DIGIMAN
master programme for digital manufacturing

# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Digital Measurement Systems for Sensing and Monitoring Applications

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

2019-1-RO01-KA203-063486

# Learning outcomes: On successful completion of this module a student should be able to:

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Use digital measurements in sensing applications

Develop digital measurement systems for Industry 4.0

**Profesional Competences**

- Applying digital measurement systems in industrial processes
- Development of customized sensing applications

**Transversal Competences**

- Applying digital measurement systems in industrial processes
- Development of customized sensing applications

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# METROLOGY AND MEASUREMENTS

## Metrology

field of knowledge related to measurements, encompassing all the theoretical and practical aspects of measurements, whatever their level of accuracy, the measured size, the manner and purpose of the measurement, as well as the field of science or technique in which they occur

## Definitions

Quality + Quantity → Entity

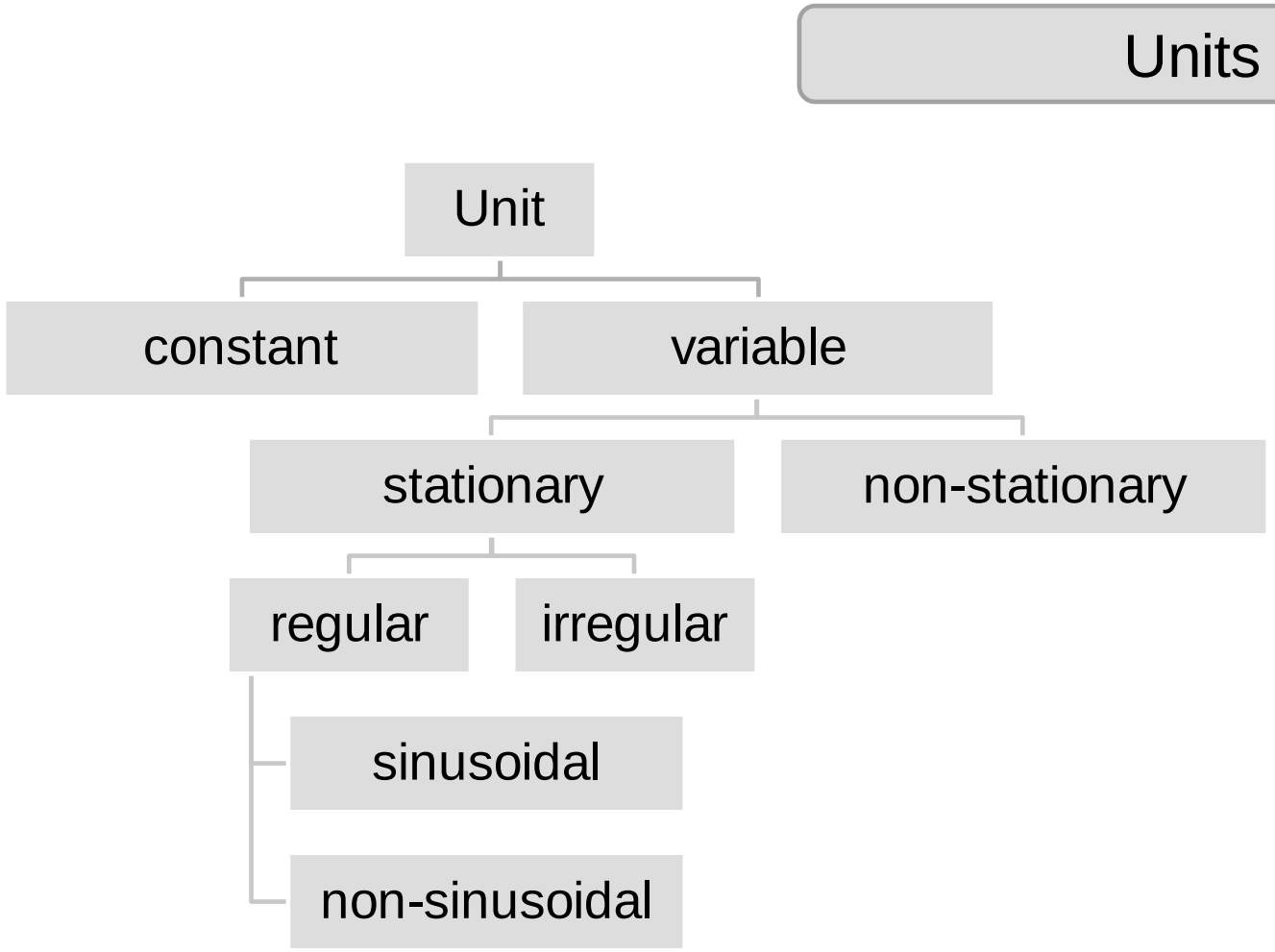
## Measurements

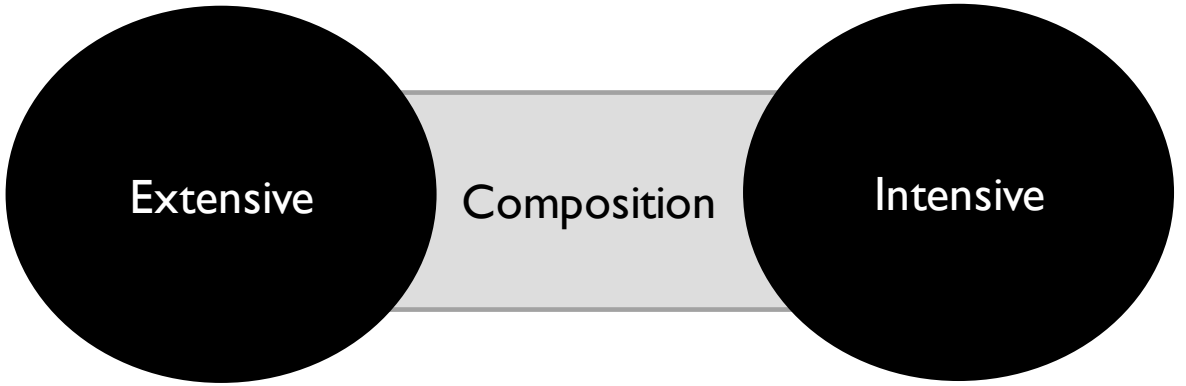
set of experimental operations performed to obtain quantitative information on certain properties of an object or phenomenon

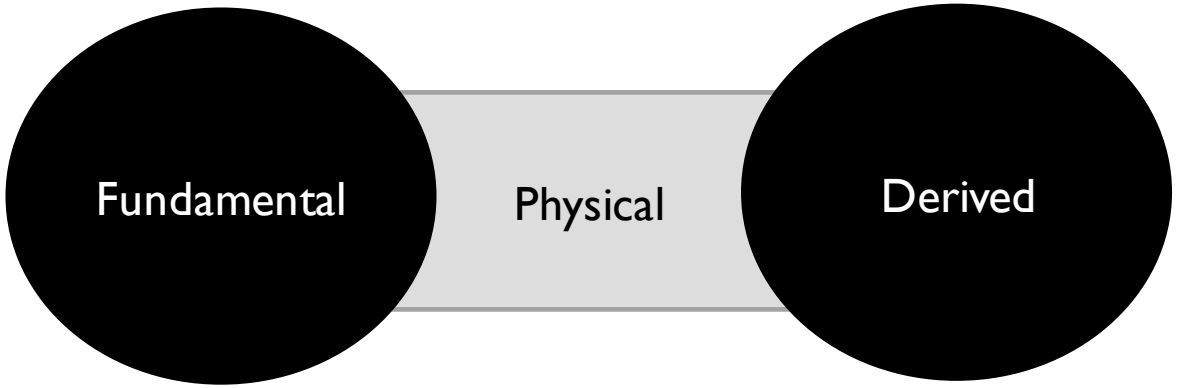
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# METROLOGY AND MEASUREMENT



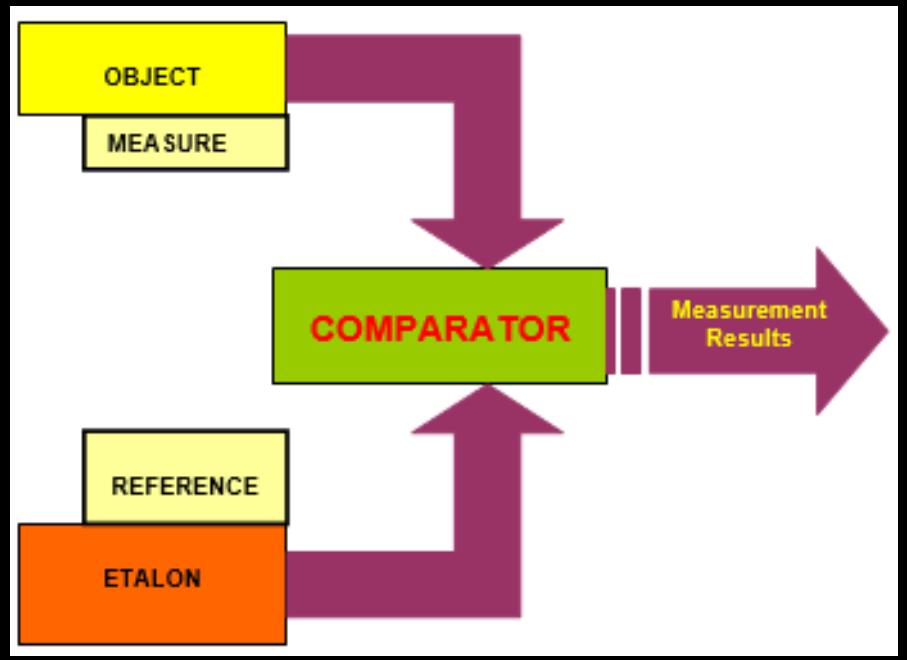

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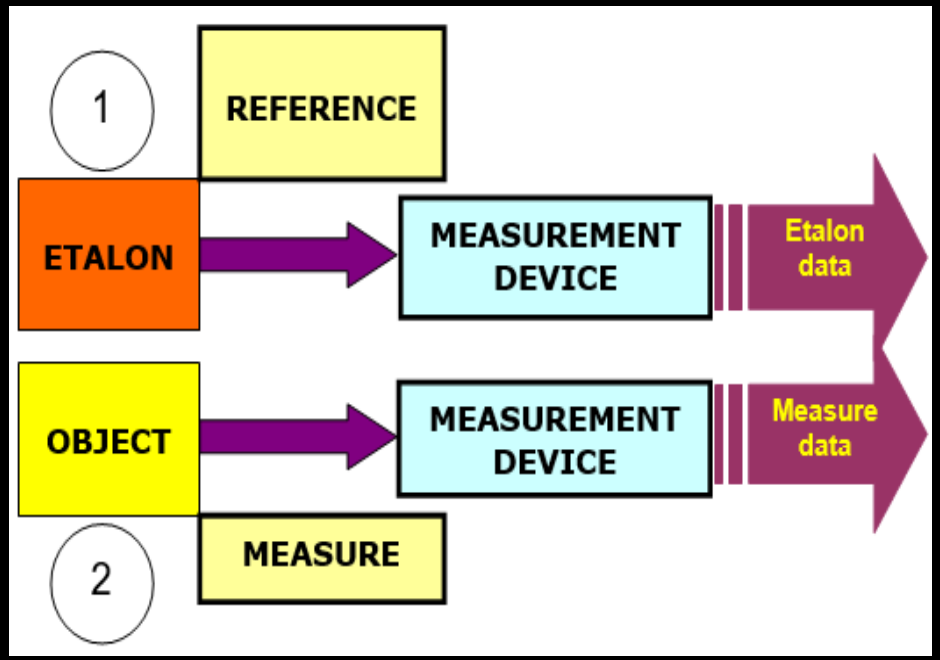
# METROLOGY AND MEASUREMENT

## Measurement Methods

### Simultaneous Direct Comparison




### Successive Comparison



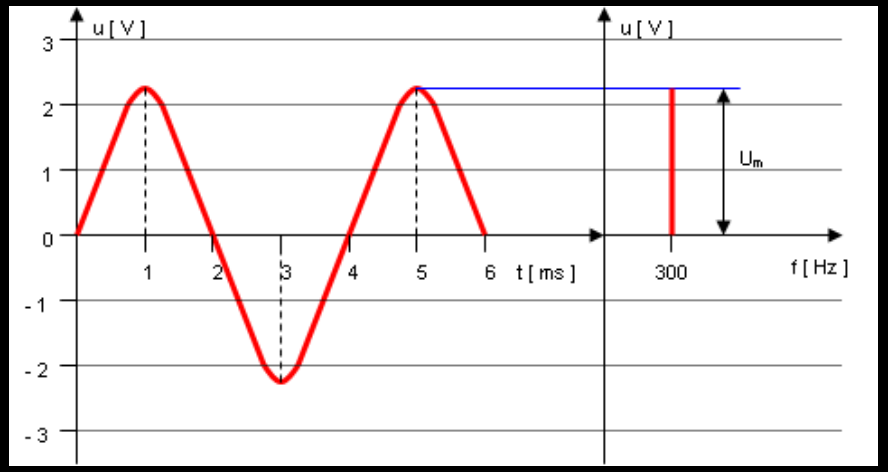

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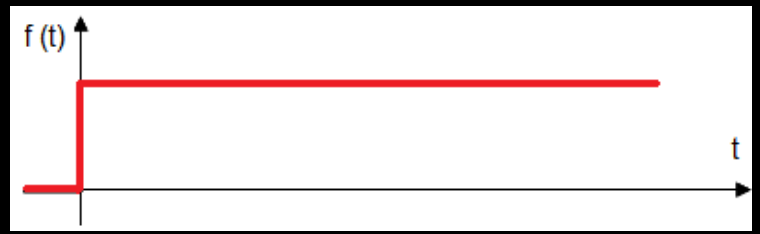
# SIGNALS, SENSORS AND TRANSDUCERS

## SIGNALS

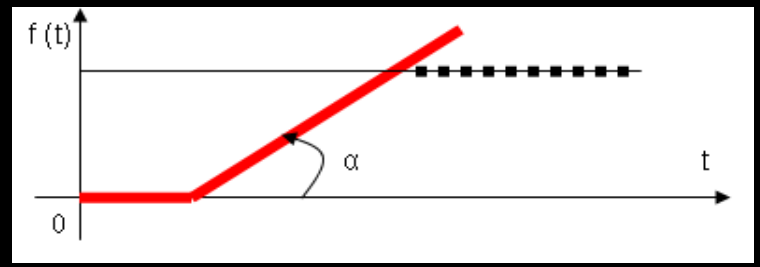
### Regular Signals




Unit Step Signal




Ramp Signal




Regular signals are those signals that reproduce in identical form after a certain interval of time called period. They can be described in time domain as amplitude, frequency and phase functions.

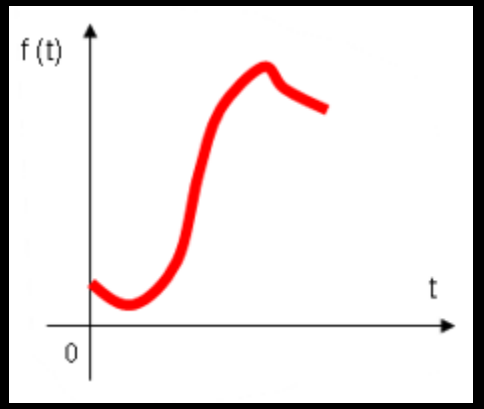
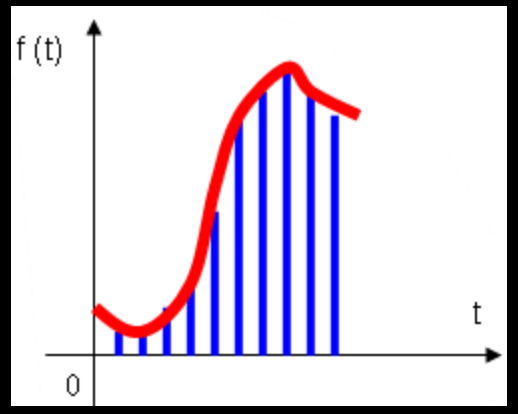
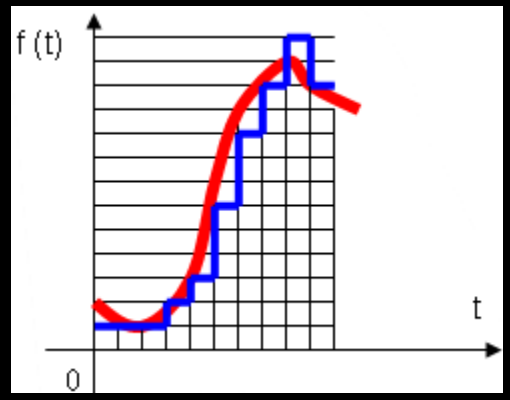
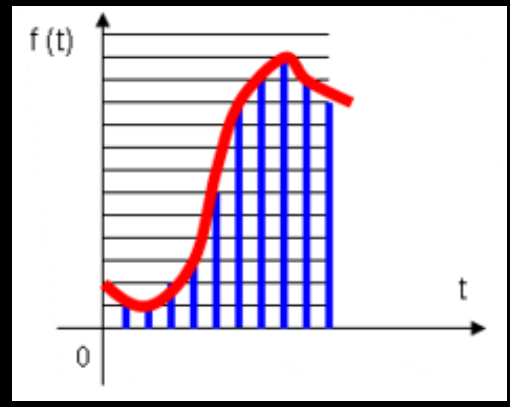
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# SIGNALS, SENSORS AND TRANSDUCERS

## SIGNALS

### Random Signals

| Constant Analog | Discret Variantion in Time | Discret Amplitude | Discret Amplitude and Time |
|---|---|---|---|
|  |  |  |  |



Random signals are those signals that have a random and unpredictable character over time, the instantaneous value of these signals is characterized by probability functions.

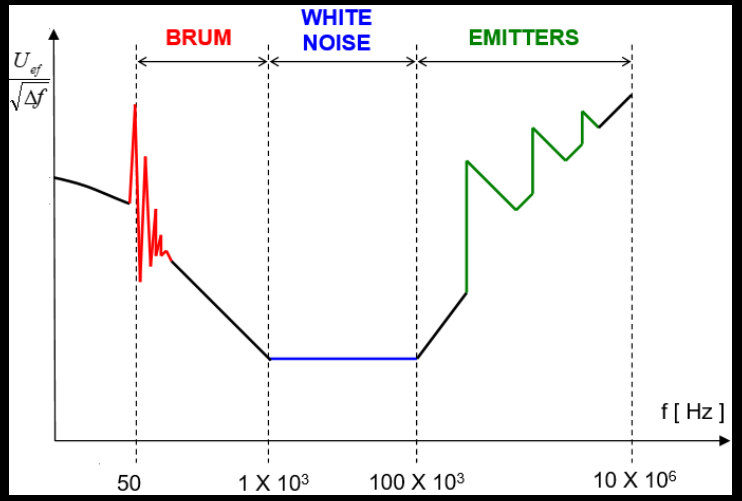
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# SIGNALS, SENSORS AND TRANSDUCERS

## SIGNALS

### Disturbances




| Disturbing signal | Frequency range | Disturbing signal source | Effect obtained |
|---|---|---|---|
| **atmospheric** | 0 - 50 Hz | Atmospheric electric discharges | Noise in the speakers |
| **mechanic** | | Mechanical vibration | howling |
| **Brum** | 50 - $10^3$ Hz | Voltage induced by the electrical cables of the mains | Noise in loudspeakers |
| **White Noise** | $10^3$ - $10^5$ Hz | Own noise of amplifiers, transistors, diodes, resistors | Internal noise |
| **Emitters** | above $10^5$ Hz | Radio TV transmitters or other high frequency industrial components | Noticeable noise |

The disturbances are those parasitic signals that do not contain useful information and unwantedly overlap the useful signal.

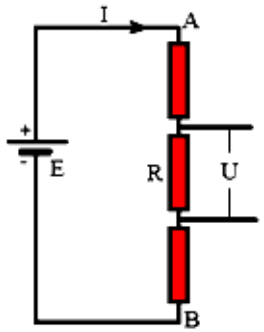
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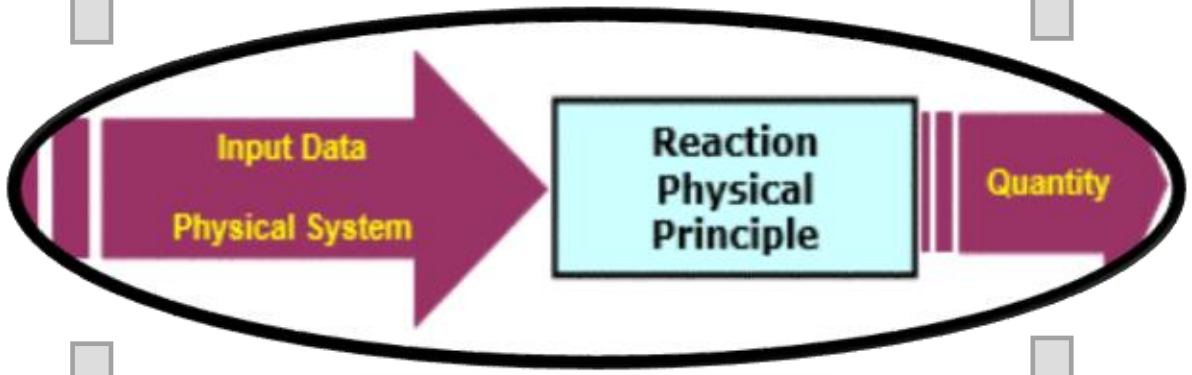
# SIGNALS, SENSORS AND TRANSDUCERS

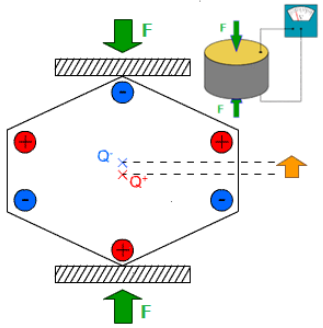
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Ohm law



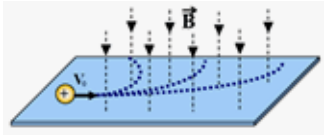

SENSORS

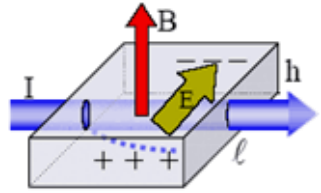



Piezo Effect

Lorentz Force




Hall Effect

The sensor represents a specific device that notifies data about the external state of a system.

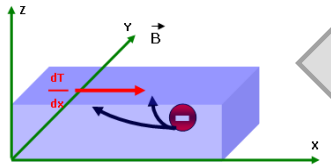
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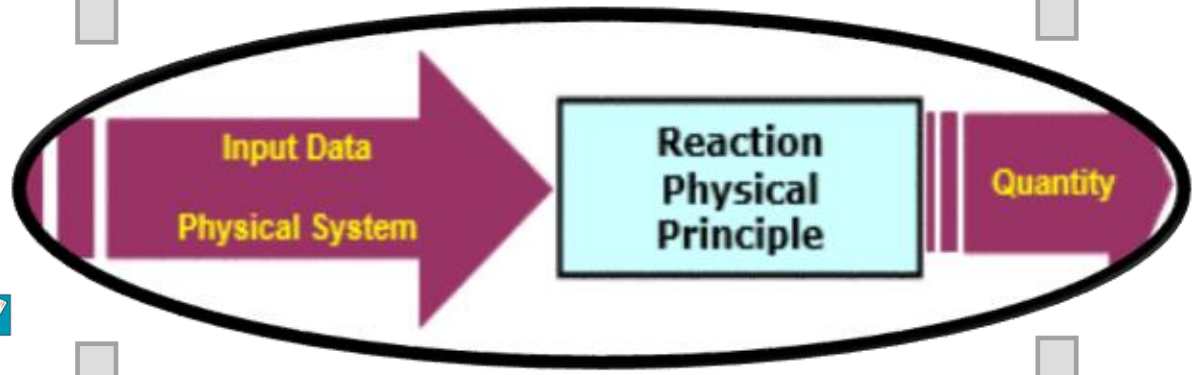
# SIGNALS, SENSORS AND TRANSDUCERS

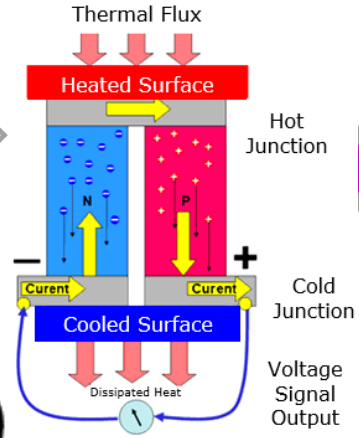
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Nerst Effect



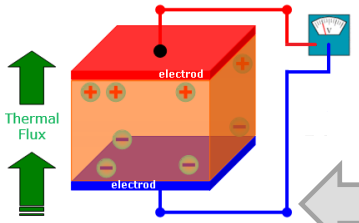

SENSORS

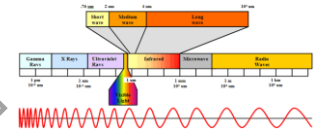



Seebeck Effect

Pyro Effect



Stefan Boltzman Law

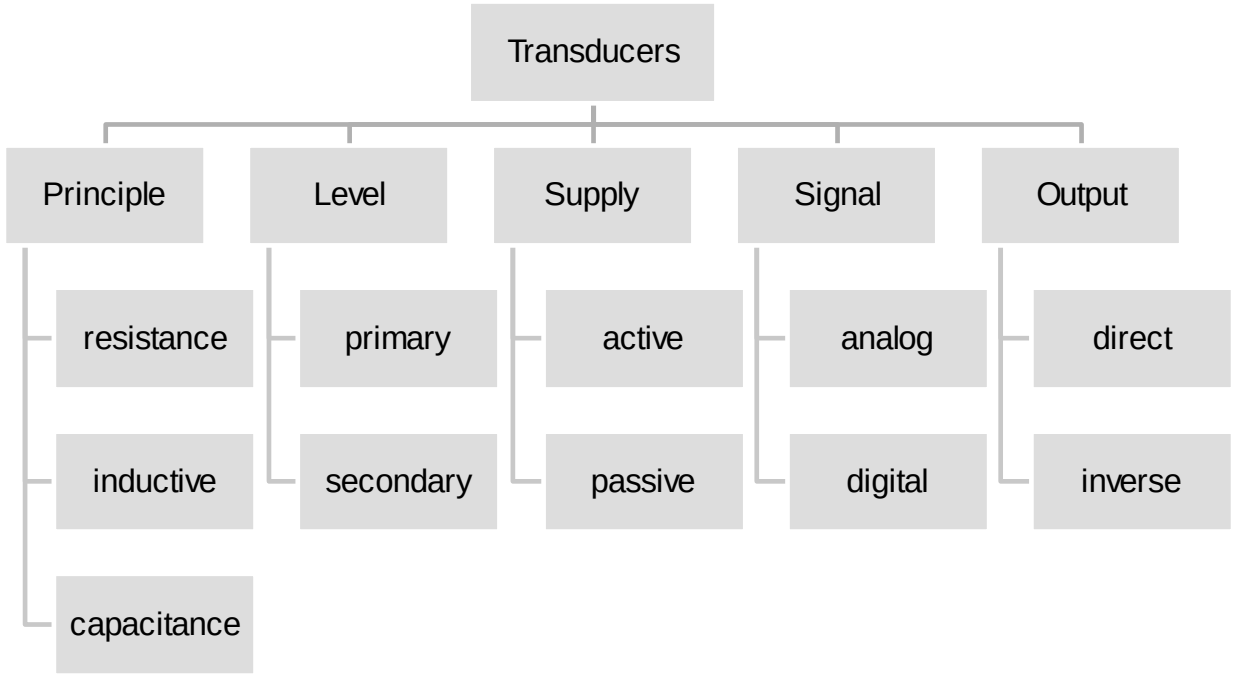
The sensor represents a specific device that notifies data about the external state of a system.

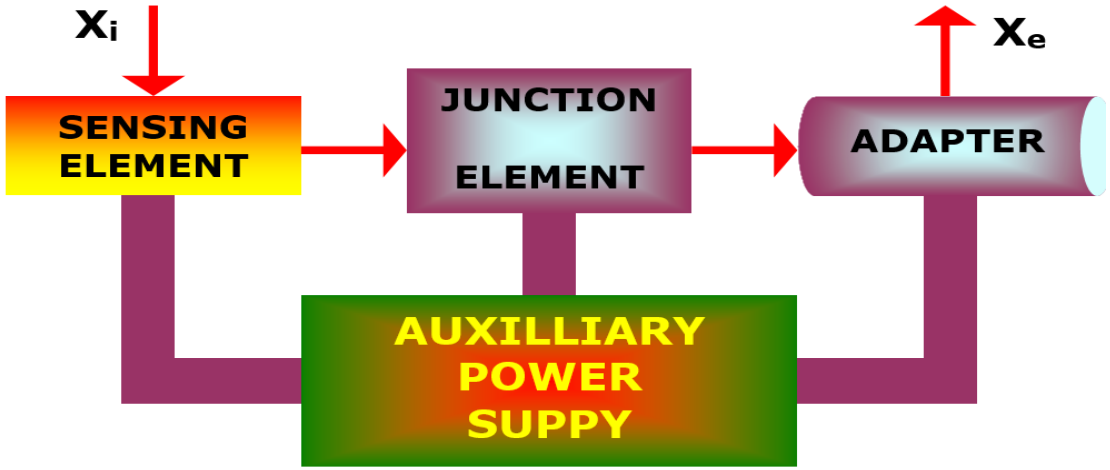
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# SIGNALS, SENSORS AND TRANSDUCERS

## TRANSDUCERS



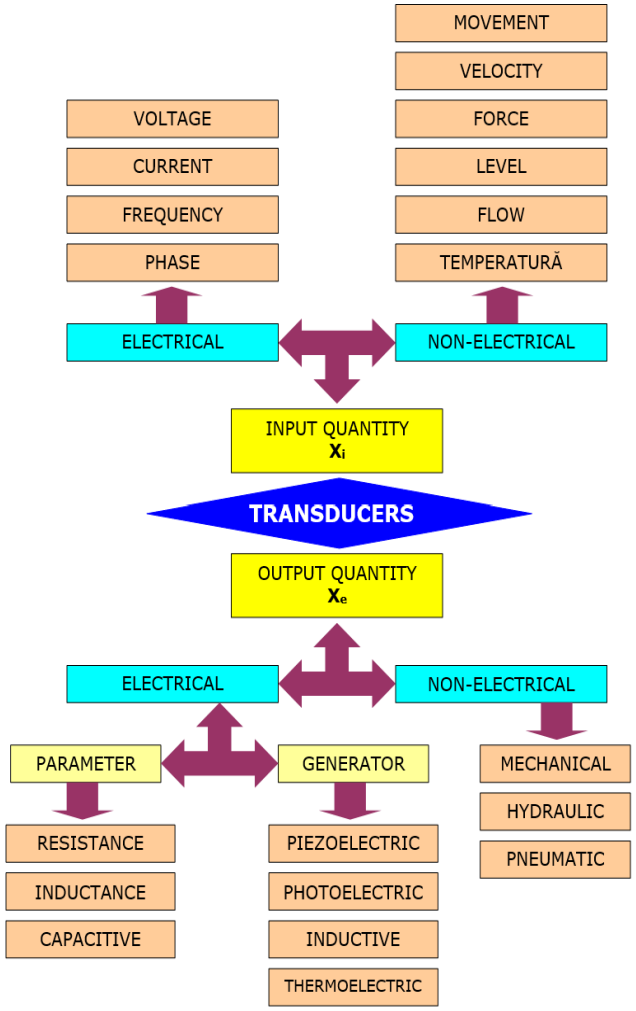




Signal transducers are components of the measurement chain that are usually part of a sensitive element assembly - the translator and have the role of converting an input size into another output size of a different nature for the purpose of carrying out the measurement process.

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# SIGNALS, SENSORS AND TRANSDUCERS




## TRANSDUCERS

- **Physical Nature**
  - Principle
  - Level
- **Nature of I/O data**
  - Supply
    - Active
    - Passive
  - Signal
    - Analog
    - Digital
- **Shape of Output data**
  - Output
    - Direct
    - Invers

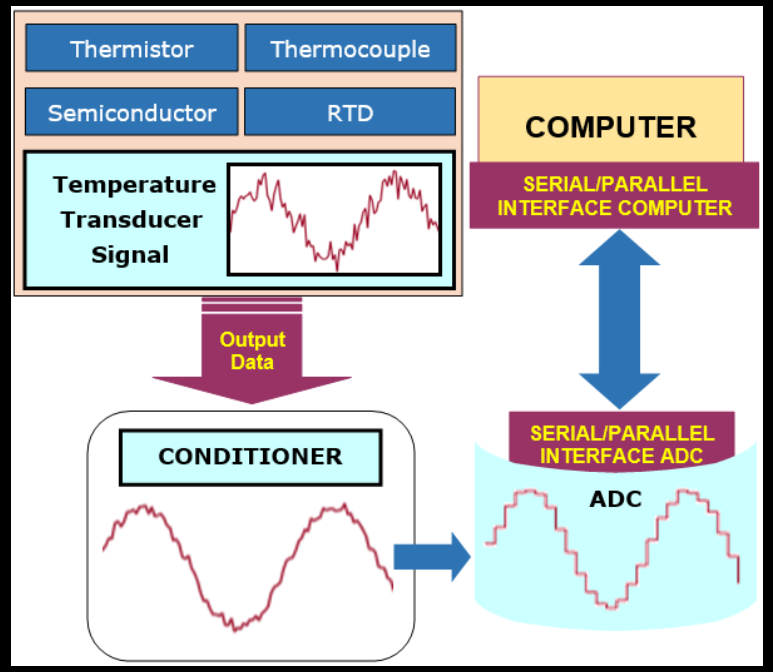
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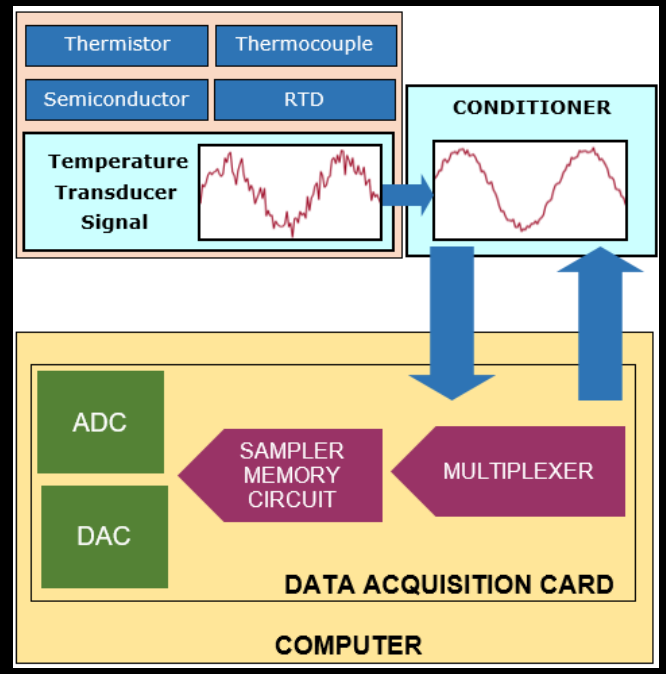
# DIGITAL MEASUREMENT IN SENSING APPLICATIONS

## STRUCTURE OF DMS

### DMS with serial/parallel COM



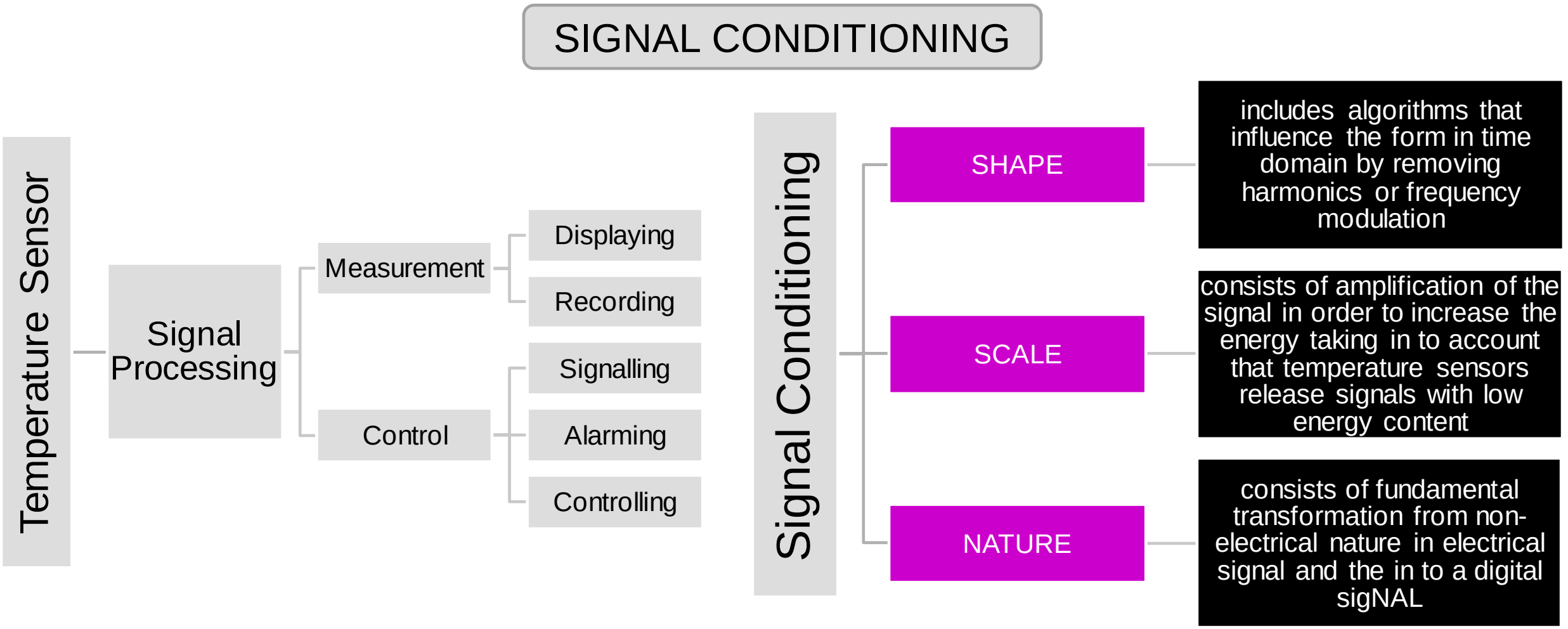

### DMS with data aquisition CARD




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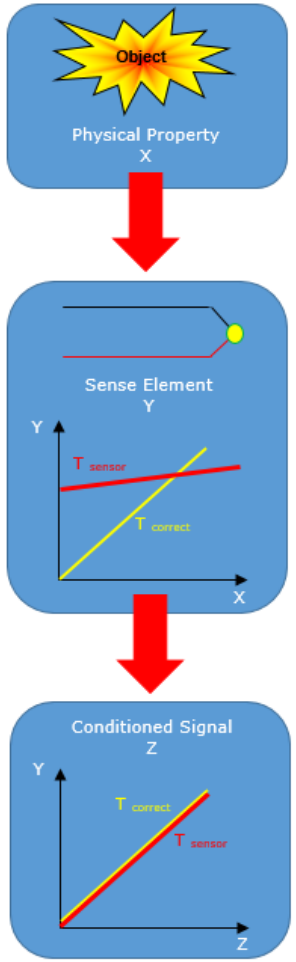
# DIGITAL MEASUREMENT IN SENSING APPLICATIONS




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# DIGITAL MEASUREMENT IN SENSING APPLICATIONS




## SIGNAL CONDITIONING

$$Y = [a_0 + a_1 \cdot (T_{sensor} - T_{20})] + [b_0 + b_1 \cdot (T_{sensor} - T_{20})] \cdot X$$

**$a_0$**
sense element offset at room temperature, or the sense element output when the physical quantity being measured is at its minimum value and at room temperature

**$a_1$**
sense element offset temperature drift coefficient, or the relative change in offset of sense element with a given change in temperature

**$b_0$**
sense element span at room temperature, or the difference in the sense element outputs at maximum and minimum physical quantity being measured

**$b_1$**
sense element span temperature drift coefficient, or the relative change in span of sense element with a given change in temperature

**$T_{sensor}$**
temperature provided by sensing element

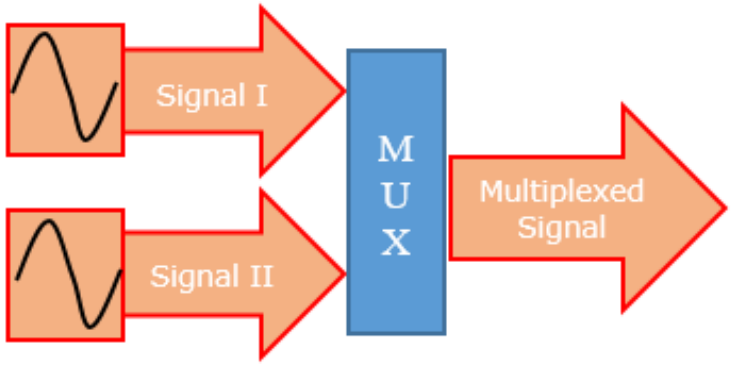
**$T_{20}$**
room temperature (considered to be $20^0$ C)

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# DIGITAL MEASUREMENT IN SENSING APPLICATIONS

## SIGNAL MULTIPLEXING




- Multiplexer
  - Analog
    - FDM
    - WDM
  - Digital
    - TDM
      - Syncronous
      - Asyncronous

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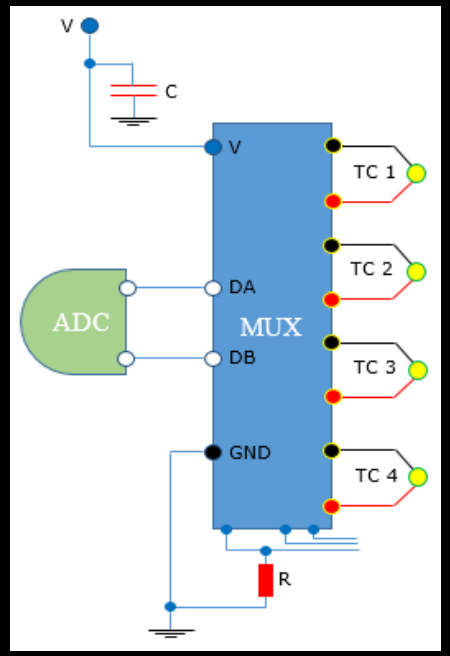
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# DIGITAL MEASUREMENT IN SENSING APPLICATIONS

## SIGNAL MULTIPLEXING

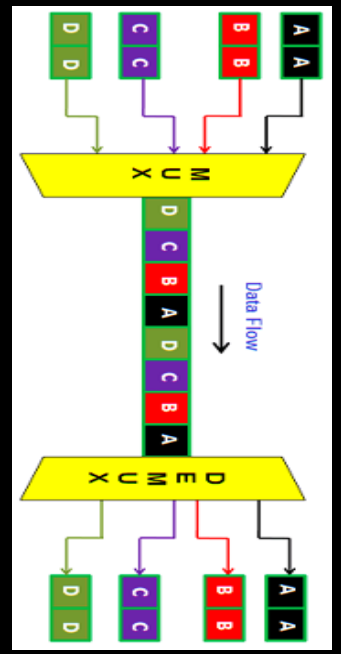
### Analog Multiplexing Circuit

Wavelenght Division Multiplexing




### Digital Multiplexing Circuit

Time Division Multiplexing




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# DIGITAL MEASUREMENT SYSTEMS FOR MONITORING APPLICATIONS

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## RESISTANCE HEATING

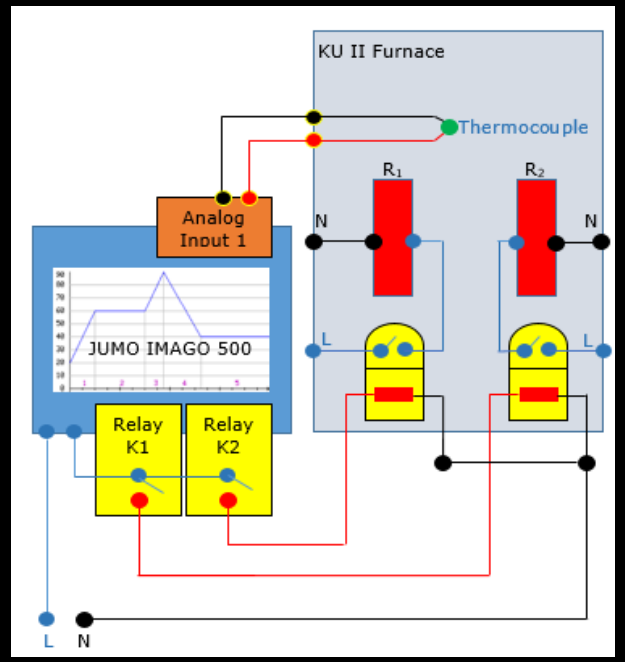
### Application: Sintering Process



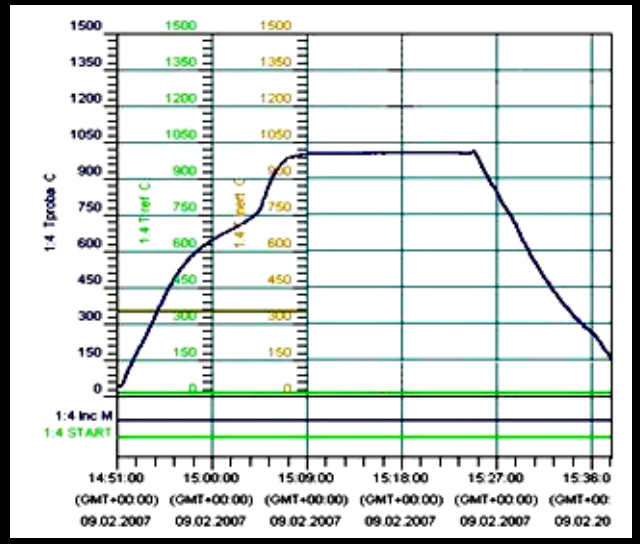
Main characteristics

| | |
|---|---|
| Power Supply | 400 V |
| Amps | 60 A |
| | 180 A |
| Voltage | 12 V |
| | 35 V |
| Control atmosphere | No |
| Sensing Element | Thermocouple type S, B |
| Maximum temperature | 1500 °c |
| Ramp control | No |

### Monitoring Solution




### Recording




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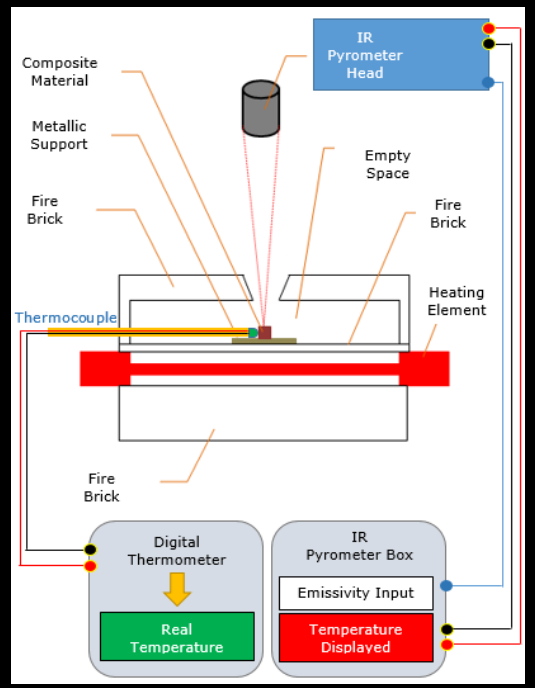
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# DIGITAL MEASUREMENT SYSTEMS FOR MONITORING APPLICATIONS

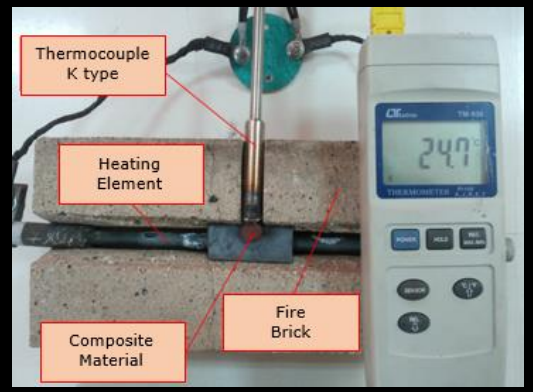
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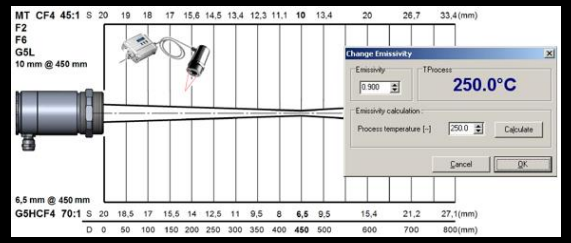
## MICROWAVE HEATING

### Monitoring Solution

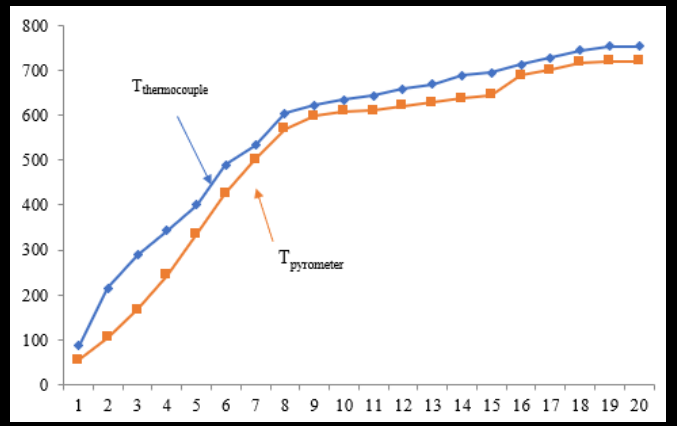



### Determination of Emissivity




### Recording




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# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Robot systems in joining processes

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# Course objectives:

- Basic structures and elements of the robot systems dedicated welding
- Using teaching pendant and other controls
- Welding processes for robot welding
- Prepare base materials for robot welding

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

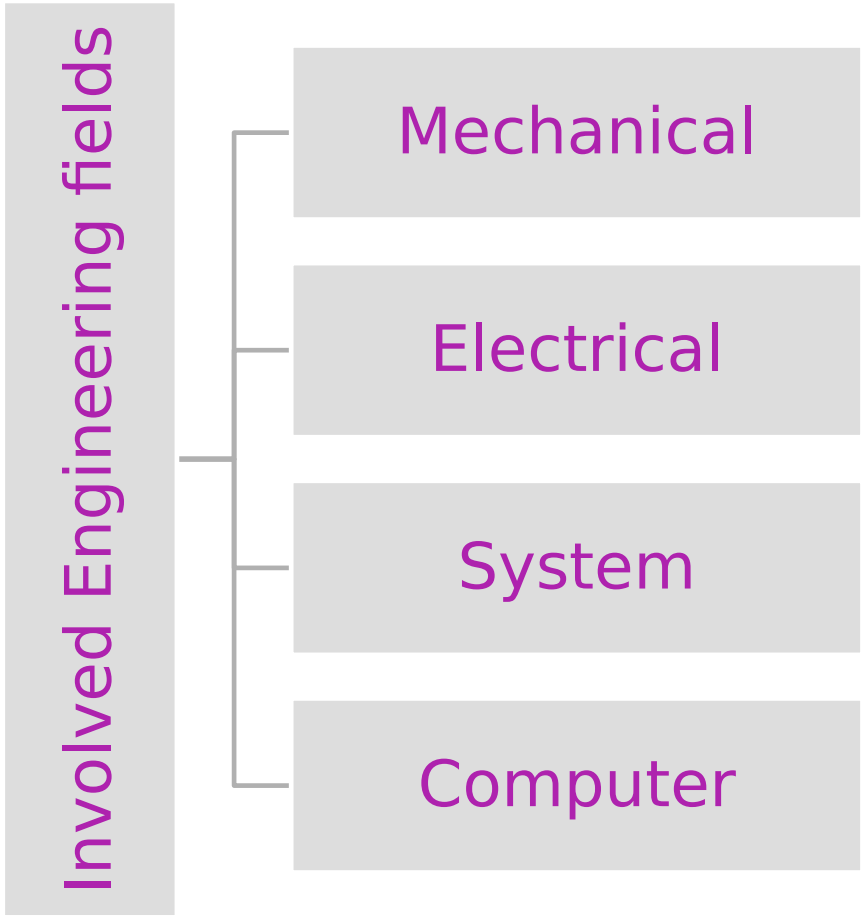
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## ISO 8373:

a robot is an “actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks.”

## International Federation of Robotics (IFR):

a robot is an “automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.”




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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

Reason:

- to do tasks that would be harmful for the human being
- the application fields are growing
- products - more complex and high precision and effectiveness.

Characteristics of robots

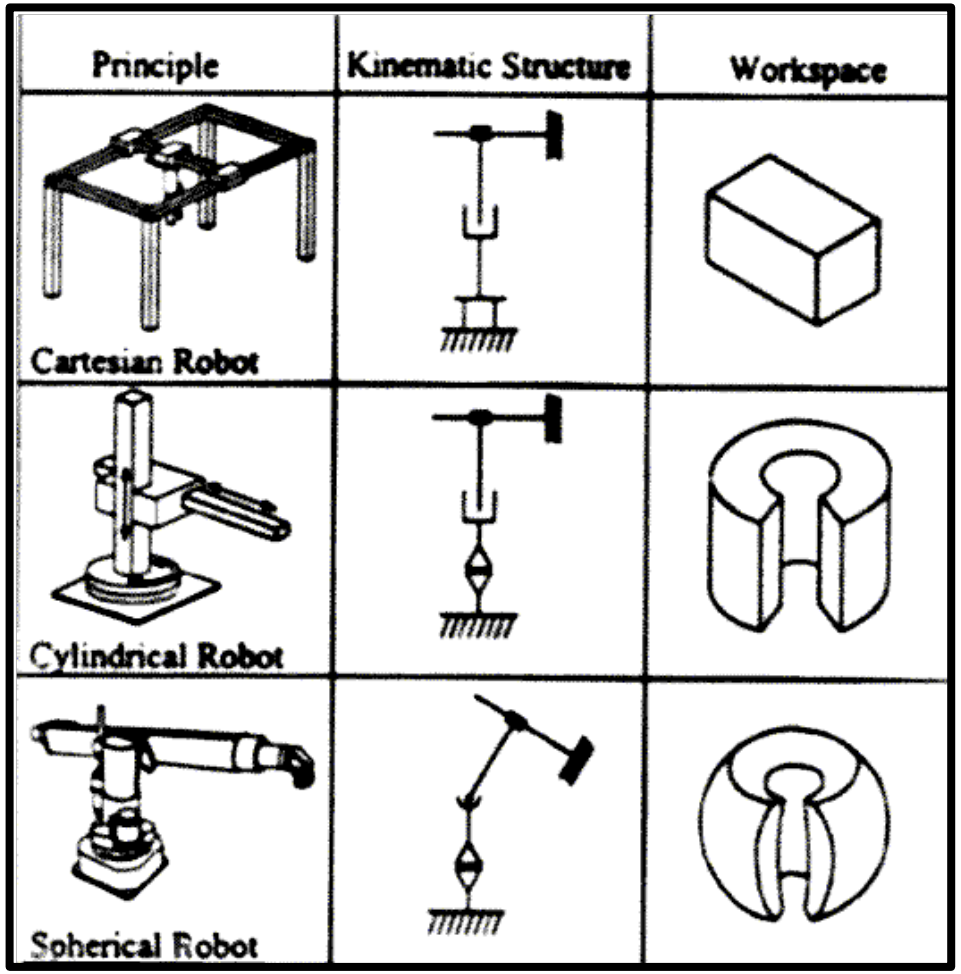
- Coordinate systems;
- Power source;
- Method of control;
- Programming method

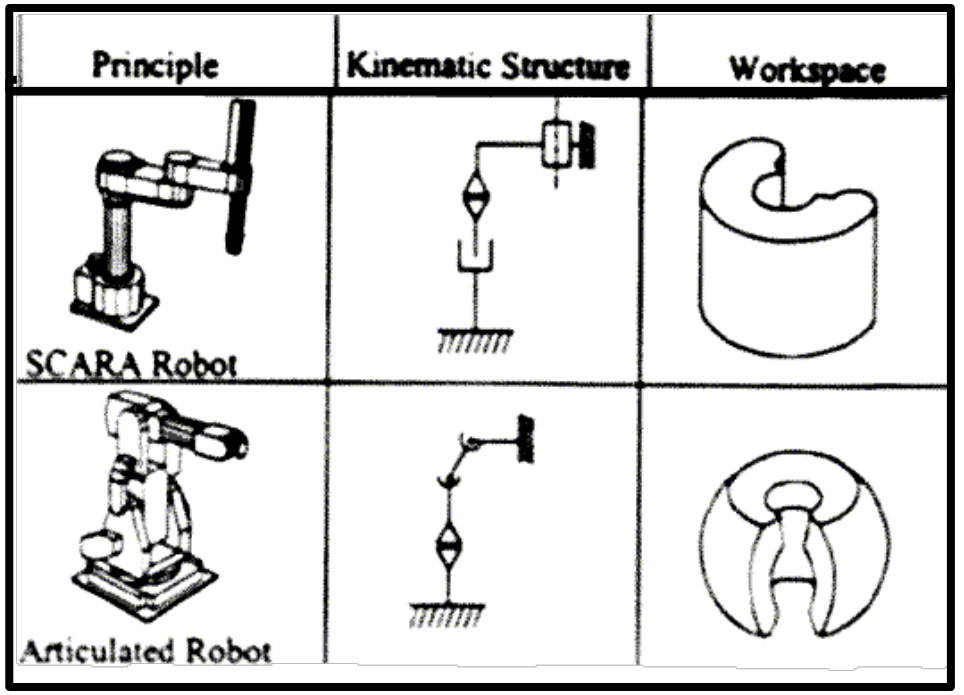
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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

Configurations:




Source: http://www.robot-welding.com/robots.htm

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## Cartesian / Rectilinear Configuration Robots

Advantages:

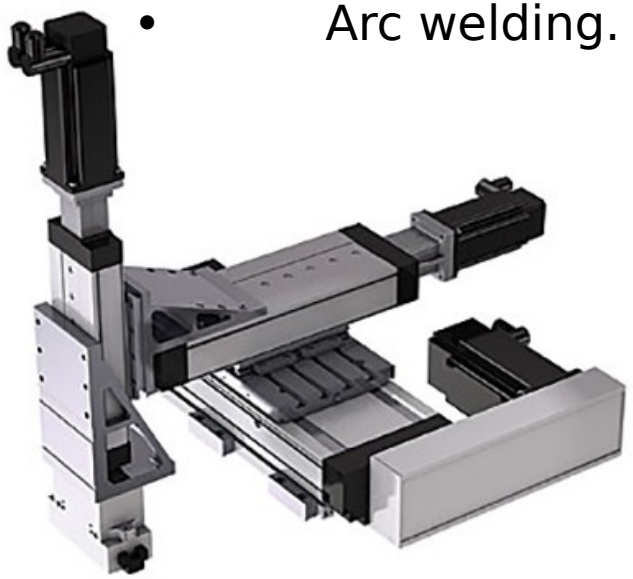
- Easy computing and programing;
- Simple controls due to totally linear movements;
- High degree of mechanical rigidity, accuracy and repeatability;
- Carries heavy loads not depending on the positioning.

Disadvantages:

- Limited to a small rectangular work space;
- Guiding surfaces exposed requiring corrosion and dust coverage;
- Can only work the front face of the work piece.

Applications:

- Pick and place;
- Sealant application;
- Assembly operations;
- Handling machine tools;
- Arc welding.



Source: https://www.linearmotiontips.com/what-is-a-cartesian-robot/

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## Cylindrical Configuration Robots

Advantages:

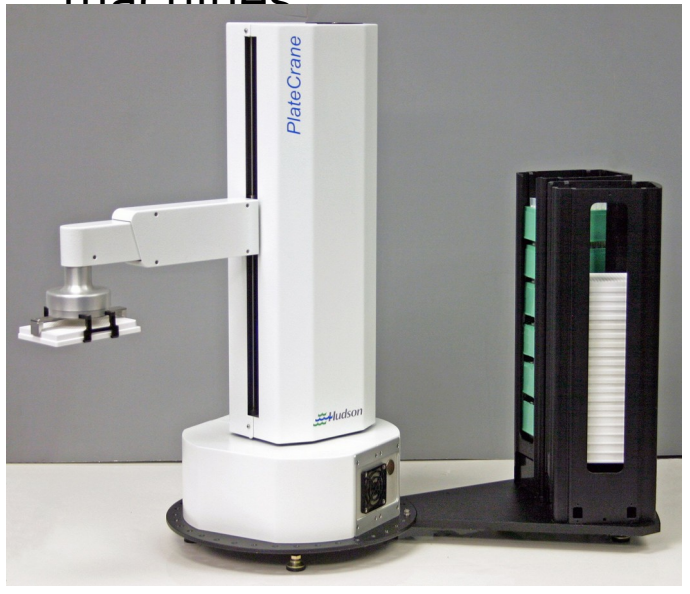
- Allows working in a 360º environment;
- Relatively easy to program;
- Rigid structure to deal with heavy loads;
- Rotary axis easy to seal;
- Good access into cavities and machine openings.

Disadvantages:

- Linear axis hard to seal;
- Hard to cover drivers from liquids and dust;
- Can’t reach space above itself;
- Reduced accuracy and repeatability in the rotary movements direction;
- Requires more sophisticated control system than CR.

Applications:

- Machine loading and unloading;
- Assembly operations;
- Handling die-casting machines;




Source: https://ro.pinterest.com/pin/413205334533024163/

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## Spherical Configuration Robots

Advantages:

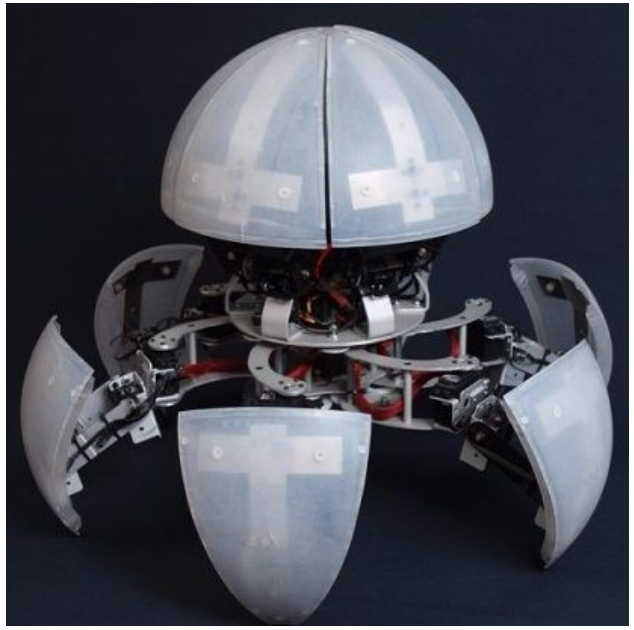
- Larger work envelope;
- Simple design;
- Good weight lifting capabilities;
- Adequate to small amount of vertical movement tasks.

