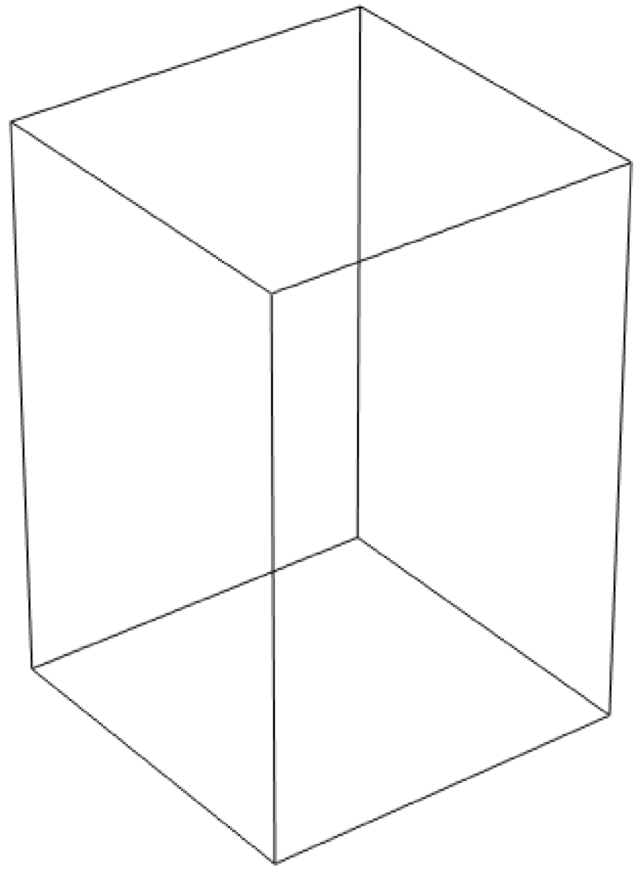
KU LEUVEN

Advanced Manufacturing Lab

COMSOL CONFERENCE 2024 FLORENCE

Investigation for thermal analysis in COMSOL for fused filament fabrication



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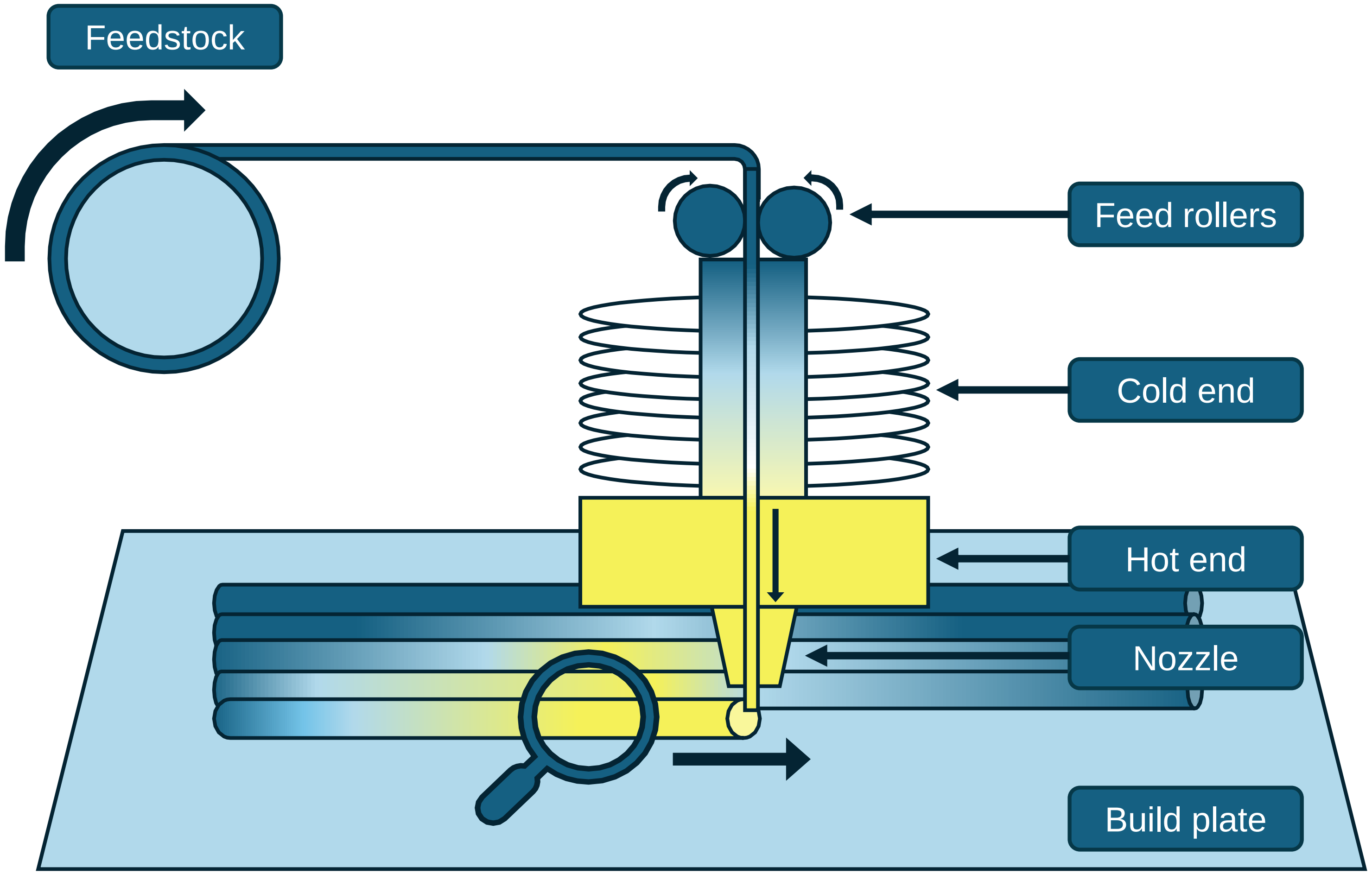
