

# **Subtractive** versus **Rapid Manufacturing**

**Dr. Janakarajan Ramkumar**

**Professor**

**Department of Mechanical & Design Program**

**IIT Kanpur, India.**

# Contents

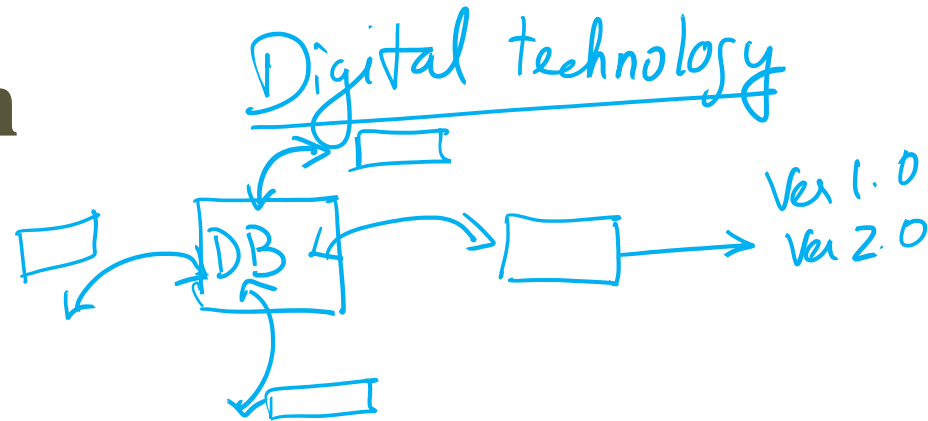
- Benefits of Rapid Manufacturing
- Effectiveness of Rapid Manufacturing
- Rapid Manufacturing versus CNC Machining
  - Material, speed, complexity, accuracy, geometry

# Introduction

In this lecture, we will discuss broadly the differences between the subtractive and additive manufacturing.

- Many people have described Rapid Manufacturing (RM) technology as revolutionizing product development and manufacturing.
- Some have even gone on to say that manufacturing, as we know it today, may not exist if we follow RM to its ultimate conclusion.
- We might, therefore, like to ask:
  - Why is this the case?
  - What is it about RM that enthuses and inspires some to make these kinds of statements?

# Introduction

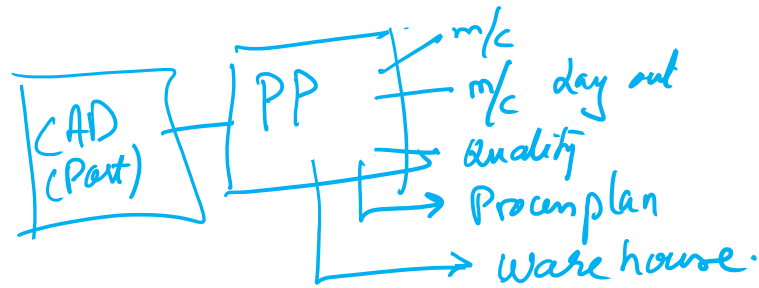


## The Benefits of RM

- First, let's consider the "rapid" character of this technology. The speed advantage is not just in terms of the time it takes to build parts.
- The speeding up of the whole product development process relies much on the fact that we are using computers throughout.
- Since 3D CAD\* is being used as the starting point and the transfer to RM is relatively seamless, there is much less concern over data conversion or interpretation of the design intent.

*\*Note: We'll discuss about CAD/CAM, Reverse Engineering in the coming weeks*

# Introduction



## The Benefits of RM



- Just as 3D CAD is becoming “What You See Is What You Get (WYSIWYG)”, so it is the same with RM and we might just as easily say that “What you See Is What You Build (WYSIWYB)”.
- The seamlessness can also be seen in terms of the reduction in process steps.
- Regardless of the complexity of parts to be built, building within an RM machine is generally performed in a single step.

