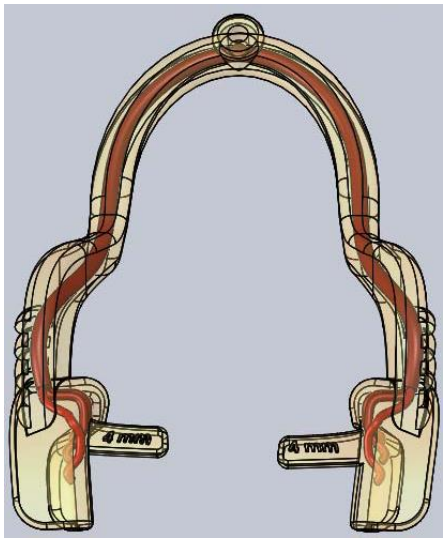
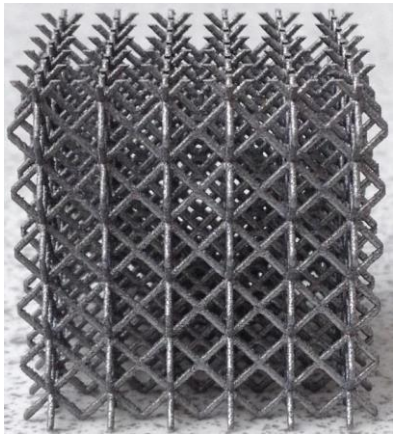
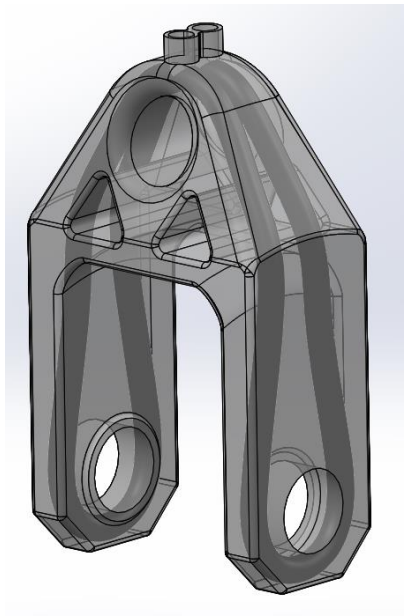
Design for AM

Taking advantage of internal features.







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uclan University of Central Lancashire | Centre for Advanced Digital Manufacturing Technology

uclan University of Central Lancashire | Jost Institute for Tribotechnology

University of Central Lancashire

(not Lancaster University)

Dr Hadley Brooks

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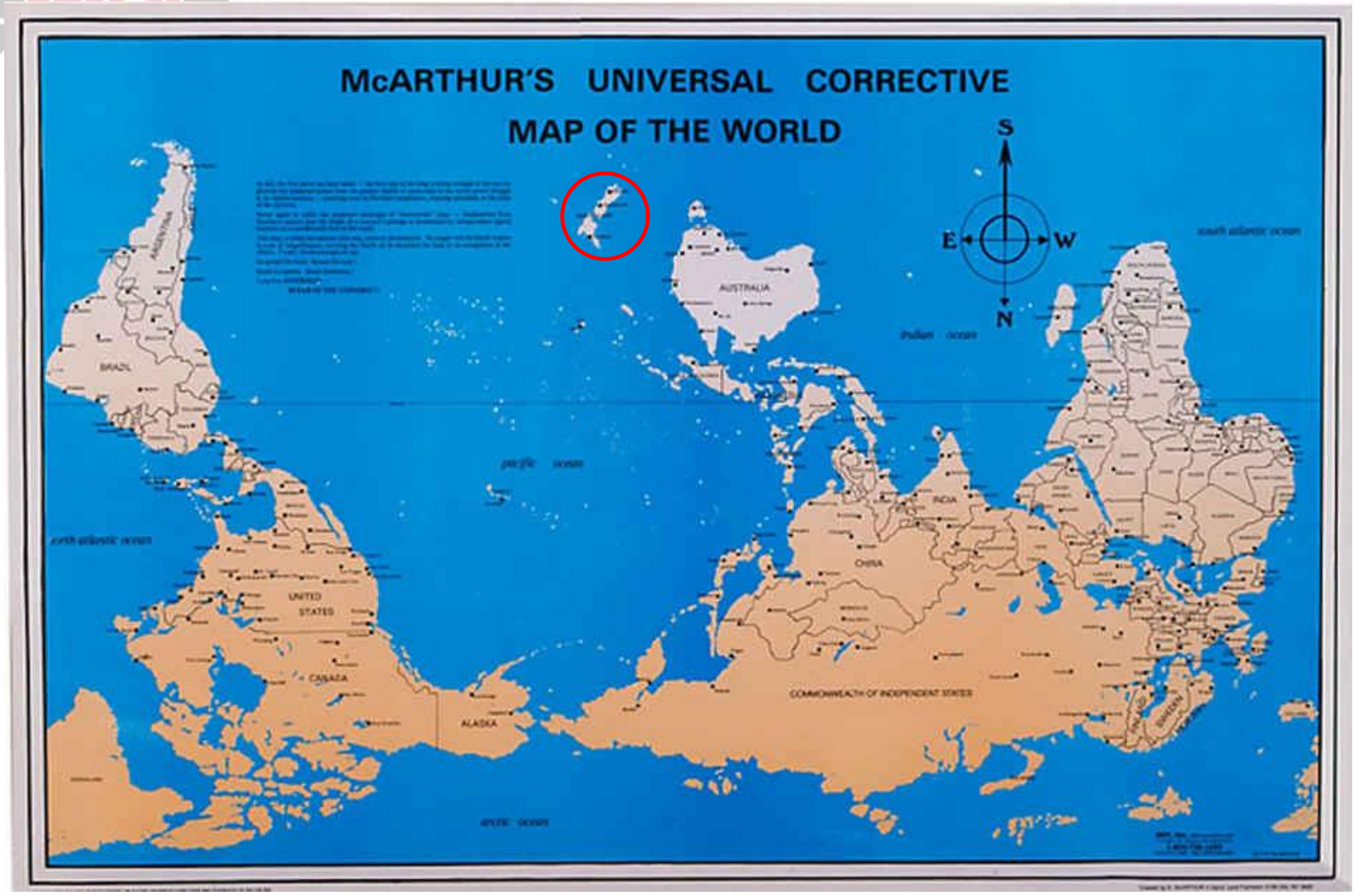
About me…


McARTHUR'S UNIVERSAL CORRECTIVE
MAP OF THE WORLD
S
E
W
N
AUSTRALIA
BRAZIL
INDIA
CHINA
UNITED STATES
CANADA
ALASKA
COMMONWEALTH OF INDEPENDENT STATES

About me…

Experience:

- PhD – University of Canterbury (NZ): Subtractive RP using robotic foam sculpting.
- Design Engineer – Lancaster University
- Lecturer of Engineering – University of Central Lancashire

Research interests:

- Meso-structures, tailoring mechanical properties
- Design methodology and application
- New materials from waste streams
- AM and systems integration, particularly for smart machines

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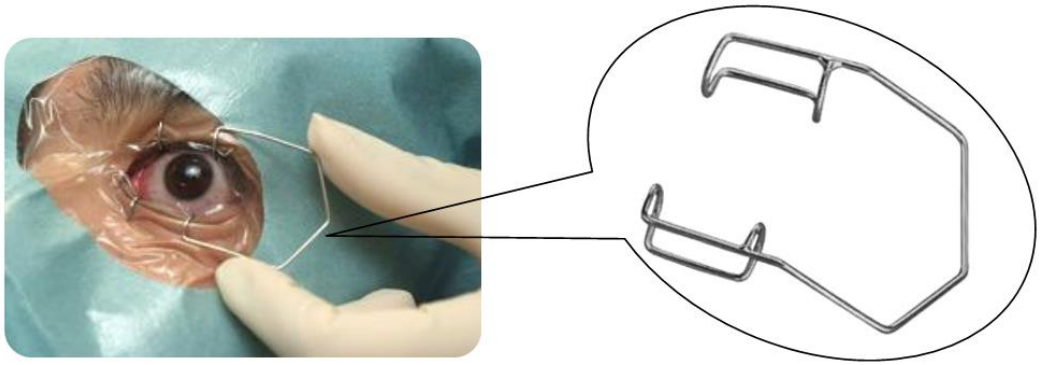
Content:

- Focus on design for AM plus design for added functionality
- Share 3 examples
- Common theme is taking advantage of internal features
- Hope to inspire creative design

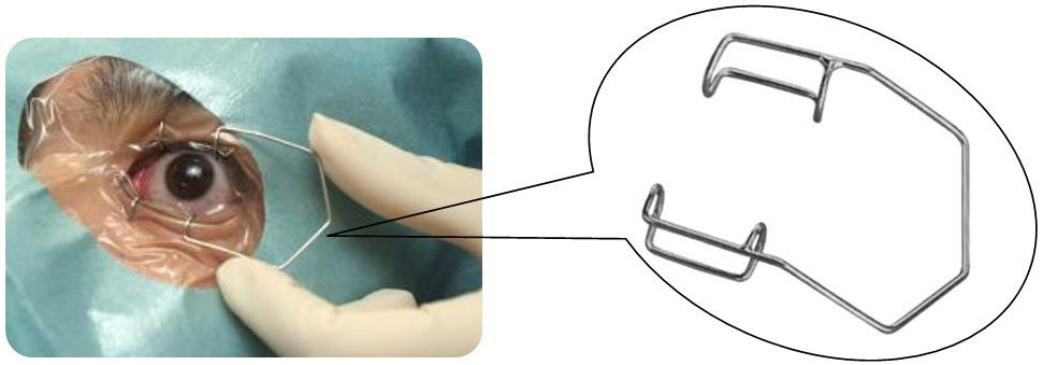
Example 1: Ocular speculum

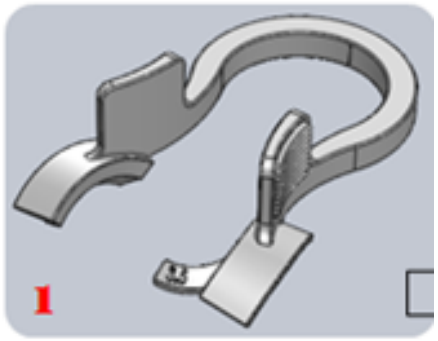


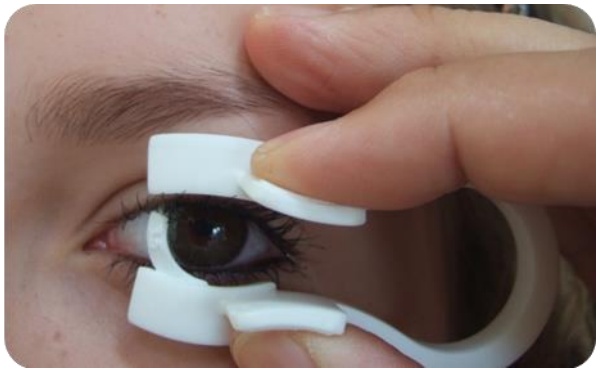
- 300,000 procedures annually
- Often painful for the patient
- Cause bleeding
- Retinal tear / detachment
- Lead to cataracts
- Dry eyes

*Lupeanu, M, Brooks, H, Rennie, A & Hill, D 2013, 'Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions' Buletinul Ştiinţific al Universităţii Politehnica Bucureşti, Seria D – Inginerie Mecanică, vol 75, no. 1, pp. 141-160.

