Lecture 1 - 3D Manufacturing Introduction

Dr Chris Steer

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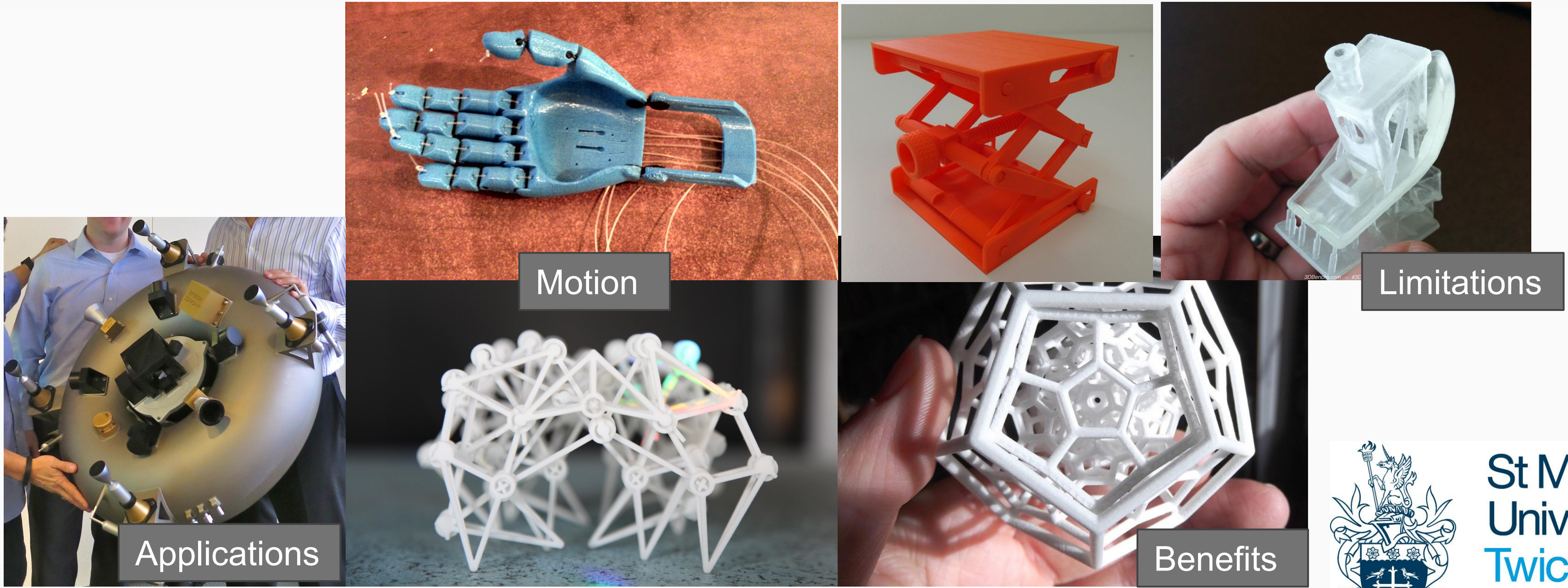

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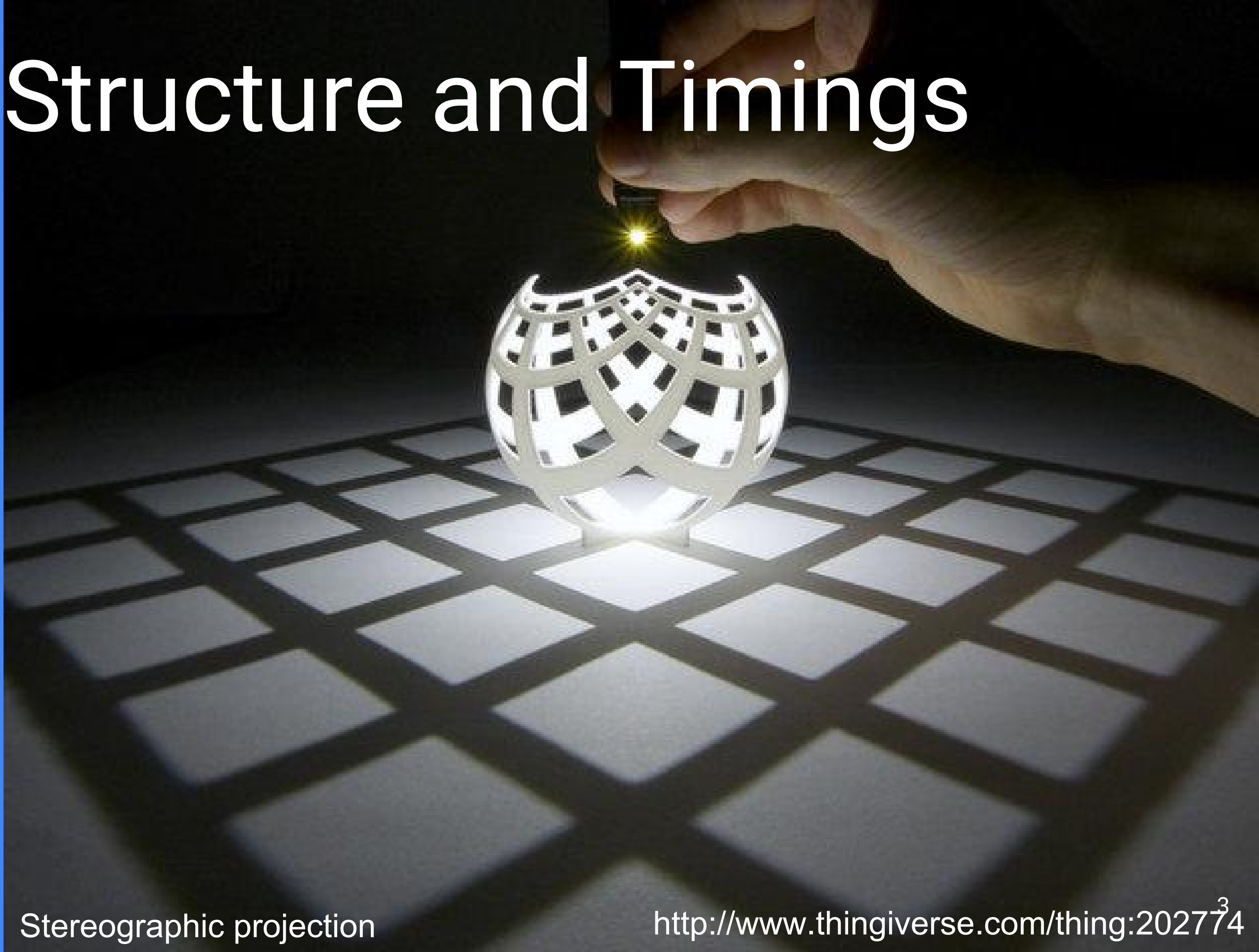
Overview