# Introduction

## Subtractive processes

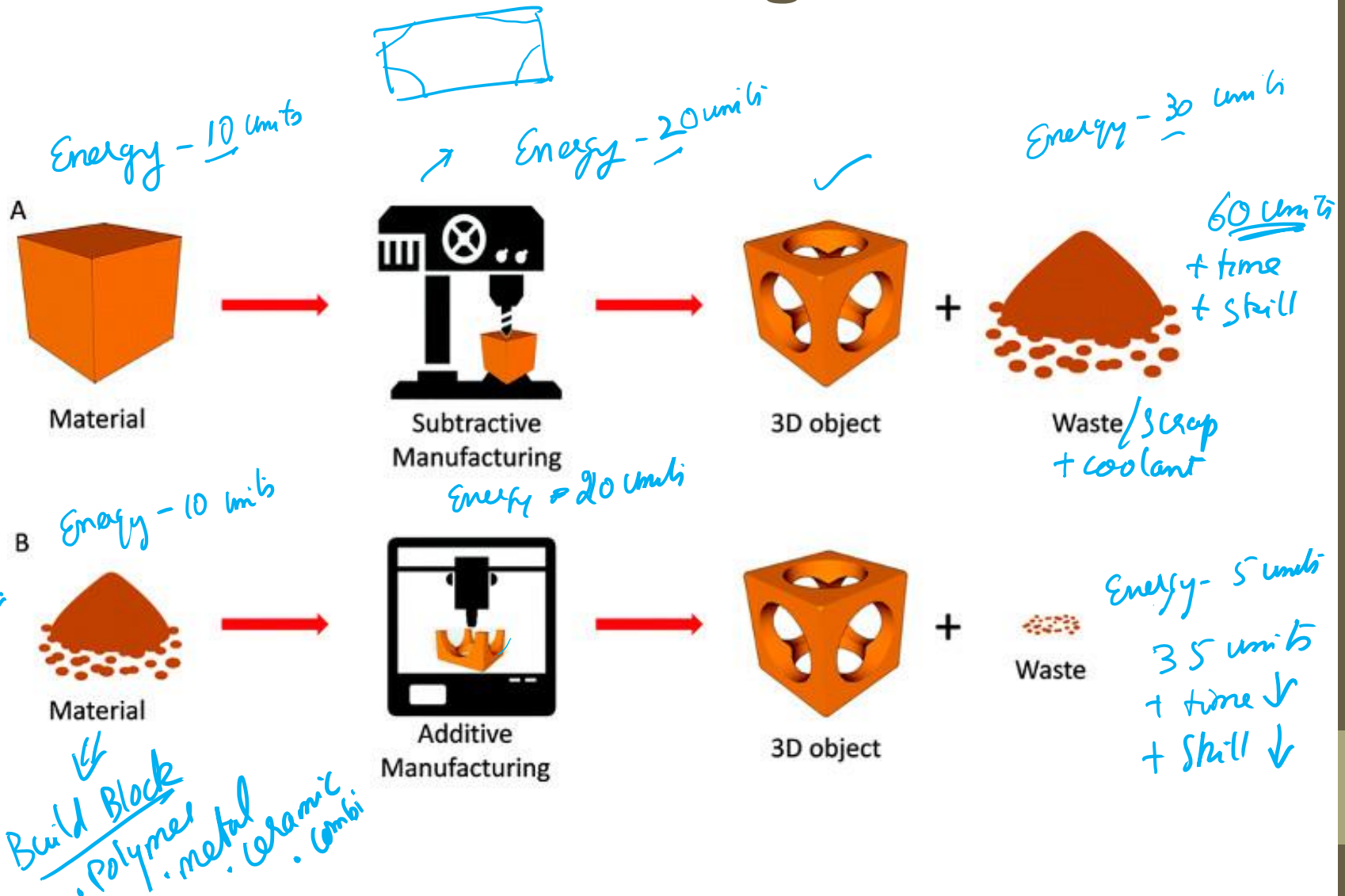
- Complex Surfaces
- few in no.
- Assembly

