INTRODUCTION TO ADDITIVE MANUFACTURING OF THERMOPLASTIC COMPOSITES

CO-HOSTED BY:

Composites Knowledge Network

sampe Canada

compositeskn.org

nasampe.org

YOUR HOST: DANIEL THERRIAULT

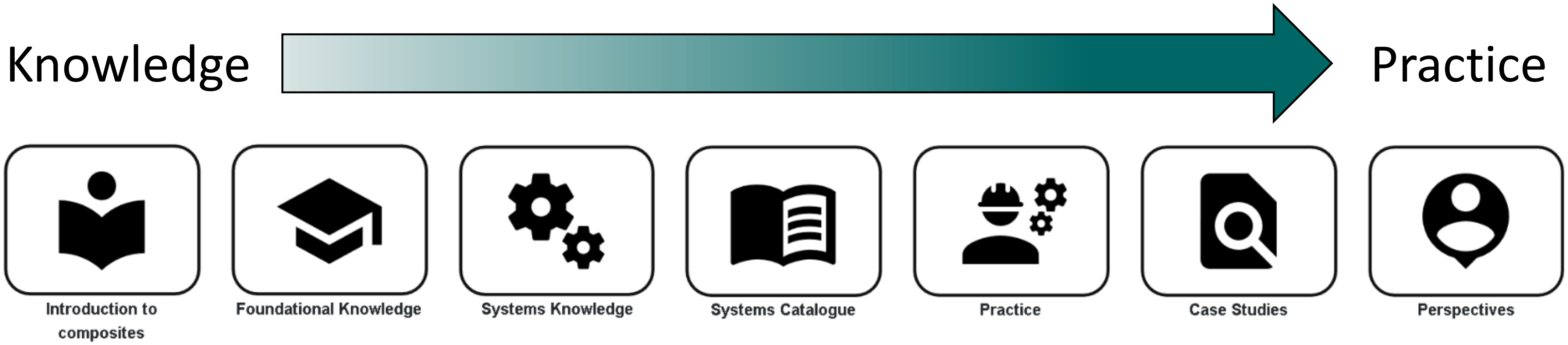
- Grew up in Rimouski, Quebec, Canada
- Bachelor in Mech. Eng. at Polytechnique Montreal
  - Space technologies orientation
  - Exchange at U of Texas at Austin and internship at MDA (formerly EMS)
- M.Eng in Aerospace Eng. at Polytechnique Montreal
  - Structures and materials
  - Internship at Canadian Space Agency
- PhD in Aerospace Eng. at UIUC
  - Supervisor: Prof. S. White (formerly at AAE)
  - Co-supervisor: Prof. J. Lewis (MATSE, now at Harvard)
- 2004 – Prof. at Polytechnique Montreal
  - Co-director of Laboratory of Multiscale Mechanics (LM2)
- 2009 – 2019: Canada Research Chair holder (advanced materials)
- 2012 – 2013: Sabbatical at Bombardier and MDA
- 2018 – 2028: Safran/Polytechnique Chair (FACMO)
- 2022 – 2023: Sabbatical at NCSU & CAMAL

KNOWLEDGE IN PRACTICE CENTRE (KPC)

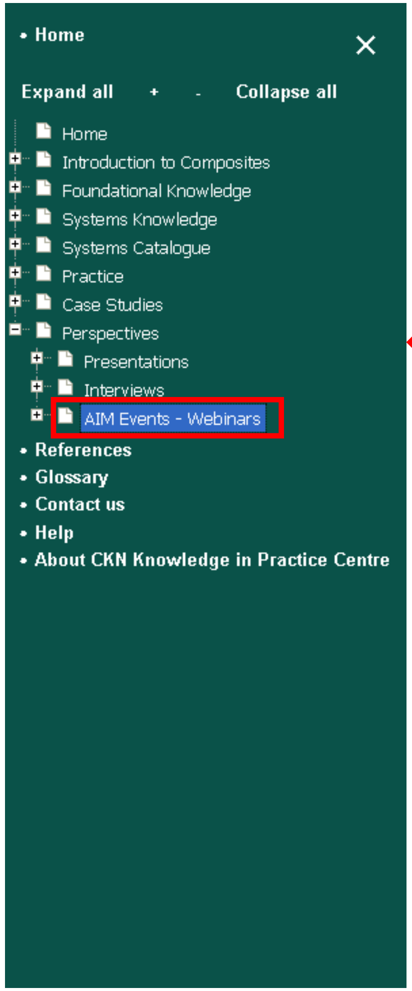
- A freely available online resource for composite materials engineering:

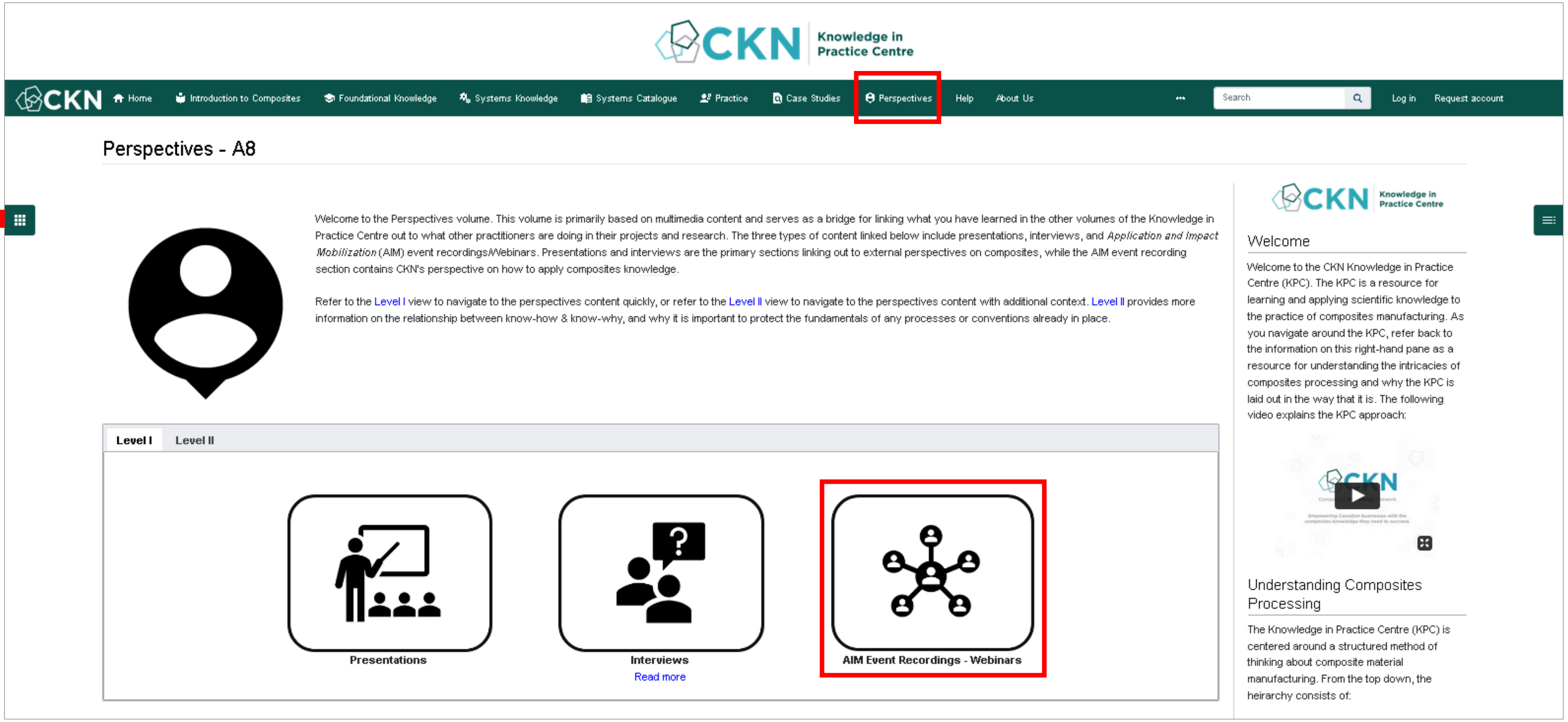
  compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE





Today's Webinar will be posted at:

https://compositeskn.org/KPC/A395

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

TODAY'S TOPIC:

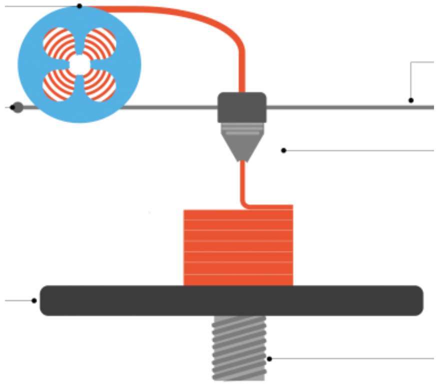
INTRODUCTION TO ADDITIVE MANUFACTURING OF THERMOPLASTIC COMPOSITES

OUTLINE

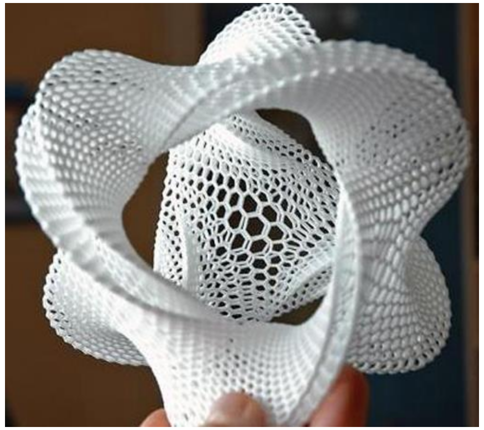
- Introduction to additive manufacturing (AM)
- Introduction to Fused Filament Fabrication (FFF)
  - Case study
- Introduction to Fused Granulate Fabrication (FGF)
  - Case study
- Introduction to Continuous Fiber Fabrication (CFF)
  - Case study
- Circular economy in AM of composites
- Industry questions… and some answers
- Future perspectives

INTRODUCTION TO ADDITIVE MANUFACTURING (AM)

- What is 3D printing?
  - Process of joining materials to fabricate objects layer-by-layer from a 3D model
    - "Fast" manufacturing of pieces, using minimal material and energy
    - Regroups several types of processes (e.g., extrusion, granular sintering or melting, light polymerized)
  - First commercial stereolithography (SLA) printer in 1987
  - Fused Deposition Modeling (FDM) commercialized by Stratasys in 1991

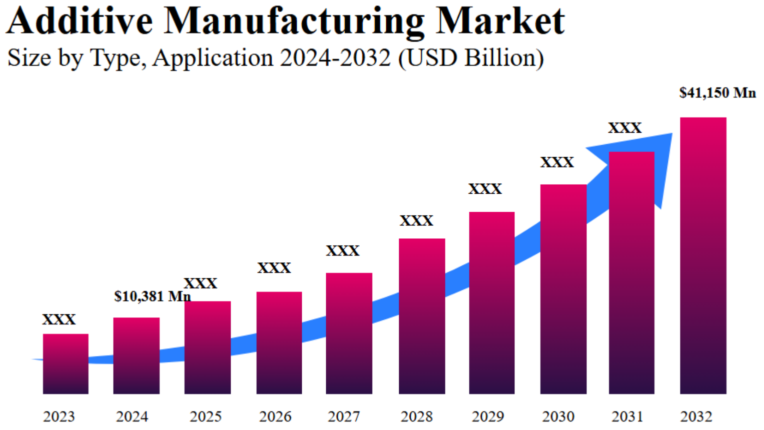


(druckwege.de)

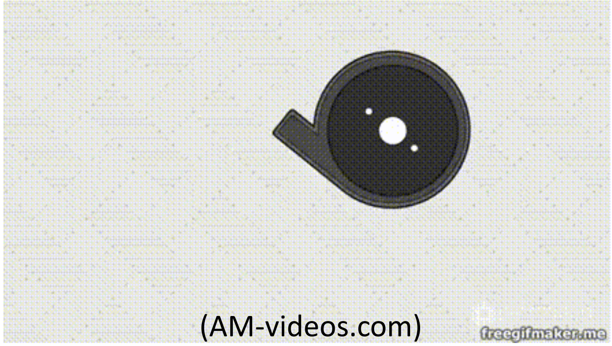


Printing of polymer prototype

Picture of SuperDraco



Growing market[1]



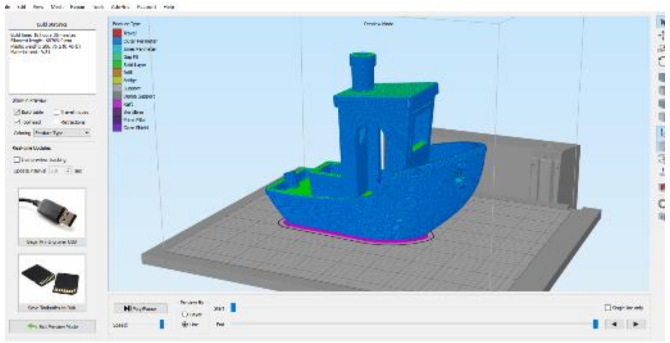
(AM-videos.com)

https://marketresearchcommunity.com/additive-manufacturing-market/

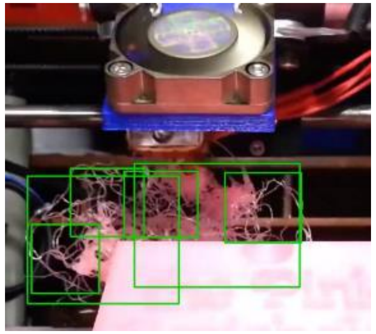
INTRODUCTION TO ADDITIVE MANUFACTURING (AM)

Main components of the AM workflow

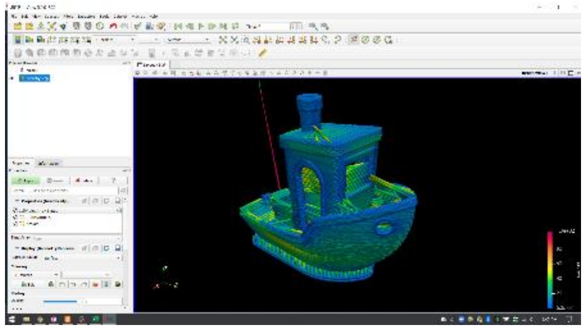
- Computer
  - Draw object in 3D (computer aided drawing - CAD)
  - Define layer-by-layer trajectory (toolpath - using Slicer software)
  - Define printing parameters (head trajectory, temperature, etc.)
  - Manage and monitor the print (*e.g.*, Octoprint, Spaghetti Detective)
  - Post-analyzing (*e.g.*, Paraview)
- Printer
  - Moving stage
  - Printing head or system
  - Control board + firmware (*e.g.*, Reprap)
  - Sensors
  - Solidification system (heat, laser, UV, solvent evaporation, chemical)
- Materials
  - Metals, ceramics, polymers, **composites**
    - Filaments, particles, liquids



Slicing (Simplify3D)



Monitoring quality (Spaghetti Detective)



Analyzing the printing speed (Paraview)

Stratasys Fortus 900mc

Polymer spools for 3D printing

Metallic particles ~20 µm

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

INTRODUCTION TO ADDITIVE MANUFACTURING (AM)

- Metals
  - Now moving into industrial production of aerospace parts
  - Full scale machine technologies are commercially available

- Composites
  - Still at an early stage
  - Limited materials and material properties
  - More R & D is essential before reaching production

Industrial-scale AM for metals (Renishaw 500M)

