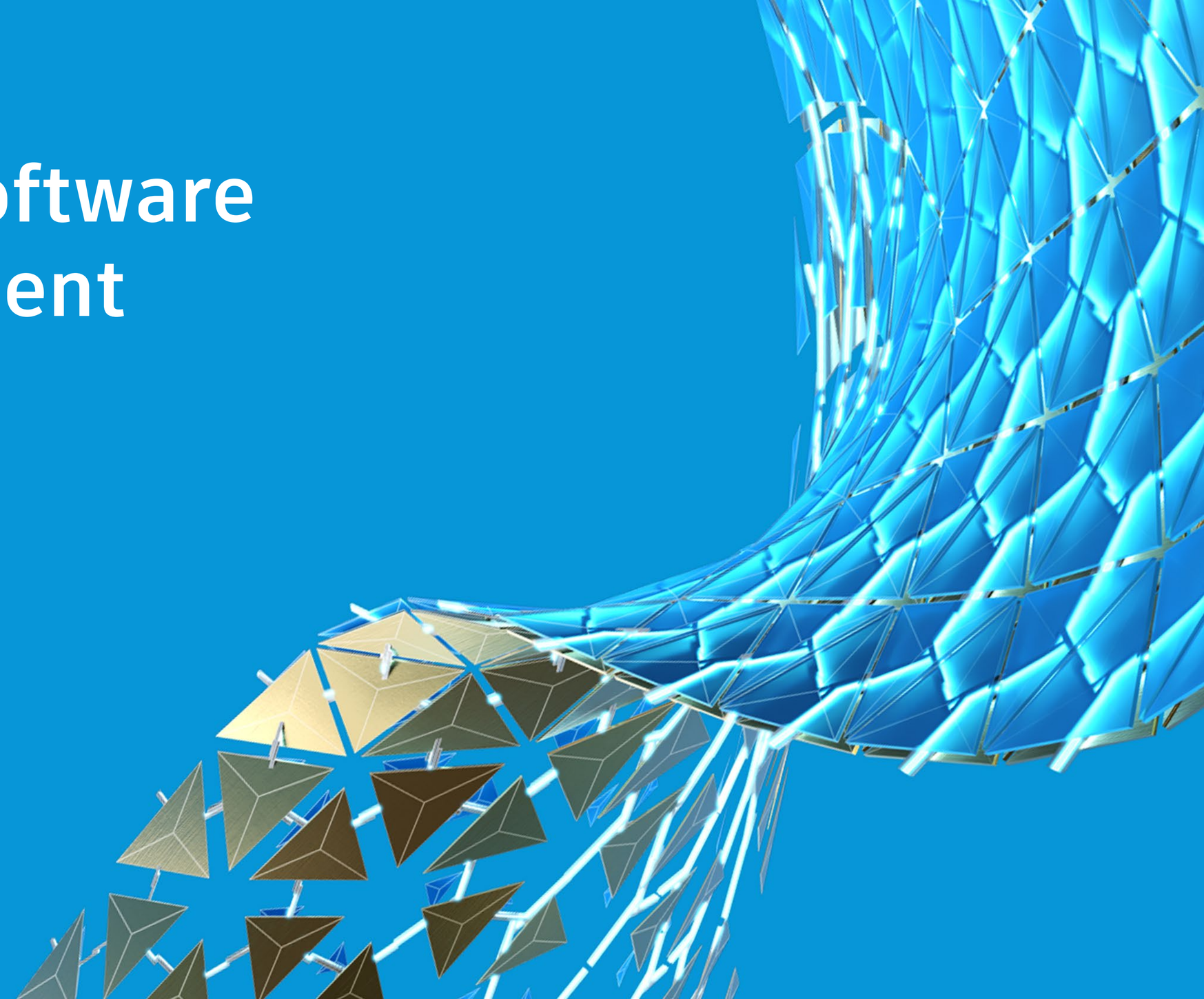
MINIMIZE SUPPORTS AND OVERHANGS

- Support structures are very difficult to remove
- Parts may require post machining.
- Overhangs may be more limited depending on print parameters

ORIENTATION

- Similar to FFF without supports
- Highly anisotropic strength
- Parts may have to be designed so that they can be printed in the orientation that supports the most strength