RM

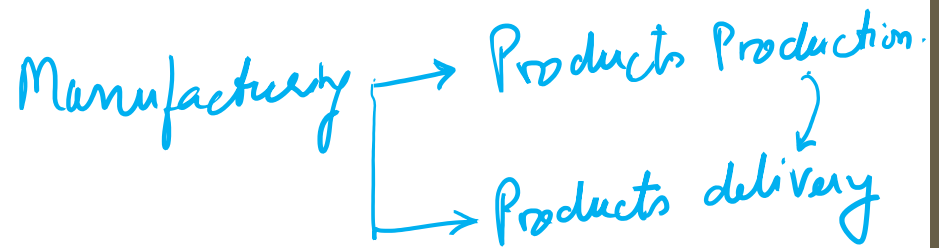
- Most other manufacturing processes would require multiple and iterative stages to be carried out.
- As you include more features in a design, the number of these stages may increase dramatically.
- Even a relatively simple change in the design may result in a significant increase in the time required to build using conventional methods.

machine/fixture  $\rightarrow$  non-modular  $\rightarrow$  parts get into fixture  
modular  $\Rightarrow$  SMED

# RM, and CNC machining



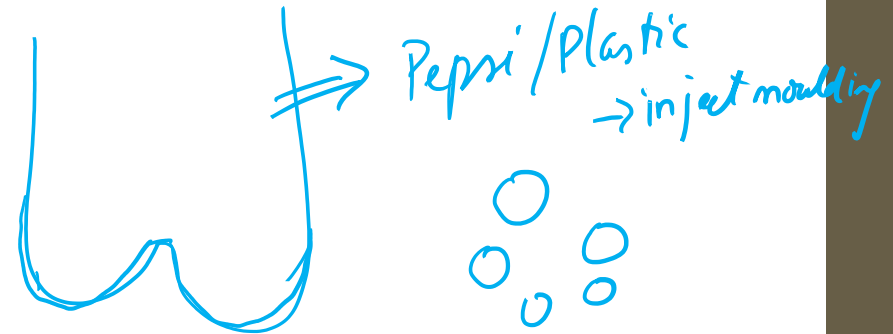
# Introduction



## Effectiveness of RM

- RM can be seen as a way to more effectively predict the amount of time to fabricate models, regardless of what changes may be implemented during this formative stage of the product development.
- Similarly, the number of processes and resources required can be significantly reduced when using RM.  
+ inserts
- If a skilled craftsman was requested to build a prototype according to a set of CAD drawings, he may find that he must manufacture the part in a number of stages.

# Introduction



## Effectiveness of RM

- In the subtractive case, this craftsman must have to employ a variety of construction methods, ranging from hand carving, through molding and forming techniques, to CNC machining.

⇒ Finishing

- Hand carving and similar operations are tedious, difficult, and prone to error. Molding technology can be messy and obviously requires the building of one or more molds.
- CNC machining requires careful planning and a sequential approach that may also require construction of fixtures before the part itself can be made.

tool path



# Introduction

## Effectiveness of RM

- All this presupposes that these technologies are within the skillset of the craftsman and readily available.
- RM can be used to remove, or at least simplify many of these multi-stage processes.
- With the addition of some supporting technologies like silicon-rubber molding, drills, polishers, grinders, etc. it can be possible to manufacture a vast range of different parts with different characteristics.

# Introduction



⇒ Solid Block



Milling ✓  
Turning ✓  
Grinding ✓  
Water-jet cutting ✓  
Sawing ✓

Subtractive machining  
removes material by physical  
or chemical processing

1D → 2D → 3D  
Build Block →   
2D ⇒ layers.