Example of 3D printed metallic bracket (Airbus)

Closed system

Disadvantages

- Equipment cost: **~400,000 USD**
- Material cost: **~ 500 $USD/kg**
- Single source supplier

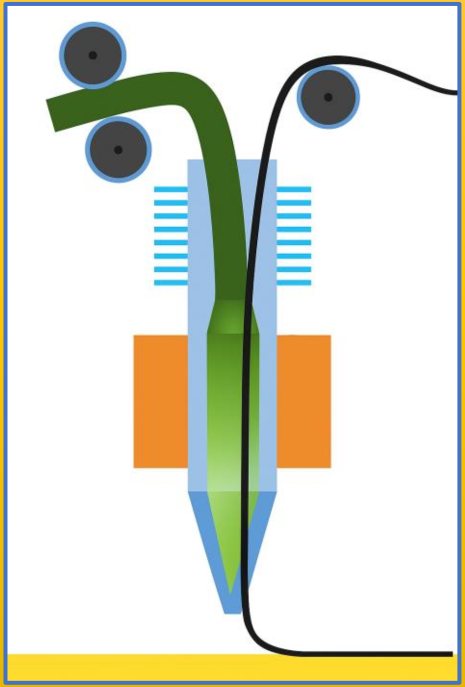
Open system

Advantages

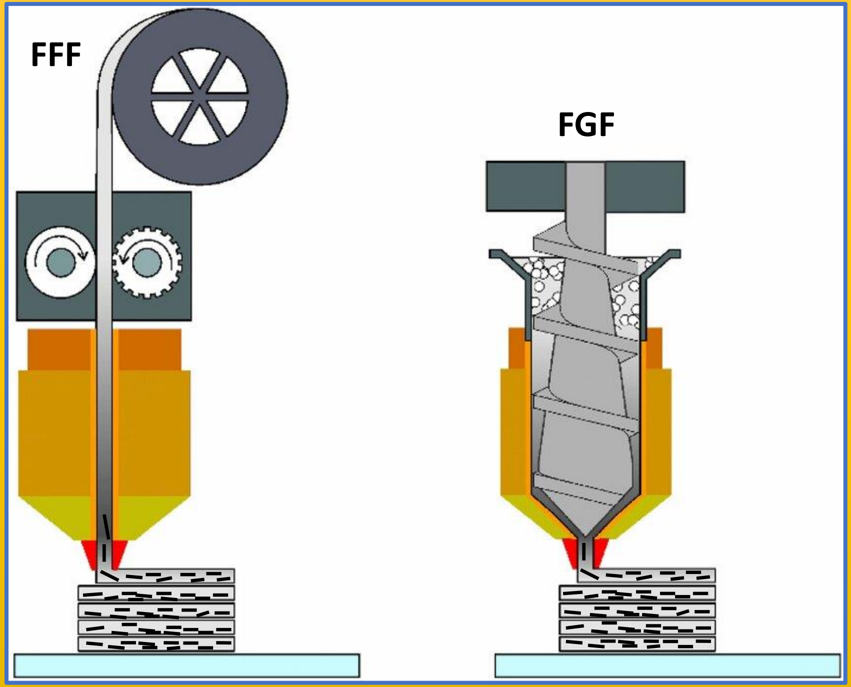
- Equipment cost: ~120,000 USD
- Material cost: **~ 90 $USD/kg**
- Potential multiple suppliers

INTRODUCTION TO ADDITIVE MANUFACTURING (AM)

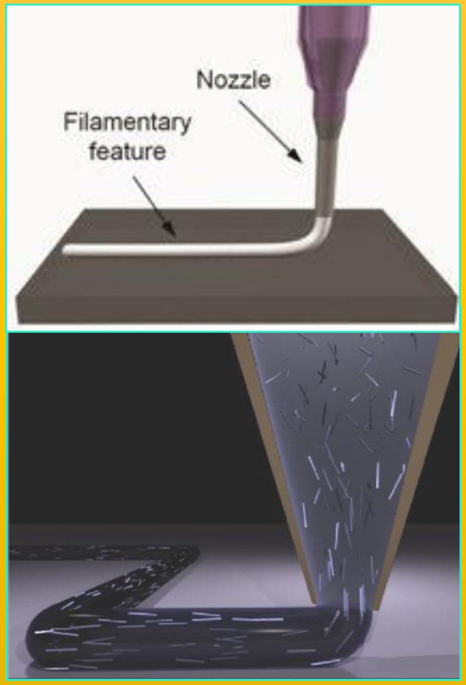
Continuous Fiber Fabrication (CFF)
Continuous fiber

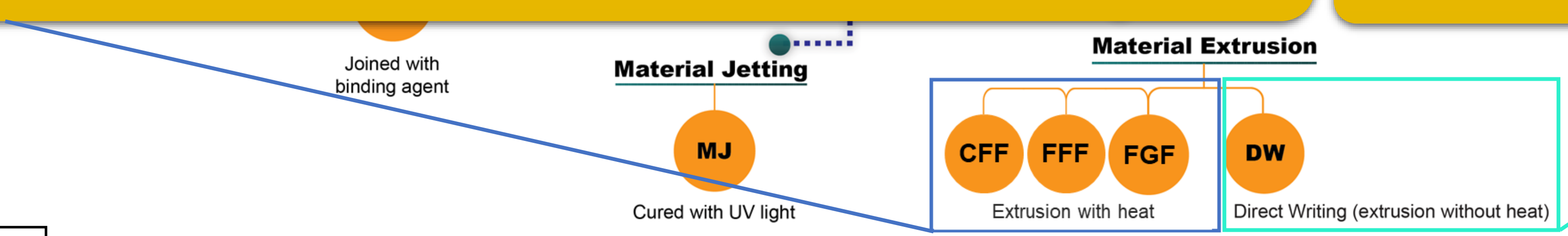


Fused Filament Fabrication (FFF) and Fused Granulate Fabrication (FGF)
Short fiber: milled or chopped



Direct-ink writing (DIW)
Short fiber: milled or chopped

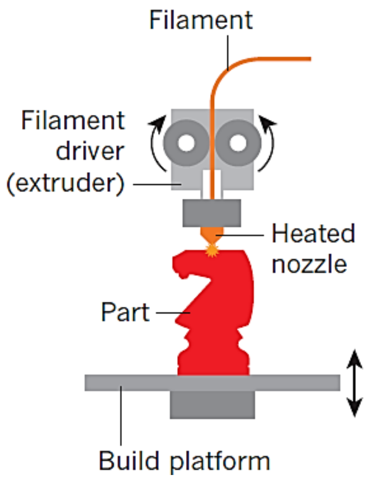




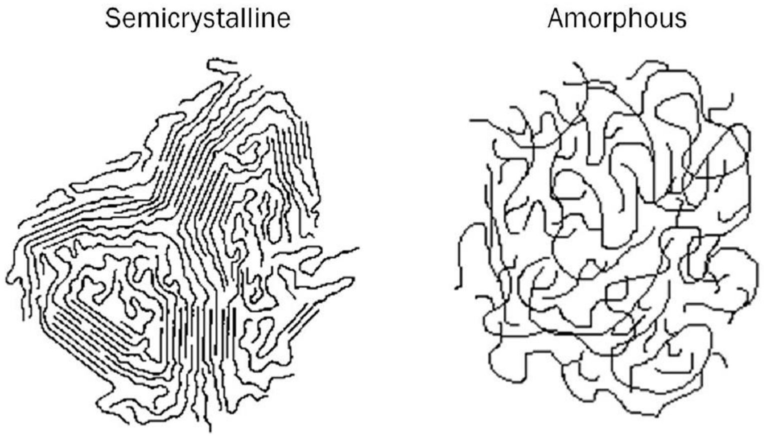
Rafiee et al., Science Advances, 2020.
Gupta et al., Journal of Process Mechanical Engineering, 2025.
Li et al., Journal of Materials Processing Technology, 2016.
Compton et l., Advanced Materials, 2014.

Material extrusion 3D printing of two main types of polymers

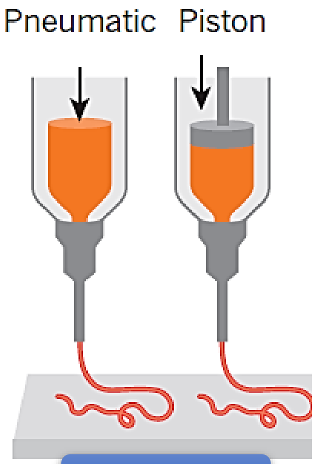
Thermoplastics



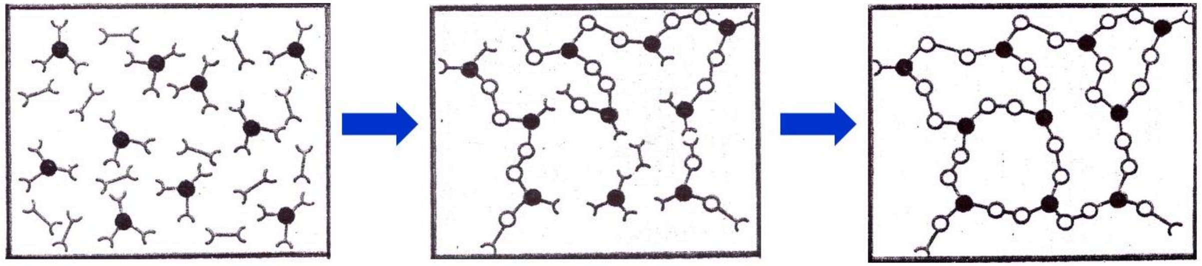
FFF or FGF



Thermosets



DIW



Lewis et al., Nature, 2016.
Polymer innovation blog

Thermoplastics vs. Thermosets

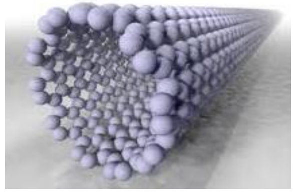
- Solid vs. liquid (room temperature)
- Reversible vs. irreversible curing and processing
- Different properties
- Different viscosity behavior = very important for any process including 3D printing

CHALLENGES TO PRINT COMPOSITES

- Increased viscosity and poor flowability
- Nozzle wear and clogging
- Inhomogeneous dispersion
- Reduced interlayer adhesion
- Thermal and rheological incompatibility
- Surface roughness and dimensional accuracy
- Orientation and anisotropy

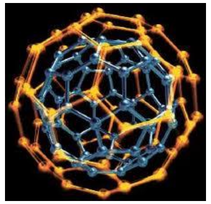
VARIOUS FILLERS FOR COMPOSITES

Size of fillers	Type of fillers	Shape of fillers	Loading of fillers
Nanoscale (1-100 nm) Mesoscale (100 nm – 1 µm) Microscale (1-100 µm)	Metals Ceramic Carbon	1D (fibrous) 2D (platelet) 3D (spherical)	Low to high



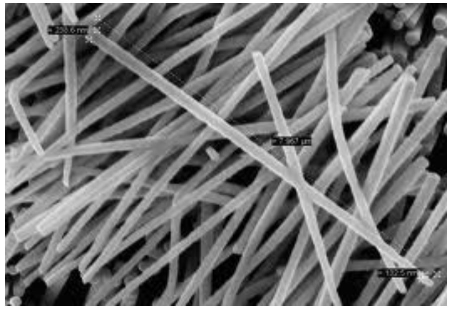
1D (fibrous)

2D (platelet)



3D (spherical)

Glass nanofibers



Nanoglass.com

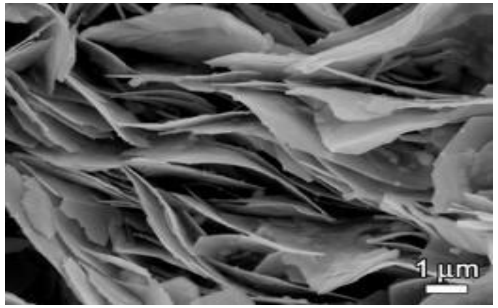
Chopped and milled carbon fibers

m-chemical.co.jp

Continuous carbon fibers

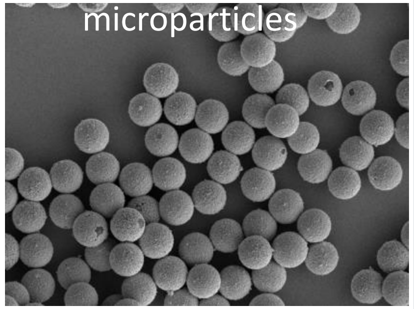
sglcarbon.com

Graphene



jcwinnie.biz

Silver-coated silica microparticles



cospheric.com

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

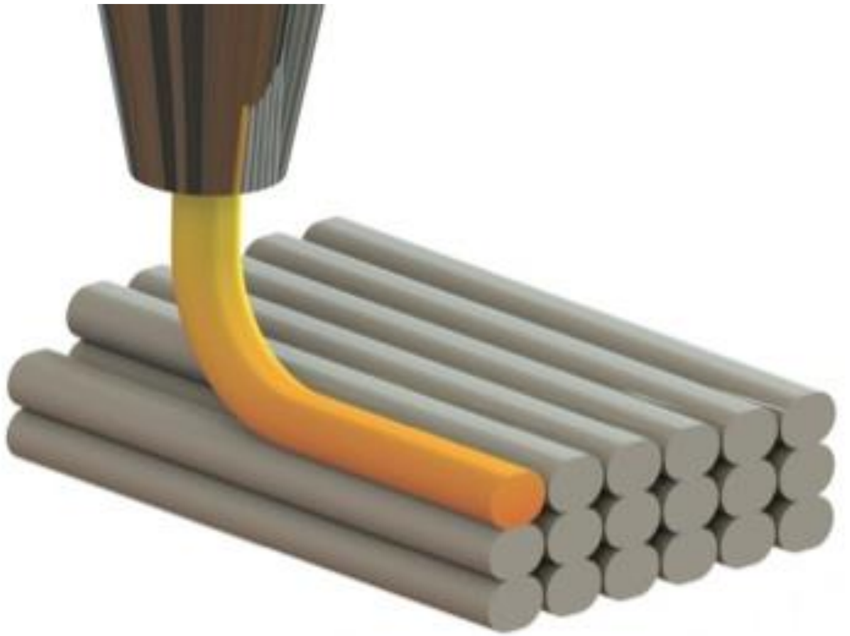
OUTLINE

- Who is Daniel Therriault?
- Introduction to additive manufacturing (AM)
- Introduction to Fused Filament Fabrication (FFF)
  - Case study
- Introduction to Fused Granulate Fabrication (FGF)
  - Case study
- Introduction to Continuous Fiber Fabrication (CFF)
  - Case study
- Circular economy in AM of composites
- Industry questions… and some answers
- Future perspectives