Ocular speculum







*Lupeanu, M, Brooks, H, Rennie, A & Hill, D 2013, 'Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions' Buletinul Ştiinţific al Universităţii Politehnica Bucureşti, Seria D – Inginerie Mecanică, vol 75, no. 1, pp. 141-160.

Ocular speculum

Ocular speculum – cost/ value structure (Iteration 2)

Component Costs		Total Costs (£)	Functions				
			F1	F2	F3	F4	F5
Speculum	Maintain eyelids position	1.80	1.80	-	-	-	-
	Keep away eyelashes	1.40	-	1.40	-	-	-
	Measuring element	1.10	-	-	1.10	-	-
	Anaesthetic delivery system	0.50	-	-	-	0.50	-
	Humidify system	0.50	-	-	-	0.50	-
	Grip element	1.20	-	-	-	1.20	-
	Use in both eyes elements	0.40	-	-	-	-	0.40
Function Costs in Value (£)		6.90	1.80	1.40	1.10	2.20	0.40
Function Costs in Percentage (%)			26.1%	20.2%	16%	31.9%	5.7%

*Lupeanu, M, Brooks, H, Rennie, A & Hill, D 2013, 'Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions' Buletinul Ştiinţific al Universităţii Politehnica Bucureşti, Seria D – Inginerie Mecanică, vol 75, no. 1, pp. 141-160.

Ocular speculum

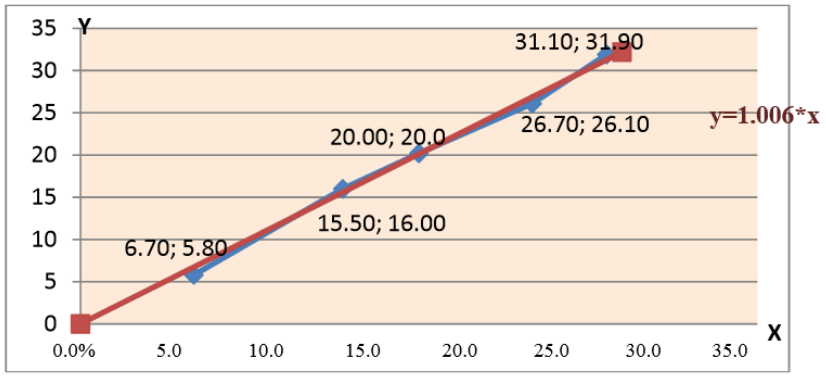


Fig. 7. The importance of functions in value (x_i) and costs (y_i) for the ocular speculum.

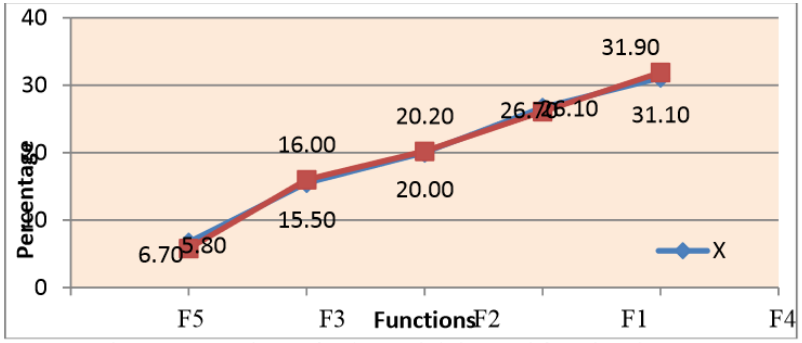
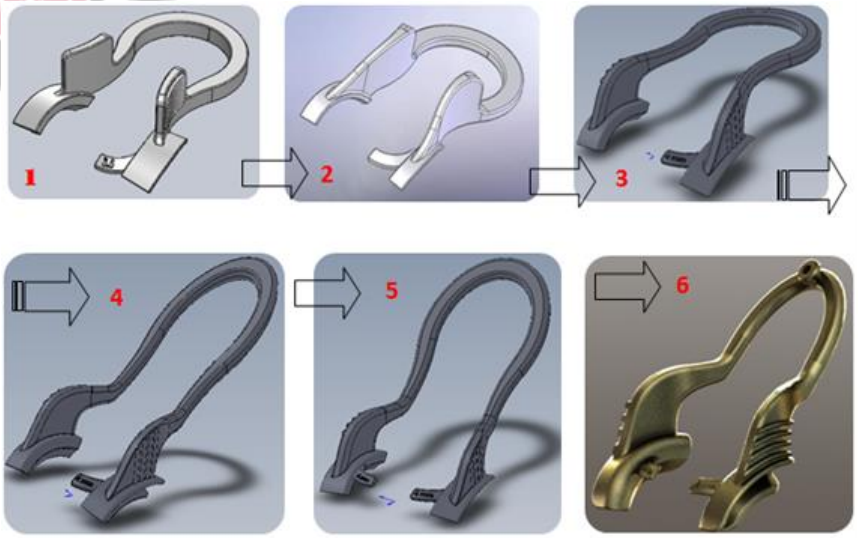
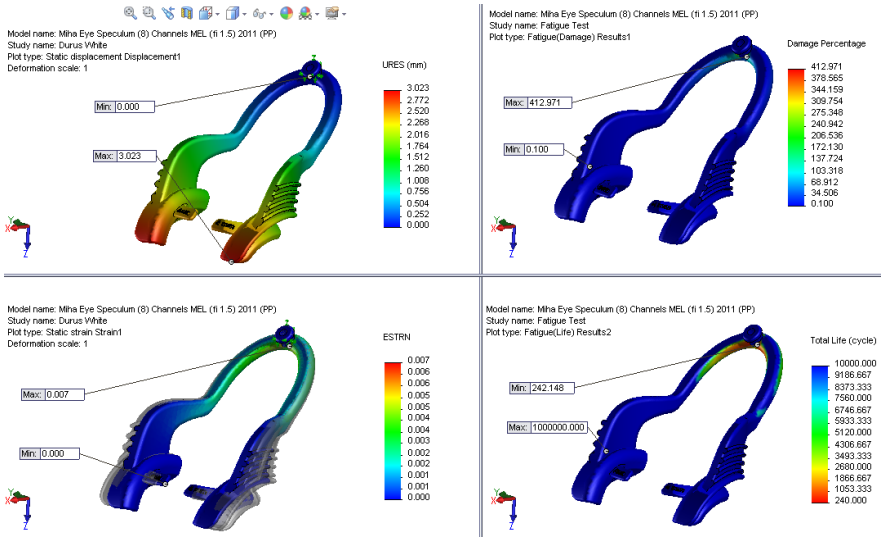


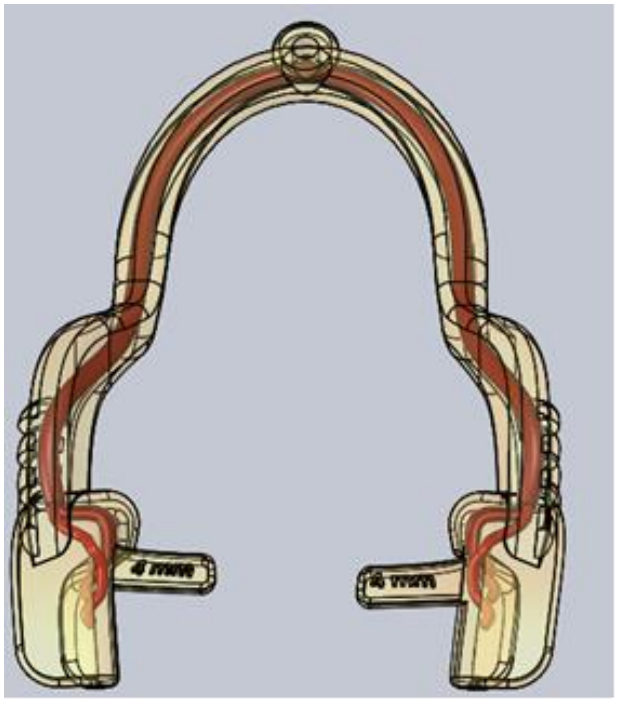
Fig. 8. Comparison of value weighting and functional costs.

*Lupeanu, M, Brooks, H, Rennie, A & Hill, D 2013, 'Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions' Buletinul Ştiinţific al Universităţii Politehnica Bucureşti, Seria D – Inginerie Mecanică, vol 75, no. 1, pp. 141-160.

Ocular speculum



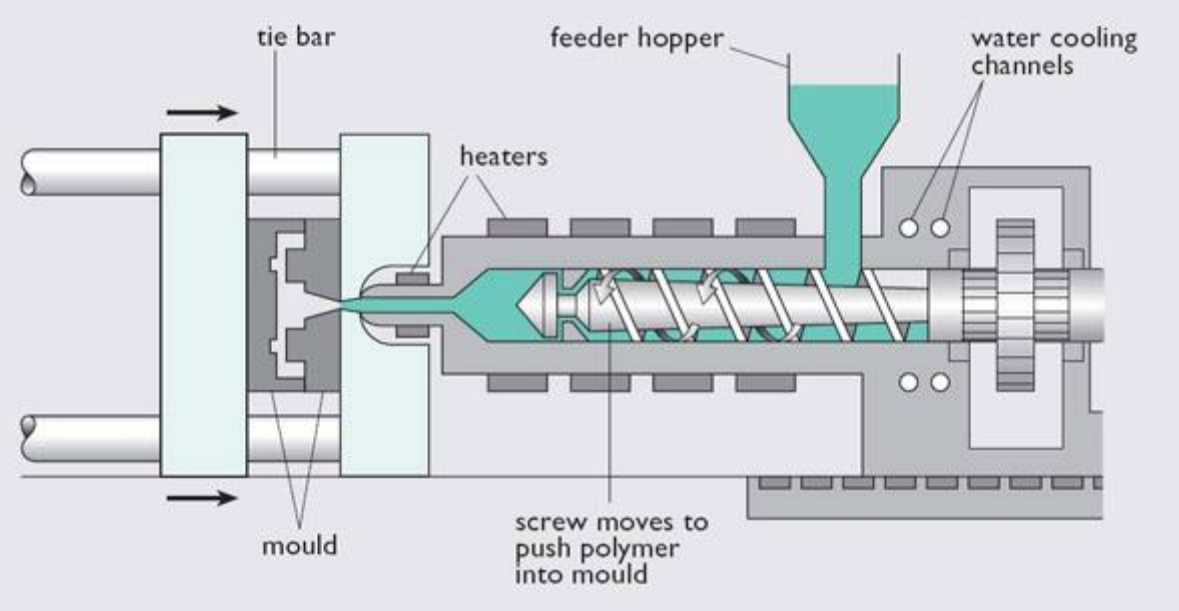




Material: MED 610 polyjet (Objet). Biocompatible material for applications requiring prolonged skin contact of more than 30 days and short-term mucosal-membrane contact of up to 24 hours.

