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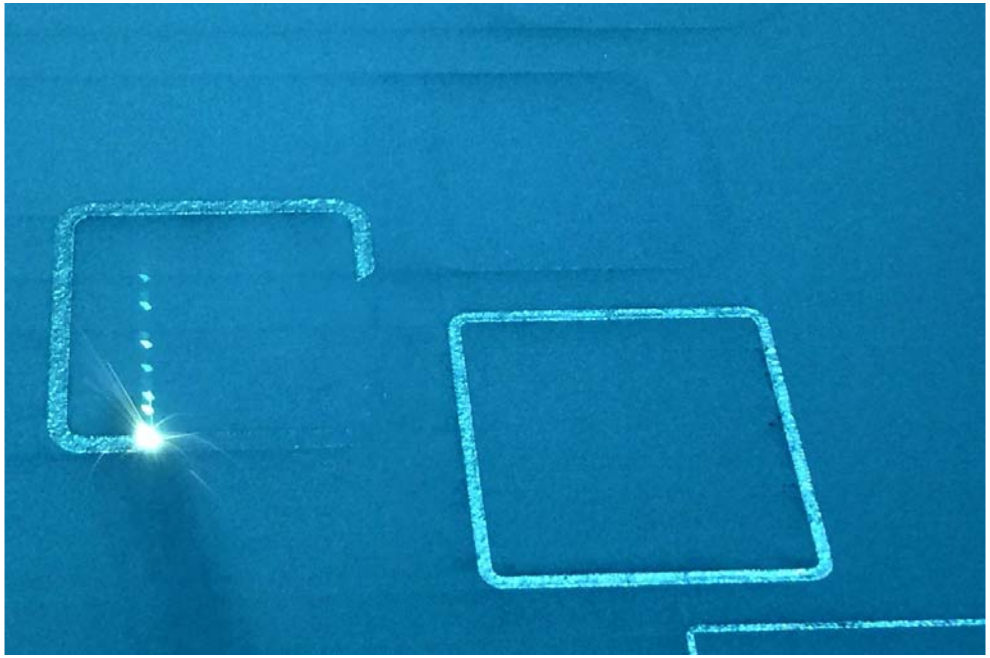
Recent research and future opportunities for stainless steel 3D printing in construction



Craig Buchanan
Leroy Gardner

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Outline

- 3D printing history
- Existing metallic 3D printing use
- Metallic 3D printing techniques
- Opportunities and challenges
- Stainless steel 3D printing research
- Metallic 3D printing in construction

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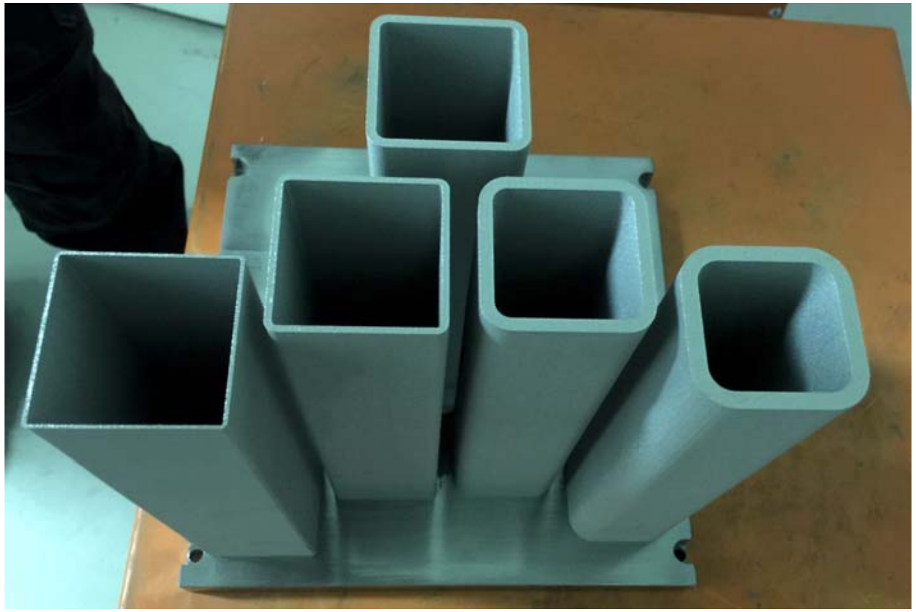

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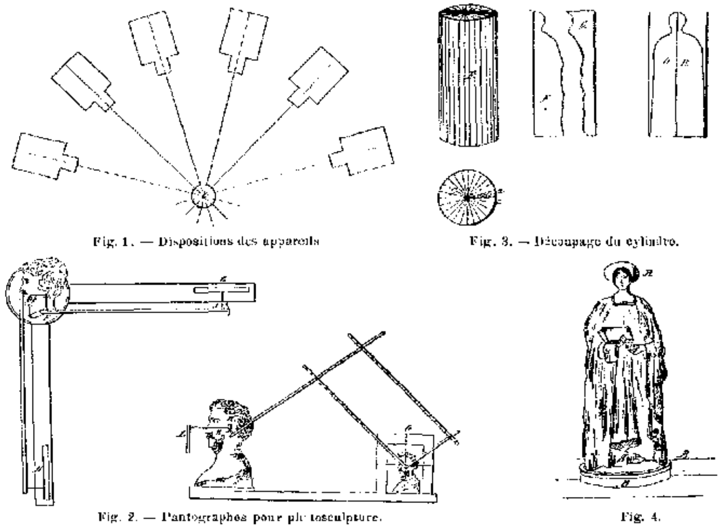
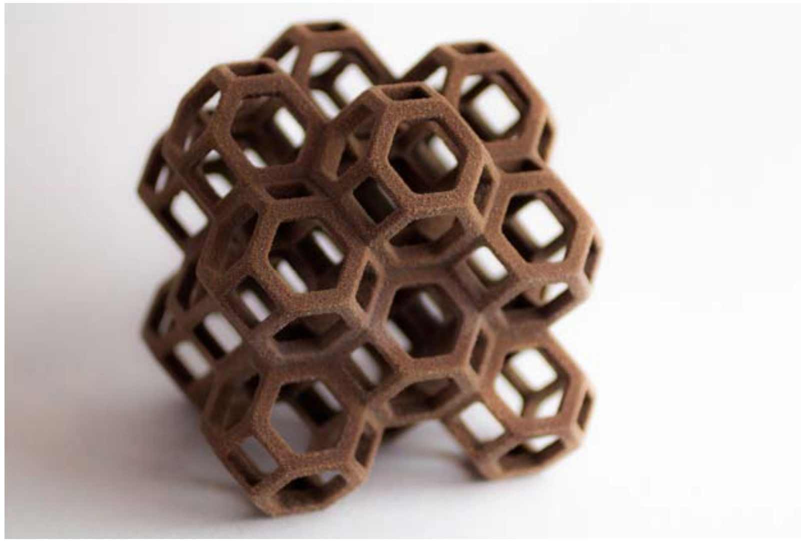
3D printing history

