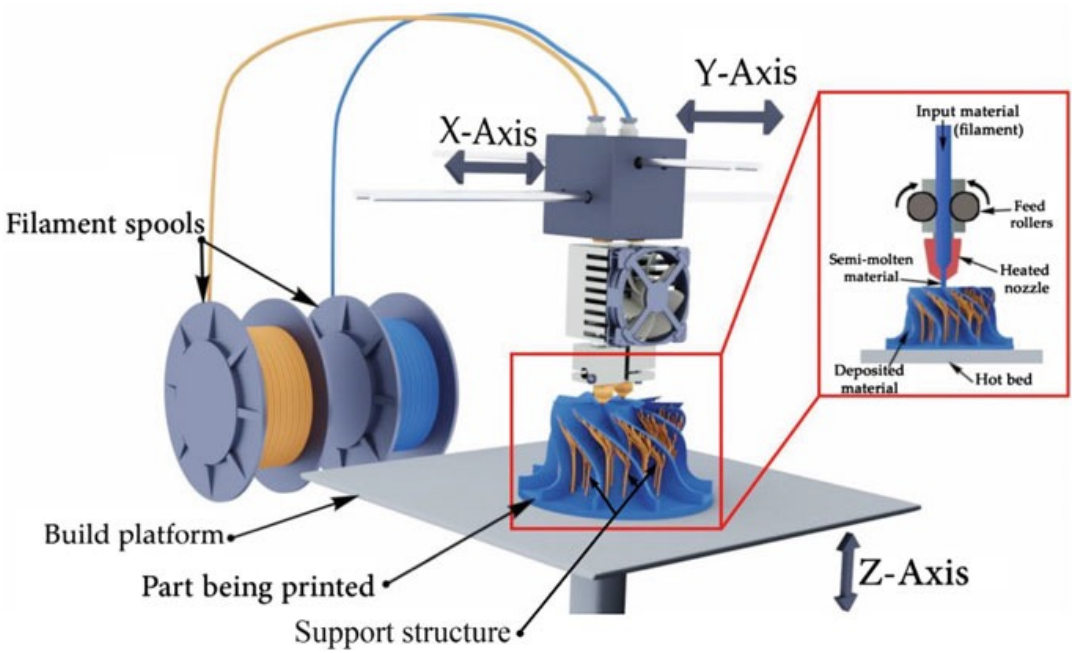
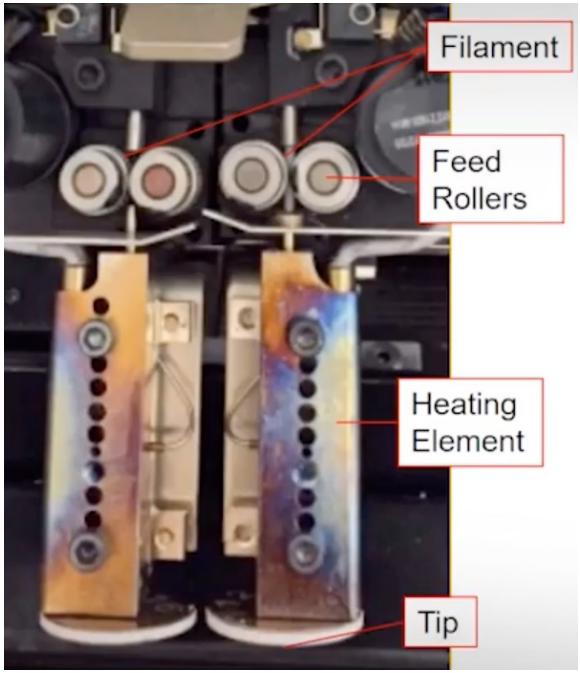
Material Extrusion

Material Extrusion

- FDM (Fused Deposition Modeling) is the most popular material extrusion-based AM method