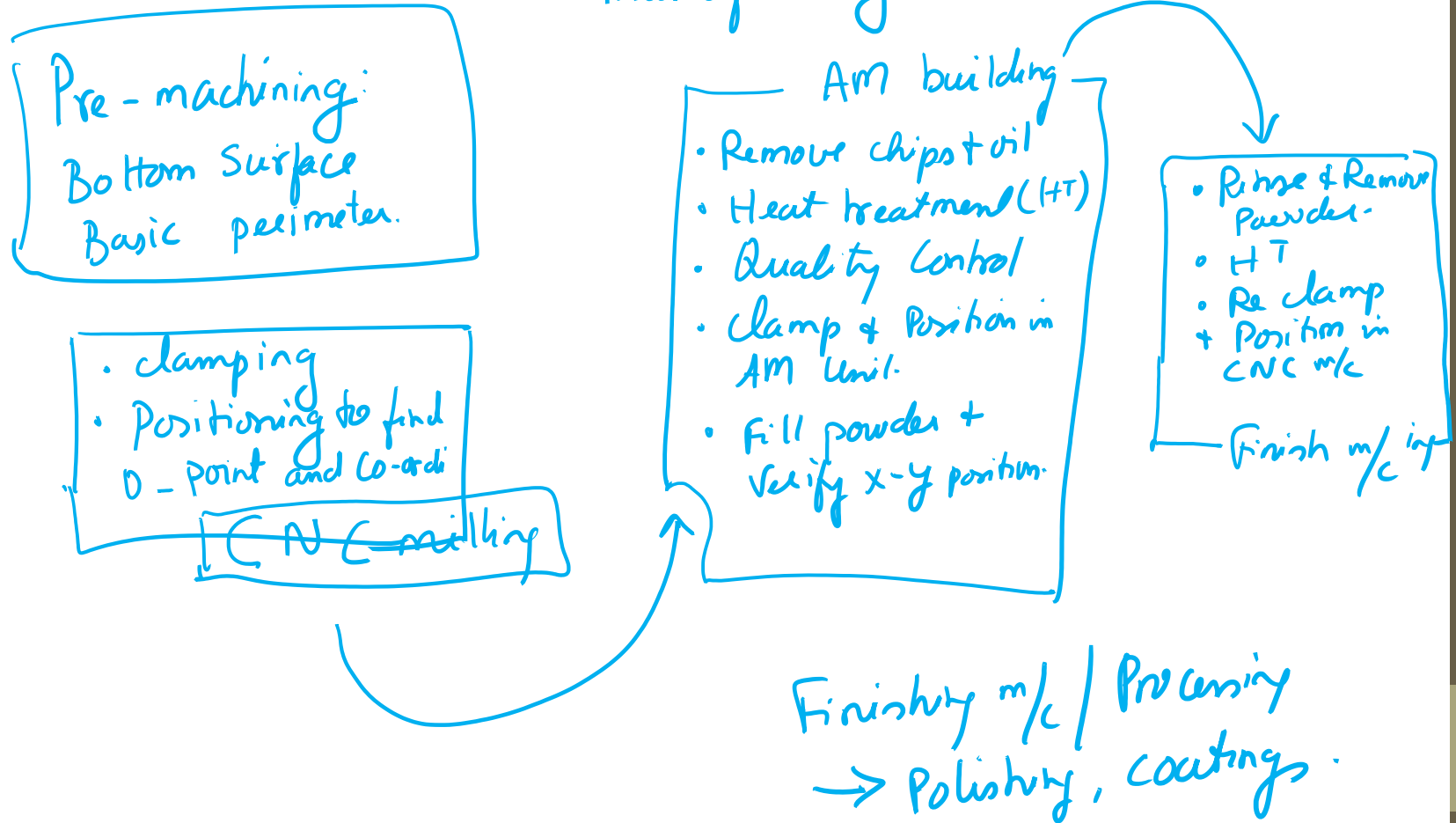
←  $y$  is in  $z$  direction  
2 smaller thickness



Wire extrusion  
Powder-bed  
Deposition

Additive manufacturing  
adds layers of material

# Introduction $\Rightarrow$ Typical Workflow for the production of injection moulding insert in hybrid manufacturing cell



# RM, and CNC machining

- As mentioned in the discussion on Automated Fabrication, RM shares some of its DNA with Computer Numerical Controlled machining technology.