- Concept traced back to photo sculpture in the 1860s
- Developments in the 1960s and 1970s led to techniques for polymers, metals and ceramics
- First technique, stereolithography, commercialised in the late 1980s
- Rapid development has led to many names, ISO/ASTM 52900 calls the field additive manufacturing (AM)
- Wide range of materials: ceramics, concrete, foodstuffs, metals, paper, plastic, wax and wood



Bibliothèque nationale de France



Make Magazine (2014)

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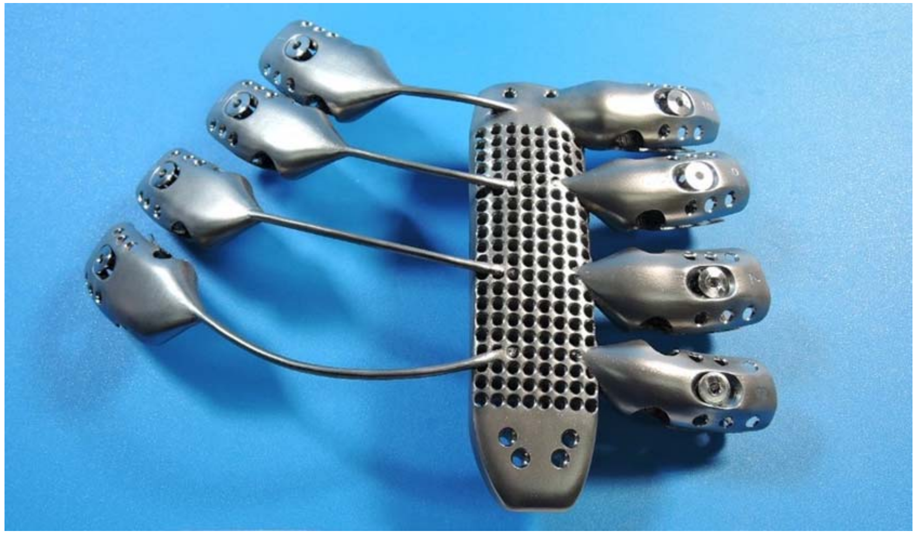
Metallic additive manufacturing

- Popular in the aerospace and biomedical industries
- GE Aviation has developed a cobalt-chrome AM fuel nozzle that is 25% lighter, 5x more durable and will be used in 8,500 engines
- AM is used for building customised titanium implants with complex geometry and engineered material properties

Grunewald (2016)



Anatomics

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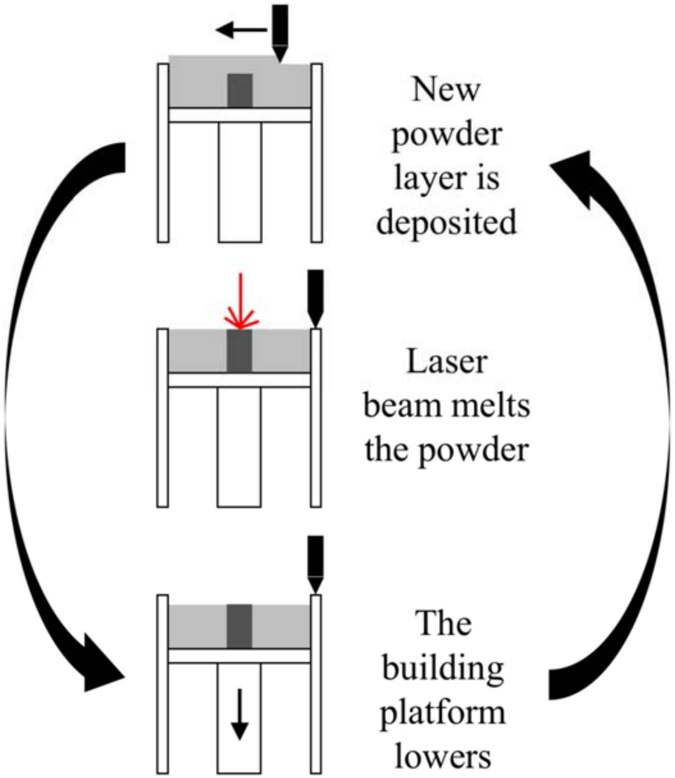
Metallic AM techniques

- ISO/ASTM 52900 – powder bed fusion, directed energy deposition, sheet lamination

	Powder bed fusion (PBF)
Maximum dimensions	250 mm cube
Deposition rate	50 g/hour
Surface roughness	20 μm



Buchanan et al. (2017)