Disadvantages:

- Reduced mechanical rigidity;
- More sophisticated control system;
- Reduced accuracy and repeatability in the rotary movements direction;
- Vertical movement is limited;
- Low speed due to the required coordination of multiple axes.

Applications:

- Machine loading;
- Material handling;
- Spot welding.



Source: https://www.pinterest.de/pin/724657396279060989/

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## SCARA (Selective Compliance Assembly Robot Arm ) Configuration Robots

Advantages:

- Large work space;
- High speed;
- Good payload capacity;
- Moderately easy to program
- Excellent repeatability.

Disadvantages:

- Few fields of application;
- Hard to program offline;
- Arm of extreme complexity.

Applications:

- Pick and place tasks;
- Assembly operations;
- Application of sealant;
- Handling machine tools.



Source: https://global.yamaha-motor.com/business/robot/lineu

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# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## Articulated (Joint Arm) Configuration Robots

Advantages:
- High speed for three degrees of freedom;
- High mechanical flexibility;
- Easy sealing of all joints.

Disadvantages:
- Extremely hard to control and program;
- Poor accuracy;
- Limited work volume.

Applications:
- Die casting applications;
- Assembly operations;
- Arc and gas Welding;
- Spray painting;
- Fettling machines.



Source:
https://processsolutions.com/what-are-t
e-different-types-of-industrial-robots-an
-their-applications/

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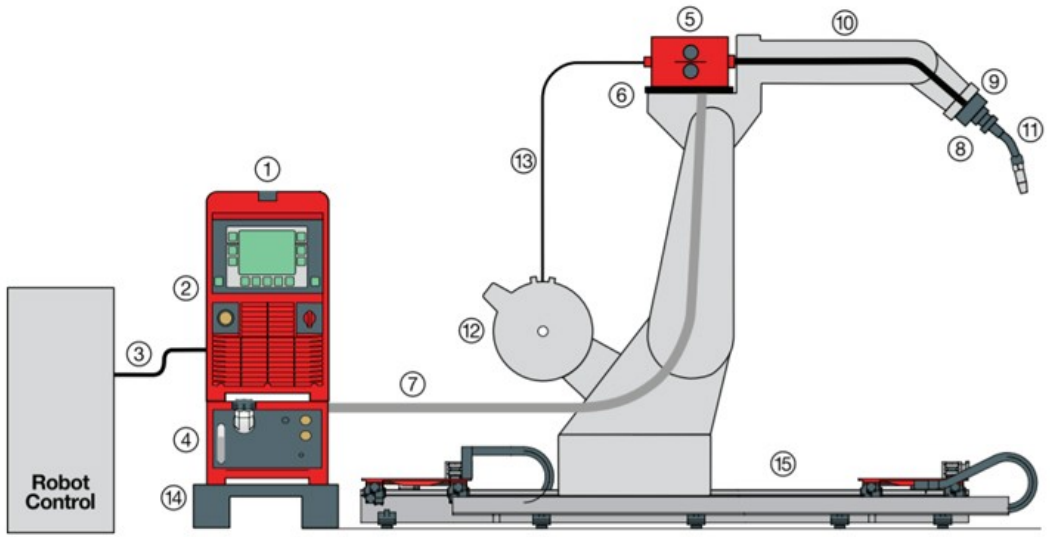
# BASIC STRUCTURES OF ROBOT SYSTEMS DEDICATED WELDING

## Basics on Robot systems

A robot system is a system composed of distinct inputs, distinct outputs and a transformation process which is based on robot service.

Components:

- Teach pendant;
- Auxiliary axis;
- Positioners;
- Material feeding;
- Sensors;
- I/O signals;
- Control Systems;
- Collision Detection Systems.




1. Welding power source
2. Interface robot controller - welding power supply
3. Interface communication cable
4. Torch water cooler
5. Wire feeder
6. Wire feeder bracket
7. Hose package
8. Torch breakaway, or collision box
9. Insulation disc
10. Torch cable, or whip
11. Torch neck
12. Weld wire holder
13. Weld wire conduit
14. Power source stand
15. Linear tracks

Source: https://www.roboticstomorrow.com/article/2017/08/robotic-welding-101/11179

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# USING TEACHING PENDANT AND OTHER CONTROLS

## Teach pendant

The teach pendant is a device designed to control the robot motions remotely.

This typically hand-held device, also called “teach box” or “teach gun”, allows the control of a wide variety of settings by experienced people in the robotics field.

The teach pendant has several features such as:

- an emergency stop button, to shut down operations immediately;
- a display screen which shows the commands and the histo., of the given commands and allows the user to edit them;
- a keyboard that varies depending on the type of robot.




Source: https://encyclopedia2.thefreedictionary.com/teach+pendant

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# USING TEACHING PENDANT AND OTHER CONTROLS

## Programming of a robot

Robot programming defines precisely which tasks will the robot execute and how they are carried out.

This permits to define each one of its movements, trajectory, speed, applied forces, among several other parameters.

Types:

- Online
- Offline




Source:
https://www.youtube.com/watch?v=I-M1x6aWPs8

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# USING TEACHING PENDANT AND OTHER CONTROLS

## Online Programming - Teach Pendant and Lead-thr

Most used: Teaching pendant programming

Advantages
- Allow precise positioning (programming using numerical coordinates)
- Facile for welding processes

Disadvantages
- Entire system is put into the „teach mode” and the fabrication is stopped until the end of programming
- Operators should receive detailed training
- Difficult for operators that are not familliar with programming

Source: https://www.youtube.com/watch?v=EA6pWwNI_wg

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# USING TEACHING PENDANT AND OTHER CONTROLS



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# USING TEACHING PENDANT AND OTHER CONTROLS

## Offline Programming - Simulation



Advantages

- Ensure that advanced control algorithms are operating correctly before moving them onto an industrial robot
- Avoid stopping fabrication until finishing the programming, so improvement of the efficiency
- Can be intuitive
- Easy to test different approaches of the same application

Disadvantages

- Mock-up difficult to build very closed to reality
- Requires time to create a mock-up
- Requires experts in programming and

Source: https://www.youtube.com/watch?v=CQlrHnOAuzs

# USING TEACHING PENDANT AND OTHER CONTROLS

## Programming of welding robot

Start data
- Ignition voltage and current;
- Gas preflow time: the time between shield gas flow and arc start;
- Hot start voltage and current: to stabilize the arc in the first stage;
- Restrike amplitude: minor change in the position of the torch to start the arc;
- Restrike cross time: Time to stay in the restrike position;
- Arc welding start maximum time. The robot stops the process if the arc does not start in this time interval

Main data
- Welding voltage;
- Welding current;
- Welding speed

End data
- End voltage and current;
- Gas postflow time;
- Burnback time;
- Cool time;
- Fill time

Weaving data
- pattern;
- width;
- Frequency
- Stop time on walls

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# USING TEACHING PENDANT AND OTHER CONTROLS

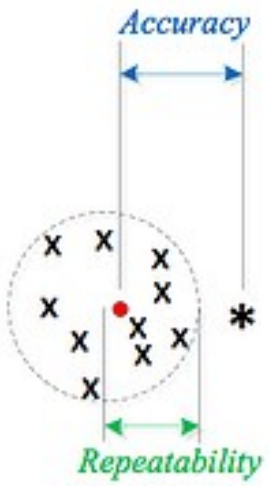
## Errors

The errors can be met in robot systems are the errors of detection and errors of recovery.

The detection problem involves the use of suitable sensors for identifying the error occurred in an operation.

Types

- Random errors: such errors are resulting from a stochastic event and they are described with the help of their statistical nature;
- Systematic errors: these types of errors are described by some preconception that takes place in the operation;
- Illegitimate errors: these errors are obtained either by the mistake of a human worker or equipment.




✱ : Desired position
x : Obtained positions
● : Barycenter of the obtained positions

Source: https://blog.robotiq.com/bid/72831/What-are-the-Sources-of-Robot-Inaccuracy

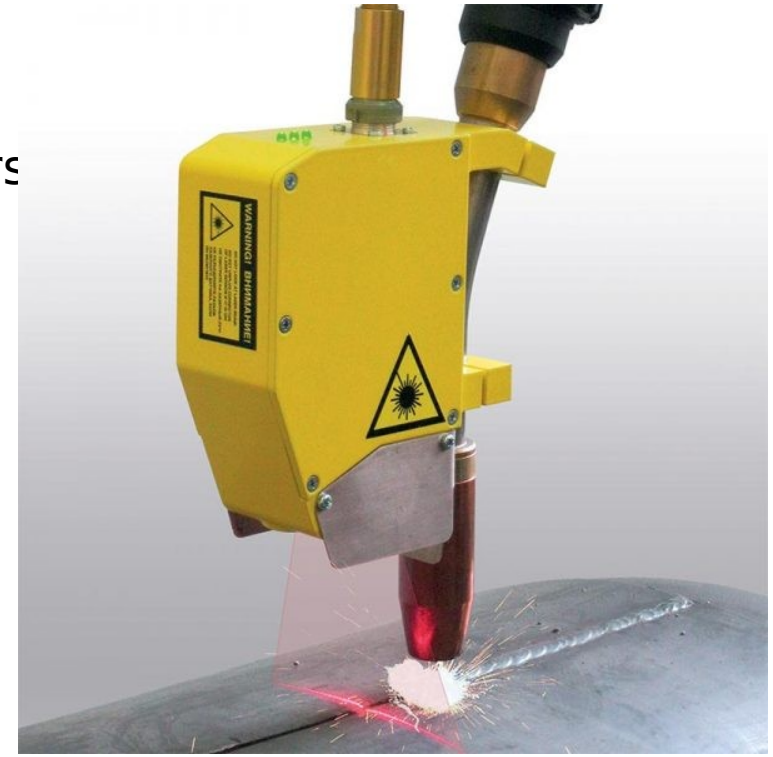
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# USING TEACHING PENDANT AND OTHER CONTROLS

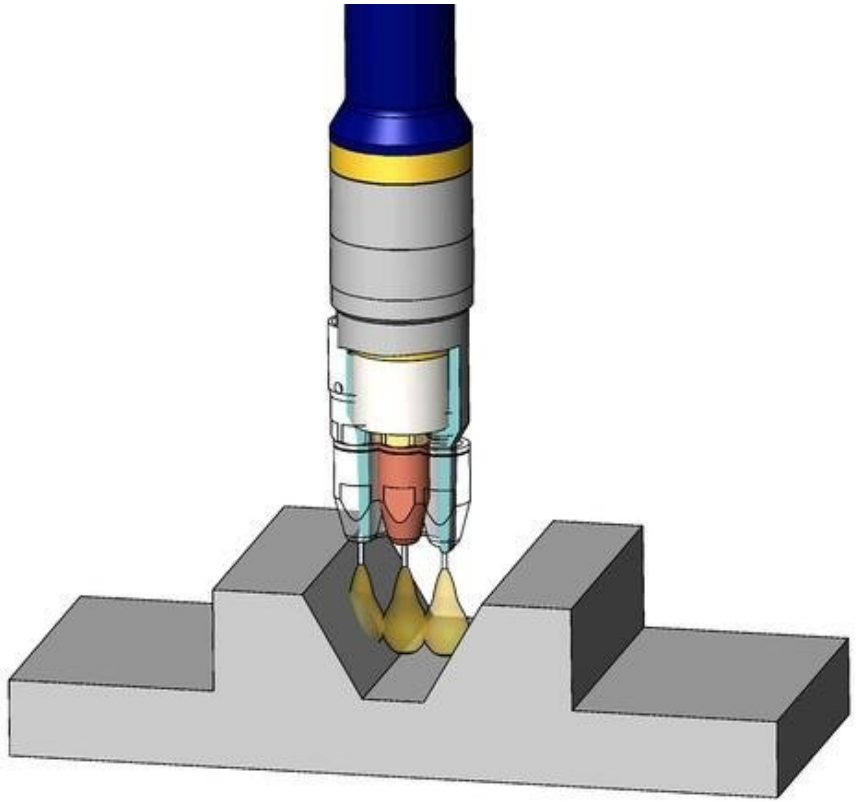
## Seam tracking systems

geometry-oriented sensors:
- Mechanical (contact) sensors
- Electric sensors
- Thermal sensors

process-oriented sensors
- Vision sensors
  - Laser
  - Image-based
- Force and torque sensors



Source: http://rovicor.com/en/products/vs-for-robots/sts-200-r/



Source: https://blog.binzel-abicor.com/how-seam-tracking-solutions-compare

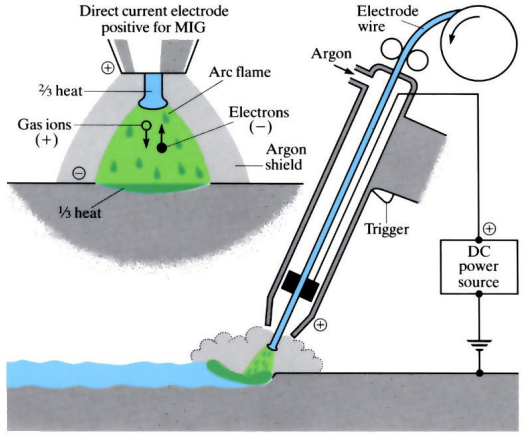
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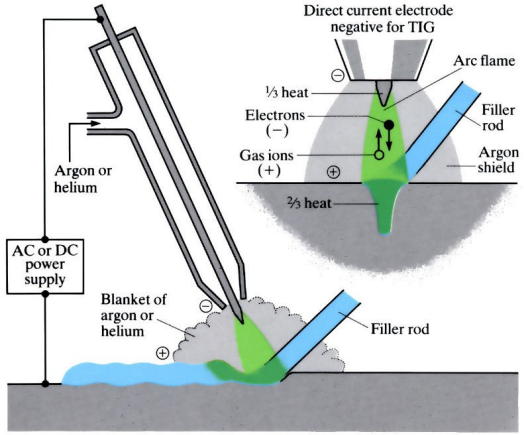
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# WELDING PROCESSES FOR ROBOT WELDING

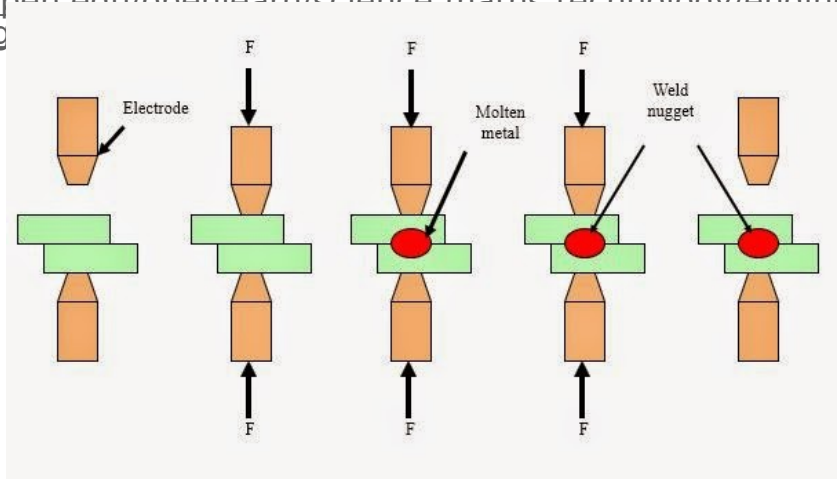
## Main used welding processes

Arc welding
Resistance welding
Laser welding

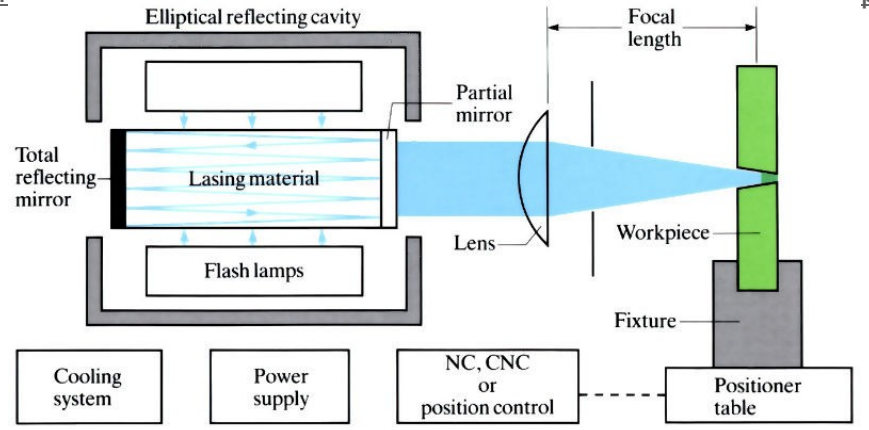



Source:
https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/gas-shielded-arc-welding-processes-tig/mig




Source:
http://mechanicalinventions.blogspot.com/2014/09/resistance-spot-welding-rsw-working-principle.html




Source:
https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/laser-beam-welding

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# PREPARE BASE MATERIALS FOR ROBOT WELDING

## A. Cleaning and B. Preparation of bevel (groove)

A. Cleaning

What?
Remove impurities (dust, fats, rust, paint, moist, ...)

How?
- By mechanical means
- By chemical means

Depending on the materials and conditions of the base materials

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# PREPARE BASE MATERIALS FOR ROBOT WELDING

## A. Cleaning and B. Preparation of bevel (groove)

B. Beveling

Why?
There are situations when steel plates are so thick that it would be impossible to obtain a good weld without weld preparation, i.e. without bevelling.
(common acceptance: if thicknes is higher than 4 mm then bevelling is required)

Bevelling of pipes or plates is usually done to prepare the ends for welding.

Bevel
Inclined shape that needs to be formed on one or both sides of the plates / pipes in order to allow the heat source to go and heat the root of a joint

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# PREPARE BASE MATERIALS FOR ROBOT WELDING

## A. Cleaning and B. Preparation of bevel (groove)

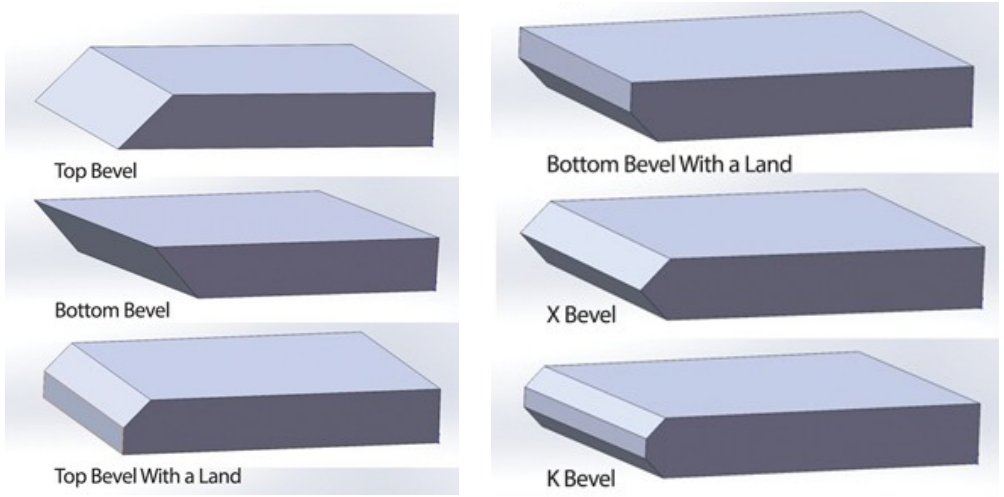
B. Beveling

How?

- By thermal means (flame cutting, plasma cutting, laser cutting, ...)
- By mechanical means (grinding, machining, cutting by plastic deformation, ...)

Shapes and dimensions

Source:
https://www.thefabricator.com/thefabricator/article/cadcamsoftware/the-art-of-bevel-cutting




**ISO 9692-1:2013**
**Welding and allied processes — Types of joint preparation — Part 1: Manual metal arc welding, gas-shielded metal arc welding, gas welding, TIG welding and beam welding of steels**

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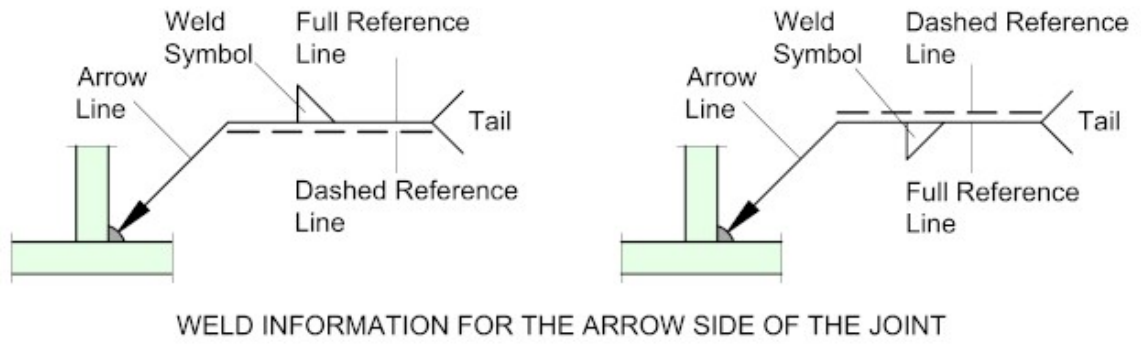
# PREPARE BASE MATERIALS FOR ROBOT WELDING

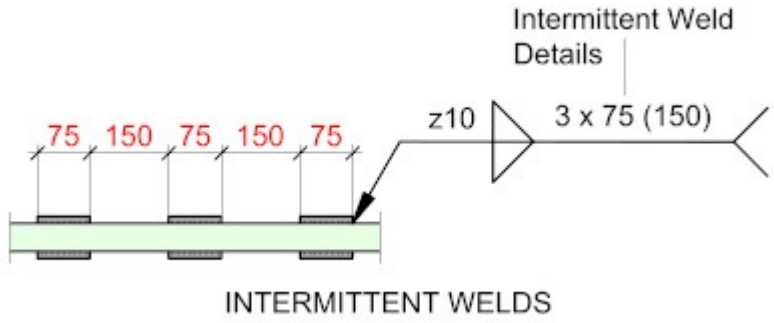
## A. Cleaning and B. Preparation of bevel (groove)

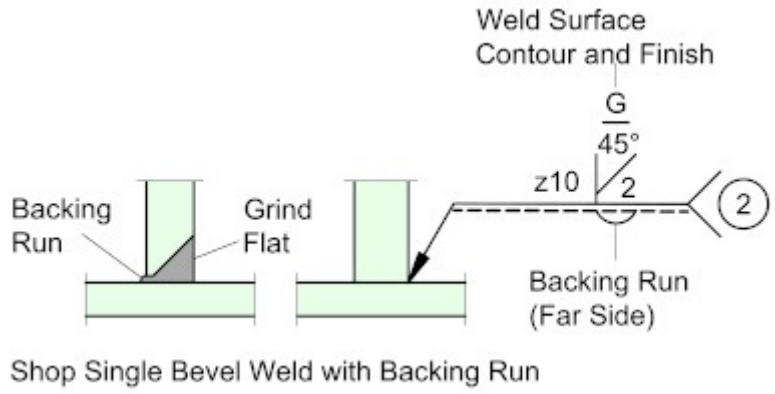
B. Beveling

Symbol

ISO 2553:2019 Welding and allied processes — Symbolic representation on drawings — Welded joints




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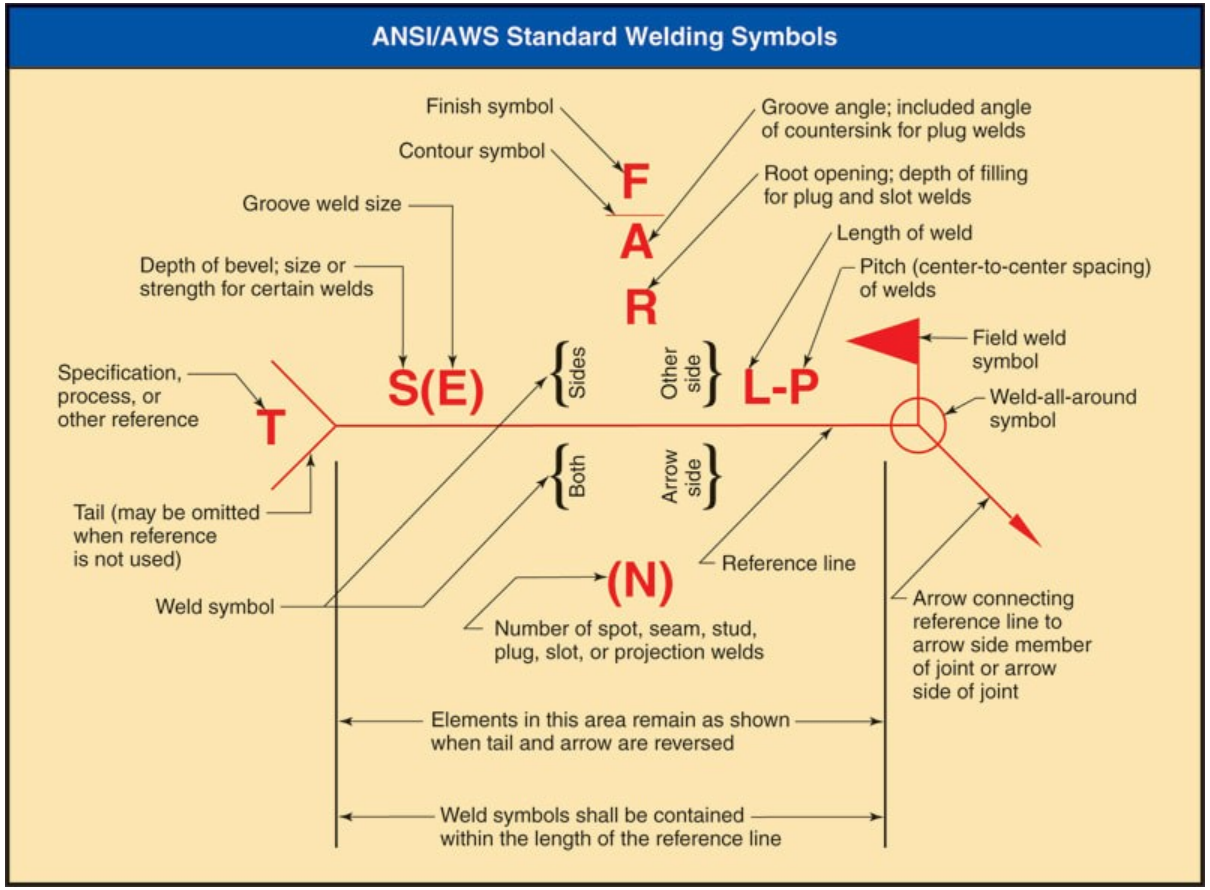
# PREPARE BASE MATERIALS FOR ROBOT WELDING

## A. Cleaning and B. Preparation of bevel (groove)

Symbol

B. Beveling

AWS A2.4:2012, *Standard Location of the Elements of a Welding Symbol*




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# HEALTH AND SAFETY IN USING OF A ROBOT SYSTEM

Robots are powerful tools often used to increase productivity or simply to perform tasks undesired by humans (dangerous, difficult, repetitive or unpleasant operations).

Their presence can however, in some cases, introduce a threat to workers' safety, as robots are machines designed to, more often than not, operate with extreme speed and produce very high amounts of force.

The danger inherent to the use of robots in the workplace is due to the injuries caused by robot failure or human error. These situations can often result in severe injuries to any nearby workers and must be carefully analysed.













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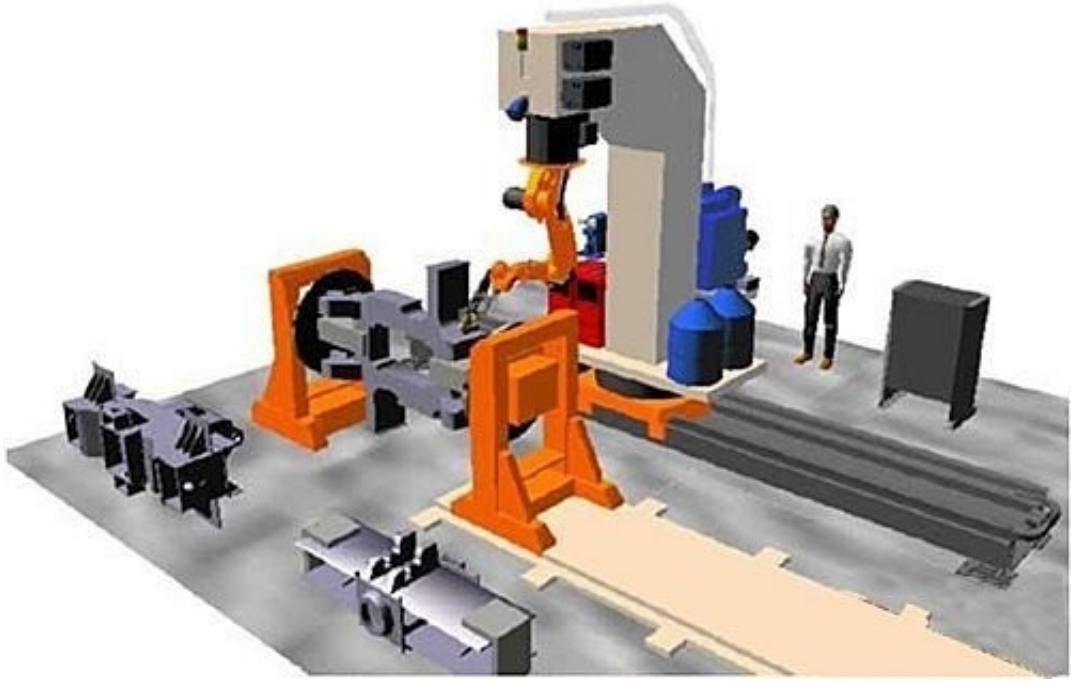
# HEALTH AND SAFETY IN USING OF A ROBOT SYSTEM

## Robot accidents

a) Engineering errors refer to situations caused by failure of mechanical components, controllers, faulty programming, etc. These situations are usually caused by mistakes made in the design, construction or assembly stages and are difficult to predict and foresee. Engineering errors may result, for instance, in undesired uncontrolled robot movements.

b) Human mistakes may occur due to factors, such as, inattention, fatigue or inadequate training. These are commonly avoidable.

c) Environmental conditions, such as, extreme temperature or poor lighting may contribute to improper robot operation, leading to an incorrect



Source: https://www.machinemfg.com/robot-arc-welding-station-safety-protection-classification/

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# HEALTH AND SAFETY IN USING OF A ROBOT SYSTEM

## Interactions of the operators with robots

a) Robot operators work in cooperation with the robot in situations, for instance, where it is necessary to hold a component to be welded or to place a part in a work station. These tasks are often repetitive and the workers may not be prepared for improper machine behaviour.

b) Maintenance workers often operate in situations where robots are known to be functioning incorrectly being, therefore, more prepared and aware of potentially dangerous events.

c) Robot programmers often deal with unfinished robot code prone to bugs and errors, which can result in hazardous situations.

ICS › 25 › 25.040 › 25.040.30

**ISO 10218-1:2011**

**Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots**

ISO 10218-1:2011 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

ISO 10218-1:2011 does not address the robot as a complete machine. Noise emission is generally not considered a significant hazard of the robot alone, and consequently noise is excluded from the scope of ISO 10218-1:2011.

ISO 10218-1:2011 does not apply to non-industrial robots, although the safety principles established in ISO 10218 can be utilized for these other robots.

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# HEALTH AND SAFETY IN USING OF A ROBOT SYSTEM



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DIGIMAN
master programme for digital manufacturing

# THANK YOU FOR YOUR ATTENTION!!!

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DIGIMAN
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# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

# Quality Assurance and Quality Control in AM

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# Learning outcomes: On successful completion of this module a student should be able to:

1. Identify Understand the concept of part quality.
2. Understand how part quality is measured.
3. Identify all the factors which can affect part quality.
4. Understand the relationship between standards and use standards to achieve required part quality.
5. Identify the basic principles of the different NDT techniques.
6. Understand the probability of occurrence of the different defect types for a selection of materials and AM techniques.
7. Assess the potential of each technique for practical applications.
8. Identify appropriate ND techniques for AM parts,
9. Select the appropriate NDT techniques for analysing the quality of MAM parts.
10. Understand and interpret ND examinations.
11. Define the materials mechanical properties.
12. Outline the most common destructive tests.
13. Select the appropriate standard for each DT
14. Determine the metals mechanical properties regarding each destructive test results.
15. Select the appropriate destructive test to evaluate the MAM part properties.
16. Interpret the test results and take decisions

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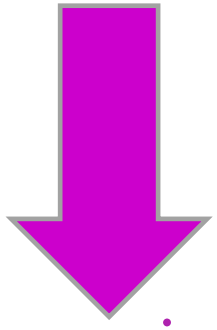
# NEEDS

For **AM** to be adopted in an even wider scale, most organizations require a more sustainable and feasible approach to qualifying and certifying parts and services.

Currently there is **the need** to:

- To comparatively benchmark the performance of different additive processes;
- Ensure that parts produced by AM have consistent "quality", strength, and reliability
- Ensure **accurate specification** of production and parts and
- offer mechanisms to provide independent test for AM verification

Quality Framework



Standards!!!!

**That must be agile, flexible, open, transparent, living, and timely**

Quality Assurance remains the biggest "issue" in AM

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# TO CERTIFY AM-PRODUCED PARTS QUALITY MANUFACTURERS SHOULD:

1. **Identify the level of QA needed for the products**, and what level of risk they are willing to assume
2. **Accurately predict** whether parts will meet specifications when built under “idealized” conditions
3. **Ensure repeatability, consistency, and reliability** across different AM machines and geographies
4. **Incorporate the appropriate technologies and capabilities** necessary to qualify AM-produced parts, based on the target QA level

Not all AM-produced end-use parts will require the same level of QA

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# QUALITY IN ADDITIVE MANUFACTURING

What does "**quality" look** like, and how is it defined in relation to a particular AM process?

Quality will not—and should not—look the same for every type of part and product.

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# PART QUALITY

…. is more than just the shape of the finished part

**“Quality is about a part’s ability to perform the task for which it was designed, while maintaining structural integrity”**

Contributing factors are usually included in a part’s specifications and typically include:

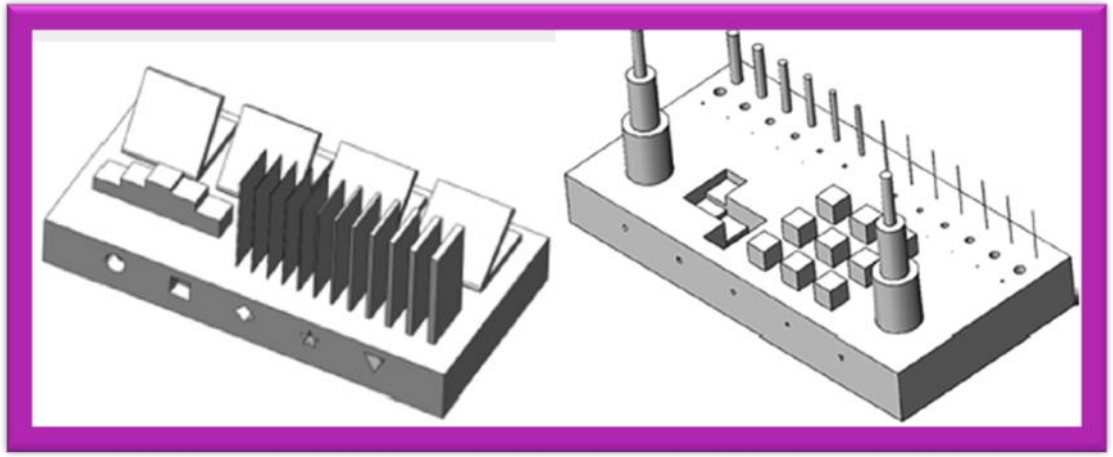
| Quality dimension | Definition |
|---|---|
| **Geometry** | The shape of the finished part and how it will fit with other parts |
| **Surface finish** | The desired smoothness, roughness, or other functional surface treatment of the finished part |
| **Material properties** | A variety of attributes, including mechanical strength, stiffness, and fatigue life |

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# INTRODUCTION TO PART QUALITY

As part of the adaptation of **ISO 9001,** the AM organization must conduct reviews of their **processes, products, and services** to establish that they meet the following requirements:



- Requirements by customer;
- Requirements by organization;
- Requirements by statutory and regulatory bodies;
- Contract / orders requirements;
- Requirements not yet specified but necessary for certain situations when the information is made known.



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# UNDERSTANDING THE PRINCIPLES OF QUALITY MANAGEMENT

**Quality** enables a user to characterize and determine which product is better than the other.

The **quality level of products and services** indicates not only their intended function and performance but also their perceived value and benefit to the customer.

in the **AM industry**, organizations are required to have a **quality framework** that addresses the new concerns specific to AM, in addition to adopting and committing to the approaches and expectations defined in **quality management standards**

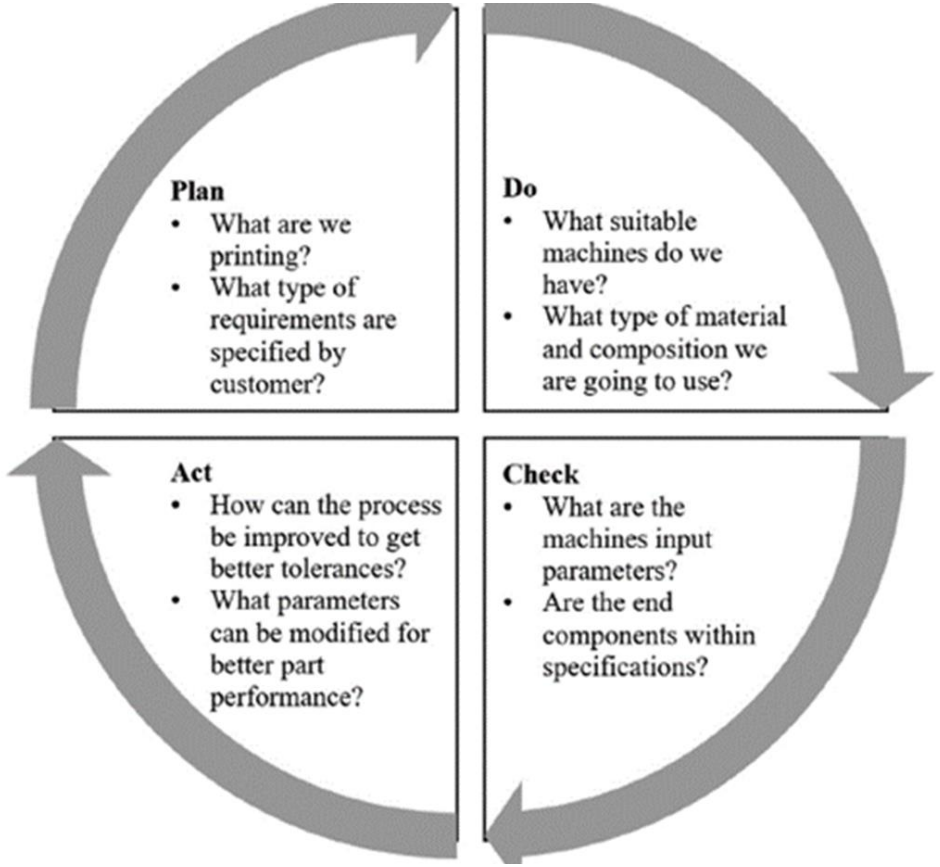
Any manufacturer using AM **must be aware of** and **compliant to** the requirements imposed by both their customers and the regulating authorities to be able to proclaim **the quality of the parts manufactured**

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# PLAN-DO-CHECK-ACT CYCLE

- **Plan** by establishing the objectives of the system and processes in AM, deliver results that meet the required standards and customer requirements.
- **Do** all the steps to ensure the manufacturing is set to reach what was planned. Ensure that you are using the right material and process parameters.
- **Check** and monitor processes, products and services, by performing the required measurements, against relevant company policies, objectives, requirements and standards and report results.
- **Act** on what is reported and improve the performance if needed





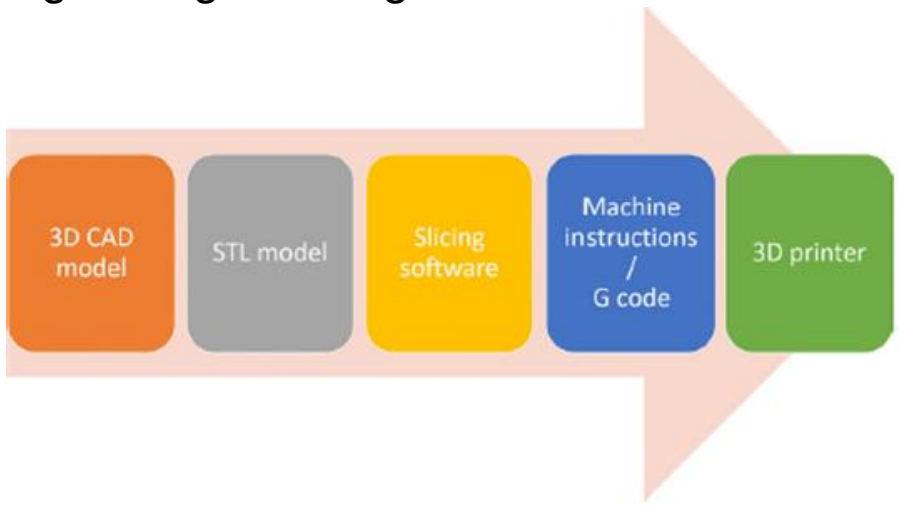

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# PRODUCTS PRODUCED BY AM COULD BE DEFECTIVE FOR VARIOUS REASONS

**Examples include**:

- Corrupted CAD files,
- Faulty equipment, Incorrect materials, material deficiencies,
- Incorrect process parameters,
- File format deficiencies,
- Human error in setting up the machine and in implementing the digital design,
- Lack of reliability and reproducibility, etc.




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# MEASUREMENT OF METAL ADDITIVE MANUFACTURING PARTS QUALITY

DIGIMAN
master programme for digital manufacturing

**Properties of Row Materials**

**Properties/characteristics of AM process and components** :

- Energy source measurement;
- Temperature range, etc




- Dimensions;
- Geometry;
- Roughness;
- Surface finish;
- Structural (microstructure and mesostructure);
- Defects (porosities, lack of fusion, warpages, etc.);









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# QUALITY ASSURANCE NEW SHIFT

Deloitte AM Quality Pyramid

DIGIMAN
master programme for digital manufacturing

"Certify AM parts based on design, as well as observations and corrections made during the build process, rather than verifying performance after fabrication enables manufacturers to achieve the consistent geometries, surface finishes, and material properties that underpin quality"

**Table 1. Key elements of quality assurance in AM**

| AM pillar | Description |
|---|---|
| **Build planning** | The use of advanced modeling and simulation to develop a plan for a machine to produce a specific part |
| **Build monitoring** | Monitoring with sensors the build process as the part is being constructed |
| **Feedback control** | Using data from the build monitoring sensors to iteratively update the build planning process in real time |

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# CERTIFYING AM PARTS

**Table 3. Examples of measurement modalities**

| Sensing modality | Function |
|---|---|
| **Accelerometers** | Measure vibration of the print head during fused deposition modeling and detect potential anomalies[37] |
| **Ultrasound sensors** | Ensure the final part is free of internal voids, an important capability since voids create stress concentrations that can lead to premature part failure[38] |
| **High-resolution photography** | Allows for near real-time inspection of parts in the build chamber[39] |
| **Thermal imaging** | Monitors size, shape, and relative temperature distribution of the melt pool[40] |
| **Pyrometry (photodiode)** | Measures light intensity at a single point and correlates to temperature[41] |

Several supporting factors such a**s standards** to guide the process, calibration, raw materials, and a build data “body of knowledge” that enables manufacturers to catalogue and take advantage past experiences should be used

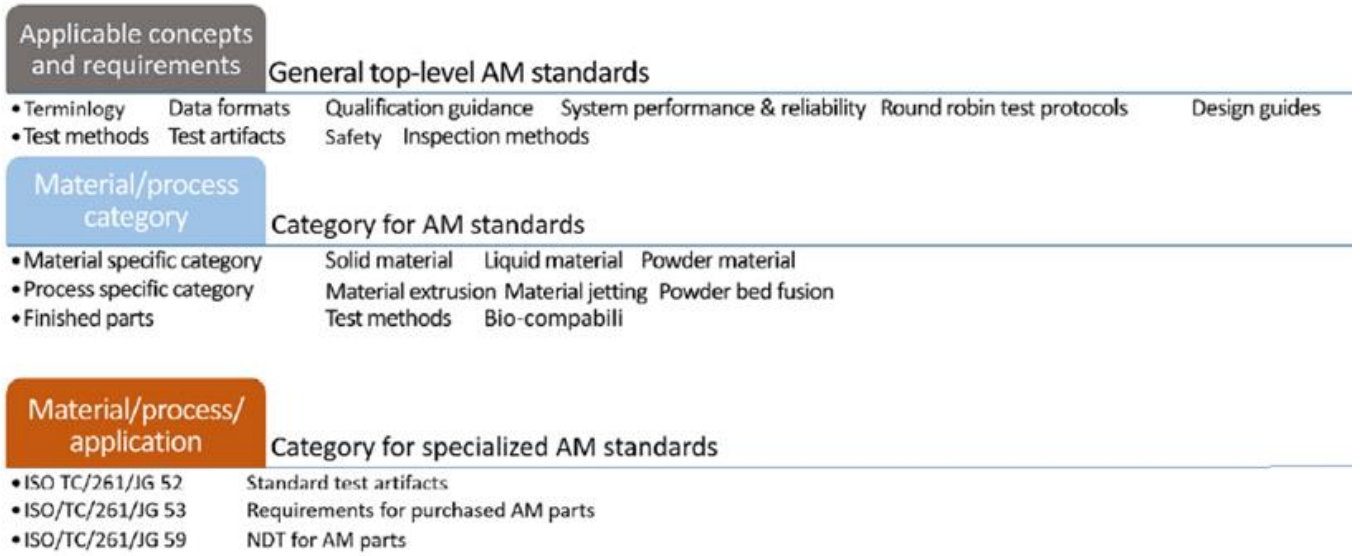
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# AM STANDARDS: ARE A QUALITY SUPORT FACTOR

The structure, consists of **three levels**, which are:

- **General standards** –that specify general concepts, common requirements, or are generally applicable to most type of AM materials, processes and applications.
- **Category standards** – that specify requirements that are specific to a material category or process category.
- **Specialized standards** – that specify requirements that are specific to a material, process or application.



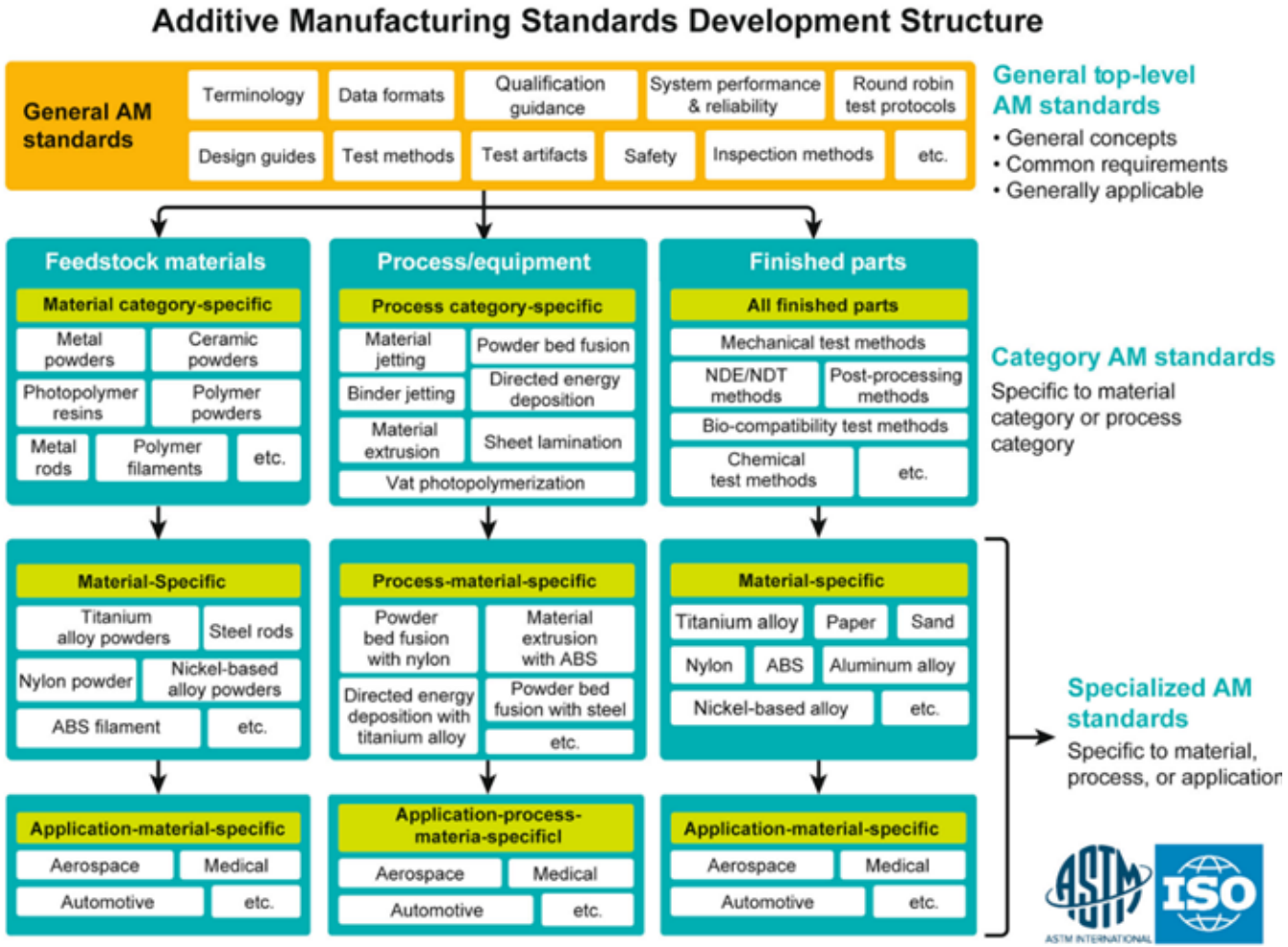




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# STANDARDS IN AM




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# STANDARDS

**"Standards are technical documents that define requirements, specifications, or guidelines to specify test procedures or quality and safety attributes of materials, products, processes and services"**

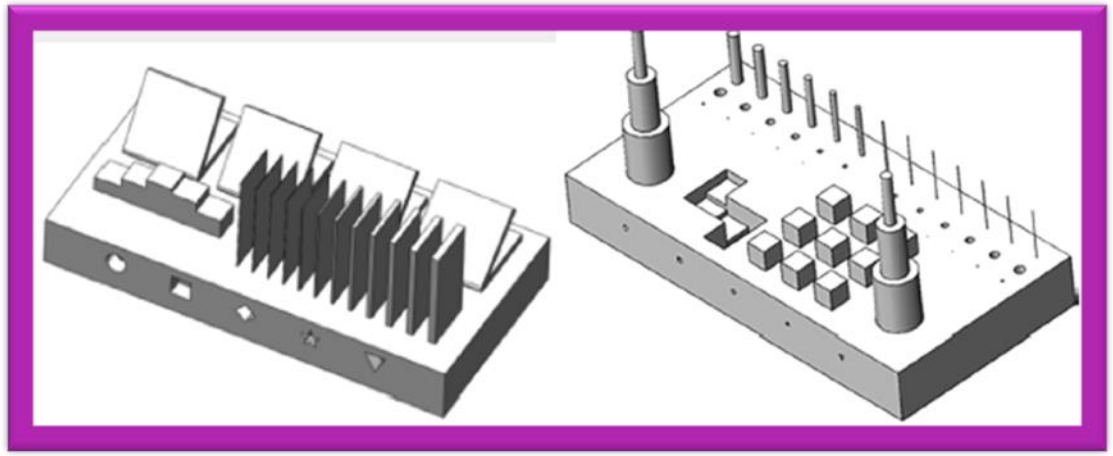
| Area | Organization | Standard | Title |
|---|---|---|---|
| Terminology | ISO | ISO 17296-2:2015 | Additive manufacturing—general principles — part 2: overview of process categories and feedstock |
| | ISO / ASTM | ISO/ASTM 52900:2015 | Additive manufacturing: general principles—terminology |
| | | ISO/ASTM 52901:2017 | Additive manufacturing – General principles – Requirements for purchased AM parts |
| | ASTM | ASTM F2792-12a | Standard Terminology for Additive Manufacturing Technologies |
| Materials and Processes | ASTM | ASTM F2924–14 | Standard specification for additive manufacturing titanium-6 aluminum-4 vanadium with powder bed fusion |
| | | ASTM F3001–14 | Standard specification for additive manufacturing titanium-6 aluminum-4 vanadium ELI (Extra Low Interstitial) with powder bed fusion |
| | | ASTM F3049–14 | Standard guide for characterizing properties of metal powders used for additive manufacturing processes |
| | | ASTM F3055–14a | Standard specification for additive manufacturing nickel alloy (UNS N07718) with powder bed fusion |
| | | ASTM F3056–14e1 | Standard specification for additive manufacturing nickel alloy (UNS N06625) with powder bed fusion |
| | | ASTM F3184–16 | Standard specification for additive manufacturing stainless steel alloy (UNS S31603) with powder bed fusion |
| | | ASTM F3187–16 | Standard guide for directed energy deposition of metals |
| Test Methods | ISO | ISO 17296-3:2014 | Additive Manufacturing -- General principles - Part 3: Main characteristics and corresponding test methods |
| | ISO / ASTM | ISO/ASTM 52921:2013 | Standard terminology for additive manufacturing-coordinate systems and test methodologies |
| | | ISO/ASTM 52902:2019 | Additive manufacturing – Test artefacts – Standard guideline for geometric capability assessment of additive manufacturing systems |
| | ASTM | ASTM F2971–13 | Standard practice for reporting data for test specimens prepared by additive manufacturing |
| | | ASTM F3122–14 | Guide for evaluating mechanical properties of metal materials made via additive manufacturing processes |
| Data and Design | ISO | ISO 17296-4:2014 | Additive Manufacturing -- General principles -- Part 4: Overview of data processing |
| | ISO / ASTM | ISO/ASTM 52915:2016 | Standard specification for additive manufacturing file format (AMF) Version 1.2 |
| | | ISO/ASTM 52910:2018 | Additive manufacturing – Design – Requirements, guidelines and recommendations |

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# PART QUALITY

- Feedstock materials – morphology, size, density, surface, distribution, microstructure and physical and physical-chemical properties.
- Size, length and angle dimensions – dimension tolerances;
- Geometrical tolerance;
- Appearance, surface finish/texture and colour;
- Tensile, Compressive, Impact and Flexural Strength;
- Shear and Creep resistance;
- Fatigue, ageing and hardness testing;



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- Companies seeking to qualify AM-produced parts generally apply the same processes as for parts produced by traditional methods, namely, extensive Non-destructive and Destructive testing.

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# NON-DESTRUCTIVE TESTING OF MAM PARTS

According to **ISO/TC 18173**, **Non-Destructive Testing (NDT)** is the “development and application of technical methods to examine materials or components in ways that do not impair their future usefulness and serviceability, in order to detect, locate, measure and evaluate flaws, to assess integrity, properties and composition, and to measure geometrical characteristics”.