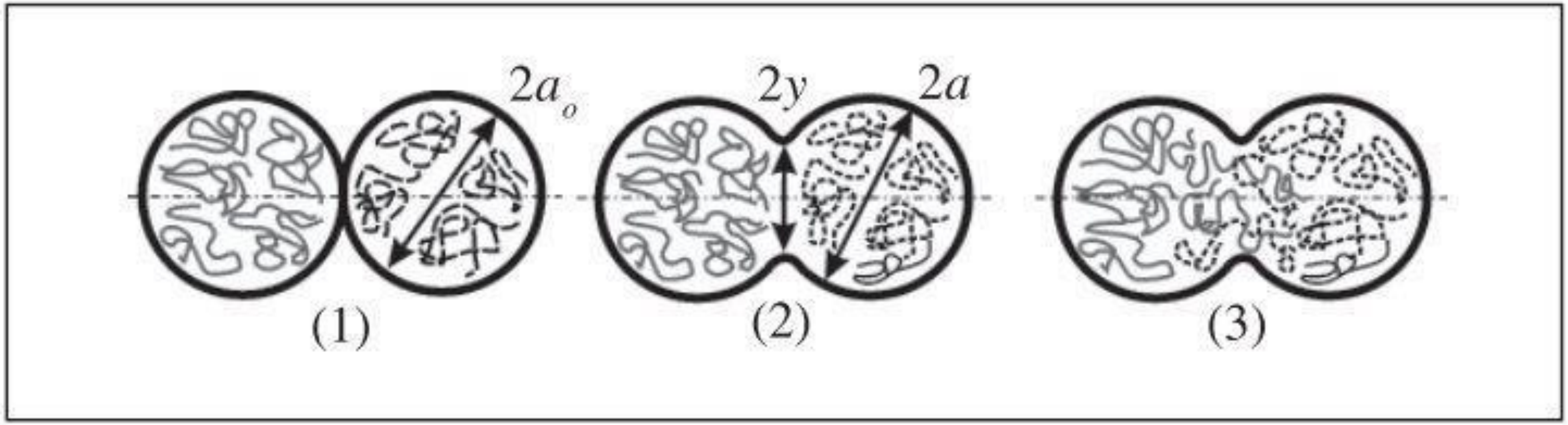
Fused Filament Fabrication (FFF)



Working principle of the Fused Filament Fabrication technology

Importance of build temperature in FFF

- Diffusion at the interface
- Temperature criterion for the (glass) phase transition ($T > T_c$)
- Cooling pattern during printing is essential