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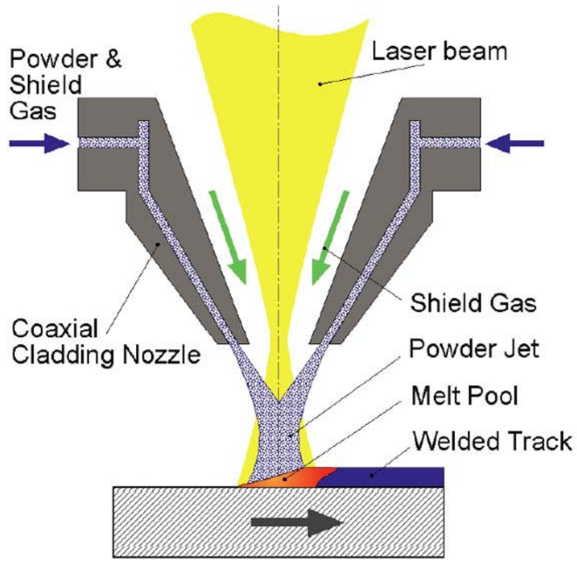
Metallic AM techniques

- ISO/ASTM 52900 – powder bed fusion, directed energy deposition, sheet lamination



3D Printer World (2014)

	Powder bed fusion (PBF)	Directed energy deposition (DED)
		Laser or electron beam based
Maximum dimensions	250 mm cube	250 mm cube
Deposition rate	50 g/hour	1 kg/hour
Surface roughness	20 μm	20-100 μm

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Photograph removed

Metallic AM techniques

- ISO/ASTM 52900 – powder bed fusion, directed energy deposition, sheet lamination

	Powder bed fusion (PBF)	Directed energy deposition (DED)	
		Laser or electron beam based	Wire and arc AM (WAAM)
Maximum dimensions	250 mm cube	250 mm cube	Unlimited
Deposition rate	50 g/hour	1 kg/hour	4 kg/hour
Surface roughness	20 μm	20-100 μm	0.5 mm

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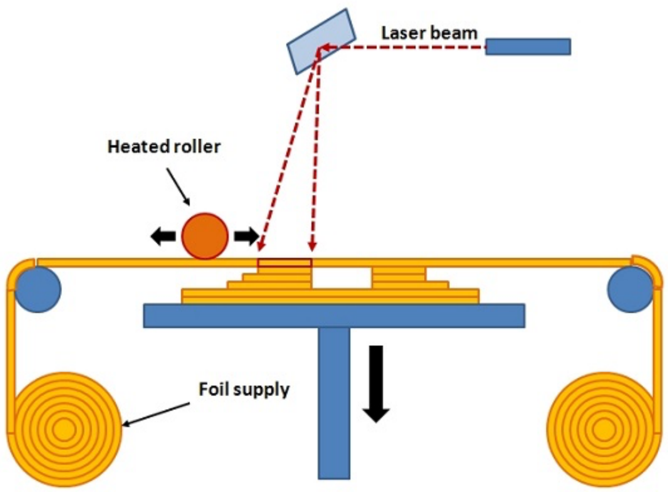

TopMax Tech

Metallic AM techniques

- ISO/ASTM 52900 – powder bed fusion, directed energy deposition, sheet lamination

	Powder bed fusion (PBF)	Directed energy deposition (DED)		Sheet lamination
		Laser or electron beam based	Wire and arc AM (WAAM)	
Maximum dimensions	250 mm cube	250 mm cube	Unlimited	Machine dependent
Deposition rate	50 g/hour	1 kg/hour	4 kg/hour	-
Surface roughness	20 μm	20-100 μm	0.5 mm	Layer thickness dependent

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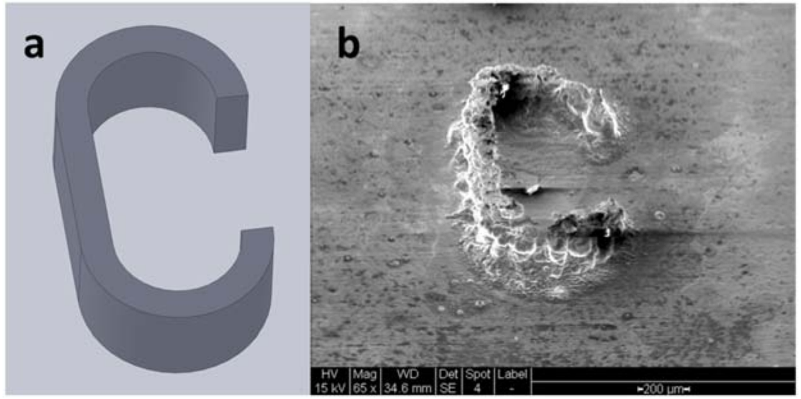
Metallic AM techniques

- ISO/ASTM 52900 – powder bed fusion, directed energy deposition, sheet lamination



Sundaram et al. (2015)

	Powder bed fusion (PBF)	Directed energy deposition (DED)		Sheet lamination	Electro-chemical AM
		Laser or electron beam based	Wire and arc AM (WAAM)		
Maximum dimensions	250 mm cube	250 mm cube	Unlimited	Machine dependent	600 μm
Deposition rate	50 g/hour	1 kg/hour	4 kg/hour	-	-
Surface roughness	20 μm	20-100 μm	0.5 mm	Layer thickness dependent	-

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Metallic AM opportunities and challenges

Opportunities
Complex geometries not previously possible to manufacture can be made
Highly optimised, lightweight structural forms
Material flexibility and mechanical property advantages
Customisation
Environmental benefits – reduced waste