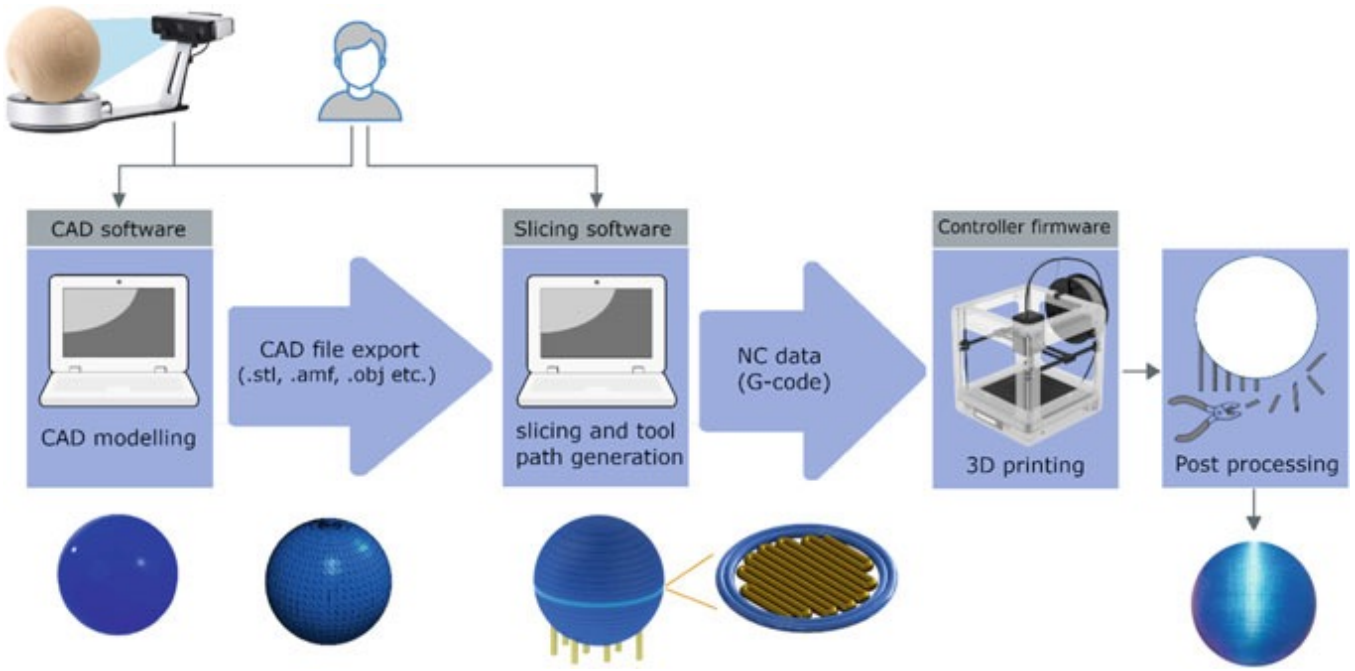
- Raw material – Filament of thermoplastic polymers