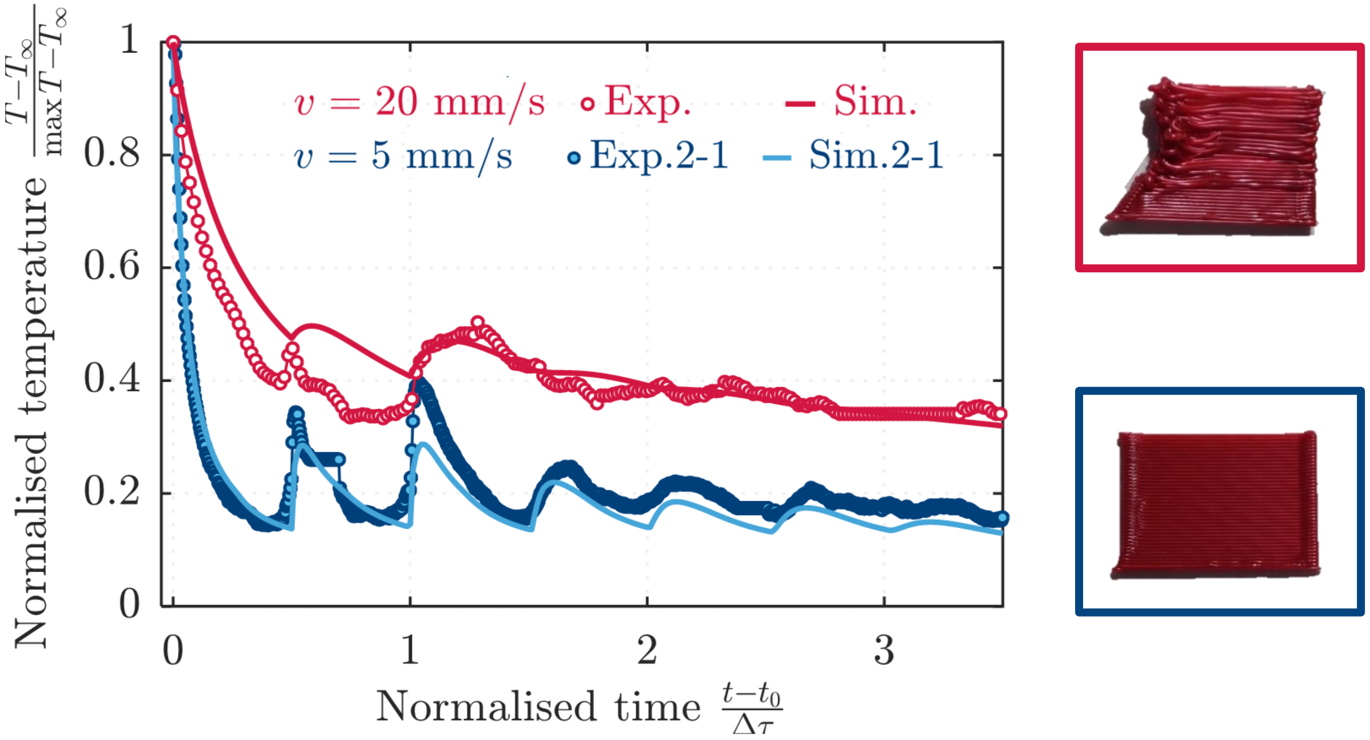


Evolution of bond formation: (1) neck formation (2) neck growth (3) diffusion at interface