www.thingiverse.com/thing:6291

- Course Structure and Timings
- Problem Sets and Worksheets
- Core and Supplementary Texts
- Course Assessment
- Project and Design Diary

Course Structure and Timings



Stereographic projection

http://www.thingiverse.com/thing:202774

Course Structure and Timings

- Read the APH6010 Module Guide - all timings and content description is in there

- Two sessions per week on Fridays
  - Friday 9am to 11am at L40
  - Friday 3pm to 5pm at M2

- Three blocks of weeks
  - Weeks 24-27 : 5/2/16 - 26/2/16
  - Weeks 29-30 : 11/3/16 - 18/3/16
  - Weeks 33-37 : 8/4/16 - 6/5/16

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Course Problem Sets

- Problem sets are given out on every other Friday

- Electronic problem sheets only submitted via MyModules
- … or by email to: christopher.steer@stmarys.ac.uk
- … or bring to Friday morning lecture for hand-written maths answers

- Problem sheets deadline is before the Friday morning session (9am)

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Course Worksheets

- Worksheets correspond to the workshop sessions and are to be worked through in class

- Various types of contact times:

- **Lectures** : Conventional, talk and **make notes**
- **Workshops** : Computer based demonstration, discussion around work sheet(s), **make notes**
- **Project week** : Time set aside for formative feedback and discussion on design project, make notes within design diary

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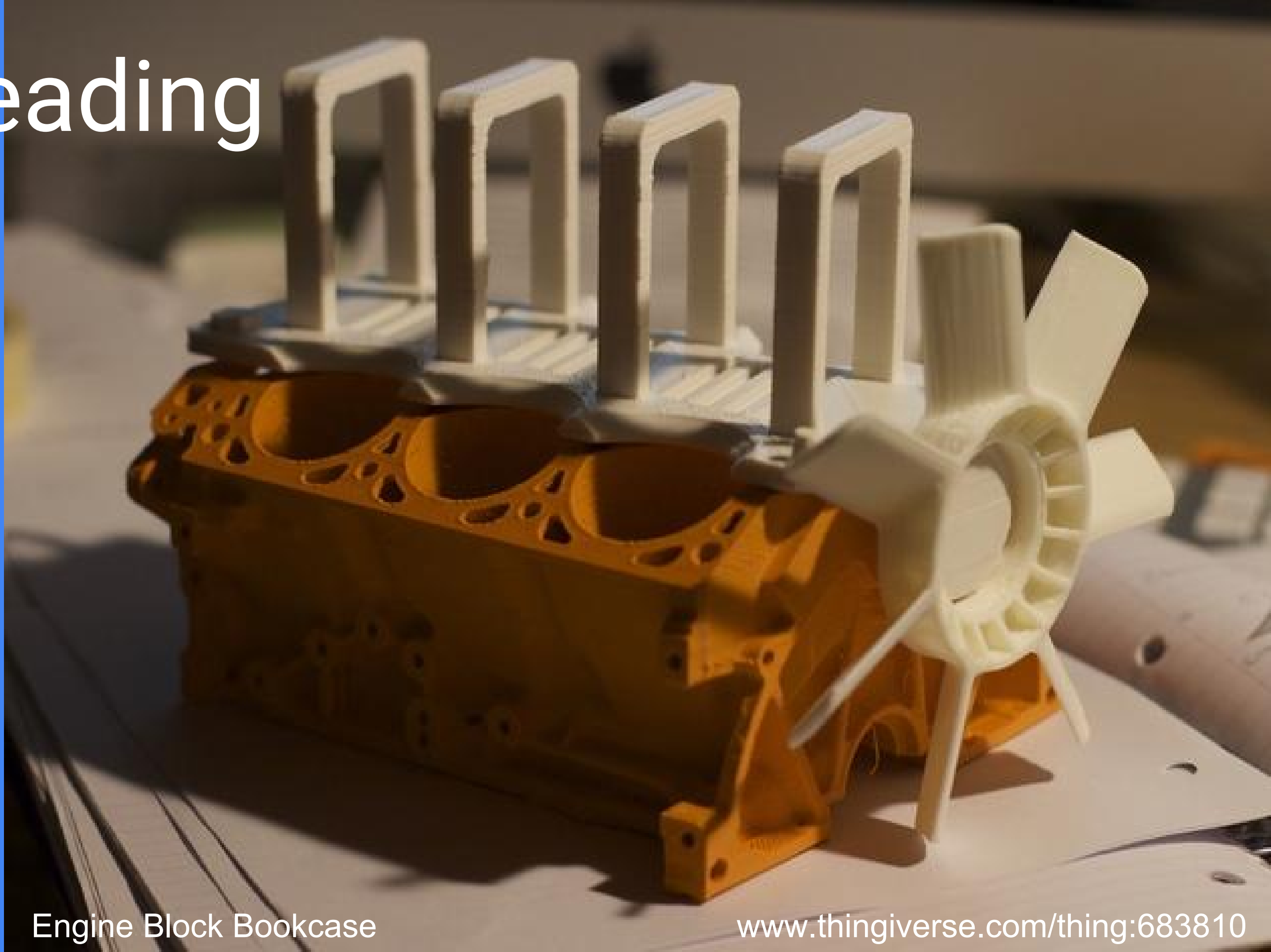
Core Reading