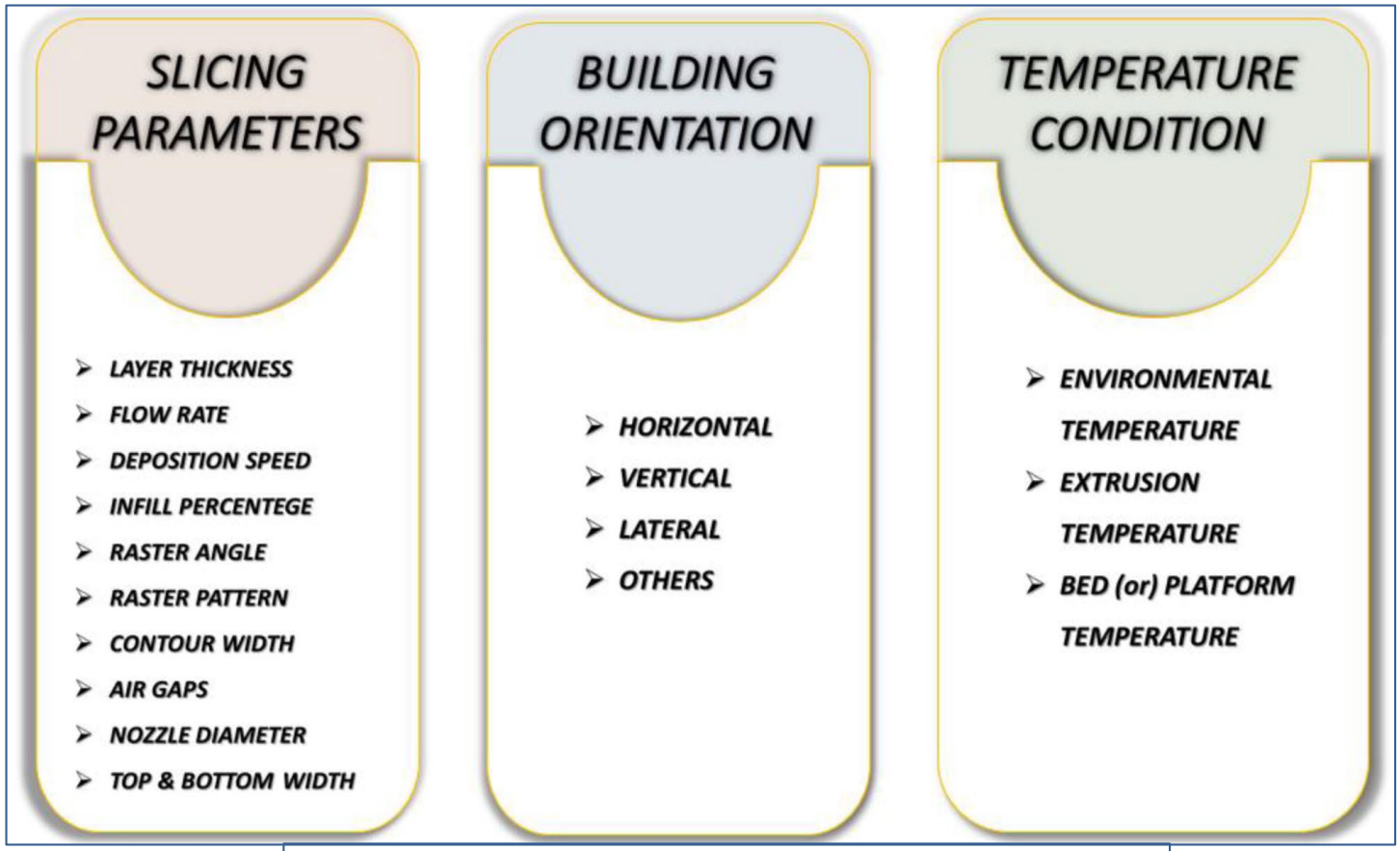
FDM

- Filament is extruded through a nozzle and heated to its softening temperature
- Preprocessing → production → postprocessing



Process flow of FDM

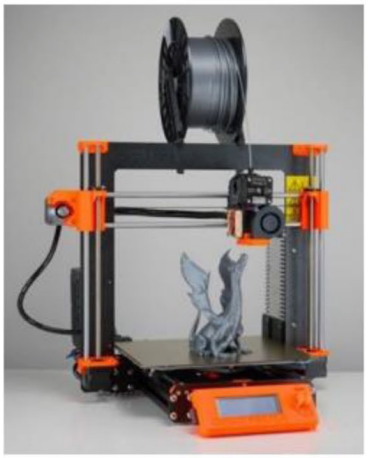
FDM



Important process parameters of FDM

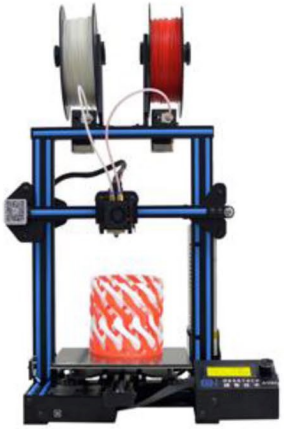
FDM

- Extrusion heads
  - Single head
  - Dual head
  - In-nozzle impregnation



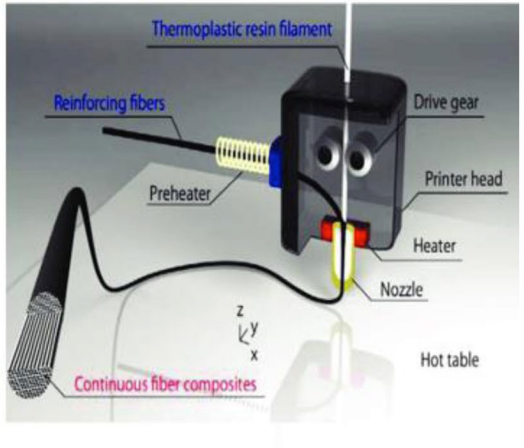
Single Head Method

Printing single materials like polymer, reinforced material, composite filament



Dual Head Method

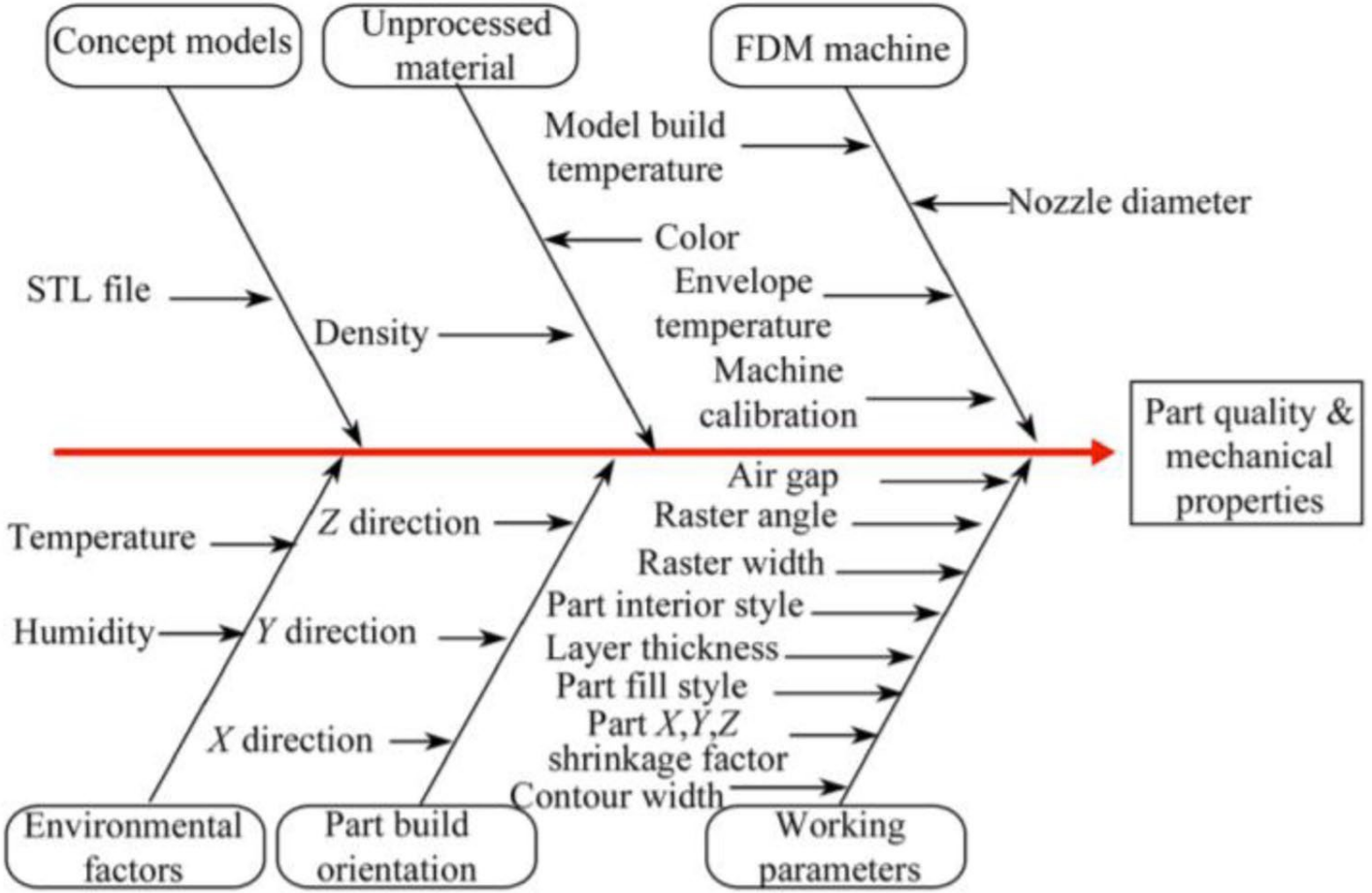
Printing of layered composites (alternative printing of two materials)