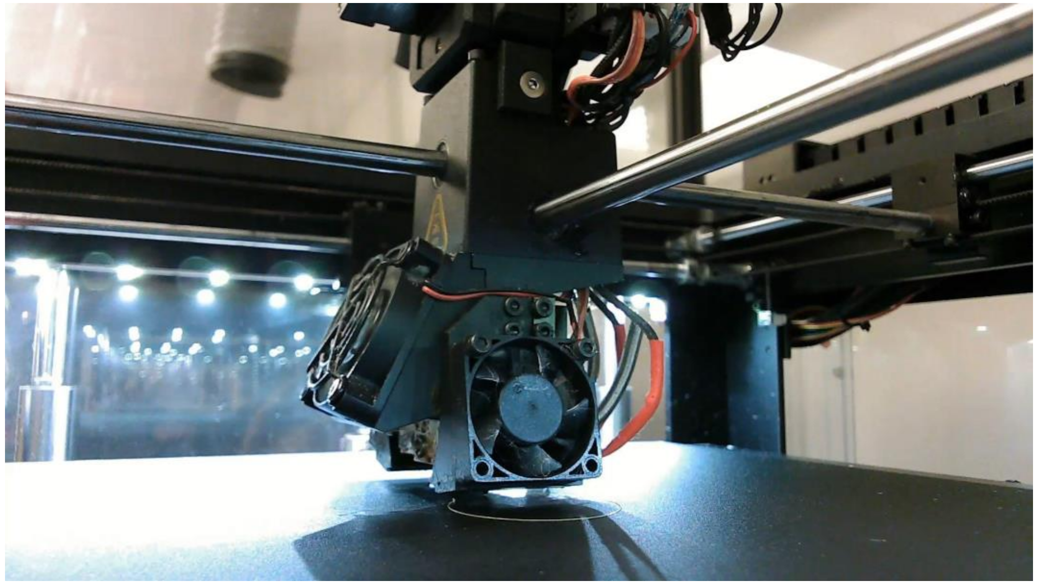
FUSED FILAMENT FABRICATION (FFF)

- Main characteristics
  - Deposition layer by layer of extruded hot filaments
  - Materials: thermoplastics (PLA, ABS, Nylon and many more) and reinforced thermoplastics
  - Main printer manufacturers: Prusa, Ultimaker, Bambulab, Stratasys, etc.
  - Most popular 3D printing method

Prusa MK4 printer

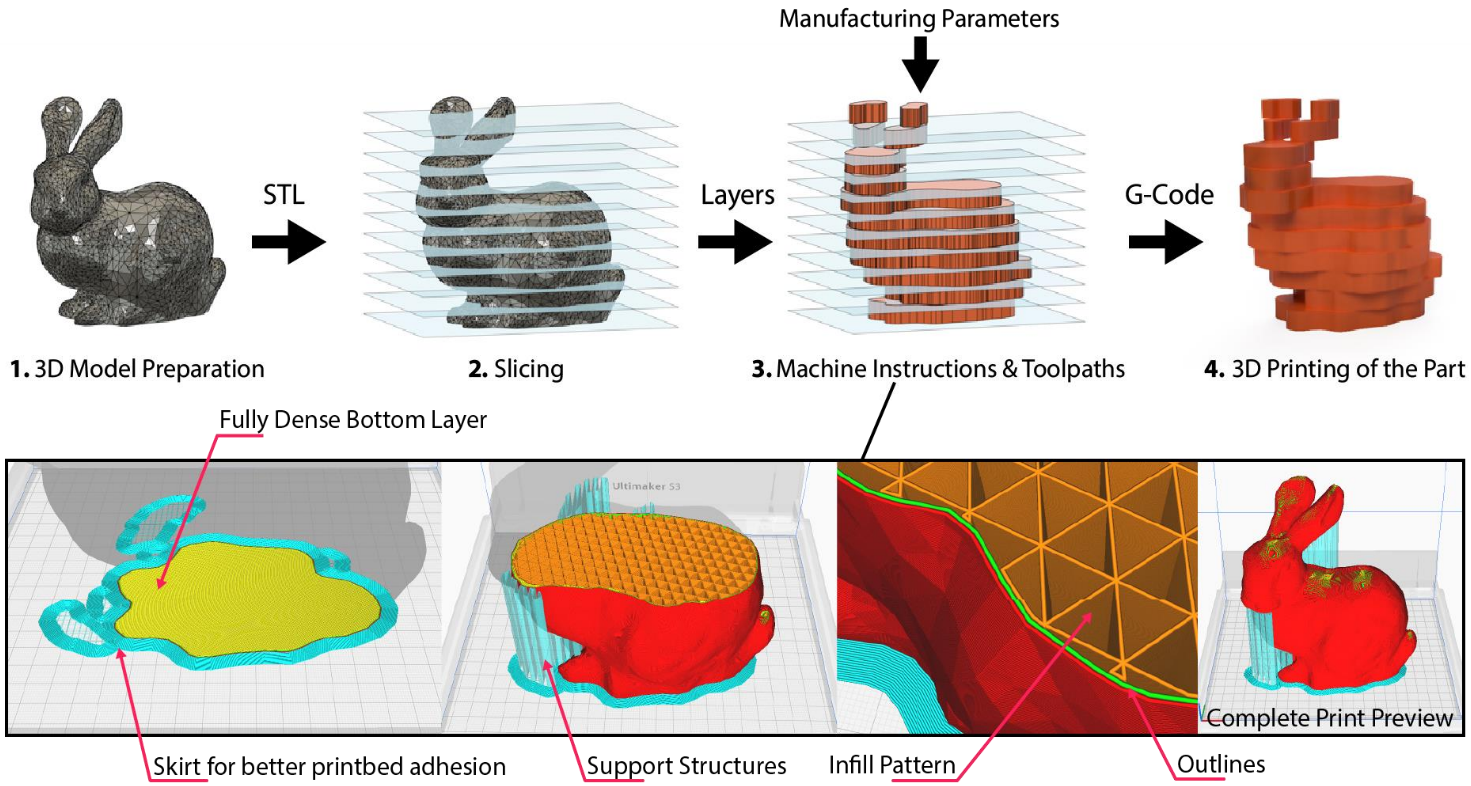


Schematic of FFF process (additive3d.com)



Printing timelapse of a PLA chess part with an FFF Raise3D printer

FUSED FILAMENT FABRICATION (FFF)



Slicing Process from 3D model to G-Code

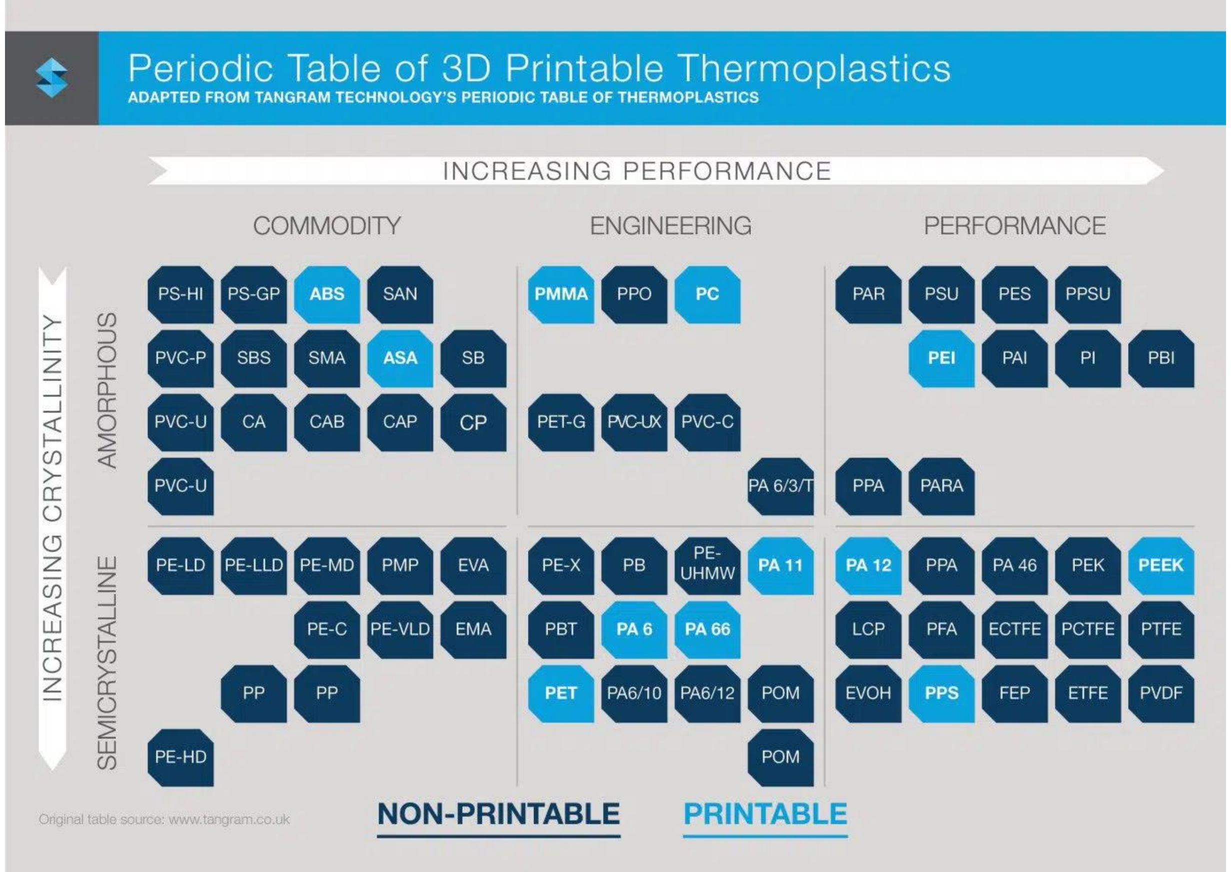
1. Starts with a 3D model in .STL format of the desired part
2. .STL mesh is separated into layers
3. Each 2D cross section is used for toolpath generation
   - Types of toolpaths: Outlines, Infill, Support, Bridging
   - Optimization of the toolpath strategy
   - Process parameters are used to calculate feeds and speeds
4. G-Code file is created for printing

Multliple slicing software available: Cura, Slic3r, Simplify3D, GrabCAD print

G. Chenier et al., Polytechnique Montreal, 2023.

3D PRINTABLE THERMOPLASTICS

2018



2025

- Polypropylene (PP)
- Thermoplastic Polyurethane (TPU)
- Polyethylene Terephthalate Glycol (PETG)
- Polysulfone (PSU)
- Polyethersulfone (PES)
- Polyphenylsulfone (PPSU)
- and many more.

COMMERCIAL AM INFRASTRUCTURE – PROS AND CONS

LOW TEMPERATURE PRINTERS

Bambu Lab XE-1

Prusa XL

PROS

- Basis of commercial and domestic printers
- Compatible with composite material printing
- Compatible with multi-material printing
- Cheap ($2-3k) and flexible
- Fast (e.g., 500 mm/s for PLA - Bambu Labs)
- Open materials and open slicer

CONS

- Small Build Volume: 256 × 256 × 256 mm³
- Maximum nozzle temperature of 320°C
- No heating environment – Room to low temp. (~60°C)
- Not suitable for high temperature materials like PEEK

HIGH TEMPERATURE PRINTERS

Hylo – AON3D

H2- 3DXTECH

PROS

- 250°C heated chamber
- Relatively large build area (450×450×650 mm)
- Maximum nozzle temperature of 500ºC
- Fast printing (500 mm/s for PLA)
- Open materials and open slicer
- Ideal for printing material such as Ultem™ PEI, PPSU, and PEEK
- Improved part strength and dimensional stability
- Print large parts or multiple small parts

CONS

- Not suitable for nonplanar parts
- Not YET suitable for multi-process

LARGE-SCALE INDUSTRIAL PRINTERS

Stratasys F3300 printer

PROS

- High temperature heated chamber (value unknown)
- Relatively large build area (600×600×800 mm)
- High temperature nozzle (value unknown)
- Fast printing (value unknown)
- Ideal for printing Ultem™ PEI, PC and Nylon
- High quality of printed parts

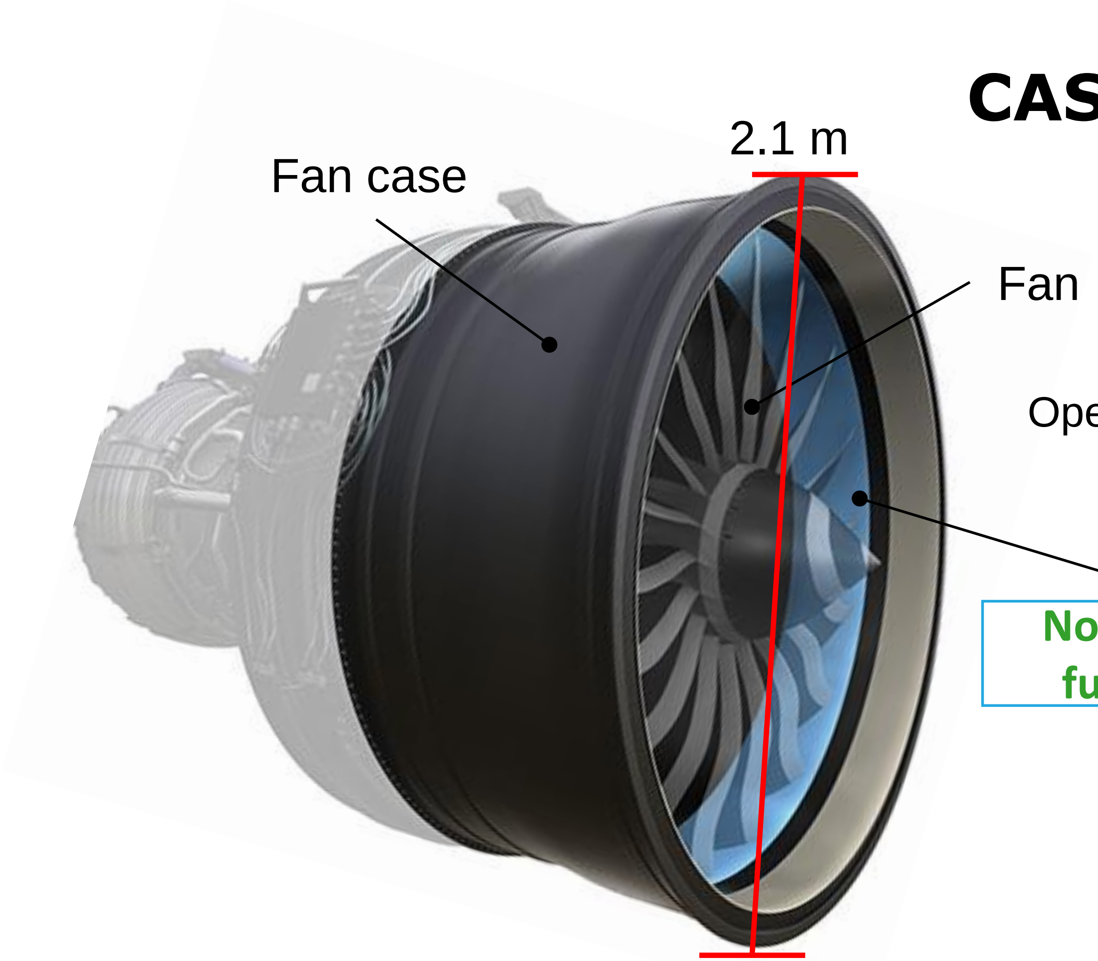
CONS

- Proprietary materials and slicer = CLOSED SYSTEM
- Not suitable for nonplanar parts
- Not YET suitable for multi-process

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

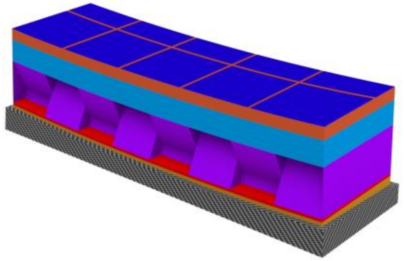
CASE STUDY



Operating temperature

0 - 500 °C

Noise reduction functionality?