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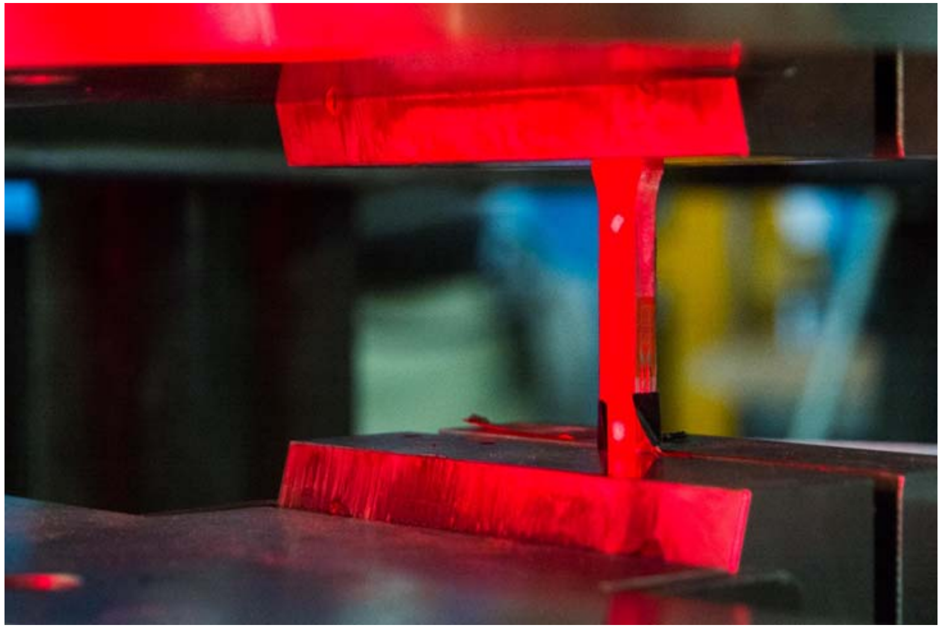
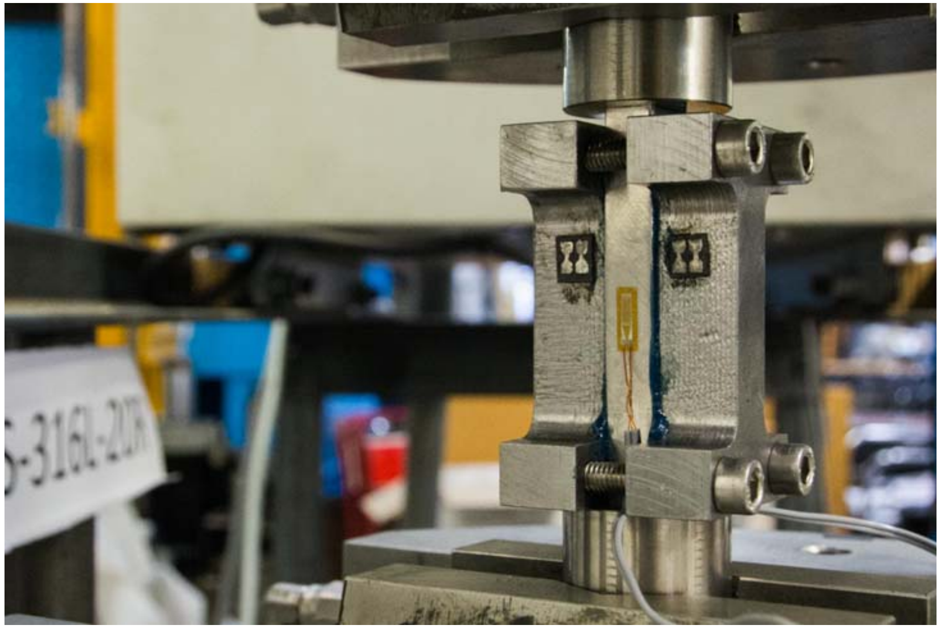
Existing stainless steel AM research

- Existing material property research for PBF manufactured Grade 316L, 304, PH1/15-5PH and 17-4PH
- Limited research for DED material properties
- Overall lack of metallic research with a construction focus

- PBF manufactured Grade 316L tension and compression tests and stub column tests at Imperial College London





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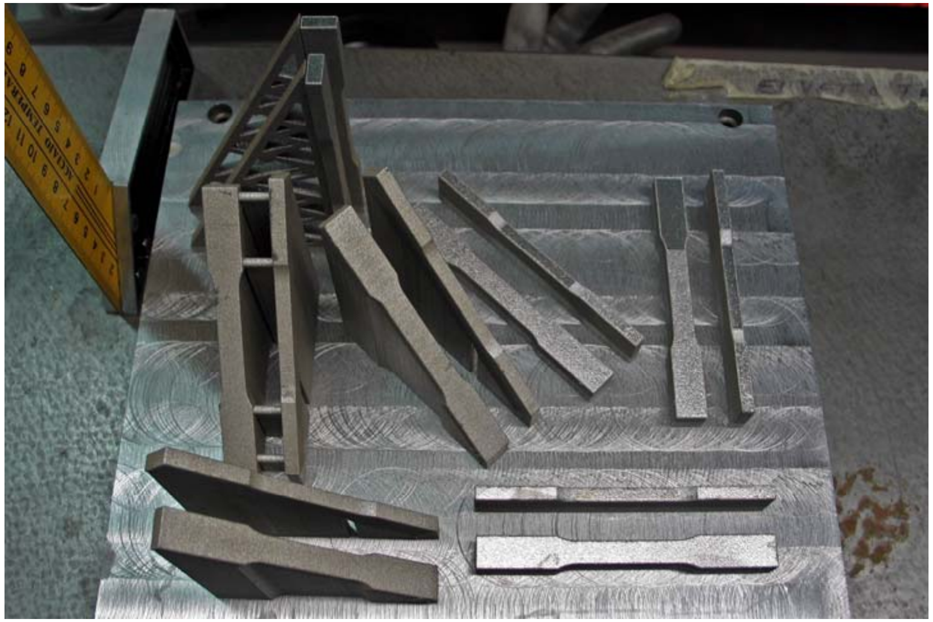
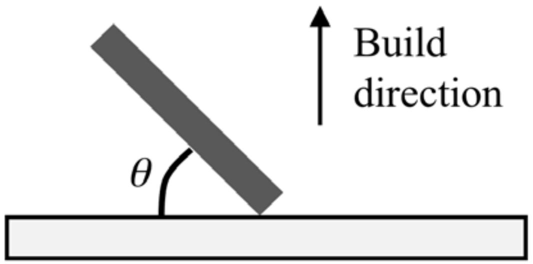
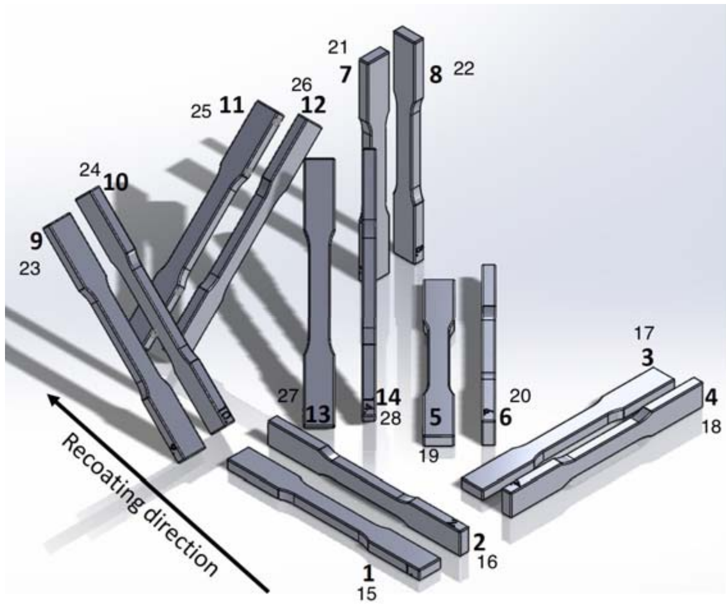
PBF manufactured 316L tension coupon tests