In-Nozzle Impregnation Method

Fibers are directly feeding into the nozzle head to form composite in nozzle

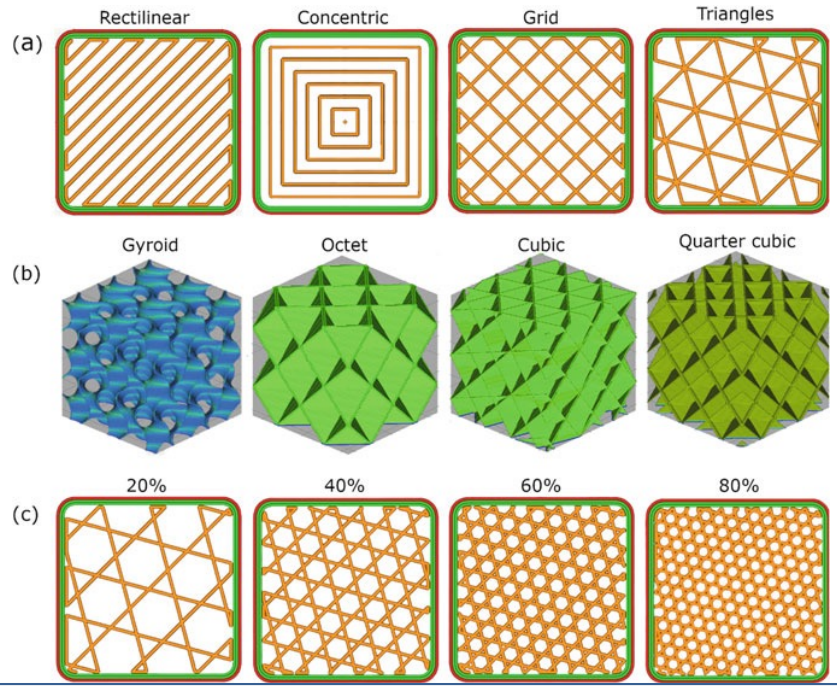
Parameters of FDM



Fishbone diagram of FDM

FDM – parameters

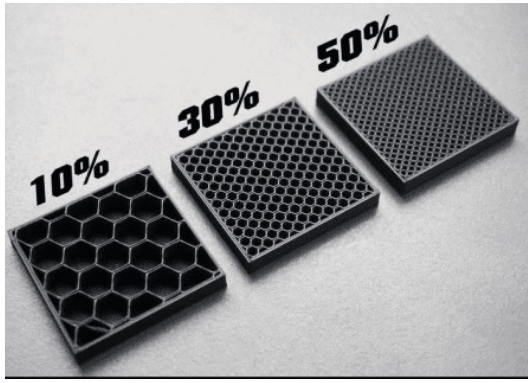
1. Infill pattern



Commonly found infill types in open software, a 2D infill patterns, b 3D infill patterns, and c various infill density for tri-hexagon/stars pattern