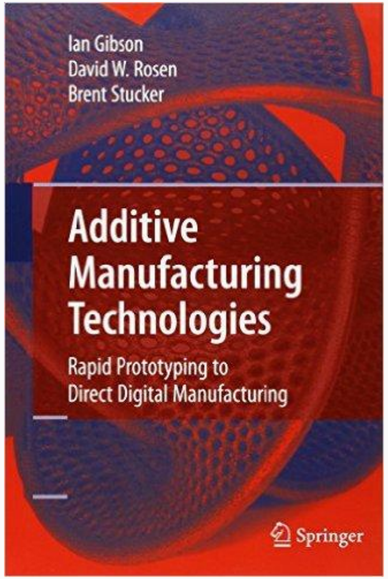


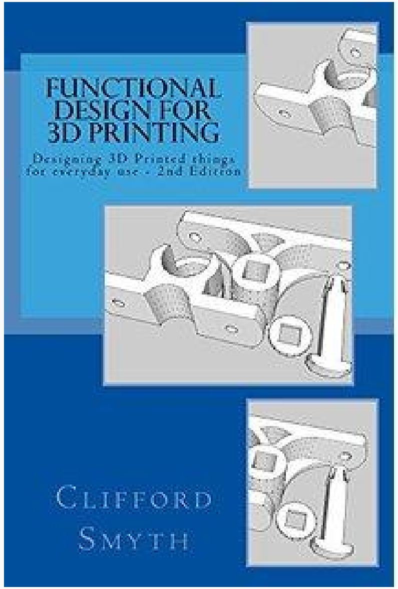
Engine Block Bookcase

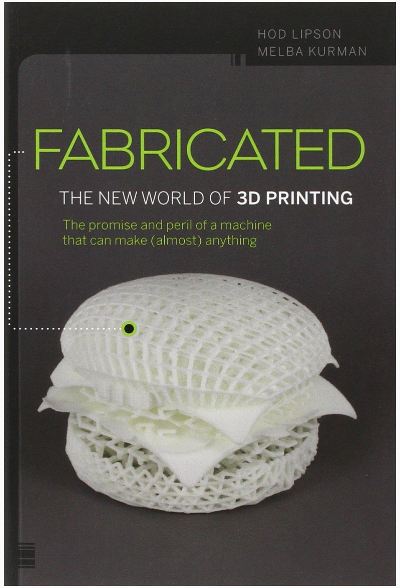
www.thingiverse.com/thing:683810

Main Core Reading

- Techniques : Gibson, Rosen, and Stucker *(the red book)*
- Design : Smyth (*the blue book*)
- Wider Context : Fabricated (*the grey book*)







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Supplementary

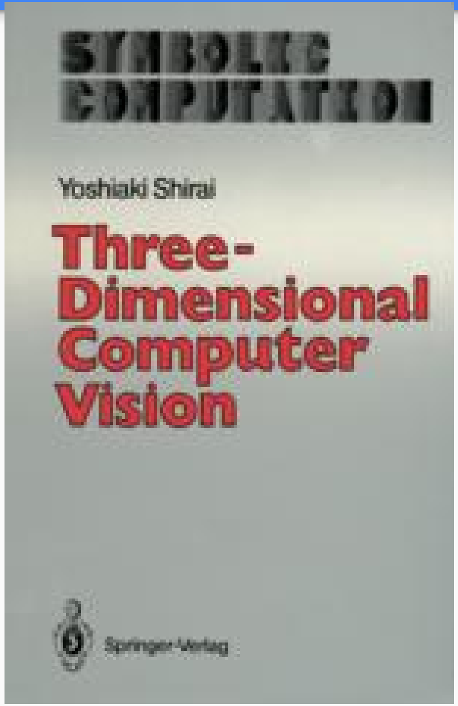
- Computer Vision

  (Reverse Engineering Surface Models) :

  1. Ballard and Brown : http://homepages.inf.ed.ac.uk/rbf/BOOKS/BANDB/bandb.htm
  2. 3D Computer Vision, Shirai

- General Physics (fluid flow)

  Mechanics and Molecular Physics, L. D. Landau, A. I. Akhiezer, and E. M. Lifshitz. Pergamon. (1967) - out of copyright and available here: https://archive.org/details/GeneralPhysics



Review Papers

- For the professional Physicist, peer-reviewed journal papers are a vital source of information
  - Anyone can use Google Scholar (scholar.google.co.uk) to search for journal papers

- Reading and developing an understanding of journal papers is an important skill

- There are two main review papers to find (and should be freely available online - search Google Scholar!)
  - Jacobs, Paul F. "Fundamentals of stereolithography." *Proceedings of the Solid Freeform Fabrication Symposium*. 1992.
  - N. Turner, Brian, Robert Strong, and Scott A. Gold. "A review of melt extrusion additive manufacturing processes: I. Process design and modeling." *Rapid Prototyping Journal* 20.3 (2014): 192-204.

FUNDAMENTALS OF STEREOLITHOGRAPHY

July 1992

Dr. Paul F. Jacobs

Director of Research & Development

3D Systems, Inc.
Valencia, California

A review of melt extrusion additive manufacturing processes: I. Process design and modeling

Brian N. Turner, Robert Strong and Scott A. Gold
Chemical and Materials Engineering, University of Dayton, Dayton, Ohio, USA

Abstract
Purpose – The purpose of this paper is to systematically and critically review the literature related to process design and modeling of fused deposition modeling (FDM) and similar extrusion-based additive manufacturing (AM) or rapid prototyping processes.
Design/methodology/approach – A systematic review of the literature focusing on process design and mathematical process modeling was carried out.
Findings – FDM and similar processes are among the most widely used rapid prototyping processes with growing application in finished part manufacturing. Key elements of the typical processes, including the material feed mechanism, liquefier and print nozzle; the build surface and environment; and approaches to part finishing are described. Approaches to estimating the motor torque and power required to achieve a desired filament feed rate are presented. Models of required heat flux, shear on the melt and pressure drop in the liquefier are reviewed. On leaving the print nozzle, die swelling and bead cooling are considered. Approaches to modeling the spread of a deposited road of material and the bonding of polymer roads to one another are also reviewed.
Originality/value – To date, no other systematic review of process design and modeling research related to melt extrusion AM has been published. Understanding and improving process models will be key to improving system process controls, as well as enabling the development of advanced engineering material feedstocks for FDM processes.