*Lupeanu, M, Brooks, H, Rennie, A & Hill, D 2013, 'Research on deploying technical functional analysis for additive manufacturing of a surgical device for intravitreal interventions' Buletinul Ştiinţific al Universităţii Politehnica Bucureşti, Seria D – Inginerie Mecanică, vol 75, no. 1, pp. 141-160.

Example 2: Conformal cooling



*http://www.anole-hot-runner.com/hot-runner-mould.htm

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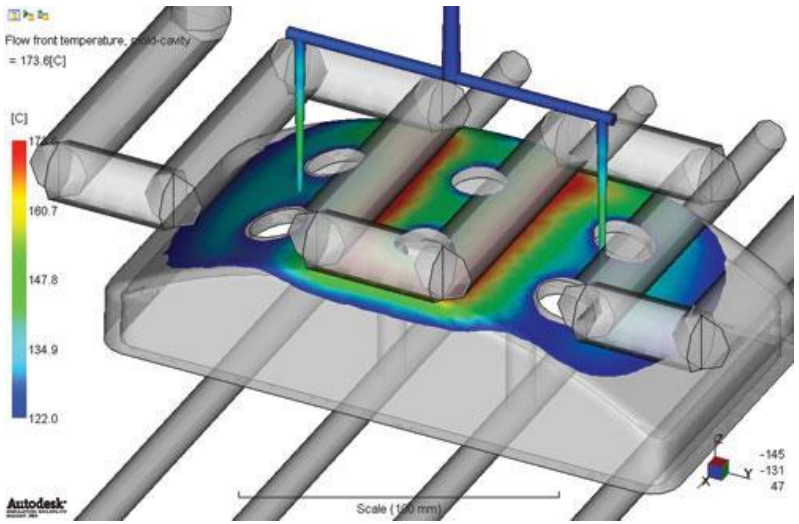
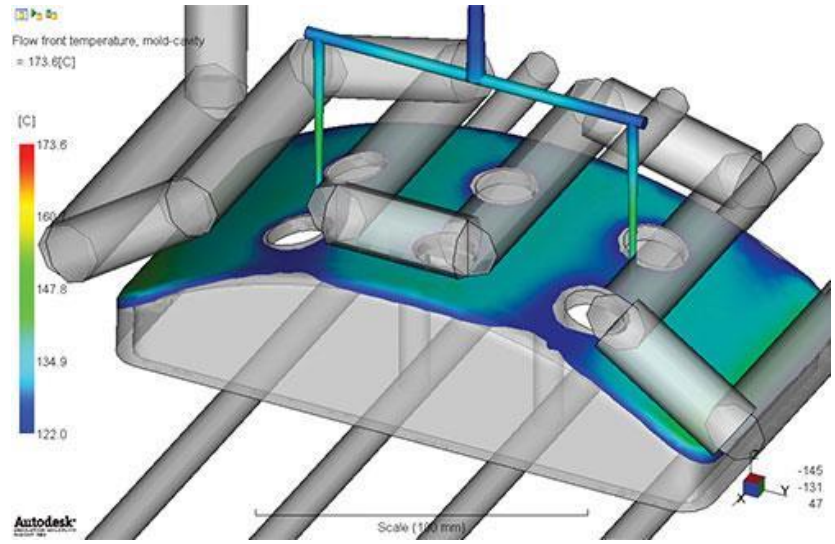
Conformal cooling





*http://www.moldmakingtechnology.com/articles/software-advances-push-limits-of-speed-and-quality

More uniform cooling and faster cycle times

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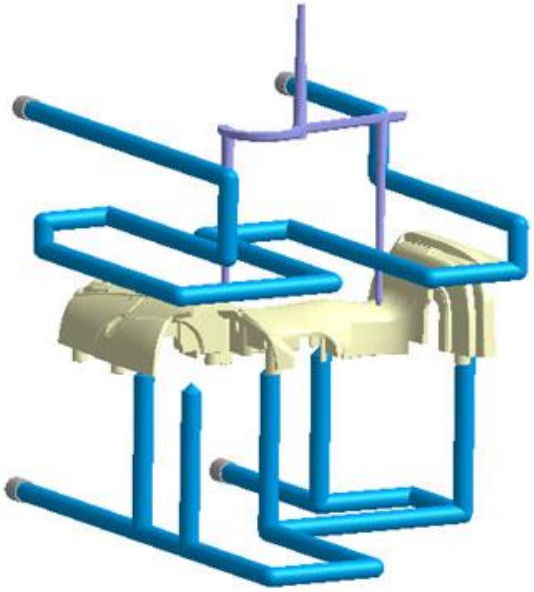
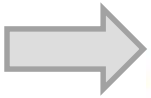
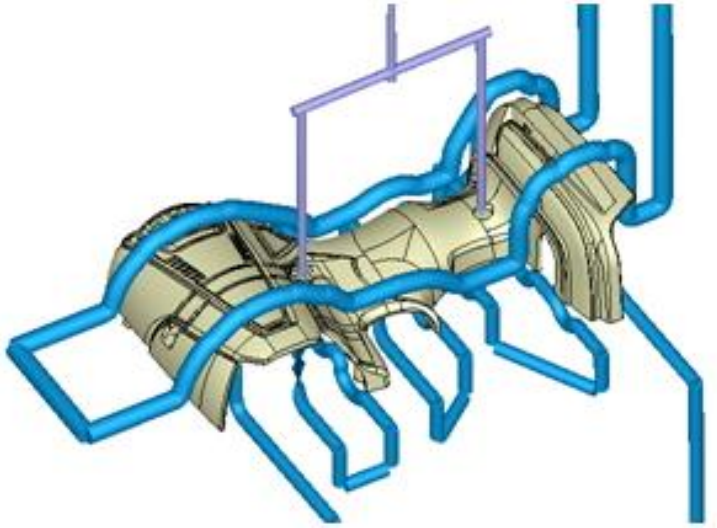
Conformal cooling







AM allows cooling to go from this…

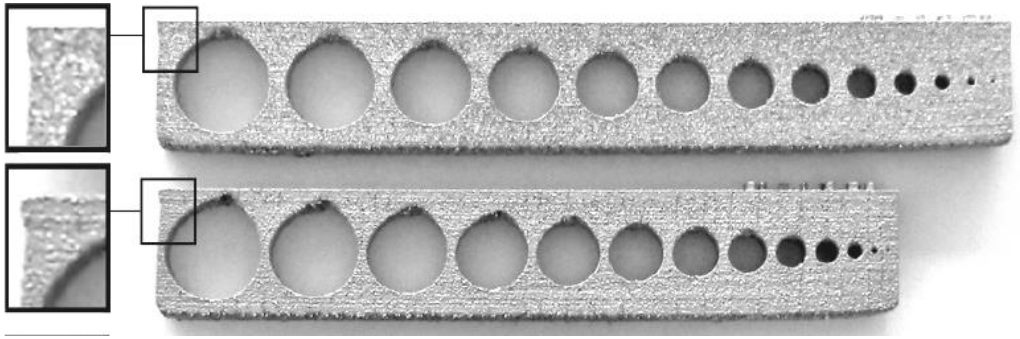
to this

The cooling channels no longer have to be straight.

But…. Why are we sticking with circular channels?

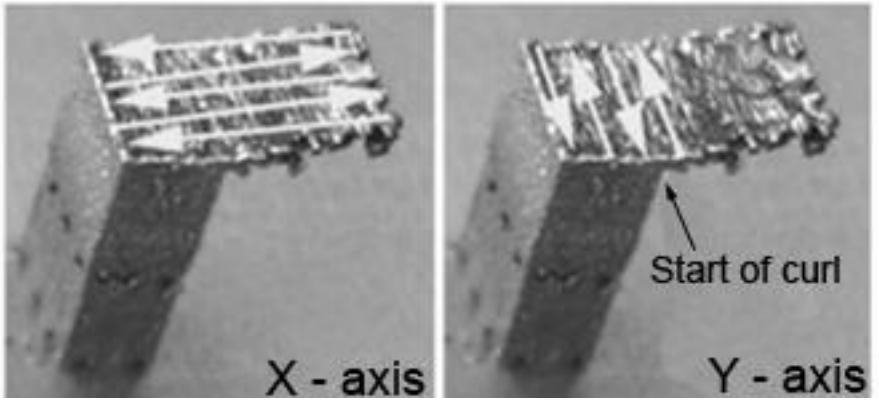
*http://www.moldex3d.com/en/newsletter/enhancing-product-quality-via-conformal-cooling-design

Conformal cooling



Small holes can often be printed without support structures

Unsupported overhangs lead to build failures



*Thomas D, PhD thesis, 'The Development of Design Rules for Selective Laser Melting', University of Wales, 2010. http://homepages.lboro.ac.uk/~cdrjb/design_for_AM_publications_files/Daniel_Thomas-PhD.pdf