Importance of build temperature in FFF

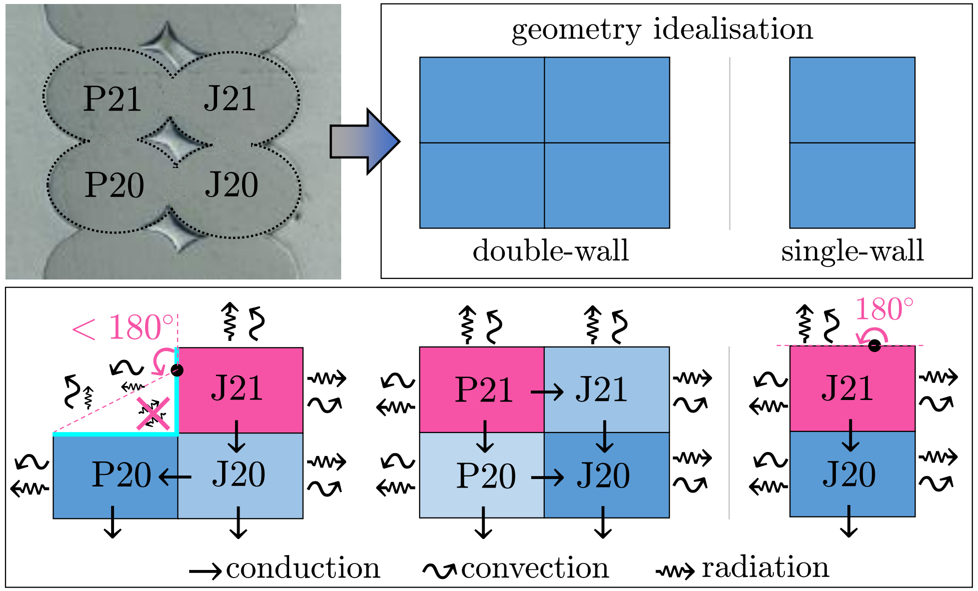
Coupled-Multiphysics

- polymer melt flow
- heat transfer
- phase change

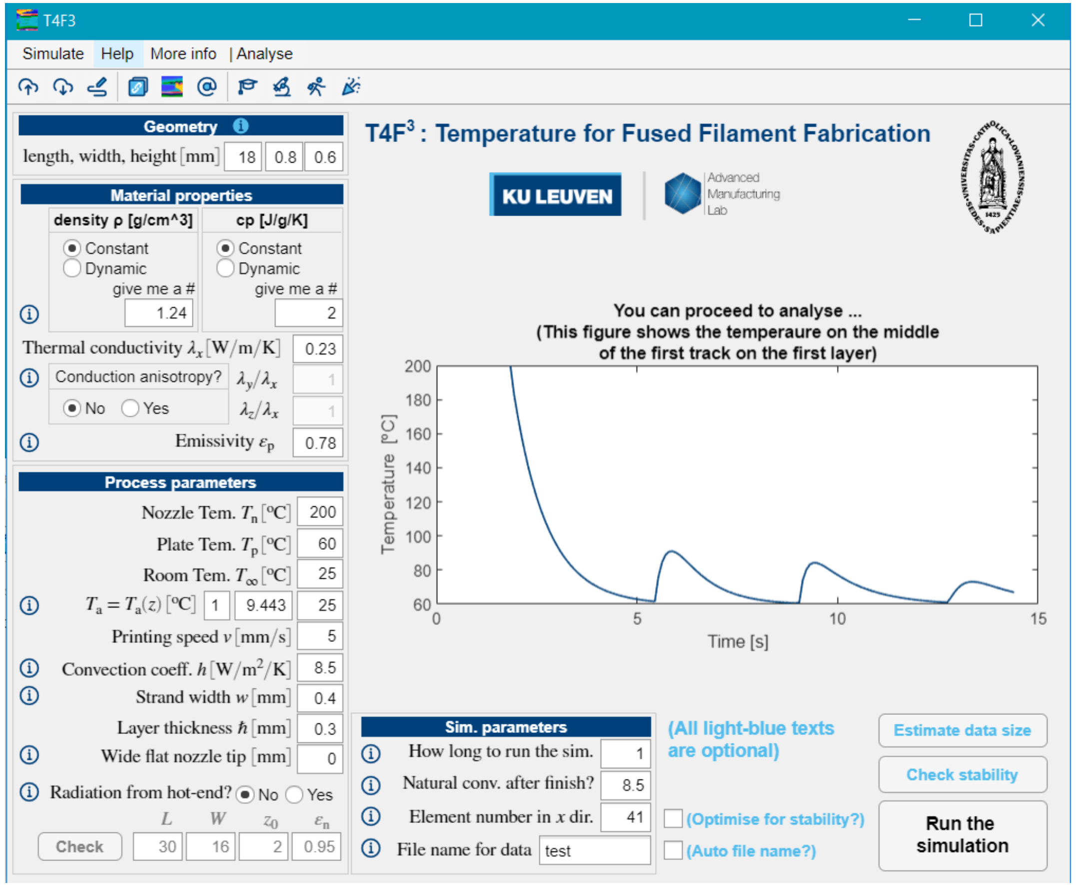


Comparison of printing speed influence on temperature and print quality