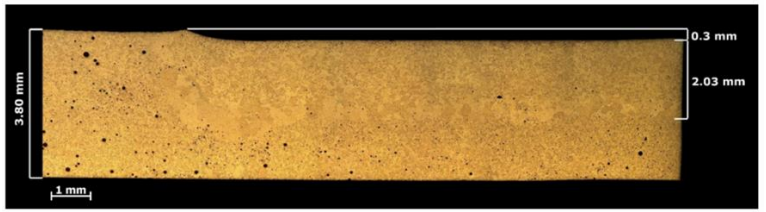


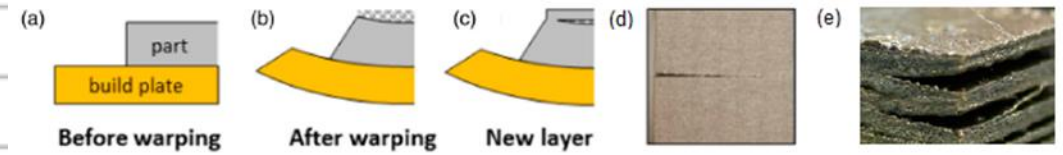

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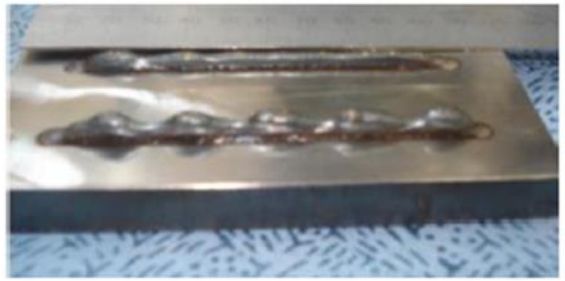
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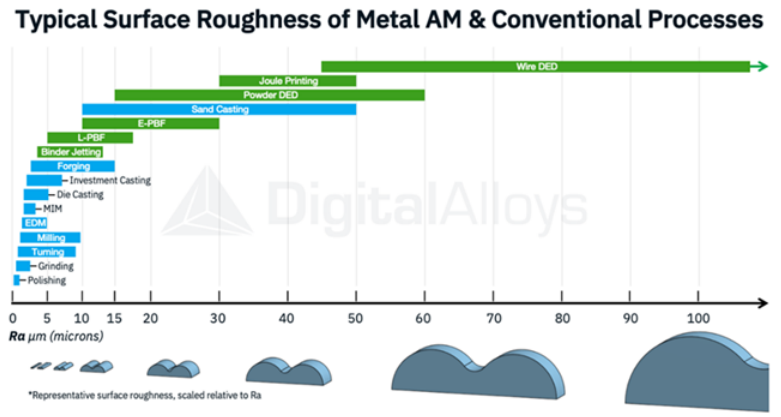
# MAPPING OF POSSIBLE DEFECTS IN MAM BASED ON ISO 6520-1

| | Designation | Reference to ISO 6520-1 |
|---|---|---|
| Surface | Crack | 100 |
| | Lack of Fusion | 401 |
| | Continous under cutting | 5011 |
| | Intermitent undercut | 5012 |
| | Excess weld metal (Humping) | 502 |
| Internal | Cracks | 100 |
| | Micro-crack | 1001 |
| | Gas Pore | 2011 |
| | Uniformly distributed Porosity | 2012 |
| | Clustered Porosity | 2013 |
| | Linear Porosity | 2014 |
| | Lack of Fusion | 401 |



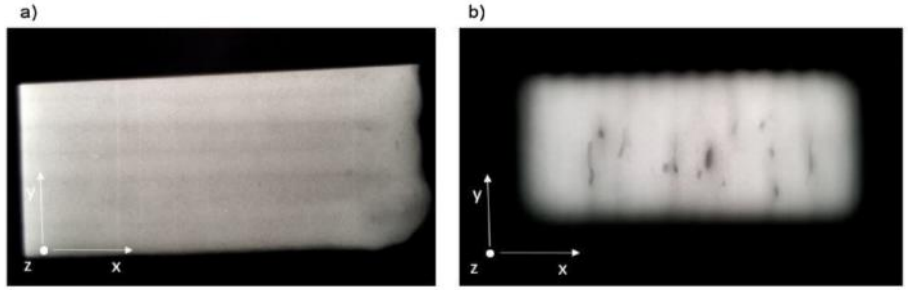



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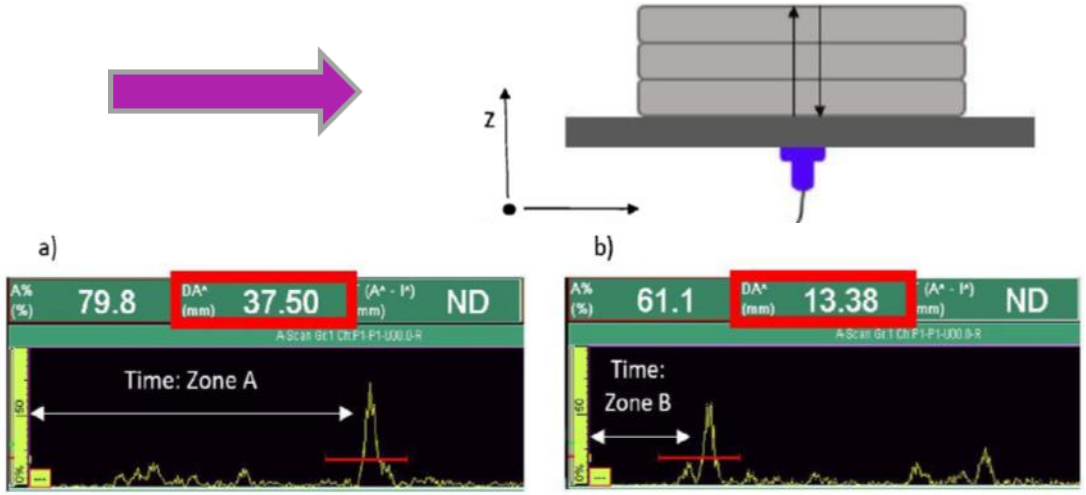
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# NON-DESTRUCTIVE TESTING OF MAM PARTS

| | NDT Technique | Physical Phenomena |
|---|---|---|
| **Imaging** | Radiographic Testing | Electromagnetic radiation (ionizing) |
| | X-ray Backscatter | Electromagnetic radiation (ionizing) |
| | Computed Tomography | Electromagnetic radiation (ionizing) |
| **Ultrasonic** | Conventional Pulse-echo Ultrasonic Testing | Mechanical vibration |
| | Phased Array Testing | Mechanical vibration |
| | Immersion Ultrasonic Testing | Mechanical vibration |
| | Electromagnetic Acoustic Transducer (EMAT) | Mechanical vibration and Electromagnetic induction |
| | Laser Ultrasonic Testing | Thermal expansion and optical measurement |




– X-ray results. (a) Aluminium and (b) Mild-steel samples produced by WAAM [

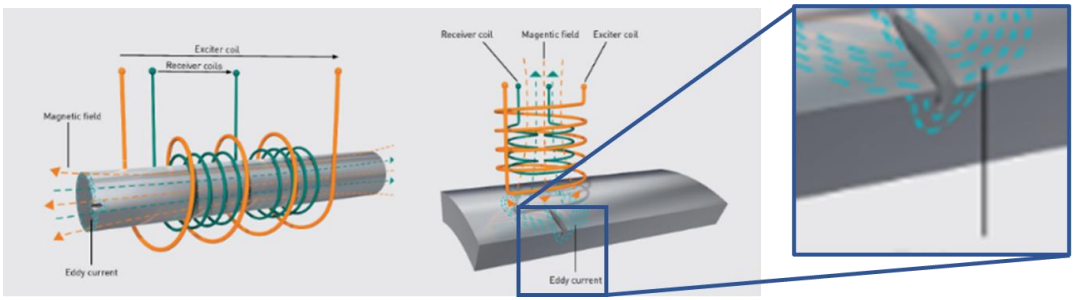



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# NON-DESTRUCTIVE TESTING OF MAM PARTS

| | | |
|---|---|---|
| **Electromagnetic Based** | Potential Drop | Electrical current |
| | Eddy Currents | Electromagnetic induction |
| | Magnetic Particle Testing | Magnetic field |



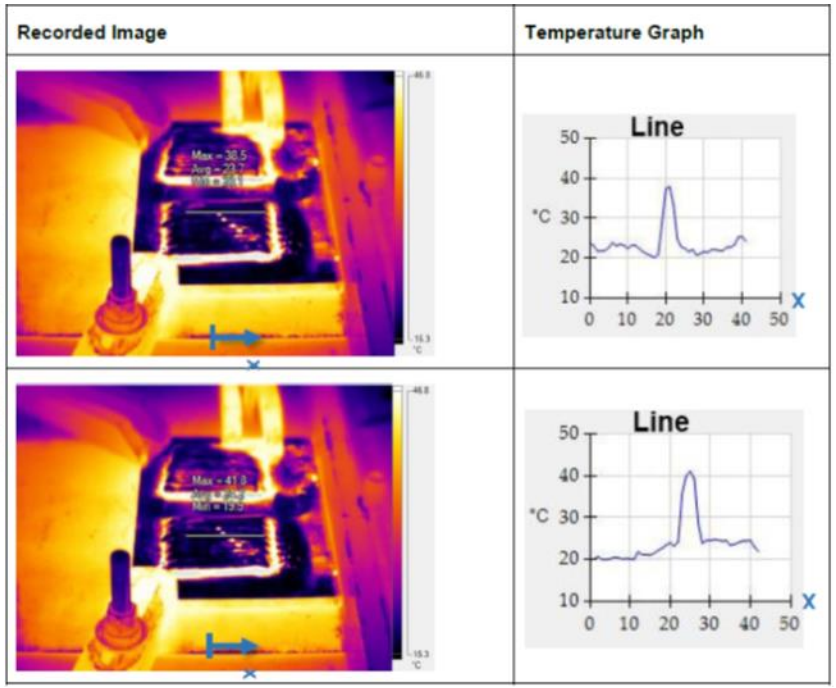

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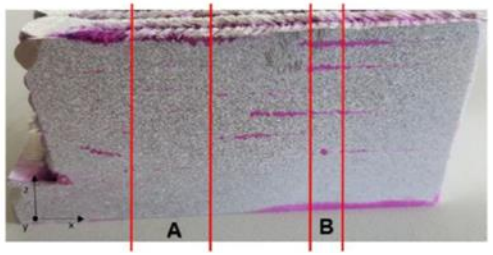
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# NON-DESTRUCTIVE TESTING OF MAM PARTS

| | NDT Technique | Physical Phenomena |
|---|---|---|
| **Thermography** | Infrared Thermography | Electromagnetic radiation |
| | Laser Thermography | Electromagnetic radiation |
| | Vibro Thermography | Electromagnetic radiation and mechanical vibrations |
| | Eddy Current Thermography | Electromagnetic induction and radiation |
| **Others** | Penetrant Testing | Capillary action |
| | Acoustic Emission | Mechanical vibration |





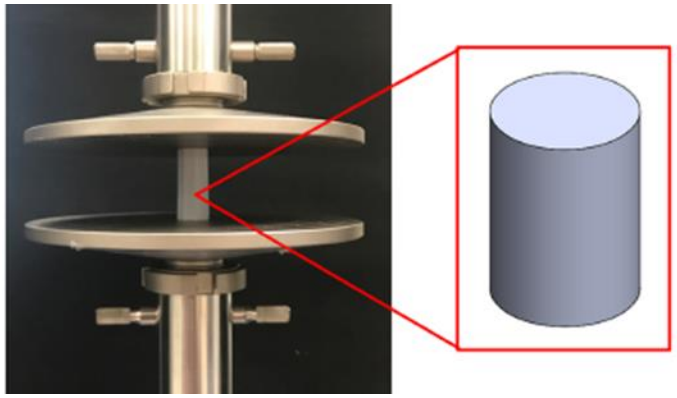



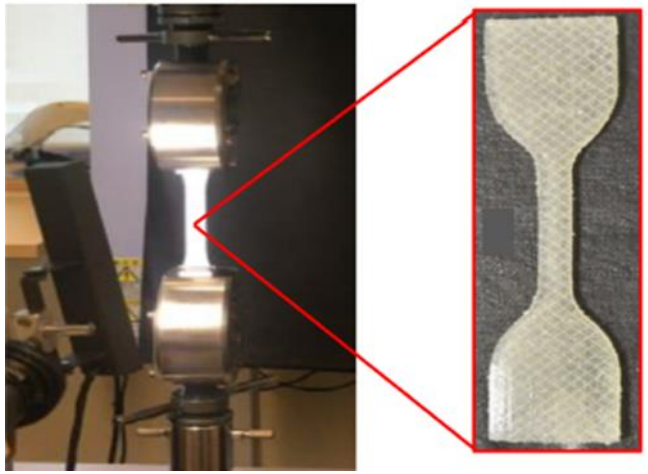

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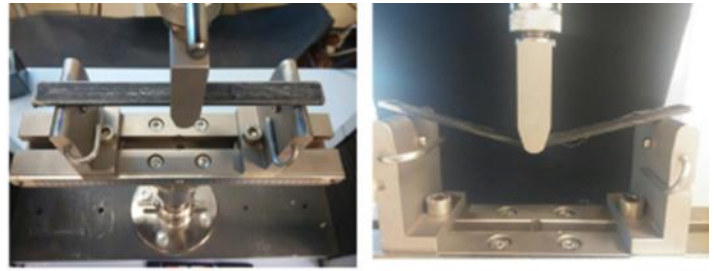
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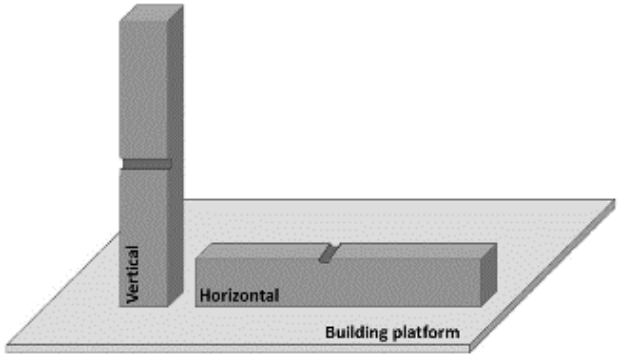
# DESTRUCTIVE TESTING

- **Destructive Testing** is most suitable, and economic, for objects which will be mass-produced, as the cost of destroying a small number of specimens is negligible. It is usually not economical to do destructive testing when only one or a few items are to be manufactured.





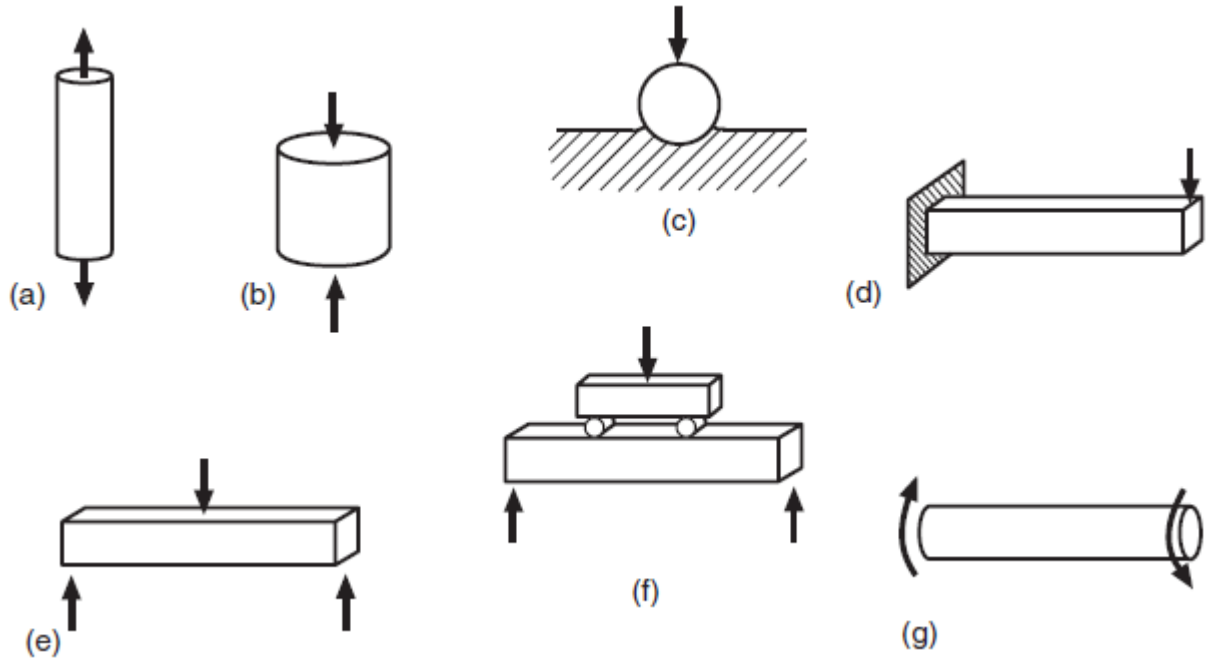







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# DESTRUCTIVE TESTING




- Tensile and compression testing
- Hardness measurement
- Fatigue measurement
- Fracture Toughness, …..

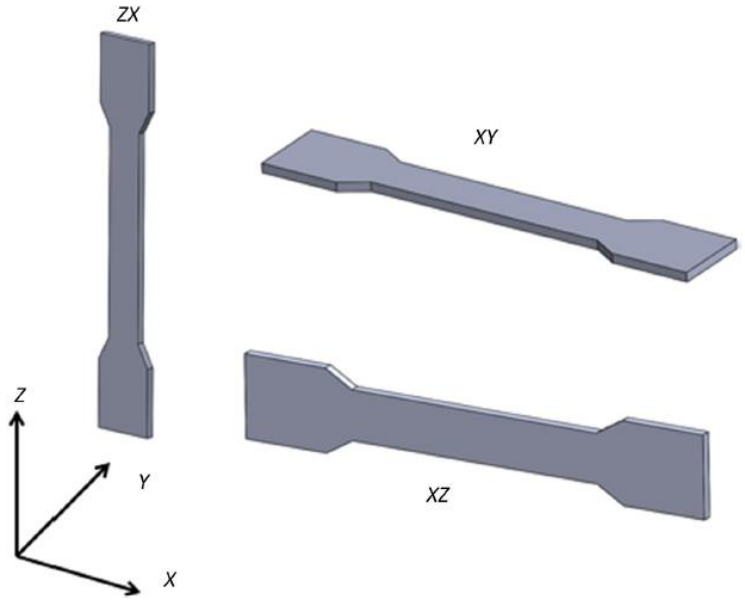
ASTM has released **ASTM F3122-14** for evaluating mechanical properties of metal materials made via additive manufacturing processes . This standard serves as a guide to existing standards or variations of existing standards that may be applicable to determine specific mechanical properties of materials made with a MAM process.

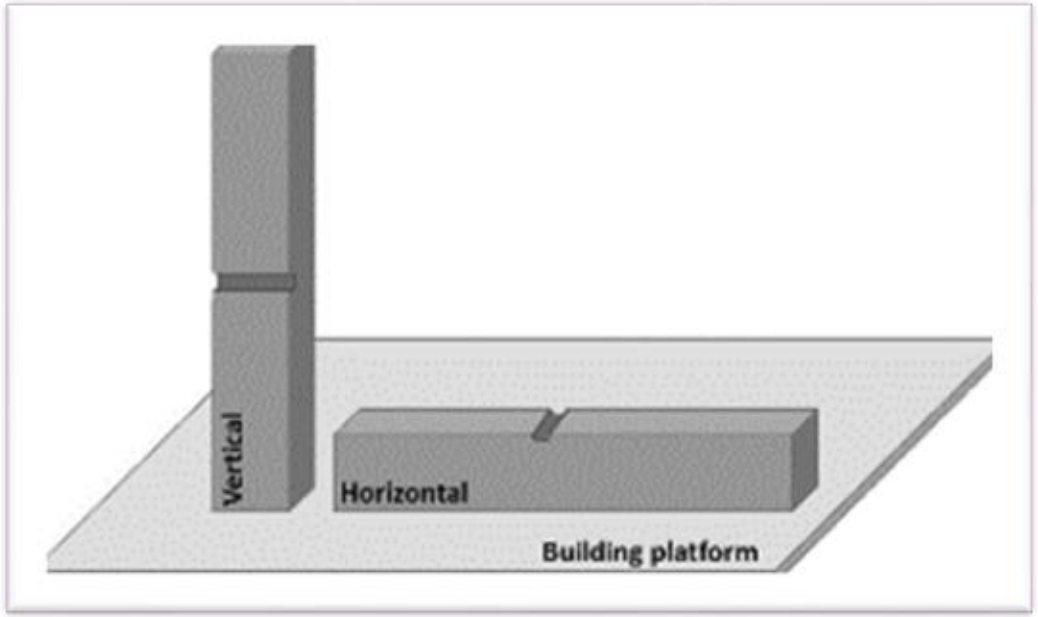
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# DESTRUCTIVE TESTING

Due to the **nature of the AM processes**, MAM parts are often **highly anisotropic**, thus caution has to be taken to ensure the testing has taken anisotropy, build direction and other factors into account.




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# PARTS QUALIFICATION

For AM parts qualification to be more fully realized aspects should be addressed




Graphic: Deloitte University Press | DUPress.com

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# FINAL NOTES

- Despite being **more than 30 years old** this manufacturing procedure is still in its infancy when it comes to its use in most industries other than the peak of the medical and aerospace industry. Consortiums help to drive this approach by by gaining a better understanding of what is needed to communicate it through clear standards and processes.

"One of the most serious hurdles to the broad adoption of additive manufacturing of metals is the qualification of additively manufactured parts"



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# THANK YOU FOR YOUR ATTENTION!!!

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# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

# Post-Processing in AM

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# Learning outcomes: On successful completion of this module a student should be able to:

1. Obtain advanced knowledge and critical understanding of the theory, principles and applicability of Post processing methods
2. Explain how post process fits in the AM chain
3. Describe the different post-processing technologies and their applications in AM process as built parts
4. Discuss the different methods that can be used to reduce residual stresses and distortion, for a variety of part geometries and AM processes
5. Describe the effect of different heat treatments on microstructure, mechanical properties, residual stresses and defects
6. Explain the steps and respective cost associated to the different post process, according to each AM process

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# POST-PROCESSING: THE LAST STEP IN THE MANUFACTURING PROCESS

…where parts receive adjustments, such as smoothing and strengthening.

- Despite all the advantages AM has over traditional manufacturing methods, **it is still imperfect**

- AM parts can have poor surface finishes and the manufacturing method can affect the mechanical properties of the component.

The main objective of post-processing is to eliminate these potentially "dangerous" defects

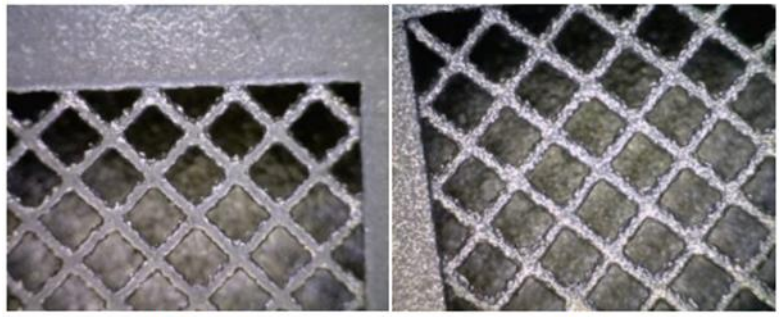
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# POST-PROCESSING

- **Post-processing is an umbrella** term that covers a variety of stages that 3D printed parts must undergo before being used for the final purpose.

- No matter what post-processing stage the AM part needs to go through, **the goal remains the same**: removing the undesired properties that have been built-in the final product during the additive manufacturing process




Water Jet Blasting of EBM titanium
Source:
https://www.belairfinishing.com/metal-process-technology/

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# POST-PROCESSING

- The type of post-processing actions as well as the amount of work at this stage of the manufacturing depends on many variables including, the type of process, applications,…

  - Post-Processing for AM

    Why?

    Why not?

    How?

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# WHY: MUTUALLY LINKED REASONS

- Mitigation of structural defects: solid or liquid cracks, entrapped gas pores, oxide films, lack of fusion, contour defects, etc…
- Enhancing the microstructural homogeneity: reduction of detrimental phases, bringing about desirable microstructure.
- Improving the (anisotropic) mechanical behaviour: tensile, fatigue, creep, etc.
- Reduction of residual stresses
- Functionality: surface finish, functional properties, etc..







Centrifugal Disc Finishing of DMLS parts

| Process | Raw | WJ | I | II | IIIX | III |
|---|---|---|---|---|---|---|
| Ra (uin): | 140 | 59 | 24 | 11 | 7 | 9 |

Attallah & co-workers, various papers.

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# POST-PROCESSING FOR AM: WHY NOT?

- Adds **costs**, increases **lead time**, disturbs the **supply chain**.
- May not help with some defects:
  - **Cracks** (surface connectivity).
  - Pores: When heat treatment operations are required, gas pores (even collapsed by HIPping) might re-open during subsequent HTs as thermally-induced pores (TIPs).
- Erases the fine microstructure resulting from the rapid solidification in AM, reducing the as-built strength.
- Tip: know the necessary & sufficient property requirements.
- **It should be our aim as researchers pushing AM boundaries to produce parts that do not require any post-processing (first-time right).**

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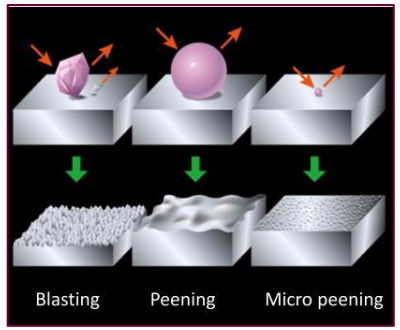
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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

## Mechanical:

- Shot peening/blasting
- Abrasive (flow, centrifugal) polishing
- Machining (e.g., interfaces)
- Laser polishing (mechanical/thermal)





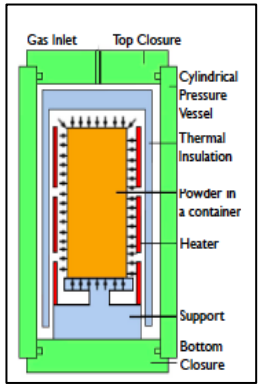

wpctreatment.com

## Chemical:

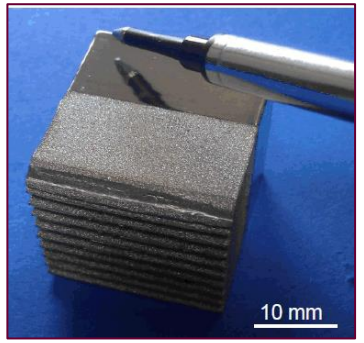
- Etching

## Thermal:

- Hot isostatic pressing
- Heat treatment (e.g., stress relief/solution




EPMA




Fraunhofer ILT

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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

## Cleaning and powder removing:

- Depowdering comes into play when components have been produced with powder-based metal additive manufacturing technologies.
- It is the first step and current bottleneck of the post-processing chain after the printing process.

Depowdering can be made with a brush, vacuum cleaner. Sandblasted can also be used to remove what the brush may have missed



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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

## Material Removal

### Support structures removal

Support structures could be considered a "necessary evil" in the Additive Manufacturing process.



sacrificial material used for supporting overhanging features being manually removed

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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

## Base Plate removal by EDM wire cutting





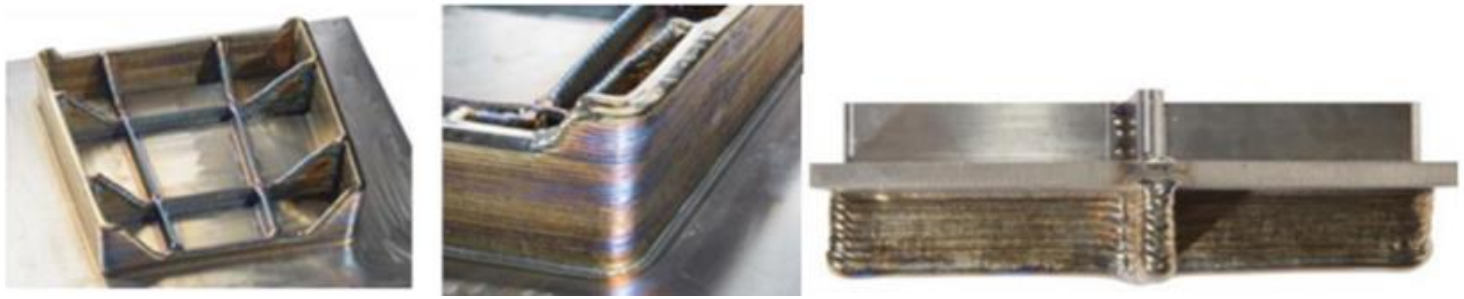
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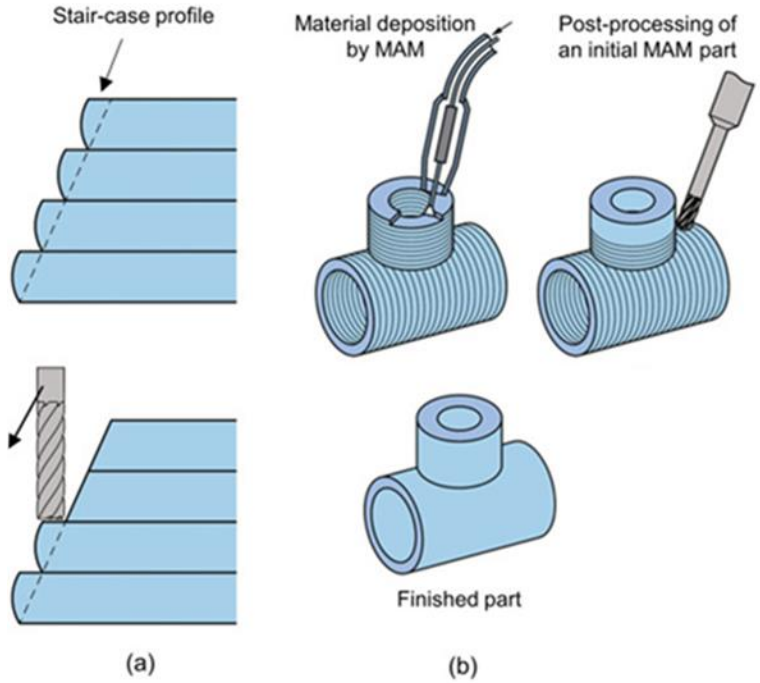
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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

## CNC Machining

Removed the parts “Staircasing effect” caused by the stacking of the layers generated.



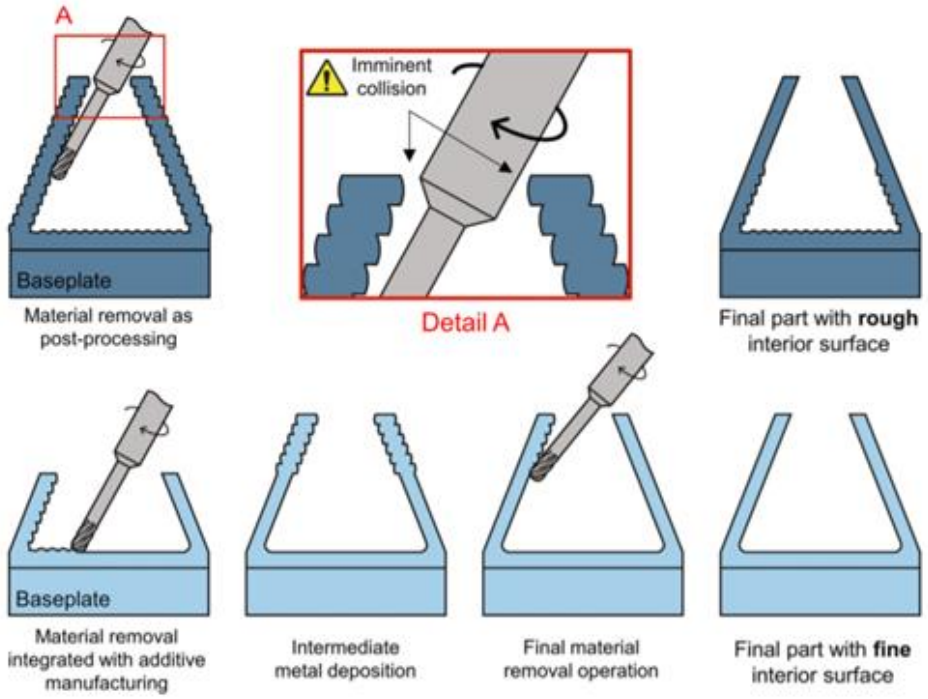



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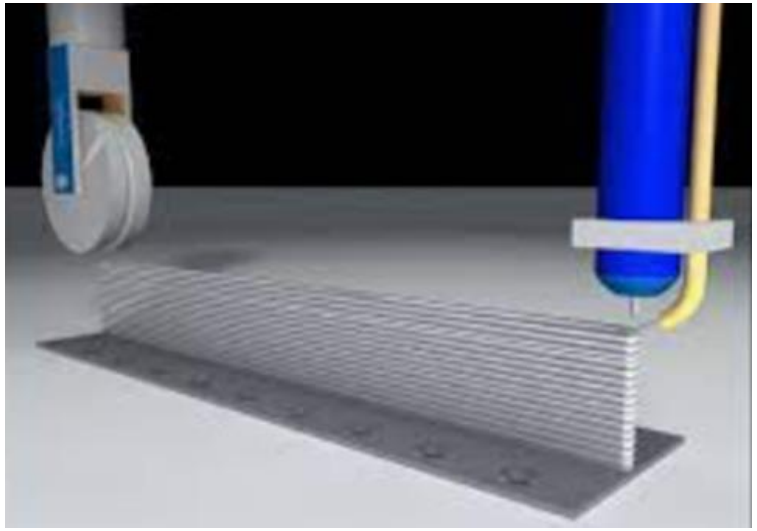
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# HOW: MECHANICAL, THERMAL, AND CHEMICAL TECHNIQUES

Hybrid fabrication
Additive manufacturing+ Machining




Additive manufacturing + Rolling



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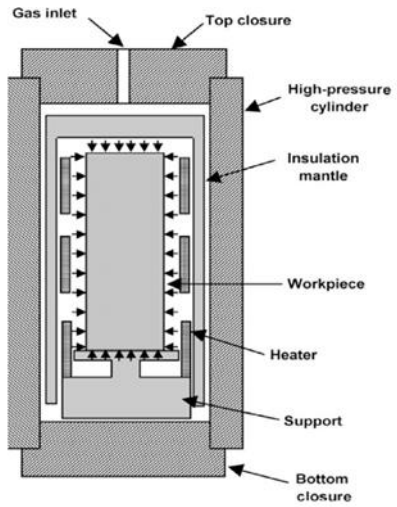
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# THERMAL TREATMENTS

## Heat treatments



## Hot Isostatic Pressing (HIP)

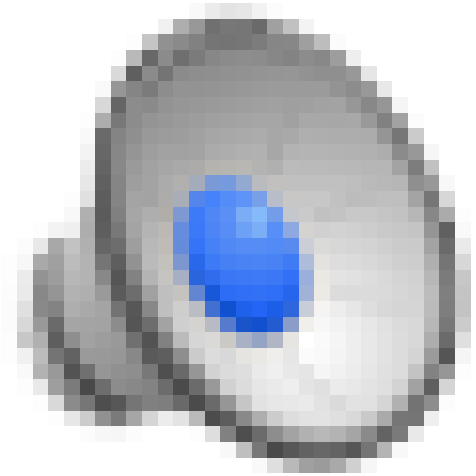



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# POST-PROCESSING FOR AM: MECHANICAL TREATMENT EXAMPLE

Vibratory Grinding / Polishing



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# POST-PROCESSING FOR AM: SHOT PEENING / BLASTING

## Shot Peening / Blasting




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# TO POST-PROCESS OR NOT TO POST-PROCESS: CONCLUSIONS

- **Post-processing can be useful to**:
  - Reduce the scatter & disparity in mechanical properties.
  - Homogenise the microstructure.
  - Improve the functional behaviour
- It can also be less beneficial when:
  - Desirable as-fabricated mech. props are lost.
  - It is used to retro-fix the unfixable (e.g. cracks).
  - It becomes too expensive (use castings or forgings then)!
  - It hits a metallurgical limit (inability to create massively coarse grains from the as-fabricated AM microstructure).
- **Tip:** know the necessary & sufficient property requirements.
- **It should be our aim as researchers pushing AM boundaries to produce parts that do not require <u>any</u> post-processing.**

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# FINAL NOTES

- Post-processing plays a huge role in additively manufactured metal parts, in their design and future applications. The different post-processing techniques depend on how the parts are produced as well as on their properties.
- Additive manufacturing is a technology that has been developing over the years, for its many advantages, such as the possibility to manufacture complex geometries, to have lighter structures and customization. However, the time and cost associated with the required post-processing are drawbacks for its development and implementation in the industry.

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DIGIMAN
master programme for digital manufacturing

# THANK YOU FOR YOUR ATTENTION!!!

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DIGIMAN
master programme for digital manufacturing

# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Rapid Tooling for competitive AM

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# Learning outcomes: On successful completion of this module a student should be able to:

- Obtain advanced knowledge and good understanding of the theory, principles and applicability of: different RT techniques: Silicone rubber moulding, Metal spray tooling for injection moulding, Investment casting, Selective Laser Sintering, Selective Laser Melting, etc.;
- Discuss and select the appropriate RT methods, which should take advantage of the master models made by 3D printing;
- Explain the competitive industrial applications of AM;
- Describe the main factors which have significant influence of the AM competitiveness and what are the main criteria to select he appropriate tooling route (volume production, type of material, complexity of the part, etc.).

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# Course purpose:

- The purpose of the course is to ensure the accumulation of technical competences on how to make AM more competitive for industrial production.
- The course deals with aspects related to Rapid Tooling (RT), which are innovative technologies working with master models made by AM, which are further used for low and medium volume production of complex parts, made from different materials (plastics, metals, composite materials, etc.).

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# Objectives of the course:

- Understand the principles of when and how AM could be a competitive technology for industrial production, not only an interesting method within the research laboratories
- Learn the basic Rapid Tooling methods and industrial applications of the patterns made by 3D printing
- Understand the principles of direct and indirect RT methods
- Select the appropriate RT techniques for specific industrial or medical applications of AM

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# Professional competences:

- Evaluate the specific productions requirements (e.g. volume production, type of material, complexity of the part), in order to select the suitable AM process to print the master model;
- Investigate, which are the available RT techniques, suitable to use the master model (printed from a simulant material), in order to get a low volume production of the parts, made from final material;
- Evaluate the possibilities of using AM in Rapid Product Development, where functional tests of the new product are required and the complex parts have to be made from final materials;
- Design the appropriate RT technology, select the splitting line, gating, venting for vacuum casting, investment casting, metal spray tooling, etc.;
- Coordinate the tasks distribution between the operators according to the work plan as well as manage the links between them.

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# Transversal competences:

- Interacting and working with others and team members to accomplish team goals and strategies;
- Contributing ideas, solutions, and efforts in a group work or project;
- Making decisions and solving problems respecting the team consensus. Ensuring that all the decisions are made according to the policies and rules. Solving the emerging problems in the work;
- Working in multidisciplinary team of people with variety of skills, knowledge, and backgrounds. Actively participating and collaborating with team members in order to get better ideas and solutions.

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# Content of the course:

- Moving AM from research laboratories to industrial production
  - Design for AM and virtual prototyping
  - Transferring the CAD model to the AM machines
  - The need and importance of AM for RPD
  - How to select the adequate AM method, for specific applications
- Vacuum Casting by SRM (Silicone Rubber Molding)
  - How does SRM works?
  - How to cast parts into SRM?
- Investment casting of metal parts and applications
- Rapid tooling by SLM
  - Steps and procedure in the SLM process
  - Simulation of SLM process
  - Technological parameters
  - Heat treatment for stress releasing
  - Supports removal and finishing the SLM parts

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# AM and RT for Rapid Product Development:

- Introduction to Innovative Manufacturing
- Experimental case studies of manufacturing complex metal parts
  - selective laser melting (SLM)
  - selective laser sintering (SLS)
  - CNC milling
- Evaluate the benefits, using different criteria
  - dimensional accuracy
  - surface roughness
  - manufacturing time and costs

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# RAPID TOOLING PROCESS SELECTION: plastic parts

| Plastic parts | Production material | Simulant |
|---|---|---|
| **1 off** | Not cost effective | FDM – ABS / SL – Epoxy resin<br>SLS - Duraform |
| **10 off** | AIM tooling<br>Ceramic cast tooling<br>Sprayed metal tooling (Zinc) | Vacuum Casting<br>Thin RIM moulding<br>RP parts |
| **100 off** | AIM tooling<br>Spray metal tooling (steel)<br>Resin Cast Tooling<br>Laser sintered tools | RIM moulding |
| **1,000 parts** | Laser sintered tools<br>Cast aluminium tooling<br>3D - Keltool | Not cost effective |
| **10,000 parts +** | Laser sintered tooling<br>Electroformed tooling<br>Investment cast tools (steel) | Not cost effective |

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# RAPID TOOLING PROCESS SELECTION: metal parts

| Metal parts | Production material | Simulant |
|---|---|---|
| **1 off** | Investment cast from SLA, SLS, FDM<br>Sand casting from RP patterns | Laser sintered metals |
| **10 off** | Investment cast from SLA, SLS, FDM<br>Sand casting from RP patterns | Spin casting<br>Laser sintered metals |
| **100 off** | Investment cast from waxes produced in RP cavities | Spin casting |
| **1,000 parts** | Die casting into Keltool<br>Die casting into laminated tools | Not cost effective |
| **10,000 parts +** | Die casting into Keltool<br>Die casting into laminated tools<br>Investment cast steel dies | Not cost effective |

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# Vacuum casting for low volume production of the plastic parts

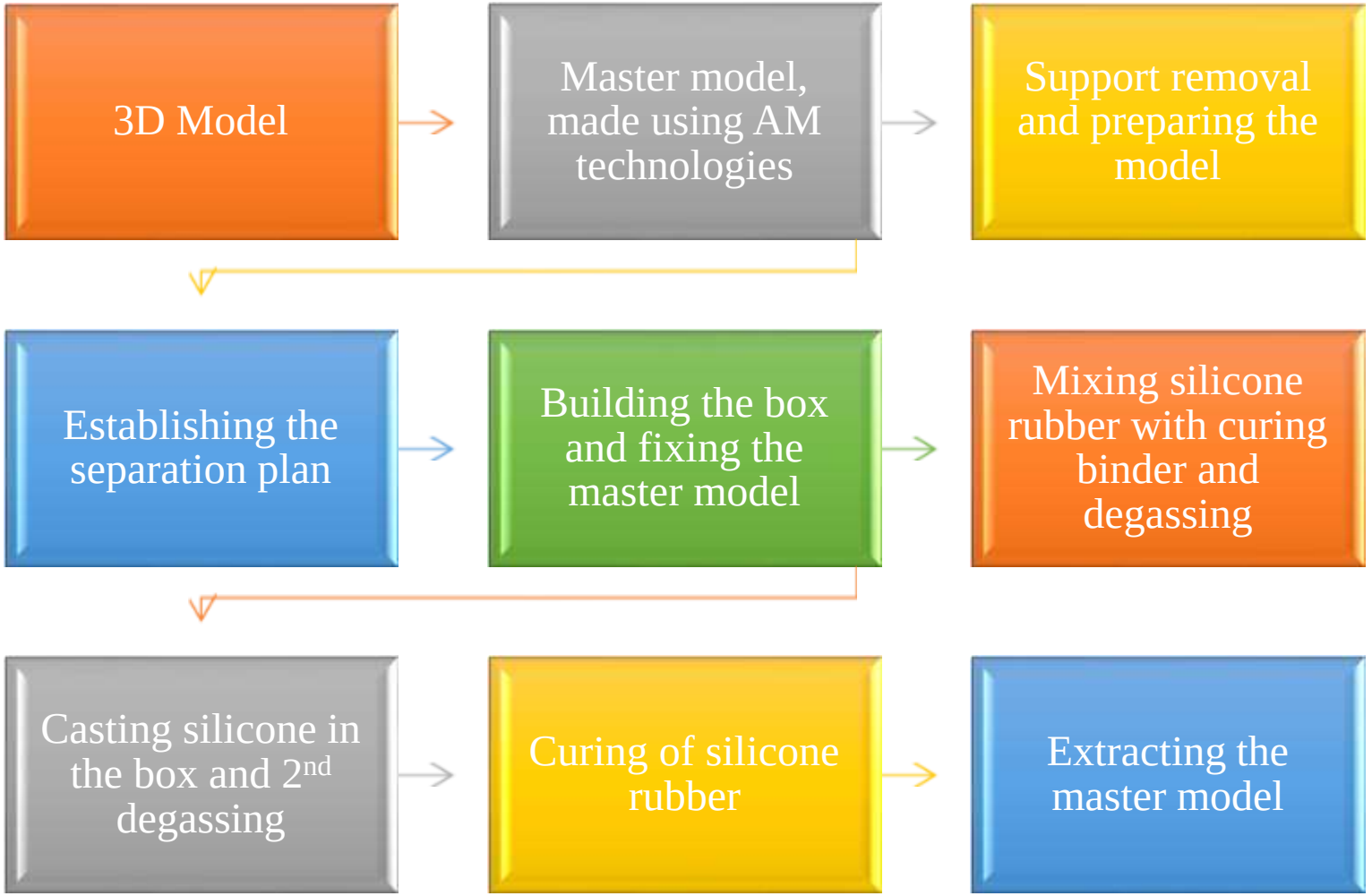





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# Vacuum casting for low volume production of the plastic parts




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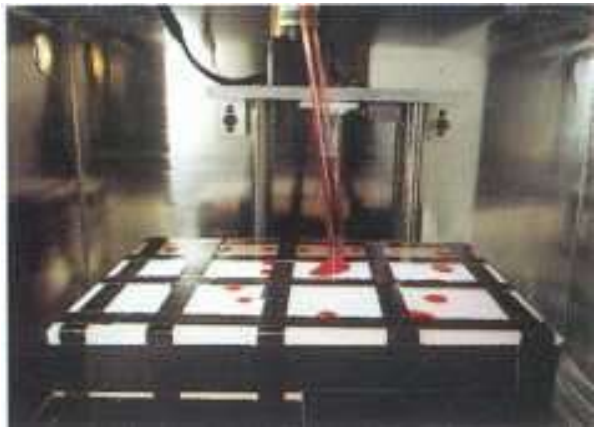
# Vacuum Casting Process









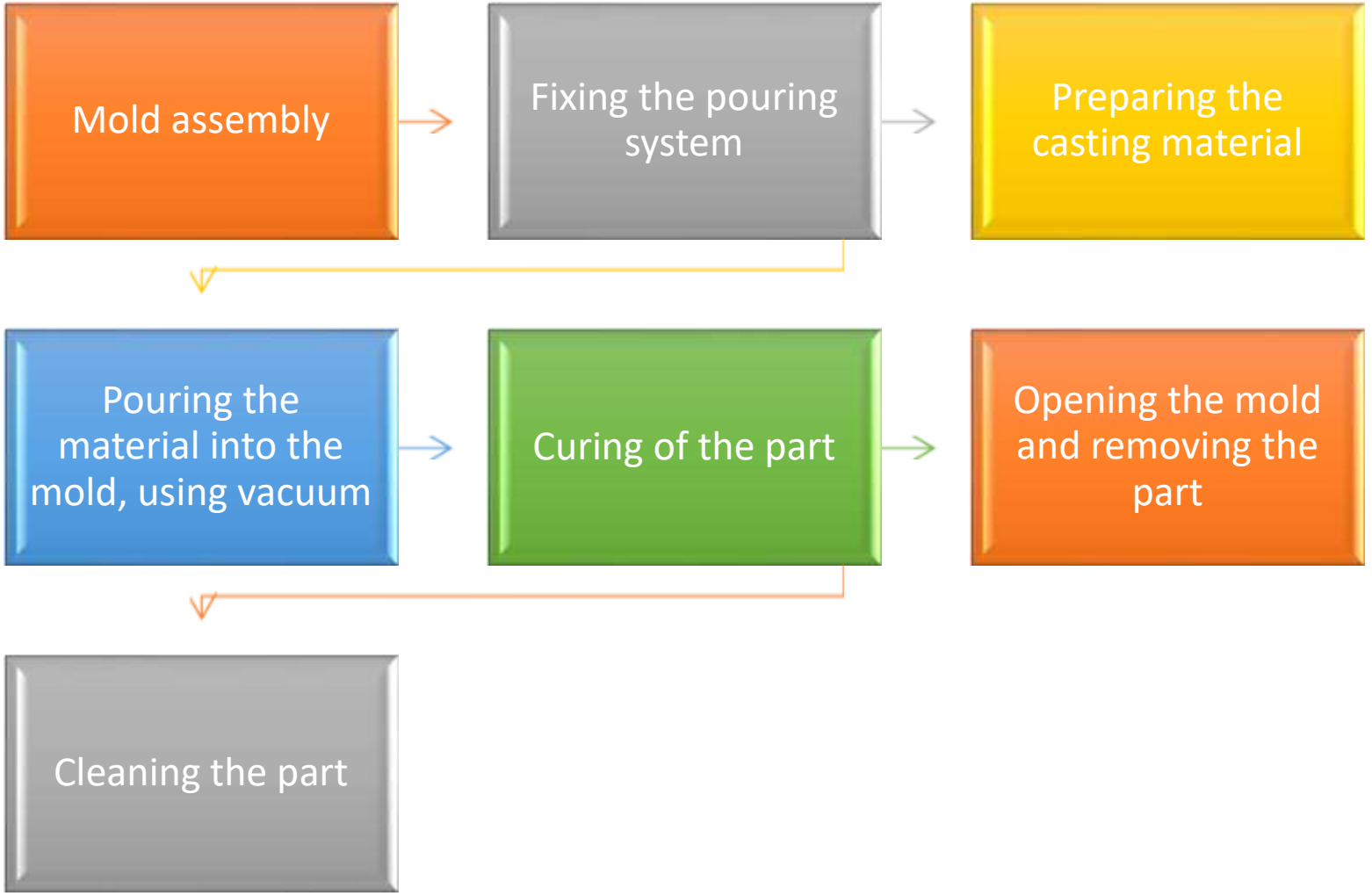





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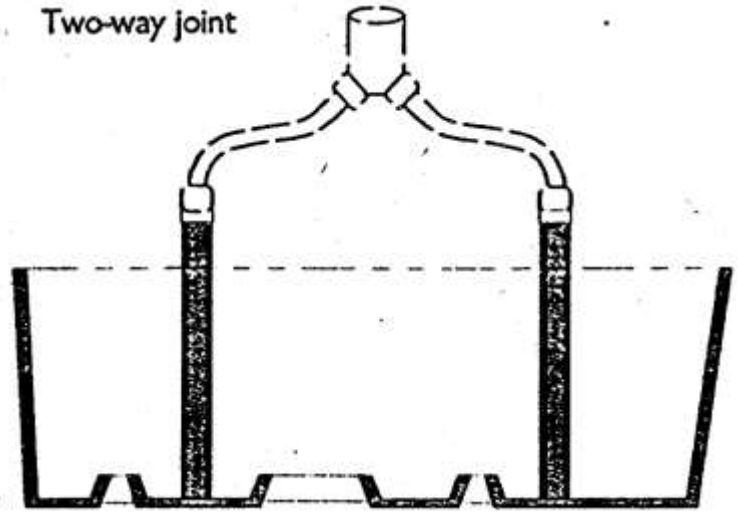
# Vacuum Casting Process

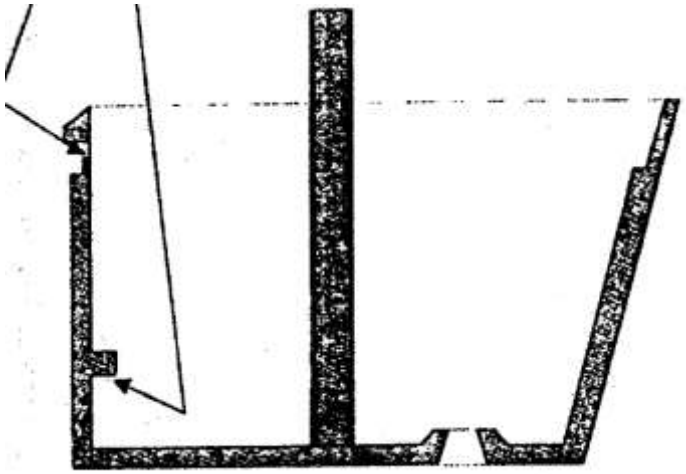


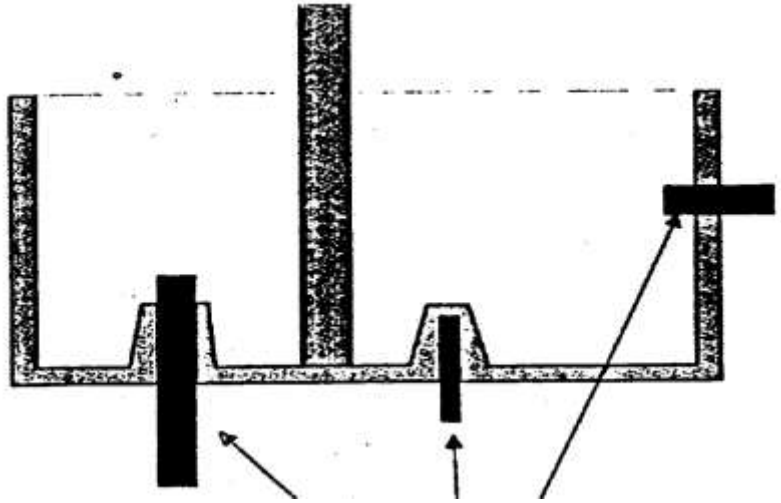

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# Gating, undercuts, inserts





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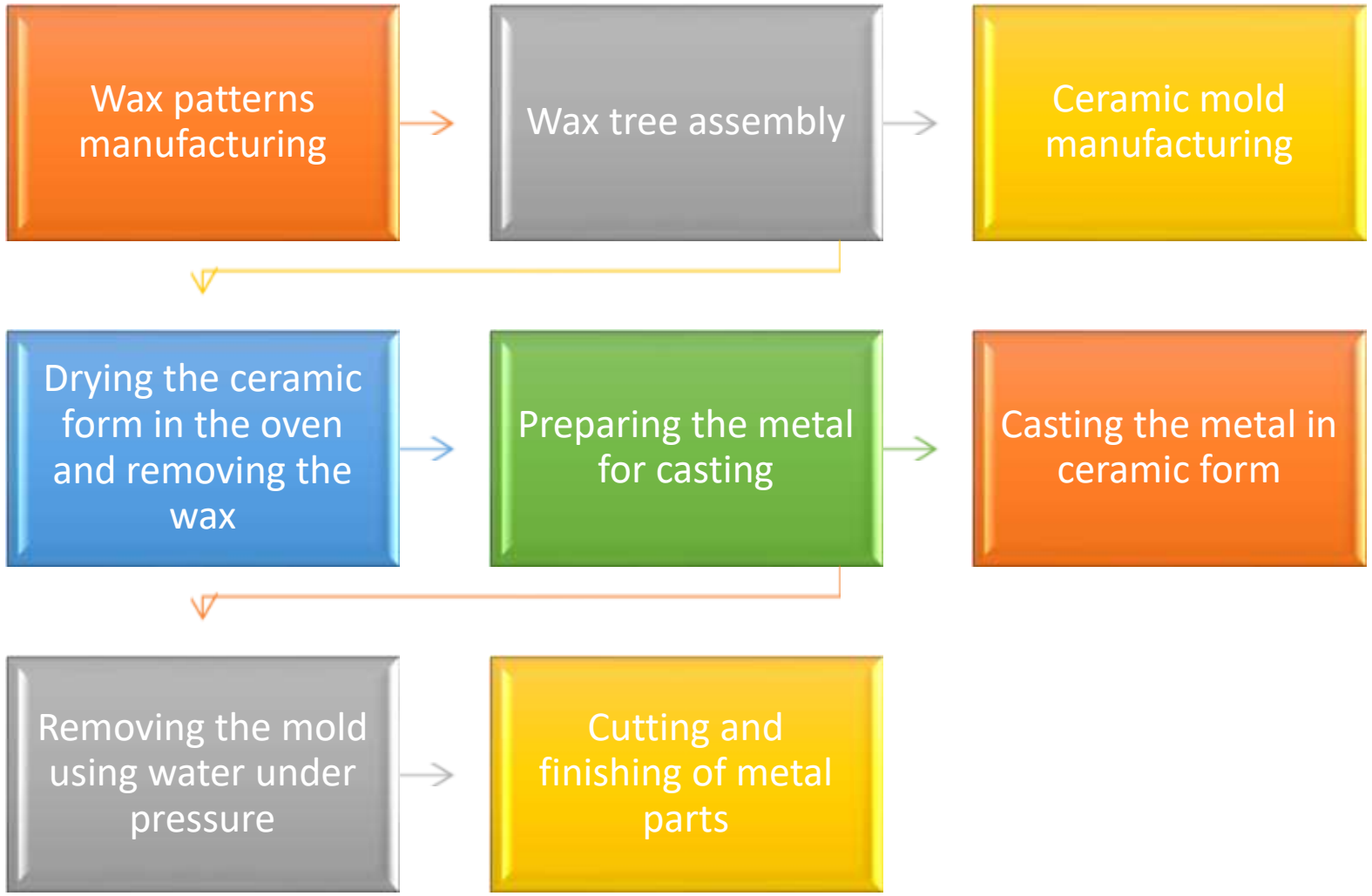
# IC - Investment Casting process, versus Die Casting




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# IC - Investment Casting process, versus Die Casting



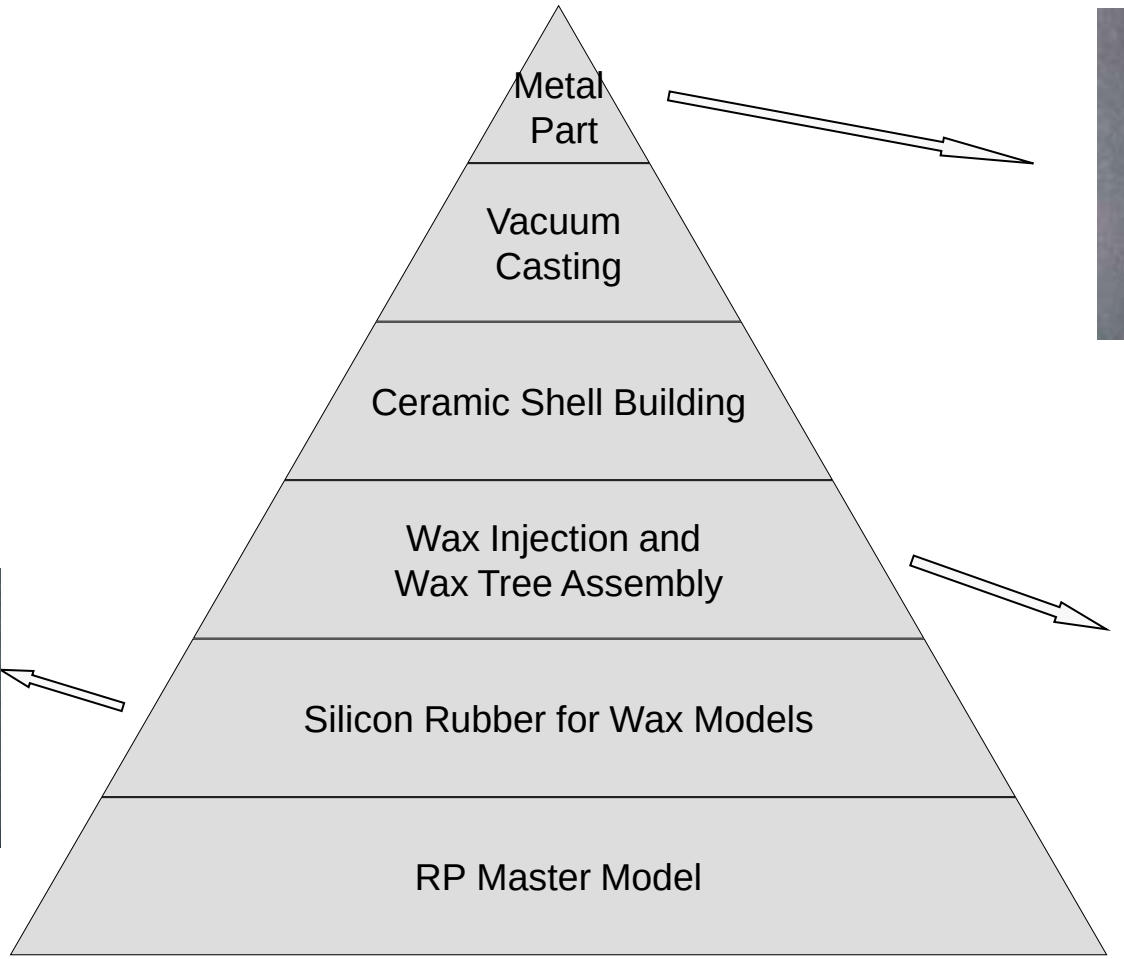

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# Investment Casting process







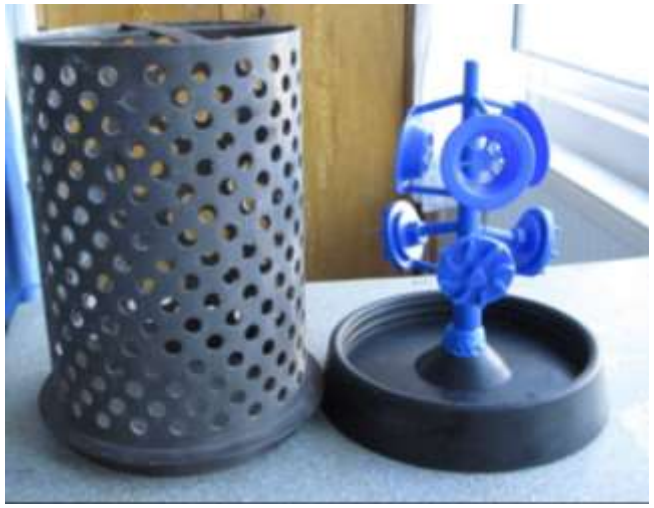




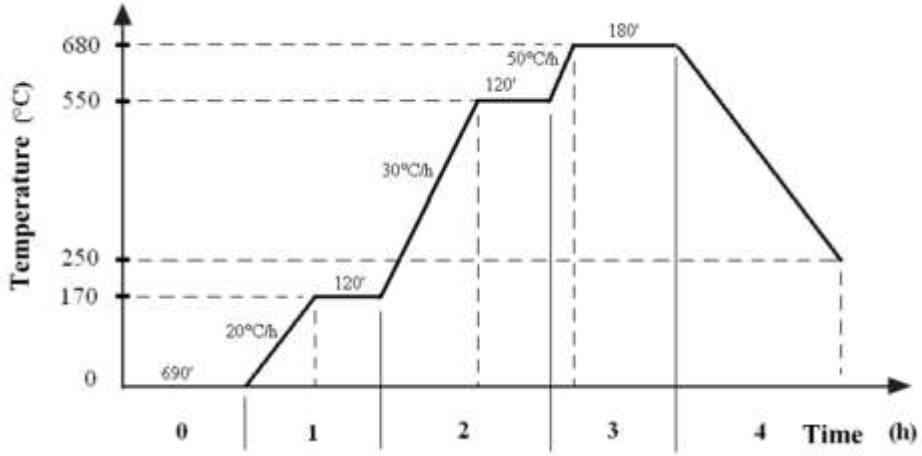

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# Investment Casting process











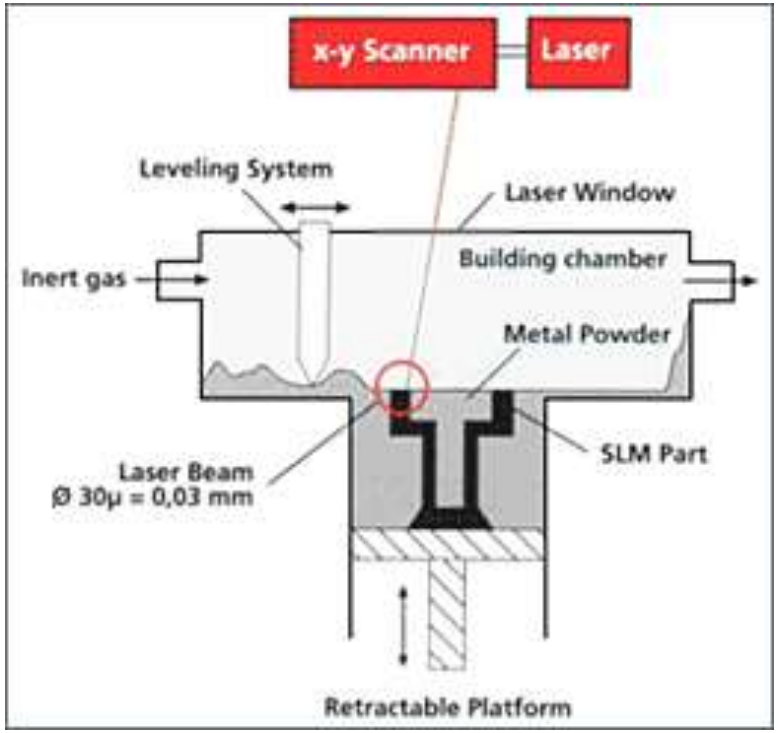




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# Selective Laser Melting (SLM) at the TU of Cluj



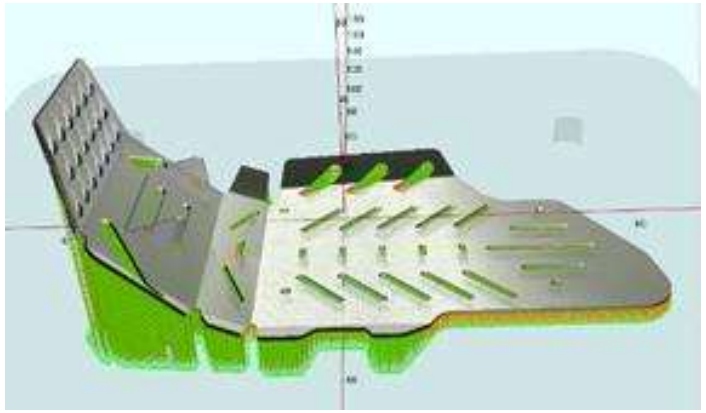


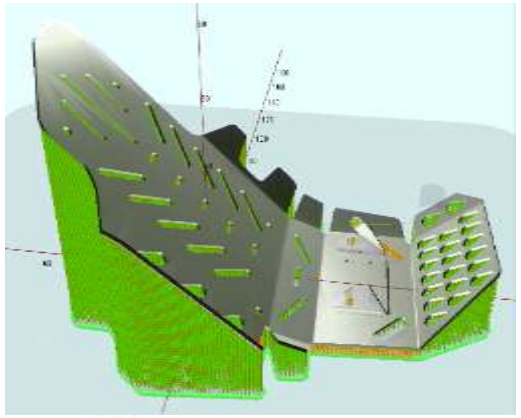


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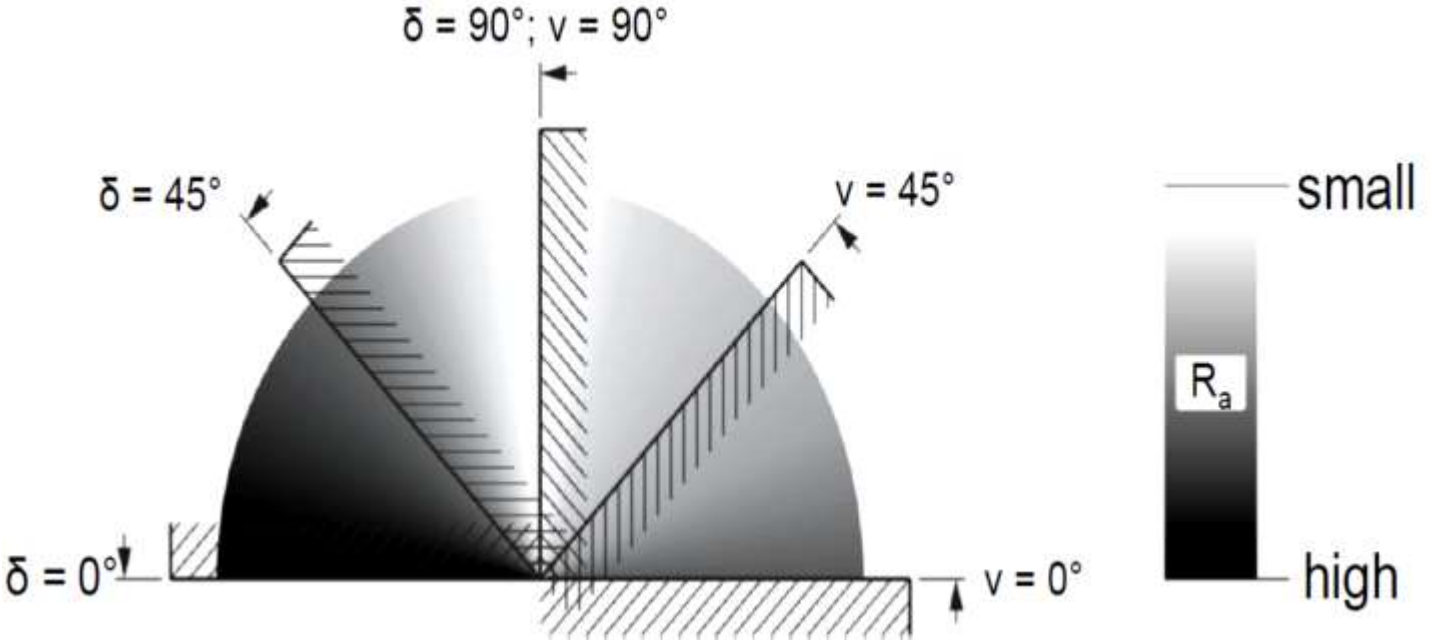
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# Part orientation: Influence of the build-up angle - Ra