- 14 different orientations
- Built in their final tested dog bone shape
- Built together at the same time



Buchanan et al. (2017)





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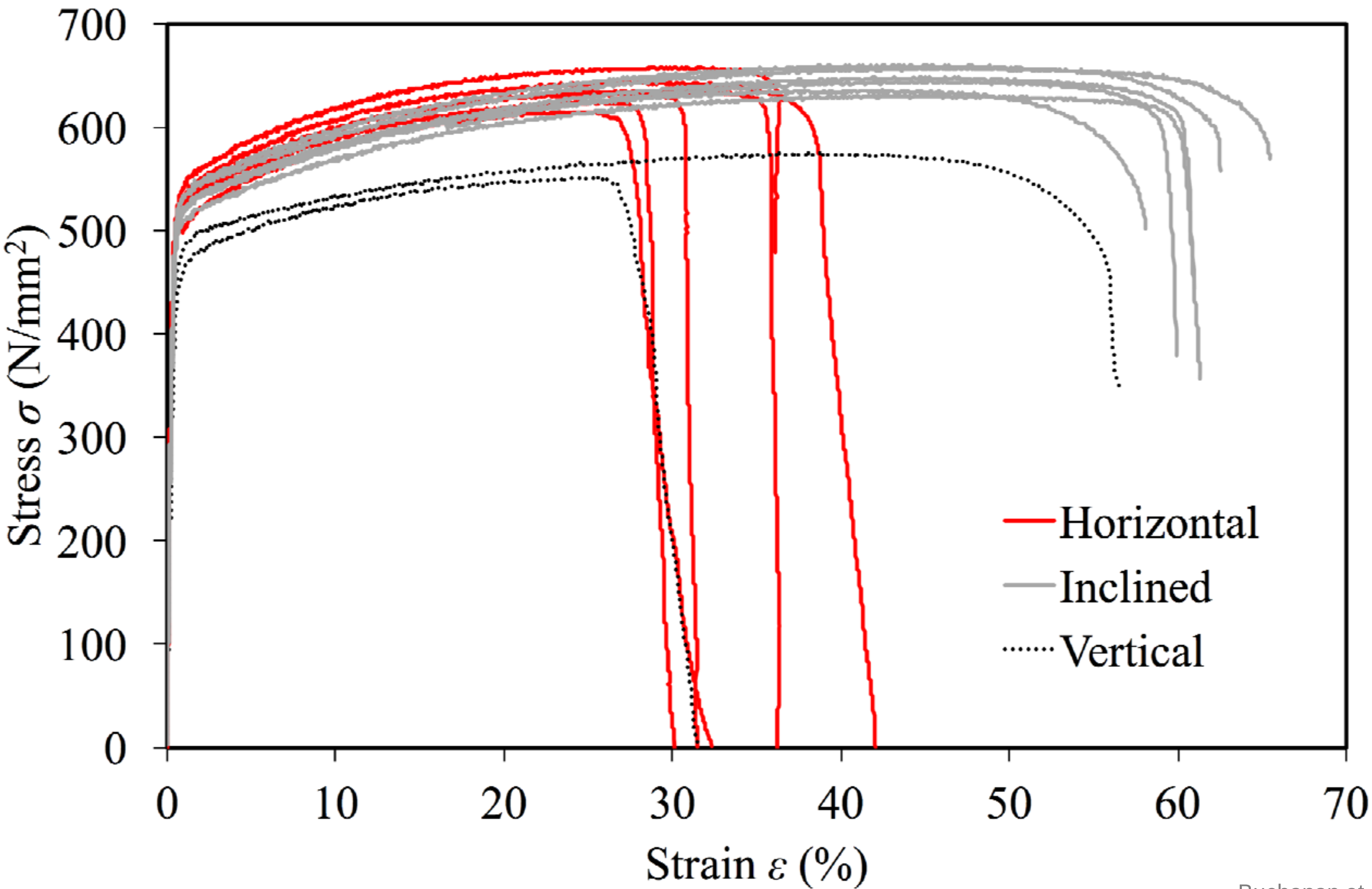

Buchanan et al. (2017)