Keywords FDM, Fused deposition modeling, Bead spreading, Liquefier dynamics, Melt extrusion manufacturing, Process modeling

Paper type Literature review

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Course Assessment

Course Assessment

- You will be assessed in two ways:
  - Written examination — 60% weight
  - Coursework — 40% weight

- Coursework is broken down further (40% total)
  - Design feasibility — 20%
  - Design report — 20%

- **Coursework is due 5pm, Friday 5th May, 2017.**
- **Exam period is 15th May - 26th May, 2017.**

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Coursework

- A design specification will be released with problem set 4 (**Friday 24th March, 2017**)
- **Good Practice :** It is strongly suggested that you plan your work irrespective of the design specification and before March 24th. For example...

    - Week 1 : Review of previous community designs
    - Week 2 : Community designs critical discussion
    - Week 3 : Develop your own designs
    - Week 4 : Report write-up and submission

- **Good Practice :** Anticipate questions you're going to need to answer e.g. where do I find community designs? What design aspects do I have to be very careful about when designing for 3D printers?...

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Coursework Good and Bad Practice

- **Essential :** Start a design diary
  - It should have the **same approach as your lab-book** - I want to see your thoughts, every modification that you suggest and make to your design, and most importantly why. Force yourself to **not remove anything**.
  - **Copy and cite designs** that you need to refer to - **do not just copy them** without noting where they come from

- **Good practice :** When writing up, use your design diary as the basis for your report.
  - If you do not hand anything in for your coursework, the mark will be 0%

- **Good practice :** Ask questions! (This is a strong trait of high-achievers)

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Coursework Example Specification

- This project will develop one or more small designs to test the performance of a 3D printer

- These design(s) may study
    - Extrusion rates
    - Compare designed dimensions with printed ones
    - Find the minimum successful overhang angle
    - Find the minimum successful printable hole
    - Build position and its effect on dimensional non-conformity

- The design(s) must be suitable to be printed on a Prusa I3 as described here: http://shop.prusa3d.com/en/3d-printers/59-original-prusa-i3-kit-with-lcd.html

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Design Diary Example

Plan

[Outline how you're going to spend the next four weeks]

Specification

[… restate specification here]

Initial Specification Consideration

[The specification discusses extrusion rates, dimensional comparison,overhang angles… etc so you need to think about what these are here]

Literature and Community Review

[State which online sources are available that you intend to use, look for people who have thought about the design problem already, copy and paste what you find (**with the web address or other citation!**)]

Summary

https://www.youmagine.com/designs/dizi-air-3d-voronoi-outsoles-by-dizingof

- Course Structure and Timings
- Problem Sets and Worksheets
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Questions

If in doubt, ask.

E-mail: christopher.steer@stmarys.ac.uk

Your Actions

- Find three UK-based 3D printing companies - what do they do?

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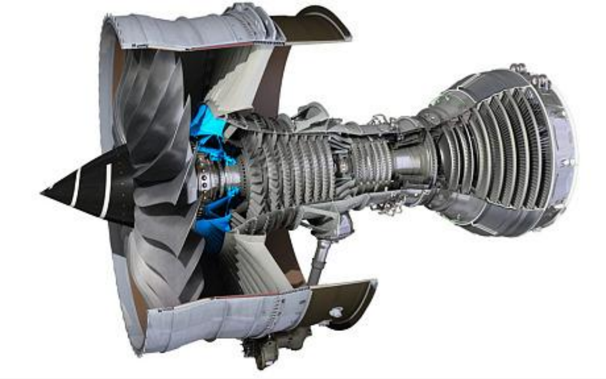
Personal 3D Printing…

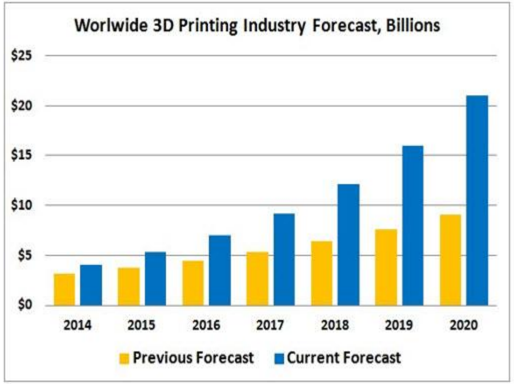
Part 2 : Why study 3D Manufacturing?