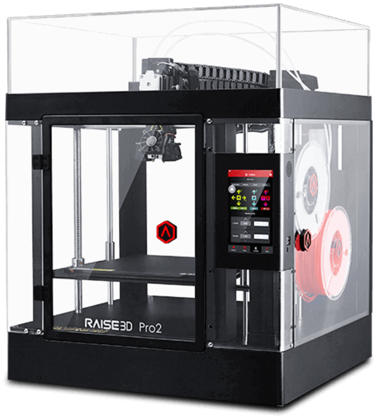
https://youtube.com/shorts/G6aLRk6LvOw?si=xmxovICN356zDaaO

- Design criteria and requirements
  - Materials to be **resistant to high temperatures**
  - To print on a **non-planar complex surface** of the fan case
  - **Reasonable production time**
  - **Multifunctionality**: abradability, acoustic, lightweight, moderate heat resistant
  - **Multi-material**: thermoplastic composites and abradable thermosets

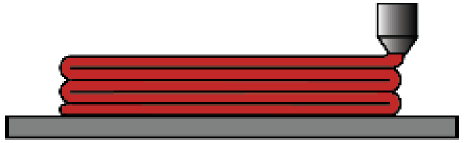
HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

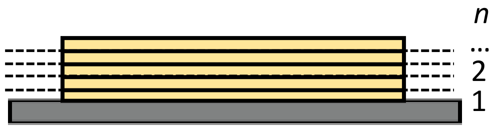
PROBLEM IDENTIFCATION AND SOLUTION



Raise3D FFF 3D printer



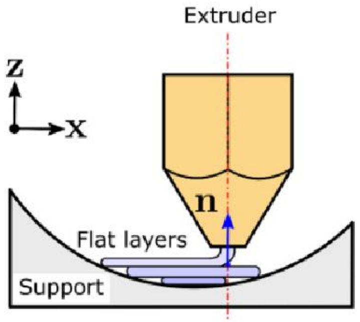
3-axis of freedom



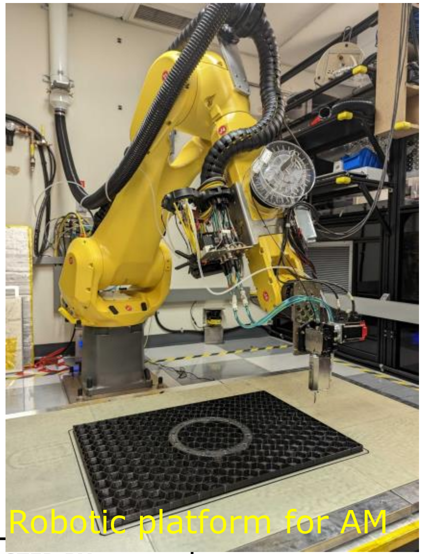
Flat layers in planar slicing

Pros
- Simple to operate

Cons
- Typically for small-scale applications
- Limited conformal printing
- Staircase effect

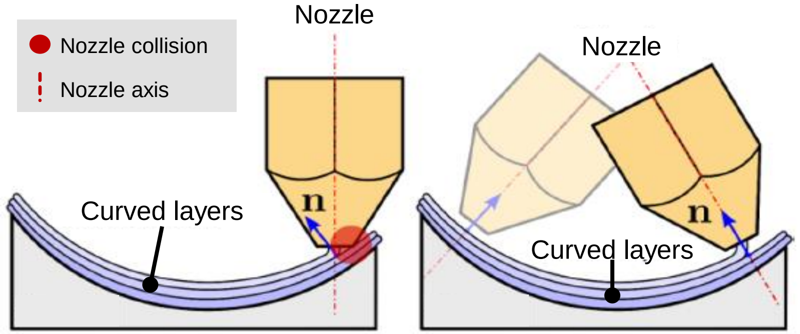


Stacking of flat layers[1]



Pros
- Suitable for large-scale builds
- Non-planar or conformal printing
- High control over nozzle and filament orientations

Cons
- Complex toolpath programming
- Higher system inertia



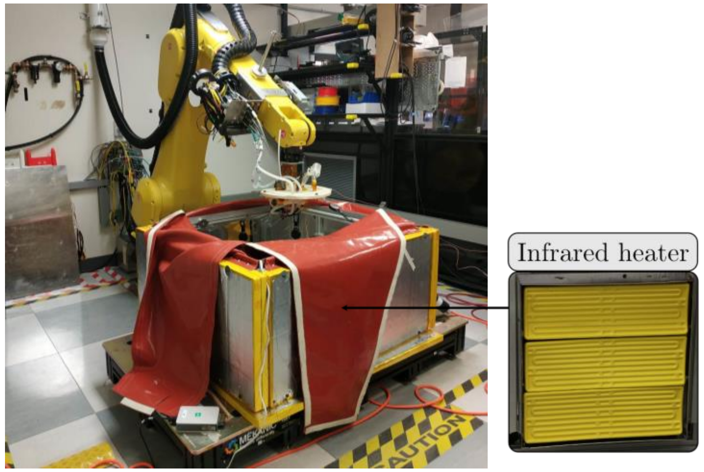
Conformal printing with and without collision[1]

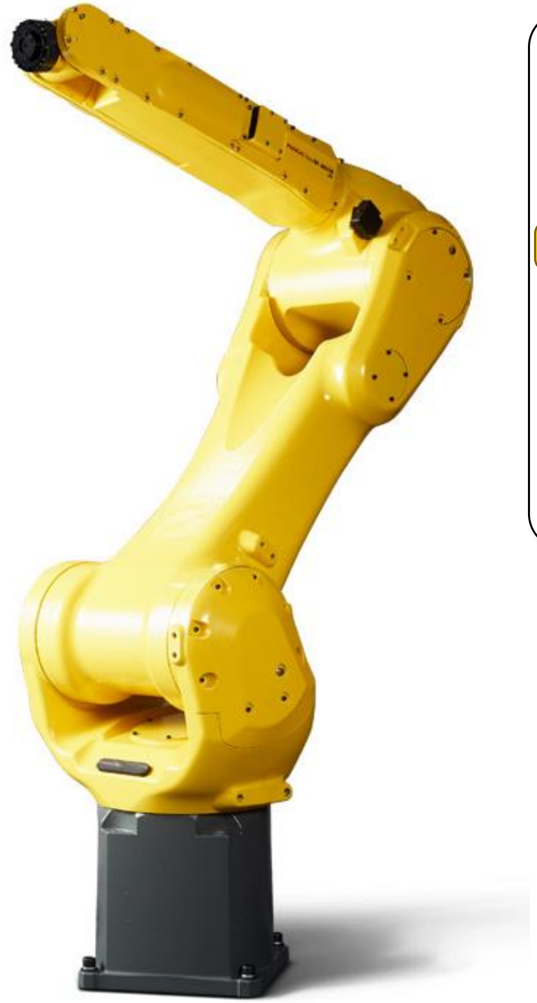
1. Adapted from Chen et al., 2019.

SOLUTION: ADAPTING 6 DOF OF ROBOT ARMS

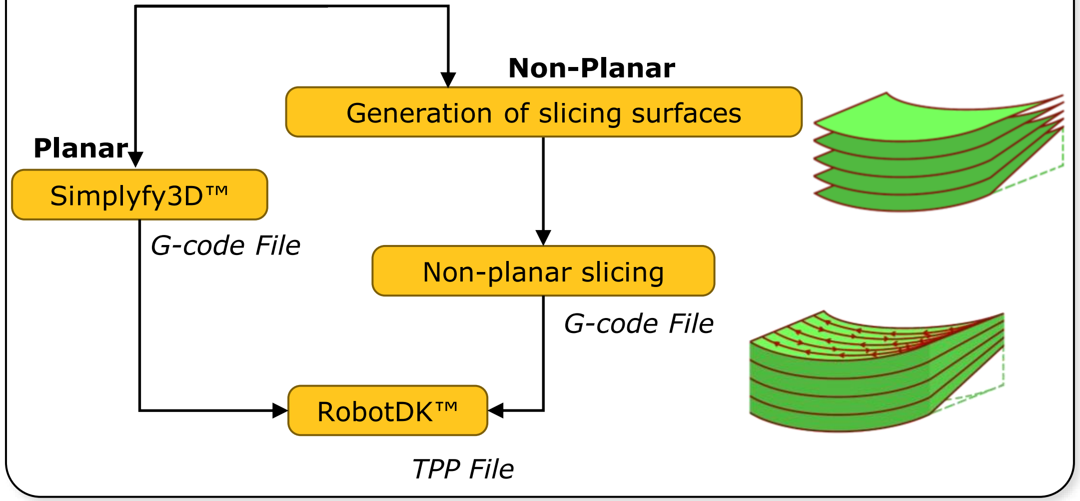
Synchronization

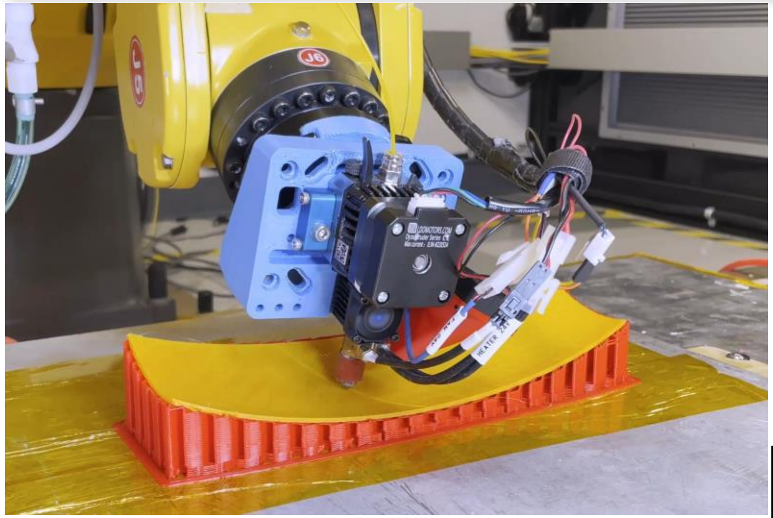
Heated printing ambient





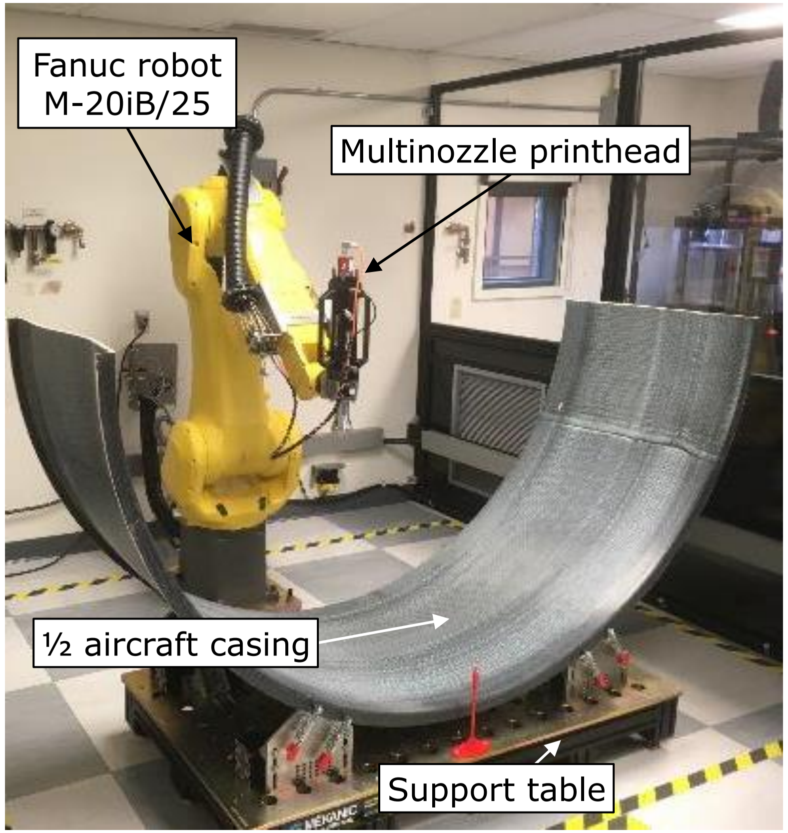
Non-planar slicing

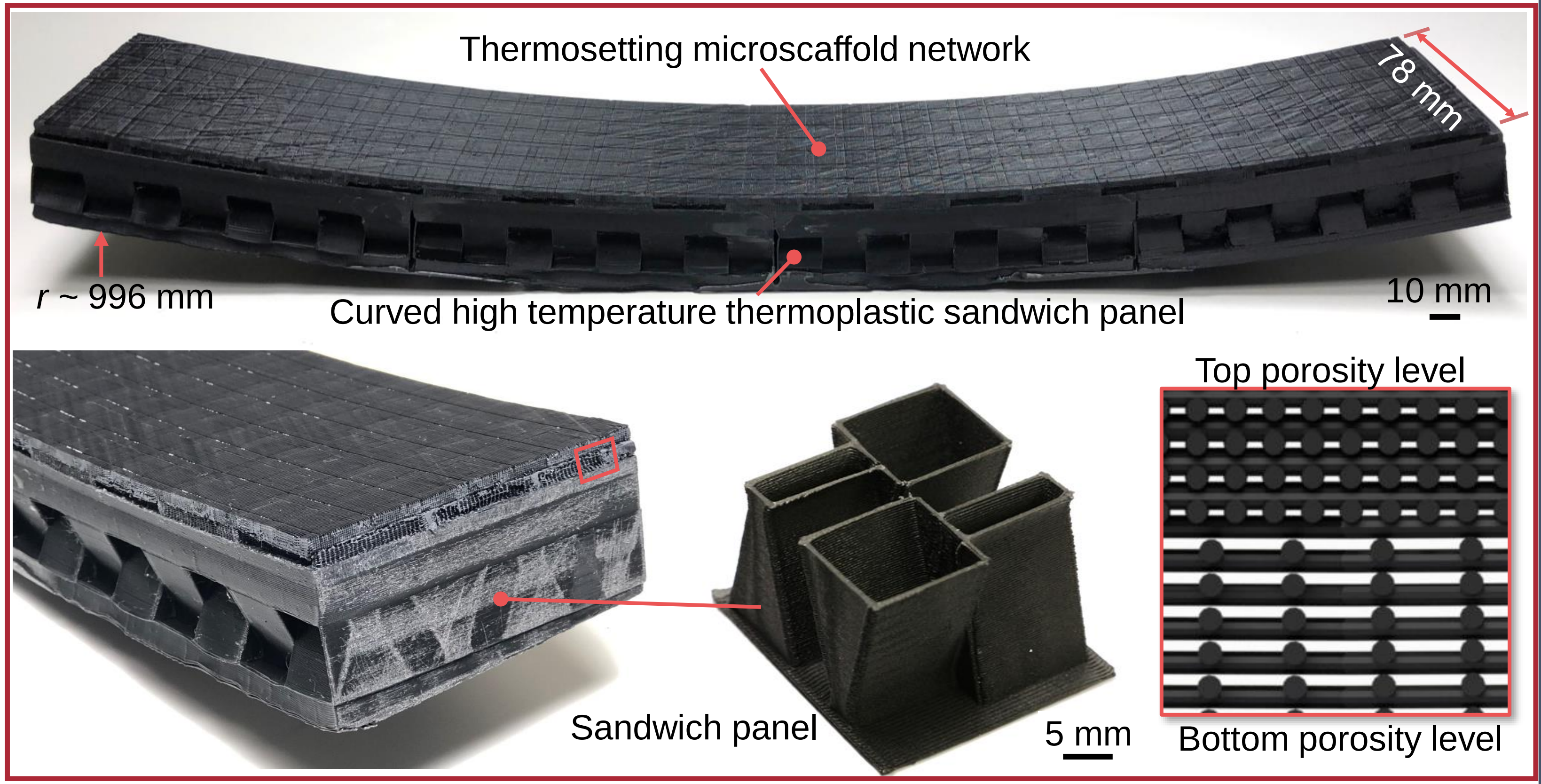




TECHNOLOGICAL DEMONSTRATOR

AIRCRAFT ENGINES – ACOUSTIC AND ABRADABLE





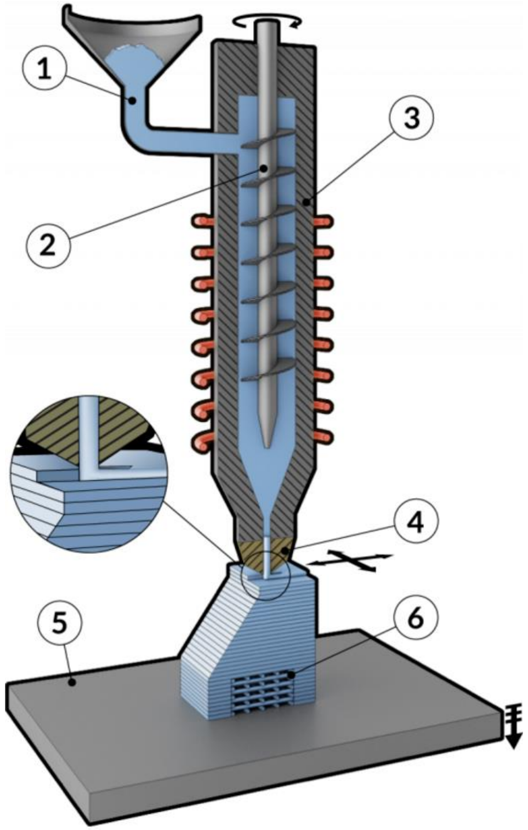
LM2 – Polytechnique Montreal.