CAD/CAM  $\Rightarrow$  CAE

- CNC is also computer-based technology that is used to manufacture products.
- CNC differs mainly in that it is primarily a subtractive rather than additive process, requiring a block of material that must be at least as big as the part that is to be made.

# RM, and CNC machining

- This section discusses a range of topics where comparisons between CNC machining and RM can be made.
- The purpose is not really to influence choice of one technology over another rather than to establish:
  - how they may be implemented
    - for different stages in the product development process, or
    - for different types of product.

# RM, and CNC machining

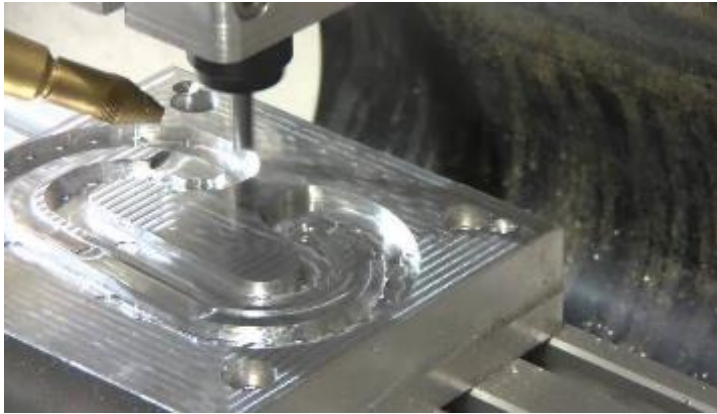
## Material

heat → flux → laser

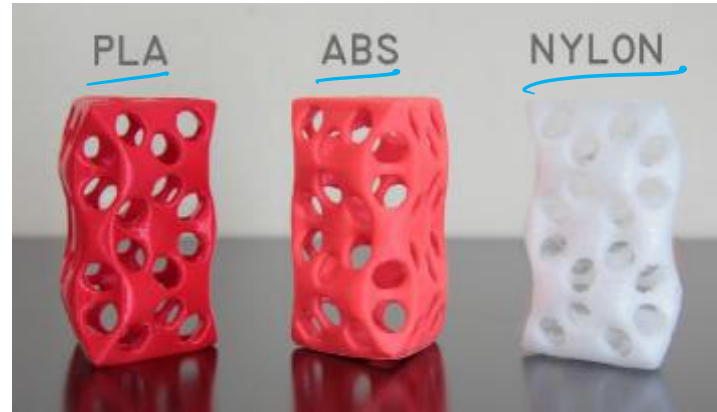
- RM technology was originally developed around polymeric materials, waxes and paper laminates.
- Subsequently, there has been introduction of composites, metals, and ceramics.
- CNC machining can be used for soft materials, like medium-density fiberboard (MDF), machinable foams, machinable waxes, and even some polymers.

# RM, and CNC machining

## Material



metal



polymer + colour.

# RM, and CNC machining

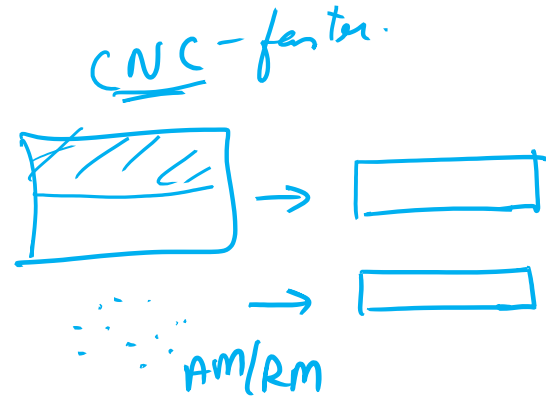
. multistage → handling  
→ reference location  
→ missing operation  
→ Quality

## Material

- However, use of CNC to shape softer materials is focused on preparing these parts for use in a multistage process like casting.
- When using CNC machining to make final products, it works particularly well for hard, relatively brittle materials like steels and other metal alloys to produce high accuracy parts with well defined properties.  
↳ Quality
- Some RM parts, in contrast, may have voids or anisotropy that are a function of part orientation, process parameters or how the design was input to the machine, whereas CNC parts will normally be more homogeneous and predictable in quality.