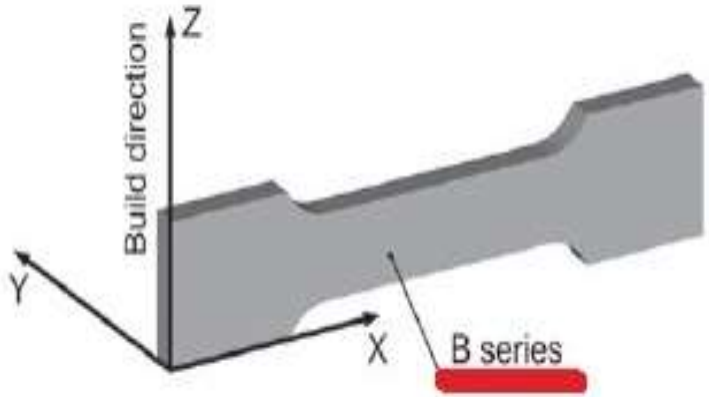


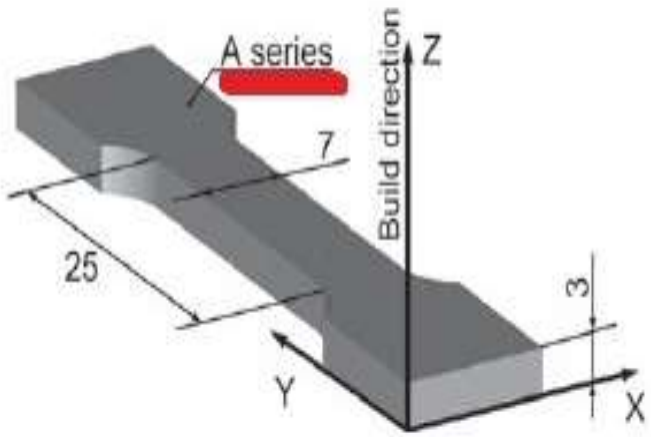





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# Influence of build-up orientation on ultimate tensile strength



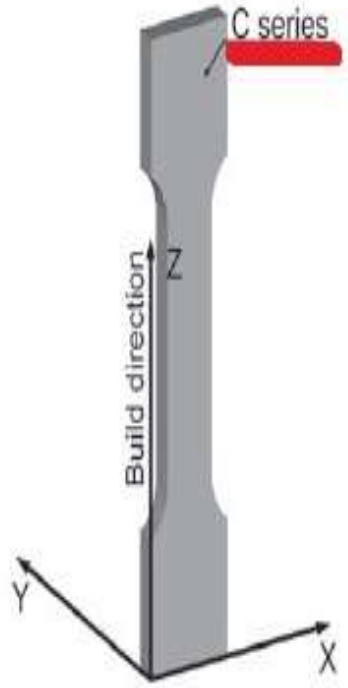



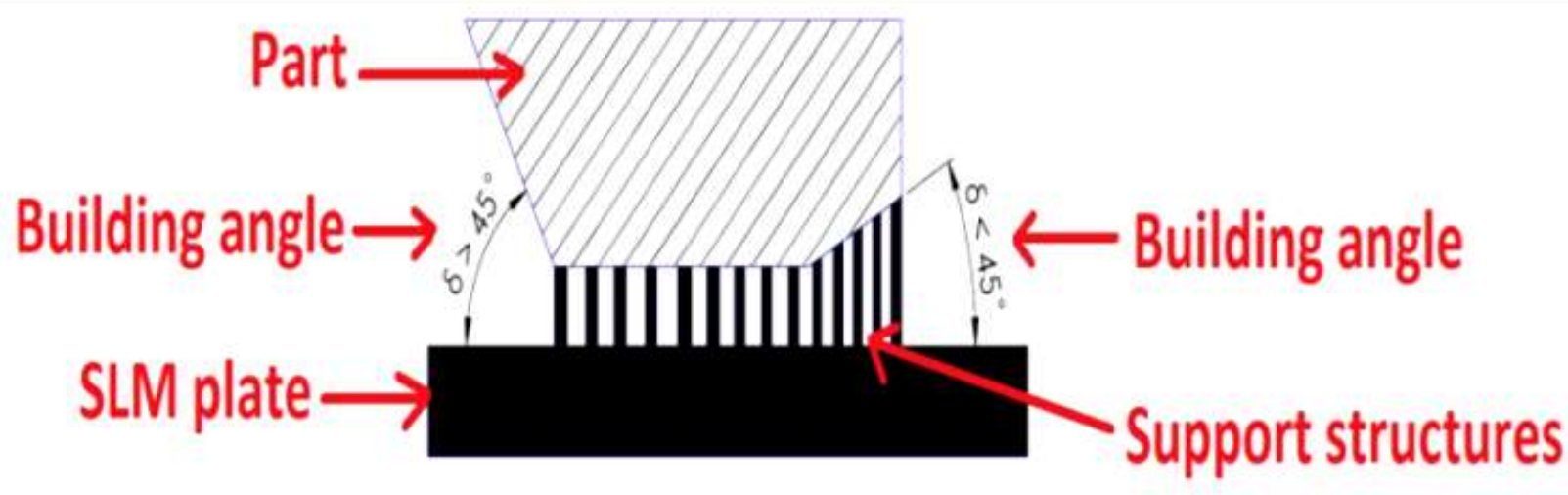

**Table - Results of mechanical tests on the as-built Ti6Al—7Nb alloy.**

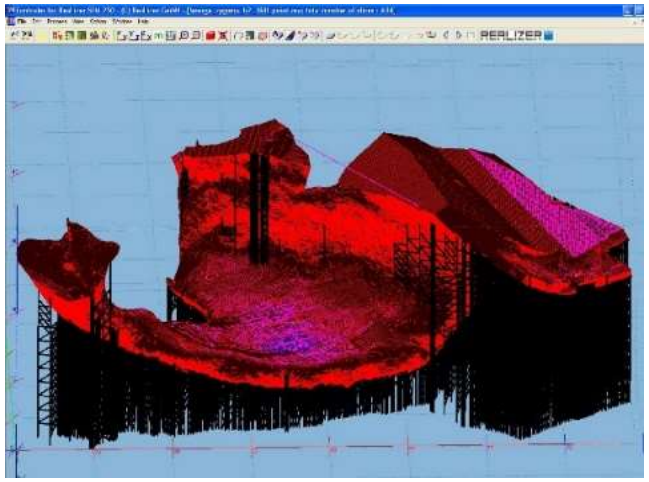
| Build direction | $\sigma_{0.2}$ MPa | $\sigma_t$ MPa | E GPa |
|---|---|---|---|
| A series | 1440±59 | 1515±60 | 88±2 |
| B series | 1360±30 | 1480±26 | 88±3 |
| C series | – | 776±40 | 121±14 |

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# Support structures needed to anchor surfaces



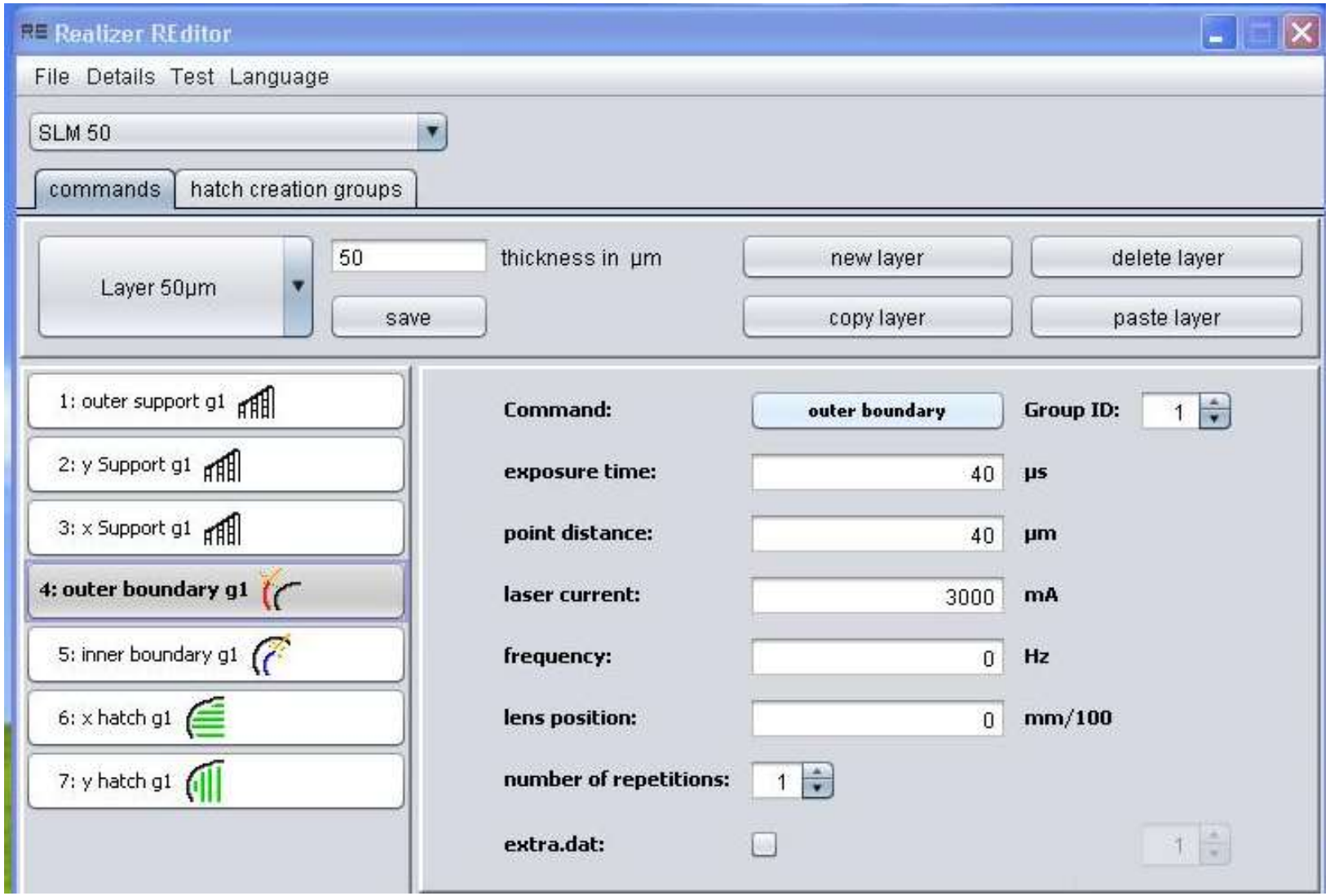





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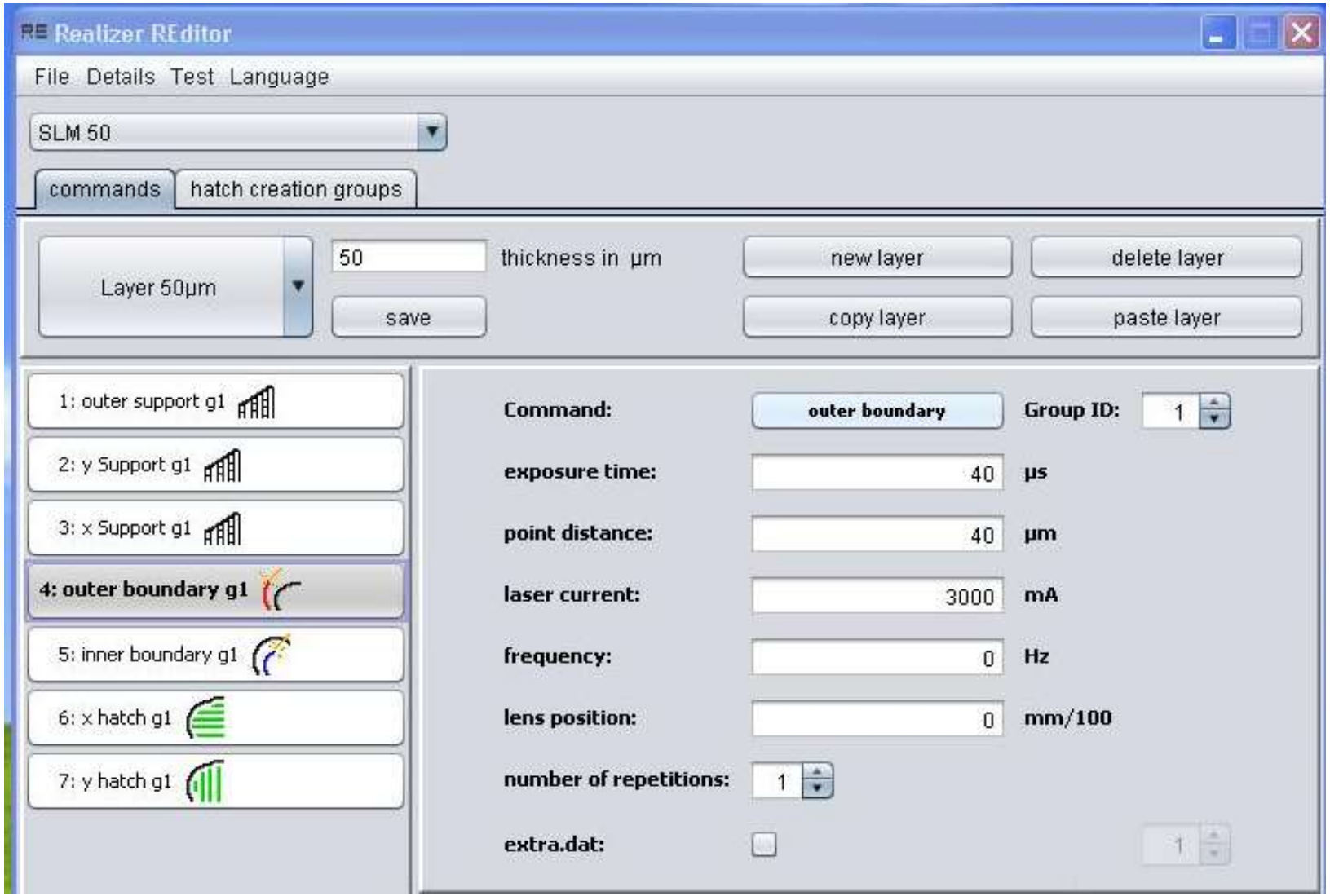
# SLM process parameters: Outer-boundary function




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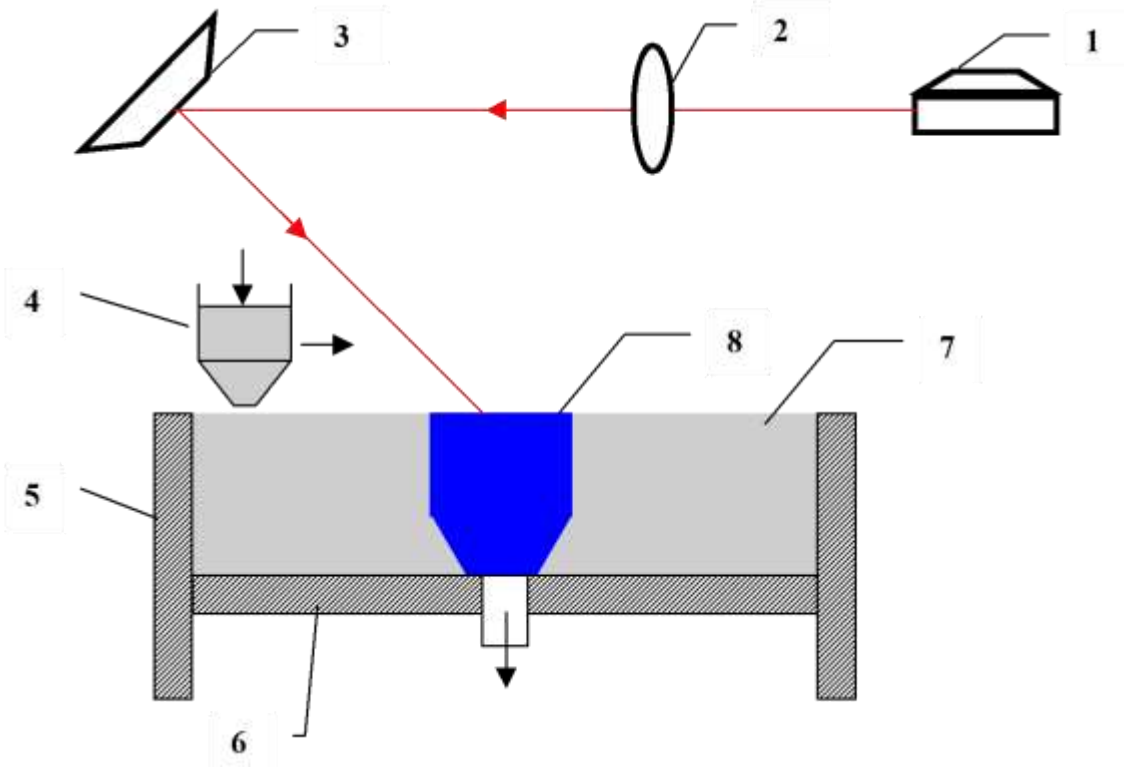
# SLM process parameters: Hatch function for scanning in X direction




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# Selective Laser Sintering (SLM) at the TU of Cluj






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# Comparison between SLM - SLS and CNC

- SLM technology is suitable to obtain fully dense metal parts
  - if the required accuracy is not high
  - The manufacturing costs are higher, as compare to similar CNC
- The are still future research needs to be done in order to improve the accuracy on the SLS/SLM
- Rapid Tooling by SLS could become a quick solution for tool makers, when dealing with rapid product development and with low volume production of the complex plastic parts

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# Comparison and limitations:

- Additive manufacturing isn't a solution to every part fabrication problem
  - After all, CNC technology is economical, widely understood and available, offers wide material selection and excellent accuracy
  - However, if the requirement involves producing a part or object of even moderately complex geometry, and doing so quickly – RP&T has the advantage
- The materials used in AM are limited
  - dependent on the method chosen ,
  - however, the range and properties available are growing quickly ,
  - plastics, ceramics, metals ranging from stainless steel to titanium, and wood-like paper are available

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# Selected references:


- A. Gebhardt, J. Kessler, L. Thurn, 3D Printing: Understanding Additive Manufacturing / Edition 2, Hanser, 2018
- N. Balc (Ed.): "Modern Technologies in Manufacturing", - MTeM 2015, Trans Tech Publications (Switzerland), Volume 808, SBN-13: 978-3-03835-653-0
  - Book available online (open access): https://www.scientific.net/AMM.808/book
- N. Balc (Ed.): "Advanced Manufacturing Technologies", MTeM 2017, MATEC Web Conf. (France), Volume 137 (2017), ISBN: 978-2-7598-9027-9
  - Book available online (open access): https://www.matec-conferences.org/articles/matecconf/abs/2017/51/contents/contents.html
- N. Balc, D. Leordean (Eds.): "Research and Applications in Manufacturing Engineering", MTeM 2019, MATEC Web Conf. (France), Volume 299, ISBN: 978-2-7598-9083-5
  - Book available online (open access): https://www.matec-conferences.org/articles/matecconf/abs/2019/48/contents/contents.html



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DIGIMAN
master programme for digital manufacturing

# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Innovative Manufacturing and Quality Engineering

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# Learning outcomes: On successful completion of this module a student should be able to:

- Obtain advanced knowledge and good understanding of the theory, principles and applicability of how to produce parts made from composite materials, using either classical methods or direct 3D printing of the complex parts made from composite materials;
- Discuss the efficiency and practical applications of the water jet machining process;
- Explain the competitive industrial applications of innovative manufacturing;
- Describe the main factors which have significant influence on the quality of the engineering products and how the quality engineering could be assured in Digital Manufacturing.

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# Course purpose:

- The purpose of the course is to ensure the accumulation of technical competences on how the composite material parts are made in low volume production, when the innovative water jet machining is efficient and how important the quality engineering is, in Digital Manufacturing!
- The course deals with aspects related to 3D printing of the master models, vacuum bag technology and direct 3D printing of the complex parts made from composite materials. The working principle for the AWJ technology is presented, together with applications and case studies. Both tactile and optical measurements methods are presented, followed by a reverse engineering case study,

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# Learning Aims:

- Evaluate the specific methods to produce parts made of composite materials, in low volume production;
- Investigate, when it's appropriate to use the classical moulding technology (compression moulding), or the direct 3D printing of the complex parts made from composite materials;
- Evaluate the possibilities of using the Water Jet Machining technology;
- Contribute with ideas, solutions, and efforts in a group work or project
- Design the appropriate method to assure quality engineering in Digital Manufacturing
- Working in multidisciplinary team of people with variety of skills, knowledge, and backgrounds. Actively participating and collaborating with team members in order to get better ideas and solutions.

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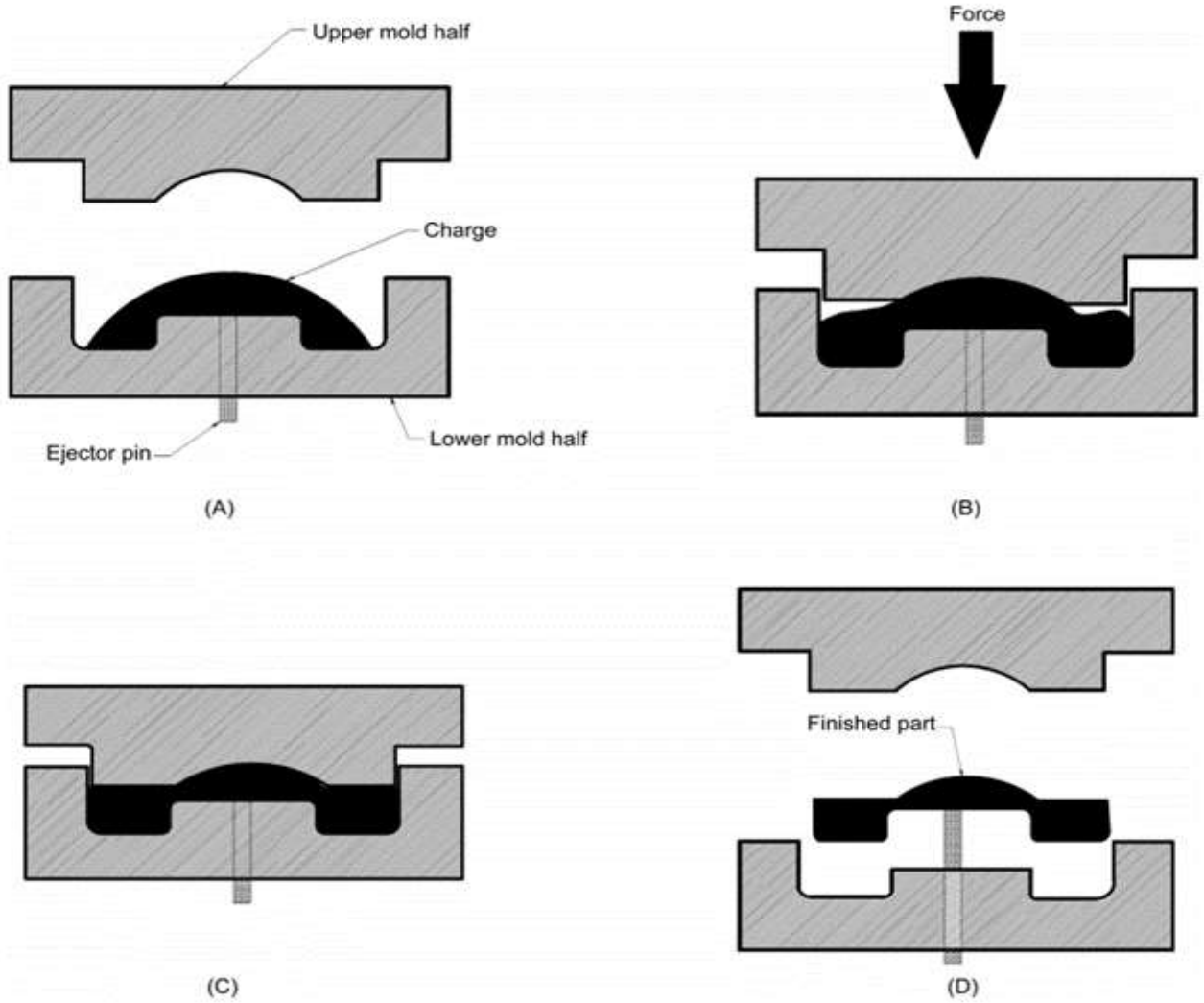
# Content of the course:

- Innovative manufacturing to produce parts from composite materials
  - Classical melding technology
  - 3D printing of the master models
  - Mould building using metal spray technology
  - Vacuum bag technology
  - Direct 3D printing of the complex parts made from composite materials
  - Software for 3D printing
- Water Jet Machining
  - Working principle for the AWJ technology
  - Types of equipment and manufactures
  - Technological parameters
  - Case study
- Quality Engineering in Digital Manufacturing
  - Inspection in quality control
  - Tactile measurement
  - Optical measurement
  - Reverse engineering a part using an optical scanner

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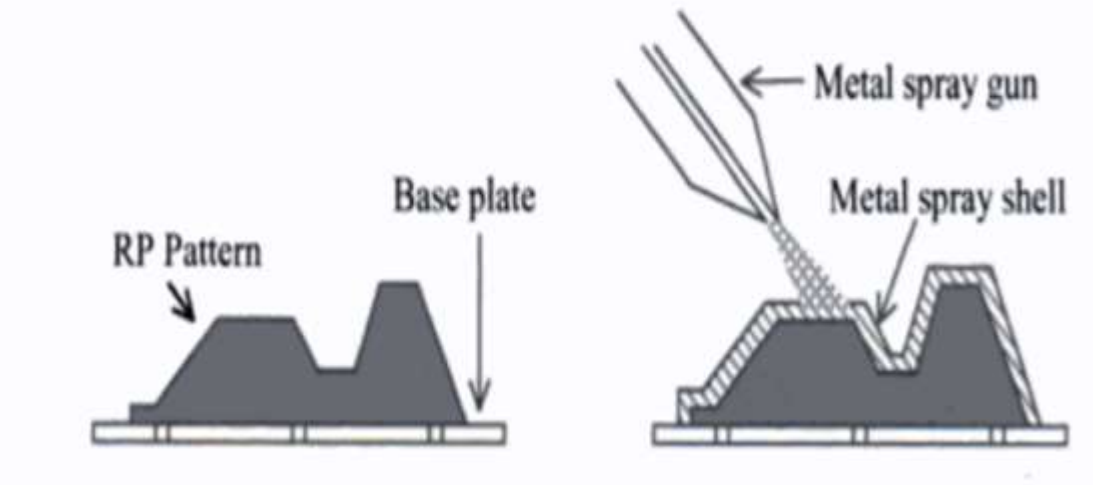
# Classical moulding technology

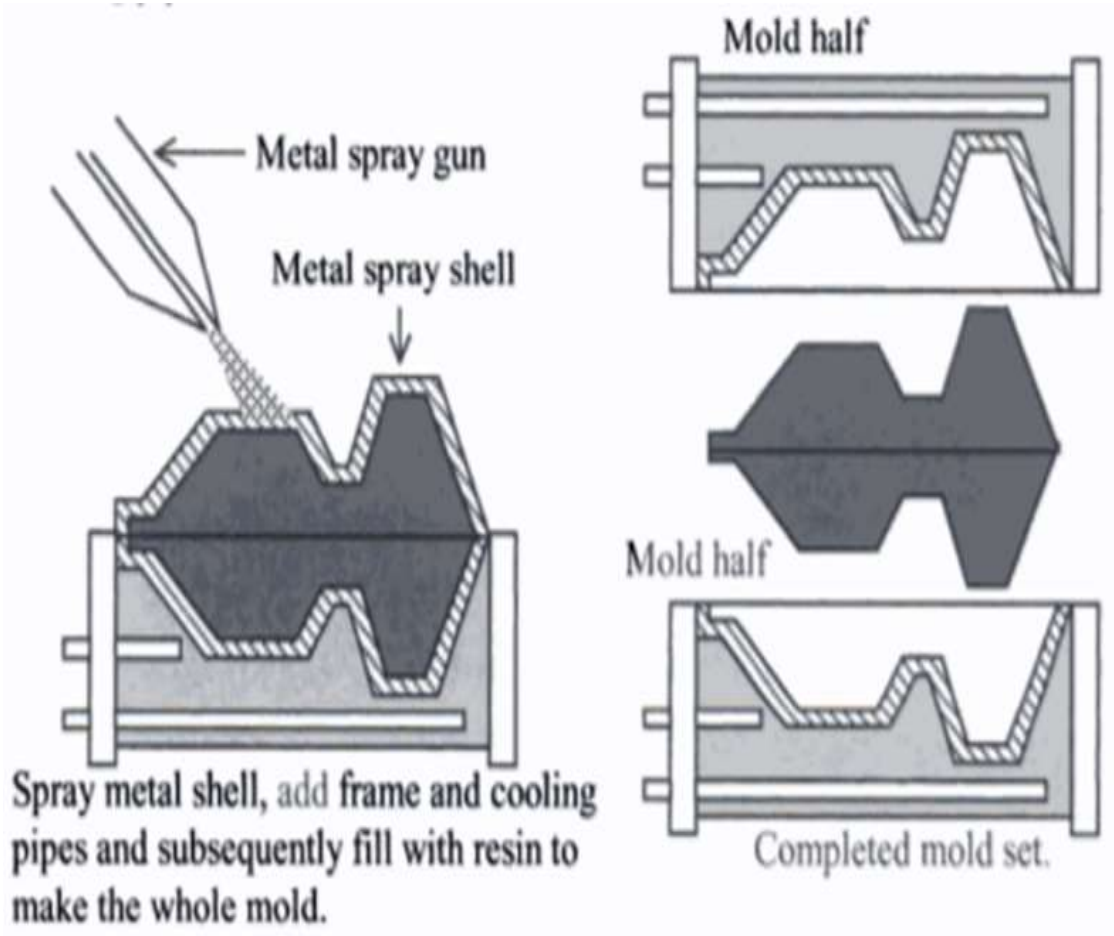



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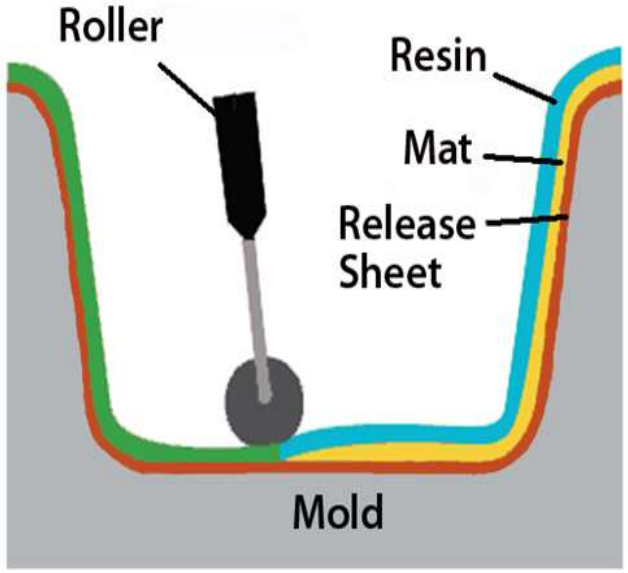
# Mold building using metal spray technology



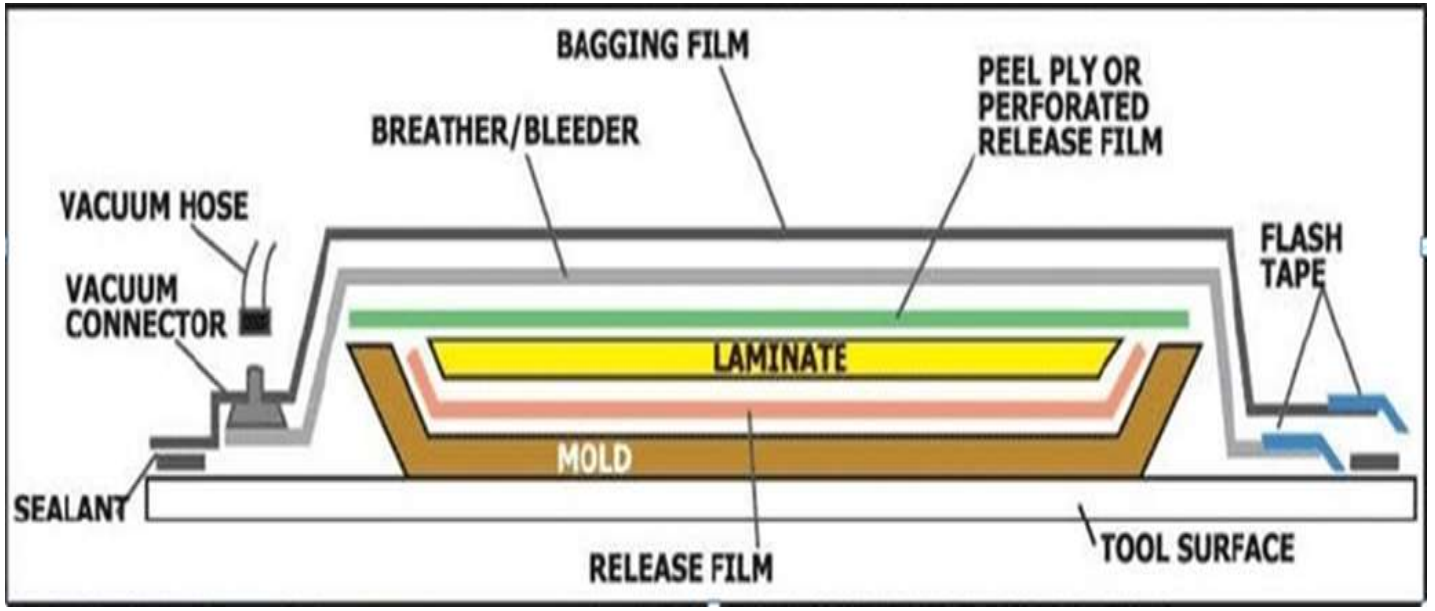




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# Vacuum bag technology




Manual lay-up of composite material




Vacuum bagging lay-up

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# Direct 3D printing of the complex parts made from composite materials



Mark Two 3D printer

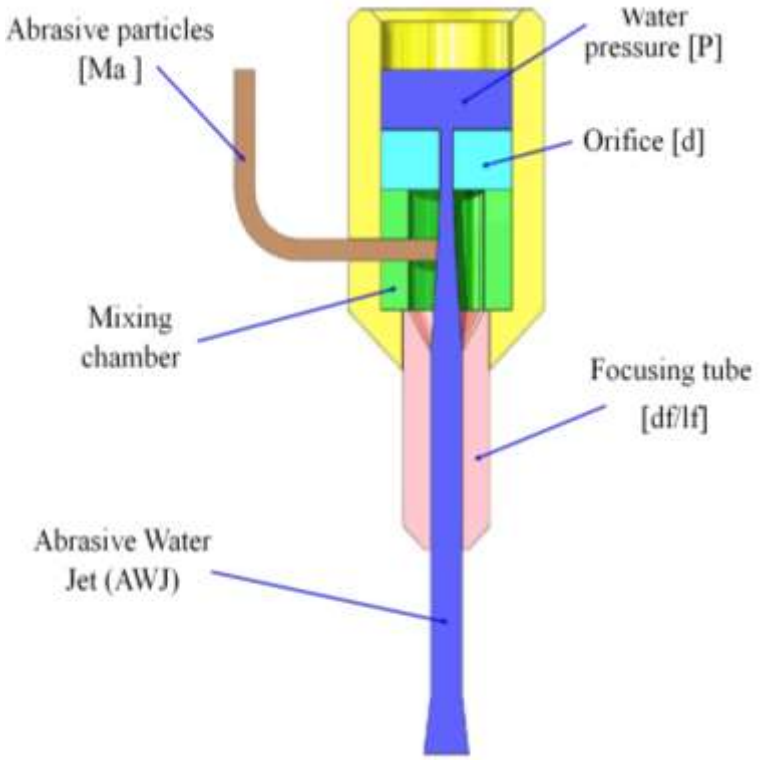


Composite 3D printed parts for automotive

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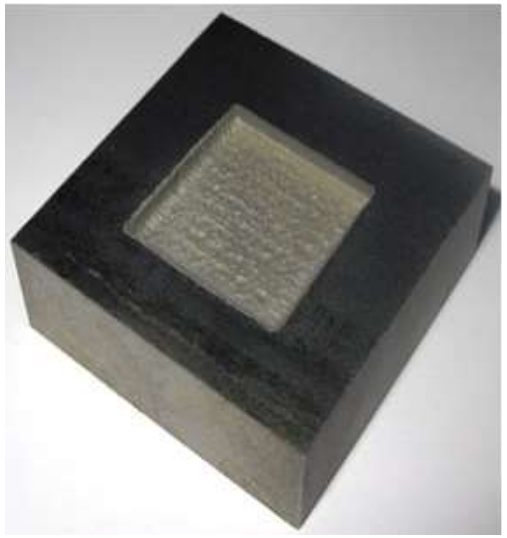
# WATER JET MACHINING




Abrasive Water Jet (AWJ) process



CFRP part cut with AWJ

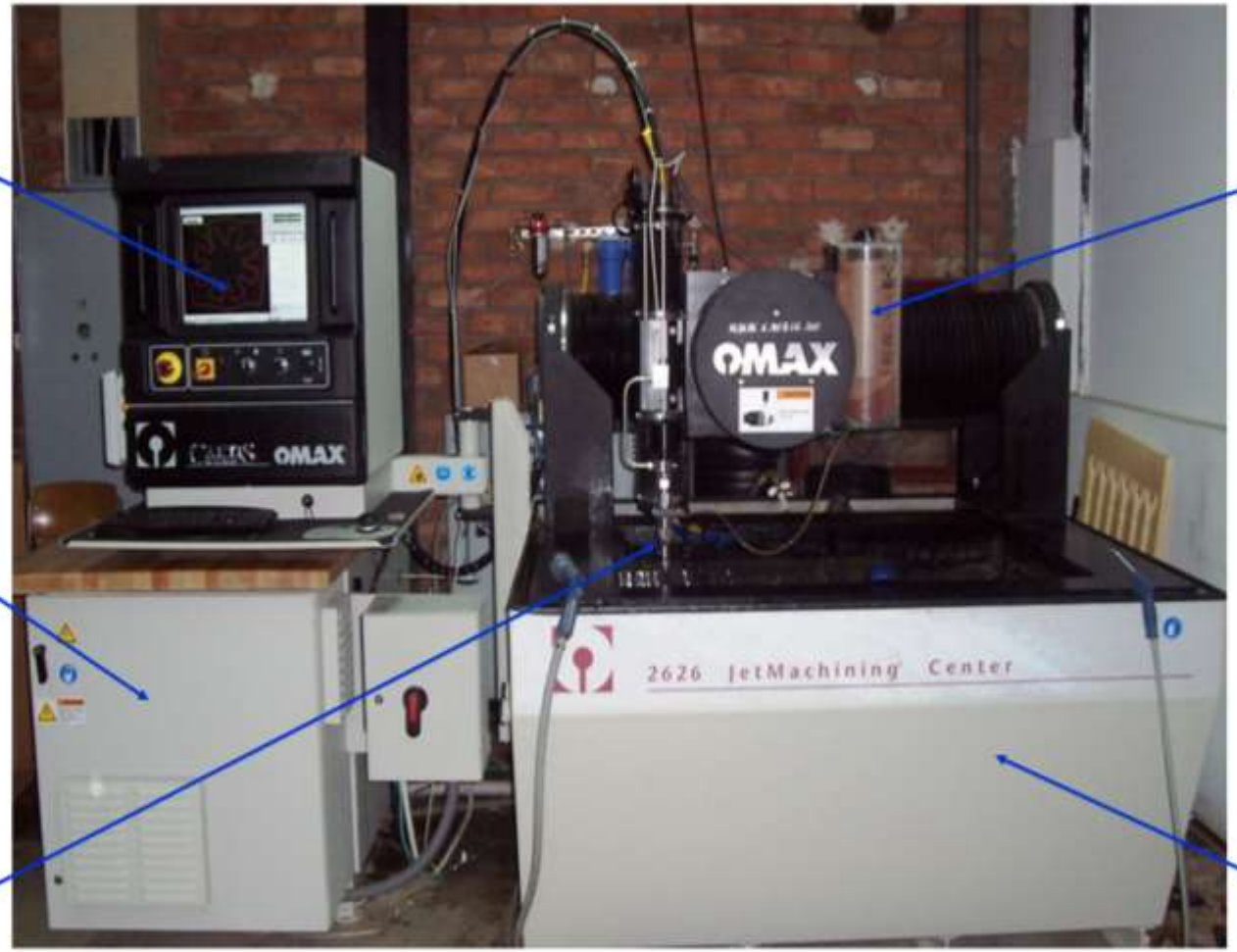


Steel part - cutting and milling

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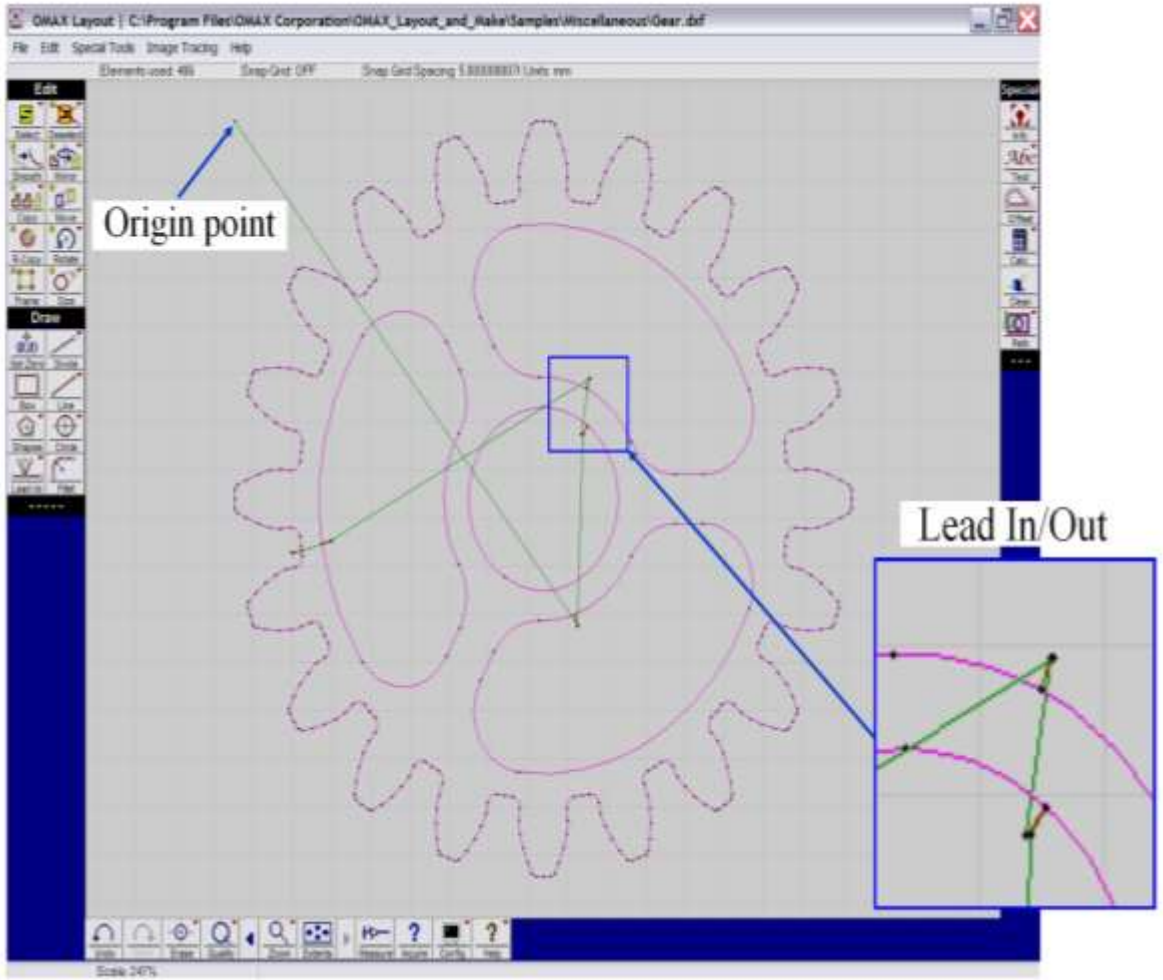
# The AWJ OMAX 2626 equipment

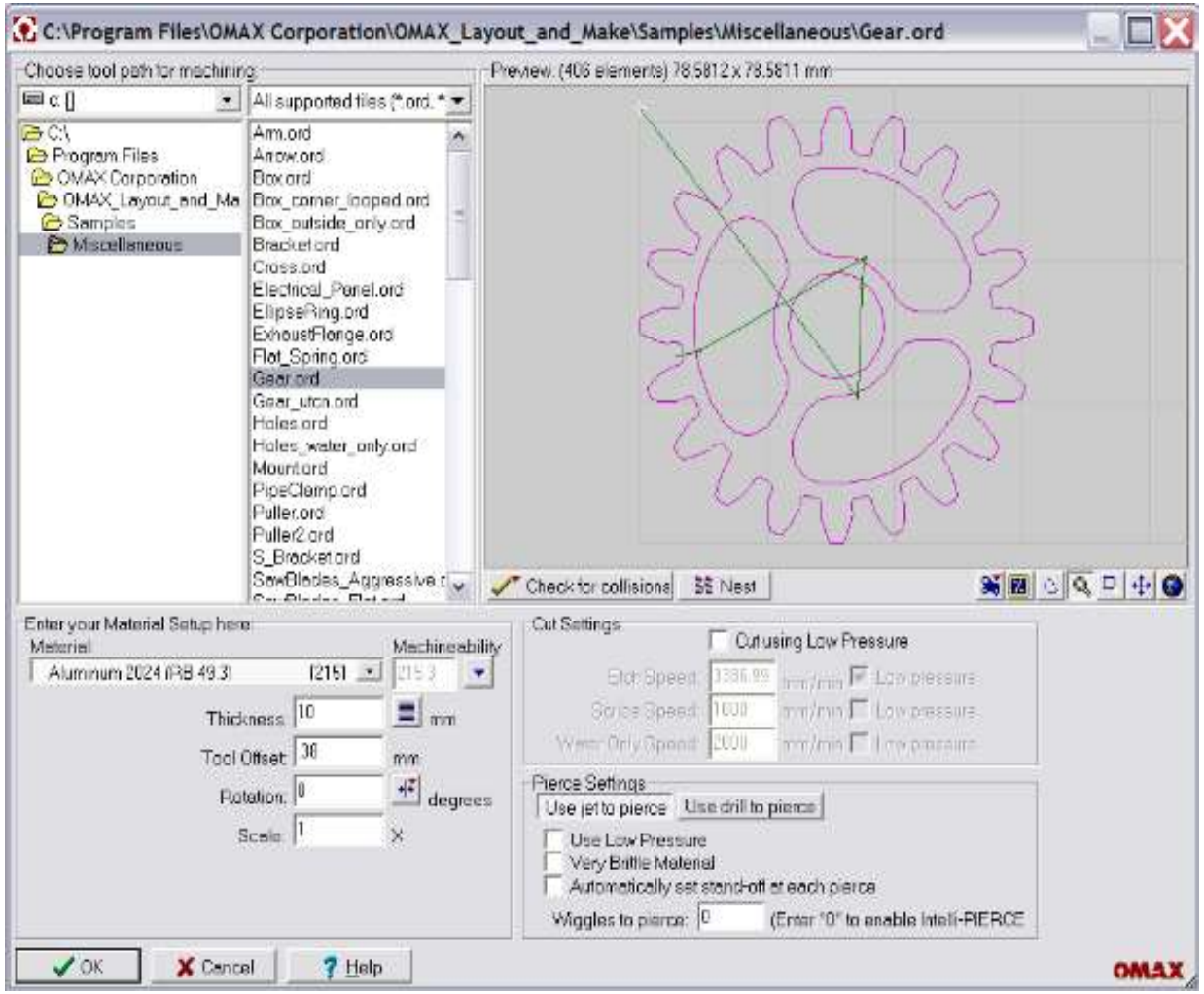



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# CAD/CAM software used in AWJ process

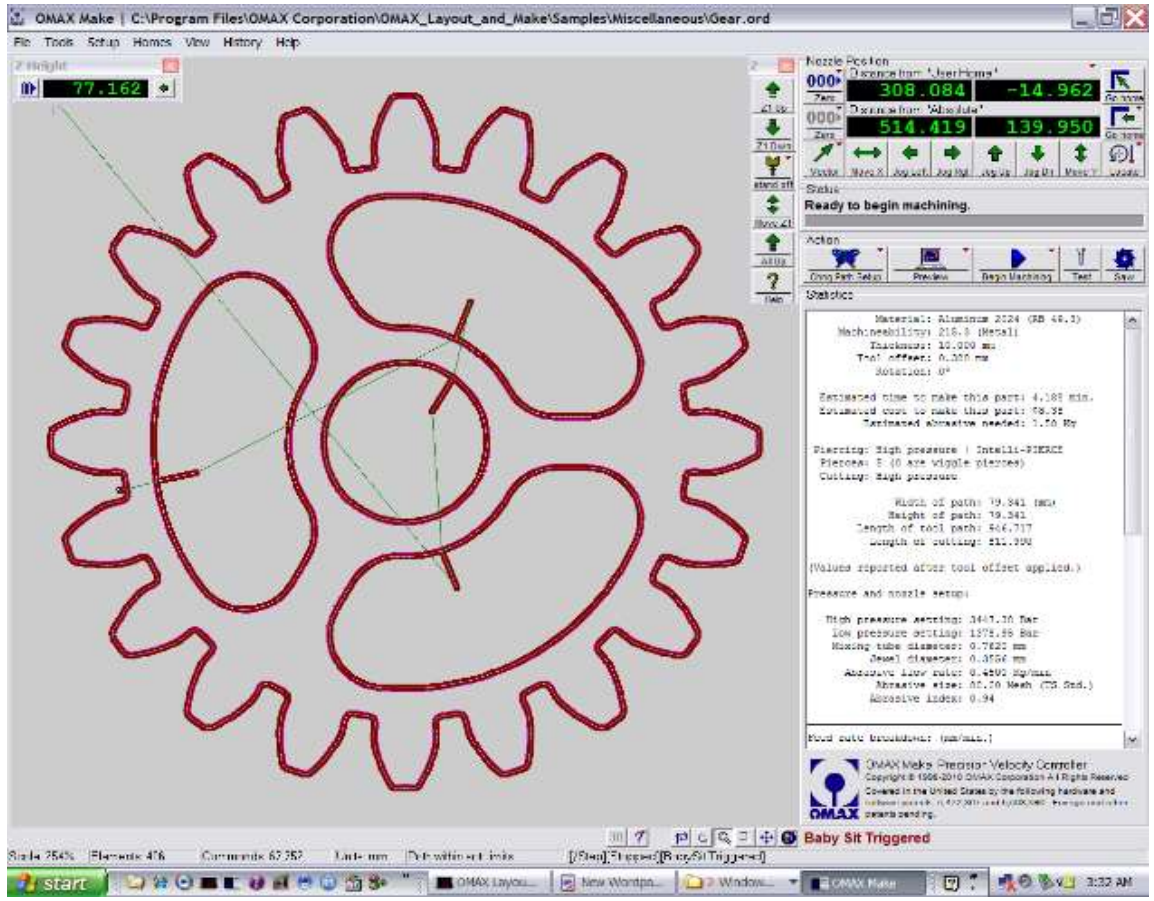


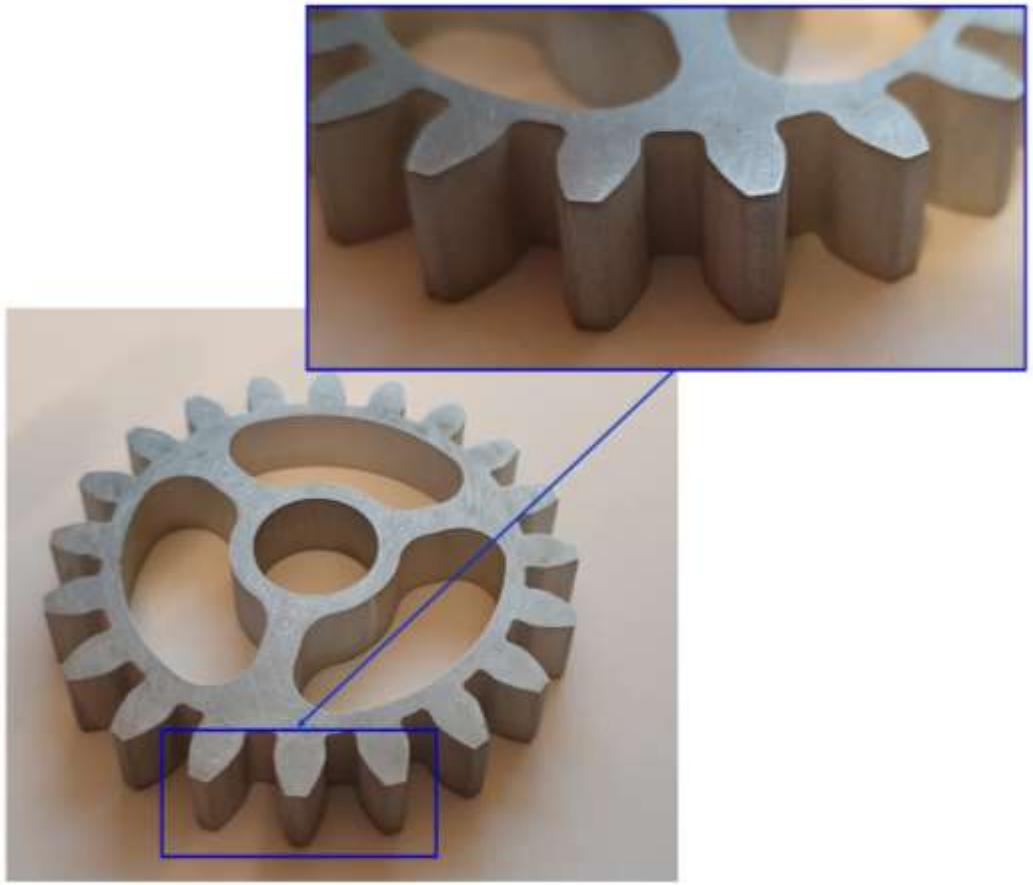




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# Case study made at TUCN

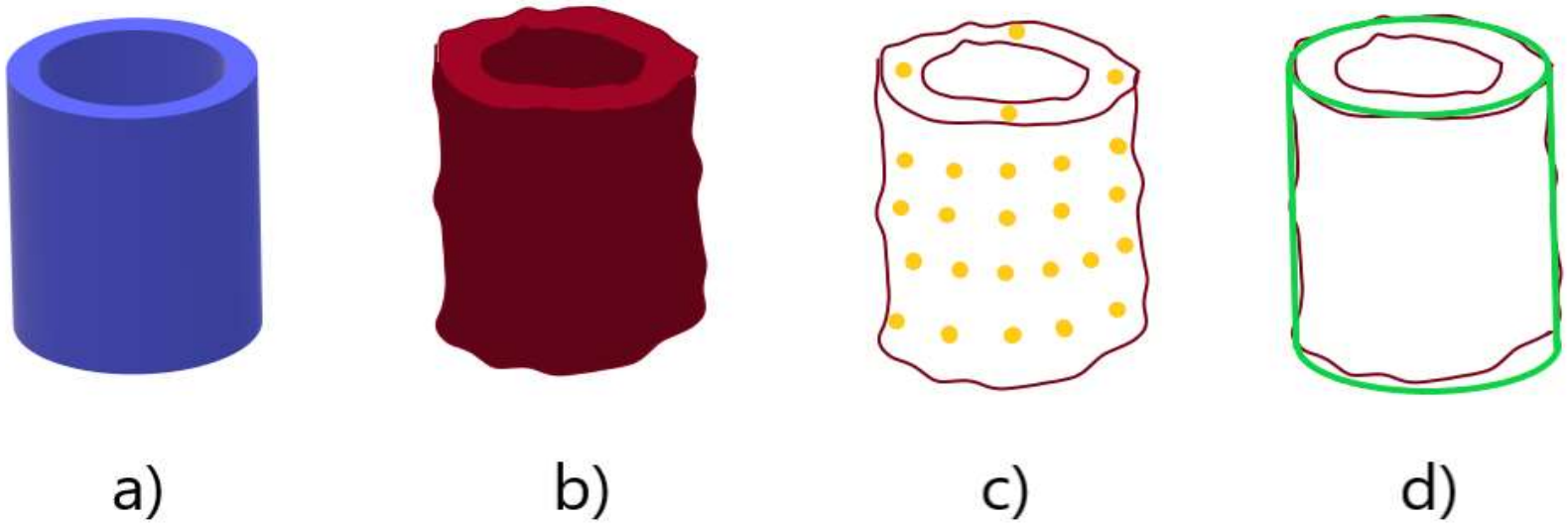


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# Quality Engineering in Digital Manufacturing

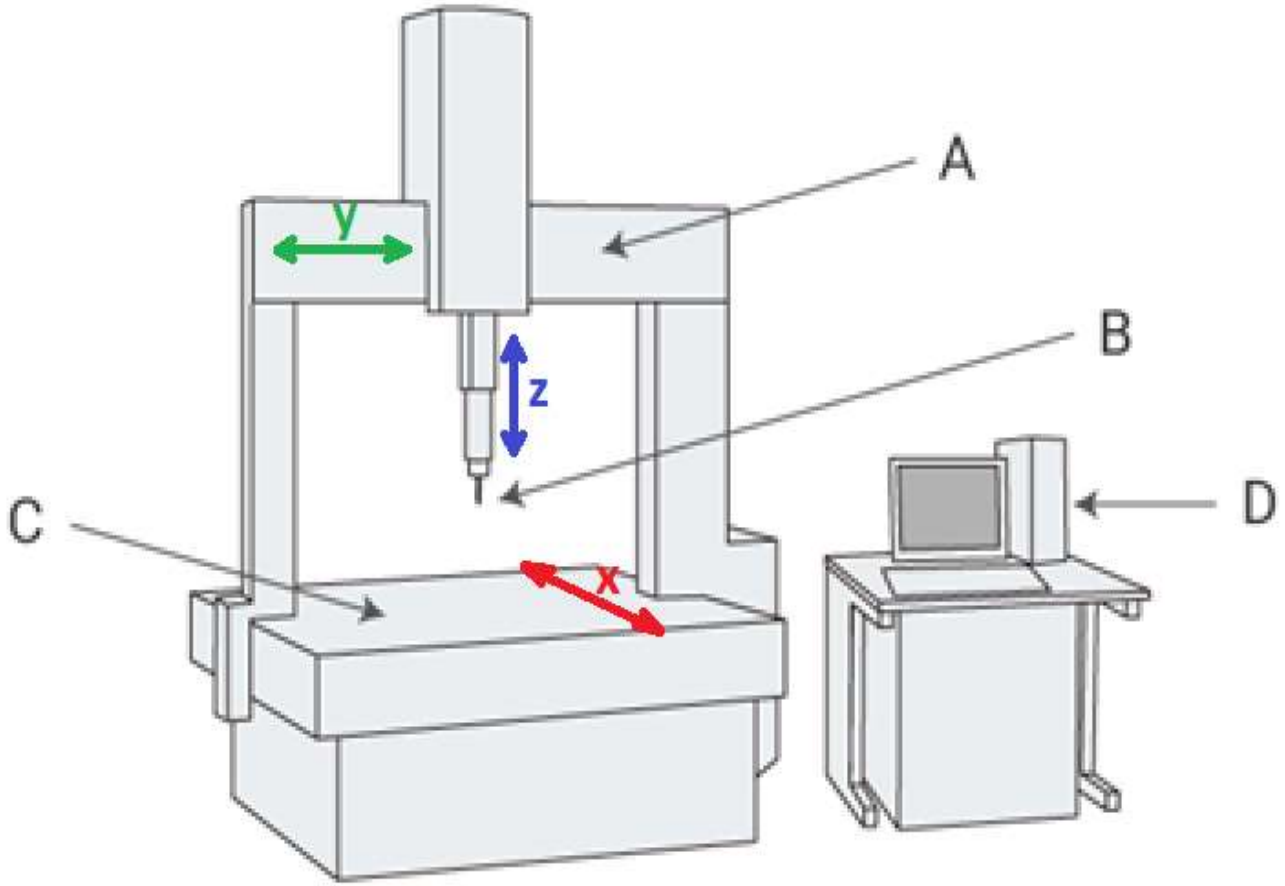



The measurement process: a) the ideal (nominal) surface, b) the real surface, c) the point cloud d) the associated surface