FDM – parameters

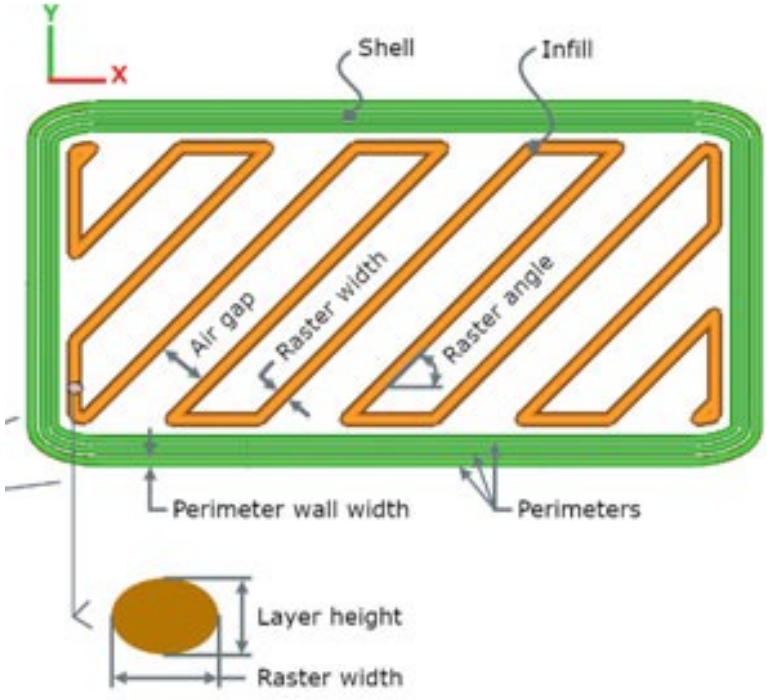
2. Infill density



3. Raster angle

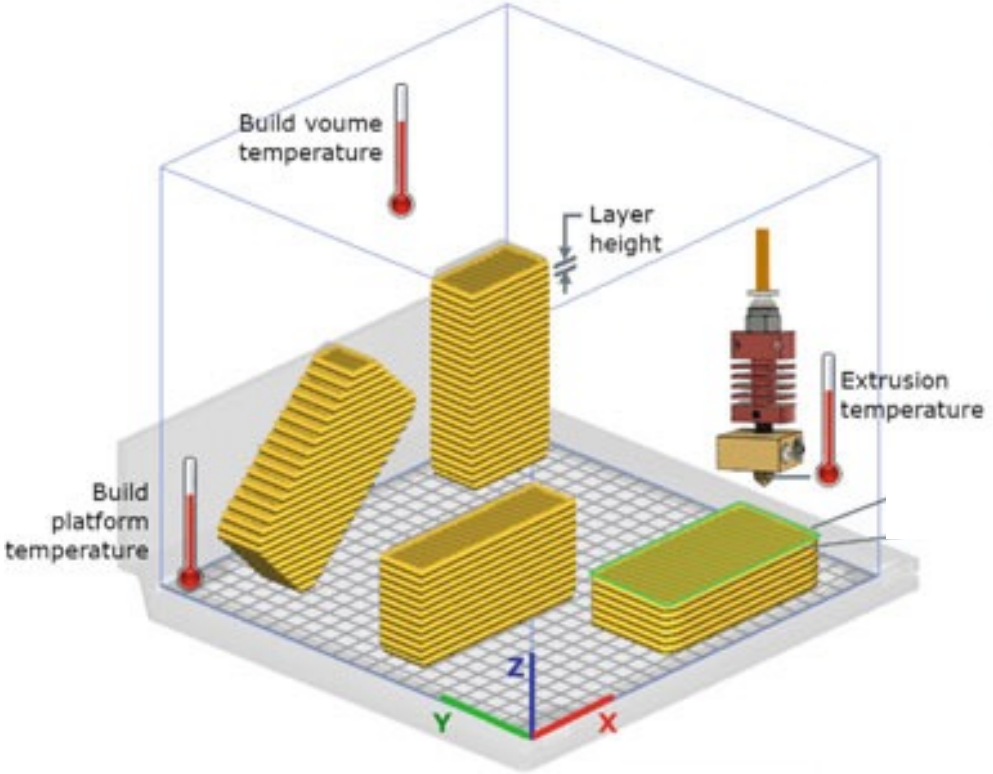
4. Raster width

5. Air gap

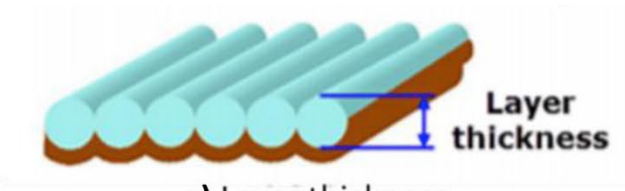


FDM – parameters

6. Build orientation



7. Layer thickness