# RM, and CNC machining

## Speed



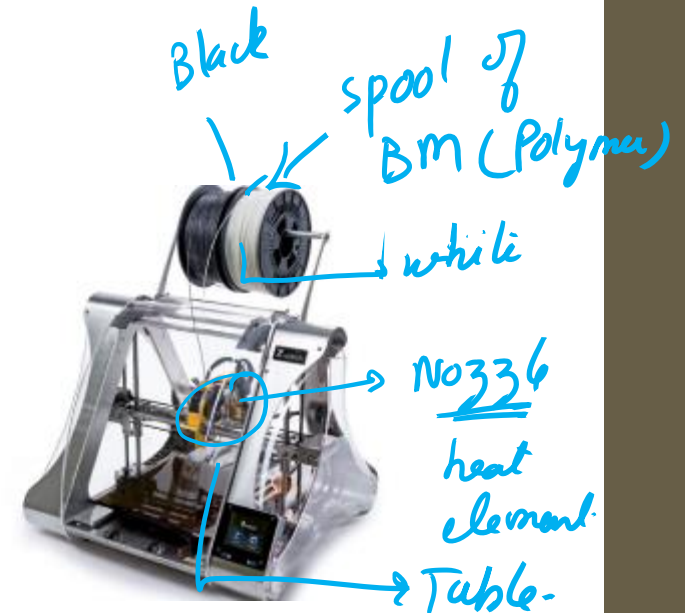
- High speed CNC machining can generally remove material much faster than RM machines can add a similar volume of material.
- However, this is only part of the picture, as RM technology can be used to produce a part in a single stage.
- CNC machines require considerable setup and process planning, particularly as parts become more complex in their geometry.

# RM, and CNC machining

Speed



CNC m/c

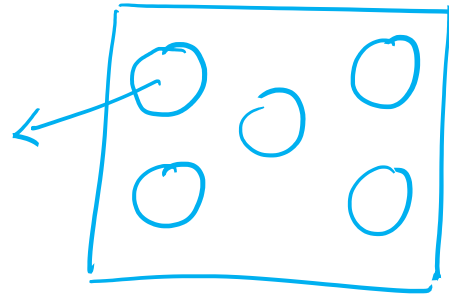


AM

# RM, and CNC machining

## Speed

20 hrs  
25 hrs



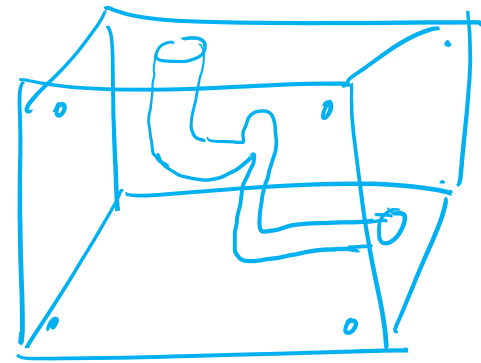
- Speed must therefore be considered in terms of the whole process rather than just the physical interaction of the part material.
- CNC is likely to be a multistage manufacturing process, requiring repositioning or relocation of parts within one machine or use of more than one machine.
- To make a part in an RM machine, it may only take a few hours; and in fact multiple parts are often batched together inside a single RM build.
- Finishing may take a few days if the requirement is for high quality. Using CNC machining, this same process may take weeks. ← die/finishing

# RM, and CNC machining

Complexity → greater → RM → advantages.

- As mentioned above, the higher the geometric complexity, the greater the advantage RM has over CNC.
- If CNC is being used to create a part directly in a single piece, then there are some geometric features that cannot be fabricated.
- Since a machining tool must be carried in a spindle, there may be certain accessibility constraints or clashes preventing the tool from being located on the machining surface of a part.