T4F3 simulation code



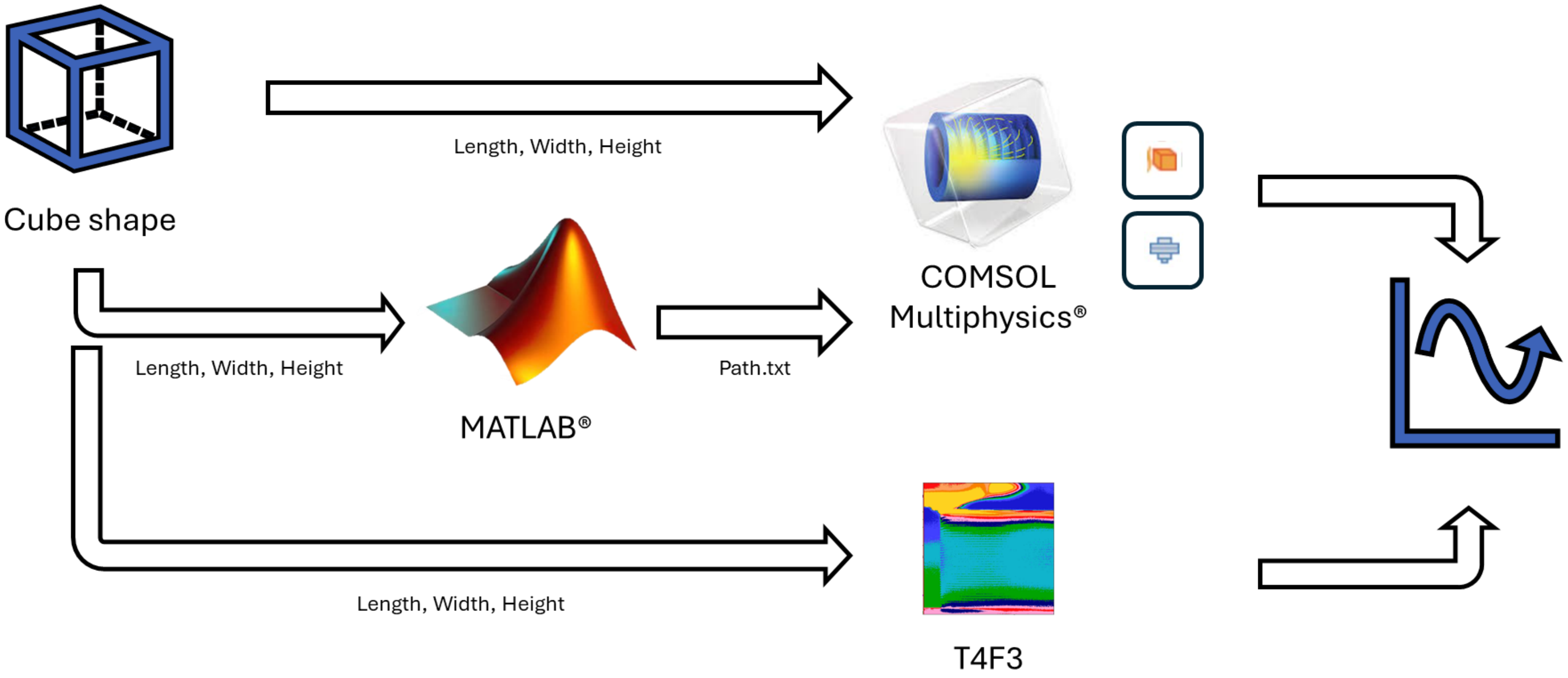
Types of energy transportation between elements



Interface T4F3-software to calculate temporal temperature

[2], software download link:
https://iiw.kuleuven.be/onderzoek/aml/technologyoffer/FFFthermalsimulation/T4F3_original

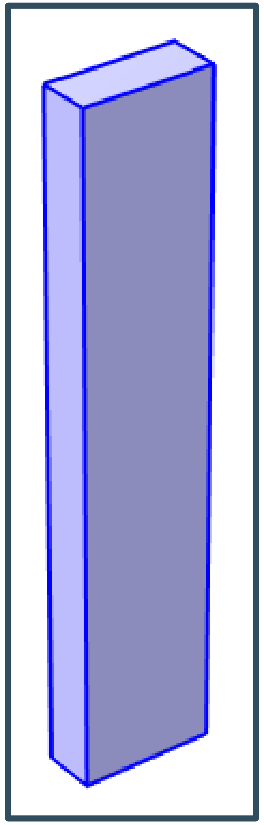
Validation methodology



Overview of working method used in this study to compare T4F3 with COMSOL

MATLAB implementation

Input



MATLAB-code

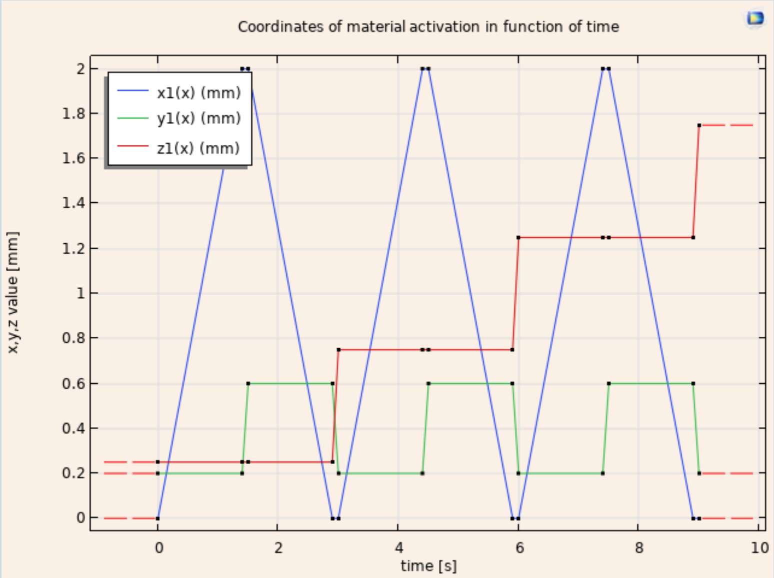
```
for z = z_list
    for y_index = 1:length(y_list)
        for x = x_list
            dist = sqrt((data.X(end)-x)^2+((data.Y(end)-y)^2));
            time = time + dist / printingSpeed;
            new_row = {time, x, y, z};
            data(row_counter, :) = new_row;
            row_counter = row_counter + 1;
        end
    end
end
```

Output

t(s)	x	y	x
0	0	0.2	0.25
1.4	18	0.2	0.25
1.5	18	0.6	0.25
2.9	0	0.6	0.25
3	0	0.2	0.75
4.4	18	0.2	0.75
4.5	18	0.6	0.75
5.9	0	0.6	0.75
6	0	0.2	1.25
7.4	18	0.2	1.25
7.5	18	0.6	1.25
8.9	0	0.6	1.25
9	0	0.2	1.75

COMSOL implementation

Interpolation & Activation



If

(abs(x-x1(t))<= x_length/4

&& abs(y-y1(t))<= Strand_width/2

&& abs(z-z1(t))<= Layer_heigth/2

,1,0)

Heat transfer module

Solid:

- Thermal cond., density, heat capacity ➔ user defined
- If(solid.isactive, PLA, Air)

Temperature:

- Build plate temperature

Heat source:

- Go to T_{nozzle} at activation function location

Heat flux:

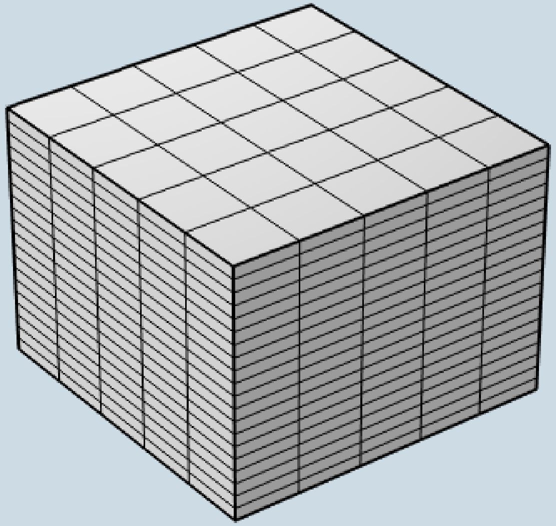
- Convection at boundary

Mesh

Cubic mesh

Mesh size:

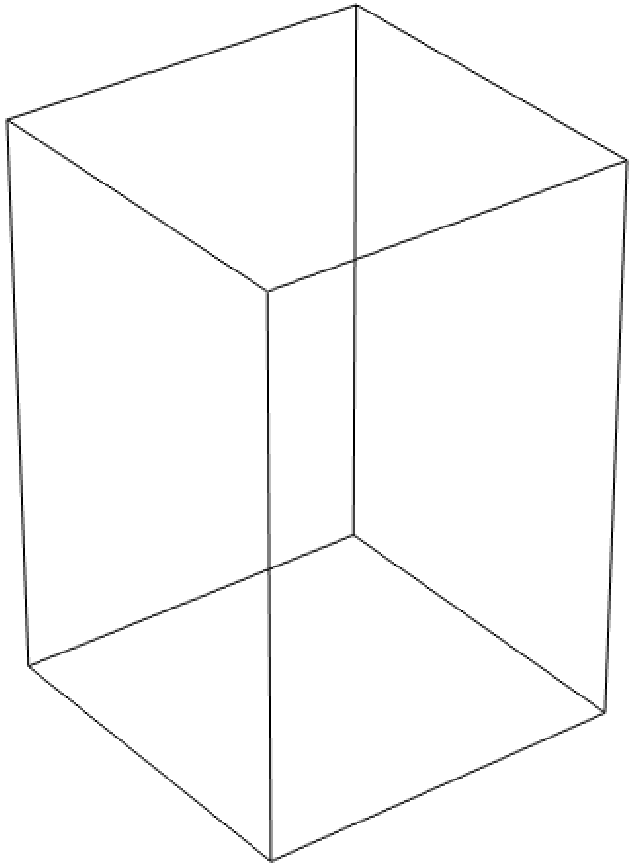
- Y: Size of strand
- Z: Layer heigth/4



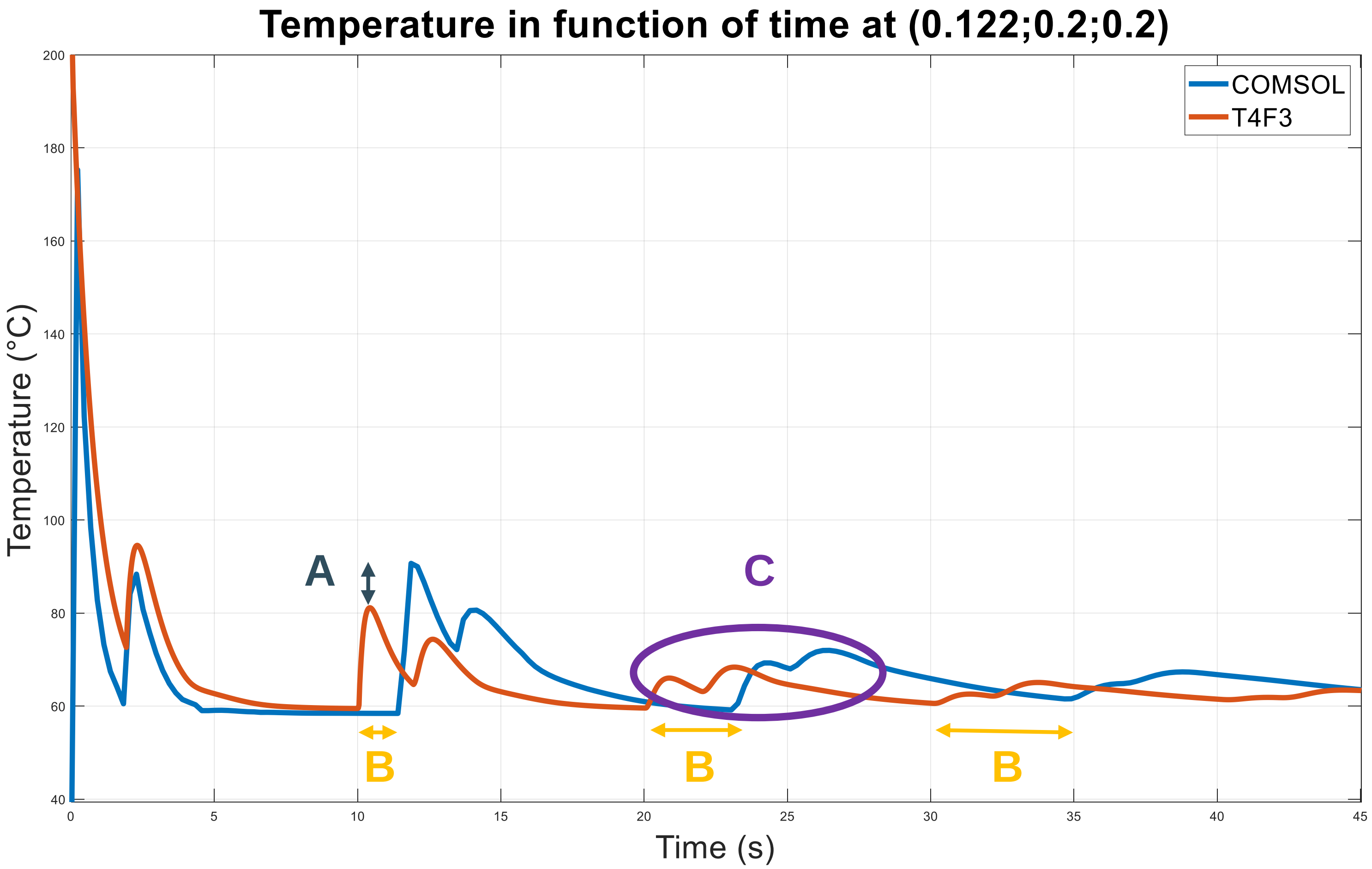
Preliminary results

Simulation settings

- 4x4x6 mm cube
- Printing speed 5 mm/s
- PLA print material
- T_{nozzle} = 200°C
- $T_{build\ plate}$ = 60°C
- T_{room} = 20°C



Preliminary results: Comparison to T4F3



A: Different temperature peaks
- Data collection method
- Source temperature difference
- Cooling rate difference

B: Time shifts
- Different path generation

C: Similar effect next layers
- More analysis of patterns is needed

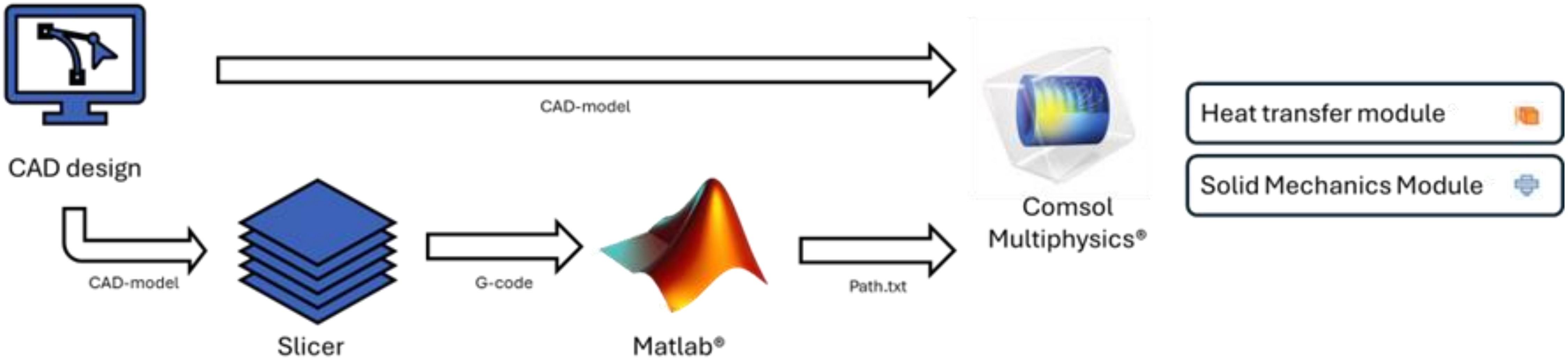
Conclusion

New insights

- Workflow for use of COMSOL in FFF thermal simulation
- Conversion from T4F3 results

Future work

- Improve current model (accuracy and calculating efficiency)
- Make step towards free-form simulations



Thank you!

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References

[1] Bellehumeur, C., Li, L., Sun, Q., & Gu, P. (2004). Modeling of Bond Formation Between Polymer Filaments in the Fused Deposition Modeling Process. *Journal of Manufacturing Processes*, *6*(2), 170–178. https://doi.org/10.1016/S1526-6125(04)70071-7

[2] J. Zhang, B. Van Hooreweder, and E. Ferraris, “T4F3: temperature for fused filament fabrication,” Progress in Additive Manufacturing, vol. 7, no. 5, pp. 971–991, Oct. 2022, doi: 10.1007/S40964-022-00271-0/FIGURES/15.