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# Tactile measurement

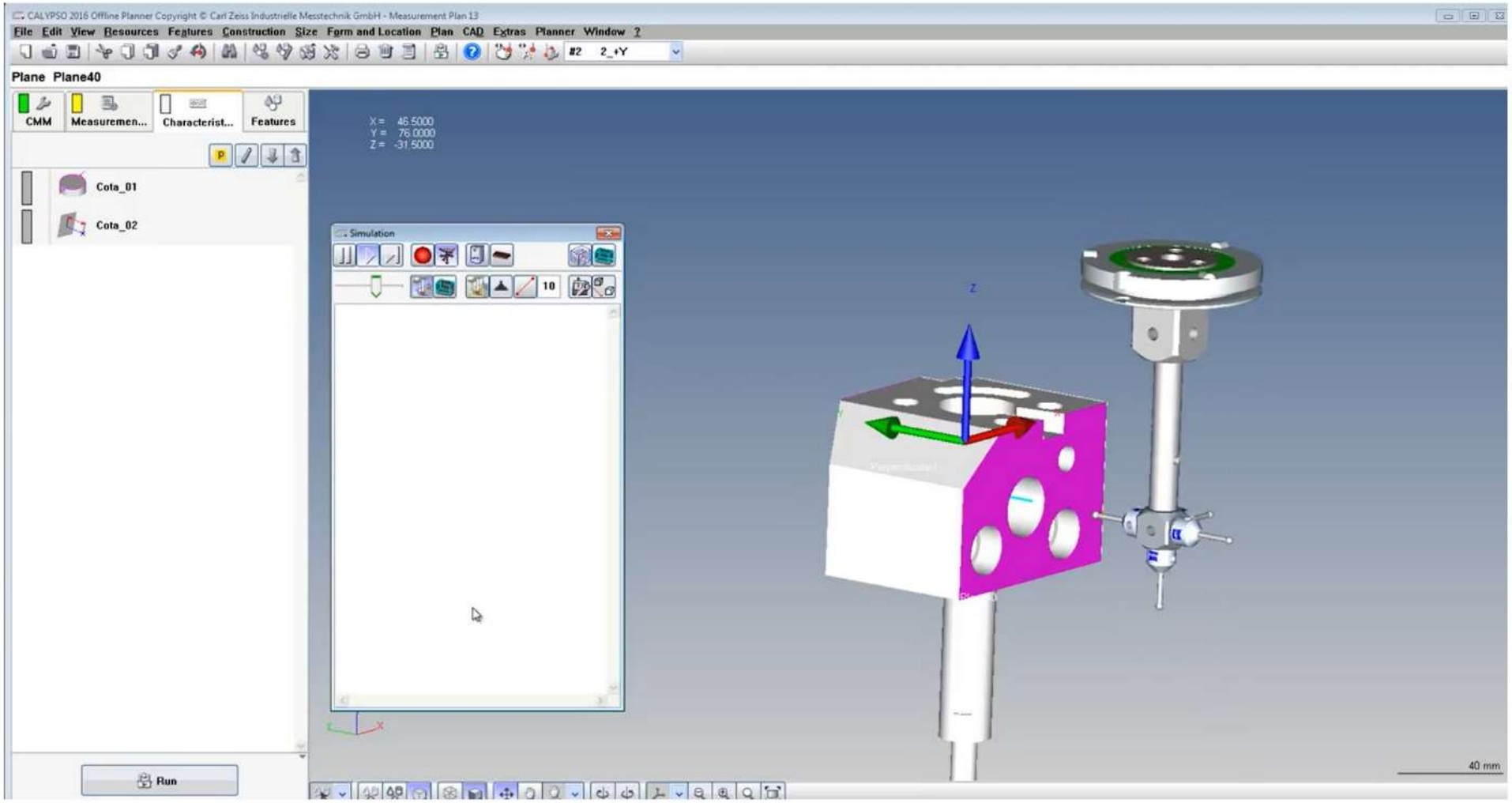



The main components of a tactile CMM: A- mobile bridge, B – touch trigger probe, C – machine table (stage); D – CMM control and processing unit (Keyence, 2021)

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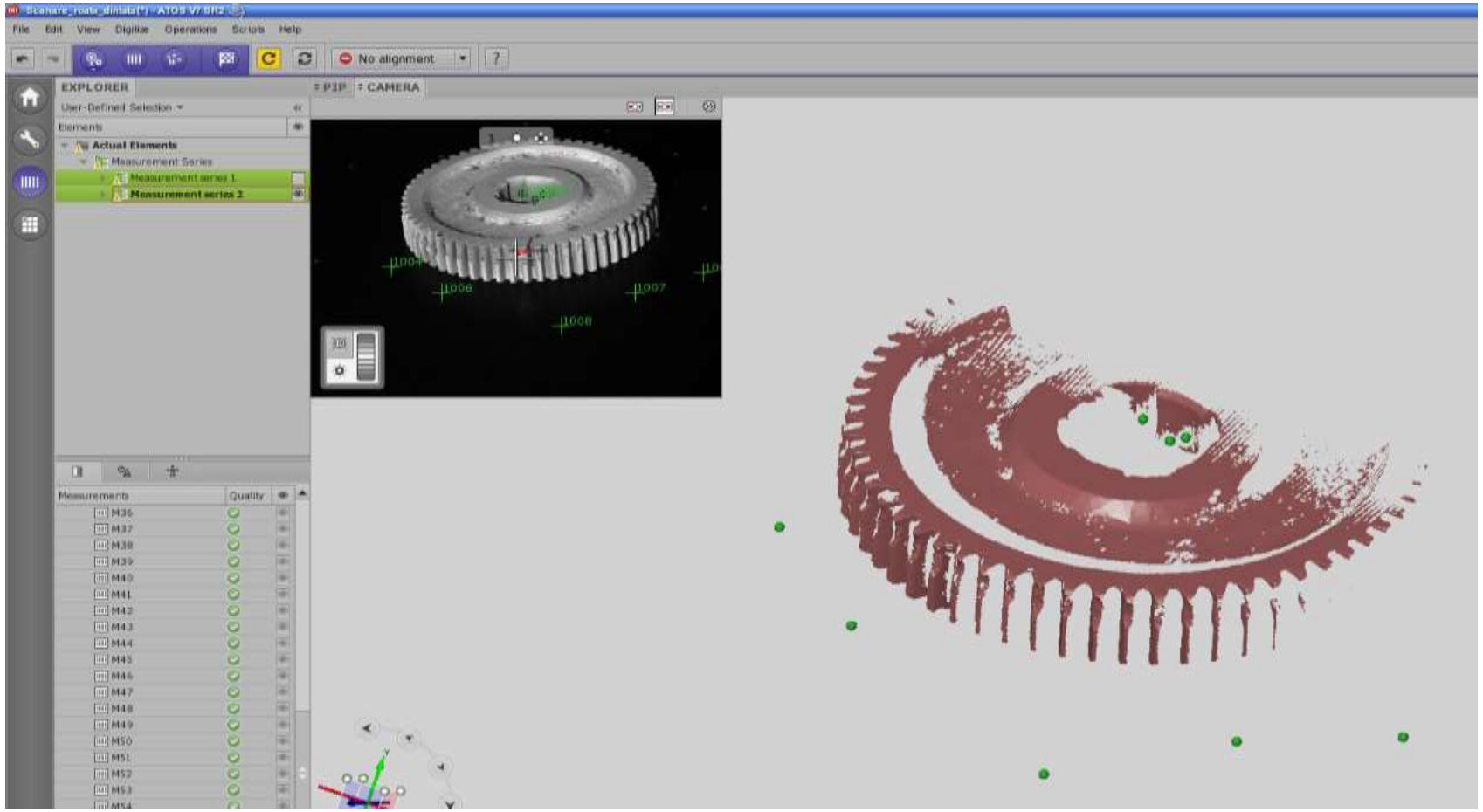
# The interface of the Zeiss Calypso software




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# Optical measurement

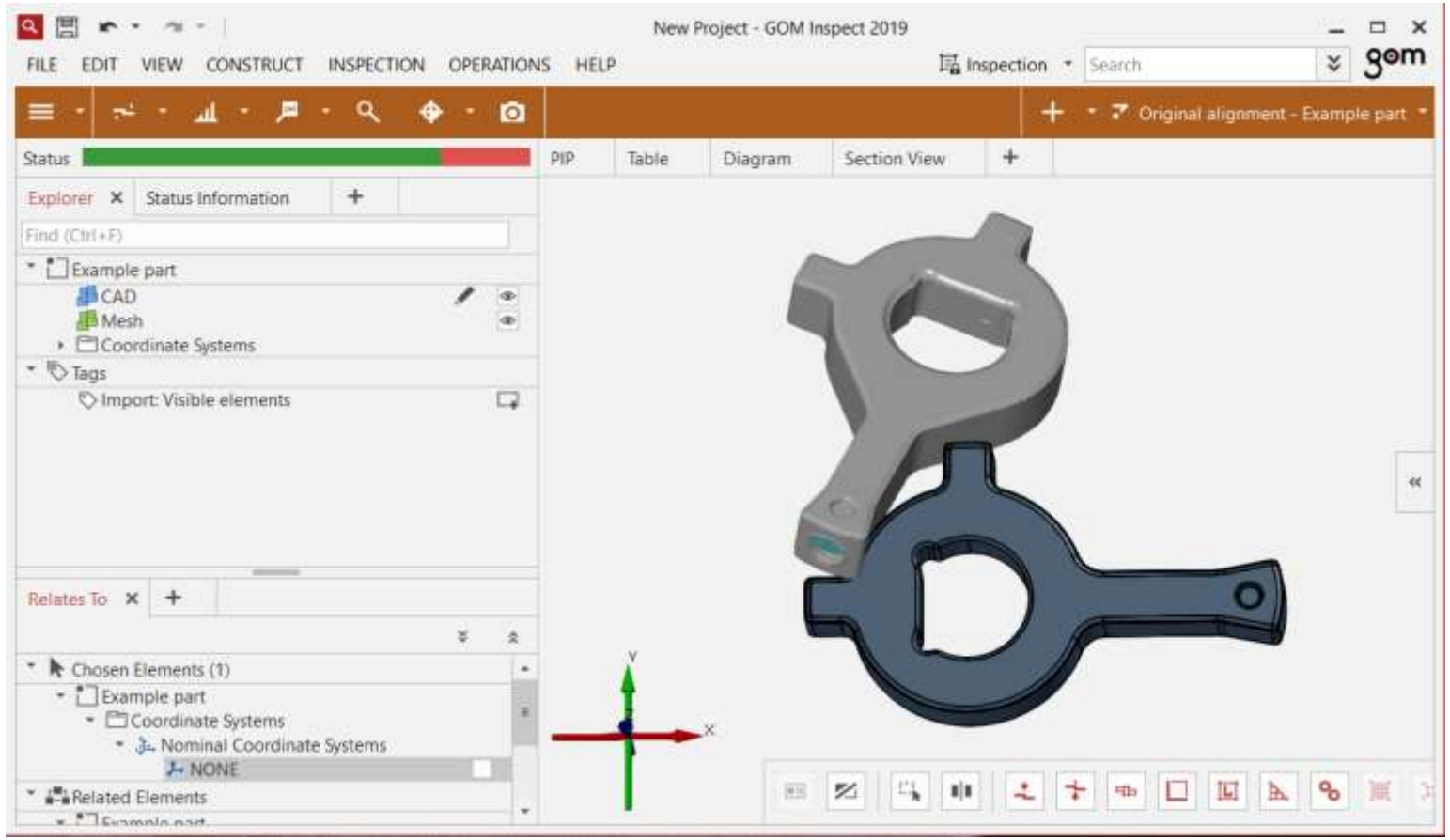



The scan of the part: top left the camera view is visible with the coded markers in green; in the main window the point cloud is visible (in red) and the identified markers (green).

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# The measuring process using GOM Inspect

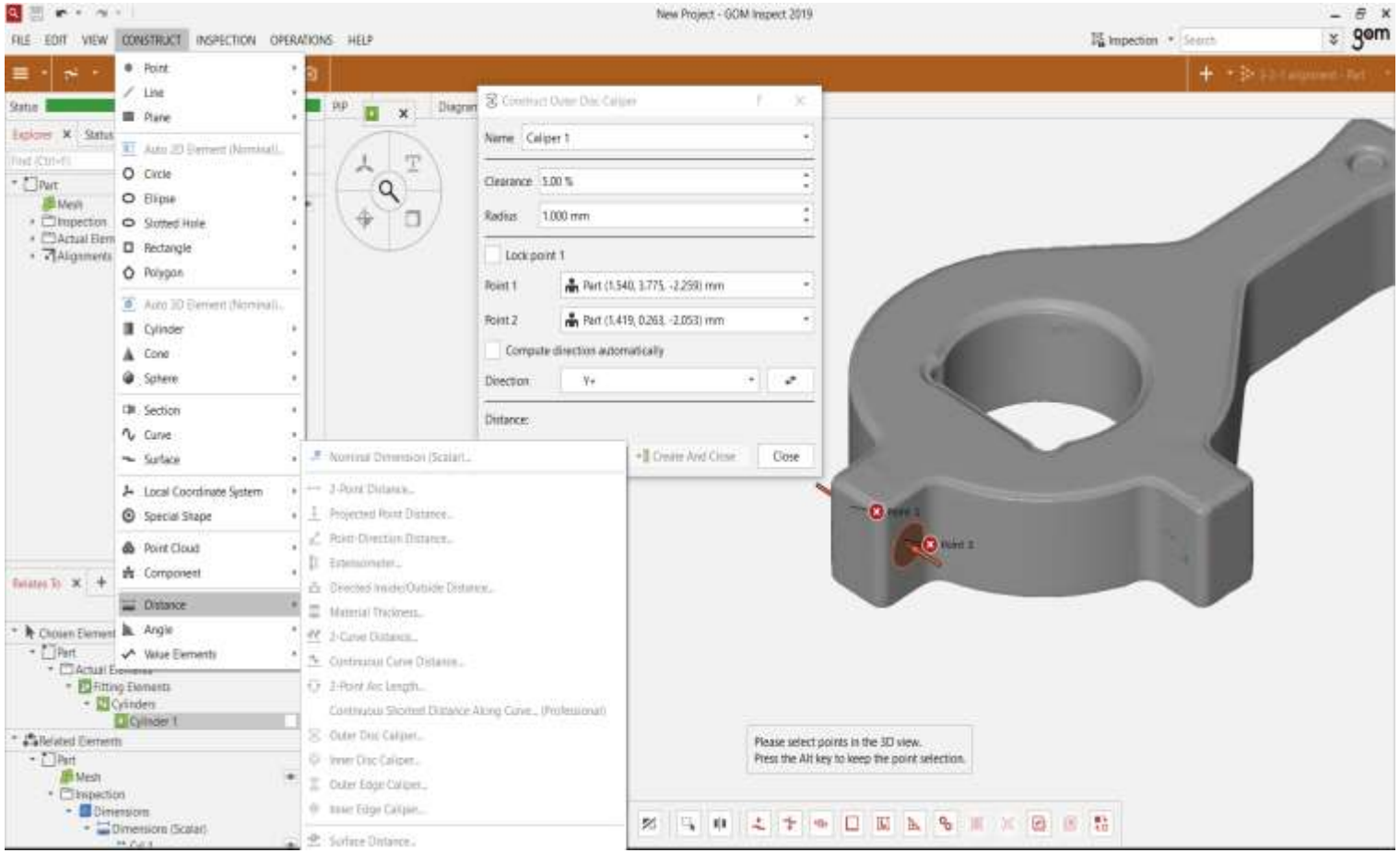



Importing the CAD and Mesh

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# Reverse engineering of a part, using an optical scanner




Measuring a distance with an outer disc caliper

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# Selected references:


- Sina Ebnesajjad, APPLIED PLASTICS ENGINEERING HANDBOOK, Chadds Ford, PA, USA,
- Y. Natarajan, P. K. Murugesan, M. Mohan, and S. A. Liyakath Ali Khan, 'Abrasive Water Jet Machining process: A state of art of review', Journal of Manufacturing Processes, vol. 49, pp. 271–322, Jan. 2020, doi: 10.1016/j.jmapro.2019.11.030.
- I. A. Popan, N. Balc, and A. I. Popan, 'Avoiding carbon fibre reinforced polymer delamination during abrasive water jet piercing: a new piercing method', Int J Adv Manuf Technol, Nov. 2021, doi: 10.1007/s00170-021-08294-7
- Keyence. (2021). Coordinate Measuring Machines | Measurement System Types and Characteristics | Measurement Fundamentals | KEYENCE America. https://www.keyence.com/ss/products/measure-sys/measurement-selection/type/3d.jsp



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DIGIMAN
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## Virtual Reality

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26.11.2021

HEILBRONN UNIVERSITY
OF APPLIED SCIENCES



# › VIRTUAL REALITY

VR AND AR | LECTURER / FACULTY / COURSE | WINTER/SUMMER SEMESTER 2017/19

# › LECTURE 1

**Introduction, Definition of Terms**
**History of VR**
**Future of VR**

# VR

- The Ultimate Display
- "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal".
- Ivan Sutherland, 1965.

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# VR

Virtual reality is…

- "a computer technology that replicates an environment, real or imagined, and simulates a user's physical presence and environment to allow for user interaction." (Wikipedia)
- "electronic simulations of environments experienced via head mounted eye goggles and wired clothing enabling the end user to interact in realistic three-dimensional situations." (Coates, 1992)
- "an alternate world filled with computer-generated images that respond to human movements." (Greenbaum, 1992)
- "an interactive, immersive experience generated by a computer." (Pimental, 1995)

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# VR

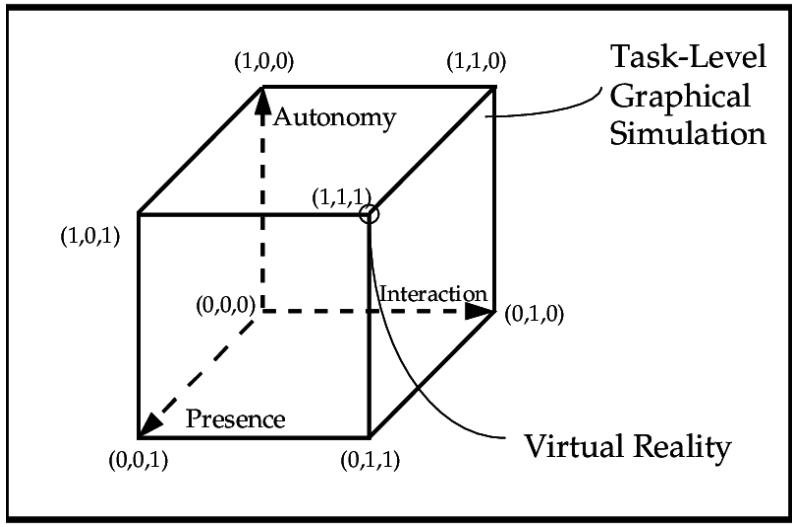
- Key Characteristics
  - 3D stereoscopic display
  - Wide field of view display
  - Low latency head tracking

  - When these three things are combined, they provide a compelling immersive experience

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# VR

- David Zeltzer's AIP Cube3D
  - Autonomy – User can react to events and stimuli.
  - Interaction – User can interact with objects and environment.
  - Presence – User feels immersed through sensory input and output channels




https://www.researchgate.net/figure/The-AIP-Cube-from-Zelt92_fig2_242374257

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# VR

- VR Experience
  - Video: "This is so real…"



https://www.youtube.com/watch?v=pAC5SeNH8jw

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# HISTORY OF VR

- 30 000 BC:
  - The history of VR is rooted in human's first attempts to reproduce the world around them



https://es.wikipedia.org/wiki/Archivo:Magura_-_drawings.jpg

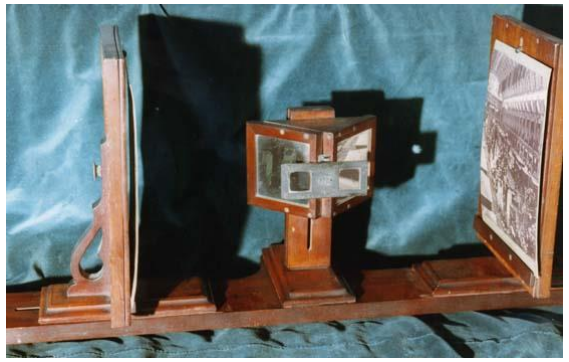
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# HISTORY OF VR

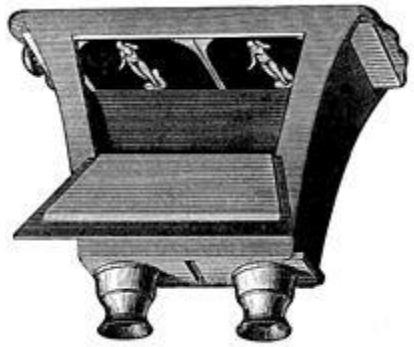
- Capturing Reality:
  - 1790s: Panoramas, Immersive paintings
  - 1832: Wheatstone stereoscope
  - 1860: Brewster stereoscope
  - Movies



https://www.wikiwand.com/en/Panoramic_painting



https://allsourcesarebroken.net/books/remediation/page/37



https://en.wikipedia.org/wiki/David_Brewster

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# HISTORY OF VR

- First interactive experiences:
  - 1929 Link Trainer Flight simulator
  - Full six degree of freedom rotation
  - Force feedback and motion control
  - Simulated instruments
  - Simulates common flight conditions
  - Over 500,000 pilots trained



https://www.youtube.com/watch?v=MEKkVg9NqGM

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# HISTORY OF VR

- First interactive experiences:
  - 1955 Sensorama
    - Experience Theater
    - Multi-sensory
      - Visuals
      - Sound
      - Wind
      - Vibration
      - Smell

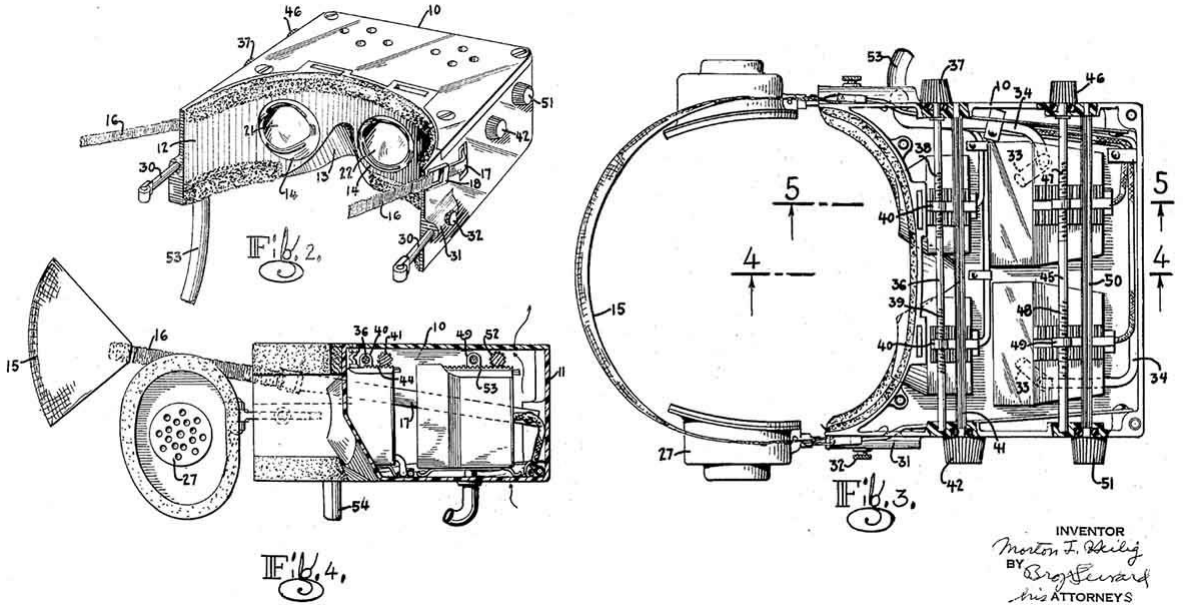


https://www.youtube.com/watch?v=vSINEBZNCks

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# HISTORY OF VR

- Early HMD Patents:

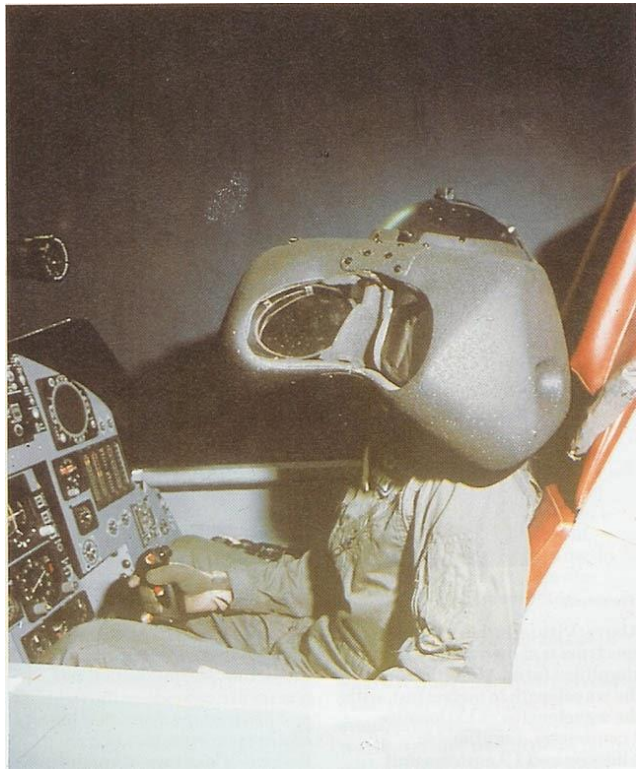



https://interestingengineering.com/the-history-and-science-of-virtual-reality-headsets

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# HISTORY OF VR

- 1965 – 80s Super Cockpit:
  - US Airforce Research only program at Wright Patterson Air Force Base
  - Multisensory
    - Visual, auditory, tactile
    - Head, eye, speech, and hand input



https://lookingglass.services/wp-content/uploads/2015/08/supercockpit2.jpg

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# HISTORY OF VR

- 1979 LEEP Optics (Large Expanse Extra Perspective):
  - Developed by Eric Howlett
  - Lens design for extremely wide field of view
    - High resolution in center, lower resolution in periphery
    - 90o direct FOV, 140o corneal FOV
  - Used as basis for most VR HMDs



https://veer.tv/blog/a-brief-history-of-vr/

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# HISTORY OF VR

- 1981 NASA VIEW (Virtual Interface Environment Workstation):
  - LEEP-based HMD
  - 3D audio
  - Data Glove gesture input
  - Simple graphics




https://vrtifacts.com/so-serious-1980s-virtual-reality-from-nasa/

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# HISTORY OF VR

- Rise of Commercial VR Companies:
  - 1985 - 97 Virtuality VR Arcades
  - 1993 -1997 Virtual I-O
    - Inexpensive gamer HMDs
  - 1995 Dactyl Nightmare
    - Video




https://vrtifacts.com/1995-virtual-io-i-glasses/




https://www.youtube.com/watch?v=jowtEbpVJrc

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# HISTORY OF VR

- Computerworld, April 2007:
  - VR Voted 7th on list of 21 biggest technology flops




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# HISTORY OF VR

- 2011 VR Second Wave:
  - Oculus Rift
    - 2012 - $2.4 million kickstarter
    - 2014 - $2B acquisition FaceBook
    - 350 USD, 110-degree FOV
    - Kickstarter video →



https://www.youtube.com/watch?v=DhcOMOWRMnA

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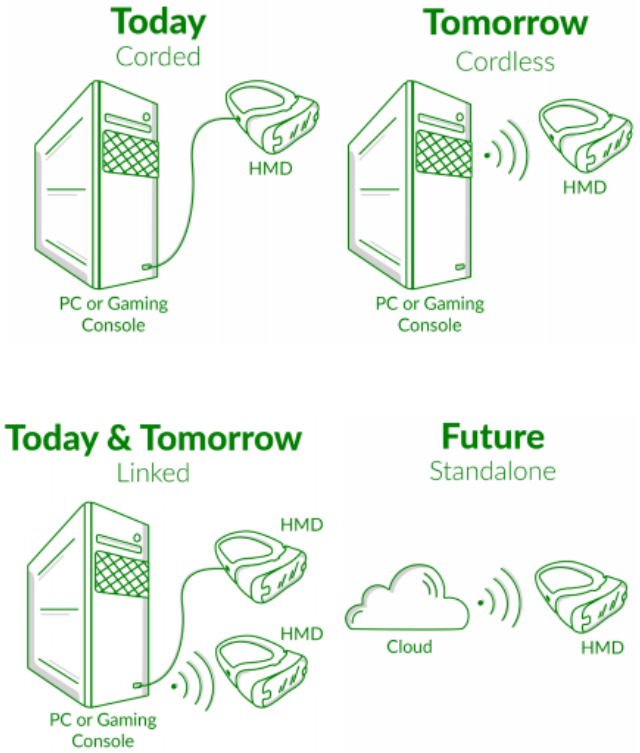
# HISTORY OF VR

- 2014 Google Cardboard
  - Early Mobile VR viewer
  - > 5 Million shipped
- 2016 Rise of Consumer HMDs
  - Oculus Rift
  - Sony Morpheus
  - HTC Vive

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# FUTURE OF VR

- VR:
  - Many big tech firms are developing standalone headsets which will be able to show HD images.
  - Also, they are working on VR headsets in 8K with more powerful processors. There are some possibilities in upcoming years that they could merge AI.
  - The latest 5G standard can be useful in the advancement of VR. This standard will allow more devices and user communities to be connected.




Source: Greenlight Insights

https://www.ge.com/news/sites/default/files/Reports/uploads/2017/02/03100048/GreenlightUntetheredIllustration.png

# FUTURE OF VR

- VR: Interaction through handheld devices
  - In the future, VR technologies will be able to make smartphones smarter and other smart devices like VR goggles, VR devices will be popular in the market.
  - Handheld devices will be the main way users interact with VR, as controllers give users a tactile feel and experience rather than using motion sensing devices.

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# FUTURE OF VR

- VR: Headsets will look like sunglasses
  - VR headsets will become sleeker as users see headsets downsize to a similar size style to sunglasses.
  - Example: Panasonic VR Glasses



https://www.tweaktown.com/news/77301/panasonics-vr-glasses-look-like-steampunk-goggles-from-the-future/index.html

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# FUTURE OF VR

- VR: Resolve phobias or fears
  - In medicine, VR will help resolve phobias or fears by transporting the patient into a comfortable situation
  - Example of fear oh height



https://www.artstation.com/dannytodo/blog/8AXA/richie-s-plank-experience-before-and-after-improvements

# FUTURE OF VR

- VR: Replacing high street shopping
  - People will make all of their purchases from home, trying on clothes in a virtual reality changing room and getting advice from AI shop assistants that know exactly how to cater for their taste.
  - Example: Walmart's VR Shopping




https://m.andnowuknow.com/headlines/walmart-files-patent-virtual-reality-shopping/robert-schaulis/59465?__cf_chl_jschl_tk__=pmd_fd63bdf01c76ded8afd17fed0c499d040254d340-1627632342-0-gqNtZGzNAnijcnBszQf6

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# FUTURE OF VR

- VR:
  - Most probably in 2050 users would have a virtual reality with a perfect emulation of sight, sounds and smells. They will also have good haptics and taste emulation.

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# FUTURE OF VR

- VR: 5G Technology in VR
  - 5G will also have larger implications as the Internet of Things (IoT) expands. Other companies like Qualcomm and T-Mobile are also investing heavily into 5G development.
  - 5G will enable cloud computing to hold and process more data at a faster rate. This will also mean that VR devices will connect directly to the cloud without the need for additional computing devices to power them.




https://www.mccourier.com/5g-in-virtual-reality-market-to-perceive-biggest-trend-and-opportunity-with-key-players-facebook-huawei-technologies-zte-corporation-samsung-electronics-qualcomm/

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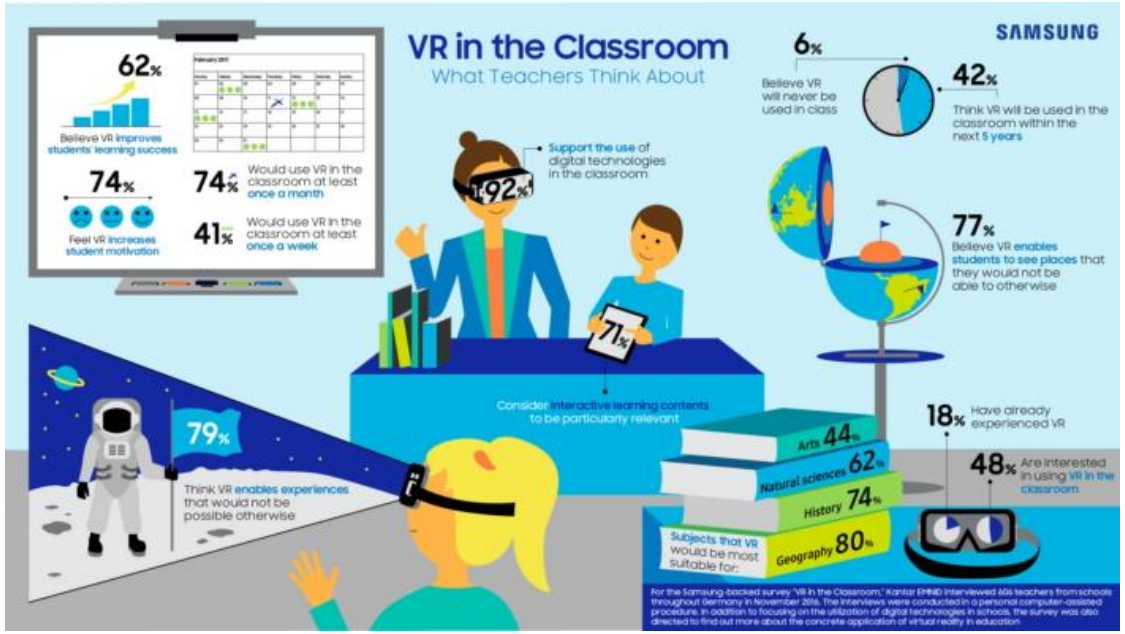
# FUTURE OF VR

- VR: In the classroom
  - The quality of learning will improve with the use of VR. Virtual reality can be used to enhance student learning and engagement. VR education can transform the way educational content is delivered; it works on the premise of creating a virtual world - real or imagined and allows users not only to see it but also interact with it. Being immersed in what users are learning motivates them to fully understand it. It'll require less cognitive load to process the information.

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# FUTURE OF VR

- VR: In the classroom
  - A recent survey, conducted by Kantar EMNID, a German research company, asked 606 teachers from schools throughout Germany to better understand what educators think about the application of new technologies – particularly virtual reality – in the classroom.




https://news.samsung.com/global/survey-shows-that-teachers-see-potential-for-virtual-reality-in-education

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# FUTURE OF VR

- VR: Travelling
  - With the use of VR users will be able to travel over the space from Earth and that will also be in 3D. With the use of 3D virtual reality, users would be able to view and feel the place before the actual arrival. Users would judge the feel of the place before going there.
  - VR has become a new form of showrooming, an incredible 3D taste of a destination that will make travelers experience the real thing. Haptic technologies will also influence the way users book travel and how they prepare for it. Through clever technologies, Users will be able to feel the sand on the beach before they get there or the mossy ground under our feet in a virtual rainforest.

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# › LECTURE 2

**VR Systems**
**Input & Output Devices**
**Hardware**
**Software**

# VR SYSTEMS

- Definition:
  - "A VR system must cover the required tasks as a human-machine interface. We need a computer system that recognizes the actions of users, simulates the world under this influence, and lets the users perceive a virtual world via appropriate stimulus generation."
    - Dörner, R., Broll, W., Grimm, P., Jung, B. (2019). Virtual und Augmented Reality (VR/AR) (2nd ed.). Springer.

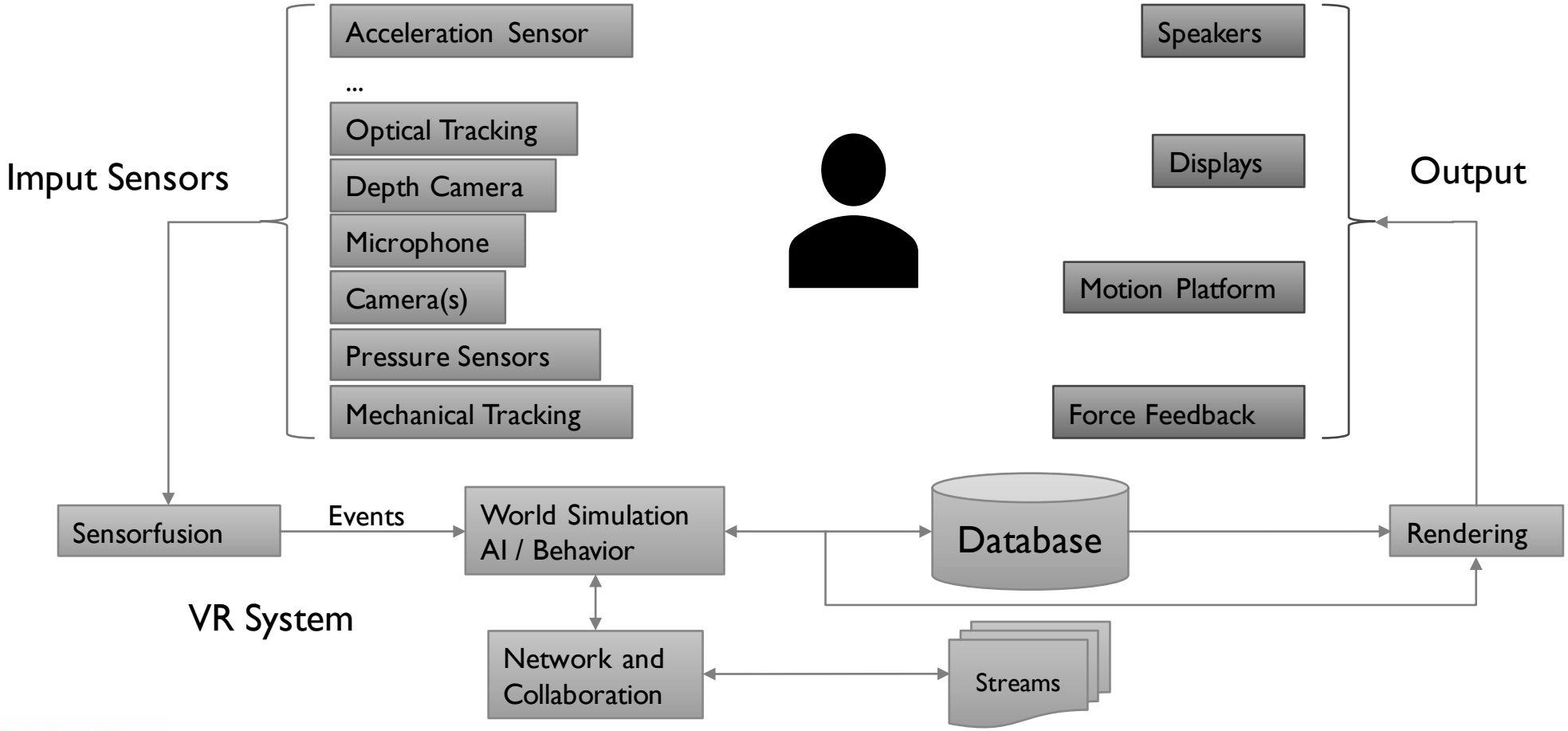
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# WORKING OF VR

- According to (Bassas, 2018) the whole concept behind VR is to replace the current reality with a better one, with use of a high-end user interface which involves real-time simulation and interaction.
- Using VR allows users to experience virtual environments in a way that makes the brain believe that they are somewhere else.
  - In this way, users can navigate and interact with virtual simulations, by combining high-level graphics, position tracking and motion sensors.

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# VR SYSTEMS - OVERVIEW OF THE SUBSYSTEMS OF A VR SYSTEM




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# VR CHALLENGES

- Latency
- Tracking
- 3D Image quality and resolution
- Rendering & bandwidth

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# VR CHALLENGES

- Simulation/cyber sickness
  - When camera motion inconsistent with head motion
  - Frame of reference helps
  - Worse with larger FOV
  - Worse with high luminance and flicker

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# VR CHALLENGES

- Content creation
  - Game engines
  - Image Based Rendering

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# COMPONENTS OF VR

- Definition:
  - The components of VR are the tools, technologies and software required to access the VR system efficiently.

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# VR INPUT DEVICES

- Definition:
  - Physical devices that convey information into the application and support interaction in the virtual environment

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# VR INPUT DEVICES

- Characteristics of input devices:
  - Size and shape
  - Degrees of freedom
    - Integrated vs. separable
  - Direct vs. indirect manipulation
  - Relative vs. absolute input
    - Relative: measure difference between current and last input (mouse)
    - Absolute: measure input relative to a constant point of reference (tablet)
  - Rate control vs. position control
  - Isometric vs. isotonic
    - Isometric: measure pressure of force with no actual movement
    - Isotonic: measure deflection from a center point (e.g. mouse)

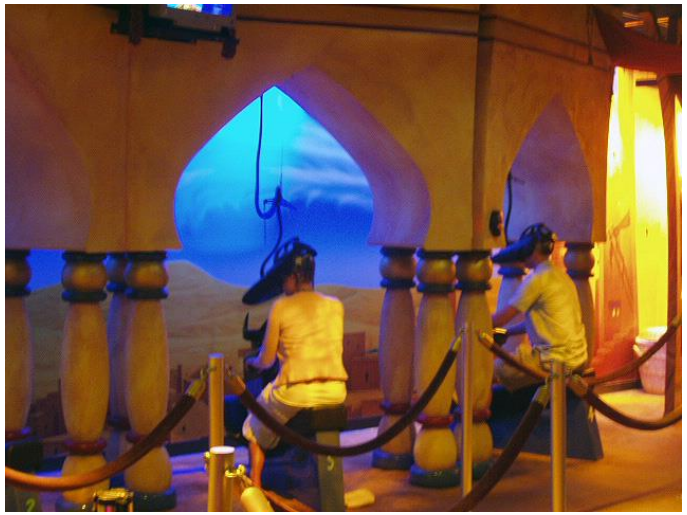
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# VR INPUT DEVICES

- Hand Input Devices – World Grounded Devices: fixed in real world (Joystick)
  - Not ideal for VR: Constrains user motion
  - Good for VR vehicle metaphor: used in location-based entertainment
  - Example: Aladdin magic carpet VR ride



https://www.startrekmagic.com/tag/biological-cybernetics/



https://www.semanticscholar.org/paper/Disney's-Aladdin%3A-first-steps-toward-storytelling-Pausch-Snoddy/446e6073f906c1c8b830fd857dcc13b6a27144d9/figure/0

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# VR INPUT DEVICES

- Hand Input Devices – Non-tracked handheld controllers
  - Held in hand but not 3D tracked
  - Example: Xbox controller



https://www.oco-7.top/ProductDetail.aspx?iid=137706133&pr=79.99

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# VR INPUT DEVICES

- Hand Input Devices – Tracked handheld devices: with 6 Degrees of Freedom tracking inside
  - Combines Joystick input plus tracking
  - One of the best options for VR applications
    - Physically enhancing VR presence
    - Hands can be held in comfortable positions – no line-of-sight issues
    - Direct mapping to real hand motion

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# VR INPUT DEVICES

- Example 1: Vive controller - https://www.youtube.com/watch?v=qYfNzhLXYGc
- Example 2: Cubic mouse - supports object rotation, zooming, cutting plane…



https://www.uni-weimar.de/en/media/chairs/computer-science-department/vr/research/hci/3d-handheld-interaction/the-cubic-mouse/

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# VR INPUT DEVICES

- Hand Input Devices – Hand worn devices: gloves, EMC band, rings…
  - Natural input with rich gesture interaction
  - Hands and fingers can fully interact with real objects
  - Examples: Myo arm band and StretchSense Glove



https://www.youtube.com/watch?v=jOEcsNmTk7g




https://www.youtube.com/watch?v=MQ00ByIEhGY

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# VR INPUT DEVICES

- Hand Input Devices – Bare hand input: tech. to recognize natural hand input
  - Using computer vision to track bare hand input
  - Challenges need to be solved
    - Not having sense of touch
    - Line-of-sight required to sensor
    - Fatigue from holding hands in front of sensor

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# VR INPUT DEVICES

- Non-hand input devices: Head or eye tracking, audio input, body tracking
  - Full body input in VR creates illusion of self-embodiment and enhances the sense of presence
  - Camera based motion capture – Optitrack: https://www.youtube.com/watch?v=aQagMqQuqrE
  - Wearable tracking system – PrioVR: https://www.youtube.com/watch?v=HnDJXYjFZUg
  - Pedestrian devices – Walking/running in VR:
    - Cyberith virtualizer - https://www.youtube.com/watch?v=aTpPq1NsgXk
    - Infinadeck - https://www.youtube.com/watch?v=7uO8Z34f0xE

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# OUTPUT DEVICES

- Head Mounted Device (HMD)

- First developed by Ivan Sutherland in 1968. A HMD is a helmet or goggles-like device. There are many types of VR HMD available on the market like 3DOF HMD (Oculus GO and Samsung Gear), 6DOF HMD like (Oculus Quest) and Computer-based VR HMD devices (Oculus Rift, Rift S). It is the most important and basic device required for a VR immersive experience.

- Most HMD devices contain in-built memory, in-built gyroscope sensors for movement tracking, RAM, processing unit, screen, and sound capabilities that provide an immersive VR experience. There are various types of HMD devices available in the market. The below image shows the HMD from Oculus(Quest).



https://scdn.slashgear.com/wp-content/uploads/2020/03/oculus_quest_headset_main-1280x720.jpg

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# HAPTIC OUTPUT DEVICES

Makes virtual objects tangible for the user by:

- Mechanical stimulation
- Pneumatic stimulation
- Electrical stimulation
- Vibration
- Application of force

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# HAPTIC MOSTLY IN INPUT DEVICES

This project has been designed as an opportunity for you to:

- Tactile feedback
  - Generates haptic sensation for user when touching a virtual object
  - Without necessarily matching the sensation of touching a similar real object
- Force feedback
  - Requires external skeletal structure
  - Restricts freedom of movement of fingers or other limbs

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# DATA GLOVES WITH TACTILE FEEDBACK OR FORCE FEEDBACK

- Most data gloves are limited to tactile feedback
  - Small vibration motors on the fingertips
  - Fingertips mechanically contract with small bands
  - Electrical pulses
- Some use external skeletal structures to restrict finger movement
- Example: HaptX glove
  - Combination of a miniaturized pneumatic actuator consisting of 12 elements on each fingertip and an exoskeleton




https://uploadvr.com/haptx-gloves-dk2-announced-backpack-roomscale/

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# AIR AND SOUND-BASED SYSTEMS

- Vortex rings
  - Air can be used over a certain distance to create a short haptic stimulus
  - With a grid of actuators even more complex objects can be simulated
- Haptic output based on ultrasound
  - Example: Stratos series from Ultrahaptics
    - Array with up to 256 transducers
    - Update rates of up to 40kHz, allows haptic output
    - at a distance of up to 70 cm



https://www.ultraleap.com/product/stratos-explore/

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# VESTS AND SUITS

Mostly for the application areas of games and military simulations

- Example: Teslasuit full body suit
  - Individual haptic output device
  - Uses transcutaneous electrical nerve stimulation
  - Electrical output via electrical pulses
  - Can influence user's temperature sensation
  - Integrates motion capture sensors for input



https://www.alza.de/teslasuit-d5250186.htm

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# OTHER NEEDED HARDWARE

- Cables for PC-based VR
  - Cord wire or cable are required to experience the immersive world of VR. They work as a link to attach the HMD with highly capable PCs and External sensors. Oculus Rift and Rift S are the best examples to understand it.
- Charging cable and Adapter
  - USB type C cables and Adapters are being employed to charge most of the recent and advanced VR devices

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# SOFTWARE

- VR requires Software support for its functioning and this section talks about the Software components required for VR systems. Below figure shows the working of the VR system.

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# SOFTWARE – COMPANION APPS FOR STANDALONE HMD

- The Companion App is an essential component to register, login, connect and access VR HMD devices.
- It connects and creates a synchronous link between a particular HMD device and respective controllers. It works as a bridge between all the components of a VR system.
- Oculus Quest is a standalone VR system which requires a dedicated companion app called Oculus app by Oculus.

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# SOFTWARE – SIMULATION SOFTWARE

- Simulation Software is responsible for providing an immersive experience to the VR system.

- Simulation software processes the input received from the input devices like Controllers and produces the reflection on the user screen with maximum consistency.

- An Internal database of all the objects in the VR world gets generated, maintained and continually monitored by the Simulation software. It also notifies the VR system when any changes are identified in the internal database.

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# SOFTWARE – MODELING SOFTWARE

- In order to achieve immersive media and effect for the real objects, 3D modelling software is used that specifies the actual shape, size and dimensions of the real-world objects in the world of Virtual Reality.

- There is lots of free and easy to use Modeling software on the market nowadays, a few examples are:
  - Blender
  - TinkerCAD
  - 3D Slash
  - FreeCad
  - SketchUp

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# › LECTURE 3

**Exercises: VR with Unity**

# OBJECTIVES

- The practical usage of VR has increased over the last years and more and more VR applications are emerging. Therefore, it is important to have knowledge about the topic "Development with VR".

- The following exercises will give you a basic overview over the important points when working with VR and also let you understand the basic principles.

- The goal is to demonstrate an easy way of developing an application that contains VR. Furthermore, we want to show how to use the Virtual Reality Toolkit inside the Unity Engine and build a small VR application. This VR application serves as a starting point for students who want to start developing VR applications or want to go deeper into the topic of creating VR content with Unity.

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# SETUP

- Step 1: Get Unity - Therefore go to https://store.unity.com/download-nuo where you can download the Unity Hub under "Get Started". Install the Unity Hub after the download has finished.

- Step 2: Create a Unity-account. After that select "Create a Unity ID" and follow the steps.

- Step 3: Start the Unity Hub and log in with your credentials. Then you click on your username and select the tab "License Management". There you select "Activate new license" to add a license for working with Unity. Select the Unity Personal license and verify that you are under the given license conditions.

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# SETUP

- Step 4: Download and install the Unity Engine in the Unity Hub. For these exercises Unity version 2019.4 was used. You can choose to install additional components for Unity like Visual Studio for coding or Android Build Support

- Step 5: When Unity is installed, create a new project through the Hub by clicking "New" in the projects section.

- Step 6: Add VRTK to your project from the asset store (https://assetstore.unity.com/packages/tools/integration/vrtk-virtual-reality-toolkit-vr-toolkit-64131). There you must log in with your Unity account. After that you can add VRTK to your assets by clicking on "Add to my Assets". Then you can. Import VRTK by opening the package manager under "Window" → "Package Manager". Inside the package manager you must select "My Assets". Select VRTK in the list and clicking "Import".

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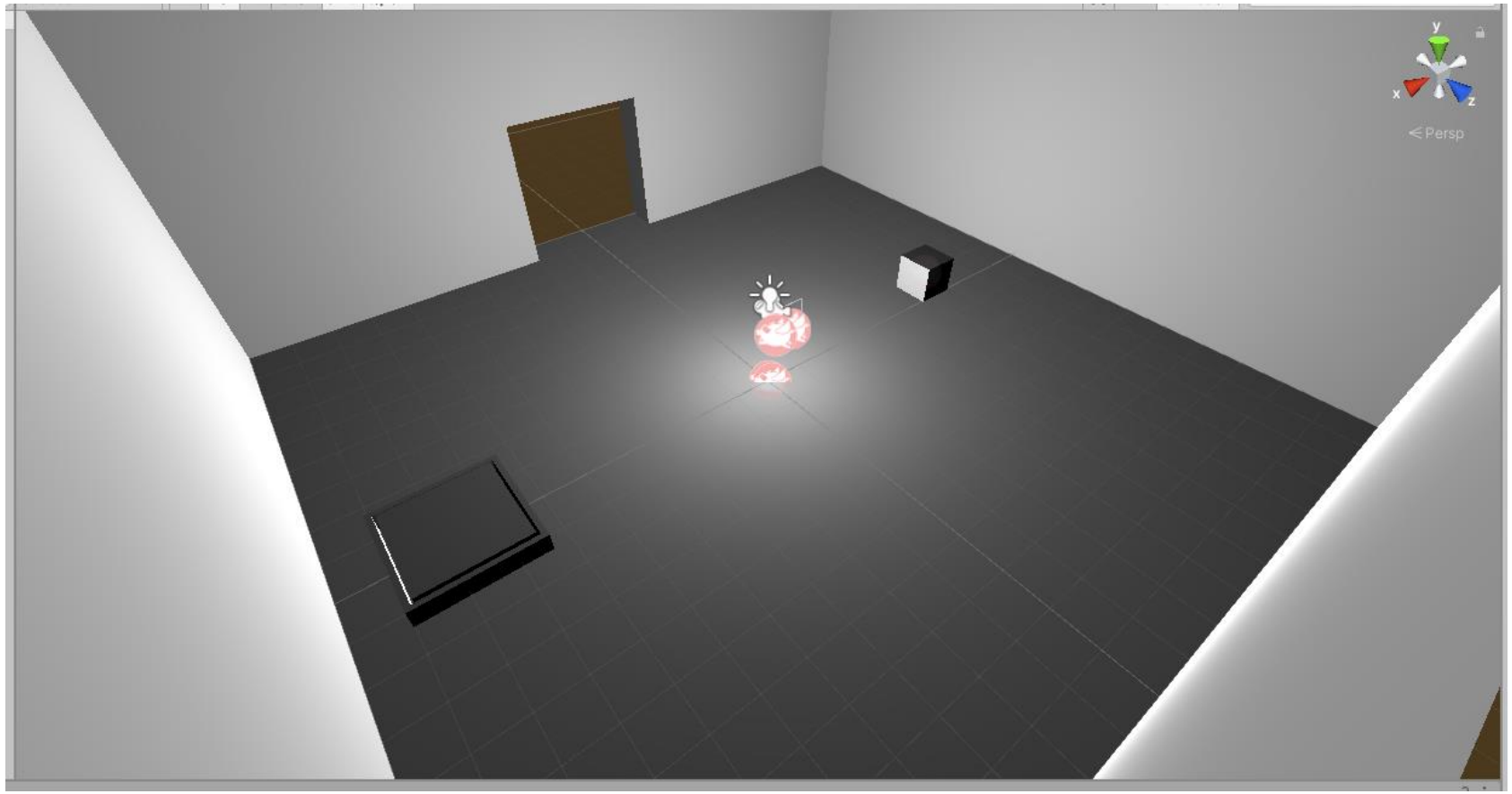
# 3D MODELS

- For the scene, some 3D-objects are needed, a room with a door, a cube and a pressure switch. For the cube we will be using the default standard cube already built in Unity. The indoor room with its door and the pressure switch were modeled using blender (https://www.blender.org/)

- Since the creation of the 3D-models is another topic, it will not be covered in this exercise. When you create your models in an external program (like blender) you must export them in a supported format (FBX is recommended) and then drag and drop your model file into the "Assets" tab in your project (see https://docs.unity3d.com/2020.2/Documentation/Manual/ImportingModelFiles.html for more information). The cube can be added by right clicking on the "Hierarchy" tab and selecting "Cube" under "3D Object". After that you need to arrange your objects in a meaningful way

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# SCENE




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# PLAYER SETUP

- After successfully importing and arranging the objects, enable VR by adding VRTK scripts to the objects. Start by adding the player to our scene.
  - Special role in VRTK because it defines with which device the game will be used.
  - For this exercise, the "VRSimulator" which can be used to build VR applications and test them inside Unity without the need to have a VR device.

- To add the player object, create an empty GameObject by right clicking on the "Hierarchy" tab and selecting "Create Empty". Rename it to SDK Manager. Inside the SDK Manager add the "VRTK_SDK Manager" script by clicking "Add Component" inside the "Inspector" tab after selecting SDK Manager. Inside the component selection add the name of the script to the search bar and select the right script.

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# PLAYER SETUP

- Create a new empty GameObject, rename it to Simulator and drag and drop it to the SDK Simulator so that it's placed indented under the SDK Manager. The Simulator becomes a child object of the SDK Manager which is important for VRTK to work.

- Add the VR simulator as a child of the Simulator GameObject. Navigate to VRTK→ Source→ SDK→ Simulator in the "Assets" tab. There you can find the [VRSimulator_CameraRig] which is a prefab provided by VRTK that contains all necessary scripts and objects for the simulator object. Drag and drop to the "Hierarchy" tab and make it a child of the Simulator.

- Connect the nested GameObjects. Select the Simulator and select the Simulator SDK in the SDK Selection section. Press on "Populate Now" to add the Simulator Camera Rig. Then select the SDK Manager and click on "Autopopulate". This adds the Simulator to the list of Setups in the VRTK_SDK Manager script. After that the player set up is almost completed.

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# HANDS

- To interact with objects, hands are needed for the player. Create an empty GameObject and rename it to hands.
- Create two more empty GameObjects, make them children of Hands and rename them to left hand and right hand.
- Add the VRTK_Pointer and VRTK_StraightPointerRenderer scripts to enable a pointer for the hands, the VRTK_ControllerEvents script to enable different kinds of interactions for the hands and the VRTK_InteractTouch and VRTK_InteractGrab scripts to enable touch and grab interaction for both hands.
- Select the SDK Manager and drag and drop the corresponding hand into the field for Left and Right Controller.

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# INTERACTABLE OBJECTS

- To enable objects for interactions with the player, make them interactable. VRTK offers an automatic way of doing that. Select the object to become interactable (e.g., the cube) and click Window→ VRTK → Setup Interactable Object in the upper menu in the Unity editor. You have the possibility to customize the basic behavior of the interactable object in a pop up, although the standard settings are sufficient for this exercise.

- Click "Setup selected object(s)" in the pop up and close the pop up. Add the Left/Right Hand object to their corresponding fields inside the VRTK_ChildOfControllerGrab script of the interactable object

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# SCRIPTS

- To give the exercise the last finishing touch add some C# scripts to provide some functionality to the VR application. These scripts do not interact with VR.

```
[RequireComponent(typeof(Collider))]
0 Verweise
public class Platte : MonoBehaviour
{
    public float speed = 1;

    public MoveWith[] attached;

    Coroutine moveC = null;

    0 Verweise
    private void OnCollisionEnter(Collision collision)
    {
        GameObject other = collision.gameObject;
        if(other.tag == "Placeable")
        {
            movePlatte(false);
        }
    }

    0 Verweise
    private void OnCollisionExit(Collision collision)
    {
        GameObject other = collision.gameObject;
        if (other.tag == "Placeable")
        {
            movePlatte(true);
        }
    }

    2 Verweise
    private void movePlatte(bool up)
    {
        Debug.Log("moving " + (up ? "up" : "down"));
        if (moveC == null)
        {
            moveC = StartCoroutine(move(up));
        }
    }

    1-Verweis
    private IEnumerator move(bool up)
    {
        float increase = 0.005f;
        float waitingTime = increase / speed;
        yield return new WaitForSeconds(0.1f);
        for(float i = 0; i < 1; i += increase)
        {
            foreach(MoveWith other in attached)
            {
                other.move(up, i);
            }
            yield return new WaitForSecondsRealtime(waitingTime);
        }
        moveC = null;
    }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

2 Verweise
public class MoveWith : MonoBehaviour
{
    public Vector3 offset;

    public bool invert;

    private Vector3 startPos;

    private Vector3 targetPos;

    0 Verweise
    private void Start()
    {
        startPos = transform.position;
        targetPos = startPos + offset;
    }

    1-Verweis
    public void move(bool toStartPos, float position)
    {
        if(toStartPos ^ invert)
        {
            moveTransform(targetPos, startPos, position);
        }
        else
        {
            moveTransform(startPos, targetPos, position);
        }
    }

    2 Verweise
    private void moveTransform(Vector3 Start, Vector3 End, float Position)
    {
        transform.position = Vector3.Slerp(Start, End, Position);
    }
}
```

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# TESTING

- To test the application, click the "Play" button in the middle upper part of the Unity editor and follow the instructions given by VRTK to move the player and its hands.
- To grab an object, hold down ctrl-key, place the appearing cross on the object and press the left or right mouse button depending on the hand you want to grab the object with.
- To release the object, press the same mouse button you used for grabbing it.
- To move the grabbed object switch to hand, move mode and move the hand that grabs the object.
- For further information on how to work with VRTK and on how to build for real VR devices consult the VRTK documentation https://vrtoolkit.readme.io/ or the VRTK YouTube channel https://www.youtube.com/channel/UCWRk-LEMUNoZxUmY1wO7DBQ.

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# SOFTWARE – 2D GRAPHICS SOFTWARE

- 2D graphics software is responsible for making the real-world objects look more detailed and interesting in the Virtual world.

- This is achieved by employing the process called Texture Mapping or Paint programs.
  - The images processed or edited by 2D graphics software must pass through the 3D modelling software as well, after the 2D model adds more detail to the surface of the objects for the Virtual world.

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# SOFTWARE – DIGITAL SOUND EDITING SOFTWARE

- Sound synchronization with the matching virtual effects gives the immersive VR experience.

- 3D graphics in VR are aesthetically very attractive but not very real without the high-resolution synchronous sound effect of the objects and actions in the VR environment.

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# SOFTWARE – VR GAME ENGINES

- VR Game Engine facilitates the game developers with the framework to build games in VR.