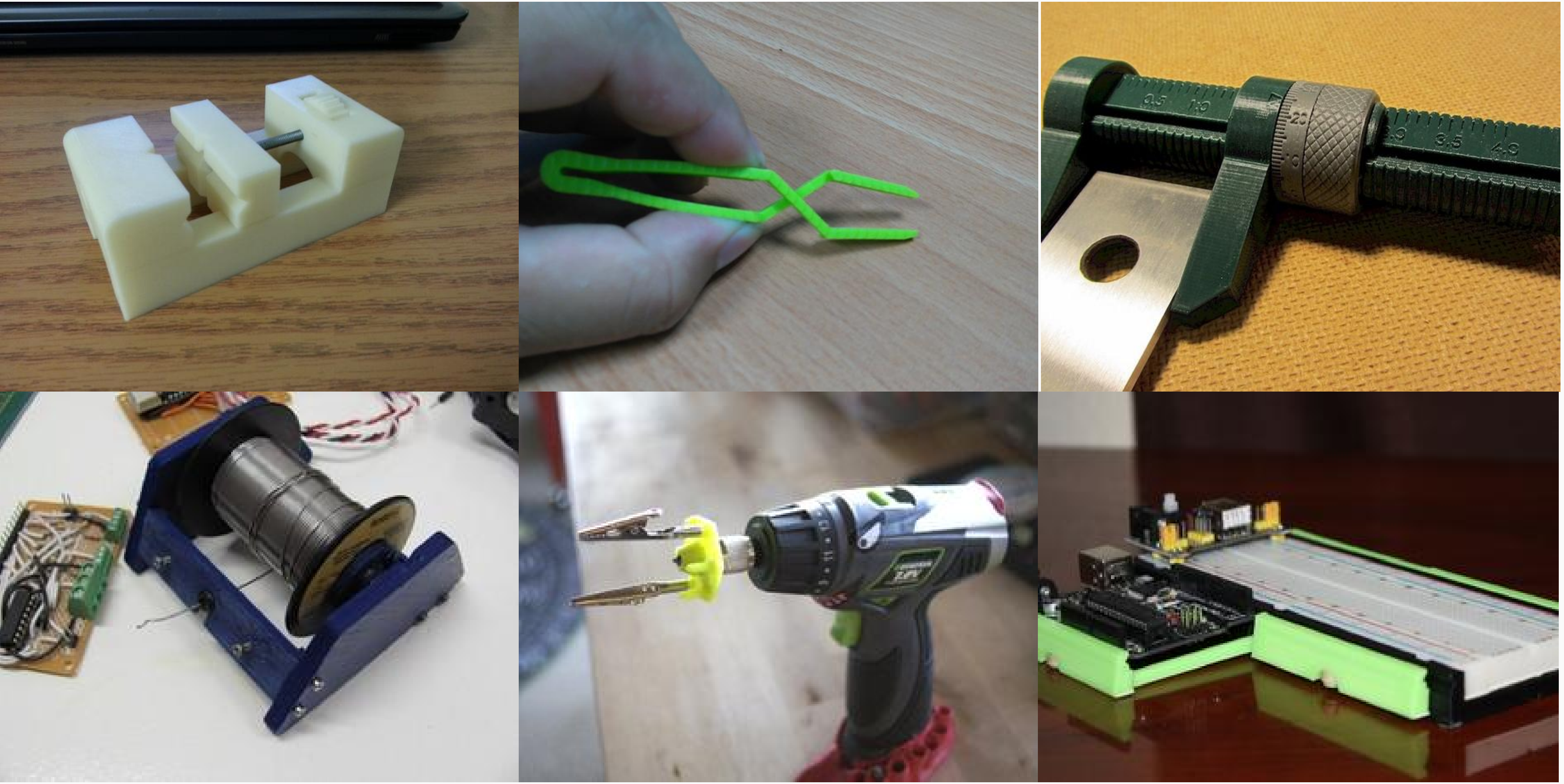
Why is it important for applied Physicists?

- **Employability** : Combination of numerical, practical and analytical skills mean Applied Physicists are well-suited to this industry
- **3D Printing Skills :** Many technical employers use rapid prototyping printers in their product development
- **Growth UK Industry** : e3donline, leapfrog… strong community of makers and small-to-medium enterprises
- **Bespoke tools** : Experimental science often requires bespoke parts, lab supports, small enclosures…
- **(... and it's enjoyable and rewarding…)**



Rolls-Royce's largest 3d-printed component





3D printing enables physicists to prototype very quickly

Mass-production and mass-customisation

- Industrial revolution (18th-19th century) caused a transition from hand-made to **mass-produced**
- **No customisation** - 'Any colour as long as it's black'
- Supply of goods developed with canals/railways
- Digital revolution and manufacturing - a transition to mass-customisation?
- Digital transportation of goods

Source : Stratasys

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Supply Chain and 3D Printing/Manufacturing

- Physical supply chain
  - Objects made in elsewhere
  - Physically transported overseas

- Digital supply chain
  - Transport digital object to end-user
  - e.g. Vinyl/CDs -> MP3s : Development of computational processing speeds to reproduce and play music

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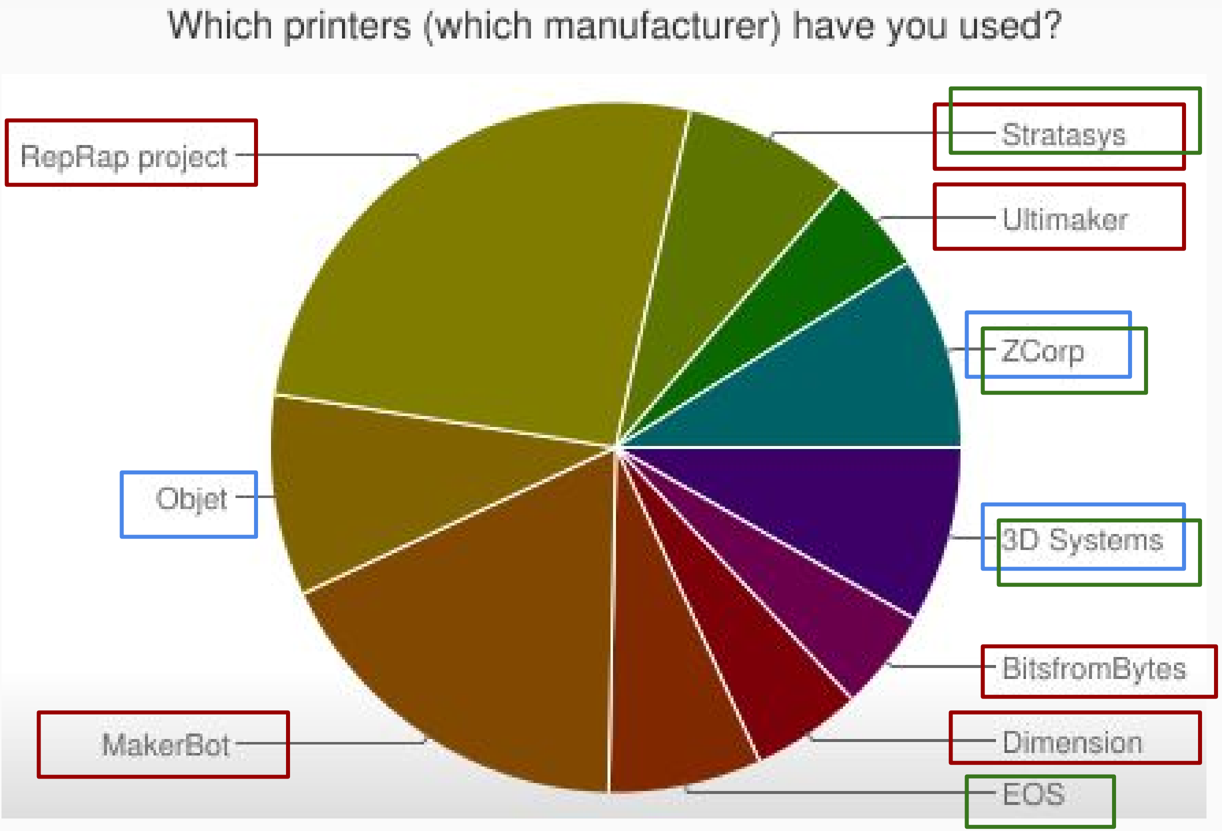
Future manufacturing