# RM, and CNC machining



## Complexity

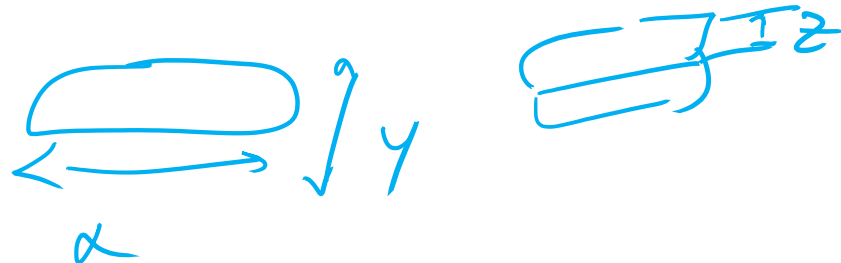
- RM processes are not constrained in the same way and undercuts and internal features\* can be easily built without specific process planning.
- Certain parts cannot be fabricated by CNC unless they are broken up into components and reassembled at a later stage.
- Consider, for example, the possibility of machining a ship inside a bottle. How would you machine the ship while it is still inside the bottle?
- Most likely you would machine both elements separately and work out a way to combine them together as an assembly process.

**\*Note: We'll discuss features in 'Design for Modularity' module in the forthcoming lectures**

# RM, and CNC machining

## Accuracy

- RM machines generally operate with a resolution of a few tens of microns.
- It is common for RM machines to also have variable resolution along different orthogonal axes.
- Typically, the vertical build axis corresponds to layer thickness and this would be of a lower resolution compared with the two axes in the build plane.



# RM, and CNC machining

## Accuracy

- Accuracy in the build plane is determined by the positioning of the build mechanism, which will normally involve gearboxes and motors of some kind.
- This mechanism may also determine the minimum feature size as well.
- For example, Stereolithography uses a laser as part of the build mechanism that will normally be positioned using galvanometric mirror drives.
  - The resolution of the galvanometers would determine the overall dimensions of parts built, while the diameter of the laser beam would determine the minimum wall thickness.

# RM, and CNC machining

## Accuracy

|                    | <u>Tolerance (mm)</u>  | Min. Layer Thickness<br>(mm) | Max. build volume<br>(mm) |
|--------------------|------------------------|------------------------------|---------------------------|
| <u>CNC Milling</u> | $\pm 0.025 - 0.125$ mm | cutting depth <u>0.01</u> mm | 2000 x 800 x 1000<br>mm   |
| <u>SLS</u>         | $\pm 0.3$ mm           | 0.7 - <u>1.0</u> mm          | 300 x 300 x 300 mm        |
| Industrial FDM     | $\pm 0.5$ mm           | 0.8 - 1.0 mm                 | 900 x 600 x 900 mm        |
| <u>DMLS</u>        | $\pm 0.1$ mm           | <u>0.4</u> mm                | 230 x 150 x 150 mm        |

# RM, and CNC machining

## Accuracy

- The accuracy of CNC machines on the other hand is mainly determined by a similar positioning resolution along all three orthogonal axes and by the diameter of the rotary cutting tools.
- There are factors that are defined by the tool geometry, like the radius of internal corners, but wall thickness can be thinner than the tool diameter since it is a subtractive process.
- In both cases very fine detail will also be a function of the properties of the build material.

# RM, and CNC machining

## Geometry

- RM machines essentially break up a complex, 3D problem into a series of simple 2D cross-sections with a nominal thickness.
- In this way, the connection of surfaces in 3D is removed and continuity is determined by how close the proximity of one cross-section is with an adjacent one.
- Since this cannot be easily done in CNC, machining of surfaces must normally be generated in 3D space.