OUTLINE

- Who is Daniel Therriault?
- Introduction to additive manufacturing (AM)
- Introduction to Fused Filament Fabrication (FFF)
  - Case study
- Introduction to Fused Granulate Fabrication (FGF)
  - Case study
- Introduction to Continuous Fiber Fabrication (CFF)
  - Case study
- Circular economy in AM of composites
- Industry questions… and some answers
- Future perspectives

FUSED GRANULATE FABRICATION (FGF)

- Main characteristics
  - Use of a single-screw pellet-extrusion printhead for printing of granules/pellets instead of filaments in FFF
  - Materials: thermoplastics (PLA, ABS, Nylon and many more) and reinforced thermoplastics
    - High flow (Faster printing)
    - Cheaper costs of materials



https://www.manufacturingguide.com/en/fused-granular-fabrication-fgf

MANUFACTURINGGUIDE

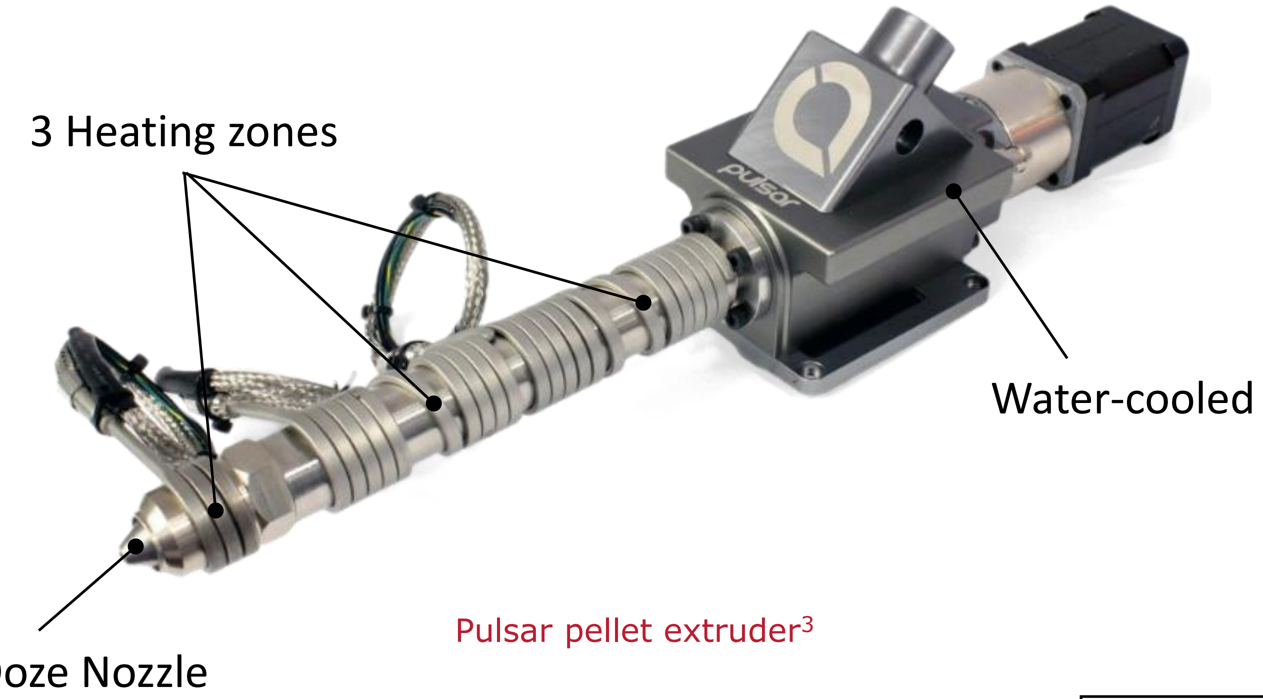
FUSED GRANULATE FABRICATION (FGF)

Issue with filament-based additive manufacturing: **mass flowrate**

- E3D V6 Hotend: **60g/h** [2]

E3D V6[1]

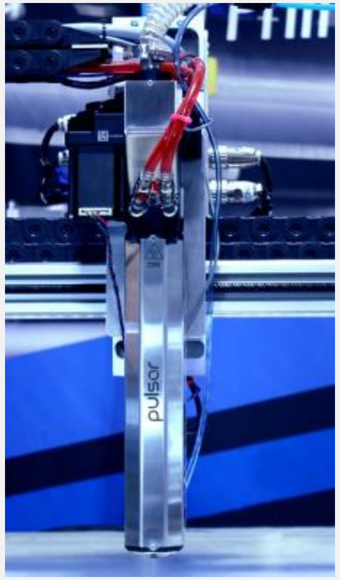
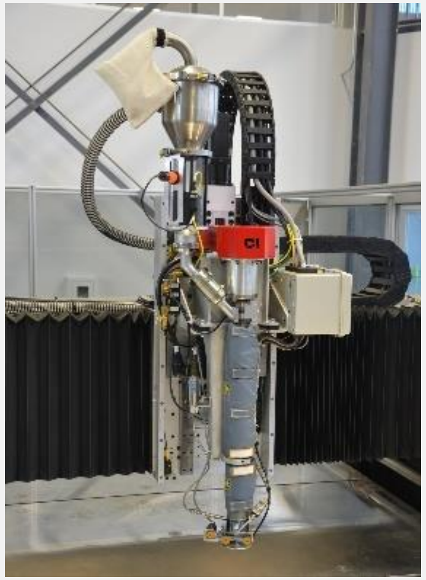
- Dyze Design Pulsar Pellet Extruder: **2.5kg/h** [3]



Pulsar pellet extruder[3]

1. https://www.matterhackers.com/store/printer-accessories/v6-hotend-full-kit-1.75mm-universal
2. https://e3d-online.com/blogs/news/finish-your-print-quicker-than-ever-before-the-supervolcano-has-erupted
3. https://dyzedesign.com/pulsar-pellet-extruder/

TAKE-HOME MESSAGE

Feature / Model	Pulsar™ Atom	Pulsar™	CEAD E50	Cincinnati BAAM
Type	Small-scale pellet extruder 	Medium-scale pellet extruder 	Large-scale pellet extruder 	Large-scale pellet extruder 
Max. Throughput	~1 kg/h	~2.5 kg/h	~12 kg/h	~50 kg/h
Max Temperature	450 °C	500 °C	450 °C	450–500 °C
Nozzle Diameter	0.4–2.5 mm	0.5–2.5 mm	2–6 mm (customizable)	3–12 mm (customizable)
Manufacturer	Dyze Design (Canada)	Dyze Design (Canada)	CEAD (Netherlands)	Cincinnati Inc. (USA)

LARGE-SCALE INDUSTRIAL FGF PRINTERS: CEAD

GANTRY SYSTEMS

Flexcube CEAD printer

- **Specifications**
  - High throughput with CEAD pellet extrusion
  - Very large print envelope (4 m x 2 m x up to 12 m)
  - Not suitable for nonplanar parts

6-AXIS ROBOTIC SYSTEMS

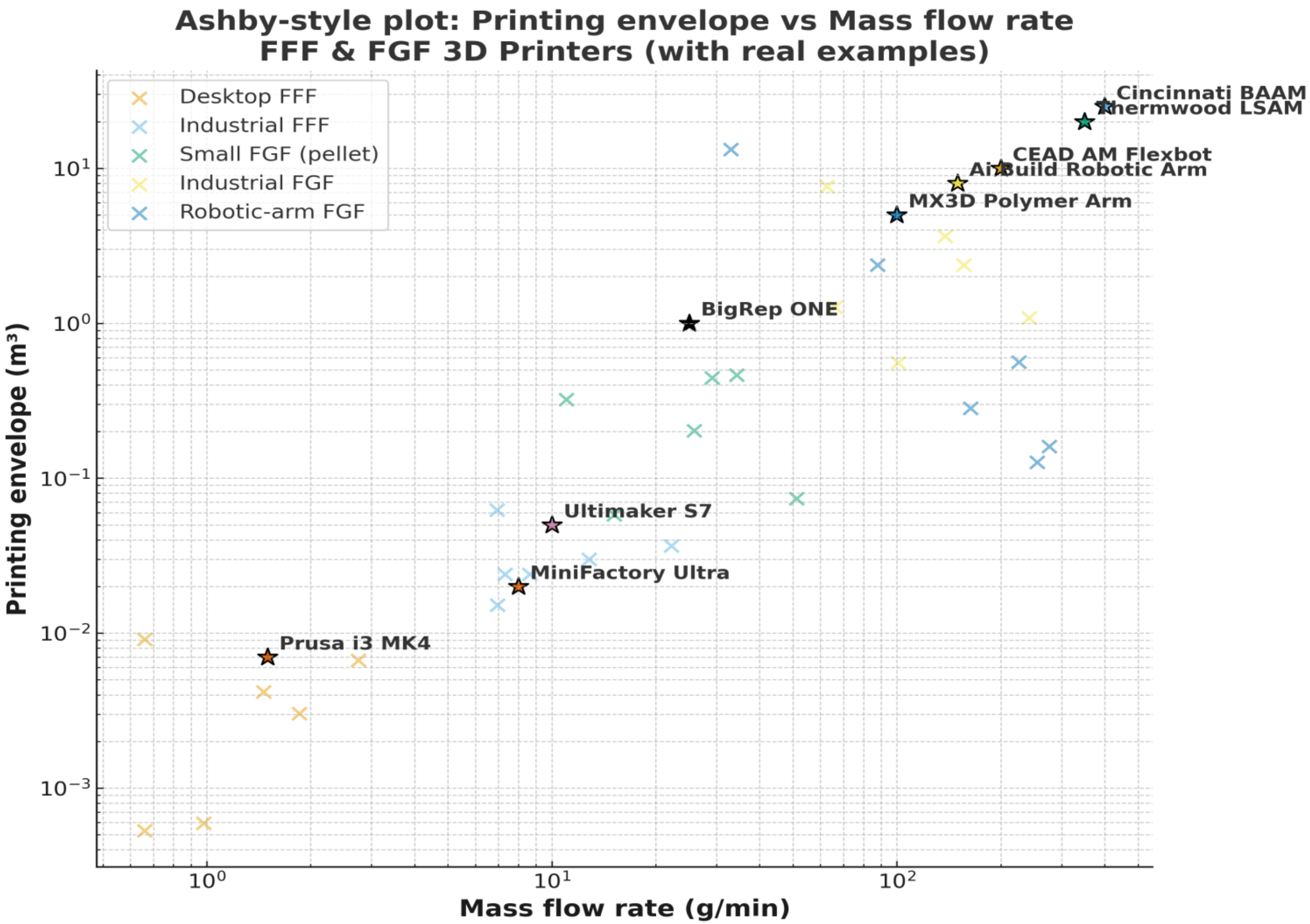
Flexbot CEAD printer

Flexbot CEAD printer

- **Specifications**
  - Six degree of freedom
  - Very large print envelope (4 m× 4 m × 3 m)
  - Suitable for large nonplanar parts
  - High throughput with CEAD Pellet extrusion (85 kg/hr)

1. ceadgroup.com

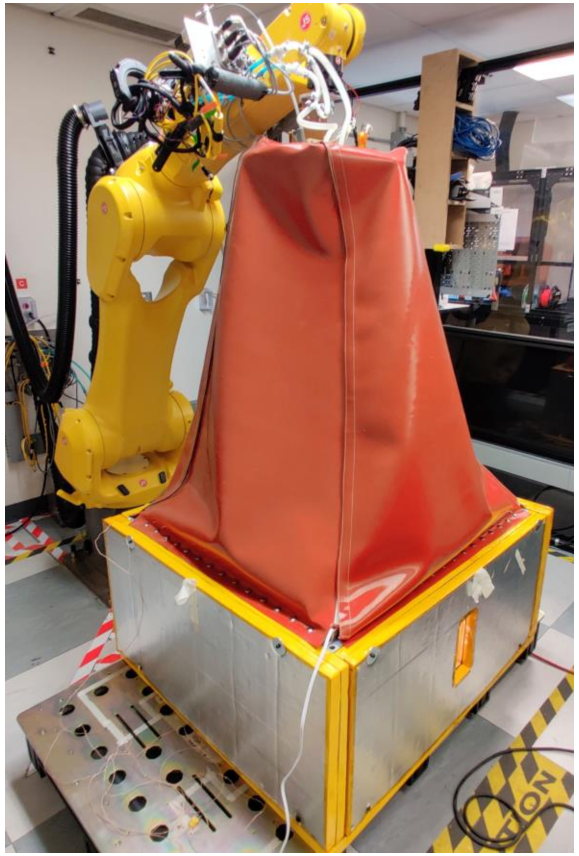
COMPARISON OF COMMERCIAL/INDUSTRIAL PRINTERS



AI generated plot.