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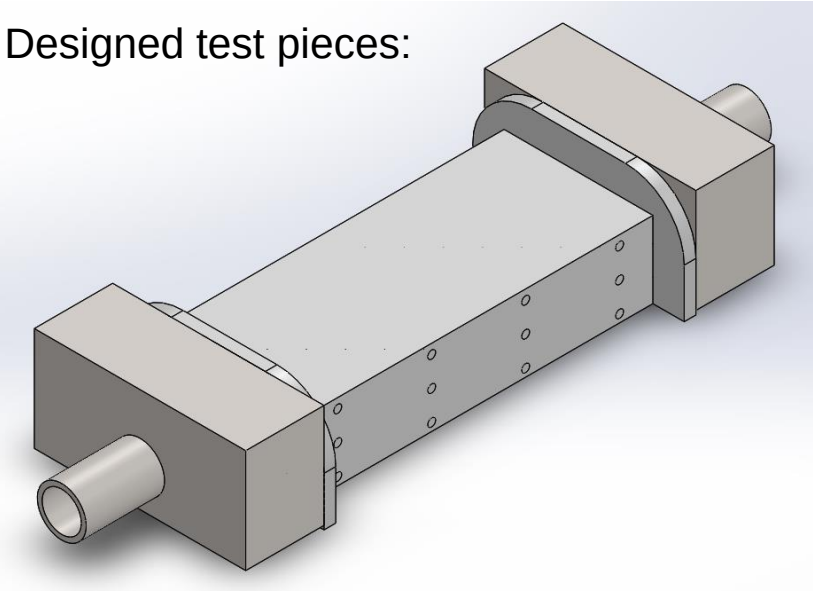
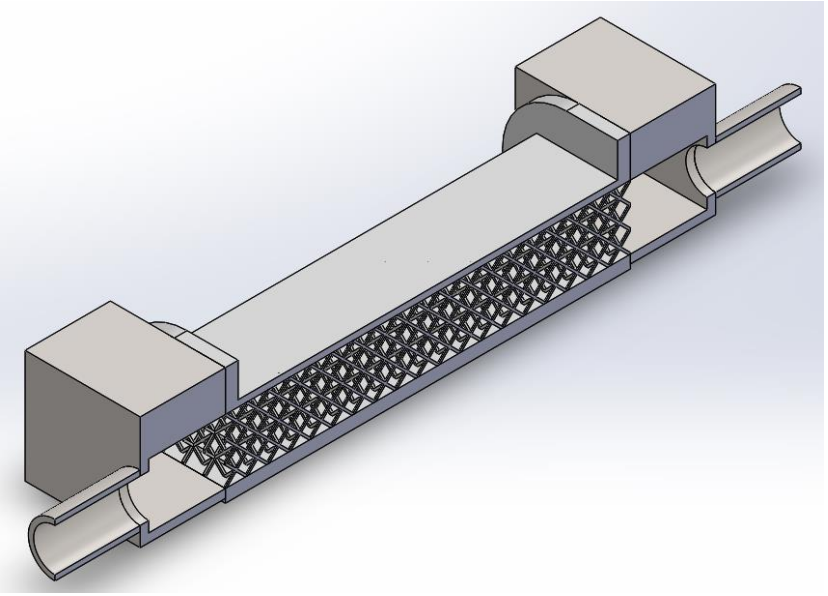
Conformal cooling

RENISHAW
apply innovation

Why not use a lattice to enable a fully flooded layer that conforms with and supports the mould surface?

Designed test pieces:





Lattice provides structural support and improves convective heat transfer with turbulent flow.

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Conformal cooling

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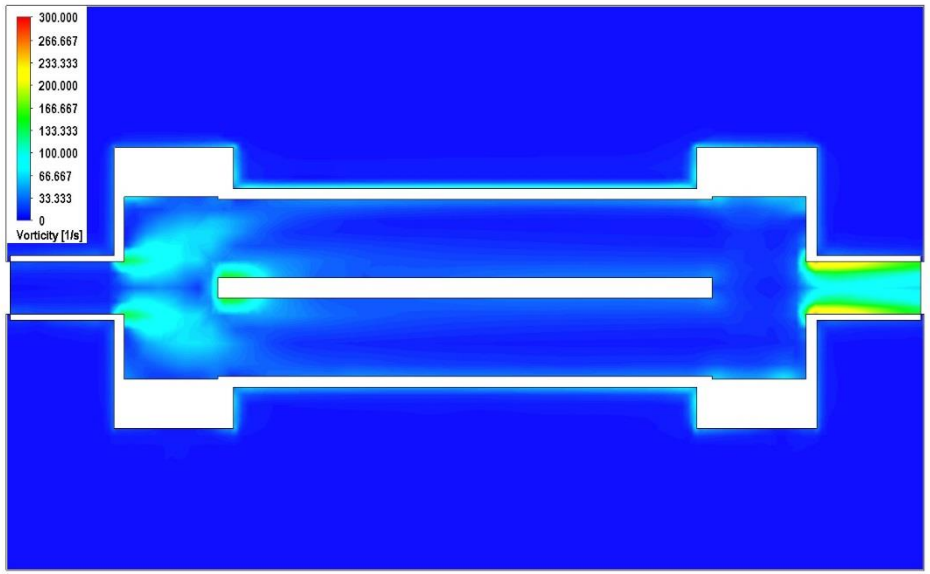
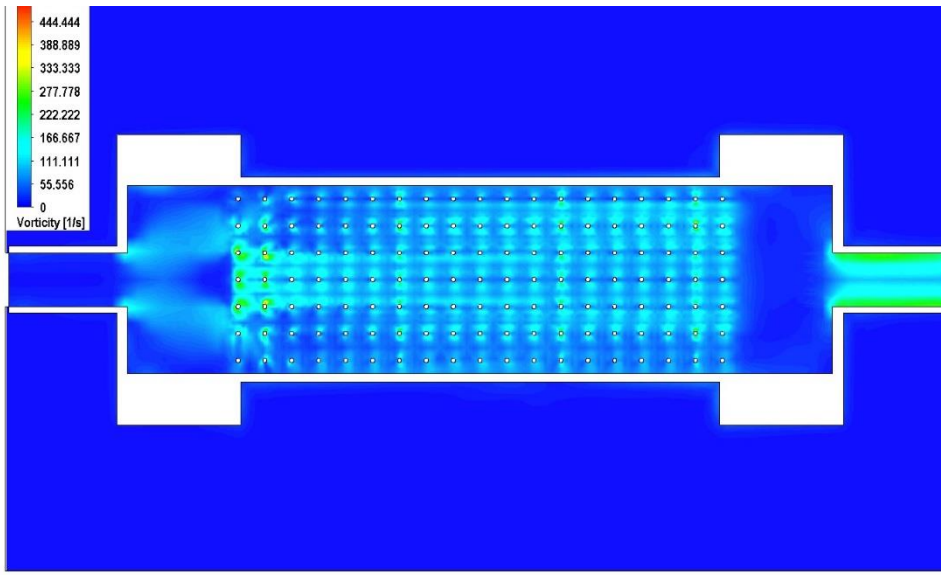
apply innovation

Drilled channels vorticity



Lattice channel vorticity



Identical flow rate

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Conformal cooling

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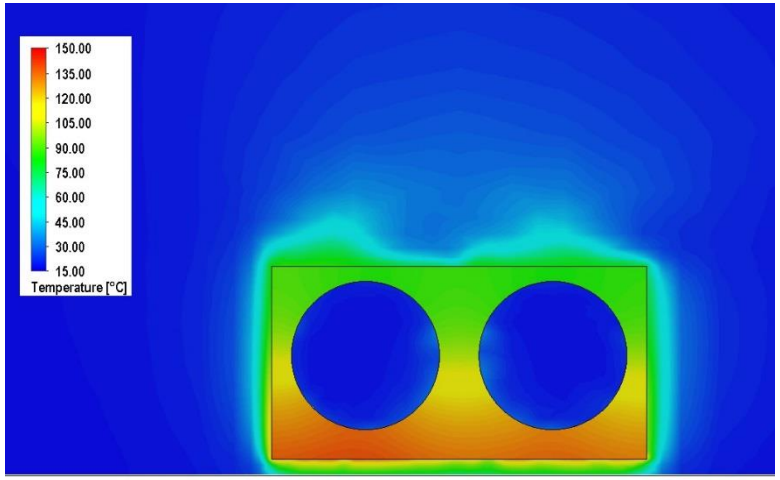
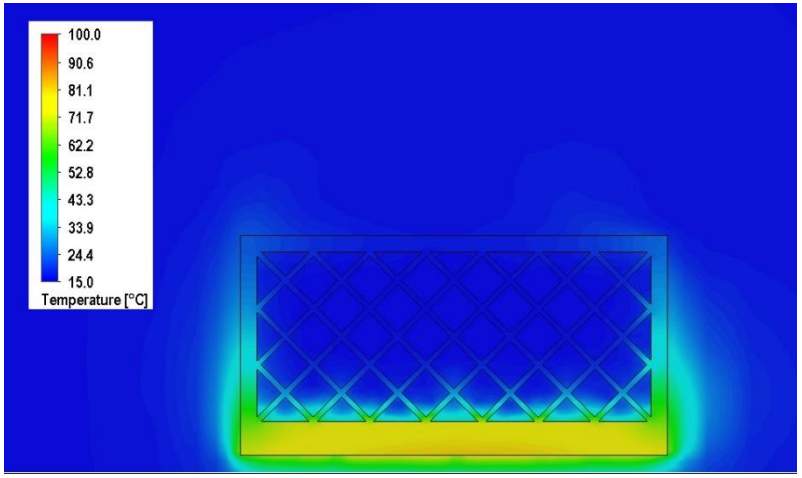
apply innovation