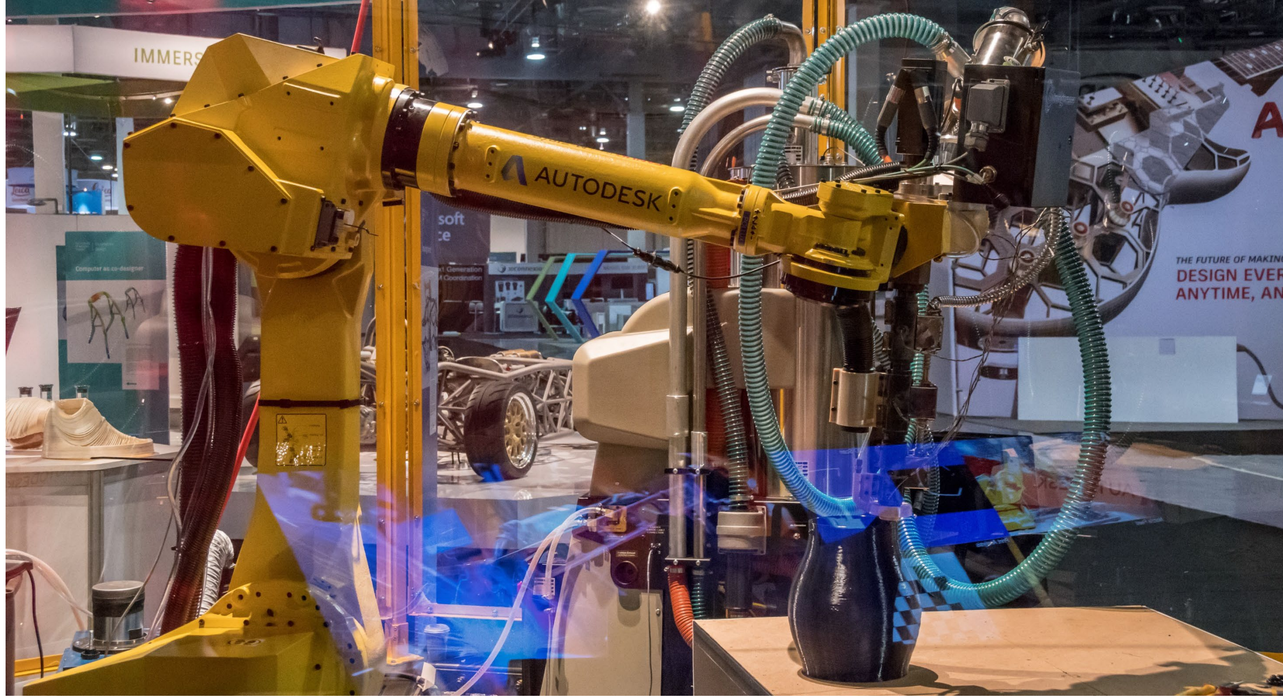
Required software and equipment



Software

- **Slicer**
  - Creates the actual toolpath
- **Simulation**
  - Machine simulation
    - Checks for toolpath accuracy and Safety
  - Process simulation
    - analyze the effects of heating and warping
- **Machine control**
  - Interface with robot or machine

Equipment

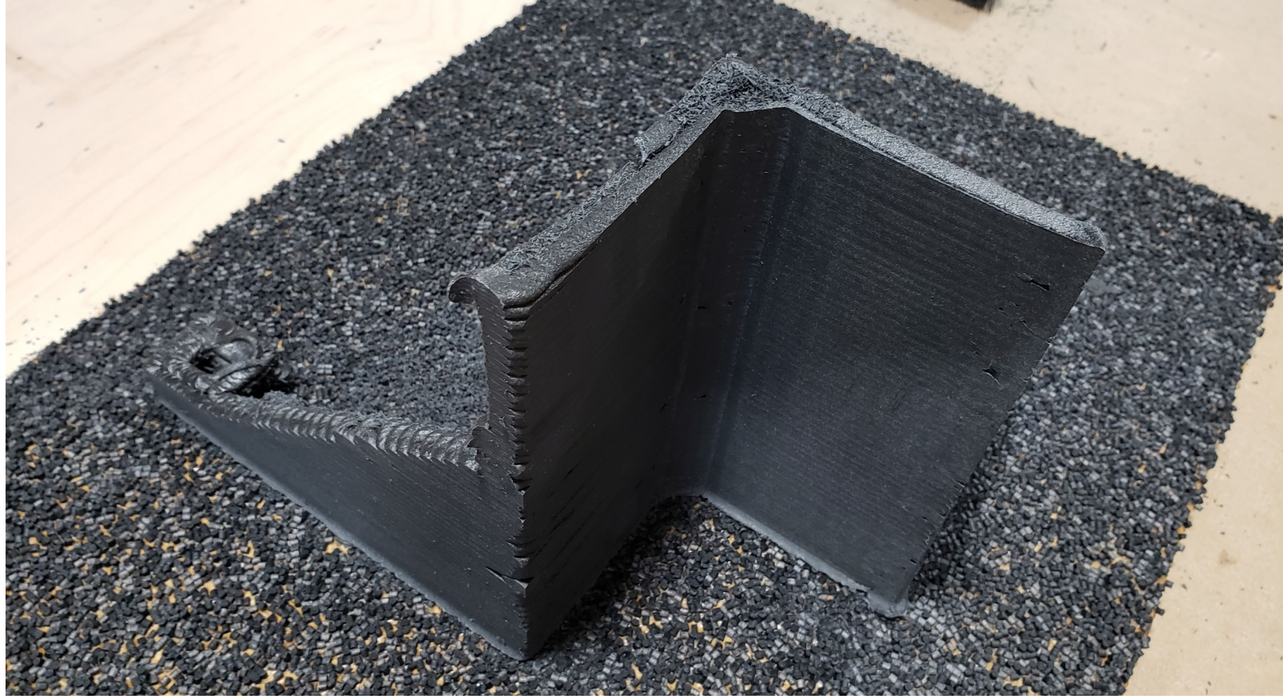


Pellet drying and feeding

- Most LFAM materials will require drying
- Hygroscopic materials like Nylon, ABS, PET, and PC
- All materials require a constant feed to the machine
- Vacuum assisted pellet feed systems are commonly sourced form injection molding industry