AM INFRASTRUCTURE AT LM2 – PROS AND CONS

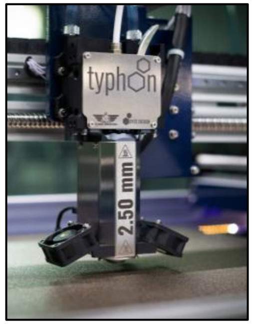
CUSTOM-BUILT 6-AXIS AM - LM2



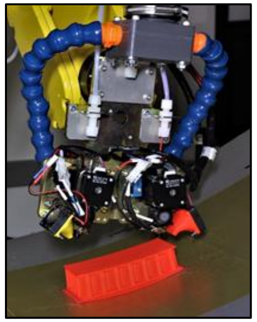
Six-axis AM platform with a heated chamber

Pulsar Atom Pellet Extruder (Dyze Design)

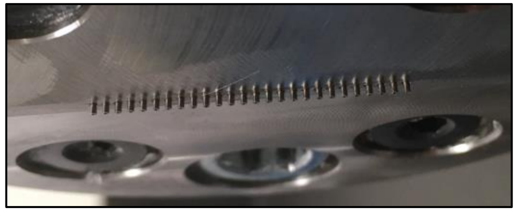
Pulsar Pellet Extruder (Dyze Design)



Typhoon (Dyze Design)



Two FFF printheads



Multinozzle printhead for thermosets

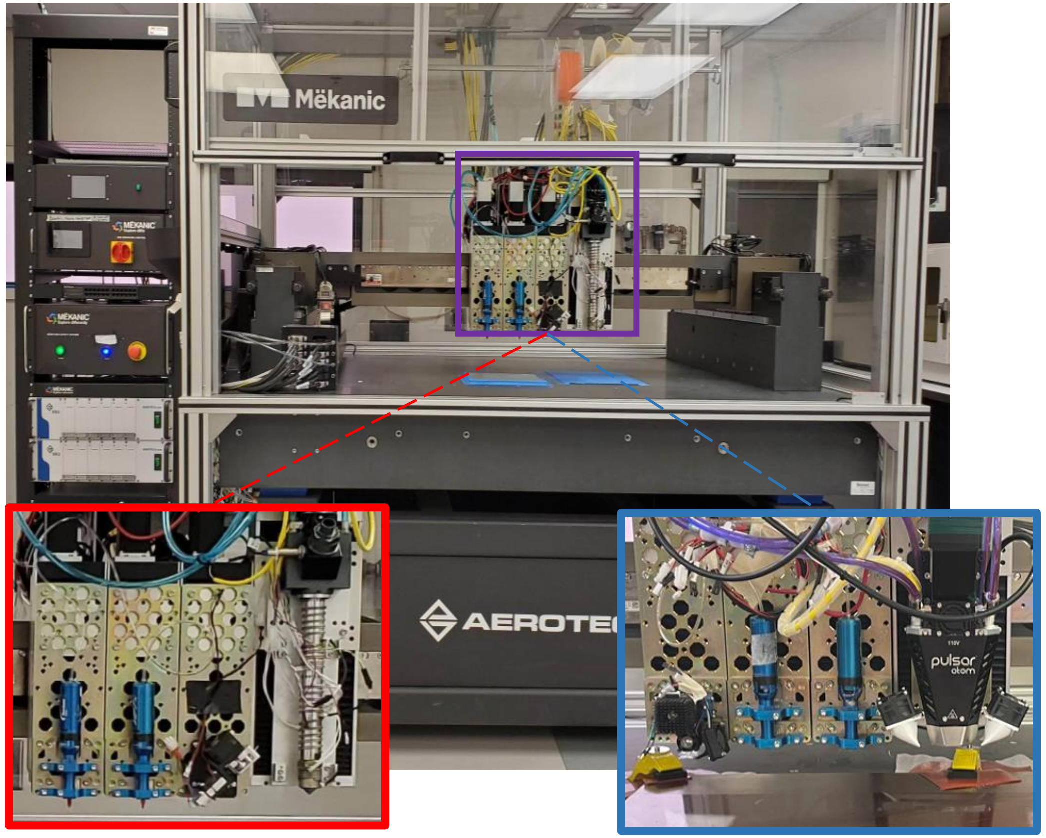
- **PROS**
  - Very large build area (800×1100 mm)
  - Six degree of freedom
  - With heating environment – up to 120°C
  - Suitable for high temperature materials
  - Suitable for large nonplanar parts
  - Open materials and open slicer
  - Compatible for various printheads
    - FFF
    - Direct-ink writing (e.g., thermosets)
    - FGF: Pellet-extrusion printheads (e.g., ATOM Dyze Design)

- **CONS**
  - Limited temperature of the heated enclosure
    - Current version: 120°C = not high enough for printing high-temperature materials

LM2 – Polytechnique Montreal.

AM INFRASTRUCTURE AT LM2– PROS AND CONS

CUSTOM-BUILT GANTRY AM - LM2



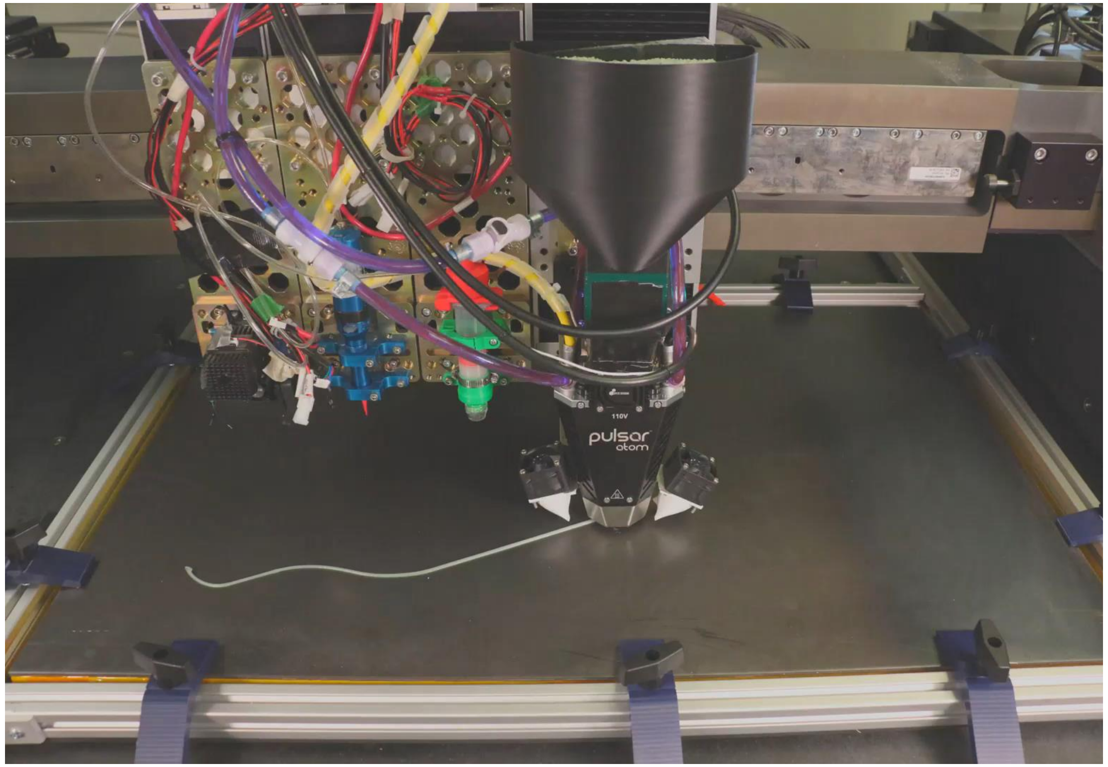
Aerotech system equipped with different 3D printing heads

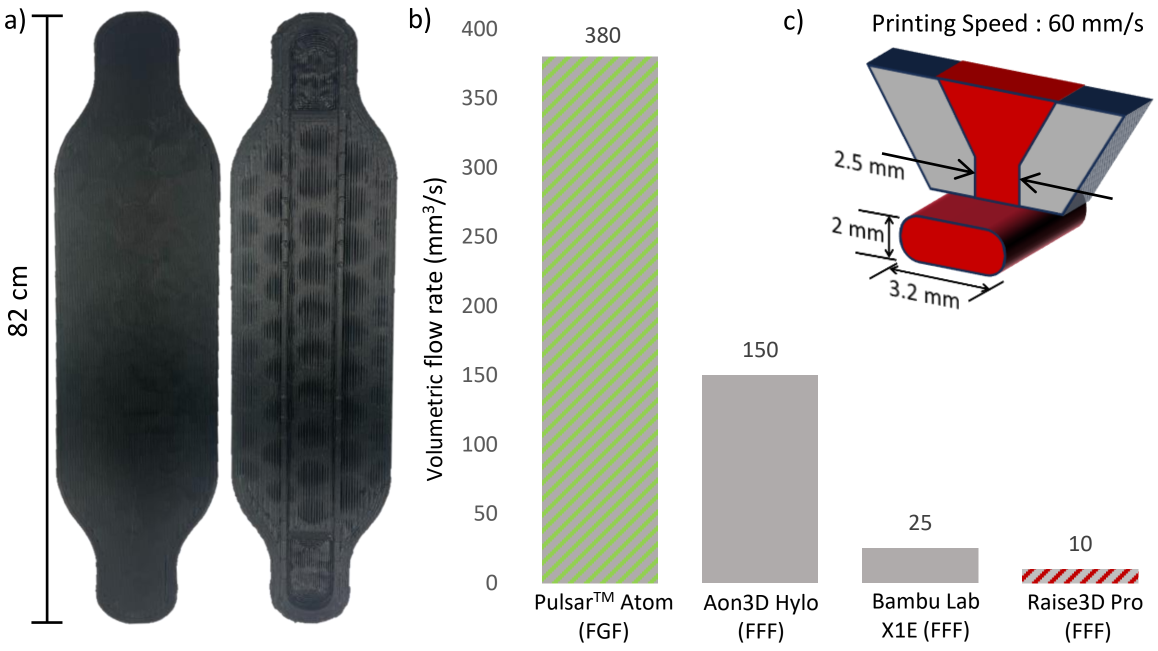
- **PROS**
  - Relatively large build area (400×400×250 mm)
  - Accurate printing with air bearing gantry system
  - Multi-material printing
  - Multi-process printing
  - Open materials and open slicer
  - Compatible for various printheads
    - FFF
    - Direct-ink writing (e.g., thermosets, UV-curable resins)
    - FGF: Pellet-extrusion printheads (e.g., ATOM Dyze Design)
- **CONS**
  - Cartesian 3 axes
  - Not suitable for nonplanar parts
  - Might need support materials
  - No heating environment – Room temperature printing
  - Not suitable for high temperature materials like PEEK

LM2 – Polytechnique Montreal.

CASE STUDY

AM OF A LONGBOARD USING THE GANTRY SYSTEM AND PULSAR ATOM PRINTHEAD





High-throughput FGF printed longboard using PETG- reinforced with recycled glass fiber, produced in 2h 45min with a weight of 1590g

1. **Very high flow rate achieved**
2. Successful printing of relatively large sandwich panel (longboard)
   - ➔ **Adapt technology to high-temperature resistant composites**
   - ➔ **Adapt to non-planar + large scale printing**

LM2 – Polytechnique Montreal in collaboration with Prof. Lassard at McGill University.

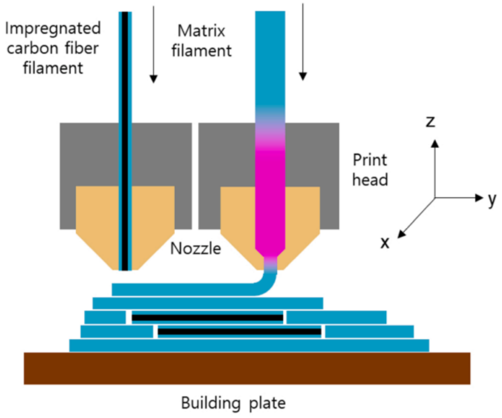
OUTLINE

- Who is Daniel Therriault?
- Introduction to additive manufacturing (AM)
- Introduction to Fused Filament Fabrication (FFF)
  - Case study
- Introduction to Fused Granulate Fabrication (FGF)
  - Case study
- Introduction to Continuous Fiber Fabrication (CFF)
  - Case study
- Circular economy in AM of composites
- Industry questions… and some answers
- Future perspectives

AM OF CONTINUOUS FIBER COMPOSITES

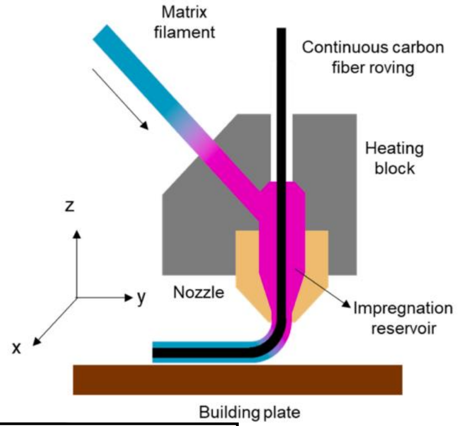
2 main approaches

Towpreg [1]



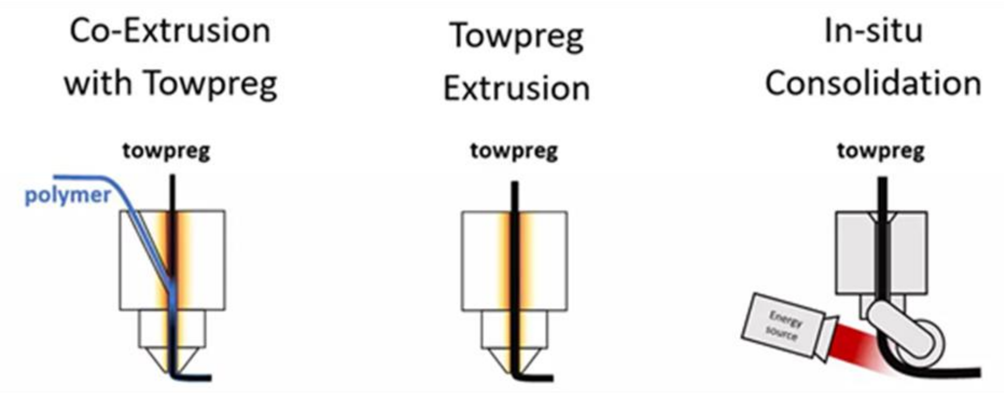
- Better fiber impregnation
- Expensive material feedstock
- Limited geometric complexity

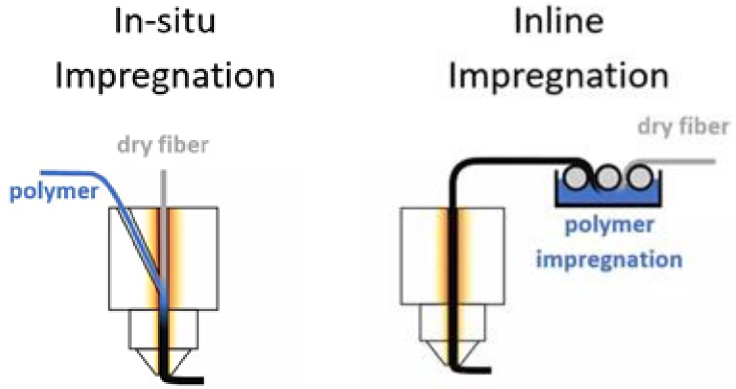
In-situ [1]



- Dry fiber feedstock possible
- Limited fiber impregnation
- Challenging cutting mechanisms
  - Very limited geometric complexity