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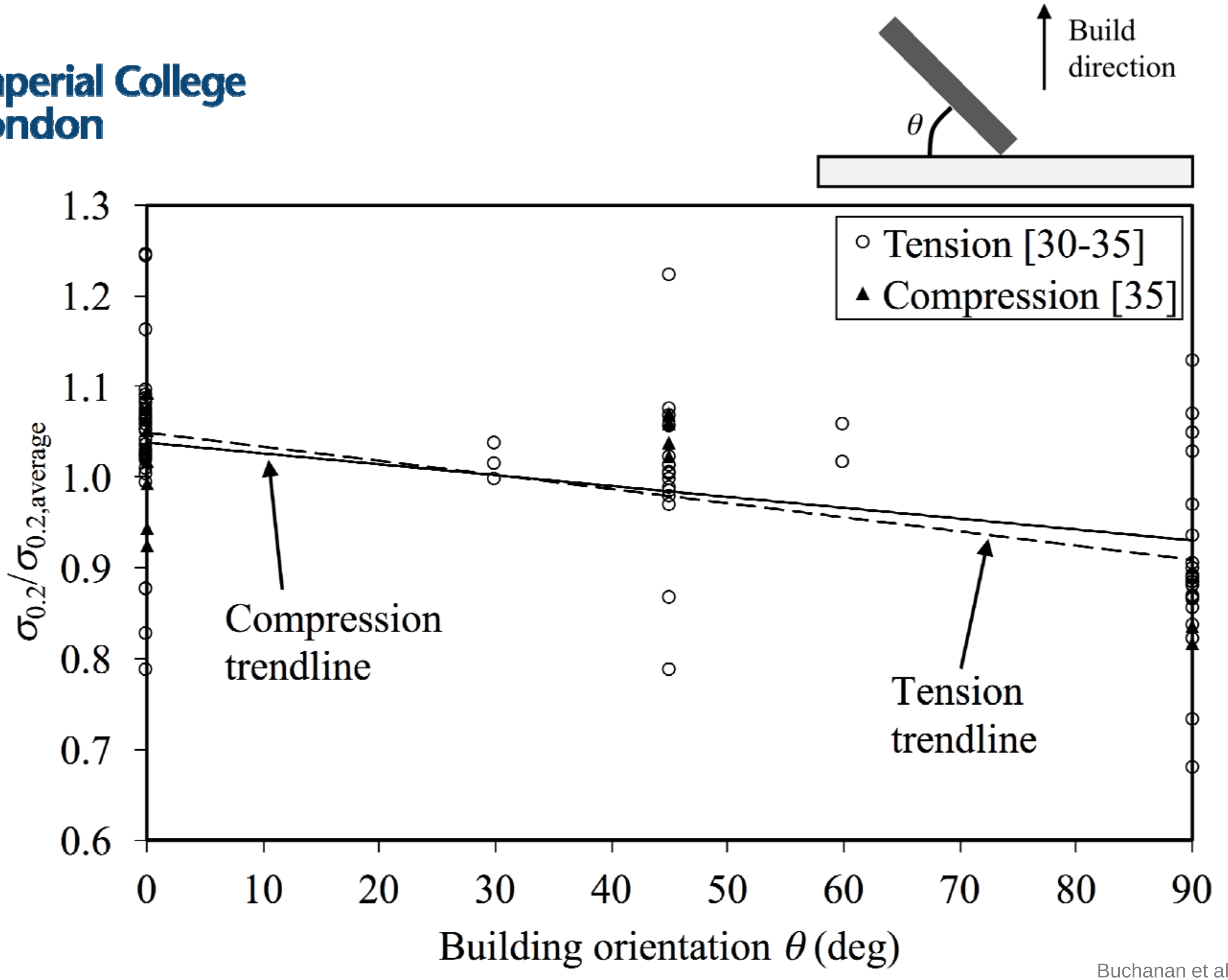

Buchanan et al. (2017)

Summary of PBF manufactured 316L tensile properties

	Young's modulus E (N/mm²)	0.2% proof stress $\sigma_{0.2}$ (N/mm²)	Ultimate stress σ_u (N/mm²)
Horizontal (average)	172,600	591	674
Inclined (average)	187,000	572	663
Vertical (average)	182,000	505	588
EN 1993-1-4	200,000	200-240	500-530

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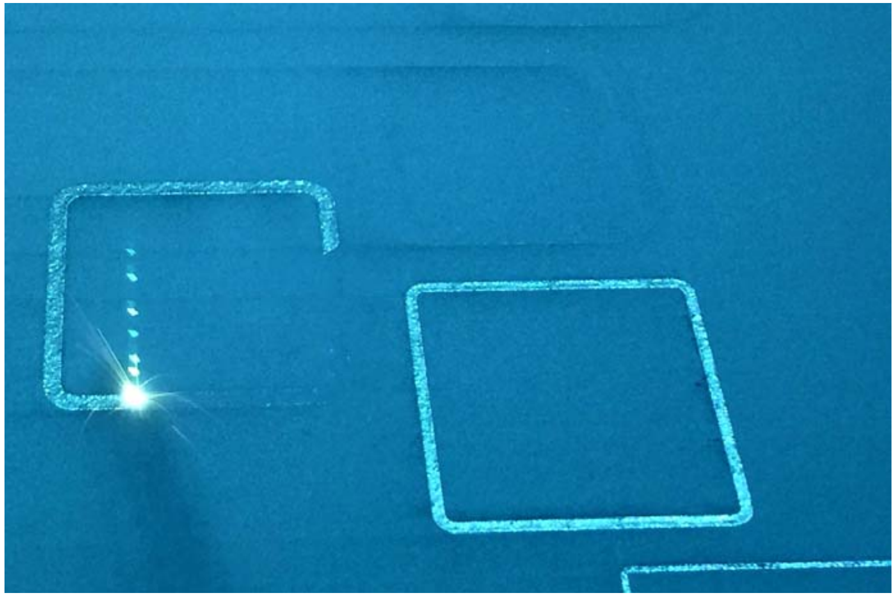
PBF manufactured 316L SHS stub columns

- Square hollow sections (SHS)
- Nominal 50x50 mm outer dimensions, 200 mm length and wall thicknesses varying from 1-5 mm
- Class 1 (2-4 mm) and class 4 (1 mm)

- Built vertically and together using PBF
- Same powder as tensile coupons



Buchanan et al. (2017)