- 3D Printing enables the digital supply chain for many physical objects

- Potential for a completely automated factory

Current usage of AM printing technologies



- **Plastic-based fused filament extrusion systems (FFF/FDM)**
- **Stereolithography systems (SL)**
- **Polyjet, metal and other printing systems (SLS,DMP)**

[http://surveys.peerproduction.net/2012/05/manufacturing-in-motion/]

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Course Motivation

- The course main techniques to be considered in-depth are
  - Fused filament fabrication (FFF)
  - Stereolithography

- To do this we need to cover:
  - **Physics of materials** under stress, and flow of viscous fluids, modelling of laser solidification of polymers...
  - **Design toolchain** for 3D printing techniques
  - And **applications** of these printing techniques to understand the unique benefits of AM production

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Section Summary

http://www.thingiverse.com/thing:1082508

- Digital supply chain of physical objects
- Mass-customisation is possible
- Physics of FFF and SL are a focus of the course
- As are development of design techniques

Your Actions

- Find an example video of a stereolithography (SL) 3D printing system in action - sketch how it works in your notes
- Sketch a Fused Filament Fabrication system and label its parts
- What does the term mass-customisation mean to you? What 3D printed products would you manufacture?

Comparison of subtractive and additive manufacturing

Conventional Manufacturing

- Control router or chisel to remove material from raw material
- Progressively remove material
- Lots of wastage

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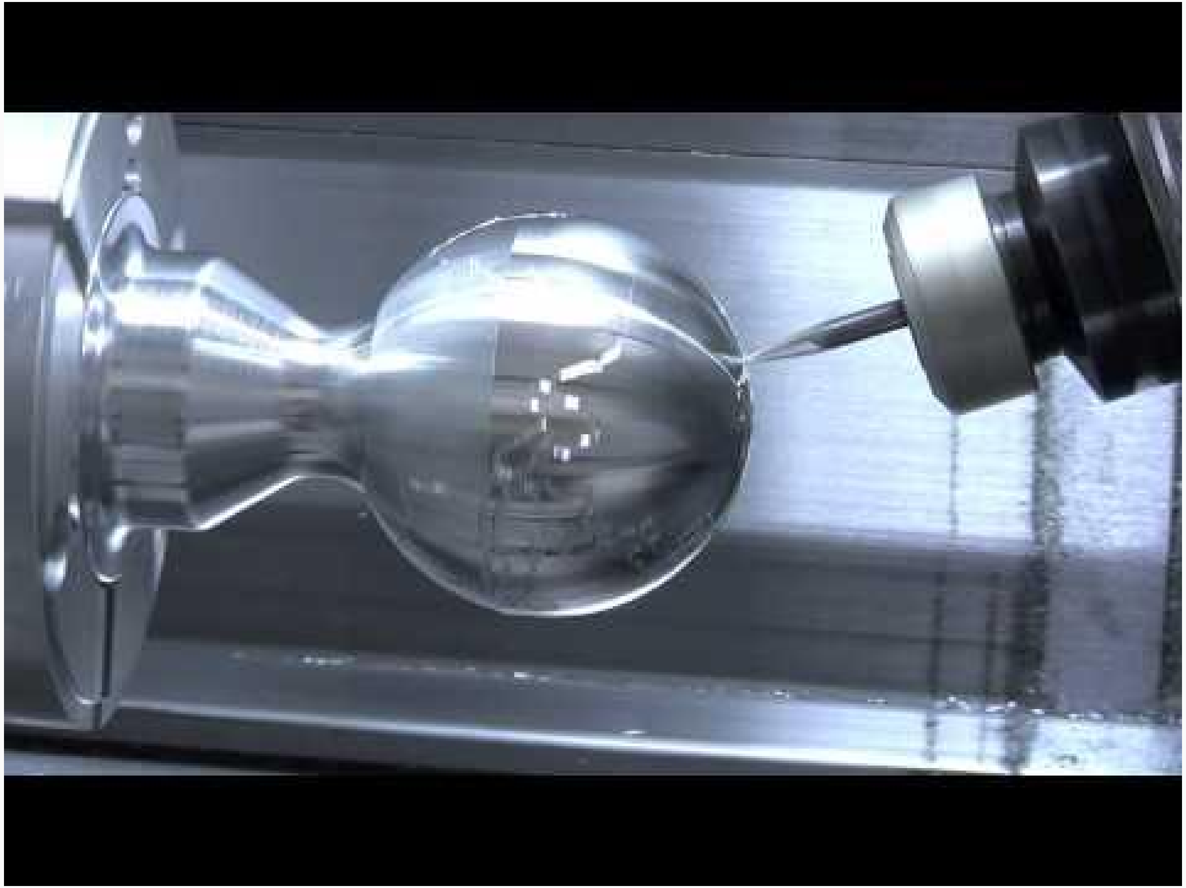
Example CNC Lathe

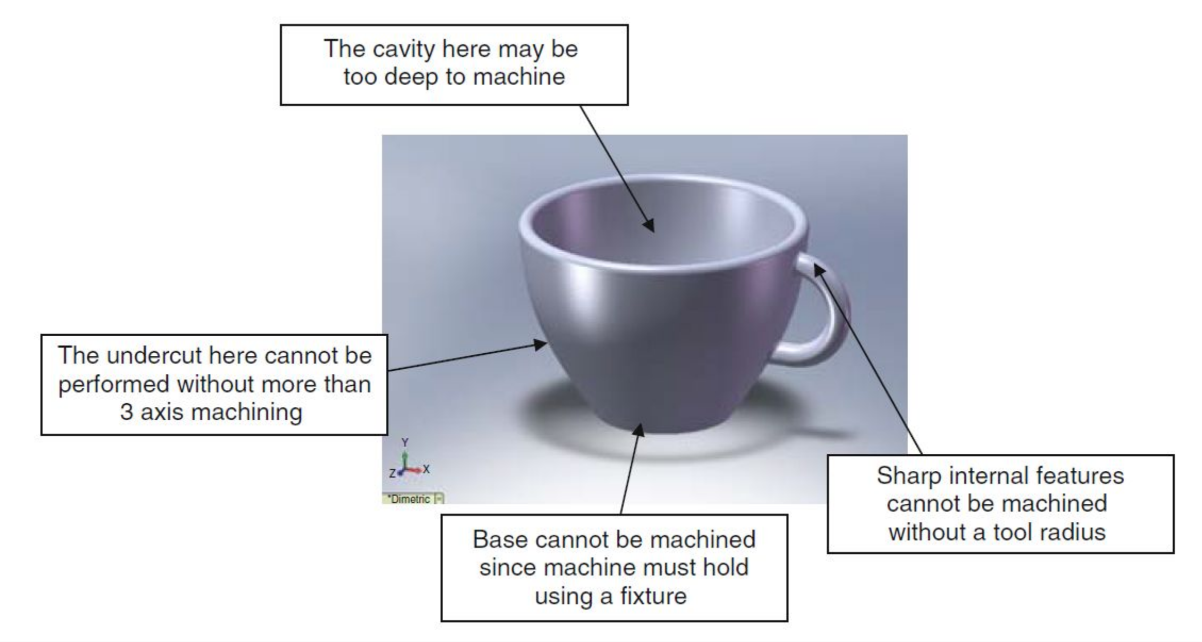


Conventional Subtractive Manufacturing

- Subtractive (conventional) manufacturing removes material from a billet by machining to achieve the final form
  - **Benefits :**
    - High degree of automation, repeatability and accuracy
    - Wide material availability
    - Good surface finishing
    - Solid objects i.e. no micro-voids from melt filament or sintered powder
    - ...
  - **Limitations:**
    - Cannot access the interior of an object
    - Wastes material and energy

Subtractive Machining Example : Computer Numerical Control (CNC) Lathe

- Tool changes
- Precise computer and motor control
- Positioning of tool head relative to piece
- Tool length limits depth of cavities



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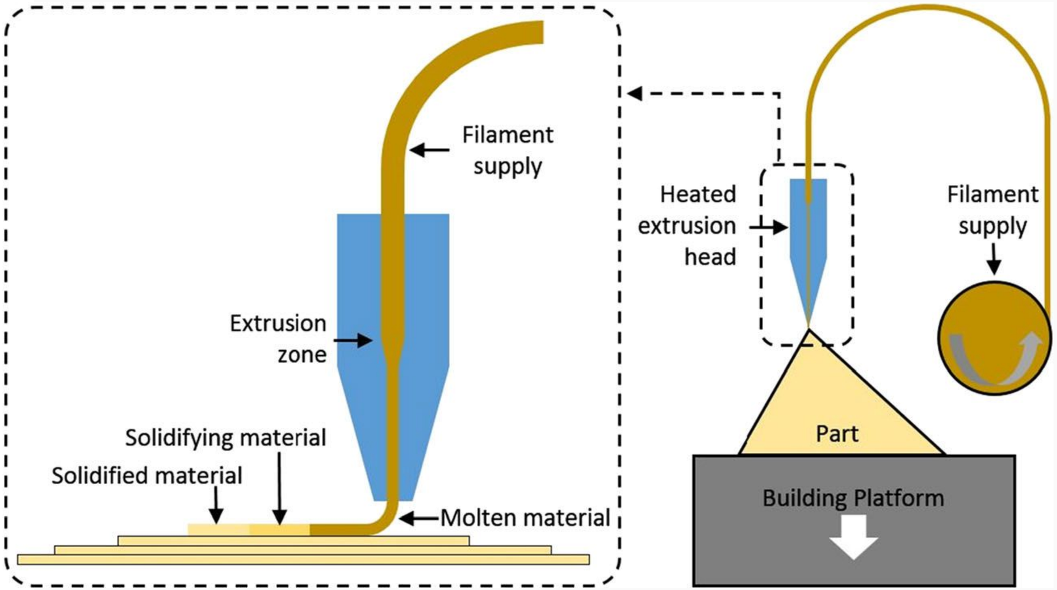
Subtractive Machining Example : Hobby

Additive Manufacturing / 3D Printing Technique Example



Additive Manufacturing / 3D Printing

- Additive manufacturing builds parts up by adding a layer at a time
    - **Benefits :**
        - High degree of automation, repeatibility and accuracy
        - Adds only material to part needed so very little wastage of materials
        - Production can be performed by designer - faster development time
        - Part can be structurally complex
    - **Limitations :**
        - Mass-production is difficult
        - Production is typically slower
        - Limited material selection
        - Requires post-processing

Additive Manufacturing Example : Fused Deposition Modelling System

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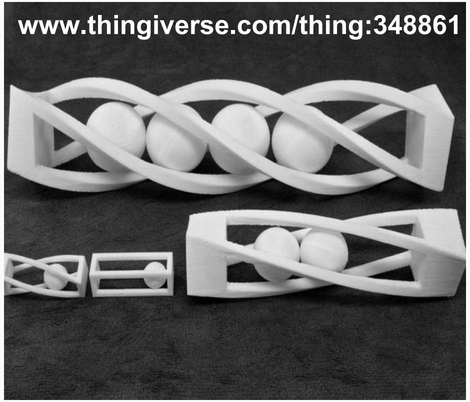
Additive Manufacturing Benefits

- **Shape** : AM can produce very complex shapes as it can access the interior of the printed object

- **Hierarchical** : AM can produce these complex designs over many scales

- **Functional** : AM can produce functional mechanical objects (not just single parts)



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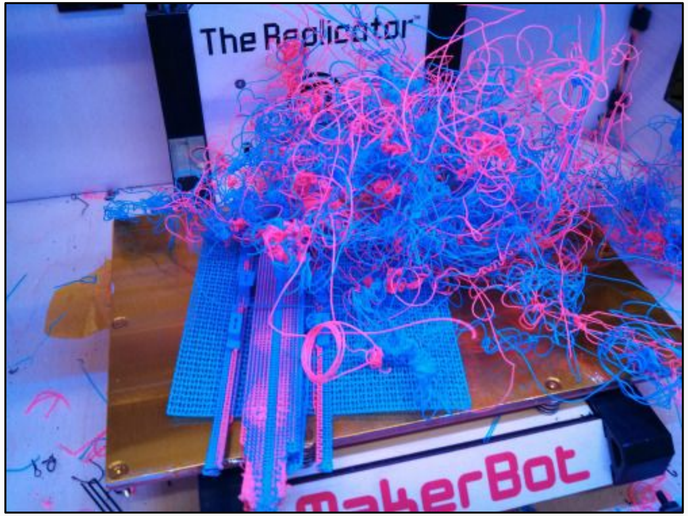
Additive Manufacturing Design Limitations

- **Object Scale** : The object's scale is limited by the finite feature resolution at the small end, and by the build volume at the other scale

- **Slope Overhang** : Unsupported sloping surfaces have a minimum slope angle

- **Speed** : The finite time it takes to place solid material limits the overall production speed of each object



http://epic3dprintingfail.tumblr.com/

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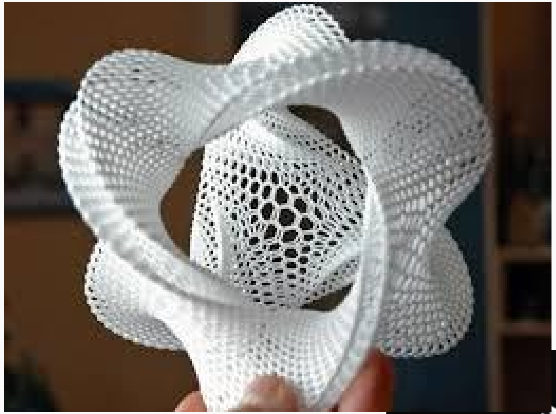
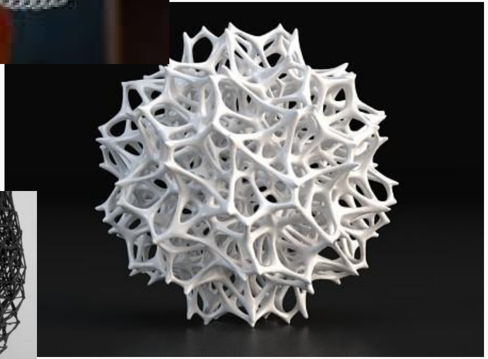
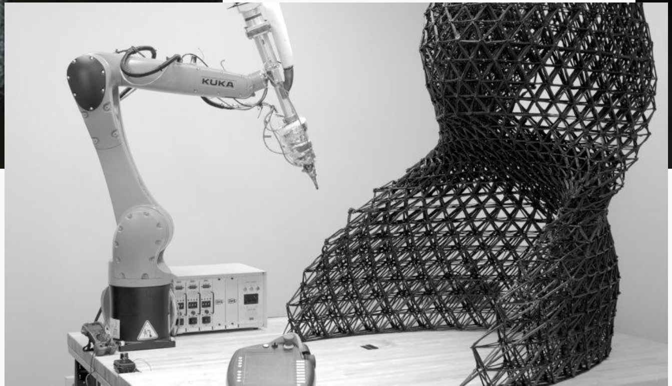
Example Structures built only by 3D printing

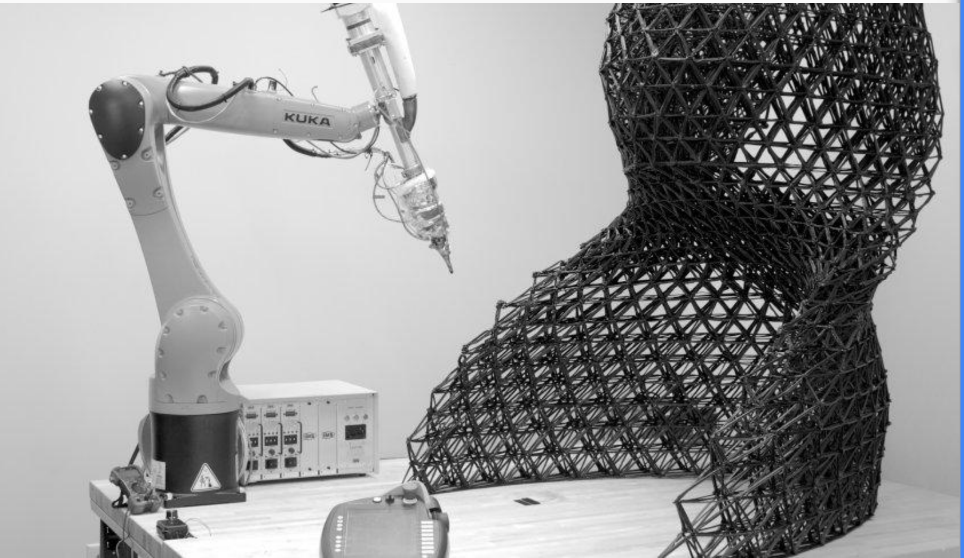






- Parametric design of bridges, walls, and lightweight structures
- Strength and lightweight

Section Summary



- Additive manufacturing adds material to successive layers to produce a part
- Benefits and limitations of conventional and additive manufacturing
- Introduced AM design limitations

Questions

If in doubt, ask.

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