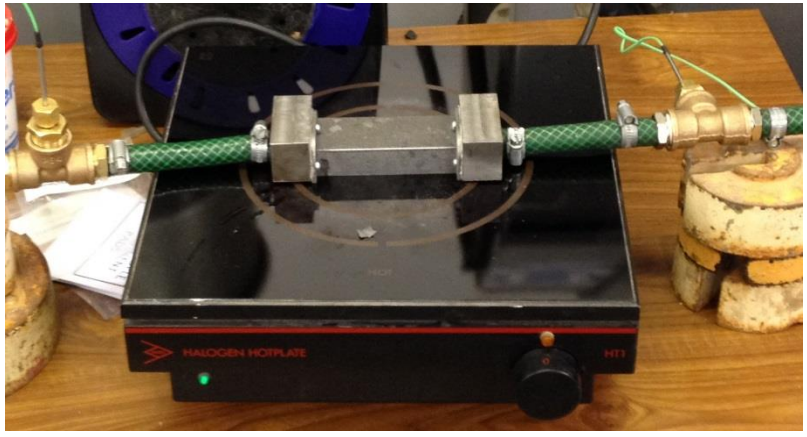
Drilled channels temperature



Lattice channel temperature



Identical heat generation on bottom surface



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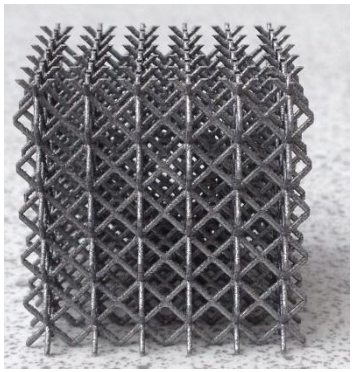
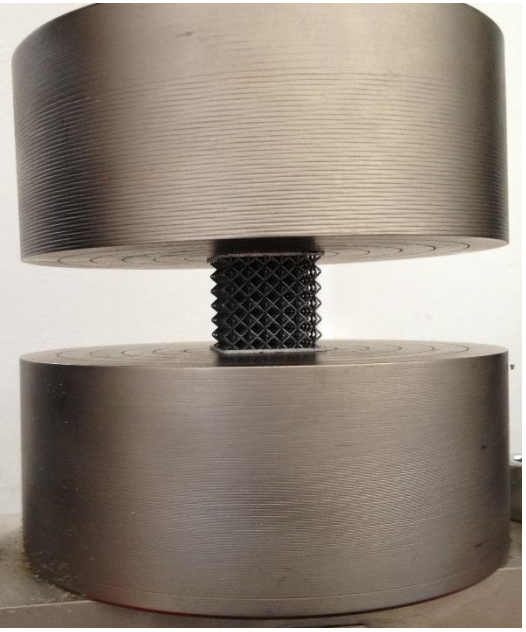
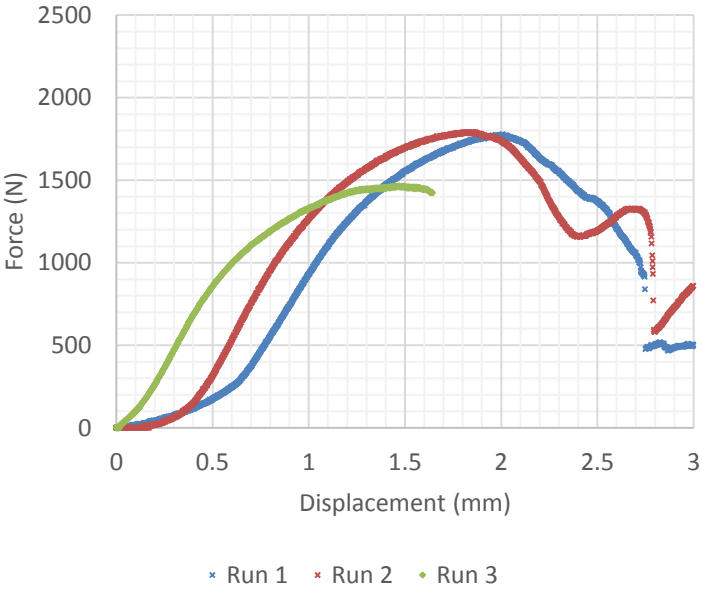
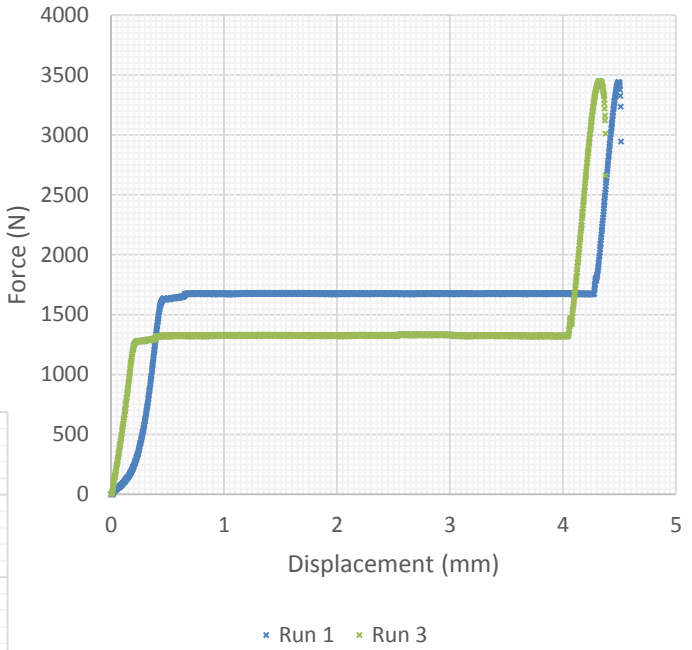
Conformal cooling

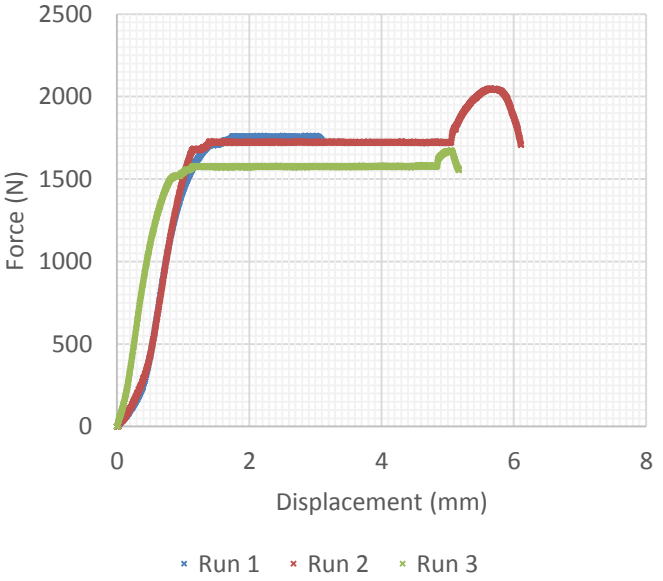
Compression characteristics











Extremely variable stress strain characteristics!

Example 3: Structural reinforcement in 3D printed parts

There are 3 main methods:

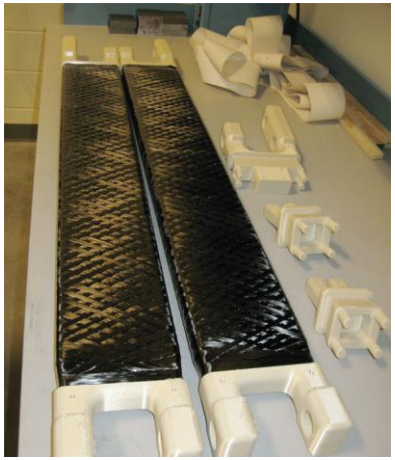
*http://www.graphite.uk.com/services/247-2

*http://colorfabb.com/xt-cf20

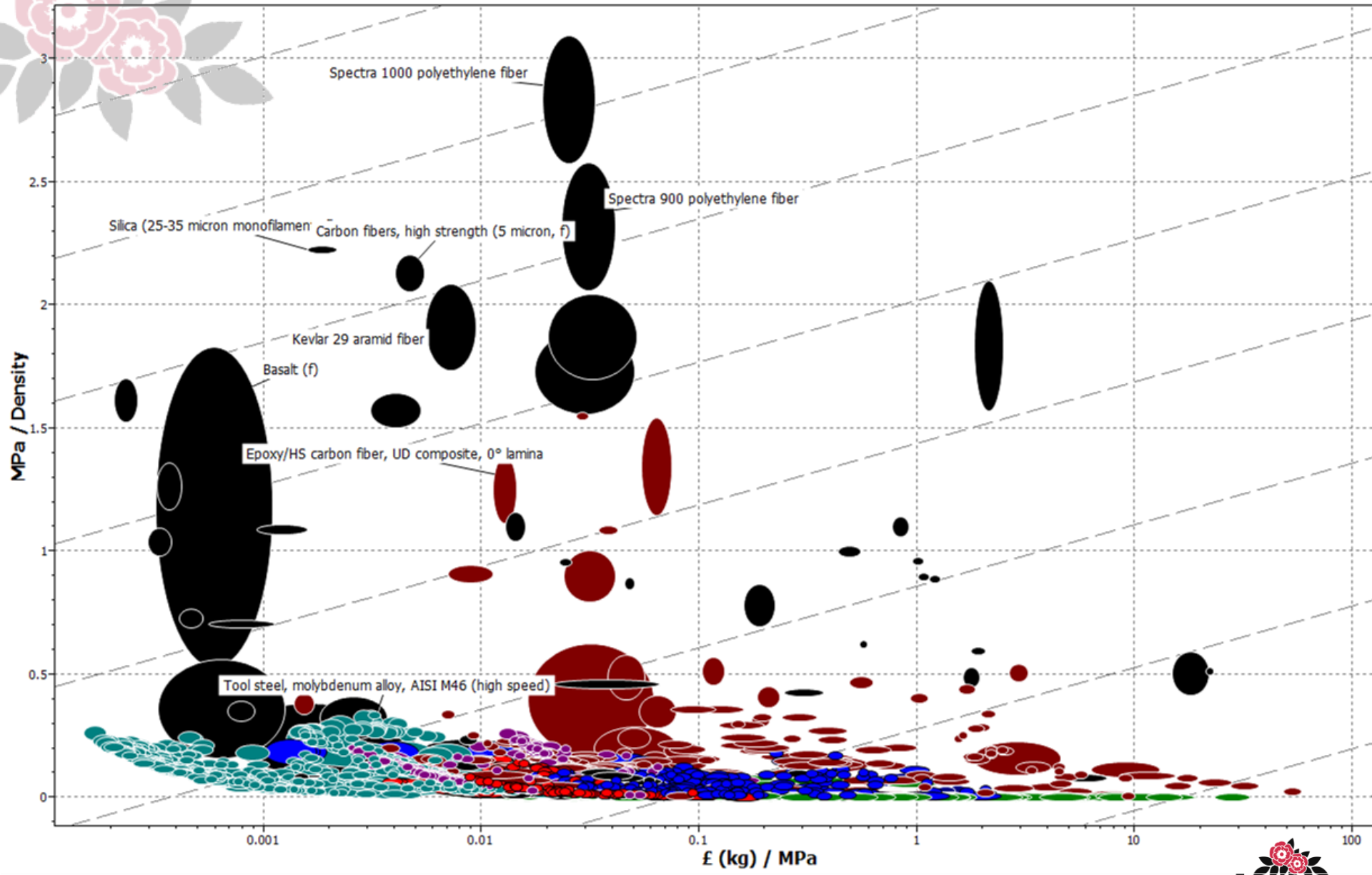
Randomly oriented short fibres

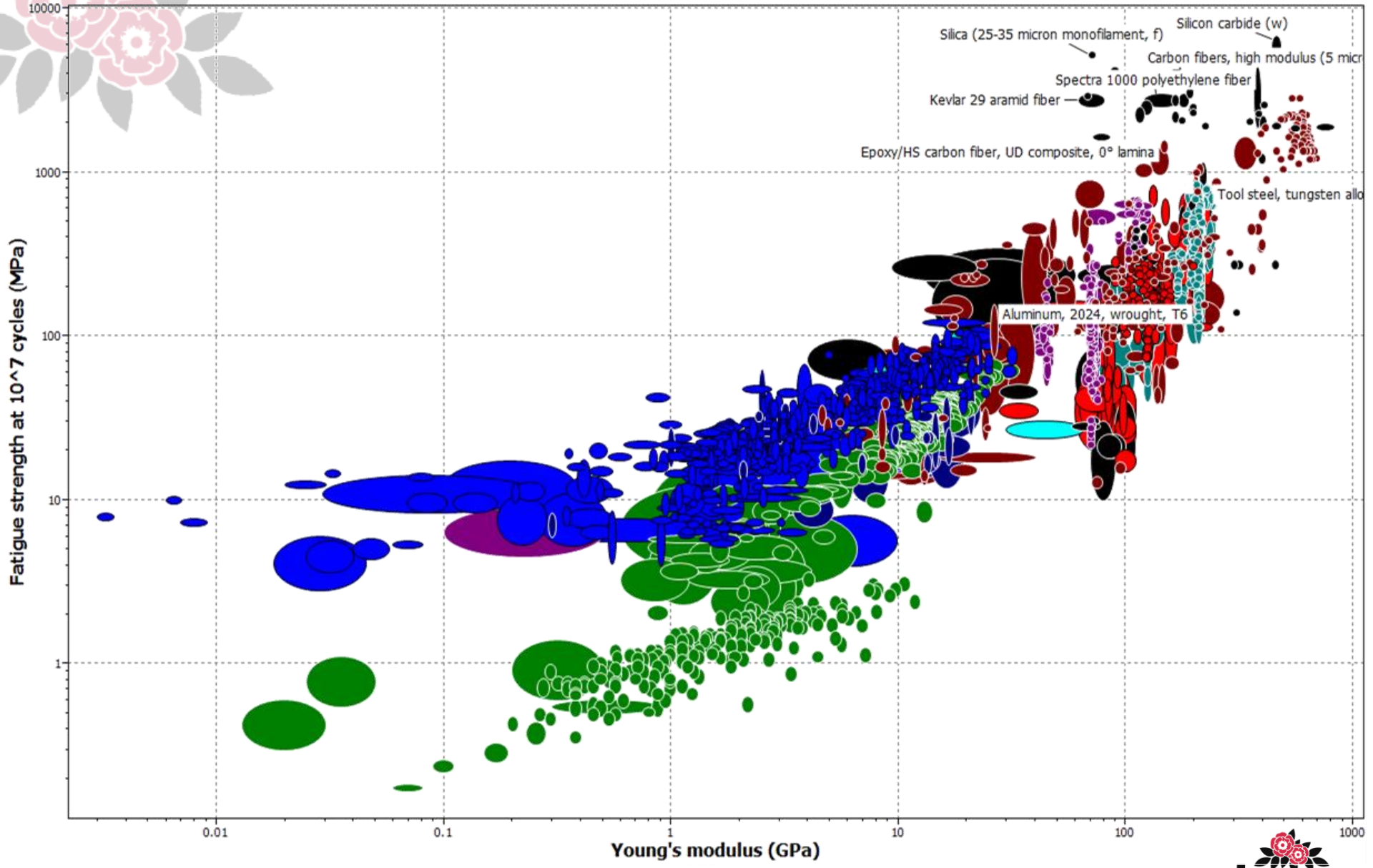
*https://markforged.com/part-gallery/

2D directional continuous fibres



3D directional continuous fibres


Spectra 1000 polyethylene fiber
Spectra 900 polyethylene fiber
Silica (25-35 micron monofilamen
Carbon fibers, high strength (5 micron, f)
Kevlar 29 aramid fiber
Basalt (f)
Epoxy/HS carbon fiber, UD composite, 0° lamina
Tool steel, molybdenum alloy, AISI M46 (high speed)
MPa / Density
£ (kg) / MPa
0
0.5
1
1.5
2
2.5
3
0.001
0.01
0.1
1
10
100


Silicon carbide (w)
Silica (25-35 micron monofilament, f)
Carbon fibers, high modulus (5 micr
Spectra 1000 polyethylene fiber
Kevlar 29 aramid fiber
Epoxy/HS carbon fiber, UD composite, 0° lamina
Tool steel, tungsten allo
Aluminum, 2024, wrought, T6
Fatigue strength at 10^7 cycles (MPa)
10000
1000
100
10
1
0.01
0.1
1
10
100
1000
Young's modulus (GPa)

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So how can you incorporate reinforcement into AM parts in the most effective way?

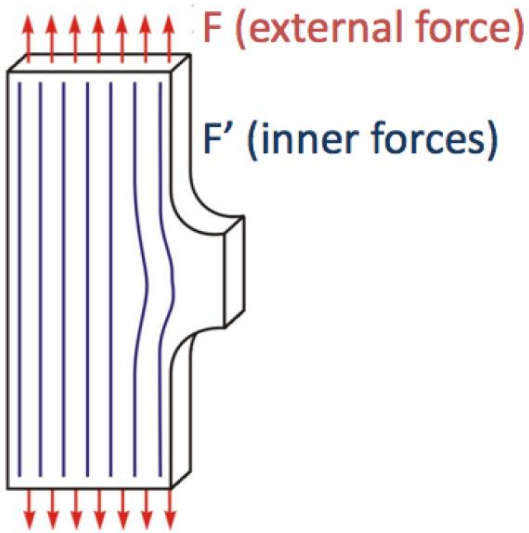
1. Qualitative analysis using force lines

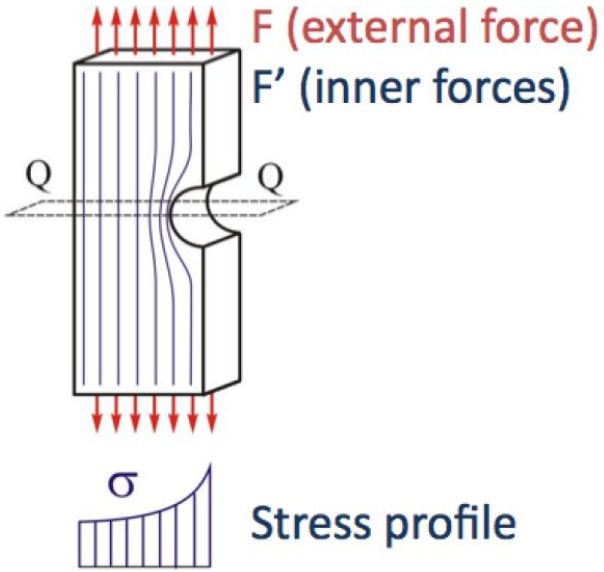
2. Quantitative analysis using topological optimisation

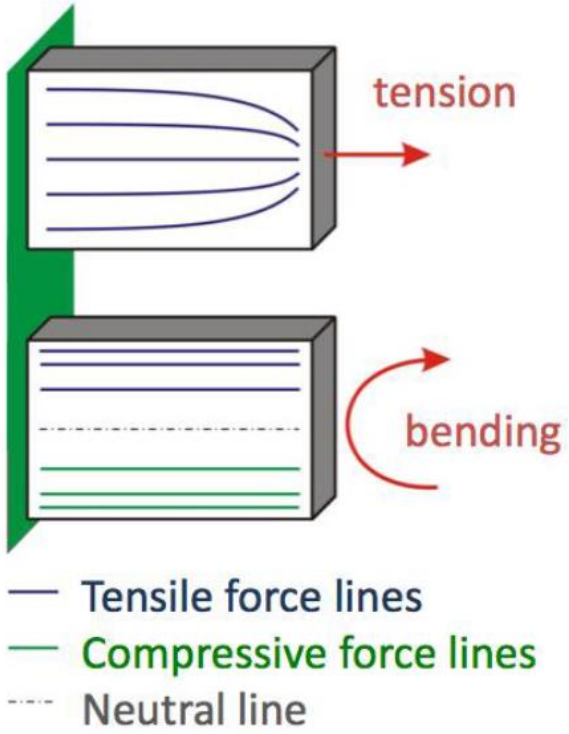
3. Tensegrity principals

Structural reinforcement in 3D printed parts

Qualitative analysis using force lines







*http://www.kokch.kts.ru/me/t1/SIA_1_Stress_Concentration.pdf

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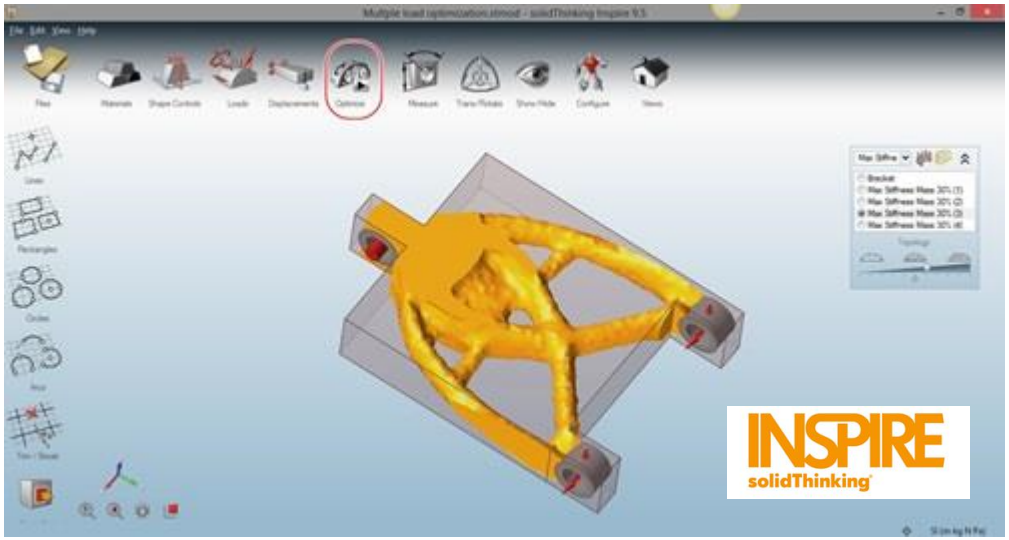
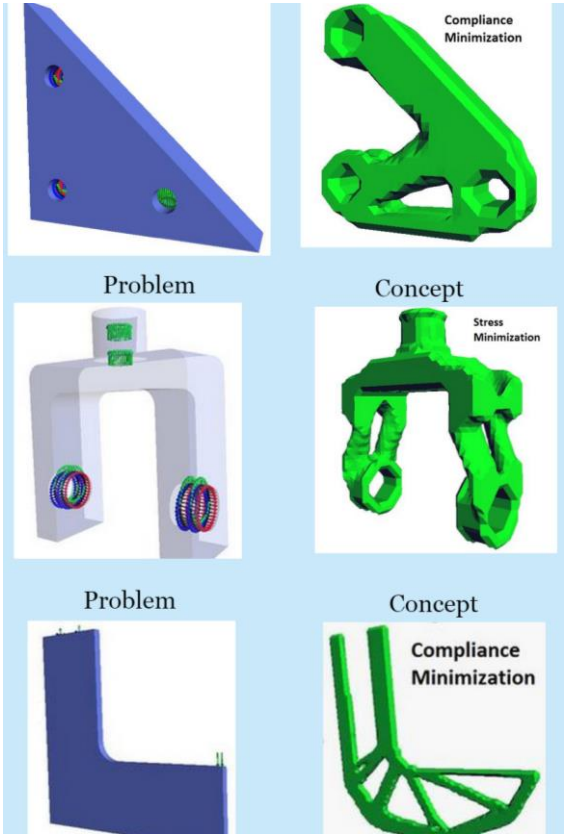
Structural reinforcement in 3D printed parts

Quantitative analysis using topological optimisation



optistruct



*http://www.sciartsoft.com/PareTOWorks.html

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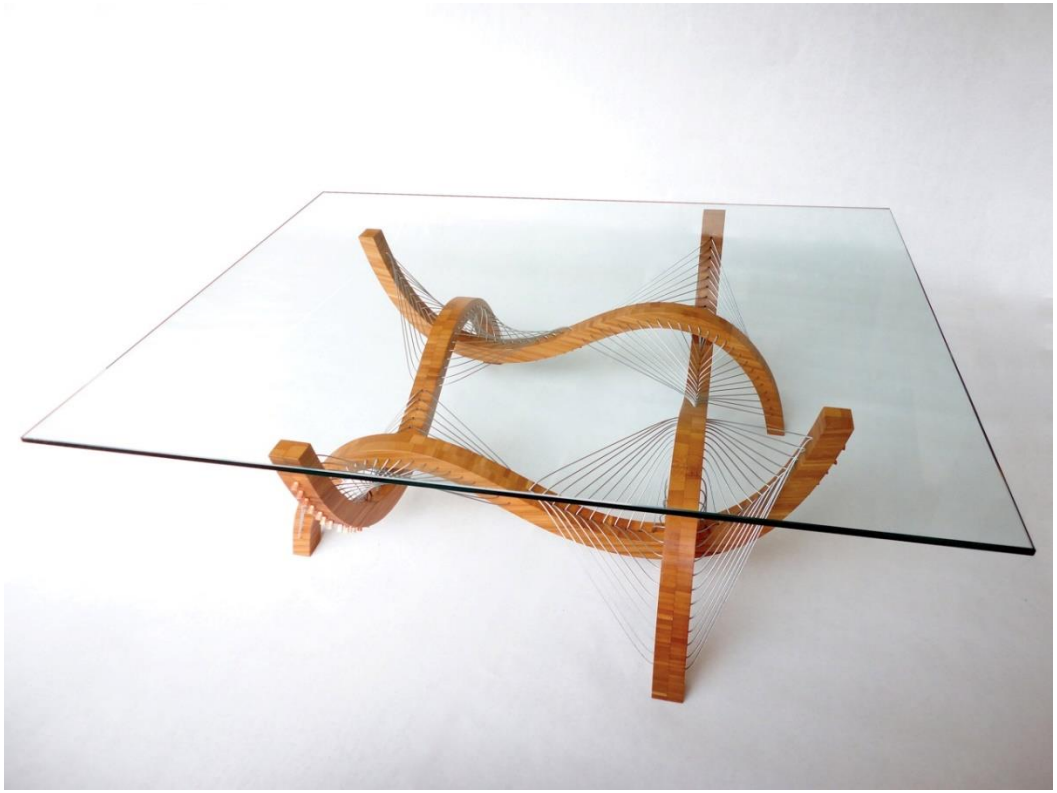
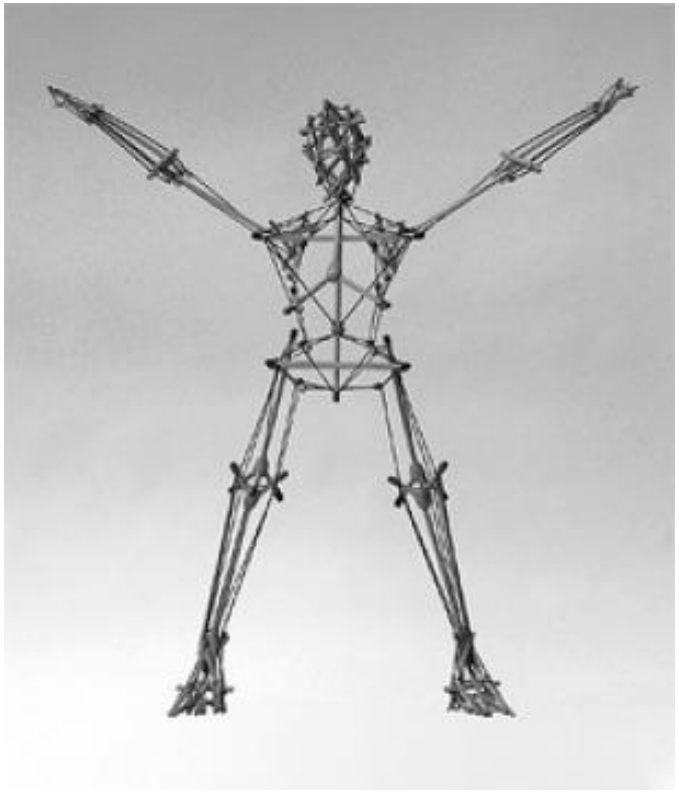
Structural reinforcement in 3D printed parts

Tensegrity principals





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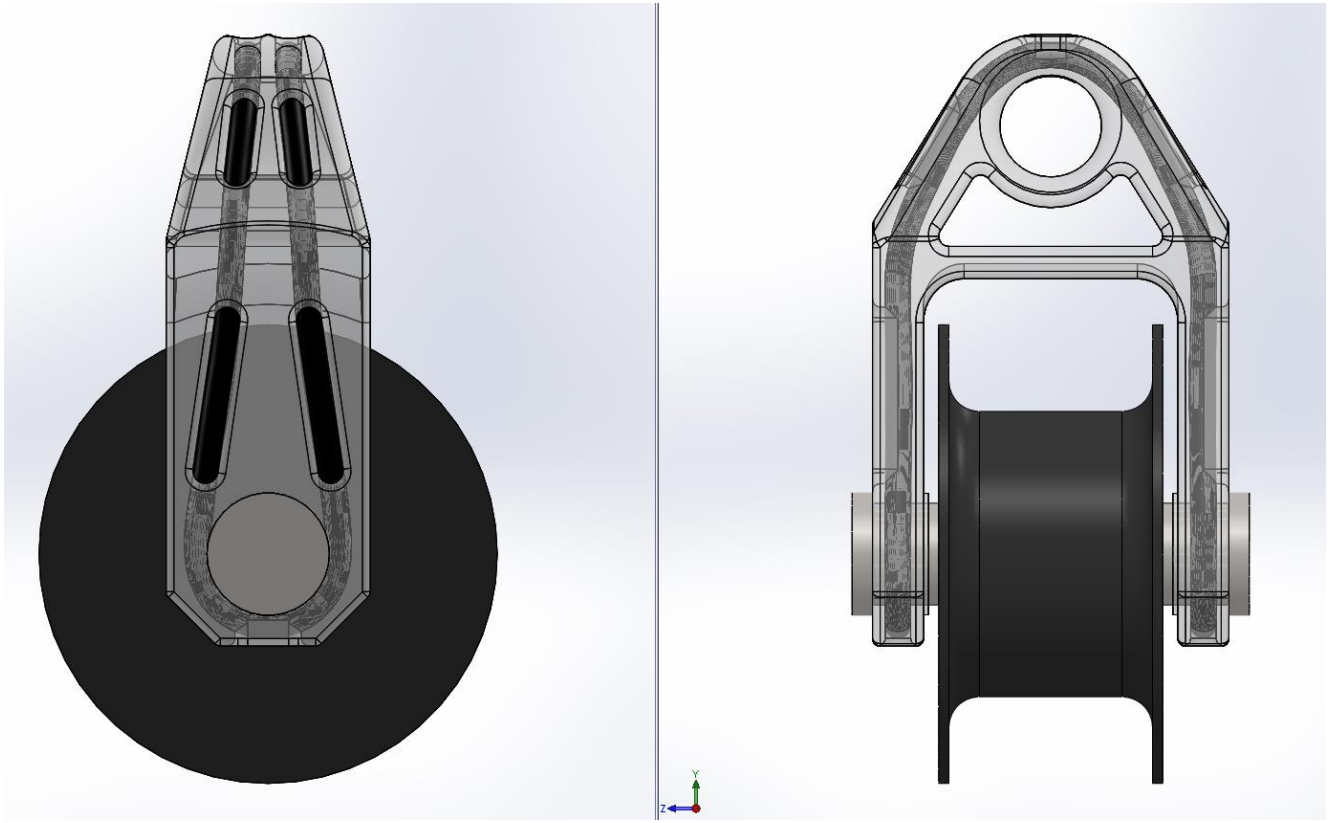
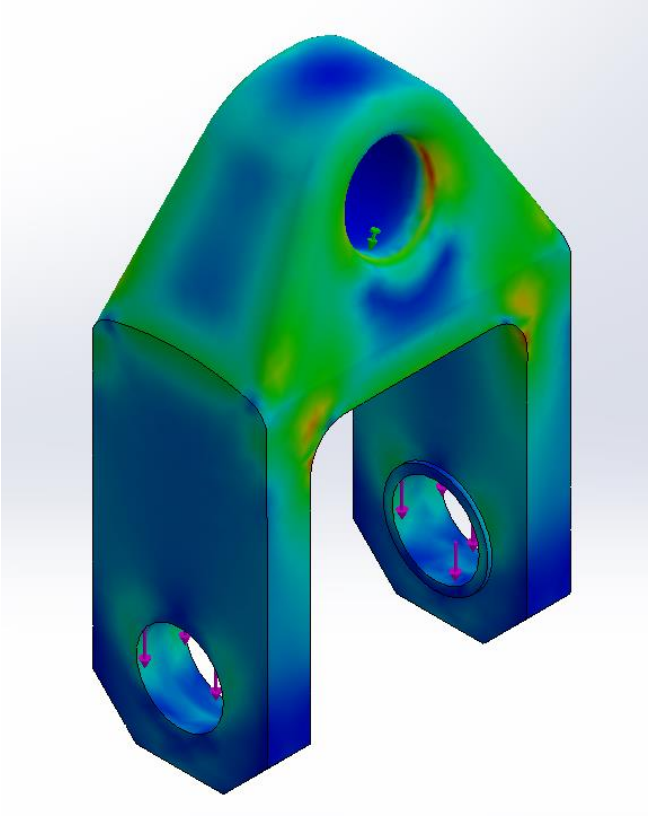
Structural reinforcement in 3D printed parts