Robot/Motion system

- Most common systems are Gantry and 6 Axis arm robot
- Gantry systems are more rigid but only allow 3 axis
- More axis may be added to print head
- 6 axis robots are more flexible but more complicated
- Becoming much cheaper

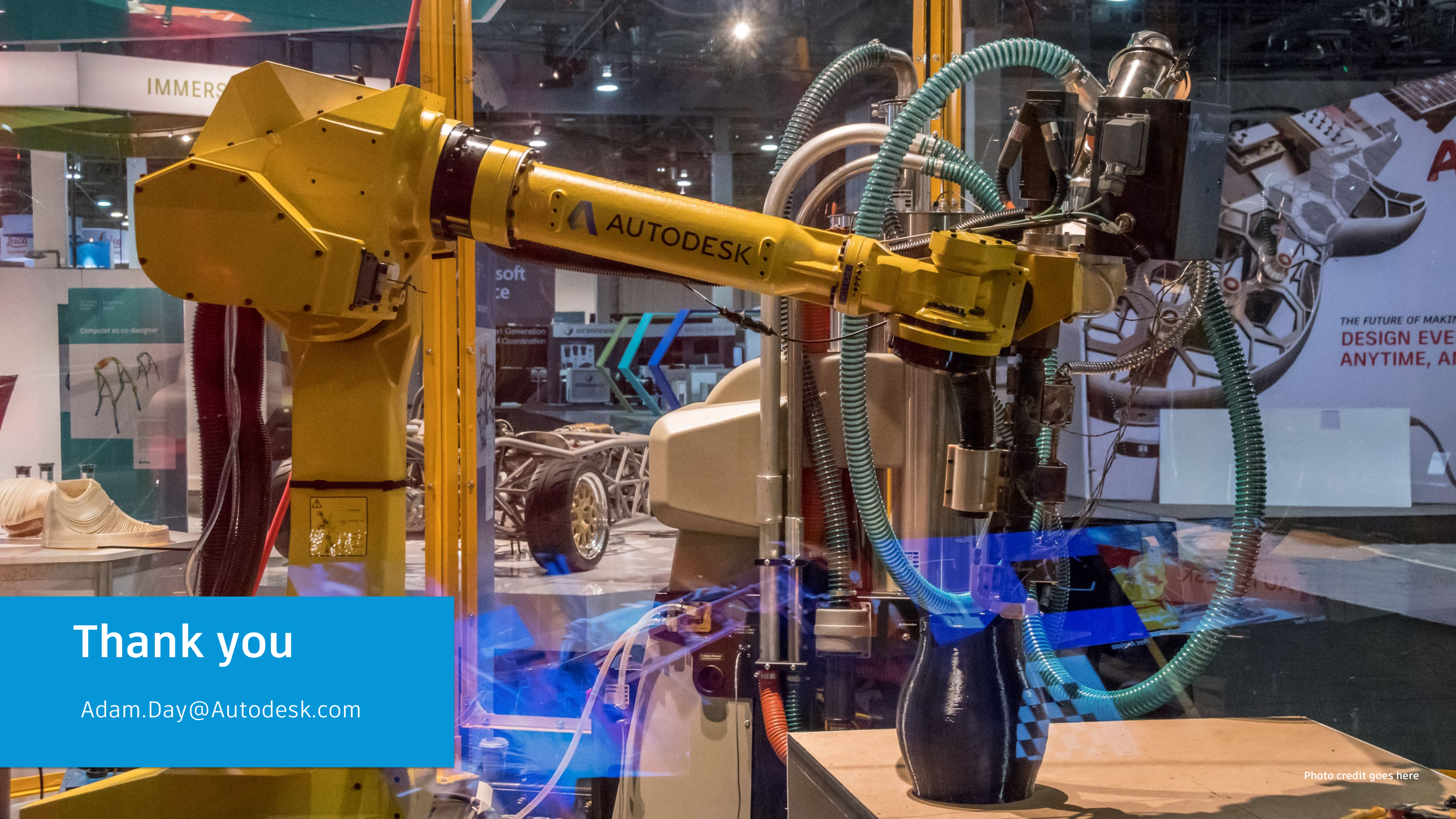


Extruder

The heart of the LFAM system is the extruder. When deciding what extruder to use you should consider a few different factors.

Print bed

The print bed is the literal foundation of the LFAM process. Your options for print bed will largely depend on the size of the parts you are trying to make and the materials you are using.



Thank you

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