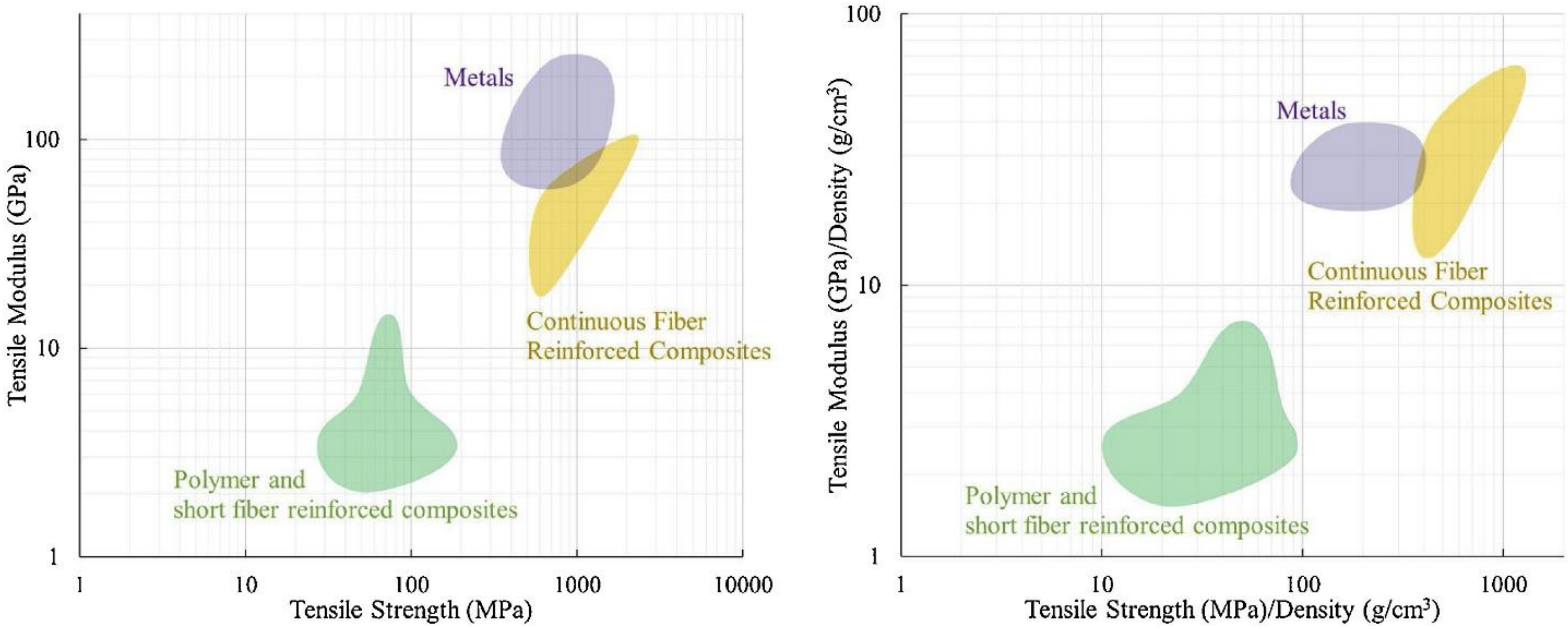
5 methods based on the 2 main approaches [2]





[1] Heitkamp et. al. (2022). Continuous fiber-reinforced material extrusion with hybrid composites of carbon and aramid fibers. Applied Sciences, 12(17), 8830.
[2] https://www.compositesworld.com/articles/3d-printing-wih-continuous-fiber-a-landscape

AM OF CONTINUOUS FIBER COMPOSITES



Ashby plot for regular and specific tensile properties of additively manufactured materials [1].

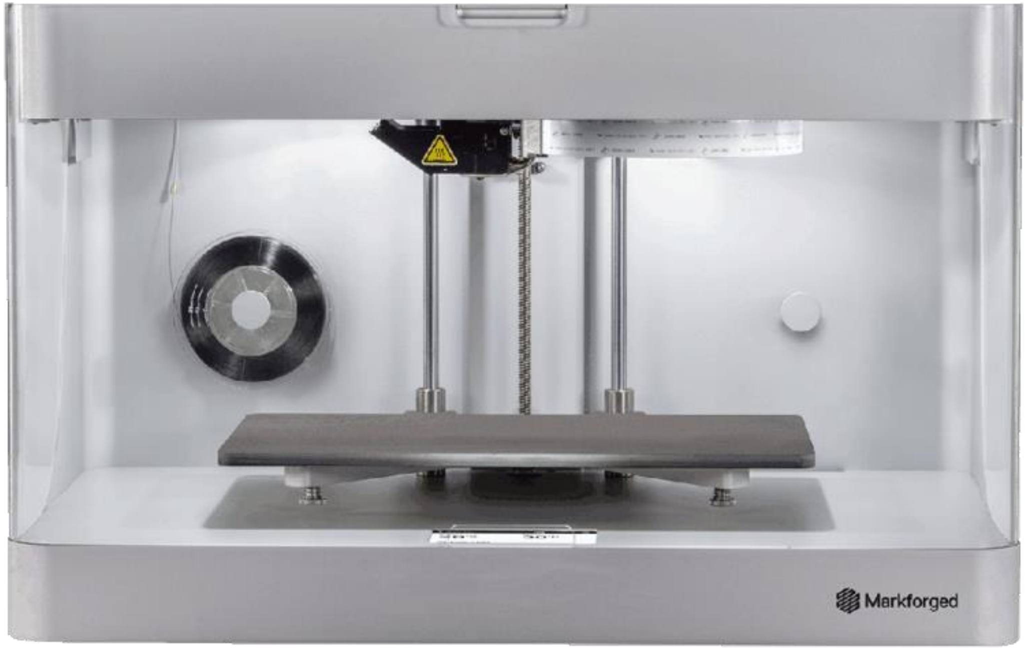
[1] Van de Werken et. al., Additive Manufacturing, 2020.

AM INFRASTRUCTURE – CONTINUOUS FIBER

ANISOPRINT COMPOSER A4

- Proprietary thermoset towpreg co-extrusion
- Fiber volume fraction (V_f) < 65 vol.%
- Rely on short fiber extrusion for complex features

MARKFORGED MARK II



- Proprietary towpreg extrusion
- V_f < 11 vol.%
- Rely on FFF printhead for complex features

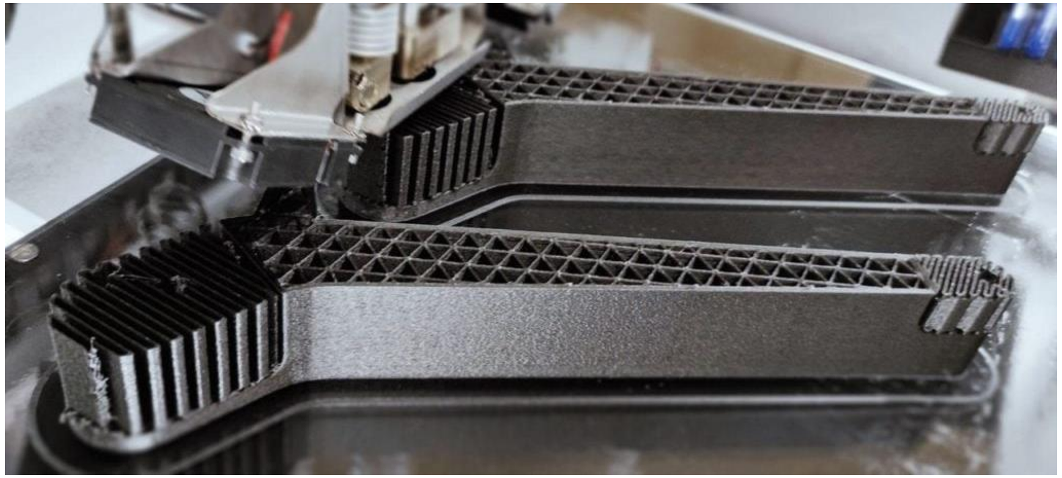
HOSTED BY: CKN Composites Knowledge Network

[1] anisoprint.com
[2] markforged.com

HOSTED BY: sampe Canada

AM INFRASTRUCTURE – CONTINUOUS FIBER

LARGE-SCALE: ANISOPRINT: PROM IS 500



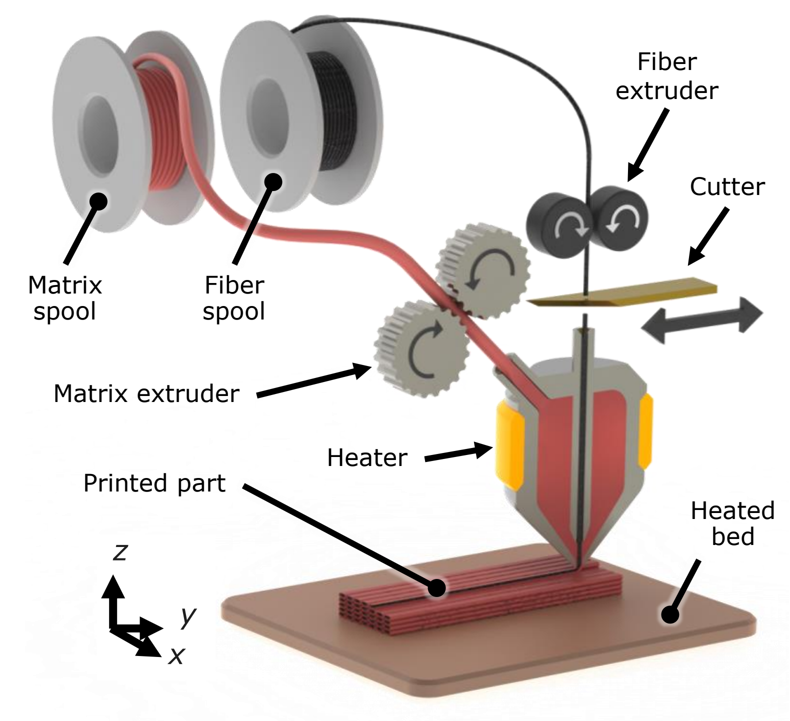
Key Specifications

- Large Build Volume: 600 x 420 x 300 mm.
- High Extrusion Temperature: Up to 410°C
- Compatible with: PEI, PEEK, PEKK, PAEK, PPSU, PSU, PA, PC.
- Relatively High Heated Chamber Temperature: Up to 160°C.
- High Printing Speed: 20000 mm/min.

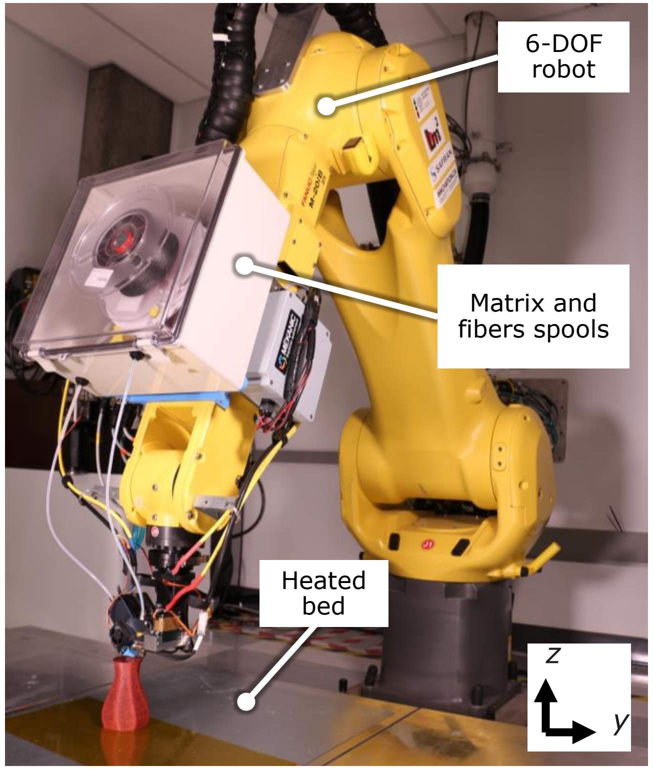
[1] anisoprint.com

CASE STUDY: COEXTRUSION APPROACH AT LM2

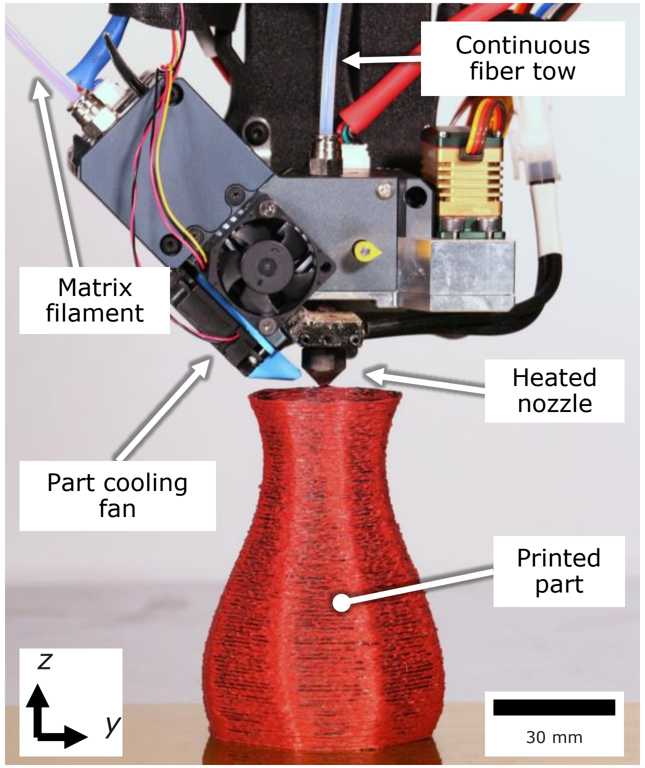
- A co-extrusion method: high-flowrate extrusion, complex geometries, and lower cost by eliminating the need for the production of expensive towpreg filaments



Co-extrusion printhead with a thermoplastic filament extrusion system, a continuous fiber tow extrusion system, a fiber cutting mechanism, a heated co-extrusion nozzle.