c) Layer thickness

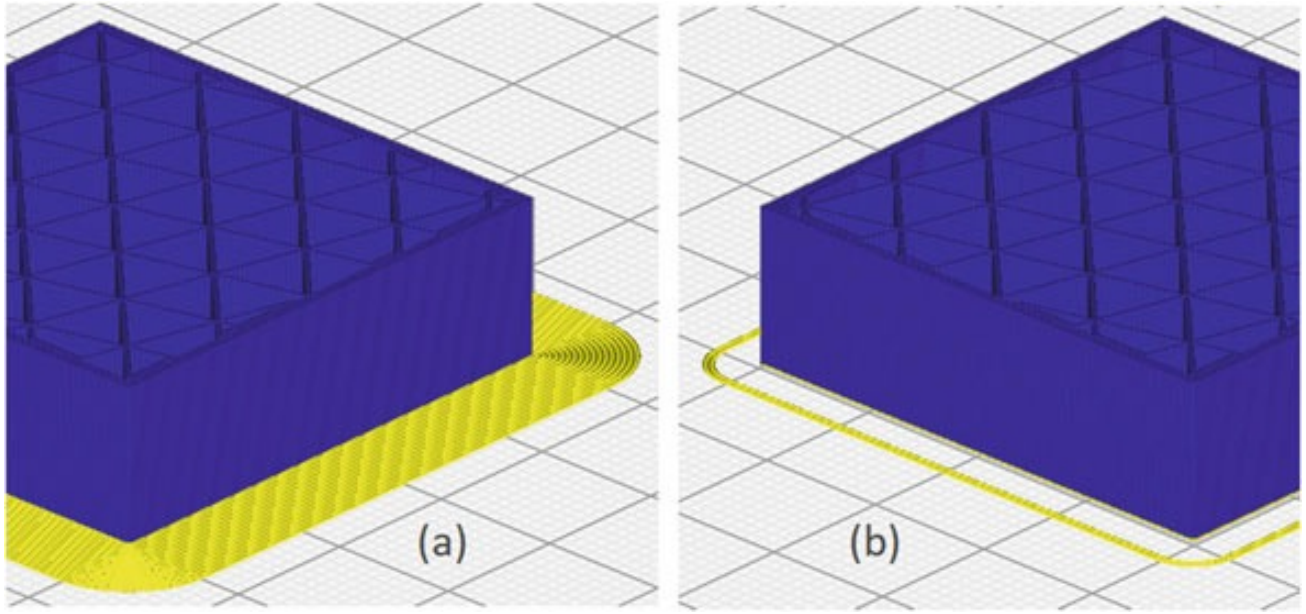
FDM – parameters

8. Printing speed

9. Operating temperature

FDM – parameters

10. Skirt and brim



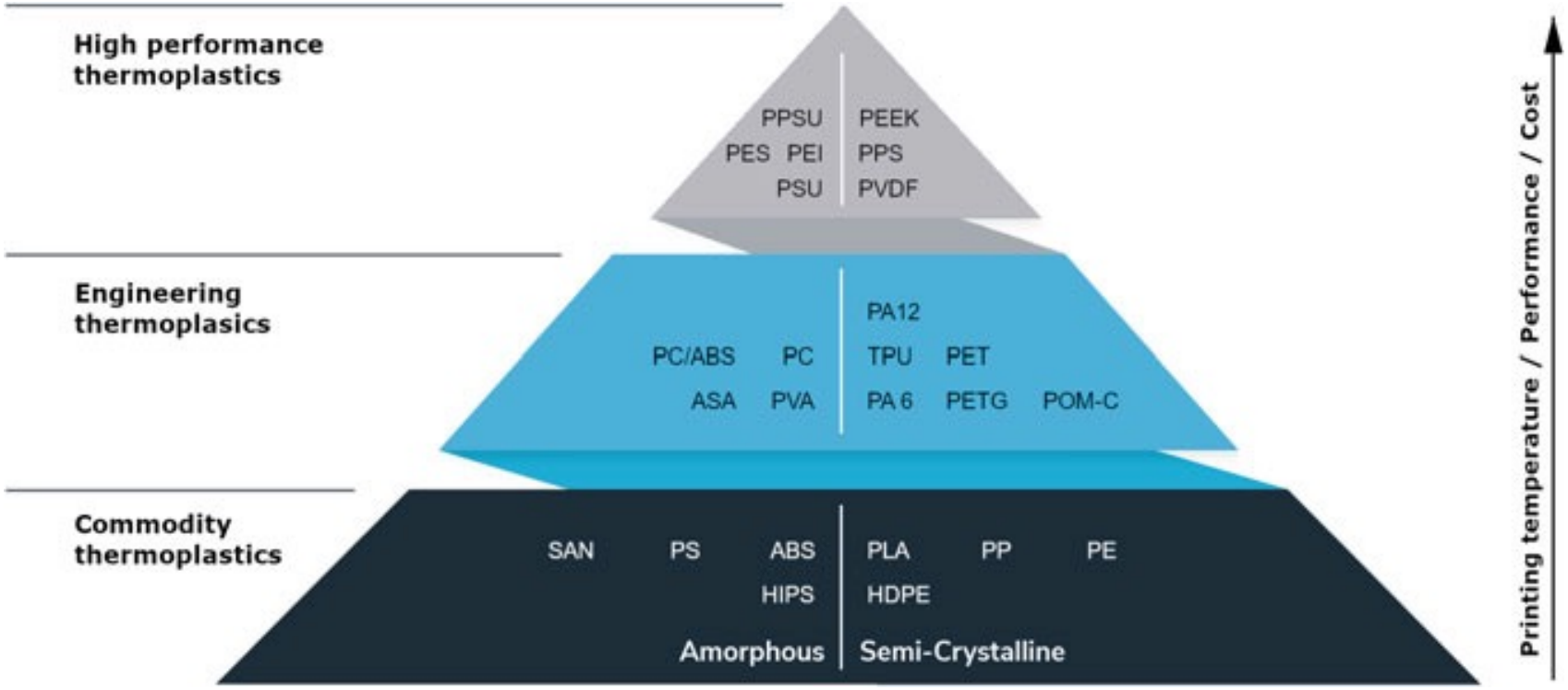
FDM printed part (blue) with a Brim (yellow) and b skirt (yellow)

FDM – Processing parameters correlation

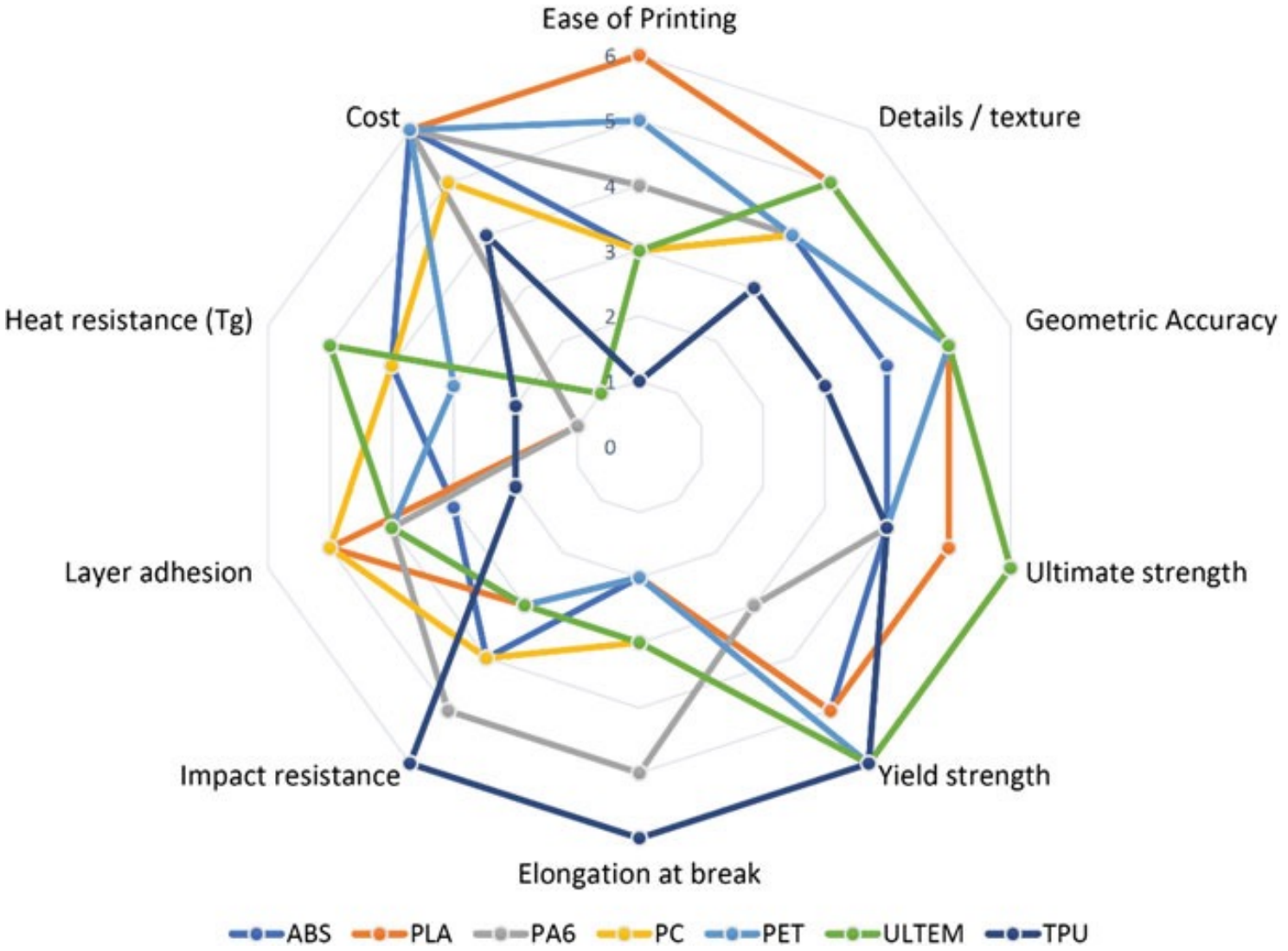
- Layer thickness, build orientation, raster angle, infill pattern, infill density and air gap are the key parameters having significant effect on mechanical properties of FDM printed parts
- Tensile strength is increased with rise in infill density and perimeters
- Build time is found minimum at higher layer thickness, low infill density, zero raster angle and build orientation having minimum support structure

Processing-structure-property relationships in FDM are complex, nonlinear and poorly understood

FDM – filament materials



FDM – filament materials



Spider web diagram – Ranking of FDM AM of various polymers

FDM – Applications

(a)

(b)

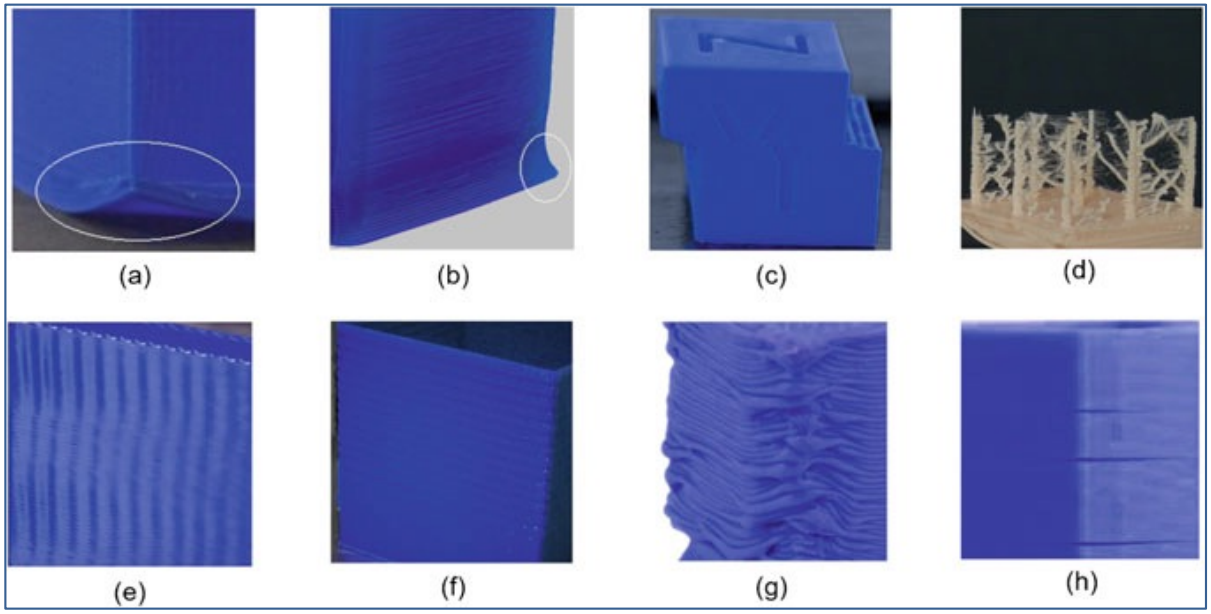
(c)

(d)

a Evektor aircraft components and FDM printed duct adapter. **b** FDM-printed electric circuit with LED **c** FDM-printed Ribcage. **d** FDM concrete printing process and the first FDM printed house by WinSun company in 2014

FDM - defects

a) Non-uniform thermal contraction
b) Close proximity of the printing nozzle to the build plate
c) Servo motors with open-loop control system
d) Retraction settings and extruder temperature
e) Printer head vibrations and/or loose machine components
f) Inconsistent extrusion (clogged nozzle/abnormal temperature variations), mechanical issues
g) Overheating
h) Poor bonding between the layers



Defects in FDM printed parts, **a** warping, **b** elephant's foot, **c** layer shifting, **d** stringing, **e** ringing, **f** z-wobble, **g** curling, and **h** layer separation

FDM - Advantages

- Compare to other major 3D printing methods, FDM is more affordable, accessible and cost-effective. Due to these reasons it is most used 3DP technology and best suited for beginners.
- FDM printer is relatively simple to operate and maintain.
- The process is relatively clean, safe and doesn't require the use of harsh chemicals.
- Feedstock materials are very diverse, readily available and affordable.
- Broad range of thermoplastic materials and exotic filaments can be printed with no or relatively few alterations on any FDM printer.
- Design of FDM printer can be scaled easily compare to other 3DP technology.

They are available in size that can fit on a desktop to size of large wardrobe.

FDM - Limitations

- The major limitation of FDM is part strength and anisotropy. Parts build by FDM are not fully dense and z-axis anisotropy arises as inter-layer bonding is not as strong as intra-layer bonding.
- Surface quality (including volumetric error, shape deviation and surface finish) of FDM is not as good as other major 3D printing methods.
- High detail prints are hard to achieve.
- Unsuitable for thin-walled products. As per thumb rule, recommended minimum wall thickness for horizontal/vertical wall is 1 mm, while curved and slant wall will require more thickness.
- FDM is primarily limited to thermoplastics based pure- and composite-materials.
  - Metal and ceramic material printing is possible by using thermoplastics based metal/ceramic reinforced filament, but it requires secondary sintering operation and resultant part will not be fully dense.