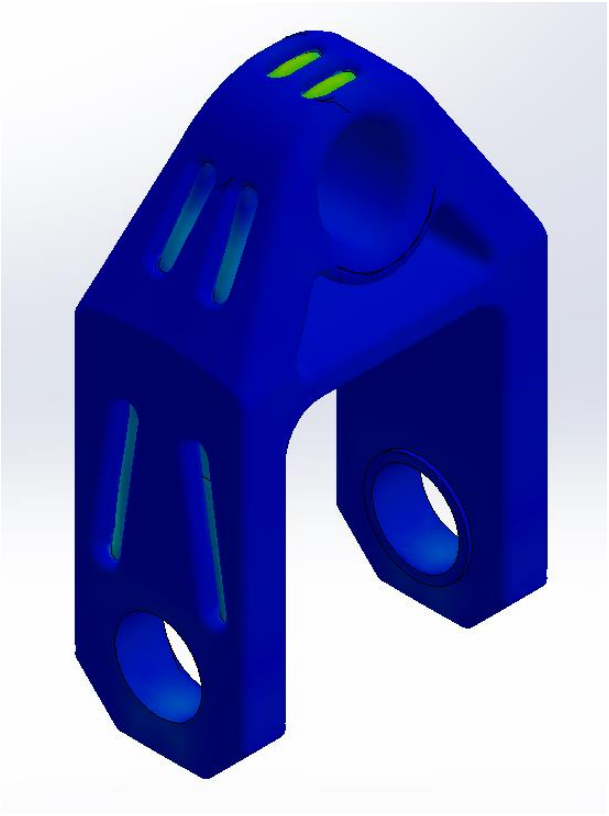


Fibre reinforced pulley block

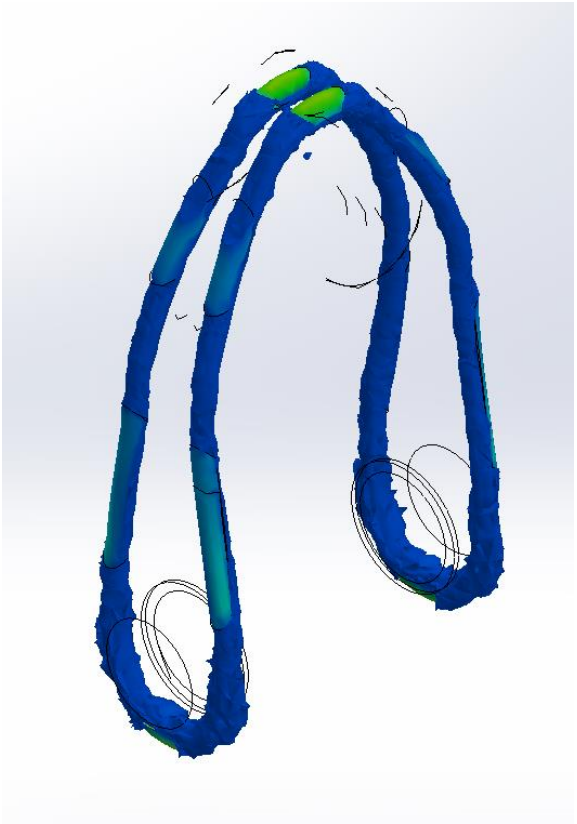
Structural reinforcement in 3D printed parts



Non reinforced



Reinforced



Isoclip >30 MPa

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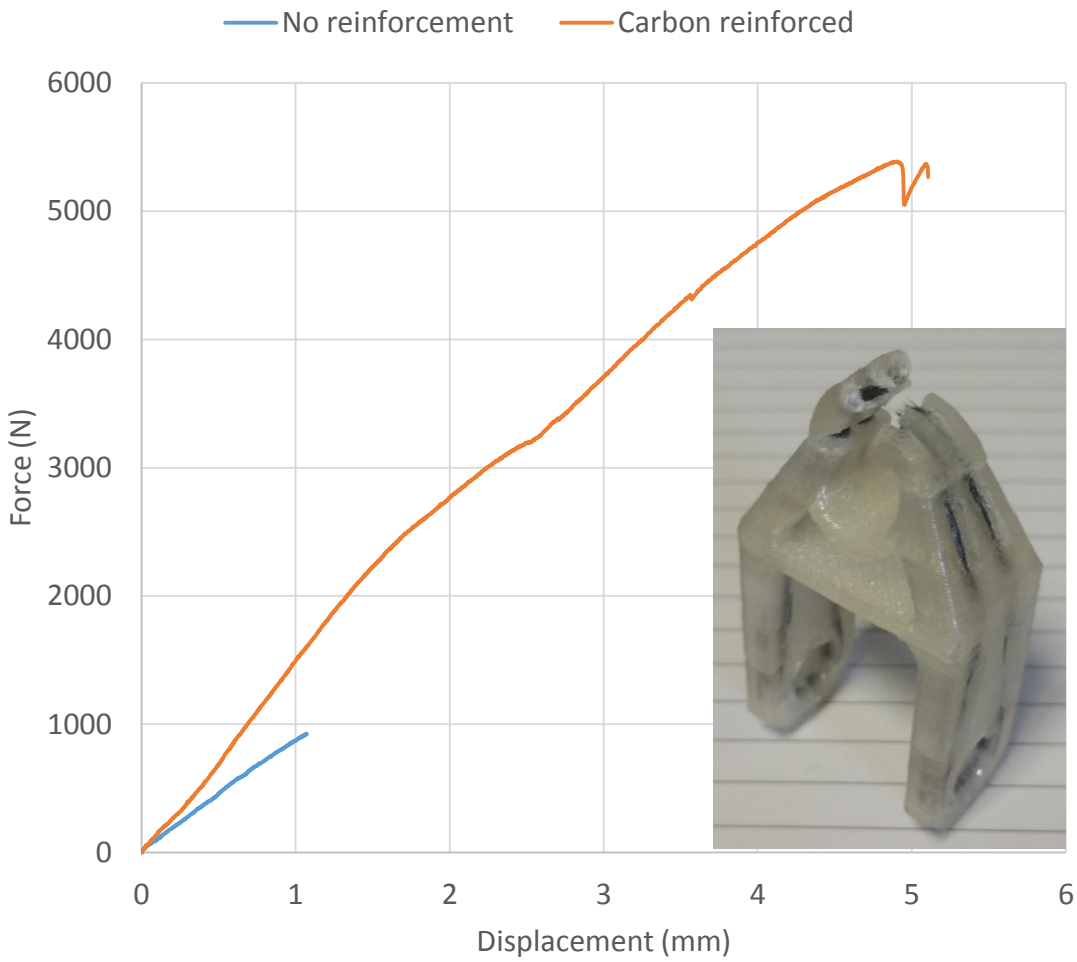
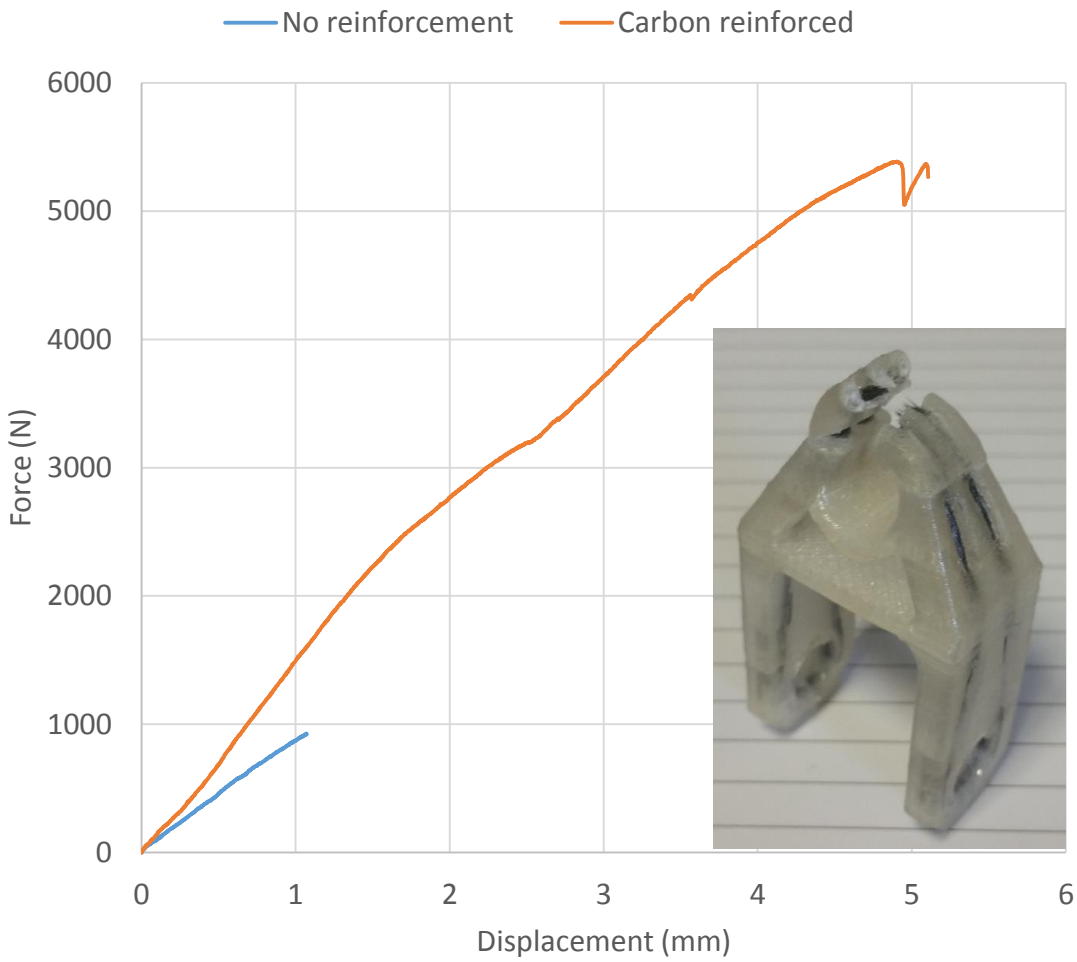
Structural reinforcement in 3D printed parts



Structural reinforcement in 3D printed parts

Interesting points

- Printed part only 25% infill
- Printed in worst possible orientation
- Static failure mode extremely predictable
- Simulations show 2.5x the specific strength of 2024 Al with same geometry



Structural reinforcement in 3D printed parts

Future work:

- Automate creation of force-lines in CAD environment using quantitative methods.
- Investigate fibre placement methods e.g. air jet assisted.
- Look at non-structural fibres such as fibre optics and piezoelectric.
- Look at surface coatings for extra thermal, tribological, mechanical and electrical properties.

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In conclusion..

- Internal features can be used to add extra functionality to underutilised part volumes
- Can be used for light-weighting and customising mechanical properties
- Can be used to integrate other materials and electronics
- We need to start seeing the inside of parts as a potential design space!

Thank you

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