Photograph of the 6-DOF robot with the co-extrusion print head installed



Photograph of the co-extrusion print head printing a vase

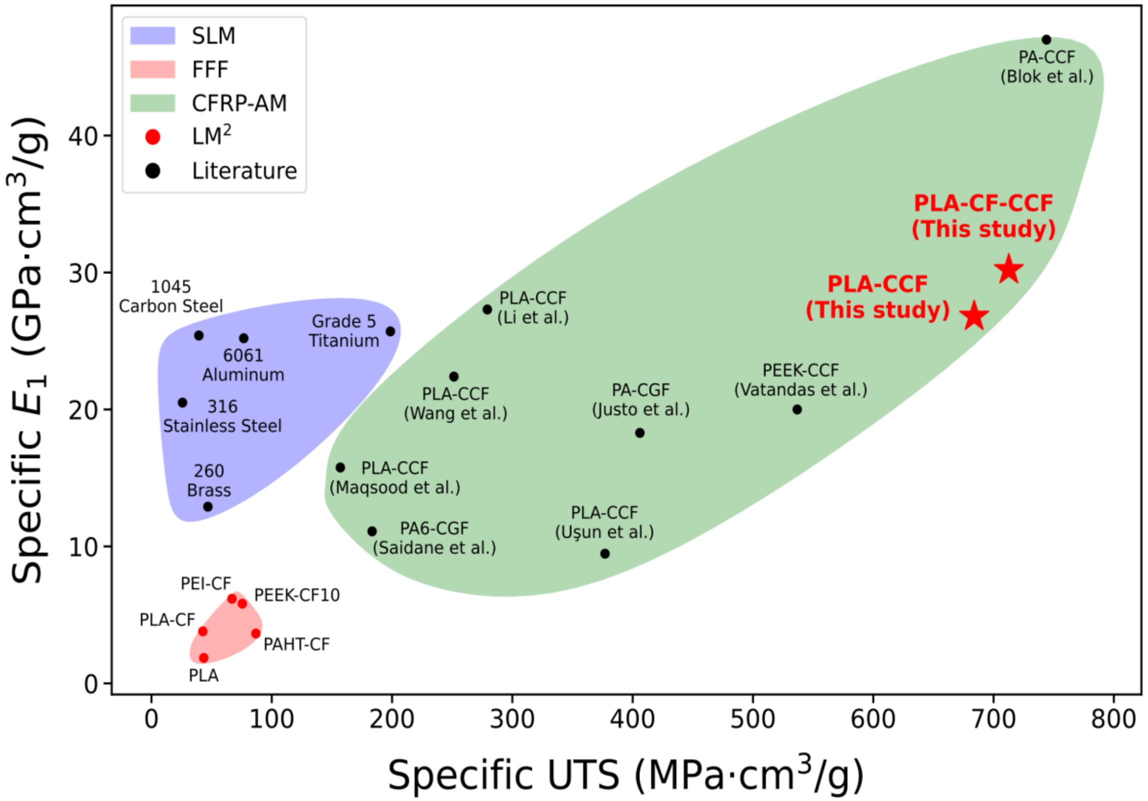
HOSTED BY: CKN Composites Knowledge Network

Submitted: M. Verville et al., 2025

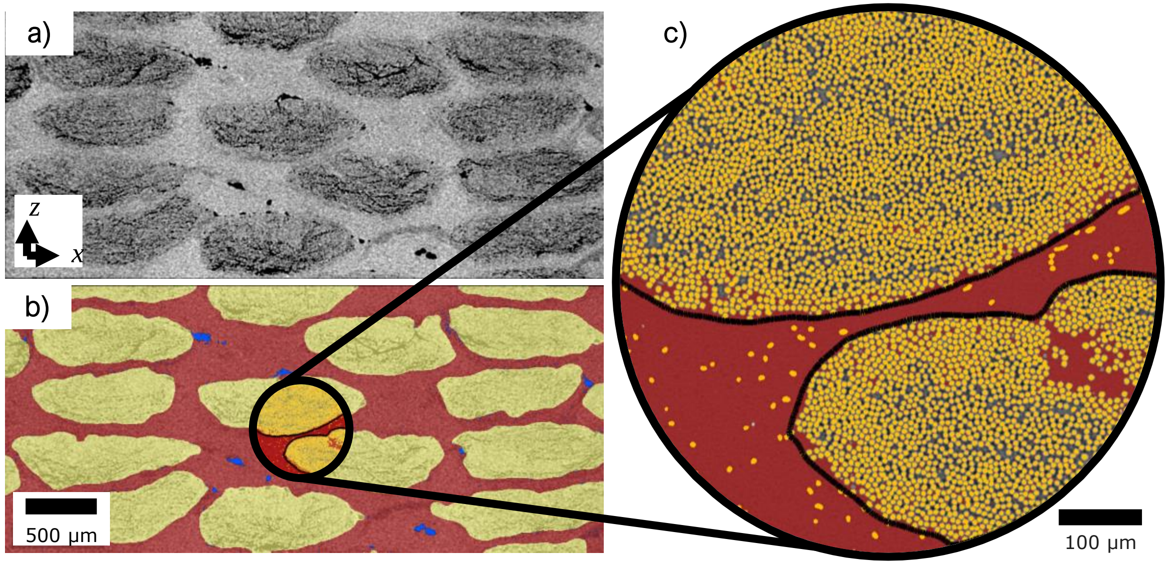
HOSTED BY: sampe Canada

CASE STUDY: COEXTRUSION APPROACH AT LM2

- Mechanical and microstructural characterization



Ashby diagram of different 3D printing materials from the literature and our results comparing their specific Ultimate tensile strength (UTS) and specific stiffness in the principal direction (*E1*).



Micro-tomography imaging of a PLA-CF-CCF printed sample. a) The mesoscale reconstruction of multiple printed layers. b) The meso-scale segmentation of multiple printed layers, and c) The micro-scale segmentation of the inter-tow region.

Continuous fibers represent ~44 vol.% (~58 wt.%) of the composite while voids and porosities represent 0.4 vol.% and 7.9 vol.%, respectively.

HOSTED BY: CKN Composites Knowledge Network

Submitted: M. Verville et al., 2025

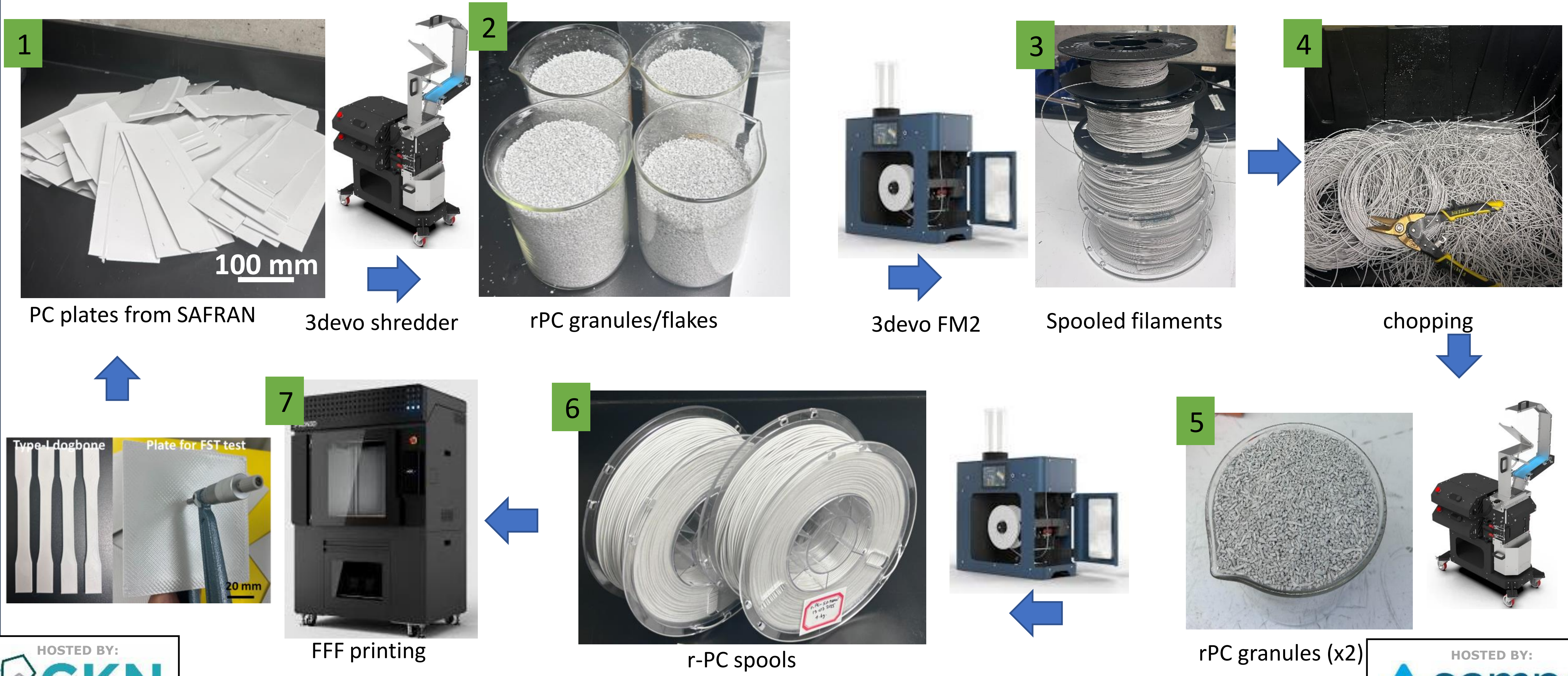
HOSTED BY: sampe Canada

OUTLINE

- Who is Daniel Therriault?
- Introduction to additive manufacturing (AM)
- Introduction to Fused Filament Fabrication (FFF)
  - Case study
- Introduction to Fused Granulate Fabrication (FGF)
  - Case study
- Introduction to Continuous Fiber Fabrication (CFF)
  - Case study
- Circular economy in AM of composites
- Industry questions… and some answers
- Future perspectives

CIRCULAR ECONOMY IN AM

- Recycling aerospace scraps: methodology for making 3D printing filament



EXAMPLES OF AM APPLICATION IN COMPOSITE MANUFACTURING

TOOLING

AM of a composite autoclave mold for carbon fiber lamination of a drone nose structure [1]


Photo of hollow complex part with sacrificial interior support using a thermoplastic material dissolvable in a basic solution [2]

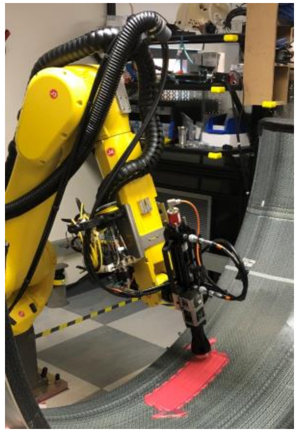
AIRFRAME STRUCTURES

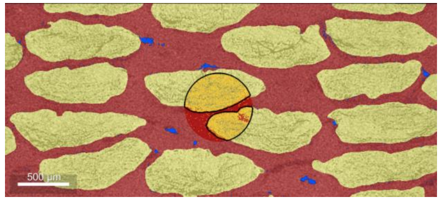

Photo of a demonstrator composed of CF/LMPAEK laminate produced by AFP and a composite core by FFF printing of PEKK filament [3]

[1] https://caracol-am.com/resources/case-studies/3d-printed-lamination-mold.
[2] https://www.theengineer.co.uk/content/product/sacrificial-tooling-and-mandrels-for-composite-part-fabrication-design-guide
[3] https://www.compositesworld.com/articles/combining-multifunctional-thermoplastic-composites-additive-manufacturing-for-next-gen-airframe-structures.

INDUSTRY QUESTIONS… AND SOME ANSWERS

- Can we print structures large and *fast* enough?
  - **Robotic and gantry systems**
  - High-flow rate printhead
  - Fused granule deposition (FGF)
  - Multinozzle design

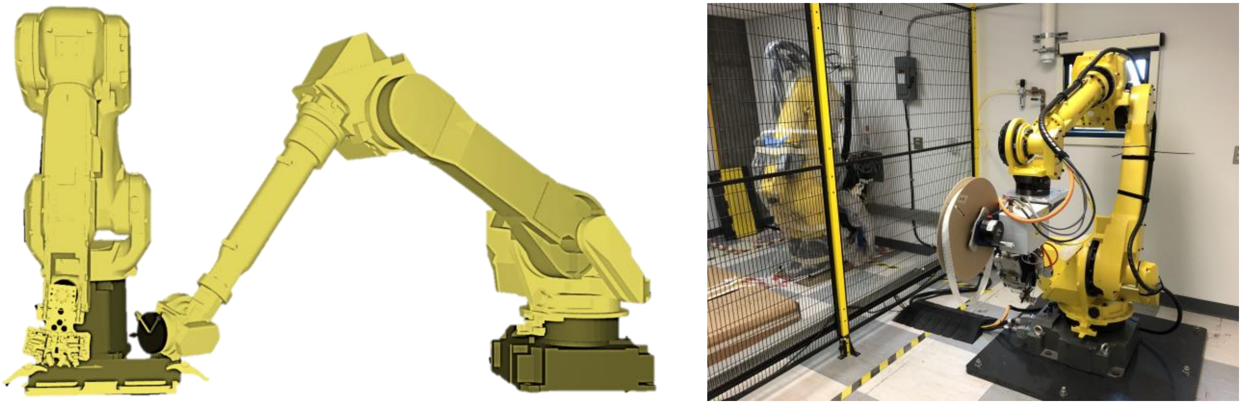




- Can we print structures STRONG enough?
  - Short fiber-reinforced polymer composites
  - **Continuous-fiber printing**

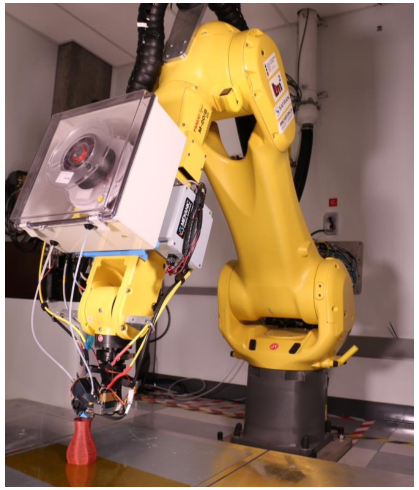
- Can we print sustainably?
  - **Recycling** and life cycle analysis

FUTURE PERSPECTIVES

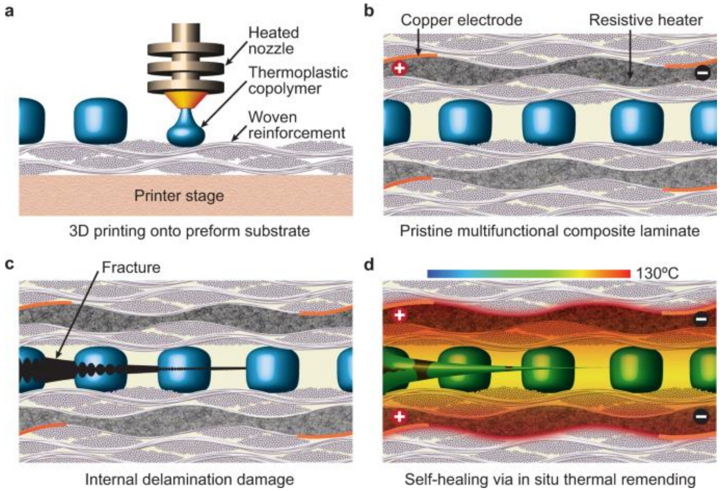


Collaborative robots: additive manufacturing and automated fiber placement (AFP)

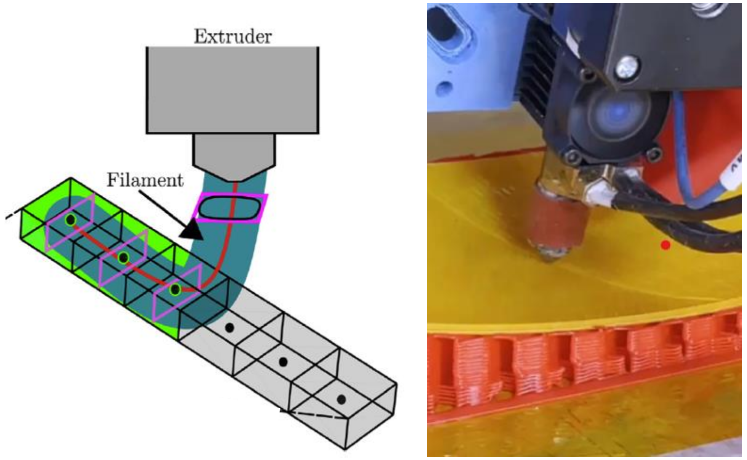
Multiprocess part: “overprinting” onto premade CFRP surface and brackets [1]



Continuous fiber printing (LM2))



Self-healing composites [2]



Digital twin of AM

[1] Composites World: Future composite manufacturing - AFP and Additive Manufacturing
[2] Snyder et al., Nature Communications, 2022.
[3] Lampron et al., Additive Manufacturing, 2023.

Thank you for joining us!

Keep an eye out for upcoming AIM events:

An Overview of Composite Tooling Construction
Hosted by Dr. Casey Keulen
November 26, 2025
https://compositeskn.org/KPC/A396

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A395

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada