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Co-funded by the Erasmus+ Programme of the European Union

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SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

3D Thinking and Design for Additive Manufacturing

SAM
SECTOR SKILLS STRATEGY
IN ADDITIVE MANUFACTURING

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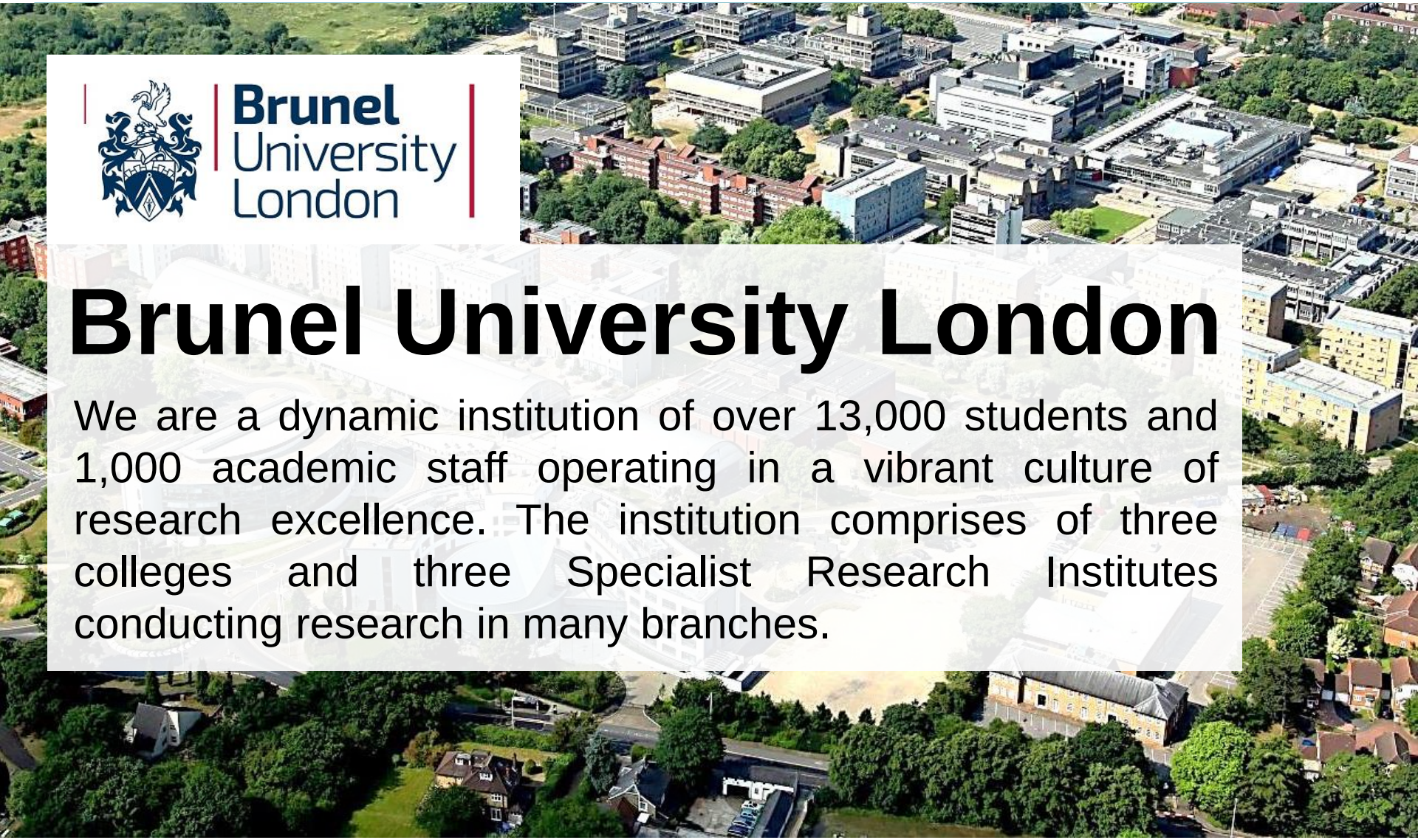

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https://www.brunel.ac.uk/research/Projects

Innovative ultra-sonic guided wave technology for intelligent sensing of defects

The development of adaptable and multi-functional building integrated photovoltaics

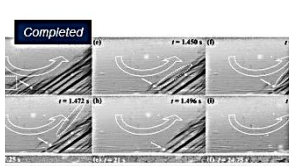
Quantification of carbon emissions and savings in smart grids

Innovative Quality Engineering and Smart Technology

Digital monitoring of ships

Quantification of carbon emissions and savings in smart grids

Innovative wrist device for high accuracy non-invasive blood glucose monitoring



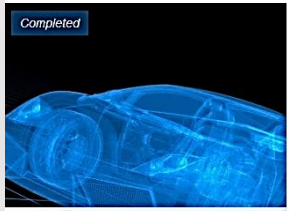
Development of efficient and scalable ultrasound-assisted solidification technologies

Increasing excellence on advanced additive manufacturing (INEX-ADAM)

Fundamental Study of Cavitation Melt Processing

Artificial intelligent system for oncological volumetric medical PET classification

Synthesis of continuous whole-body motion in hexapod robot for humanitarian demining



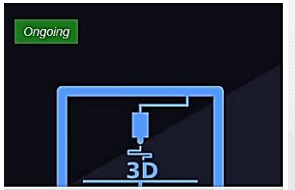
CHAMAELEON - vehicle lightweighting

Development of a constitutive model to simulate unbounded flexible composite riser pipe elements

Boiling Heat Transfer with Controlled Arrays of Nucleation Sites on Silicon Surfaces

Non-Linear Finite Element Analysis of Flexible Pipes for Deep-Water Applications

Developing an end-to-end Digital Manufacturing solution



Sector Skills Strategy in Additive Manufacturing

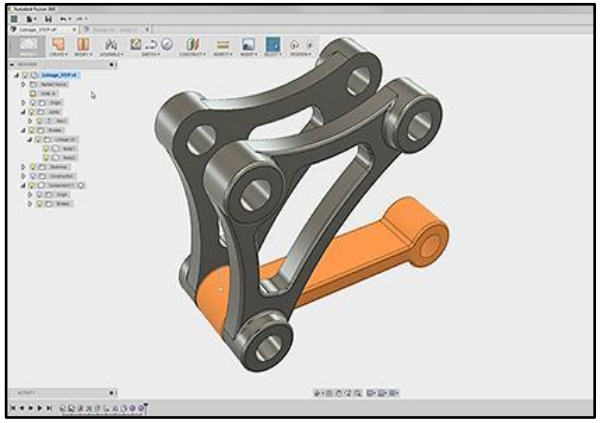
Speaker's Biography - Eujin Pei

- Research focus on Design for Additive Manufacturing & 4D Printing
- Director, Postgraduate Research, Brunel University London
- Director, BSc Product Design Engineering
- Lead, Additive Manufacturing Research Group
- Convenor, ISO/TC261/WG4, Additive Manufacturing Data & Design
- Chair, British Standards Institute, BSI/AMT/8, Additive Manufacturing
- Chartered Engineer and Chartered Technological Product Designer
- Editor-in-Chief, Progress in Additive Manufacturing Journal (SpringerNature)

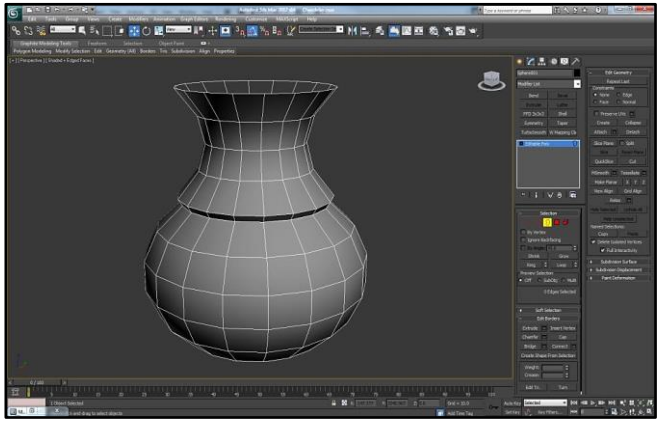
Why Design? What is Design for AM?

3D Thinking - Starting Out: Creating a 3D CAD Model

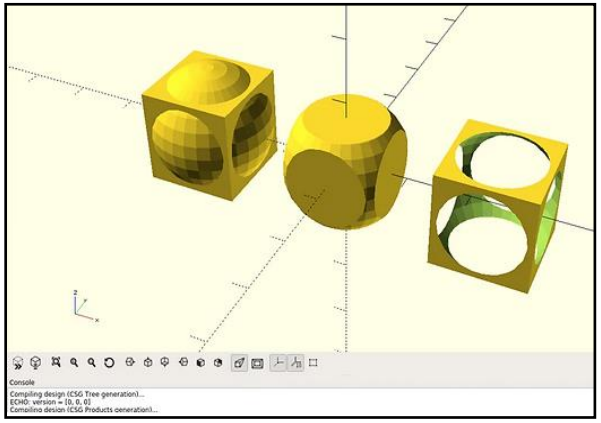
(1) Solid Modelling:



(2) Surface Modelling:



(3) Script-based Modelling:



3D Thinking: Additive Manufacturing Digital Chain

3D Model Created

- 3D CAD model is designed and file saved in a native format / proprietary CAD software format.

Slicing Process

- Final 3D CAD model saved in .STL or .AMF
- Other formats include .3MF, .OBJ, .IGES, etc.

Toolpath Generated

- .Gcode is generated as a machine-readable format and sent for print.

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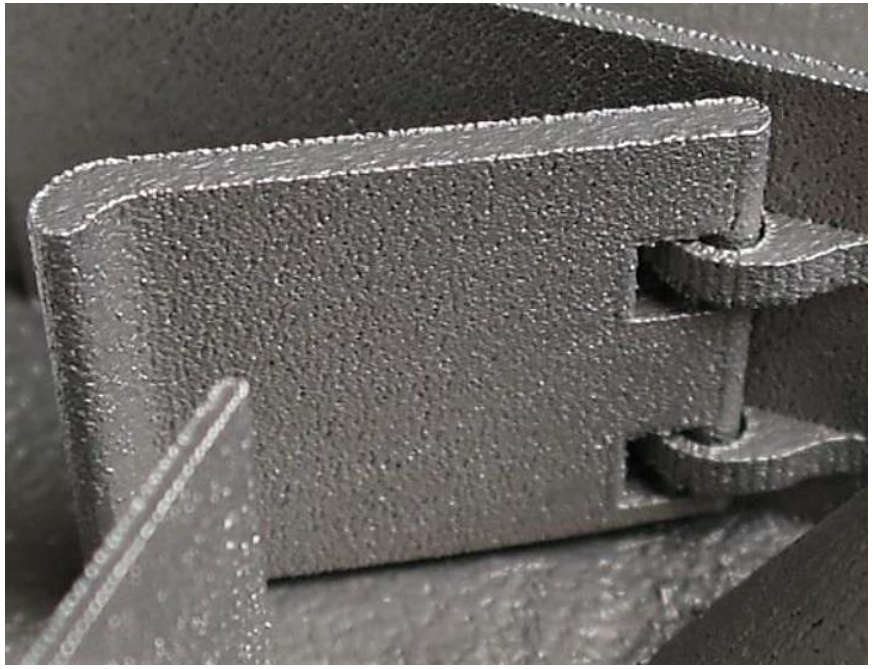
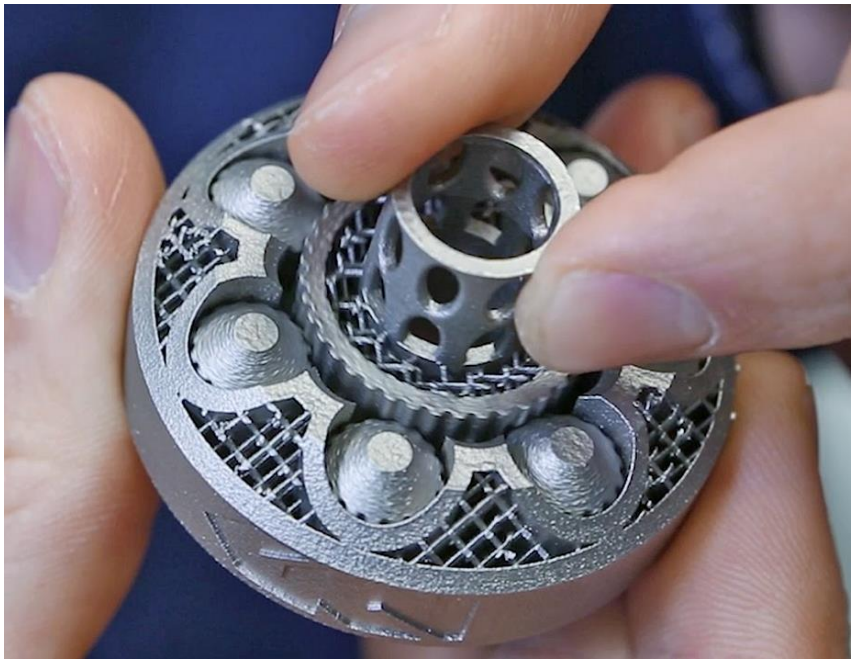
3D Thinking: Design for Additive Manufacturing

Using design rules, methods or tools to ensure that the functional performance or product considerations including manufacturability, reliability, cost are optimized by using the capabilities of Additive Manufacturing.



Integrated hinge assemblies

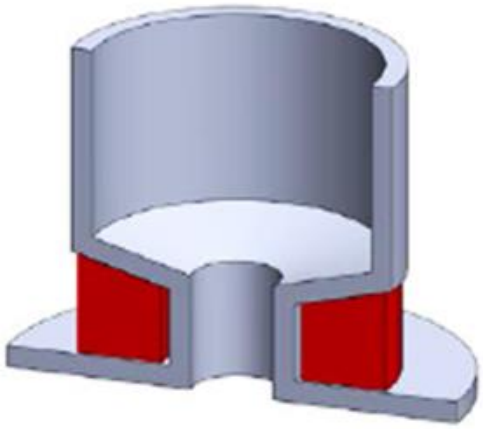
3D Thinking: Design for Additive Manufacturing



Integrated assemblies and lightweight features

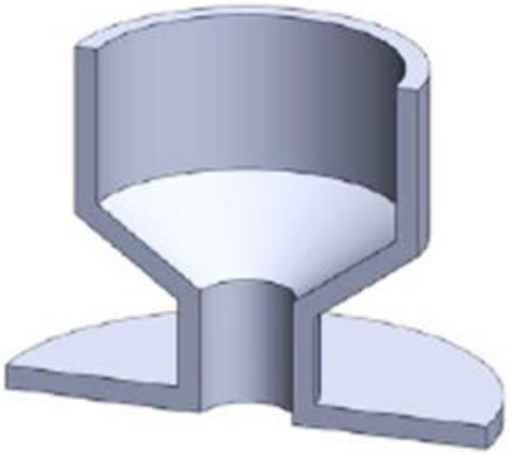
Hydraulic manifold (Olaf Diegel, 2018)

3D Thinking: Design for Additive Manufacturing

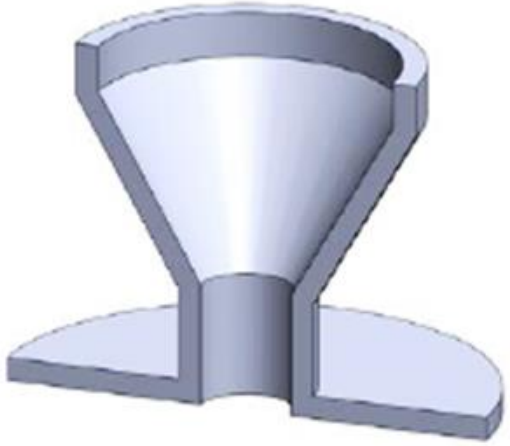


Not Self-Supporting

D. Rosen (n.d.) Self-Supporting Structures



Self-Supporting with Rough Surface Finish (30° - 45°)



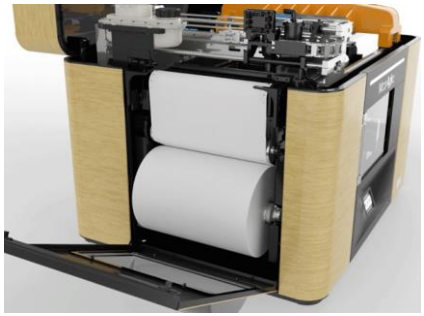
Self-Supporting with Smooth Surface Finish (>45°)

Additive Manufacturing Processes

Binder Jetting

Material Extrusion

Powder Bed Fusion



Sheet Lamination

Directed Energy Deposition

Material Jetting

Vat Photopolymerisation

3D Thinking:
Considerations for Additive Manufacturing

- **AM Design - Rules and guidelines**
- **Manufacturing process capabilities**
- **Mechanical properties of the material**

Considerations for Additive Manufacturing

- **AM Design rules and guidelines**

General design rules

Process specific design rules

- **Manufacturing process capabilities**

Minimum feature sizes

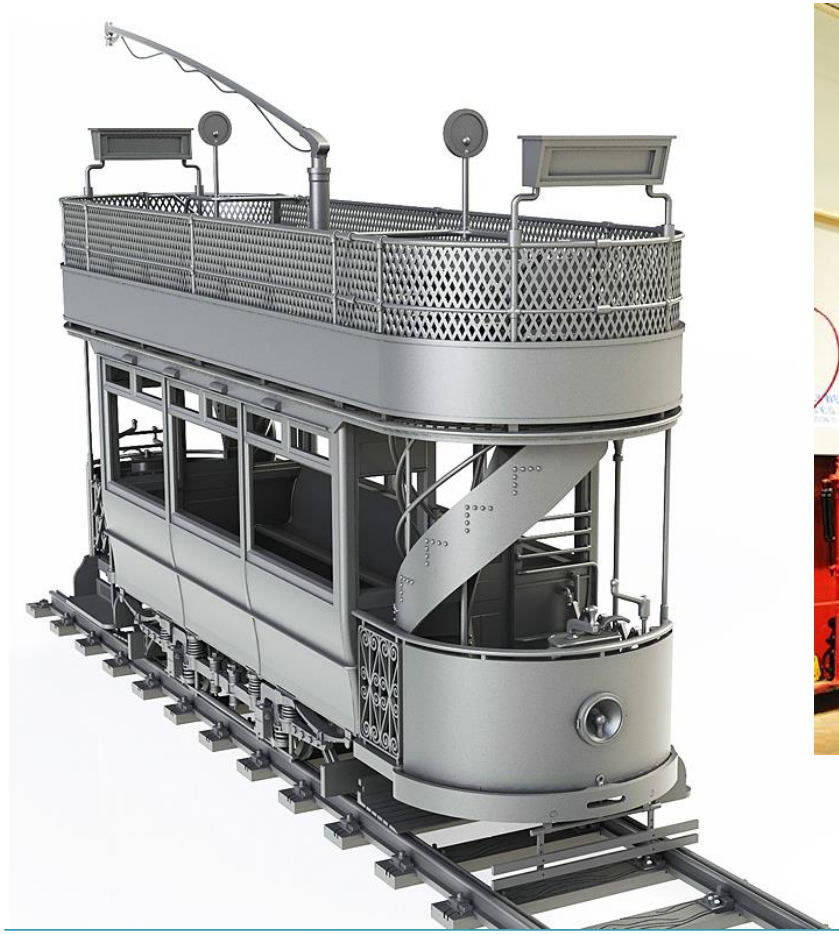
Accuracy capabilities

Surface finish

- **Mechanical properties of material**

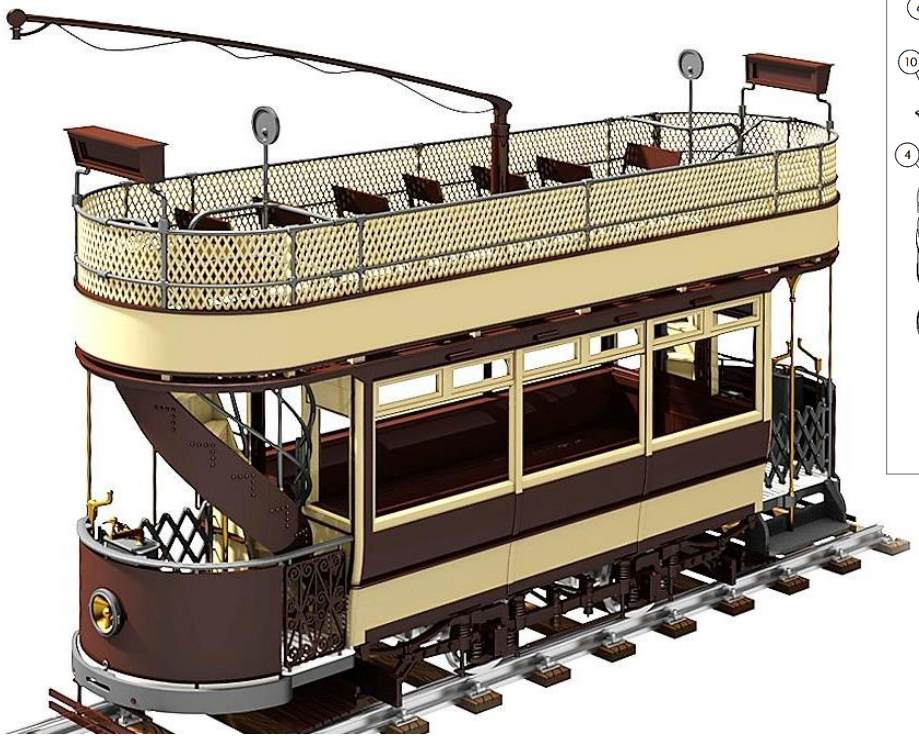
Reverse Engineering of Tram,
© Eujin Pei, Crich Tramway Museum, 2014

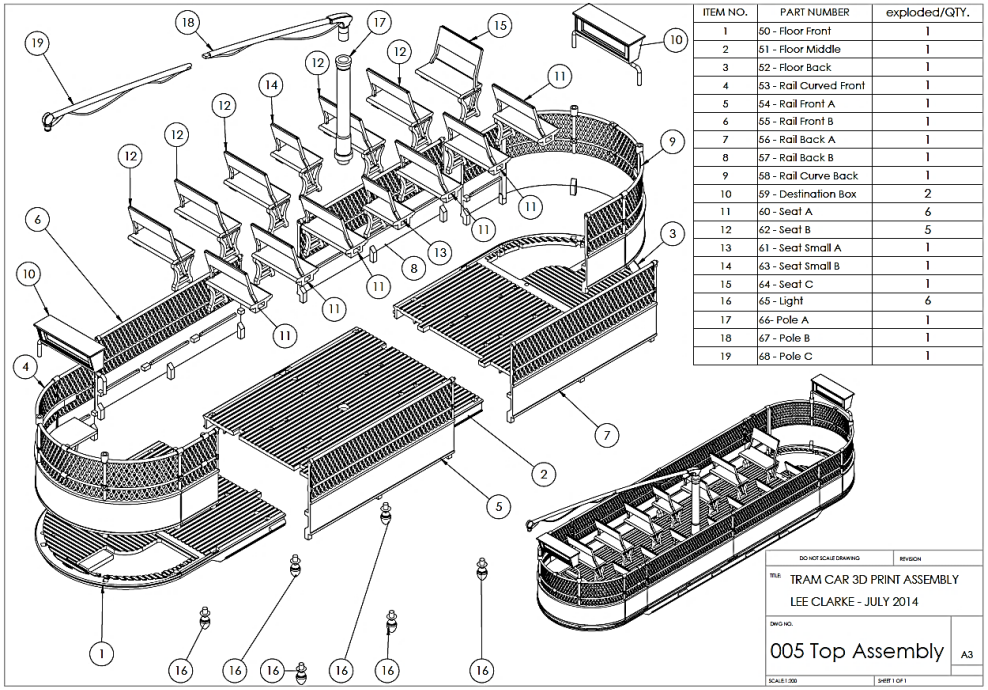
Considerations for Additive Manufacturing



Reverse Engineering of Tram,
© Eujin Pei, Crich Tramway Museum, 2014

Considerations for Additive Manufacturing





ITEM NO.	PART NUMBER	exploded/QTY.
1	50 - Floor Front	1
2	51 - Floor Middle	1
3	52 - Floor Back	1
4	53 - Rail Curved Front	1
5	54 - Rail Front A	1
6	55 - Rail Front B	1
7	56 - Rail Back A	1
8	57 - Rail Back B	1
9	58 - Rail Curve Back	1
10	59 - Destination Box	2
11	60 - Seat A	6
12	62 - Seat B	5
13	61 - Seat Small A	1
14	63 - Seat Small B	1
15	64 - Seat C	1
16	65 - Light	6
17	66- Pole A	1
18	67 - Pole B	1
19	68 - Pole C	1

Reverse Engineered Tram Carriage,
© Eujin Pei, Crich Tramway Museum, 2014

Considerations for Additive Manufacturing

- **AM Design rules and guidelines**

General design rules

Process specific design rules

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Minimum feature sizes

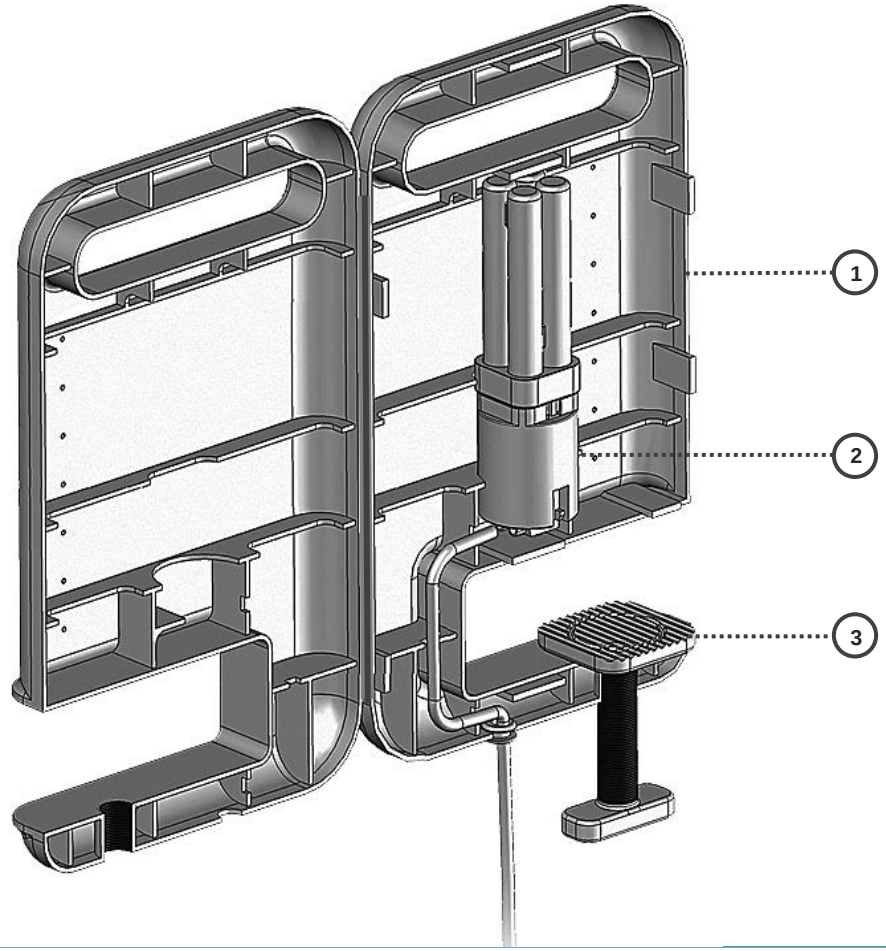
Accuracy capabilities

Surface finish

- **Mechanical properties of material**

Clamplight, © Eujin Pei, 2007

Considerations for Additive Manufacturing



Clamplight, © Eujin Pei, 2007

Considerations for Additive Manufacturing

- **AM Design rules and guidelines**

General design rules

Process specific design rules

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Minimum feature sizes

Accuracy capabilities

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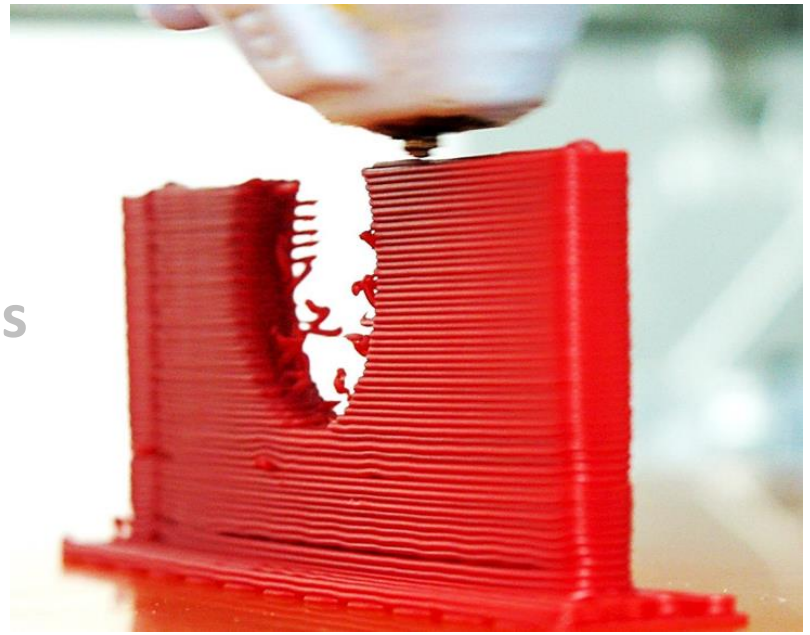


Retraction settings of Material Extrusion,
© Eujin Pei, Vaal University of Technology, 2010

AM Design - Standardisation Documents

- ISO/ASTM 52910 AM -- Design -- Requirements, guidelines & recommendations
- ISO/ASTM PWI 52923 AM -- Design decision support
- ISO/ASTM PWI 52914 AM -- Design -- Standard guide for material extrusion processes
- ISO/ASTM DIS 52911-1 AM -- Technical design guideline for powder bed fusion -- Part 1: Laser-based powder bed fusion of metals
- ISO/ASTM DIS 52911-2 AM -- Technical design guideline for powder bed fusion -- Part 2: Laser-based powder bed fusion of polymers
- ISO/ASTM PWI 52911-3 AM -- Technical design guideline for powder bed fusion -- Part 3: Standard guideline for electron-based powder bed fusion of metals
- ISO/ASTM PWI 52922 AM -- Design -- Directed energy deposition
- ISO/ASTM TR 52912 AM -- Design - Functionally graded additive manufacturing

Examples of Standardisation Documents

General Guide for Data and Design:

- ISO/ASTM **52910** Additive manufacturing -- Design -- Requirements, guidelines and recommendations

Process-Specific Design Guide:

- ISO/ASTM DIS **52911-1** Additive manufacturing -- Technical design guideline for powder bed fusion -- Part 1: Laser-based powder bed fusion of metals

ISO/ASTM 52910 Additive manufacturing -- Design -- Requirements, guidelines and recommendations

- The document helps determine key design considerations or to take advantage of the capabilities of an AM process.
- Specific considerations for different process categories are described. For example:

INTERNATIONAL STANDARD **ISO/ASTM 52910**

First edition
2018-07

Additive manufacturing — Design — Requirements, guidelines and recommendations

Fabrication additive — Conception — Exigences, lignes directrices et recommandations

6.8.2.1 Binder jetting

Key process variables to consider include powder selection, binder selection, formulation, powder-binder interactions, infiltrant selection, saturation (amount of binder deposited per unit volume of powder) and post-processing treatments.

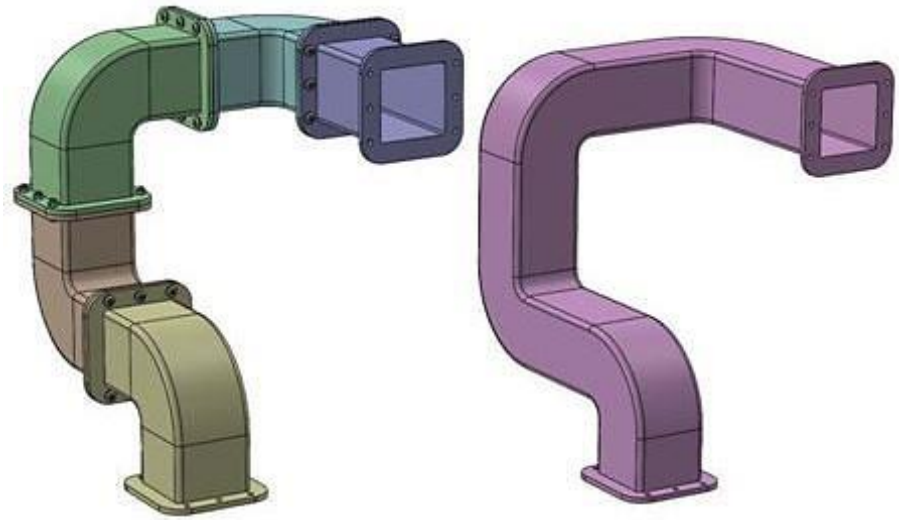
ISO/ASTM 52910

Product considerations include:

- Part or product consolidation
- Assembly features
- Multi-part mechanisms

Geometrical considerations include:

- Accuracy and precision
- Surface roughness
- Minimum feature size & spacing
- Maximum unsupported feature
- Data interchange considerations



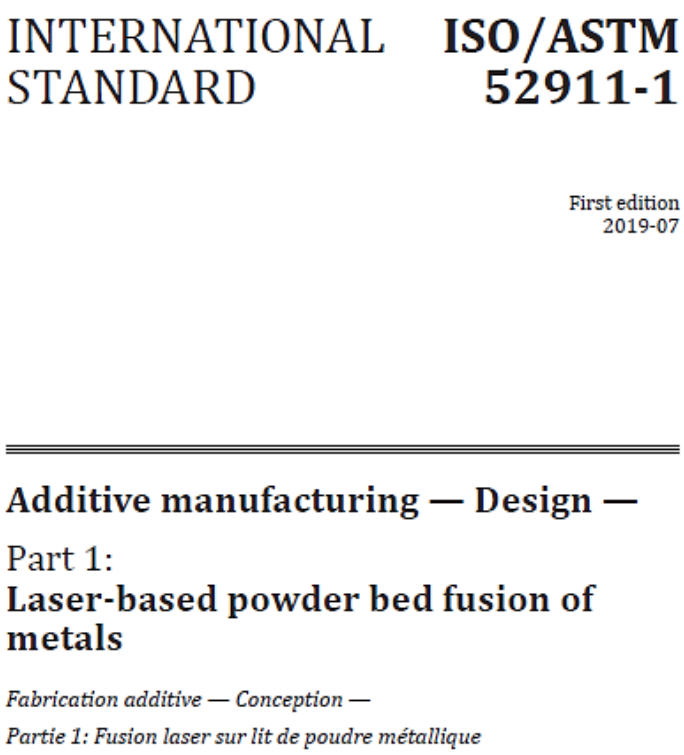
Five parts and 24 fasteners (left) versus one part (right), courtesy of Olaf Diegel

Image credit: http://wohlersassociates.com/blog/wp-content/uploads/2018/05/DfAM-assembly.jpg

ISO/ASTM DIS 52911-1 Additive manufacturing -- Technical design guideline for powder bed fusion -- Part 1: Laser-based powder bed fusion of metals

Characteristics of powder bed fusion (PBF) processes:

- Benefits with regard to the PBF process
- Limitations to consider
- Feature constraints (islands, overhang, stair-step effect).
- Dimensional, form and positional accuracy


INTERNATIONAL STANDARD

ISO/ASTM 52911-1

First edition
2019-07

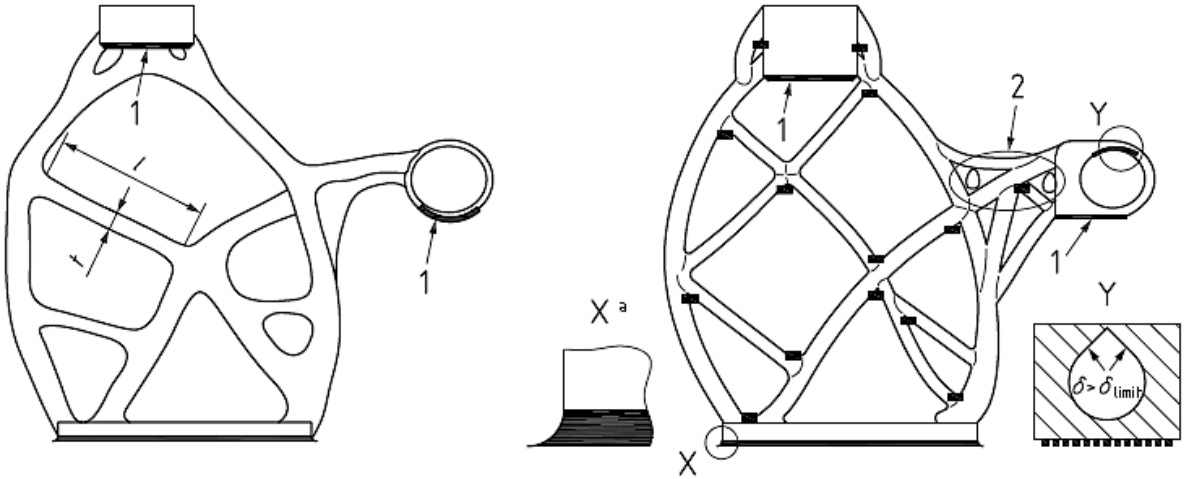
Additive manufacturing — Design —

Part 1:
Laser-based powder bed fusion of metals

Fabrication additive — Conception —
Partie 1: Fusion laser sur lit de poudre métallique

ISO/ASTM DIS 52911-1

Figure 8 — Modifications of geometry for PBF-LB/M



a) Initial shape, after topological optimization

b) New shape for LBM process

Key

1 supports required
2 thin wall
a Fillet radius.
t thickness
l length

Minimum thickness of the tubes should be > 1 mm. Avoid sharp corners. To avoid crack due to residual stress, the part should join the plate smoothly as the connecting area (fillet radius). The radius in the connecting area should be < Ø6 mm.

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3D Thinking and Design for Additive Manufacturing

In summary:

- AM Design - Rules and guidelines
- Manufacturing process capabilities
- Mechanical properties of the material

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