# RM, and CNC machining

## Geometry

- With simple geometries, like cylinders, cuboids, cones, etc., this is a relatively easy process defined by joining points along a path; these points being quite far apart and the tool orientation being fixed.
- In cases of freeform surfaces, these points can become very close together with many changes in orientation.
- Such geometry can become extremely difficult to produce with CNC, even with 5-axis control or greater.

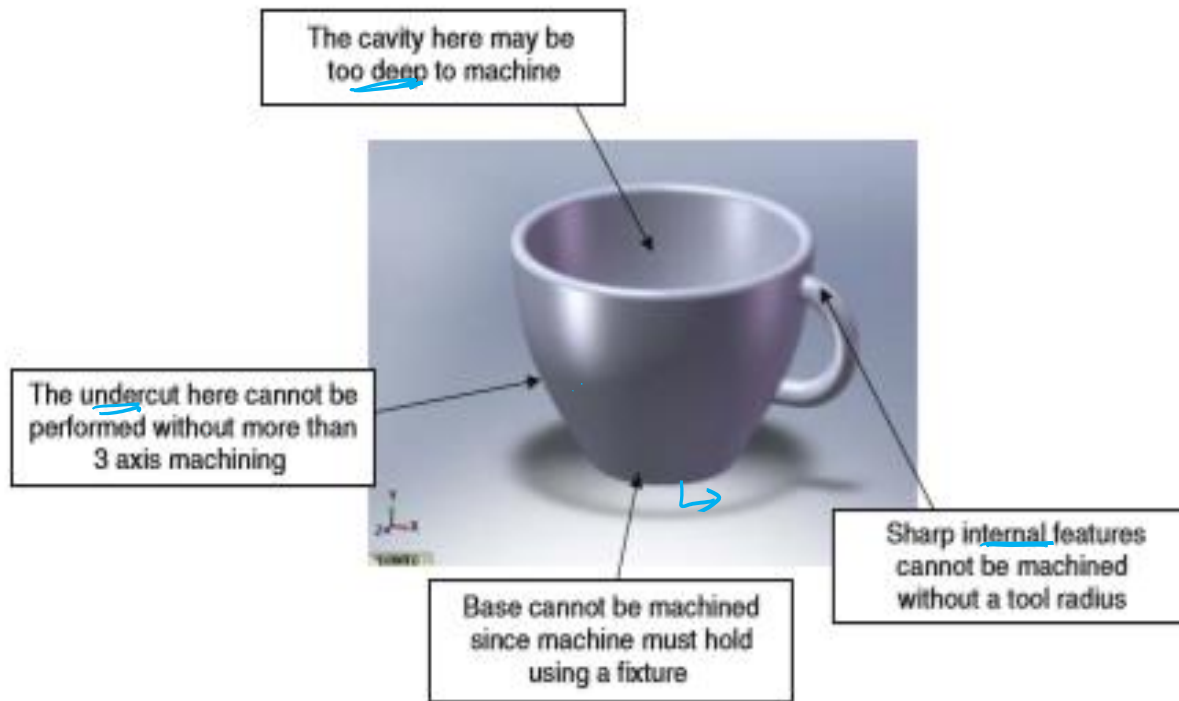
# RM, and CNC machining

## Geometry

- Undercuts, enclosures, sharp internal corners and other features can all fail if these features are beyond a certain limit.
- Consider, for example, the features represented in the part in below Figure.
- Many of them would be very difficult to machine without manipulation of the part at various stages.

# RM, and CNC machining

Features that represent problems using CNC machining



I. Gibson, Additive Manufacturing Technologies, 2010

# To recapitulate:

1. What are the benefits of Rapid Manufacturing?
2. Difference between traditional and Rapid Manufacturing?
3. What is accuracy in RM?
4. Specify the role of geometry in RM.

# Task for students

- draw CNC part where
  - internal features
  - under cut
  - deep m/c are involved
- CNC part drawing understand the concept of
  - tolerance
  - tool path simulation
  - tool decision.
- Plastic parts which has high strength and reliability
  - not down dirt.
  - made by RP/AM

**Thanks**