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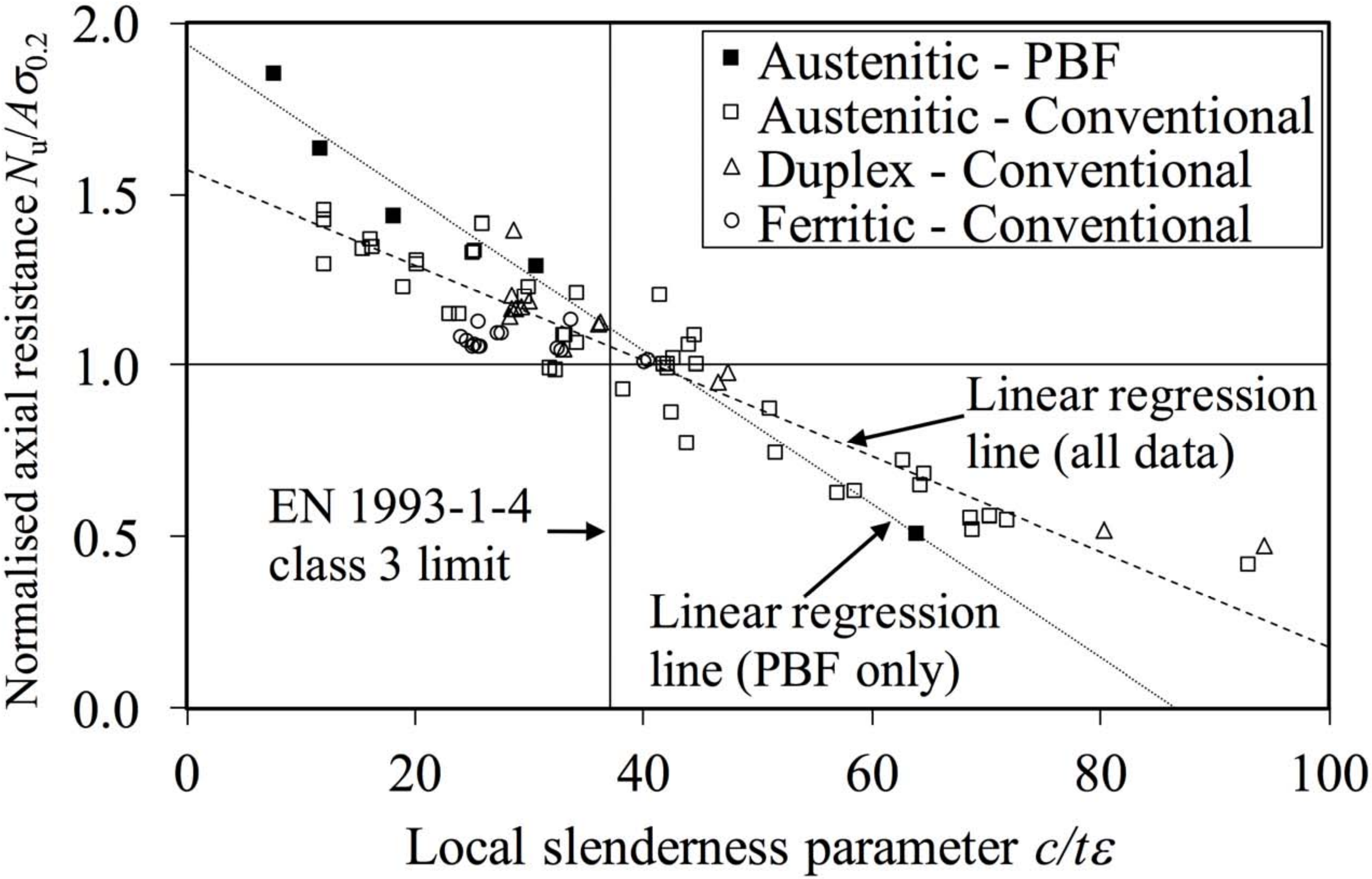

Buchanan et al. (2017)

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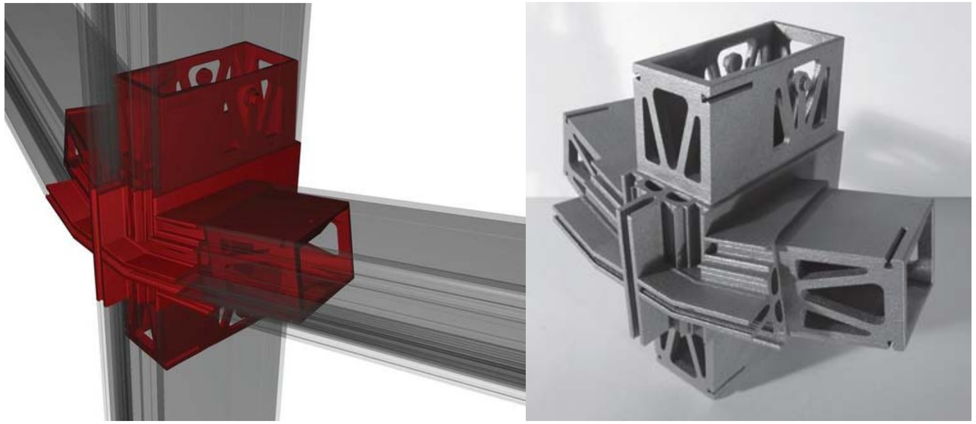
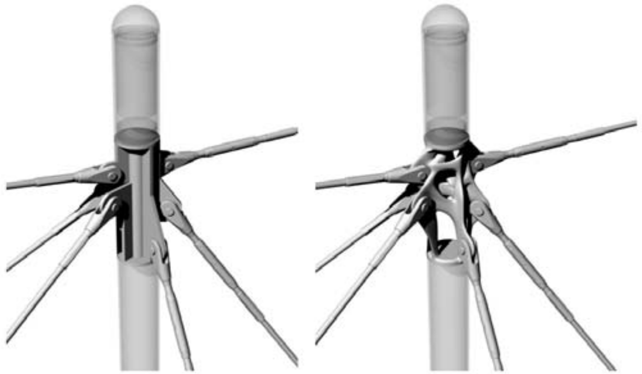
Metallic AM in construction (1)

- Nematox façade node allows for more complicated façade geometry and reliable environmental sealing
- Full size aluminium prototype built using PBF, took 76.5 hours

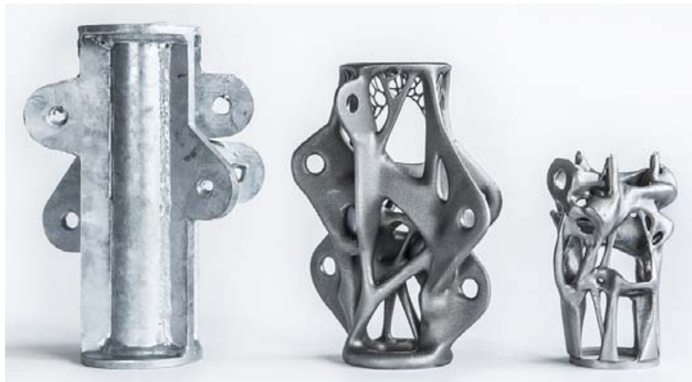
- Arup redesigned a lighting node, undertaking topology and manufacturing optimisation, 75% lighter than a conventional node
- 40% models built using PBF
- In 2014 cost 3x more, but predicted to become cheaper within 5 years



Strauss et al. (2015)



Galjaard et al. (2014)

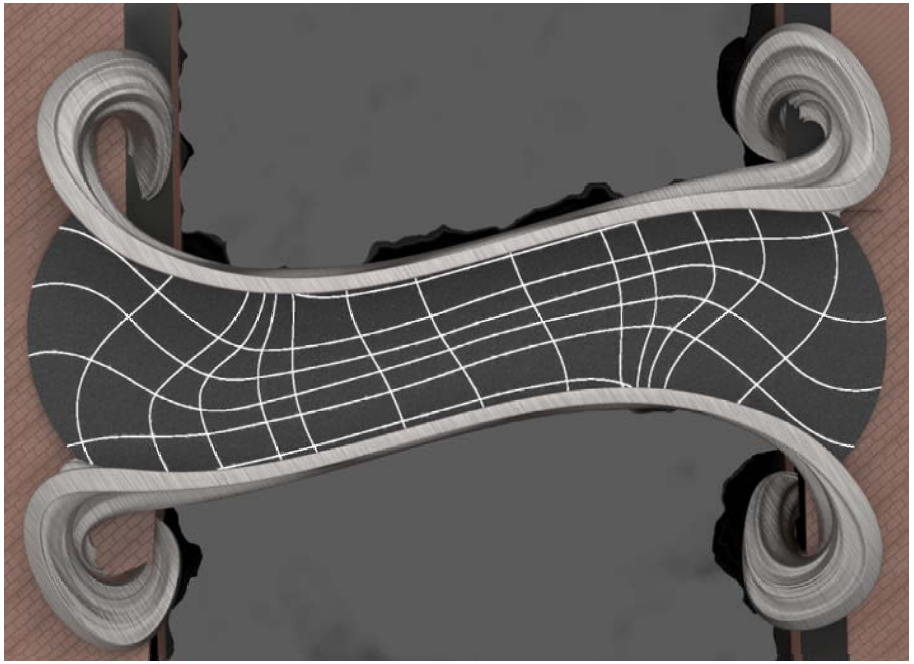


Arup (2015)

Imperial College London

Metallic AM in construction (2)

- MX3D are building an AM stainless steel pedestrian bridge using WAAM
- 10 m span, 2.5 m wide
- Being built using 6-axis robotic welding arms
- Complicated geometry
- Entirely different surface finish to conventional manufacturing processes
- Will be placed in the centre of Amsterdam, Netherlands



Joris Laarman Lab (2017)

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Concluding remarks

- Metallic AM is used in the aerospace and biomedical sectors
- For construction, powder bed fusion and directed energy deposition methods most likely to adopted
- Many opportunities, some challenges still to be overcome
- Testing shows different behaviour to conventional stainless steel at the material level, more construction focused research required
- Metallic AM started to be considered in construction, MX3D bridge will be a halo structure for metallic AM

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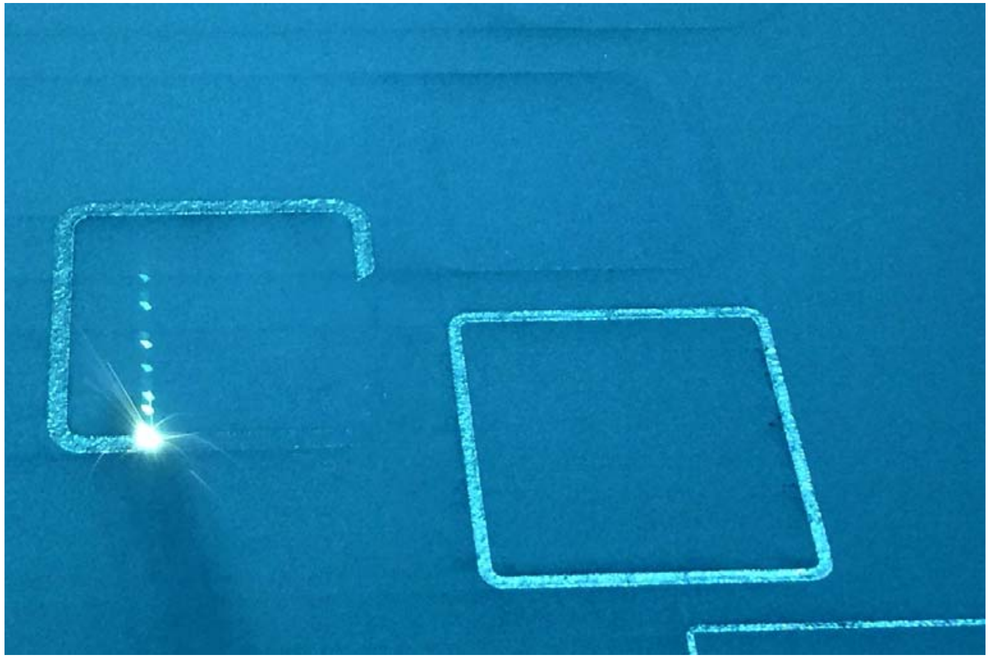

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