- SDKs ease the work for developers to design, develop and test their VR Games and App. There are also lots of free VR game engines on the market, a few of them are for example:
  - Unity
  - Unreal Engine
  - Maya
  - CryEngine

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# › LECTURE 4

**Definition of terms**
**User interfaces**
**Selection, manipulation and navigation methods**

# HUMAN-MACHINE INTERACTION

- Has been a topic since industrialization
- Interaction between people and machines
  - Ergonomics, human factors
  - Increasing productivity
  - Safety



https://www.mcny.org/event/past-event-moonlight-movies-modern-times

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# HUMAN-COMPUTER INTERACTION (HCI)

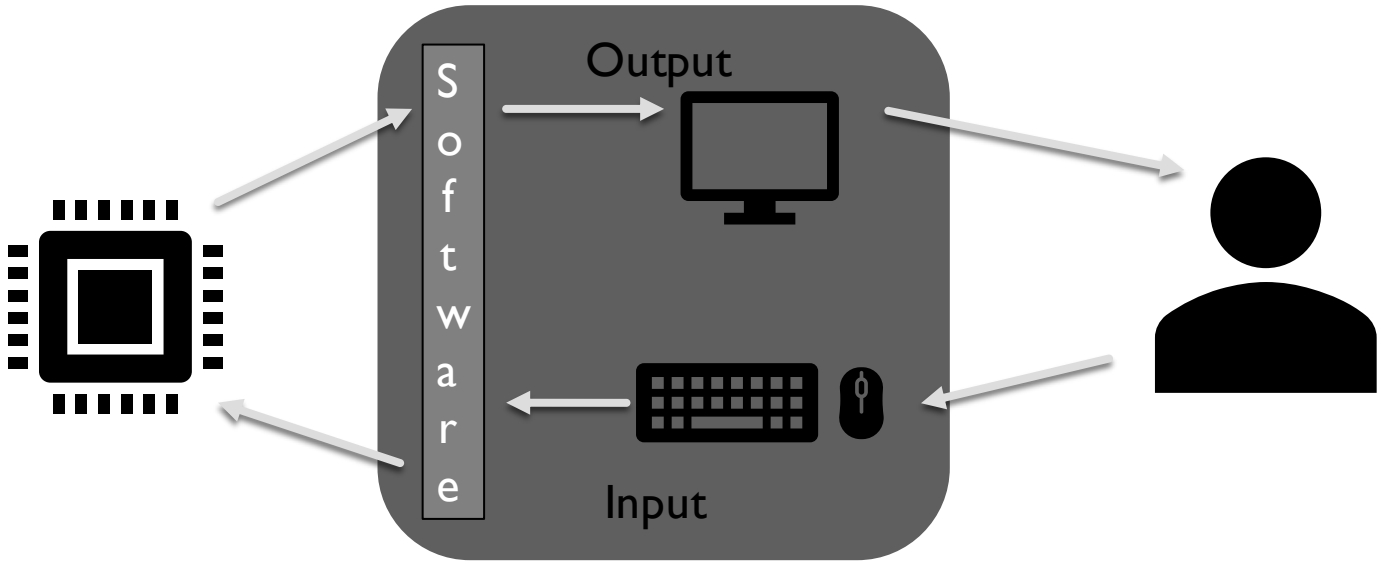
- How can the user perform his tasks with a computer?
  - Design
  - Implementation
  - Evaluation

- User and system do not speak the same language
- Interface is composed of devices and software

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# HUMAN-COMPUTER INTERACTION (HCI)

- Input and output channels at use and system
- Communication flows over these channels
- Information is translated into different "languages"




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# DEFINITIONS

- Interaction Task
  - Entering information into the system
  - Basic Interaction Tasks: Position, Selection, Text
- Interaction technique
  - The way the input interface is used to enter information into the system.
- Interaction metaphor
  - Use of already existing knowledge about interaction techniques from other domains

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# 3D USER INTERFACES

- 3D environments place high demands on the user interface
  - More degrees of freedom in movement when compared to interaction in 2D (Position and orientation in 3D)
  - Virtual worlds are very different from physical worlds
    - - Missing / different haptics
    - - Missing / different depth perception

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# 3D USER INTERFACES

- Many hardware configurations
  - Desktop
  - Immersive environments
  - Many input devices



http://www.mrmark.co.uk/input-and-output-devices.html



https://www.eurekalert.org/pub_releases/2019-12/asoa-dhi112619.php



https://de.cleanpng.com/png-x4q8mm/

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# 3D USER INTERFACES

Basic interaction tasks:

- Positioning
  - Of virtual objects (3D manipulation)
  - User perspective (3D navigation)

- Selection
  - Selection of virtual objects
  - Change of state of virtual objects

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# 3D INTERACTION TECHNIQUES

- 3D Selection
  - Selection of one or more objects
  - Confirmation of selection
- 3D Manipulation
  - Positioning, Orientating, Scaling
- 3D Navigation
  - Setting user position
  - Setting user orientation

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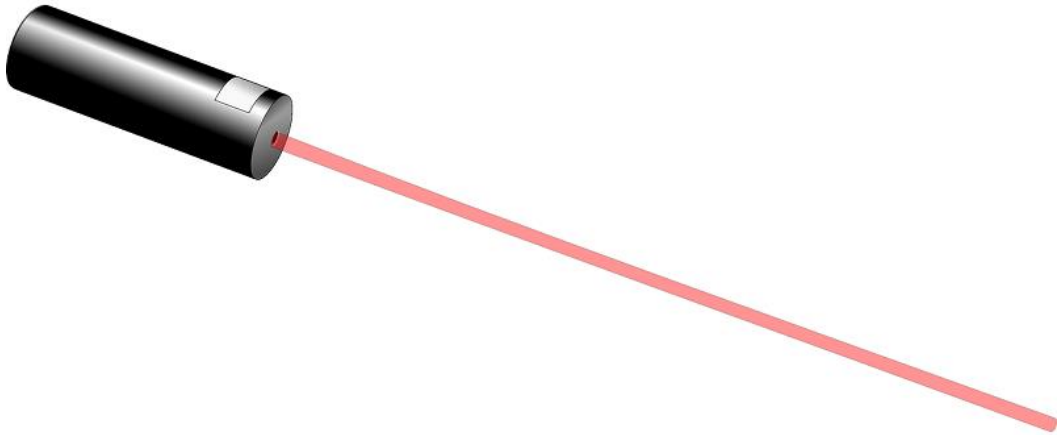
# 3D SELECTION

- Selecting object by
  - Pointing on the object
  - Touching the object
- Confirm selection by
  - Pressing a button
  - Speech
- Point and click approach dominates

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# 3D SELECTION: RAY CASTING

- Selecting objects casting a ray
  - Position
  - Orientation



https://www.eyemichigan.com/laser-pointer-dangers/

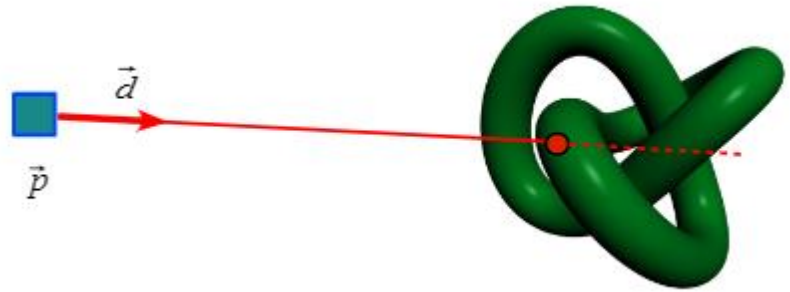
- Analogy: Laser pointer
- Direction of input device
- Position of user

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# 3D SELECTION: RAY CASTING

Implementation:

- Origin and direction of ray: $\vec{R}(t) = \vec{p} + t * \vec{d} \quad mit \; |\vec{d}| = 1$




- List of all objects
- Test all objects for intersection
- Select object with foremost intersection (smallest t)

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# 3D SELECTION: RAY CASTING

Ray cast Selection is widely used

- Problems:
  - Precision decreases with distance of objects
  - Hand tremor (with some input devices).

- Determination of position / direction of the ray cast
  - Directly from input device, tracker
  - Indirectly from input device (e.g., 2D mouse, 3D direction by polar coordinates)

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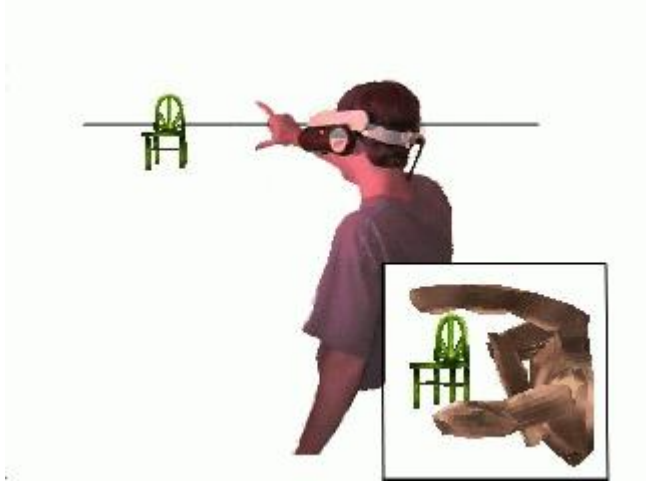
# 3D SELECTION: IMAGE PLANE INTERACTION

Selection in image space

- Only 2 DOF needed to select objects
- Assignment of pixels to objects
  - Render object in a single color (own passport)
  - Color as unique ID

Also possible in immersive environments

- Selection rectangle:
  - Beam from eye through finger
  - Intersection with image plane



https://cs.brown.edu/stc/resea/interaction/research_I5.html

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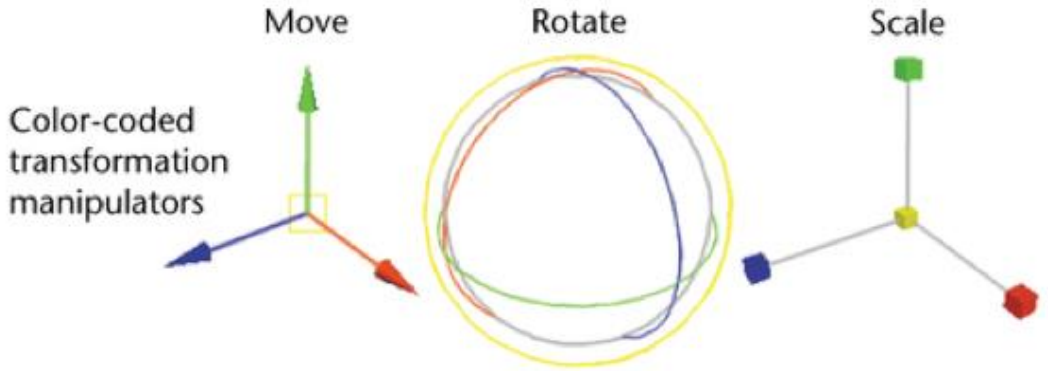
# 3D MANIPULATION

- Set position and orientation of virtual Objects (6 DOF).
- Problems:
  - Mapping degrees of freedom from input device to virtual object
  - Too few degrees of freedom in input device (desktop).

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# 3D MANIPULATION:WIDGETS

- Graphical controls for
  - 3D transformation
  - 3D Rotation
  - 3D scaling
- Mostly to be found in the 3D modeling area



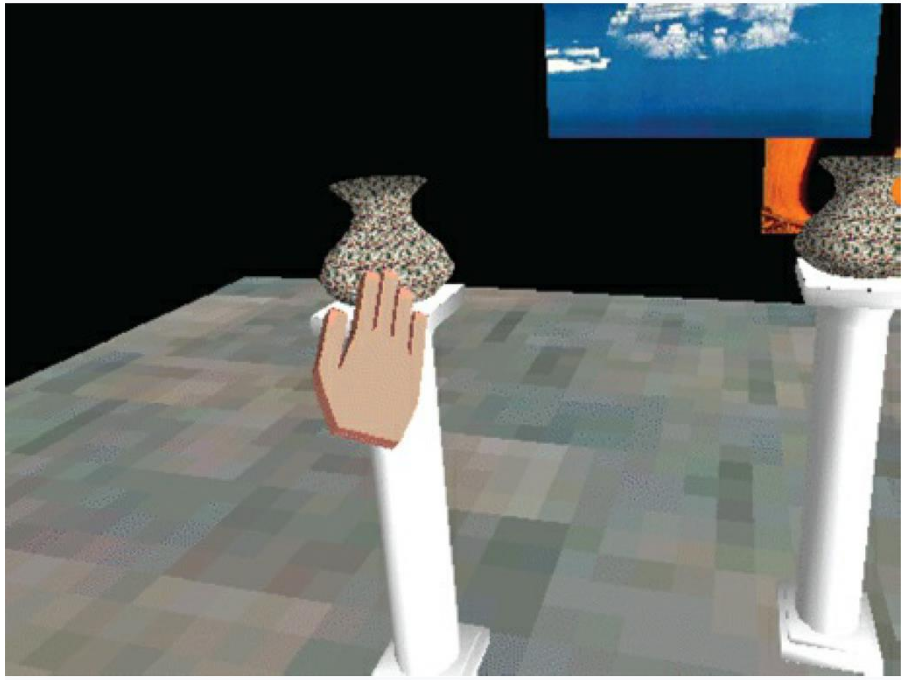

https://gamedev.stackexchange.com/questions/79972/how-to-implement-translation-scale-rotation-gizmos-for-manipulating-3d-object

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# 3D MANIPULATION:VIRTUAL HAND

## Selection in image space

- User moves a 3D cursor in the virtual world
  - Can look like a hand
  - Can act like a hand



https://s3dit.cs.uni-potsdam.de/detail/1

# 3D NAVIGATION

- Generally said, setting the
  - Position of viewer
  - Orientation of viewer
- Interaction tasks of Navigation
  - Exploration: Moving without a specific target
  - Search: Target is known
  - Maneuvering: Small, precise movements

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# 3D NAVIGATION

- Can be split into
  - Getting around
    - - Moving to a certain position / in a certain direction
  - Pathfinding
    - - The path to follow is defined by the environment
    - - Cognitive process

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# 3D NAVIGATION TECHNIQUES

- Active / passive techniques
  - Motion control by user vs. system
- Virtual / physical techniques
  - What causes movement in the virtual world?
  - Movement of the body vs. simple button press
  - Specification of target / direction
  - Specification of speed / acceleration
  - Constant motion / motion only on input

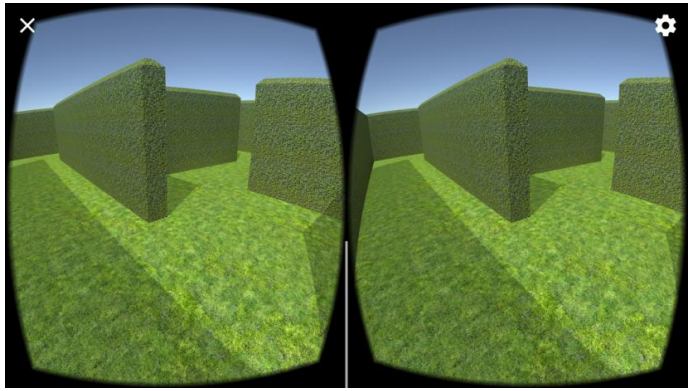
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# 3D NAVIGATION TECHNIQUES

- Overall problem: Orientation loss
- Reduction of Fields of Freedom
  - Not a free flight
- Collision detection: No navigation through walls



https://www.polygon.com/2019/8/15/20806094/no-mans-sky-beyond-pc-vr-impressions-rift-s-index-psvr



https://alishbaimran.medium.com/entering-building-the-virtual-maze-bc5e8bf88409

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# 3D NAVIGATION TECHNIQUES: WALKING

- First person perspective, ego perspective
- Specification of movement direction
  - Common: Direction of movement equals view direction
- Movement is activated / deactivated by user
- Specified height above the ground

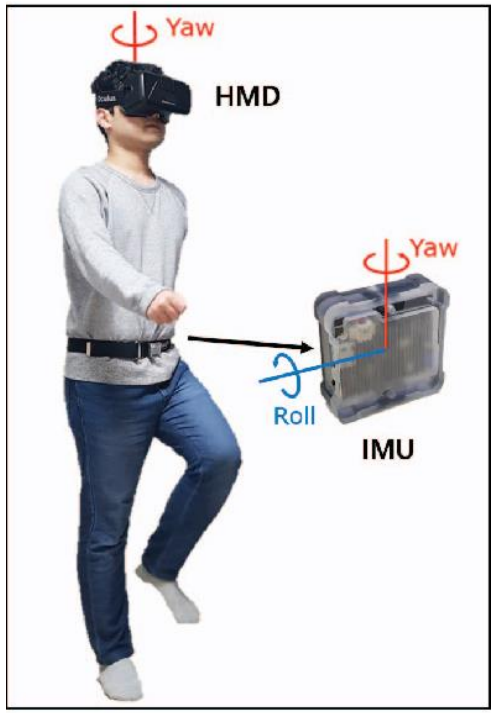


https://www.vrnerds.de/dying-light-zombie-horror-spiel-wird-offiziellen-oculus-rift-support-bekommen/

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# 3D NAVIGATION TECHNIQUES: WALKING

- Orthonormal base on the camera
  - Roll, yaw, pitch
  - Movement in the direction of the roll axis
- Viewing direction from horizontal and vertical viewing angle (polar coordinates)




https://www.semanticscholar.org/paper/Walking-in-Place-for-VR-Navigation-Independent-of-a-Park-Jang/185ef3e30ee7530af5dc6714bd3112104e994802/figure/2

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# 3D NAVIGATION TECHNIQUES: PATH

- Path through the virtual world is predetermined
- Possible control options of the user:
  - speed, direction
  - direction of view



https://www.iconpacks.net/free-icon/pointer-path-64.html

# 3D NAVIGATION TECHNIQUES: PATH

- Variations in the choice of viewing direction
  - Fixed on a point
  - Automatic viewing direction from tangen
- Automation of the movement
  - Start/stop by user
  - Preset points
- Semi-automatic path
  - Corresponds to a road
- If you want to save on collision detection....

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# 3D NAVIGATION TECHNIQUES: ORBIT

- Special expression of the path metaphor
- Path leads around viewpoint
  - Point of view can, for example, be directed at an object
- Degrees of freedom for the user are conceivable
  - Distance
  - Height

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# 3D NAVIGATION TECHNIQUES: TELEPORT

- Teleportation: movement without covering a distance
- Alternative view: Movement does not need time
- Already possible in VR...

- Mini Map
  - Teleportation to any place in the world
- Dedicated teleporters
  - Connects central points in the world
- Problem with teleport: loss of orientation

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- THANK YOU FOR YOUR ATTENTION!!!

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## Augmented Reality

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# › AUGMENTED REALITY

AR | LECTURER / FACULTY / COURSE | SEMESTER

HEILBRONN UNIVERSITY
OF APPLIED SCIENCES

# › LECTURE 4

**Introduction, Definition of Terms**
**History of AR**
**Future of AR**

# AR

- Definition and Characteristics (Ronald T. Azuma 1997)
  - Combines Real and Virtual Images
    - Both can be seen at the same time
  - Interactive in real-time
    - The virtual content can be interacted with
  - Registered in 3D
    - Virtual objects appear fixed in space

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# HISTORY OF AR

- 1862 Pepper's Ghost:
  - Dates back to Giambattista della Porta (1584)



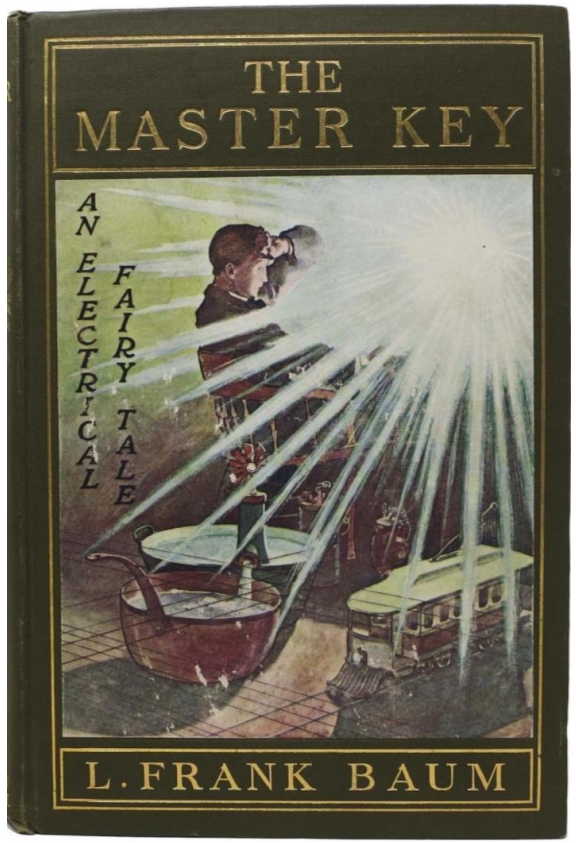
https://www.youtube.com/watch?v=FekGPSiOtvw

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# ORY OF AR

*"It consists of this pair of spectacles.While you wear them everyone you meet will be marked upon the forehead with a letter indicating his or her character.The good will bear the letter 'G,' the evil the letter 'E.' …Thus you may determine by a single look the true natures of all those you encounter."*
L. Frank Baum

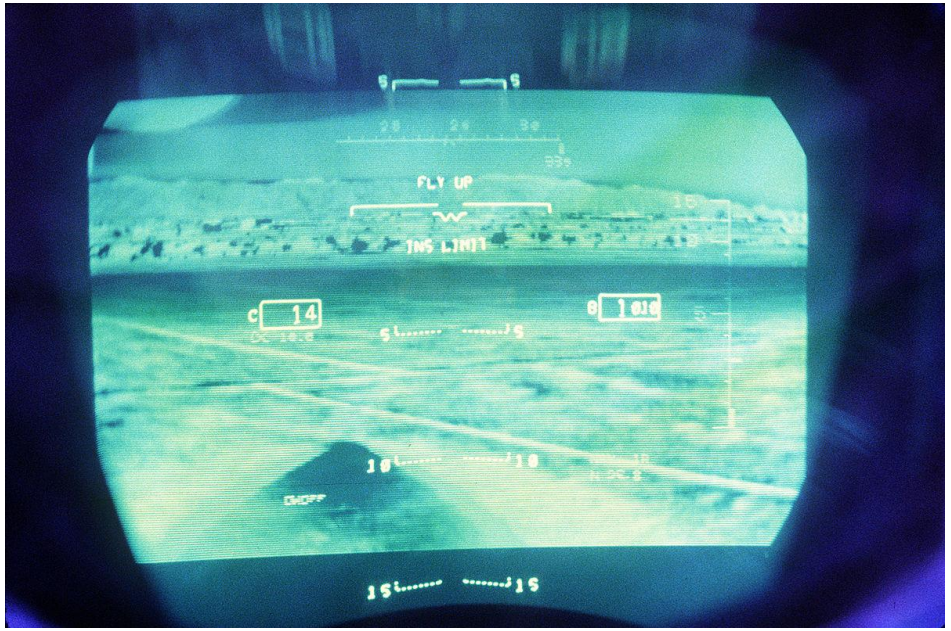
- 1901 Book:The Master Key – AR Glass:




https://historyofinformation.com/detail.php?entryid=4698

# HISTORY OF AR

- 1958 Early HUD – F-16 jet Head Up Display:




https://commons.wikimedia.org/wiki/File:F-15E_LANTIRN_IR_HUD_image.jpg

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# HISTORY OF AR

- 1968 Sutherland / Sproull's first HMD system:



https://www.youtube.com/watch?v=NtwZXGprxag

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# HISTORY OF AR

- 1960 - 70's: US Air Force HMDs (T. Furness III):



https://www.researchgate.net/figure/Integrated-Helmet-and-Display-Sighting-System-IHADSS-used-by-United-States-Army-Apache_fig1_332814496

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# HISTORY OF AR

- 1985 Modern Airforce HMDs:
  - F-35 AR HMD

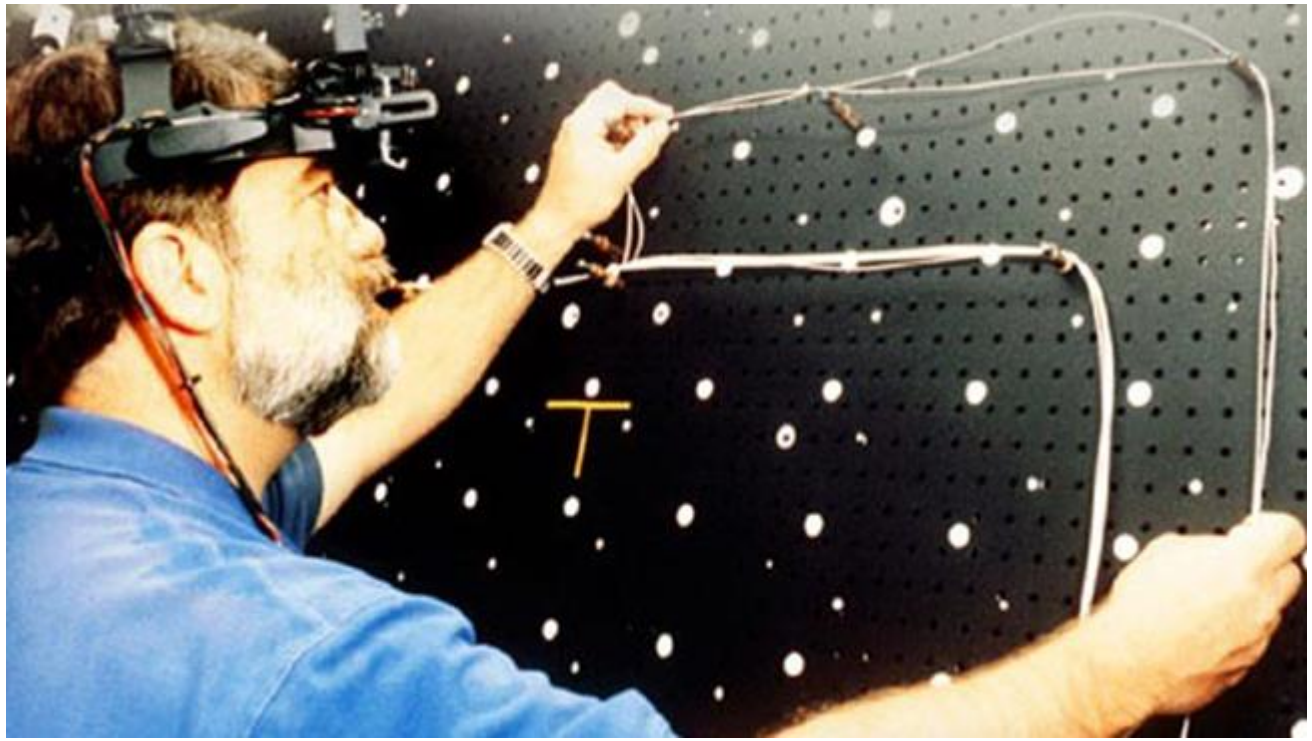



https://www.youtube.com/watch?v=Ay6g66FbkmQ

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# HISTORY OF AR

- 1990's First Industrial Use: Boeing came up with the term "AR" (Wire harness Assembly):

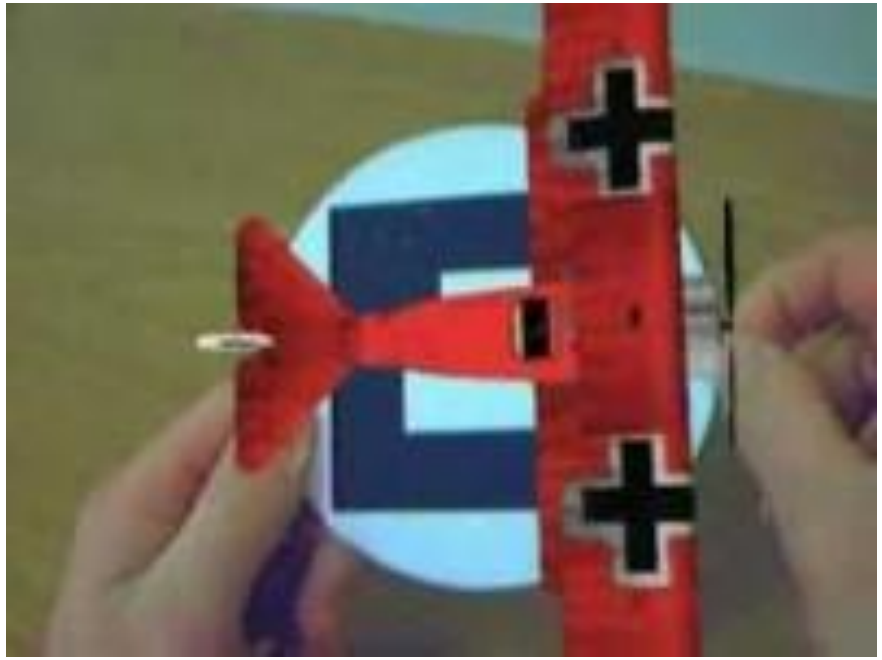


https://www.ario.com/blog/how-well-do-you-know-augmented-reality

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# HISTORY OF AR

- 1999 AR Toolkit - Open-source tracking library:



https://www.youtube.com/watch?v=TqGAqAFIGg0

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# HISTORY OF AR

- 2007 AR Reaches Mainstream:
  - MIT Technology Review, March 2007:“List of the 10 most exciting technologies”
  - Economist, Dec 2007:“Reality, only better”

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# HISTORY OF AR

- 2007 AR Advertising (HIT Lab):
  - Text message to download AR application
  - See virtual content popping out of real paper advert




https://www.unitear.com/blog/3-ways-to-use-augmented-reality-in-your-marketing-campaigns

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# HISTORY OF AR

- 2011 Google Glass:



https://resources.altium.com/de/p/google-glass-enterprise-edition-breaks-into-workplace-markets

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# HISTORY OF AR

- 2016 HoloLens:
  - Integrated system – Windows
  - Depth sensing tracking
  - Voice and gesture interaction



https://www.inexhibit.com/case-studies/microsoft-hololens-mixed-reality-device-test-and-review/

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# HISTORY OF AR

- Today:
  - Key Technologies Available
    - Display (Handheld, HMDs)
    - Input Devices (Kinect, etc.)
    - Developer tools (Vuforia, AR Toolkit)
  - Commercial Business Growing
    - Gaming, GPS/Mobile, Online Advertisement
    - > 600 Million USD in 2016

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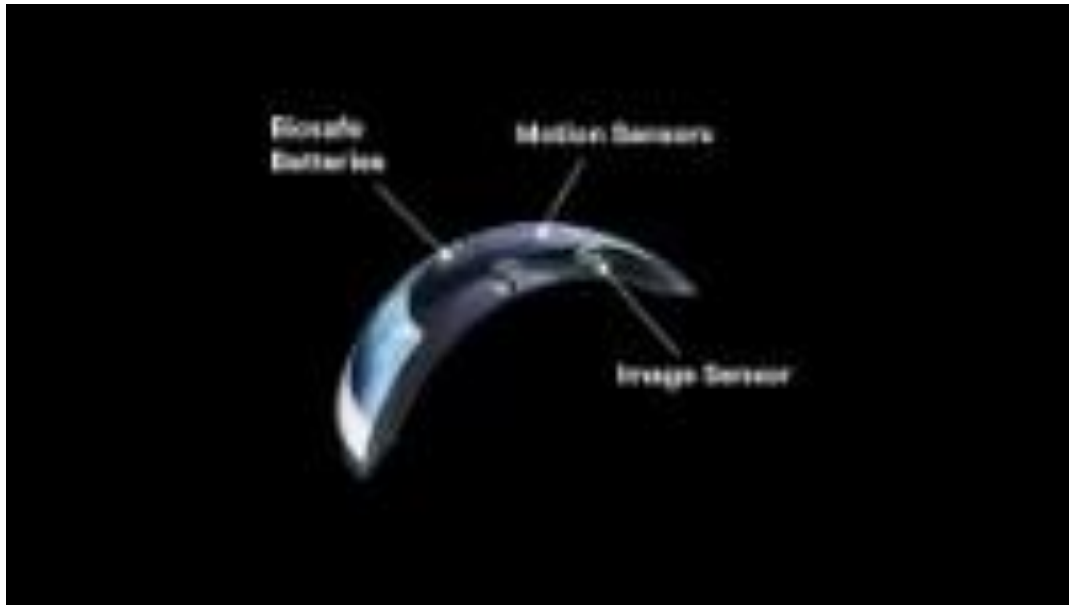
# FUTURE OF AR

- AR:
  - The application of AR/MR is currently being intensively researched, developed, and tested in various areas.
  - However, until the use of most AR/MR technologies can become commonplace, many challenges must be overcome, and further research must be done.

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# FUTURE OF AR

- AR: Smart lenses
  - The future use of AR or MR devices like socially suitable HMDs might replace smartphones when they overcome certain challenges. Additional research is ongoing on AR-enabled contact lenses.
    - Example: Mojo Lens
    - In 2021 Apple also released, that they plan to offer lenses with AR within 10 years, which would work as a miniature of Google Glass.



https://www.youtube.com/watch?v=TzVAMRe3kmA

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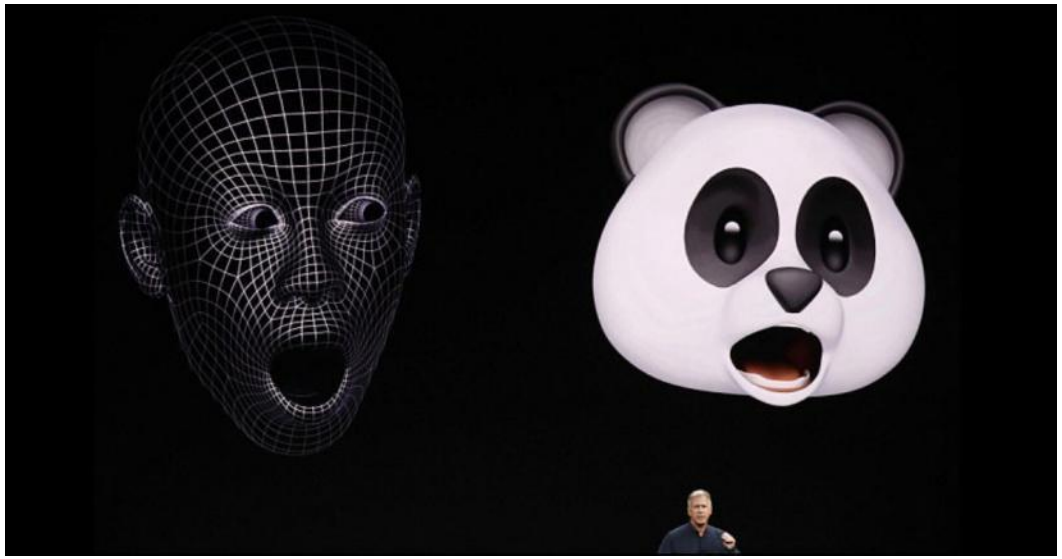
# FUTURE OF AR

- AR: Brain computer interaction
  - In the future, users of wearable hardware will be able to work hands-free when future devices work on voice commands or gestures.
    - Could be the end of physical controllers such as a keyboard or a mouse cursor.
    - Research is going on for brain computer interaction methods that enable AR content selection via brain activity or other physiological sensors that enable AR devices to react upon the heart rate or emotional state of the user.

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# FUTURE OF AR

- AR: Combination of AI, AR, VR and MR
  - The combination of AI, AR, VR and MR, the transfer between the virtual and the real world will become easier and quicker. Recent developments in the field of AI, specifically deep learning, that support real-time image and speech recognition have helped to combine VR and AI for new applications.
  - Example: Apple's Animoji: used to create custom animated messages that use the voice and facial expressions of the user as a reference to reflect on.



https://www.inews.id/techno/read/gara-gara-animoji-di-iphone-x-apple-kena-gugat-perusahaan-software?sub_slug=gadget

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# › LECTURE 5

**AR Systems**
**Input & Output Devices**
**Hardware**
**Software**

# AR SYSTEMS

- Definition:
  - "We call an AR system a computer system that consists of suitable hardware and software to enrich the perception of the real world with virtual content as seamlessly and indistinguishably as possible for the user."
    - Dörner, R., Broll, W., Grimm, P., Jung, B. (2019). Virtual und Augmented Reality (VR/AR) (2nd ed.). Springer.

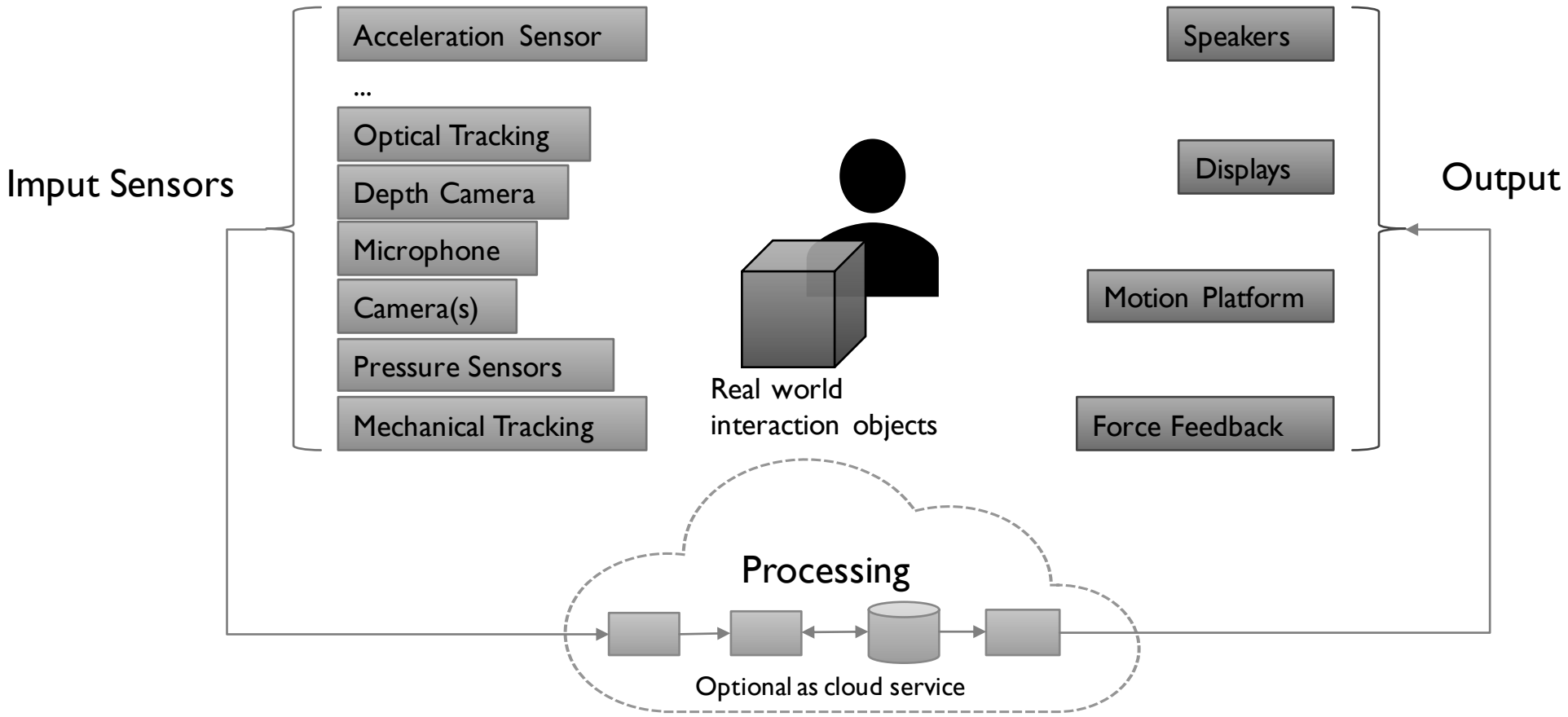
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# AR SYSTEMS

- Whereas in VR systems the sensor technology, world simulation and stimulus generation are often distributed among many computer systems to ensure the required performance of the overall system, most AR systems are limited to a single computer system. This can be a mobile device such as a smartphone or tablet or is sometimes completely integrated into AR data glasses (as in the case of the Microsoft HoloLens, for example). However, there are also approaches where tracking or rendering is outsourced to external systems to improve quality.

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# AR SYSTEMS - OVERVIEW OF THE SUBSYSTEMS OF AN AR SYSTEM




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# AR SYSTEMS

## Strong vs. Weak AR:

- Weak AR
  - Imprecise tracking
  - No knowledge of environment
  - Limited interactivity
  - Handheld AR
- Strong AR
  - Very accurate tracking
  - Seamless integration into real world
  - Natural interaction
  - Head mounted AR

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# WORKING OF AR

- There are several ways to make AR work. According to Czettritz (2019) there are generally 5 steps that are needed for AR to work:
  - Video-recording
    - A video stream of the environment gets recorded by using a smartphone camera for example.
  - Tracking
    - This happens by calculating the position of the viewer in the environment. Point of view and angle are important for tracking as well. Tracking can either be done by using real-time-GPS, marker-tracking or 2D- and 3D-modelling.
  - Registration
    - an artificial coordinate system is established to help fixating the position of virtual objects in the real world. For this to work the position of the viewer has to be connected with the coordinate system.
  - Representation
    - the whole scene is being „generated". This is where the actual augmentation is happening.
  - Output
    - these augmented video images are displayed in the last step of the output on the respective end device.

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# AR CHALLENGES

- Latency
- Tracking
- 3D Image quality and resolution
- Rendering & bandwidth

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# AR CHALLENGES

- Simulation/cyber sickness
  - When camera motion inconsistent with head motion
  - Frame of reference helps
  - Worse with larger FOV
  - Worse with high luminance and flicker

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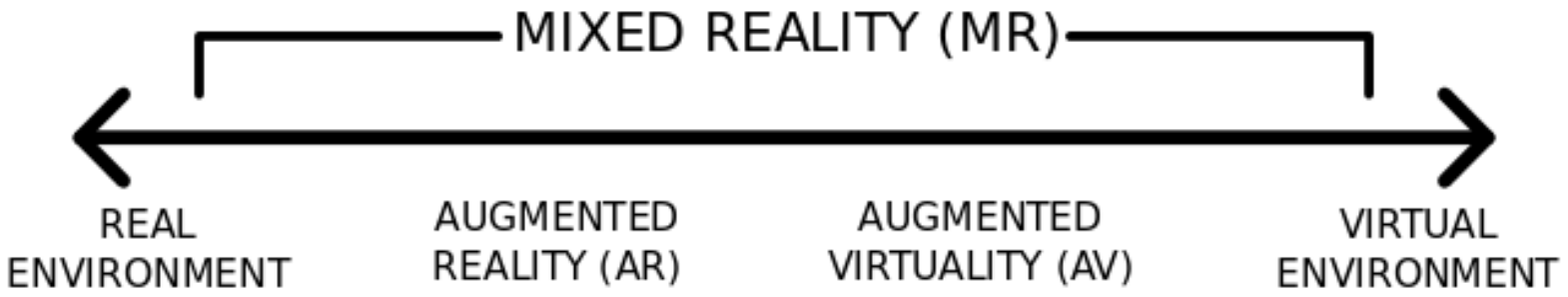
# AR VS VR

| | **Virtual Reality**<br>*Replaces Reality* | **Augmented Reality**<br>*Enhances Reality* |
|---|---|---|
| *Scene Generation* | Requires realistic images | Minimal rendering okay |
| *Display Device* | Fully immersive, wide field of view | Non-immersive, small field of view |
| *Tracking* | Low to medium accuracy is okay | The highest accuracy possible |

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# MIXED REALITY

- Definition:
  - "Mixed reality is unique in that the term usually refers to artificial products that interact with users in the real world. Augmented virtuality (AV) is a subcategory of mixed reality that refers to the merging of real-world objects into virtual worlds. call an AR system a computer system that consists of suitable hardware and software to enrich the perception of the real world with virtual content as seamlessly and indistinguishably as possible for the user. - Wikipedia




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# COMPONENTS OF AR

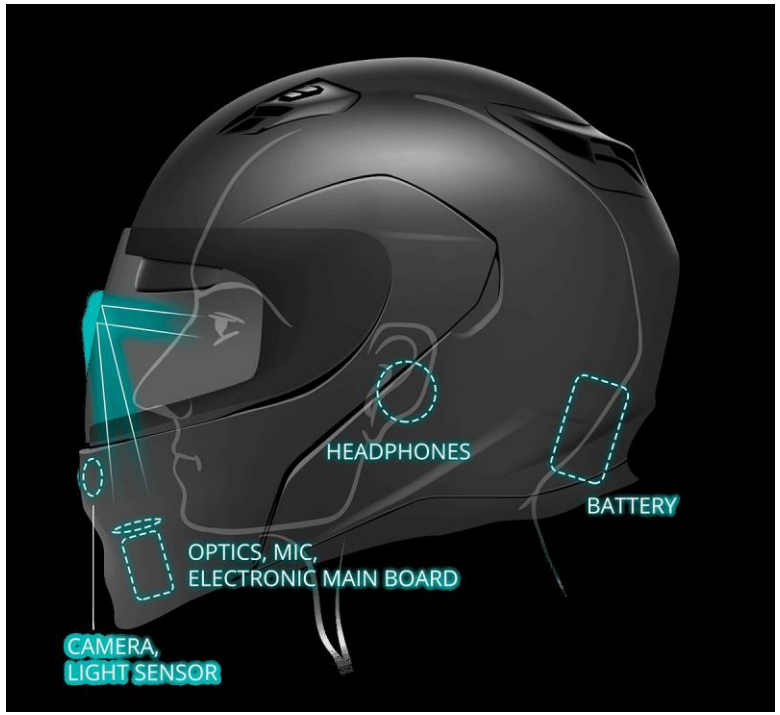
- Definition:
  - An augmented reality system is more than just a pair of glasses with digital lenses. It is much more than that. First and foremost, the main components are divided into three categories. Hardware, software, and the application are all involved.
    - (Craig, 2013)

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# AR DEVICES – HELMET

- When a device covers most of the head, it is referred to as a helmet. As though it were a regular helmet. The helmet frequently covers the ears, head, and a large portion of the face.

- Example: AR Motorcycle Helmet from LiveMap



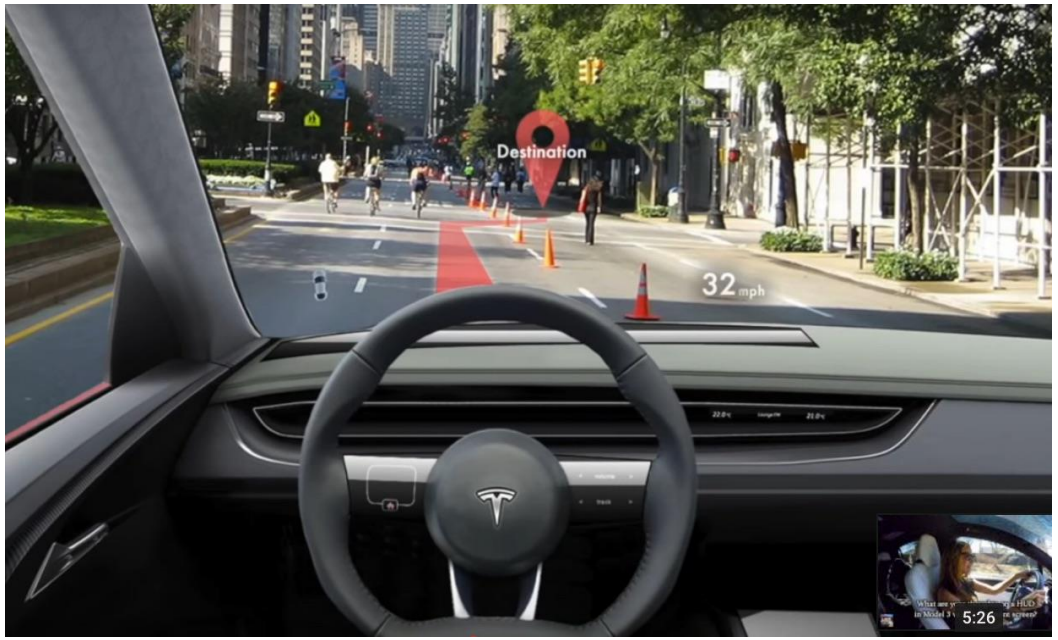

https://www.displaydaily.com/article/display-daily/livemap-developing-an-ar-motorcycle-helmet

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# AR DEVICES – HUD

- Cars are frequently associated with a Head Up Display. The speed, fuel consumption, and a variety of other data can be presented here. The display can be projected three-dimensionally for the eye in the windshield, among other things.

- It's unknown when or if this will become a reality and be available for purchase. Of course, Head Up Displays are also available in buses, vehicles, and airplanes.




https://www.teslarati.com/deep-look-tesla-model-3-hud-may-just-work/

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# AR DEVICES – SMART GLASSES

- In terms of size, the wearable smart glasses are like regular glasses.
  - Serves as a display and can be used to create visualizations.
  - Some can be used both inside and outside. It has something to do with the illumination.




https://www.eenewseurope.com/news/google-buys-ar-canadian-smart-glasses-startup

- Example: Smart Glasses from North

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# AR DEVICES – HANDHELD

- We're probably most familiar with the portable version.
  - Phones
  - Computers
  - Tablets

- Popular Example:
  - Pokémon Go
  - 3D models that appear after scanning a QR code



https://www.doctissimo.fr/forme/news/pokemon-go-activite-physique

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# HARDWARE

- The hardware section is subdivided into three major sections. It consists of sensors, processors, and displays. These are the three areas where hardware is required for the purpose of data capture, calculation, or visualization

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# HARDWARE – SENSORS

- Sensors provide information about our real world and send it to the AR application.
  - Location and the orientation of the participant.
  - These values are either gained through the glasses or from the cell phone. Furthermore, sensors provide much more information, such as the temperature, lightness, darkness and some more types of values about the environment (Craig, 2013)

- Optical tracking is also used through accessing the camera. It is the most used technique because by using the camera you get a lot of different information about the environment. Through optical tracking you can detect the location and orientation of the user from a handheld device (Craig, 2013).

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# HARDWARE – PROCESSOR

- The processor is a heart element in the entire AR system. Multiple processes can be handled by the processor at the same time.
  - Processor processes the sensor data.
  - Processor runs as a typical CPU and sometimes supports the GPU.
- It can be used in different ways. Additionally, it is different where the processor is located. The most common options are listed below:
  - Application run on handheld system such as a smartphone
  - Application run on handheld system connected to remote server(s)
  - Application run on desktop/laptop computer
  - Application run on desktop/laptop computer connected to remote server(s)
  - Application run as a web application
  - Application run on a cloud with a thin client
  - Other combinations of local and remote systems

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# HARDWARE – DISPLAY

- A display can provide information to the user of AR glasses in a variety of ways.
  - Through visualization and audio signals. Audio and visual information are frequently combined. An audio signal, for example, can indicate that there is new information that is visualized.
- The visualization can be done in two dimensions or three dimensions.
- Measured values or more complex content, such as the content from applications designed for targeted interaction with the user, can be displayed.
- An example of this is that the user could use his hand to touch the displayed content, and the application would respond accordingly.

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# SOFTWARE – IN THE AR DEVICE

- The internal Software is working in different ways. The Software stays in contact with the environmental sensors, the application engine, other sensors and rendered visual and audio information. That is the basic work for this software in the AR Device.




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# SOFTWARE – IN THE AR DEVICE

- The software which interacts with the environmental sensors is working to get information on how the environment looks around the user.
  - It uses the camera and analyses the image.
- The sensor integration is necessary to read the sensor values and prepare it into a piece of information for the app engine.
- The Application Engine is the heartbeat for the AR Device. It is listening to sensor, audio and the video data and provides some information for the participant.
  - Shows some information about the environment. The Rendering Software makes sure all information is being made visible to the participant.
  - Renders all information and sends it to the display devices.

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# SOFTWARE - APPLICATION

- The development of an AR application is, for the most part, similar to the development of other applications.
  - Though there are special and recommended AR application environments that can be used to develop an application.

- As a result, the development of an application must be carefully considered. The libraries which are available are also affected by the environment and hardware. Even though AR application development involves content such as 2D, 3D, and audio, there are also individual specialization tools that can be used to create content in these areas

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# › LECTURE 6

**Exercises: AR with Unity**

# OBJECTIVES

- Simple example projects to demonstrate how AR can be included into an application. For this the Unity Engine (https://unity.com/) and Vuforia (https://www.ptc.com/en/products/vuforia) will be used.

- Vuforia is a tool mainly for recognizing images and objects. Vuforia will be used to recognize various images or objects (targets) and to react to the recognition of a target. For this purpose, Vuforia provides free licenses for developers and projects under development.

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# EX. 1: SETUP

- Install Unity and the Unity Hub, when installing the Version make sure to add the "Android Build Support".
- Create a new Unity project
- Download Vuforia
  - Vuforia can be downloaded from https://developer.vuforia.com/downloads/sdk. There select the download for Unity and download it.
- Create a Vuforia account on the same site by clicking "Register".
- Drag and drop the downloaded .unitypackage file into the Assets tab in Unity. Follow the prompted steps and import Vuforia into the Unity project.

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# EX. 1: SETUP

- Get a Vuforia license key for the project. This can be done in the Vuforia Developer Portal under https://developer.vuforia.com/. Log in on the page and navigate to "License Manager". Select "Get development key" to obtain a license for developing with Unity. Follow the steps and copy the license key to your clipboard.

- Go back to the Unity project and navigate to the VuforiaConfiguration-Script under Assets/Resources.

- Open the script in the inspector and paste the license into the field "App License Key". Activate the license by clicking "Add License".

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# EX. 1: USING ANDROID DEVICES

- Activate developer mode on the android device you want to use. To do this go to "About your device" in the device's settings. There should be a build number at the bottom of the page. Tap ten times on this number to activate developer mode.

- You are now able to connect the device via USB with the computer and build and run the application directly on the device.

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# EX. 1: IMAGE TARGETS

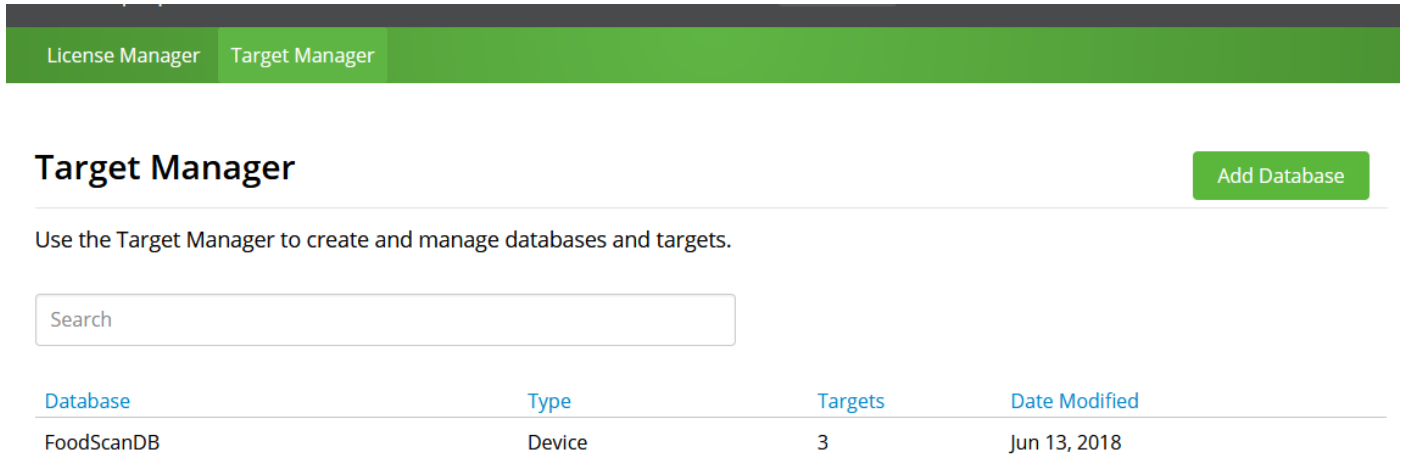
- Using Image Targets is the simplest way of including AR into the application and therefore it is the first exercise.

- Create a database for the used images. Vuforia will analyze the image(s) and identifies parts that can be used to identify the whole image. This information is stored in a database and can be used to add Image Targets to the Unity project.

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# EX. 1: IMAGE TARGETS

- Log in into the Vuforia developer portal (https://developer.vuforia.com). In the Target Manager tab, create a new image target database by clicking "Add Database".
- Provide a name for the new database as well as specifying the type. For this exercise only the type "device" will be used, which means that all data will be stored on the target device and the recognition will also be performed on the target device. Other types may cause costs.




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# EX. 1: IMAGE TARGETS

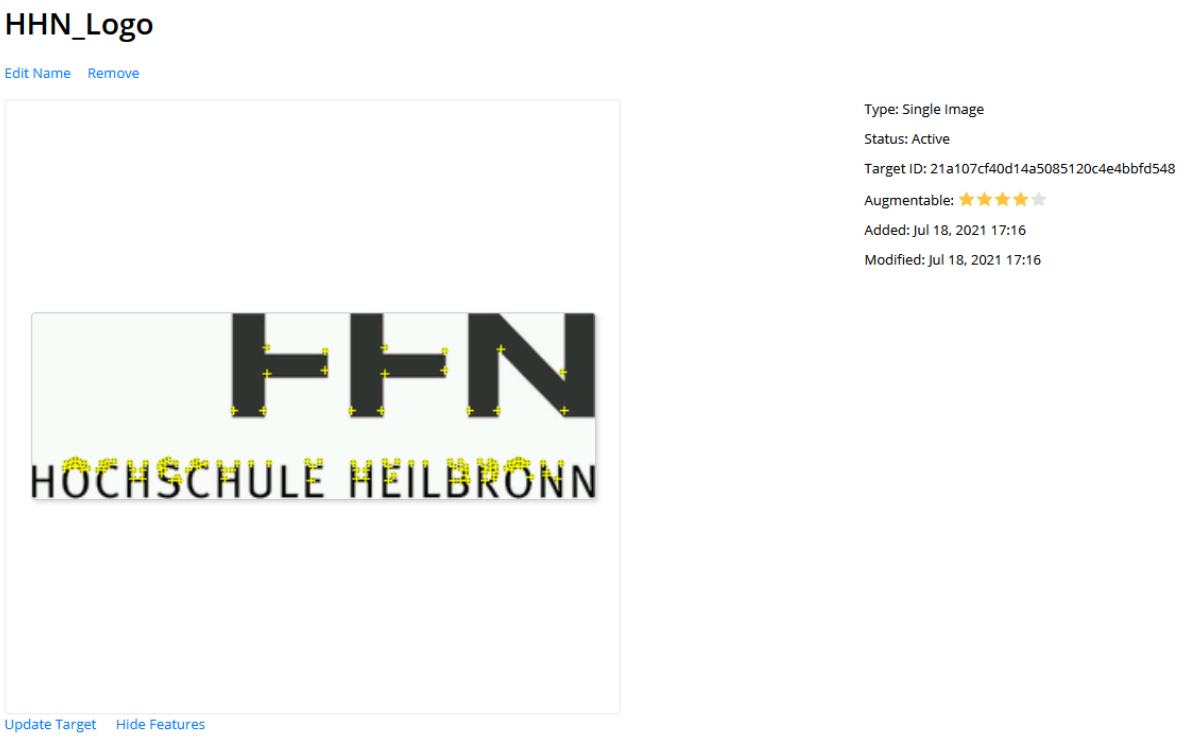
- After successfully creating the database, add a new target by clicking on the newly created database and clicking on "Add Target".
- For this example, the HHN logo will be used.
- Keep in mind that this process does not support transparency with RGBA images.

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# EX. 1: IMAGE TARGETS

- After importing the pictures, click on the newly imported picture and select "Show features" to see the points Vuforia uses for recognizing the image.

- To download the database, click "Download Database" and select "Unity Editor" as the development platform. After the download has finished drag and drop the .unitypackage into the "Assets" tab in the Unity project.



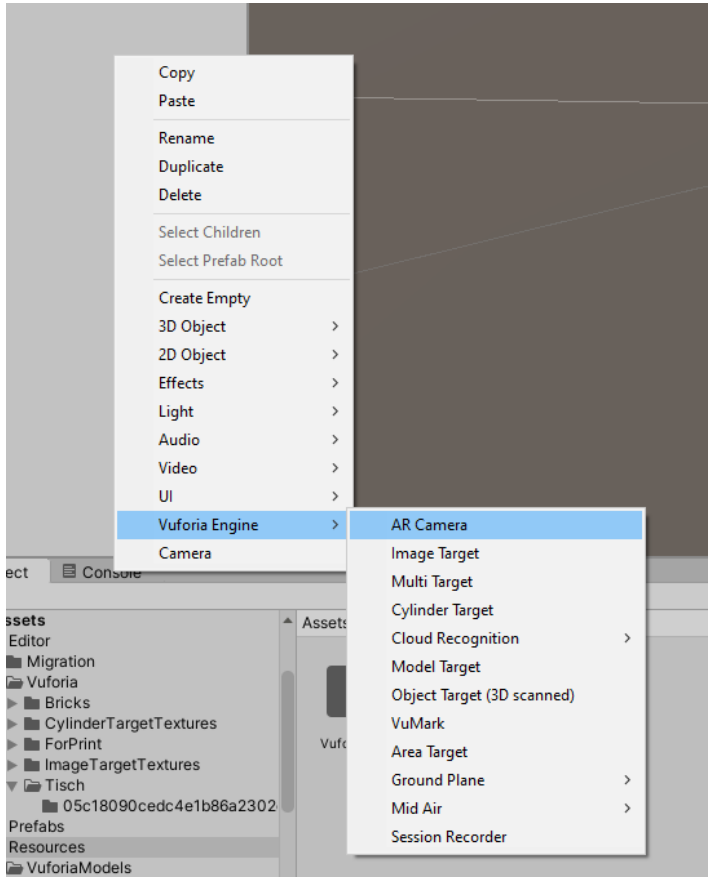

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# EX. 1: CREATING IMAGE TARGET

- To add the Image Target to the Unity project after importing the previous image target database, make sure Vuforia is imported and contains a valid license key in the VuforiaConfiguration script in the Resources directory.

- Remove the default camera and add an ARCamera by right clicking on the "Hierarchy" tab and selecting ARCamera under Vuforia Engine. The ARCamera is needed to enhance the default camera with the Vuforia functionalities.

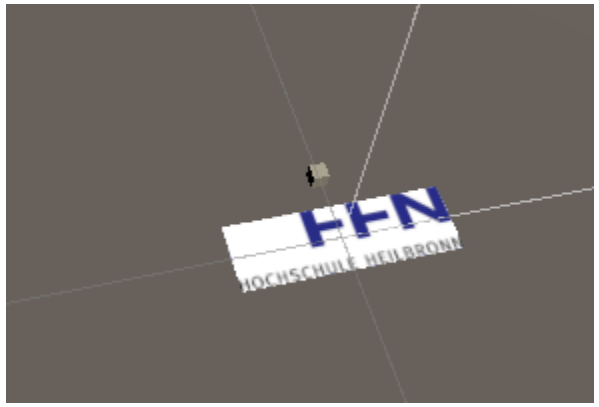
- To add Image Targets, right click on the "Hierarchy" tab and select Image Target under Vuforia Engine. Then select the Image Target and look at the Image Target Behavior script in the "Inspector" tab. Change the type to "From Database", select the database in the database section and select the image in the "Image Target" section.




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# EX. 1: IMAGE TARGET RECOGNITION – ATTACH GAMEOBJECT

- There are two basic ways of reacting to the recognition of an image target. In the first way a GameObject as a child of an Image Target is added. When the Image Target gets recognized all child objects will be displayed as to the image target.






# EX. 1: IMAGE TARGET RECOGNITION – PROGRAMMATICALLY

- The second way works programmatically. In this approach, methods as event listeners for the events when a target has been found or lost are added. This can be done in the "Inspector" view of an image target. In the Default Trackable Event Handler, the two sections "Event(s) when target found" and "Event(s) when target lost" are to be found.

- By clicking on the plus, custom action to these events can be added. By dragging and dropping a specific GameObject into the empty Object field this gameObject is assigned to the corresponding event and its public methods can be used/assigned.

- The assigned methods will then be executed when the corresponding target has been found or lost.

- To demonstrate this, a little script that displays the current status of our image target has been added.

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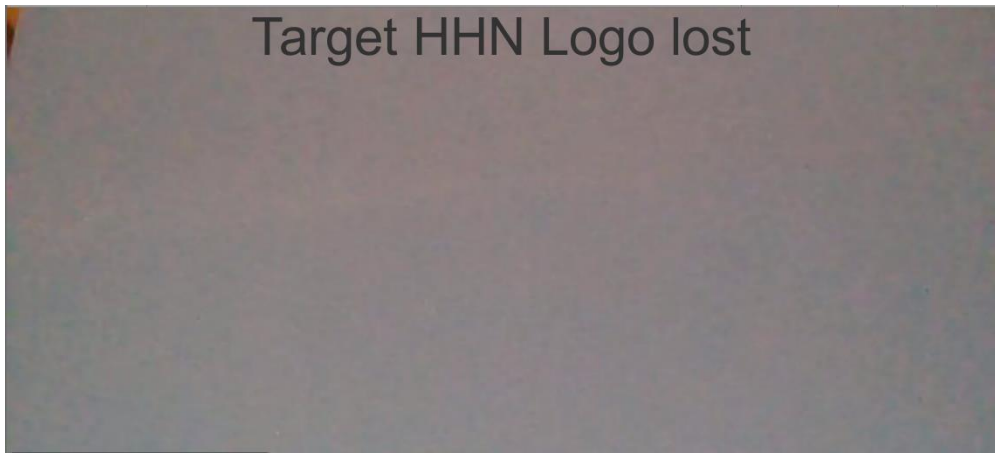
# EX. 1: IMAGE TARGET RECOGNITION – PROGRAMMATICALLY

- The second way works programmatically. At this approach you add methods as event listeners for the events when a target has been found or lost. This can be done in the "Inspector" view of an image target. In the Default Trackable Event Handler you will find the two sections "Event(s) when target found" and "Event(s) when target lost". By clicking on plus you can add custom action to these events. By dragging and dropping a specific GameObject into the empty Object field you assign this gameObject to the corresponding event and therefore you are able to use its public methods. A specific method can be selected in the list on the top right side next to the assigned GameObject. There you have the ability to browse through all assigned scripts and select a public method. If this method has additional properties, fields for them will be prompted underneath the selected method.
- The assigned methods will then be executed when the corresponding target has been found or lost. To demonstrate that we wrote a little script that displays the current status of our image target

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# EX. 1: IMAGE TARGET RECOGNITION – PROGRAMMATICALLY




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# EX. 2: MODEL TARGETS

- The second exercise will be about using 3D models as targets for virtual content.
  - It's a more advanced way of including AR into the application and offers some advantages over Image Targets.

- Since reacting to the recognition of a Model Target works the same way as it does for Image Targets, this topic will not be covered again in this section.

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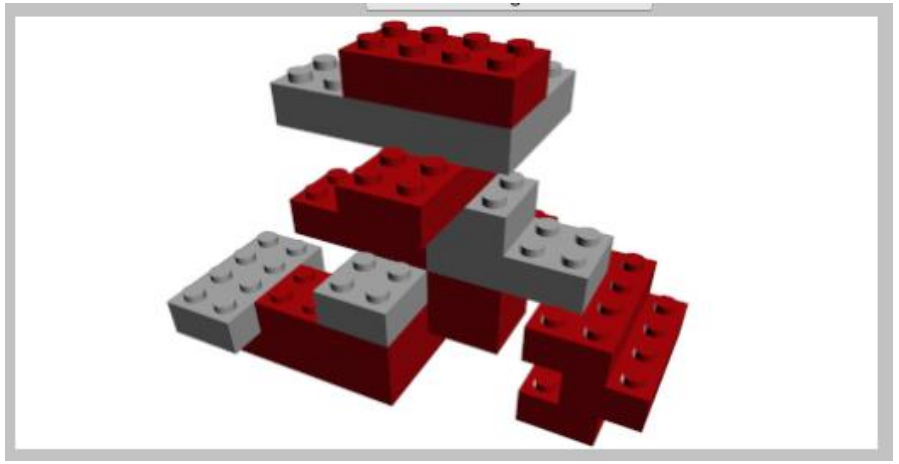
# EX. 2: ADDITIONAL SOFTWARE

- The recognition of 3D models is more complicated than the recognition of images.
- Therefore, the Model Target Generator (MTG) from Vuforia is additionally needed.
  - It can be downloaded from https://developer.vuforia.com/downloads/tool.
  - Be aware that the software needs an active Vuforia developer account and only provides 20 targets for free.
  - The MTG is used to translate 3D (CAT) models into Model Target Database which is used to generate Model Targets.

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# EX. 2: MODEL TARGET DATABASE

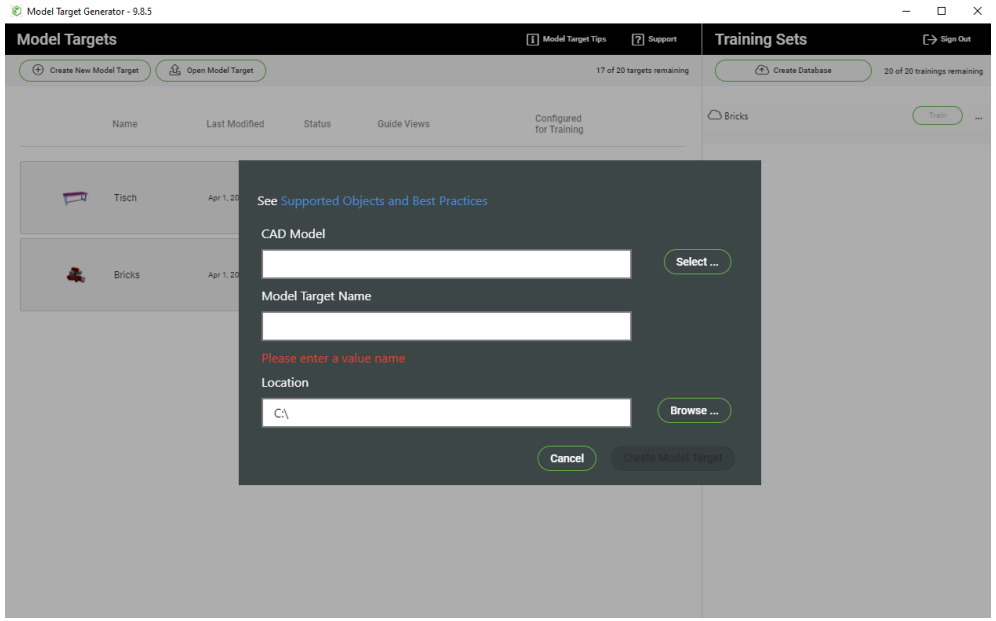
- To generate Model Target Databases using the MTG a 3D representation of the real-world object is needed. It must match the criteria mentioned under https://library.vuforia.com/articles/Solution/model-target-generator-user-guide.html.
- For this exercise, a brick model that was remodeled as a 3D model in blender is used. This approach was chosen because the model contains many edges that provide more features for the Vuforia recognition process. Furthermore, it is easy to build and easy to remodel in blender.



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# EX. 2: MODEL TARGET DATABASE

- To generate a model target database, open the MTG, log in and select "Create New Model Target". In the following pop up specify the location of our 3D model file and a location where the generated database shall be saved




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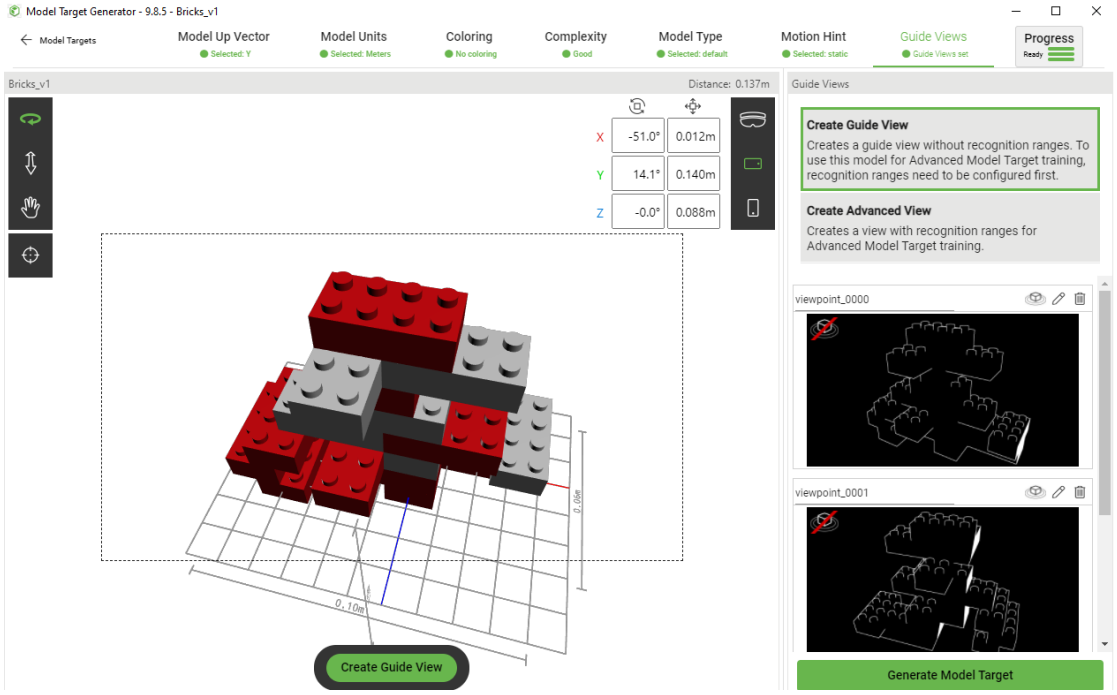
# EX. 2: MODEL TARGET DATABASE

- Select the correct up axis, the model units, additional coloring and the model type. Usually, the default values can be used for these selections.
  - Be careful when it comes to the model units because they have a larger influence on the recognition process and therefore should match the size of the real-world object.
- Now specify a Motion Hint.
  - Select Static for static objects and Adaptive for moving objects.
- Specify Guide Views.
  - These views are images of the model and will be used to detect it. There is also an option to create Advanced Views that work with machine learning and allow the recognition of the object without the need for separate images, but this is an advanced topic which will not be covered in this exercise.

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# EX. 2: MODEL TARGET DATABASE

- To create the Guide View, select "Create Guide View" and press "Next Step". Then select the type of target device for which the Guide View is created for.
- Adjust the model by rotating, panning and zooming until the model shows enough detail and fits into the dotted rectangle.
- Press "Create Guide View" and repeat the whole process for different perspectives. When enough Guide Views are created, press "Generate Model Target" to finish the whole process.
- When the model target has been created there will be a link to the generated data. Click it to have a look at the generated data in your explorer.



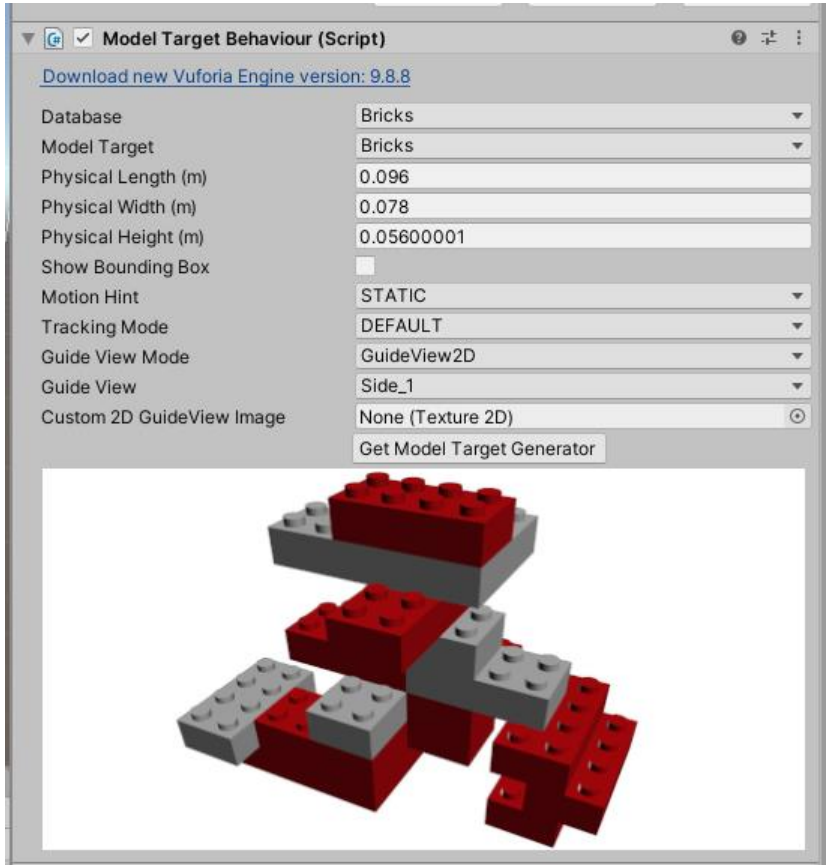

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# EX. 2: CREATING MODEL TARGET IN UNITY

- To create a Model Target, import the newly created Model Target Database. Open the directory where the data for the Model Target Database has been saved. There should be a unitypackage file which that has to be drag and dropped into the "Assets" tab of the Unity project.

- Create a Model Target by right clicking on the "Hierarchy" tab and selecting Model Target under Vuforia Engine. Select the newly created Model Target and open its "Inspector" view.

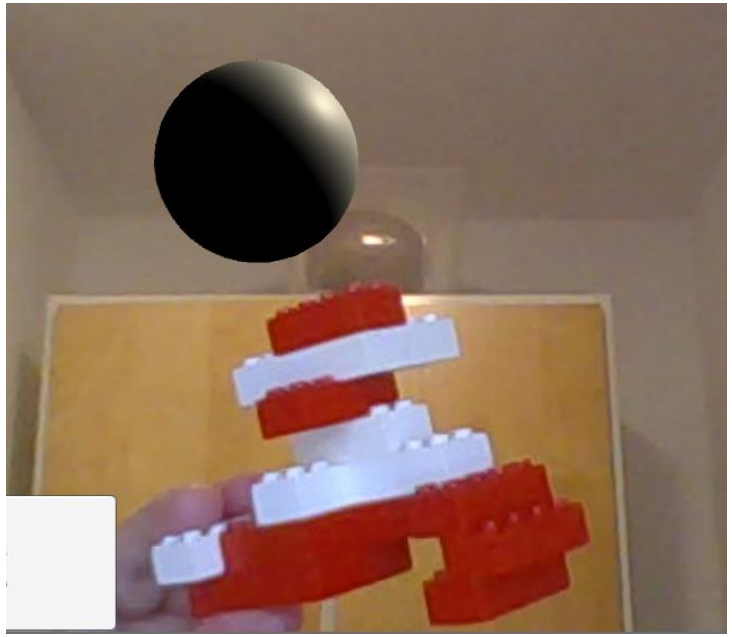
- In the Model Targets Model Target Behavior script, specify a Database and a Model Target. Adjust the Physical size to your real-world object. Select a Guiding View for the Model Target.




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# EX. 2: TESTING

- Testing of Vuforia AR applications is straight forward. If the device has a camera just start the application by pressing the play button in the upper middle menu inside the Unity Editor. Then place the real-world model in front of the camera.



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# › LECTURE 7

**VR/AR Applications**
**Military**
**Industry**
**Education**
**E-Commerce**
**Treatment of disease**
**Real Estate**
**Gaming**
**Construction and Architecture**
**Civil aviation**
**Business and marketing**

# MILITARY

- When people talk about virtual or augmented reality, they might initially think of more playful and entertaining applications.

- But the origins of many major VR/AR developments can be found in the military. Development costs money - which at least the U.S. military has plenty of.

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# MILITARY – TRAINING

Necessity of "virtual" training methods:

- Danger for humans as well as material cost increase with the degree of realism
  - Early research conducted by the U.S. military's STRICOM (U.S. Army Simulation, Training, and Instrumentation Command)



https://commons.wikimedia.org/wiki/File:Engagement_Skills_Trainer_(EST)_2000.jpg

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# MILITARY – TRAINING

- With the emergence of the first first-person shooters in the consumer sector, STRICOM discovered the potential of wargames.
  - The first big shooter "Doom" was immediately turned into a "Marine Doom" to train marines in close combat
  - The makers of the game "DeltaForce2" were commissioned by STRICOM to adapt the game for Army training purposes in order to introduce soldiers to the use of the new "LandWarrior".
  - Other "training games“ include:
    - Rainbow Six Rogue Spear
    - Microsoft Flight Simulator.

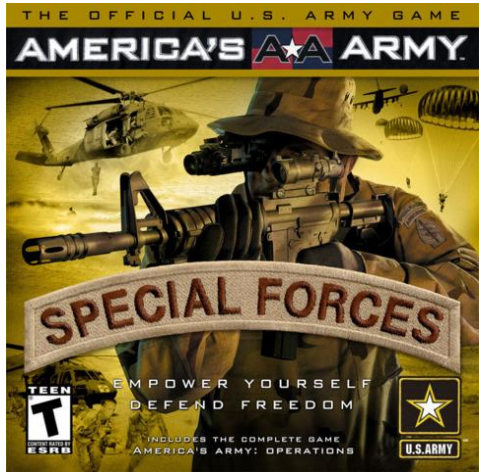



https://www.youtube.com/watch?v=0W5I59EPdTE

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# MILITARY – TRAINING

- Recently the U.S. Army has also started to produce its own wargames, the idea being to attract young people to the Army and to exploit the potential of long-time players who, in the Army's opinion, have developed valuable skills through "training".
- Example: "Americas Army“
  - The player can play, as realistically as possible
  - The game is absolutely competitive with consumer programs in terms of quality but is absolutely free
  - According to a director of the U.S. Army's Office of Economic & Manpower Analysis (OEMA), "The computer game is a very cost-effective way to reach potential recruits.“




https://www.giantbomb.com/americas-army-special-forces/3030-6437/

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# MILITARY – SIMULATION

- At the end of the 1980s, the Defense Advanced Research Projects Agency (DARPA) launched the SIMNET (Networked Simulation).

- Network several individual simulators so that they can all participate in a simulated maneuver.
- Up to 800 participants scattered around the world can participate
- Completely different VR simulators (tank, helicopter or fighter jet simulators) can interact in a networked system

- SIMNET was probably used in the preparations for the "Desert Storm" maneuver in the Gulf War.

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# MILITARY – IN COMBAT

- The goal of VR/AR applications in real combat operations is to provide humans with certain enhanced capabilities that should help them achieve superiority in combat operations. A major DARPA project here is the "Land Warrior".
- Via the HMD the soldier can access tactical data, maps, or other information,
- At the same time, he is constantly networked with the control center and can send and receive messages.
- As a weapon, he has a sophisticated thermal weapon at his di with automatic target tracking and a built-in camera
- Under development by DARPA since 1991, first used for trair in 2000 and finally deployed in the Iraq war



https://www.theglobeandmail.com/technology/us-militarys-land-warrior-system/article788987/

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# MILITARY – IN COMBAT

- A classic AR application can be found in the field of fighter jets.
- A HeadUp Display (HUD) gives the pilot:
  - An extended view
    - Radar and other measurement data are displayed directly in the pilot's field of view.
  - Automatic target acquisition systems
    - allow other aircraft to be highlighted that might not even be visible to the eye.

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# INDUSTRY

- A lot of money is also available in industry, although it is not spent there out of a love of research, but at least wherever something promises an advantage in the form of cost savings or profit growth.

- In industry, the applications are more complex, but generally go down to the fact that virtual models save costs in development and maintenance.

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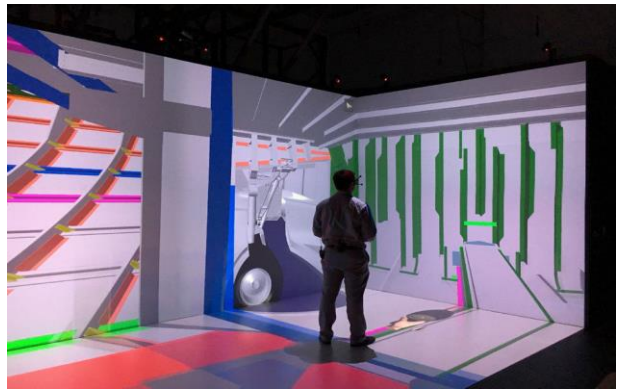
# INDUSTRY – PRODUCT DEVELOPMENT

- VR techniques can accelerate many processes in product development, automate and ultimately also significantly improve efficiency.
- Shorter development times
- Better products.
- The product is planned, designed and tested digitally, and even manufacturing is simulated completely virtually.
- Advantage: only one model exists, which can be (re)used for various purposes with minor adjustments, expensive physical prototypes can thus be largely eliminated.

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# INDUSTRY – DESIGN

- Digital methods have become indispensable in the field of product design.
- In the automotive industry, VR applications have been used for some time now to give designers a realistic impression of their design.
- In contrast to physical prototypes,
- Changes can be made quickly and made visible immediately
- The model is displayed in a kind of CAVE, making it real for the designer.



https://www.archpaper.com/2016/07/vr-cave-wichita-state-university/



https://www.tagesspiegel.de/berlin/rolls-royce-in-dahlewitz-flugzeugturbinen-aus-dem-holodeck/26818170.html

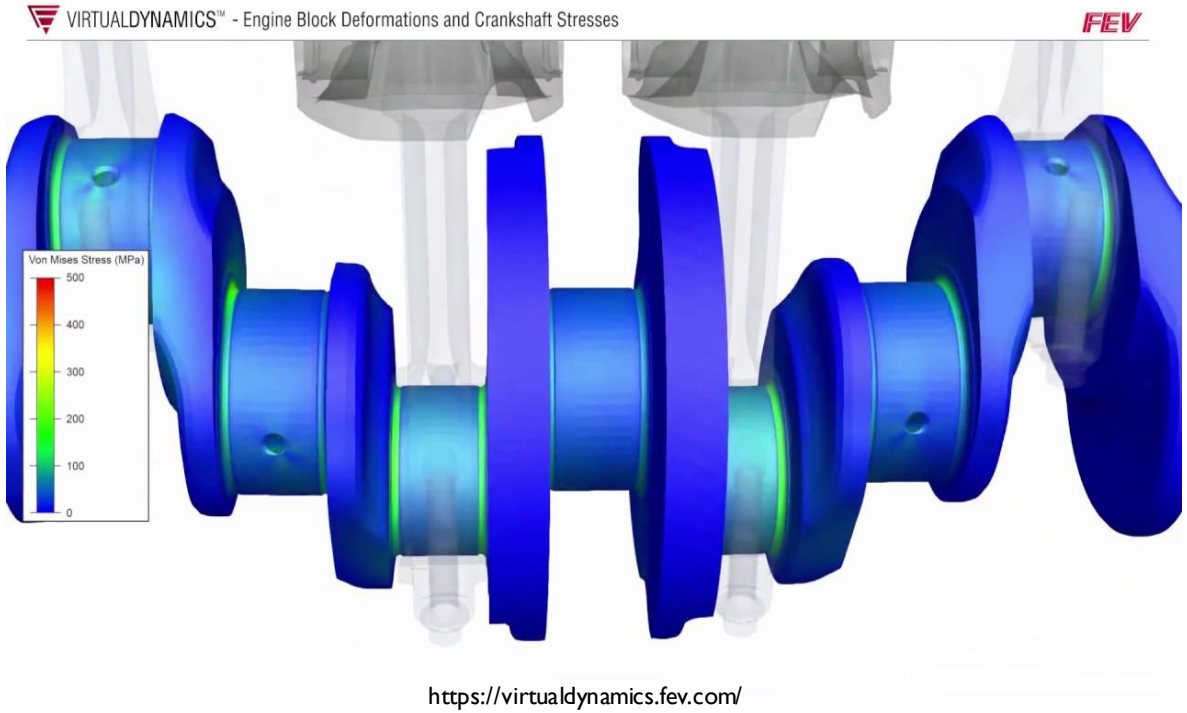
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# INDUSTRY – SIMULATION

- Today's simulation techniques can deliver very precise and correct results that allow completely virtual simulation to be performed reliably. On the one hand,
- Individual components can be tested as intensively as desired for their suitability and compatibility (with respect to other components), in this way, the long-term use of a component can be simulated in the overall system
- Small errors with a large effect can be detected at an early stage.
- Simulation on a larger scale can be found, for example, in crash tests in the automotive industry.
  - Enormous cost savings
  - Detailed physical simulation of each individual component within the crash vehicle
    → Behavior of individual components during the crash can later be viewed in isolation.
  - 3D data → The crash can be viewed from any position.

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# INDUSTRY – SIMULATION




https://virtualdynamics.fev.com/



http://ritmindustry.com/catalog/calculation-simulation-modeling-software/crash-test-simulation-software/

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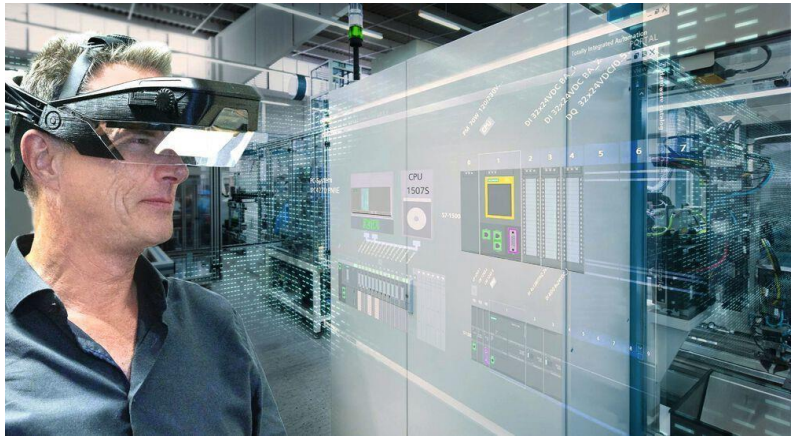
# INDUSTRY – MAINTENANCE/REPAIR

- The idea here is to depict complex systems, such as a Boeing, completely in a 3D model with additional information on all important individual parts. A technician who is inside this system can then access this data.
- Non-experts can also be used in such application areas
- The technician is relieved of a lot of work that he would otherwise have spent troubleshooting and reading documentation.
- The user is equipped with an HMD. Information is then automatically displayed over a relevant component in the user's see-through HMD.

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# INDUSTRY – MAINTENANCE/REPAIR

- There is a research project of the bmf+b: Augmented Reality in industrial applications (ARVIKA). The goal is to research and create AR Technologies to support work processes in development, production, and service.
- SEAR (Speech Enabled Augmented Reality) project from Siemens builds on ARVIKA but adds the dimension of speech. Here, it is made possible to receive a direct response by "addressing" a component



https://www.maschinenmarkt.vogel.de/keine-angst-vor-der-einfuehrung-von-augmented-reality-a-872531/

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# EDUCATION

- Several studies have shown that people who learn and train in VR retain the information much more deeply and for longer periods of time than those who simply use books, videos and other traditional methods.

- In one case, students learning construction management were broken into two groups, one using VR and the other traditional methods. The VR group scored higher on tests about the information both immediately after the lesson and a month after.

- In another case, medical students using VR did much better on live patients than those who learned via traditional methods. VR allows students to run the lesson as many times as needed, and they cannot be distracted while in the headset.

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# EDUCATION

Example:

- Virtual Reality teaching: Harvard launches public 3D lecture
  - https://www.youtube.com/watch?v=0C8a6GBF8Bg&t=26s

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# E-COMMERCE

- AR will absolutely revolutionize the e-commerce industry and has already started doing so. The possibilities are endless, but one big change will be the shift to "virtual showrooms."

- Consumers at stores like Uniqlo and Gap can already try on different colors and styles of clothing in a virtual dressing room, with mainstream expansion soon to follow. And it only extends from there.

- Imagine actually being able to "see" furniture in your home before you make your purchase, or checking out a car and all its features, right from your phone.

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# E-COMMERCE

- Example:Virtual mirror:




https://www.youtube.com/watch?v=da8wgPnVIH8

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# TREATMENT OF DISEASE

- VR and AR are unique in that they are immersive technologies. Unlike video, VR actually puts you in the environment and AR puts digital things in your environment.
  - It is interactive as well but mostly it is safe.
  - If a person has a fear of snakes, it is risky to expose that person to real snakes but far safer to expose the person to virtual snakes.

- PTSD treatment has been shown to benefit from VR and AR as well
  - Exposing the subject to the stimuli that caused the PTSD in a safe manner
  - Allowing the subject to work through the trauma at the subject's own pace.

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# TREATMENT OF DISEASE

- Training in handling tense situations also benefits from VR and AR
  - Allowing people to work through various scenarios with no consequence and
  - Learning experimentally how to handle them in the real world.

- What we learn in VR and AR carries over to real life and we can practice safely as many times as we want.

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# REAL ESTATE

- The future of this technology is virtual showings. Home buyers will be able to use VR/AR devices and walk through a home anywhere in the world. Home shoppers relocating from across the world can visit a home without ever leaving the comfort of their existing home.




https://medium.com/@Immersivegaze/how-augmented-reality-benefits-real-estate-business-90af57b7d3b2

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# REAL ESTATE

- Adding to this exciting change in real estate will be the introduction of augmented reality. Home shoppers will be able to virtually stage the potential home within their VR goggle view. Within the view, they can also find data:
  - Nearby schools, shopping, dining.
  - Realtors can leave post-it notes in the virtual tour describing information a consumer may want as they take a virtual tour of their new home.

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# GAMING

- Virtual Reality has positively impacted the entertainment industry.VR provides an immersive experience to the Gamers and provides a great movie watching experience.




https://mein-mmo.de/neues-vr-laufband-koennte-gaming-aendern/

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# CONSTRUCTION AND ARCHITECTURE

- Builders and architects can examine the construction site, finalize construction design and suggest changes accordingly with the help of Virtual Reality. Also, Builders can show the prototypes to customers using this impressive immersive VR technology




https://www.code-brew.com/impact-of-ar-and-vr-on-construction-firms/

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# CIVIL AVIATION

- Various national and multinational firms do provide training to their newly joined employees and provide on-job training to their existing employees via VR system.
- Using VR, employers can create real life scenarios for their employees and train them accordingly. Sometimes it is difficult to provide training for various tasks and requires a lot of effort, technological advancements and finance.
- Example: RampVR project by IATA
  - Combines highly configured VR hardware and software to train Airport Ground operation professionals.



https://www.youtube.com/watch?v=WKKTJmiChSk

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# BUSINESS AND MARKETING

- Product models are being developed in VR technology to provide an immersive experience to the customers about product and related services, that can help customers to decide whether to buy or not and benefits businesses to not invest more on developing real products for customer demonstration.



https://www.youtube.com/watch?v=9w6_QBNuNuA&t=45s

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# SUMMARY

- The quality of AR/VR applications has improved by leaps and bounds in recent times, and it is foreseeable that this will not change significantly in the future either, as Computers and virtual worlds are taking an ever-larger place in our lives.

- But new applications will also bring new problems and challenges, which are already becoming apparent today. The question of violence in games will take on an entirely new dimension when the real war becomes indistinguishable from the virtual one and vice versa. Or what if the immersion level of a first-person shooter reaches a degree at which our brain can no longer distinguish between reality and virtuality?

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DIGIMAN
master programme for digital manufacturing

# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Design of Digital Manufacturing

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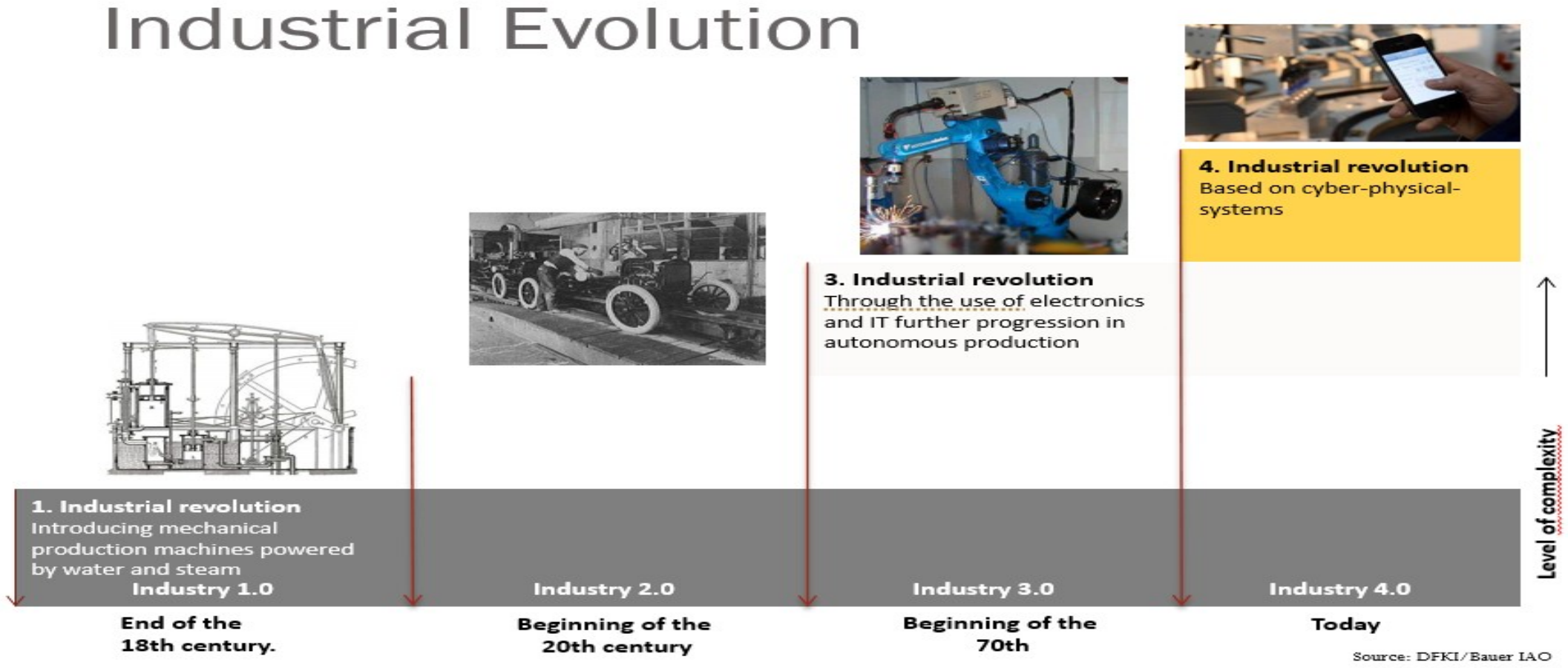
# Learning outcomes: On successful completion of this module a student should be able to:

- Understand what Digital Manufacturing is, what is possible and what tools and technologies are available.
- Know the techniques of synchronizing real (physical) and digitally simulated (cyber) production.
- Be able to analyze the operation of production systems digitally utilizing simulation, having knowledge of IT.
- Understand the transformation process of digital manufacturing from the position of traditional manufacturing methodologies.
- Understand the workflow of digital manufacturing: from scanning to modelling to printing.

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# HISTORY OF DIGITAL MANUFACTURING




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# HISTORY OF DIGITAL MANUFACTURING

Phases of earlier 3 Industrial Revolutions

1. 1760 to 1840 - Ushered in Mechanical production; railways and steam engine
2. 1870 to 1940 - Mass production; electricity and assembly line
3. 1960 to 2010 - Computers; semi conductors, main frame computing, personal devices, internet




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# HISTORY OF DIGITAL MANUFACTURING




- iPhone
- iPad
- Kindle
- 4G
- Uber
- Airbnb
- Android
- Instagram
- Whatsapp

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# HISTORY OF DIGITAL MANUFACTURING

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## Time to reach 100 Million customers

- Telephone 75 Years
- Web 7 Years
- Facebook 4 Years
- Instagram 2 Years
- Pokemon Go 1 Month



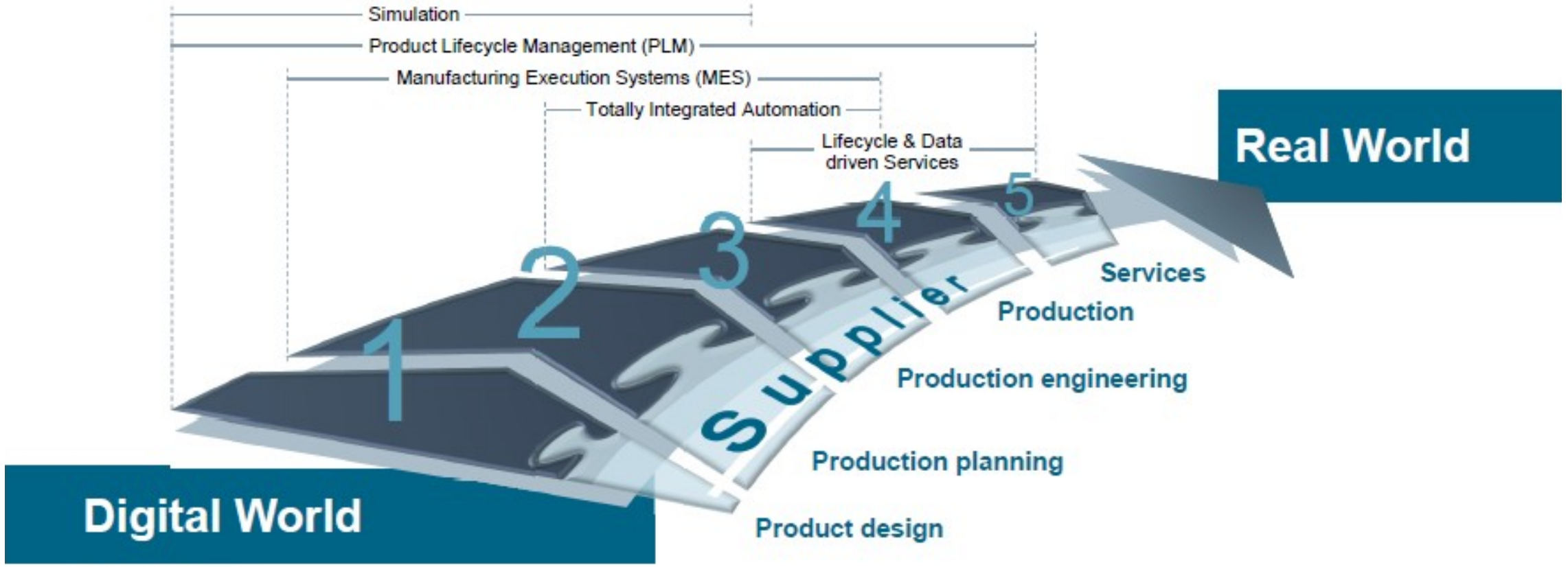

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# HISTORY OF DIGITAL MANUFACTURING

## Digital Enterprise

Entire value chain is digitized and integrated



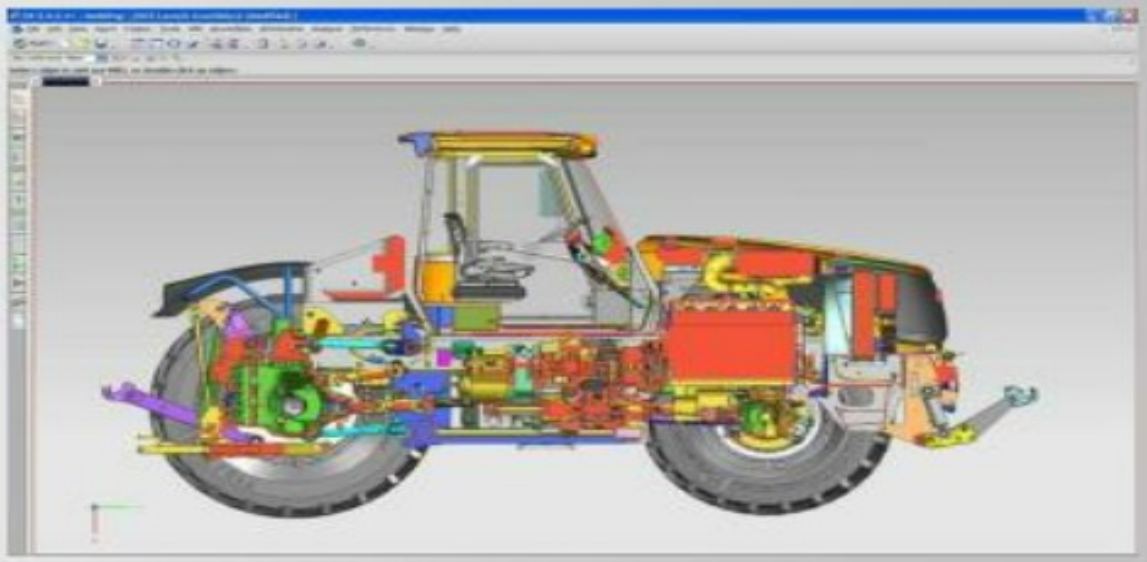

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# COMPUTER AIDED DESIGN

- The use of computer technology
  to aid in the design of a product
  - 2D vector base drafting systems
  - 3D solid and surface modelers





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# CAD SOFTWARE

- Animation
- AutoCAD Add-ons – Mechanical
- Parts and Details
- MCAD Programs
- Sheet Metal Design
- Specialized MCAD Programs
- Surface Modeling
- Tolerance Analysis
- Viewers
- Virtual Prototyping

SolidWorks
CATIA
NX
Autodesk
PTC
Rhinoceros
NURBS modeling for Windows





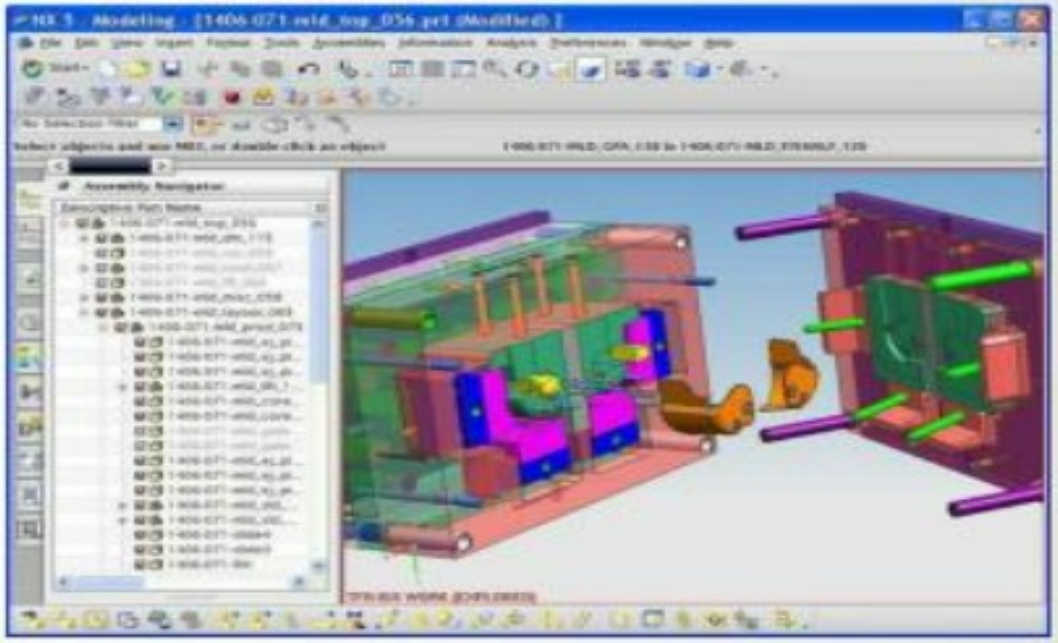

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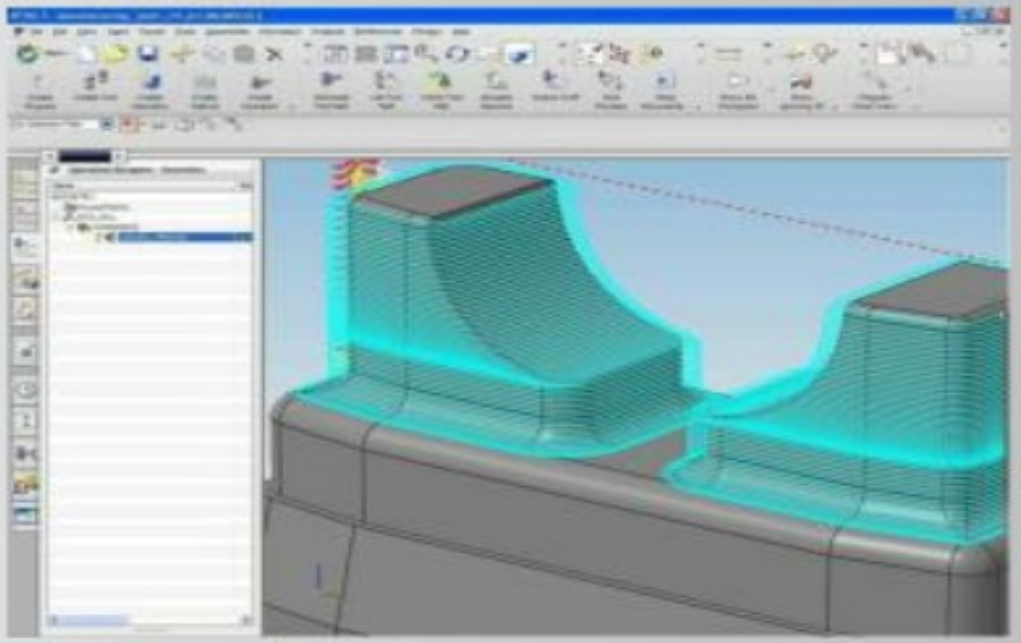
# CAM - COMPUTER AIDED MANUFACTURING

**Typical areas of concern:**

- High Speed Machining: streamlining of tool paths
- Multi-function Machining
- 5 Axis Machining



Mold and Tooling Example



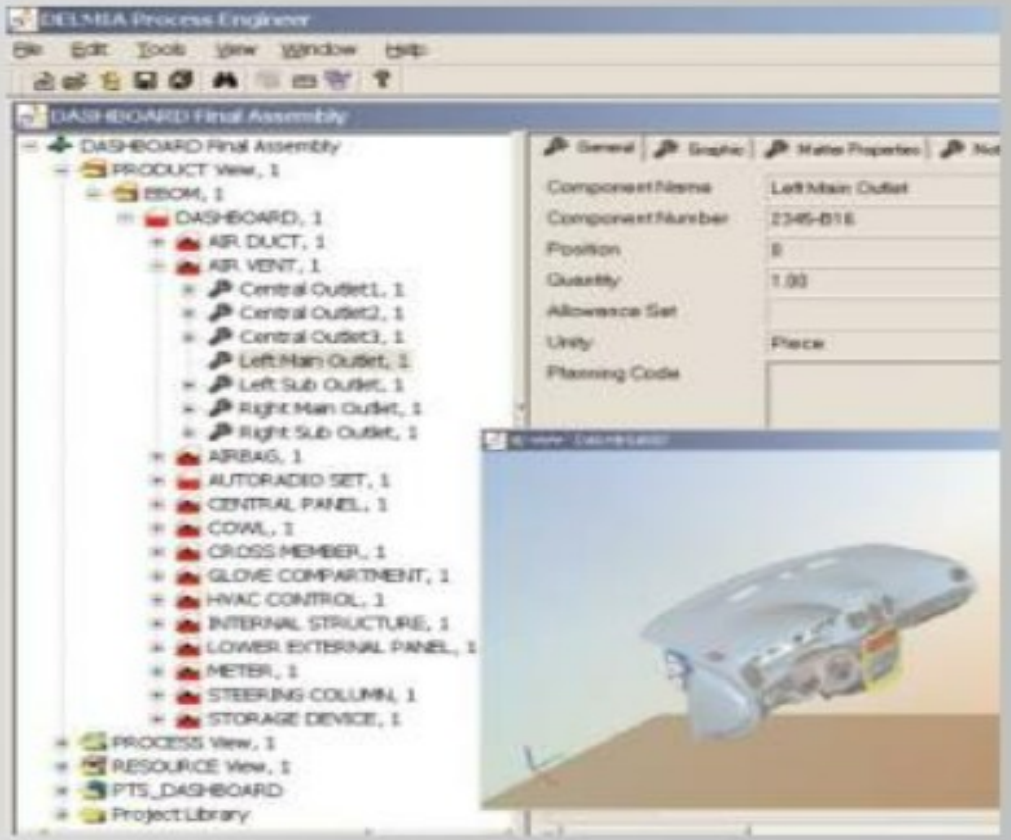
Tool path generation

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# CAPP – COMPUTER AIDED PROCESS PLANNING

- To prepare:
  - Detailed set of plans
  - Instructions to produce a part
- Begins with
  - Engineering drawings
  - Specifications
  - Parts or material lists
  - Forecast of demand
- The results of the planning are:
  - Routings
  - Process plans
  - Fabrication & assembly drawings



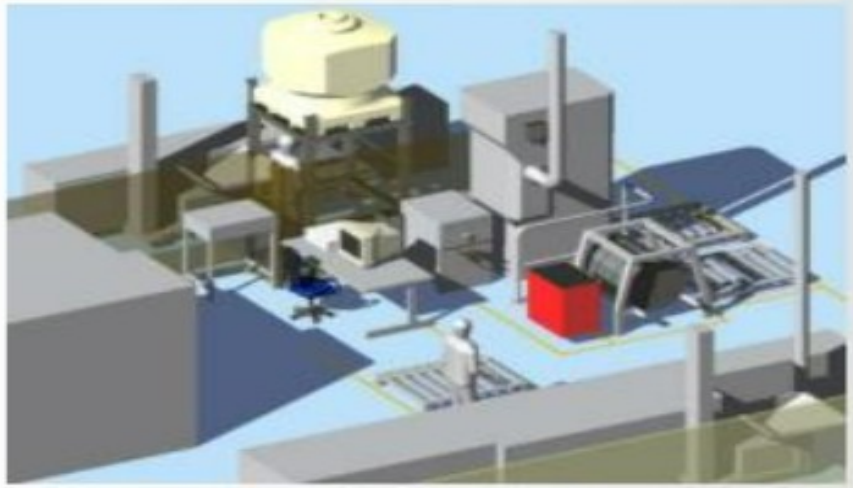

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# FACTORY LAYOUT PLANNING

- Creation of layout from 3D models for:
  - Virtual 3D models: sales personnel
  - Photo-realistic images or animation
  - Potential customers
  - BOM: basis for price calculations



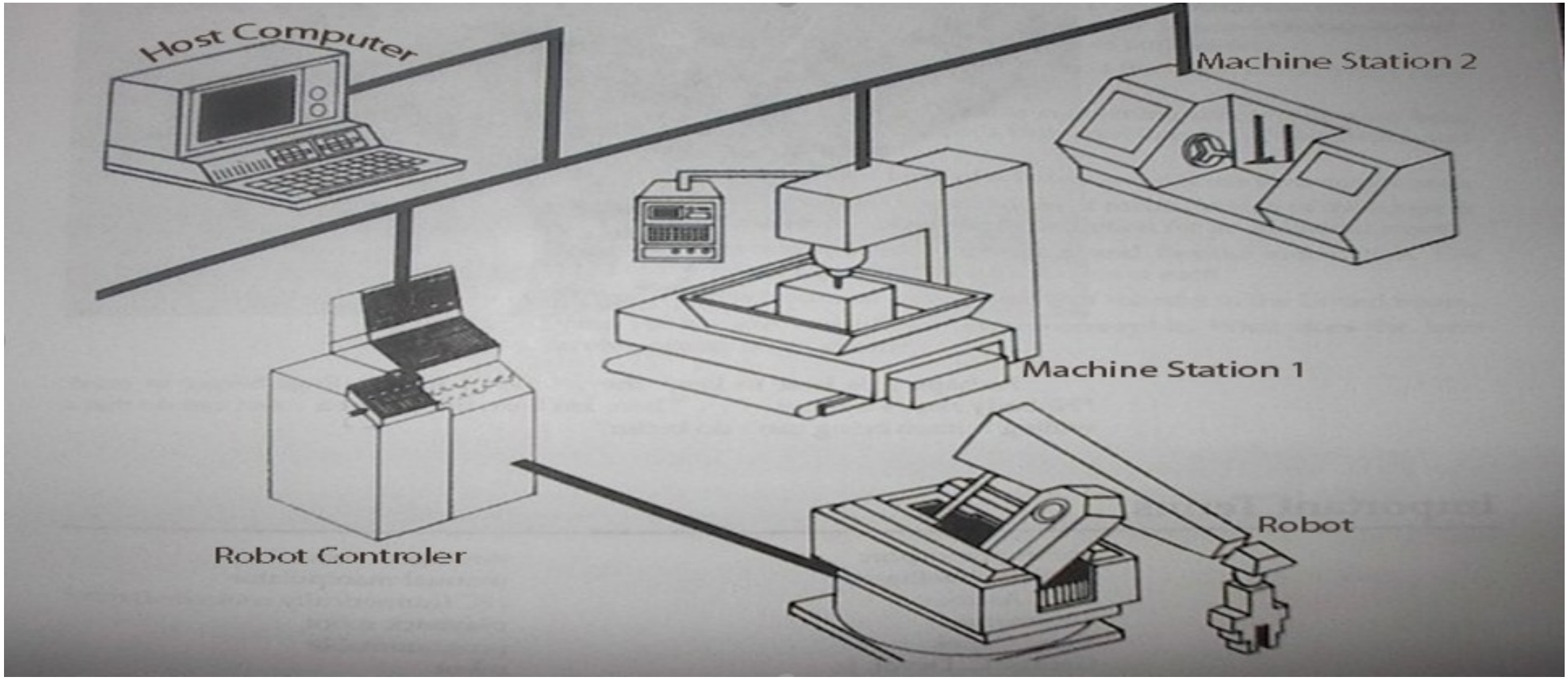




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# FLEXIBLE MANUFACTURING SYSTEM

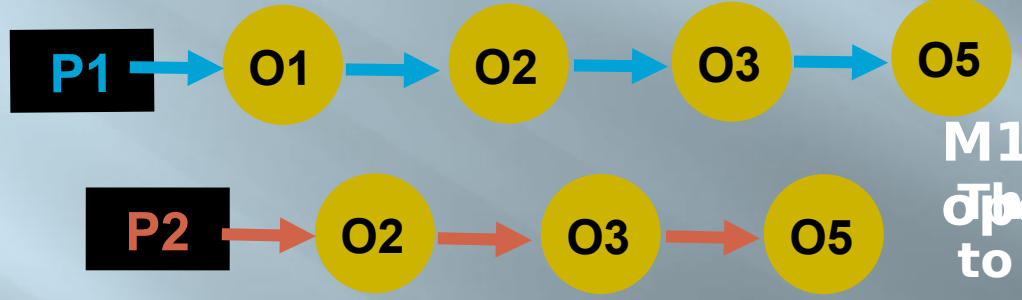


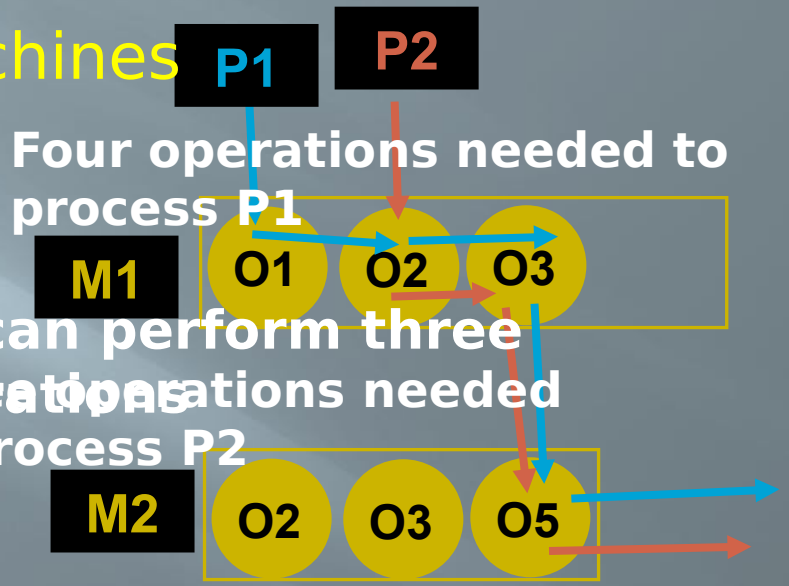

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# Example

Two part types & Three Machines



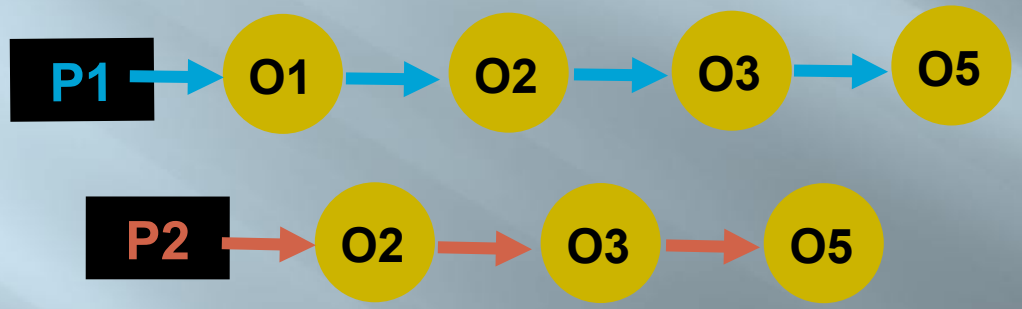



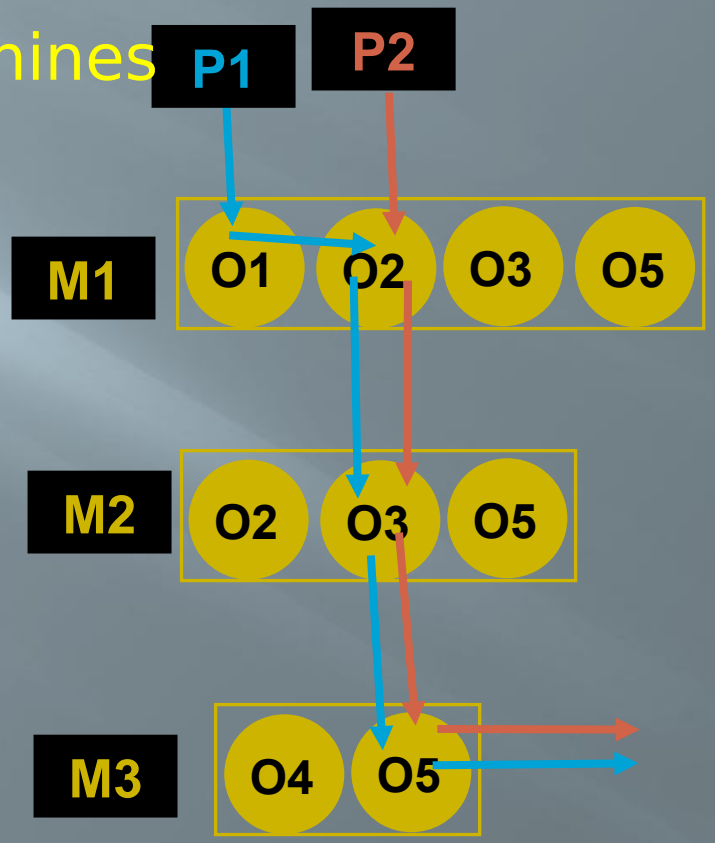

This choice tries to minimize part transfer between machines

**M2 can perform three operations**

**M3 can perform two operations**

## Two part types & Three Machines

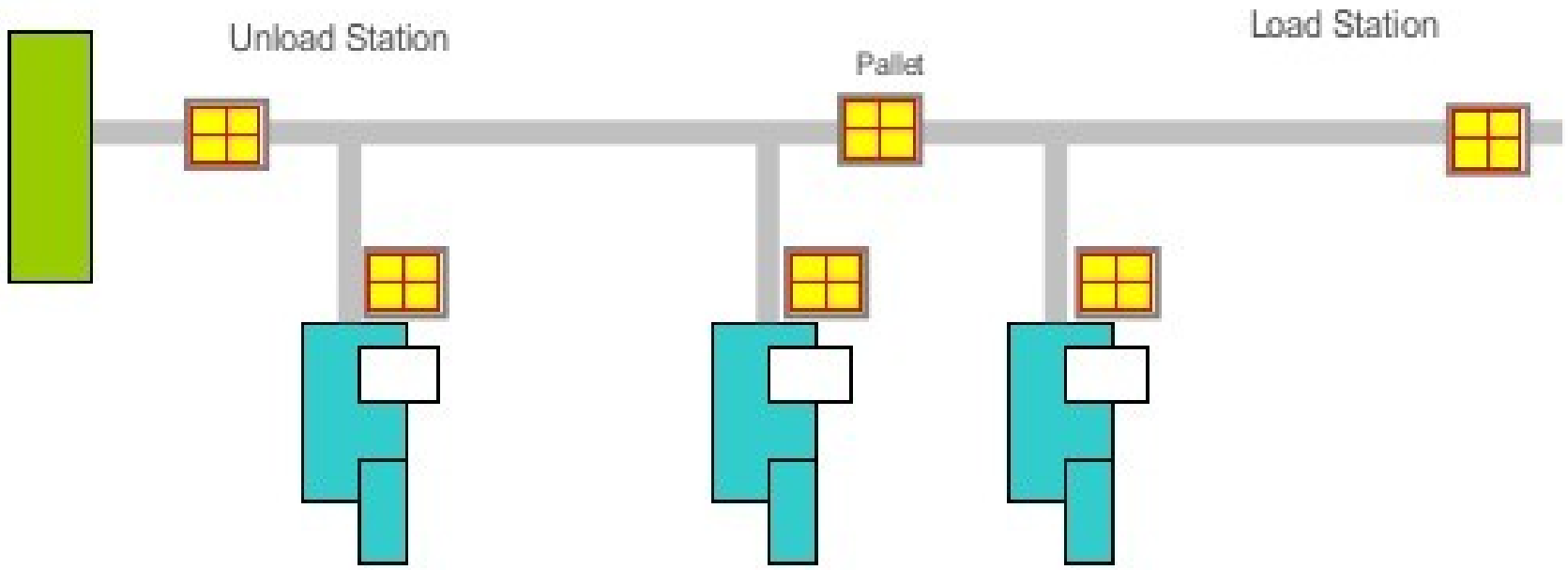



This choice tries to distribute workload (operations) evenly between machines

# FACTORY LAYOUT PLANNING

- **Progressive Layout-** All parts in the production process follow the same progression through the machining station
  - Best for producing a variety of parts




Progressive FMS

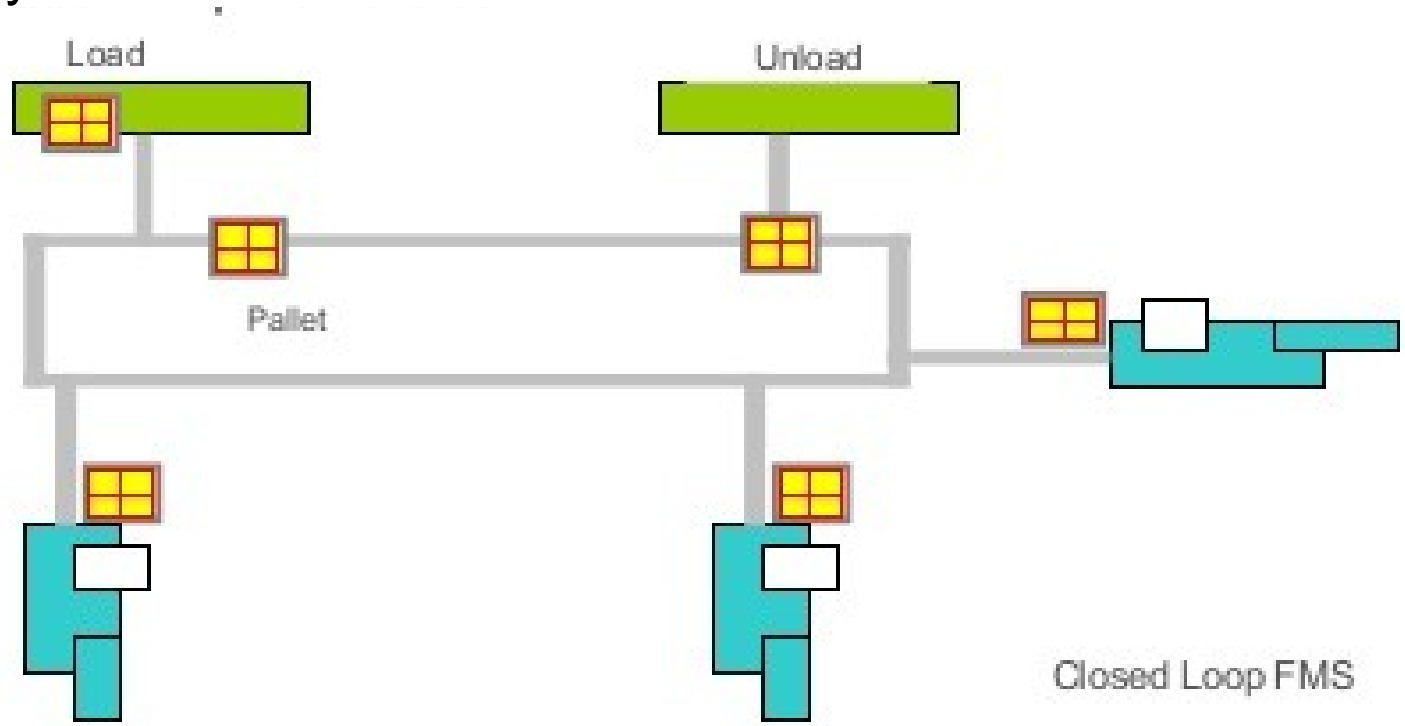
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# FACTORY LAYOUT PLANNING

**Closed Loop Layout** - Arranged for the general order of processing for a larger variety of parts

- Parts can skip stations for flexibility
- Used for large part sizes
- Best for long process times



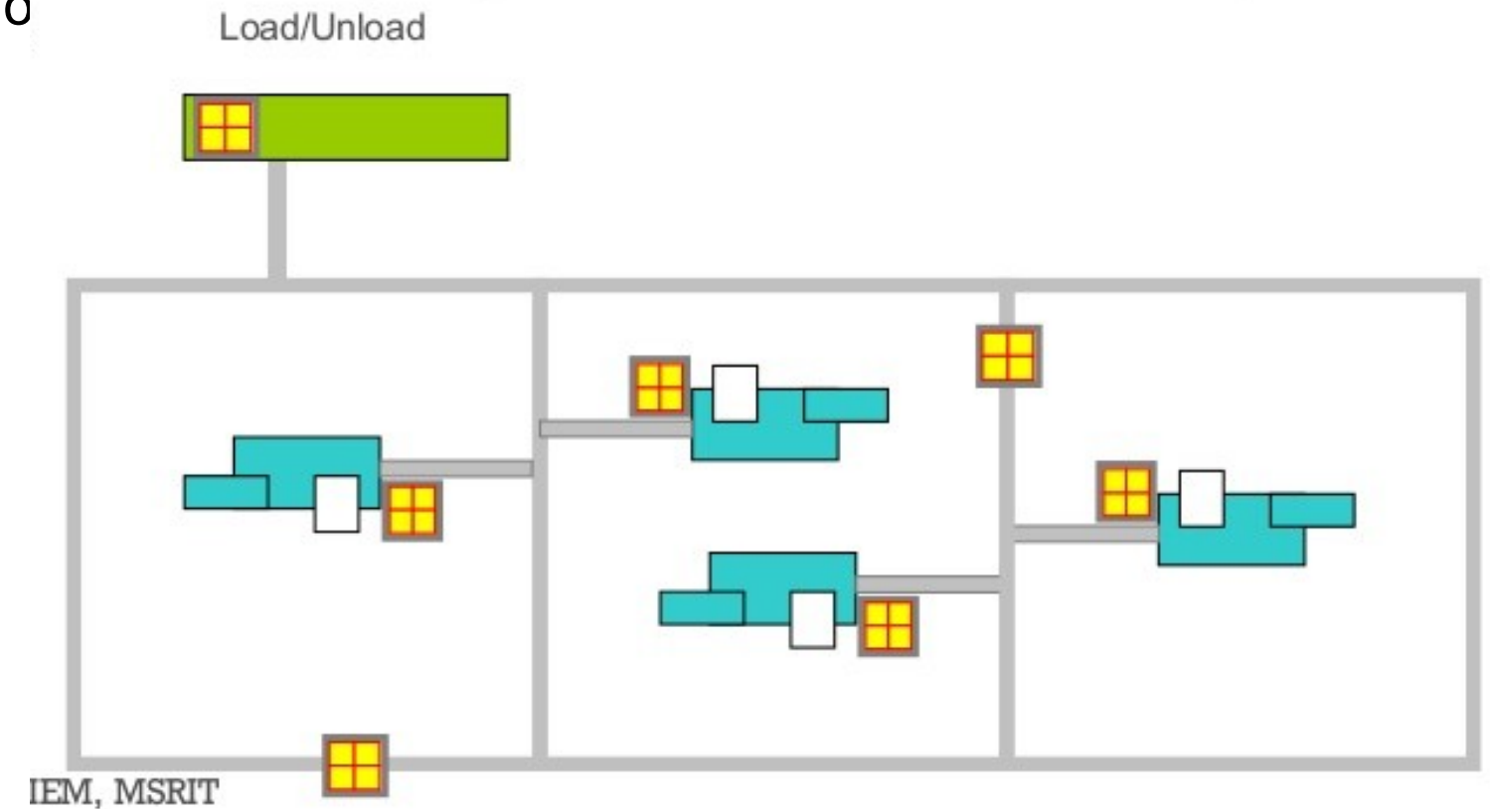

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# FACTORY LAYOUT PLANNING

**Ladder Layout** - Allows two machines to work on a product at the same time

- Parts can be sent to any machine in any sequence
- Parts not limited to particular part families

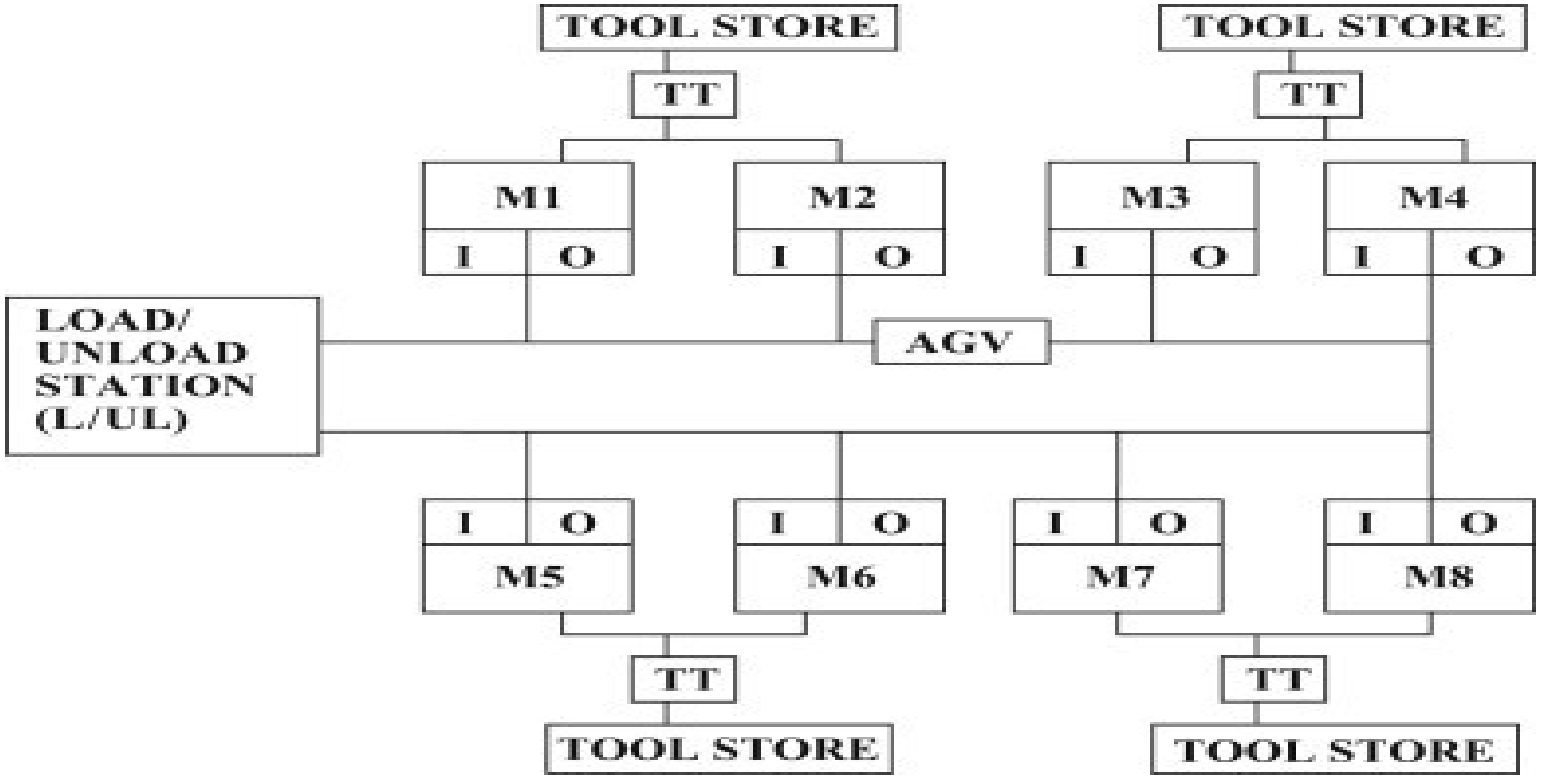



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# FACTORY LAYOUT PLANNING

- **Open Field Layout** - Enables material to move along the machine centers in any particular order necessary
  - Most complex FMS layout
  - Includes several support stations

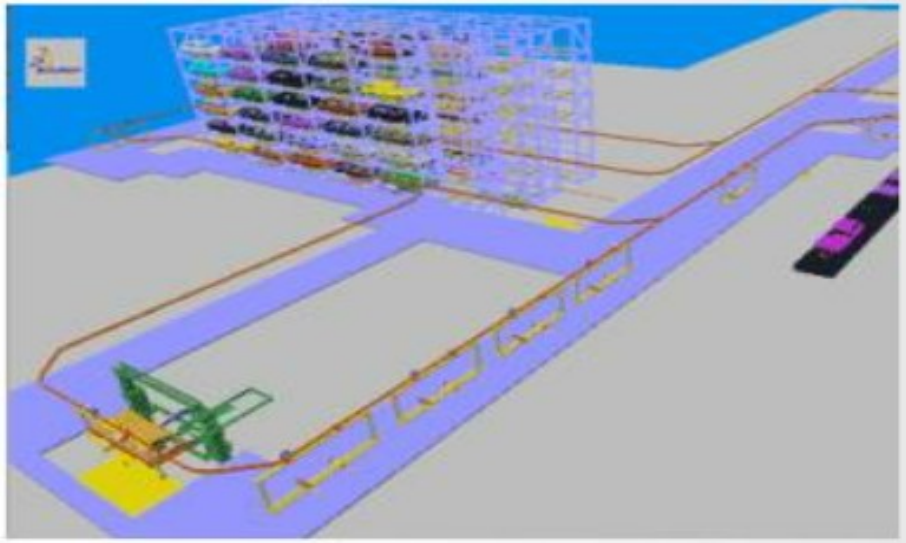


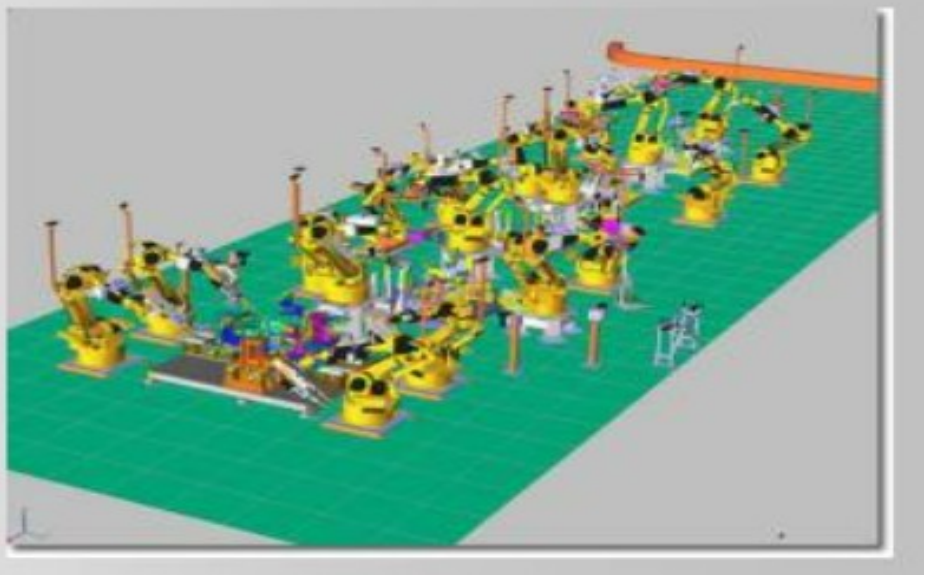

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# PRODUCTION PROCESS SIMULATION

- Define problems & identify bottlenecks
- Validation of proposed implementations under time constraints
- Capacity Planning
- Lead time reduction
- Work in progress reduction





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# CIM - COMPUTER INTEGRATED MANUFACTURING

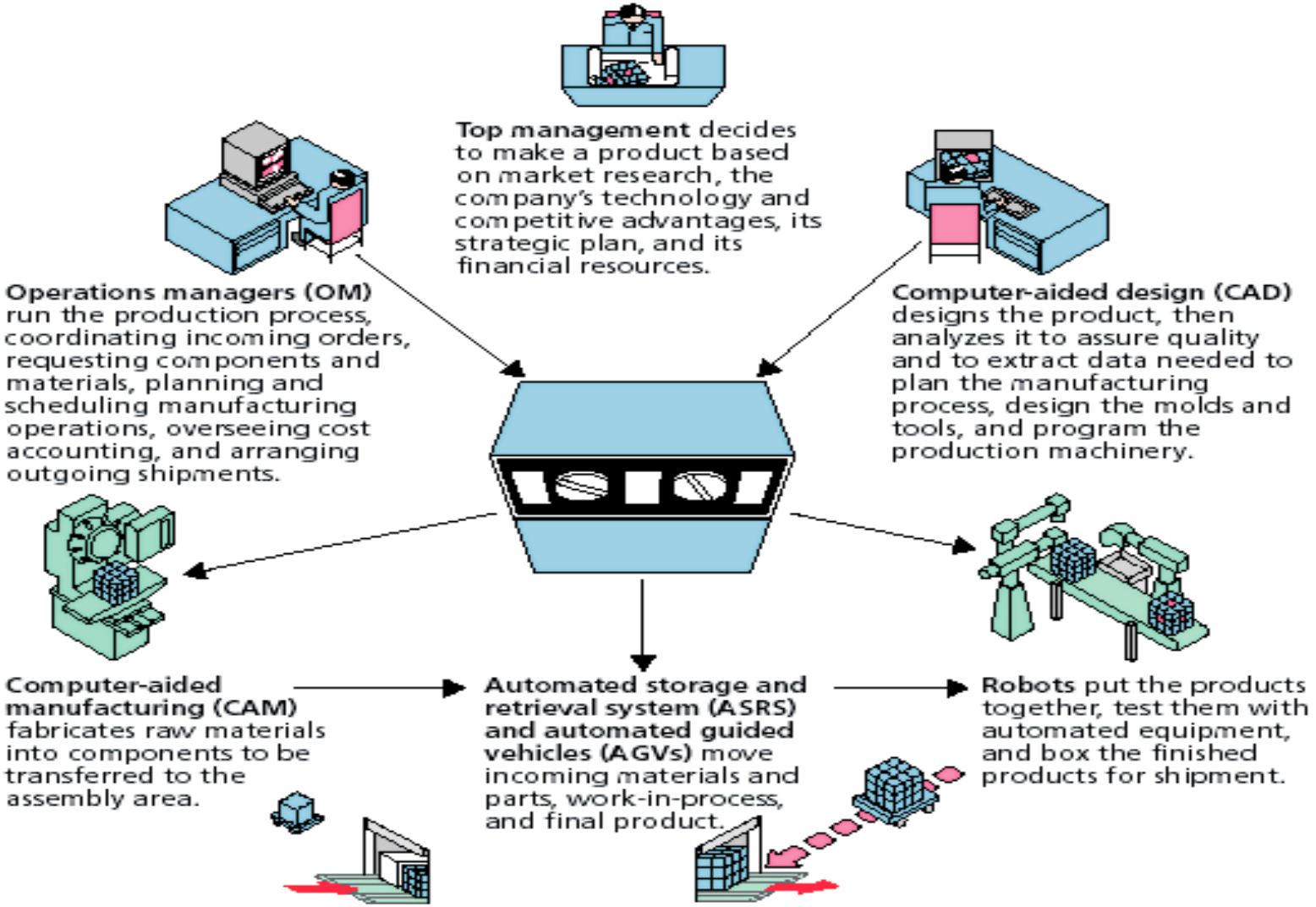
## COMPONENTS OF CIM

- CAD Computer Aided Design
- CAM Computer Aided Manufacturing
- CAE Computer Aided Engineering

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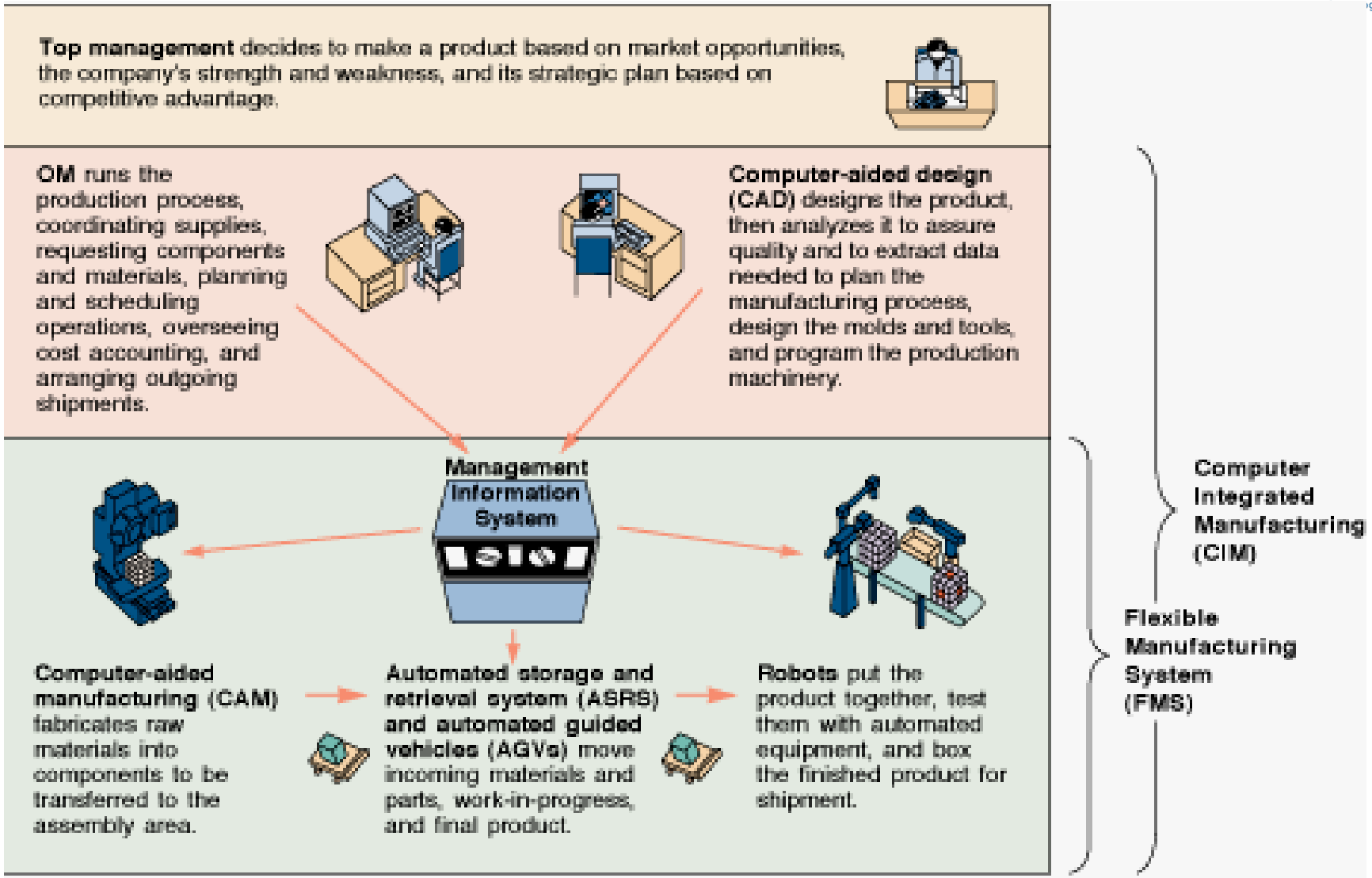
# CIM - COMPUTER INTEGRATED MANUFACTURING




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# CIM - FMS




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# PRODUCT LIFECYCLE MANAGEMENT

The process of managing the entire lifecycle

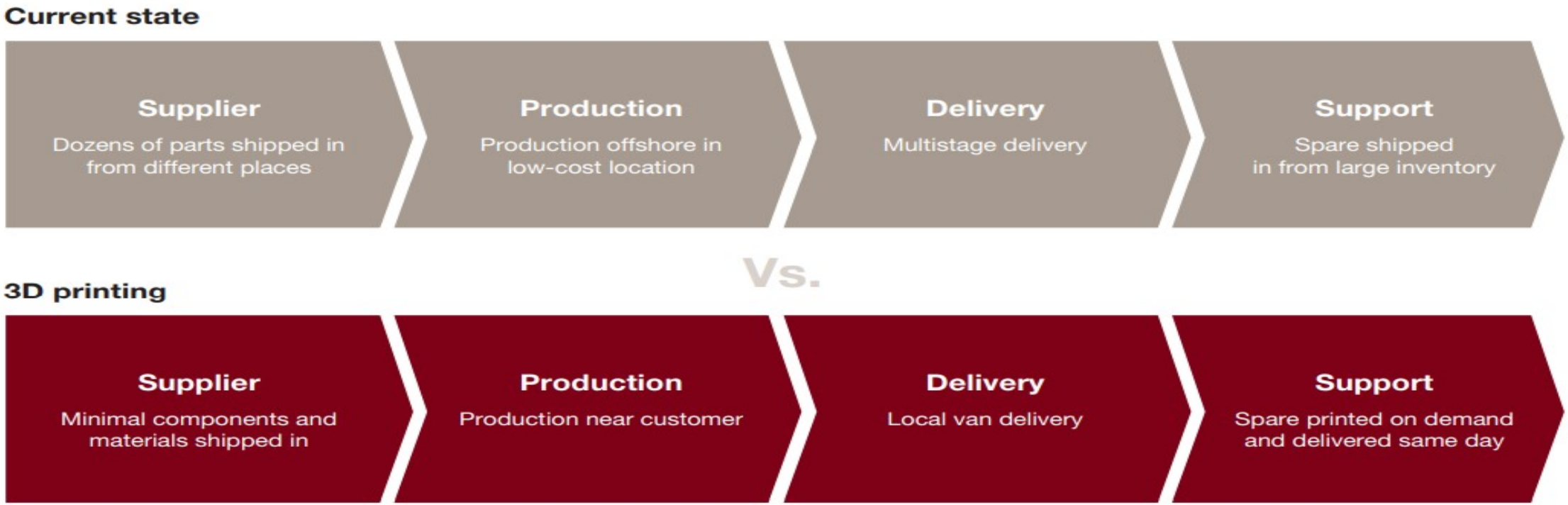
- From its conception
- Through design and manufacture
- To service and disposal




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# 3D PRINTING




***Benefits of 3D printing***

Simplified supply chain, fewer suppliers

Lower labor unit and transport cost

No need to "follow cheap labor rates"

Fast local delivery

Reduced inventory cost

Low-cost delivery

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DIGIMAN
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# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Computer modelling and simulation

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# Learning outcomes: On successful completion of this module a student should be able to:




- Gain knowledge of the basics of computer-aided parallel engineering.
- Gain knowledge of computer design resources, resource sharing, system design, and management.
- Gain knowledge of current areas of virtual reality (VR) development.
- Create the product or process model using CAD systems.
- Understand the possibilities and limits of computer simulation in terms of digital manufacturing.

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# COURSE PURPOSE & OBJECTIVES & OUTCOMES

- The aim of the course is to presents the process and technologies of construction design, the concept and areas of CAD, product and process modelling, computer drawing / editing, finally methods and systems of computer geometric modelling.
- The students of this course will gather knowledge in the principles of computer simulations and computer aided design process, which will be the basis of a deeper knowledge in manufacturing. The students will have detailed insight into the simulation and design. During the semester project, the students will solve a case study like task, which gives them problem solving skills in industrial environments.
- Knowledge of:
  - CAD
  - VR development
- Skills:
  - Desing using digital tools
  - Production overview
- Attitude:
  - Constantly monitors work
  - Continous learning

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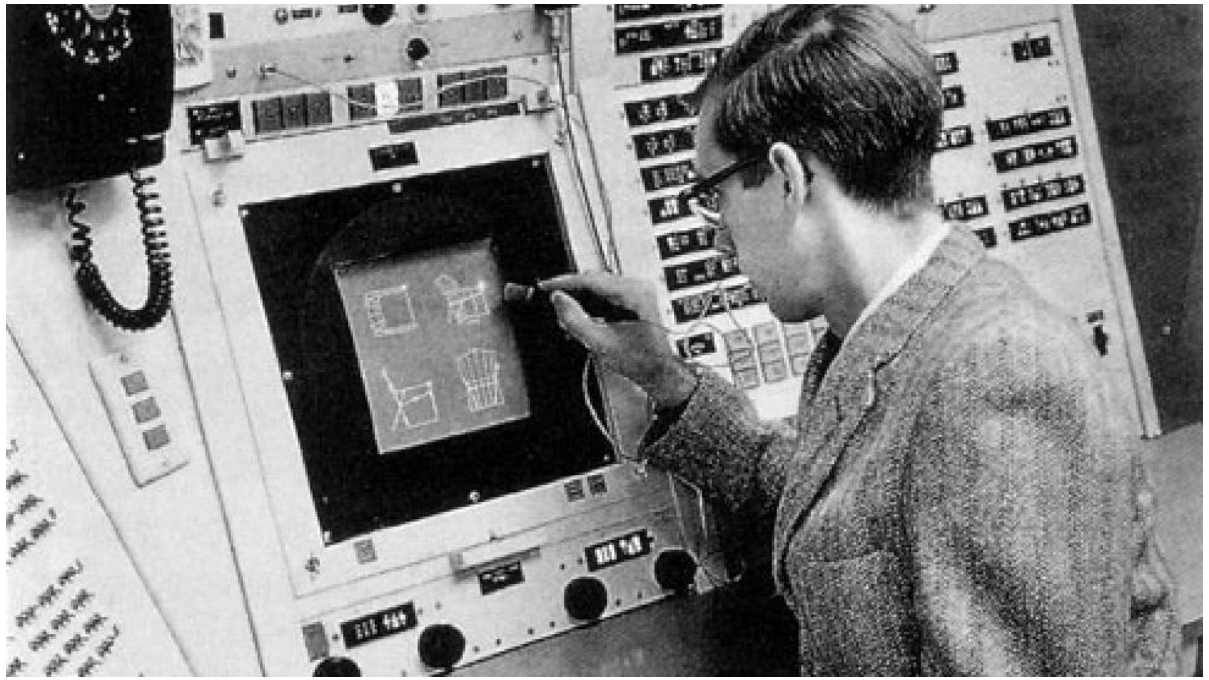
# TERMINOLOGY

- computer-aided design = design activities, including drafting and illustrating, in which data processing systems are used to carry out functions such as designing, simulating, or improving a part or a product
- computer-aided design and manufacturing = activities of computer-aided design and computer-aided manufacturing. Note 1 to entry: computer-aided design and manufacturing; CAD/CAM; CADM: term, abbreviations and definition standardized by ISO/IEC [ISO/IEC 2382-24:1995].
- computer model, computerized model = operational computer program that implements a conceptual model;
- simulation = exercise or use of a calculation method to represent components of a system, their interaction and their progression over time
- simulation model = computer model that treats the dynamic relationships that are assumed to exist in the real situation as a series of elementary operations on the appropriate variables

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# INTRODUCTION TO CAD SYSTEMS



https://bimaplus.org/news/the-very-beginning-of-the-digital-representation-ivan-sutherland-sketchpad/

1960s
- Sketchpad, using a special pen to draw on a display
- Only could handle points and curves, no surfaces
- No NC programming is available

1970s
- Bloom az automotive and aerospace industries
- 2D CAD softawre → CADAM
- First 3D CAD software → CATIA

1980s
- Development of UNIX system
- First Autocad by Autodesk on an IBM PC
- Pro/ENGINEER in 1987

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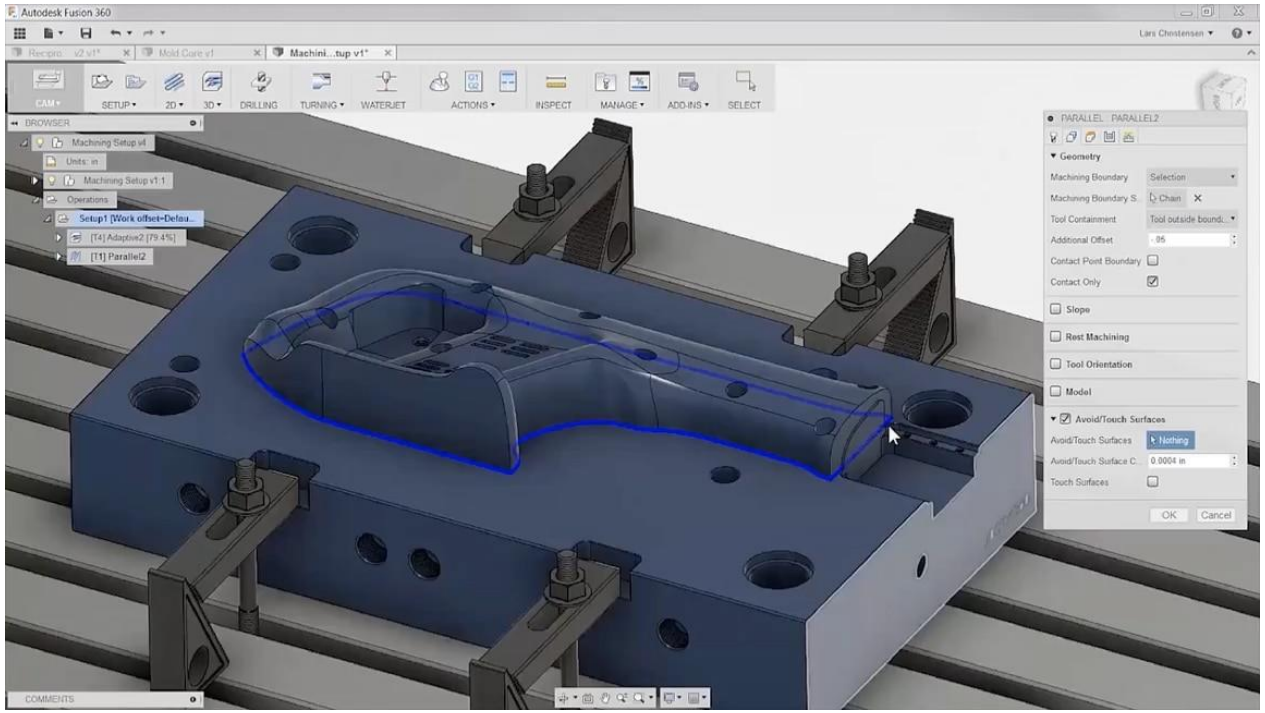
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# INTRODUCTION TO CAD SYSTEMS

1990s
- Pro/ENGINEER is dominating the CAD system market
- SolidEdge, CATIA, Autodesk Inventor is being developed

2000s
- Integrated CAD/CAM/CAE systems
- Reducing total production time

2020s
- Integrated CAx systems
- Using VR and AR technologies
- Reverse engineering




https://www.autodesk.hu/collections/product-design-manufacturing/fusion-360

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# FEATURES OF CAD SYSTEMS

- Application area. Usually generally applicable systems are available nowadays, but specialized modules can be used for each area of industrial design and manufacturing.
- The modelling environment can be 2D and/or 3D.
- The applied modelling method can be curve, surface, solid or hybrid.
- The modelling method can be parametric or direct. In parametric modelling the designer captures design intent using features and constraints, thus the user is allowed to automate repetitive changes. In direct modelling, the geometry can be captured much quicker, without features and constraints, thus this type of modelling method is often compared to modelling with clay.



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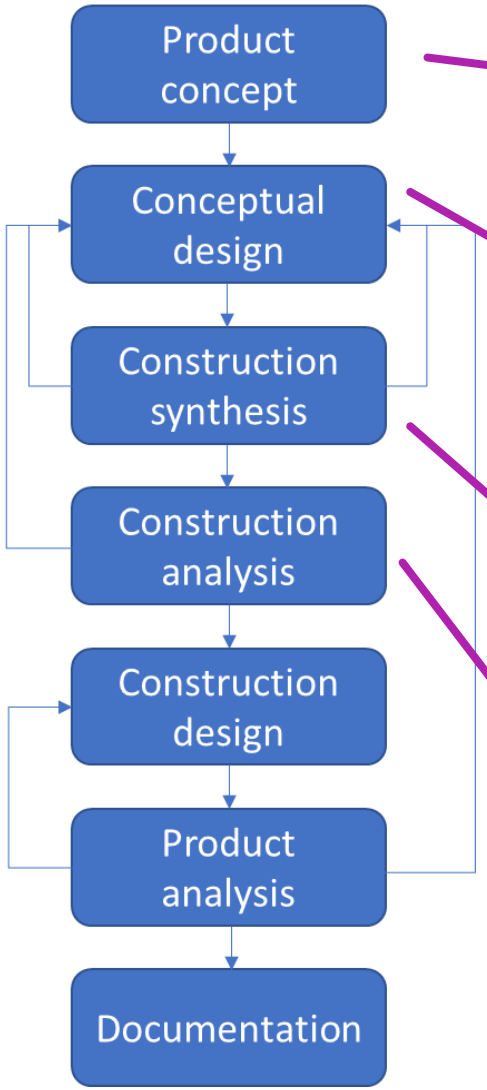
# FEATURES OF CAD SYSTEMS

- The modeling is based on 3D parametric shape features, or volume modeling.
- Free-form surface modelling.
- Bidirectional parametric associativity: the model can be modified from different aspects and the effect of these modifications is mutually exclusive (e.g. the modification of the shape properties of the 3D model appears in the drawing, the meter modified in the drawing changes the 3D model).
- Modeling a complete assembly, the components of which can be parts or other assemblies.
- Preparation of a technical drawing from the volume and surface model.
- Preparation of workshop drawings and parts lists.
- Provide rendering aids (hatching, rotating, removing obscured lines, etc.).
- Reuse of design details.
- Easy model variability.
- Generate standard parts based on catalog.
- Adaptation of plans to design rules and specifications, simulation of designs without prototyping.
- Kinematics, collision analysis, tolerance analysis.
- Possibility to exchange data with other software (export, import).
- Direct connection to rapid prototyping and rapid production systems.
- Mass and moment of inertia calculation.
- Design of sheet metal parts.
- Design of flexible pipes and cables.
- Wiring of electrical components.

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# GENERAL STEPS OF INDUSTRIAL DESIGN




the technical, economic, quality and environmental requirements of the design to be determined

determine the type of construction (new, redesigned, modified), the functions of the product, the scientific relationships that form the basis of the operation, the structure of the product, the value of the parameters that determine the operation, the shape and colour scheme

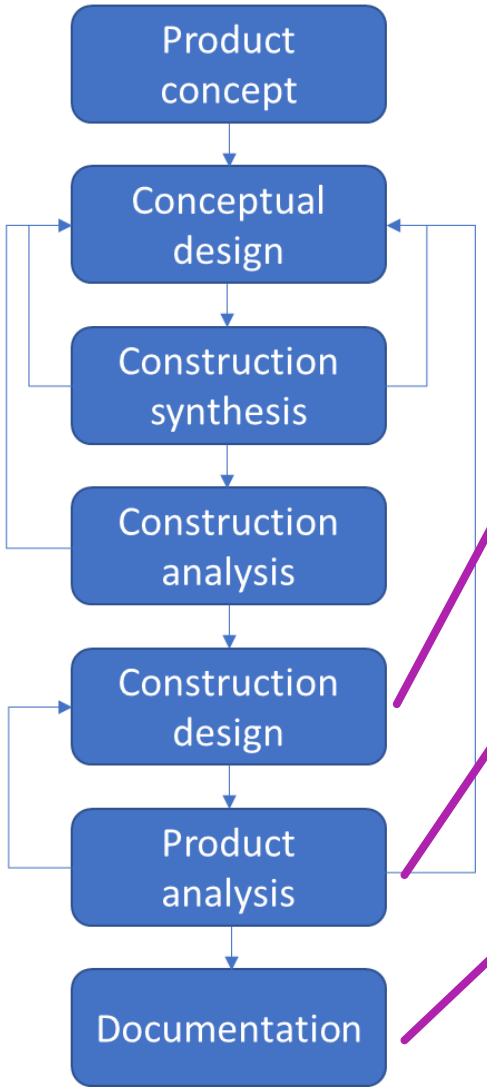
system-based modelling of the product is performed, it is divided into subunits and parts, the approximate size, shape and material characteristics of the parts are determined

the loads and stresses of the parts and components are determined, the operation of the product is simulated, and the technical parameters of the optimal design are determined

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# GENERAL STEPS OF INDUSTRIAL DESIGN




determine the shape, material, material characteristics, size, tolerances of dimensions that affect operation, and to systematize additional information required for manufacturing

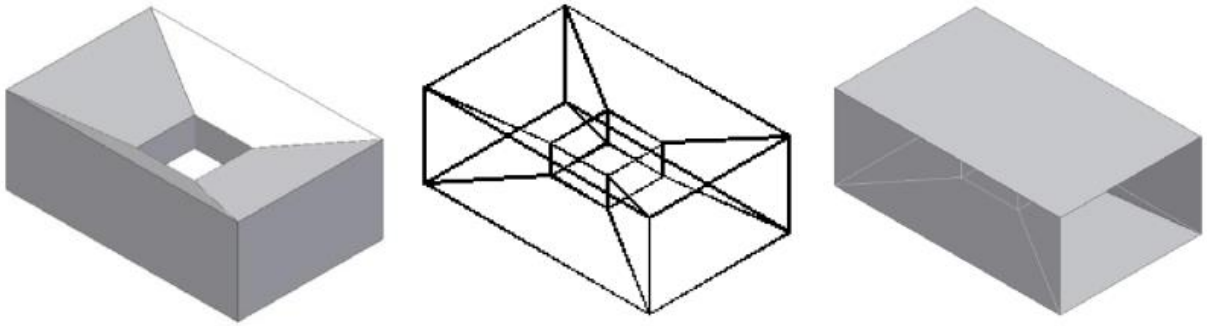
the conformity of the product is examined. Conformity can be assessed from several aspects: performance, installability, manufacturability, cost, relevant standards, safety regulations, and so on

the product documentation, we prepare the assembly drawings and component drawings of the product, as well as the related parts list, material requirements plans, operation, maintenance, assembly and test descriptions

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# GRAPHIC GEOMETRY MODELLING TECHNIQUES

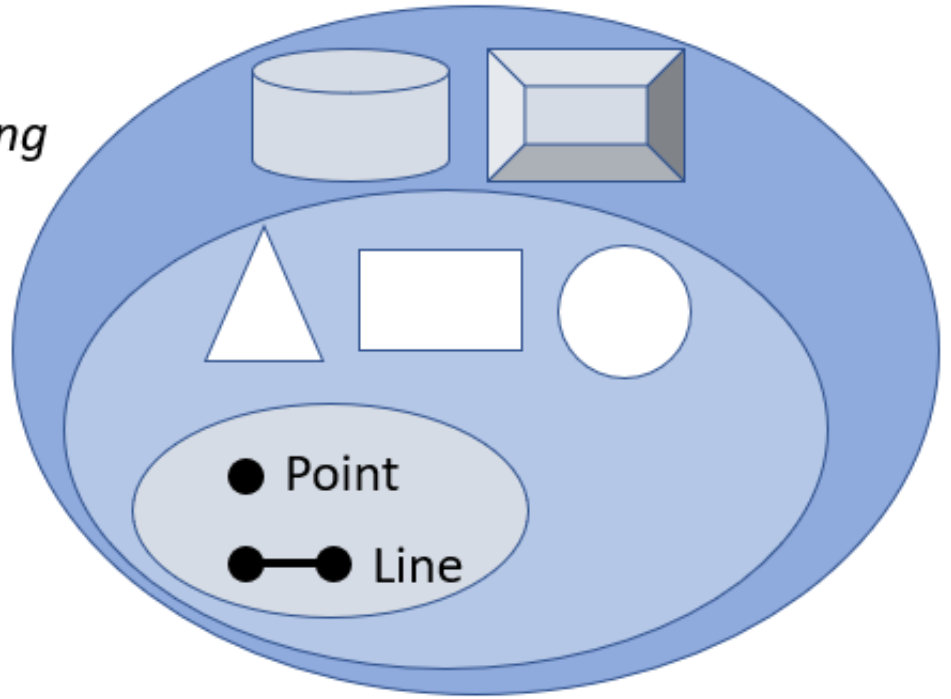


- Point, lines/curves
- Object is defined by its boudnaries
- Not clearly illustrate the object
- Only a supporting method

*Solid modelling*

*Surface modelling*

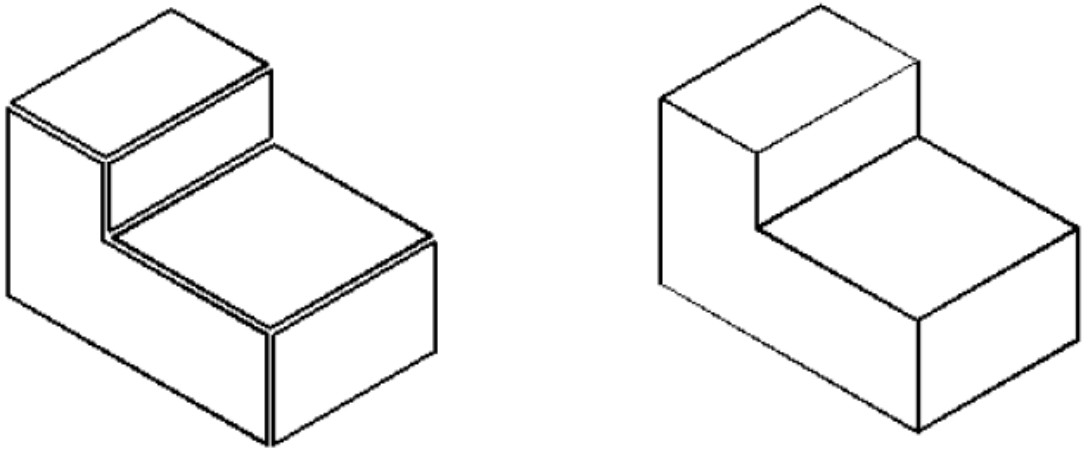
*Wireframe modelling*




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# GRAPHIC GEOMETRY MODELLING TECHNIQUES

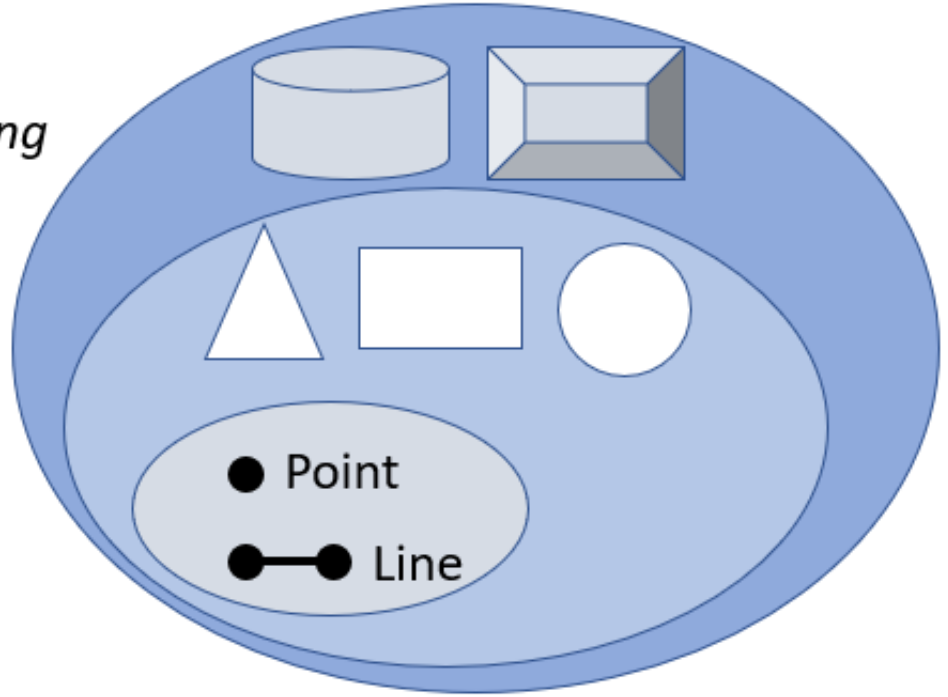


- Finite number of surface patches
- No thickness
- No mass, density, collision analysis, numerical calculations

*Solid modelling*

*Surface modelling*

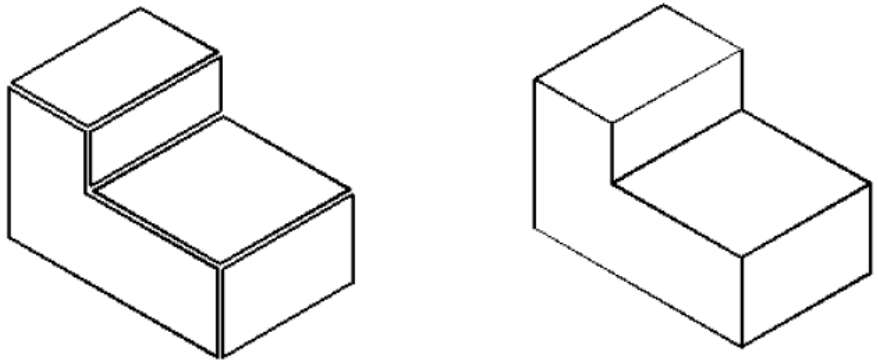
*Wireframe modelling*




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# GRAPHIC GEOMETRY MODELLING TECHNIQUES



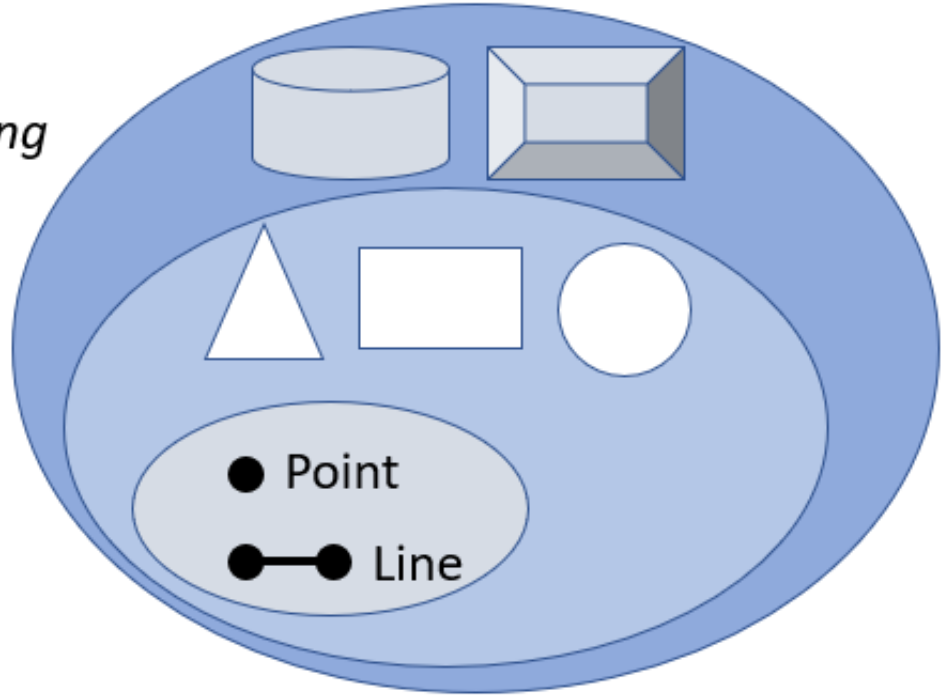
- Finite, closed, regular set of points
- 2D sketch + 1D depth
- 1D path +1D thickness + 1D width
- 1D path + 2D profiles
- Calculations are available

- Finite number of surface patches
- No thickness
- No mass, density, collision analysis, numerical calculations

*Solid modelling*

*Surface modelling*

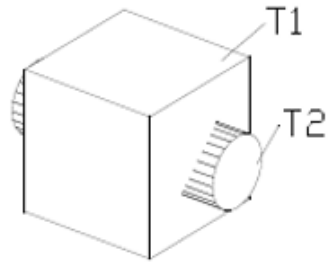
*Wireframe modelling*



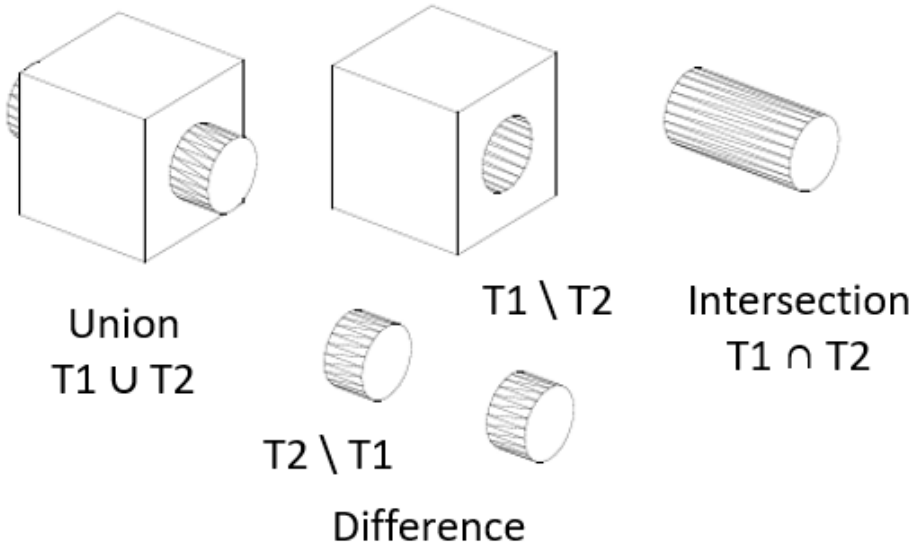

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# FEATURE AND KNOWLEDGE BASED MODELLING




Cube and cylinder




## Feautre-based

The solid object is then composed of a set of constitutive features by the operations called constructive solid geometry (CSG). These operations can be union (∪), intersection (∩), and difference (\)

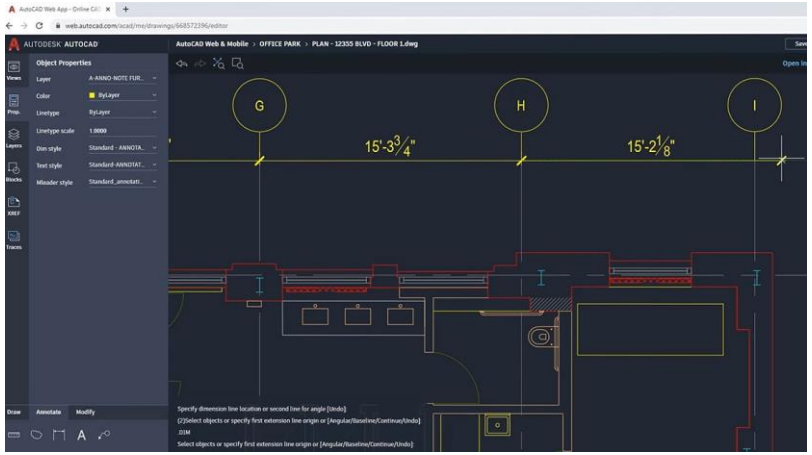
## Konwledge-based

Design intents should be used. Design intents are embedded in a graphic model, and the design intent updating the dimensions and relations automatically.

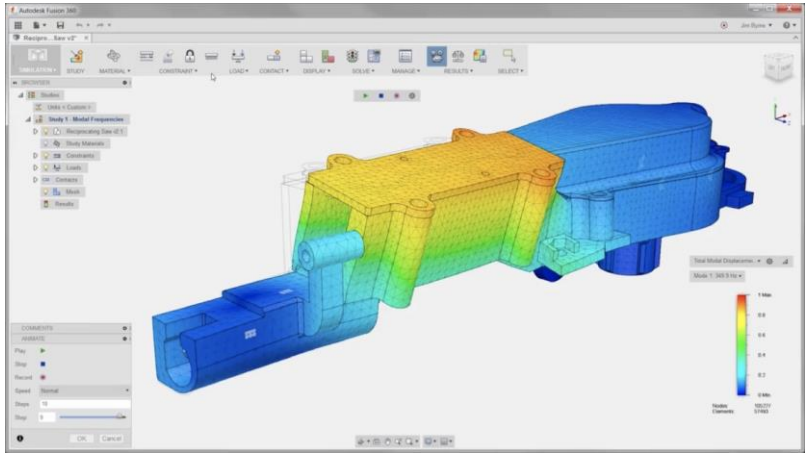
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# INTEGRATED CAD SYSTEMS IN DIGITAL MANUFACTURING




Conventional CAD systems



Industry 4.0

CAD systems in digital manufacturing

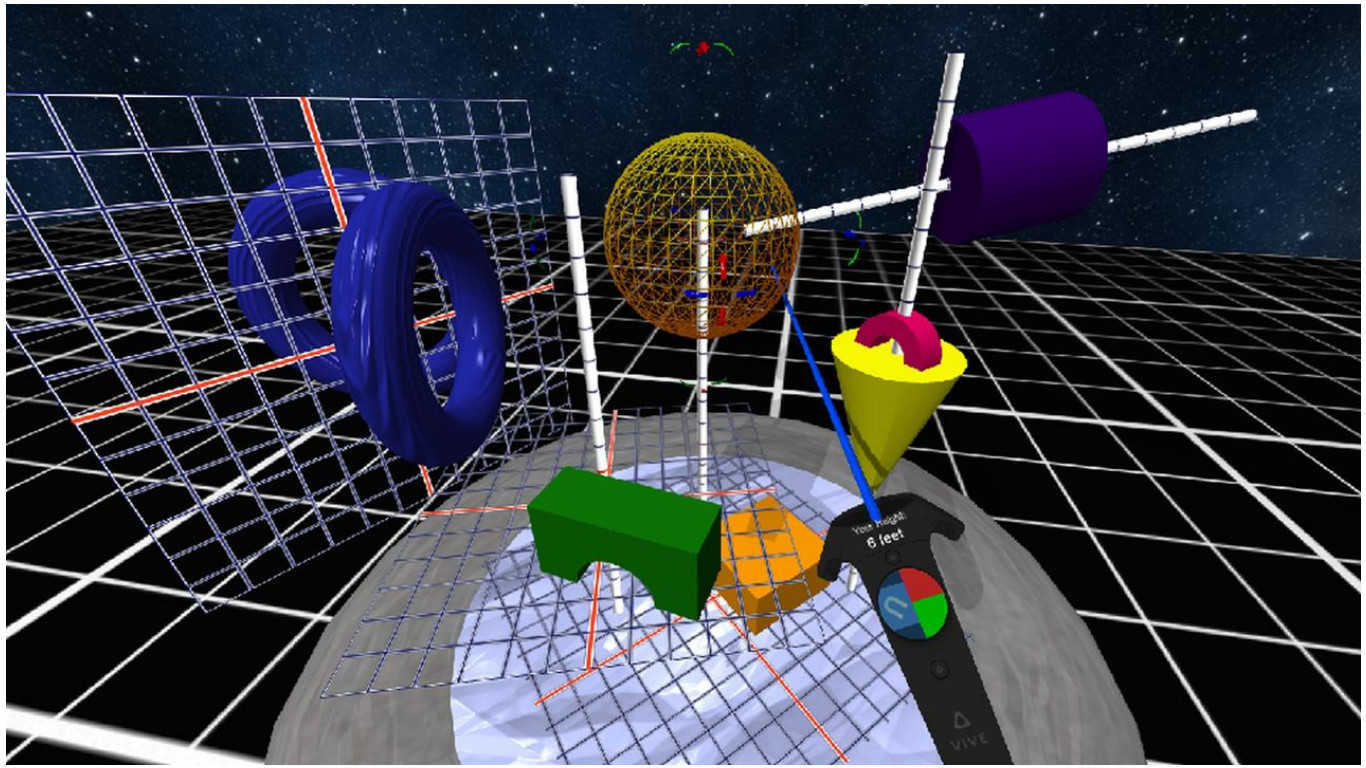
- Integrated and comprehensive solutions
- CAx tpye methodology
- Suitable for CNC machining
- Manufacturing optimization
- Network, cloud-based technologies
- VR and AR

https://www.autodesk.hu/products/autocad/overview?term=1-YEAR&tab=subscription
https://www.autodesk.hu/collections/product-design-manufacturing/fusion-360

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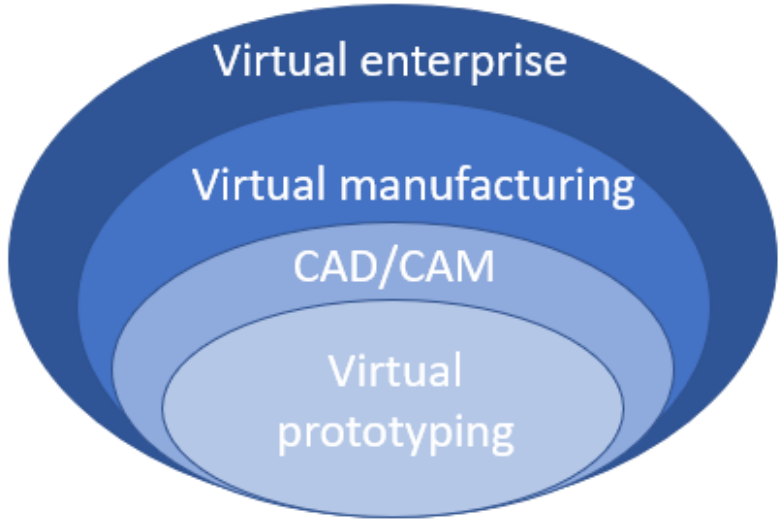
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# VR AND AR IN CAD SYSTEMS



https://store.steampowered.com/app/569180/MakeVR_Pro/

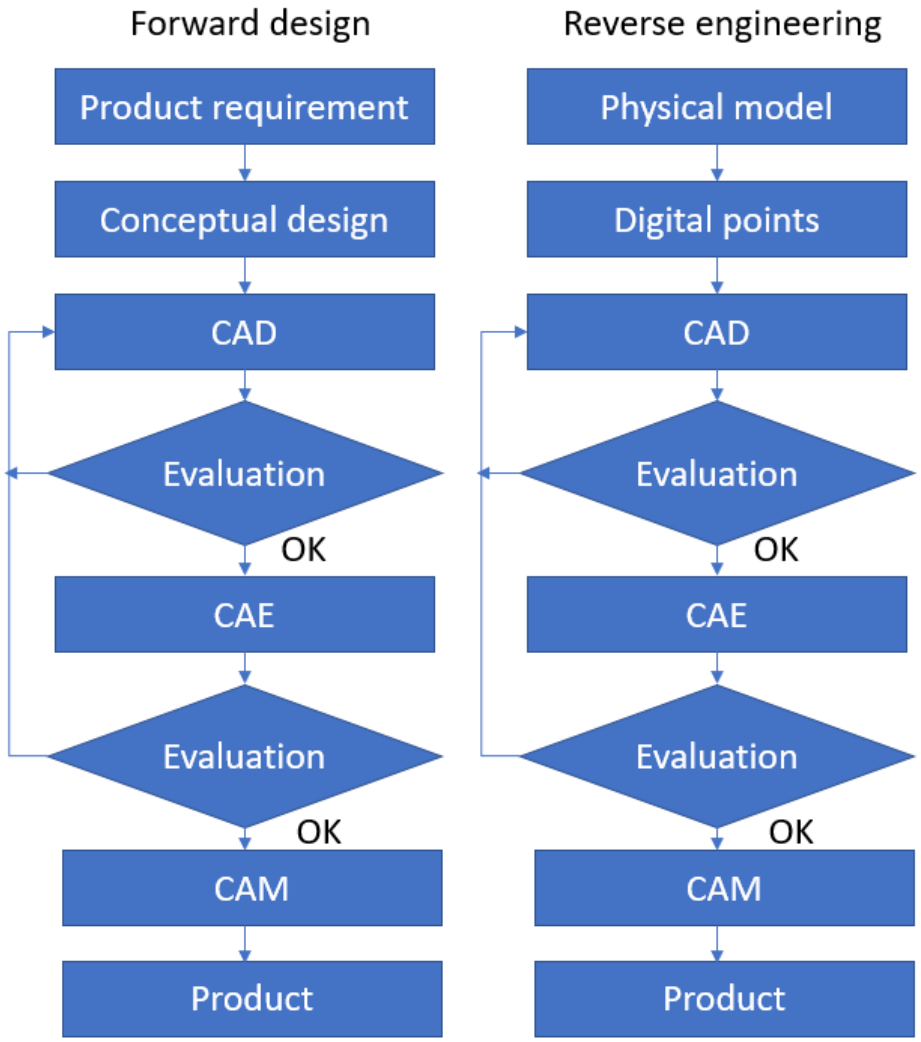
- Create a model in the virtual space
- 1:1 scale, comparable
- Can be modified, appoved before the final design stage
- Reducing the number of consultations with the partners
- Possibility for virtual prototyping




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# REVERSE ENGINEERING




1. Scanning
2. Post processing
3. CAD model



https://all3dp.com/2/reverse-engineering-software-reverse-engineering-tools/

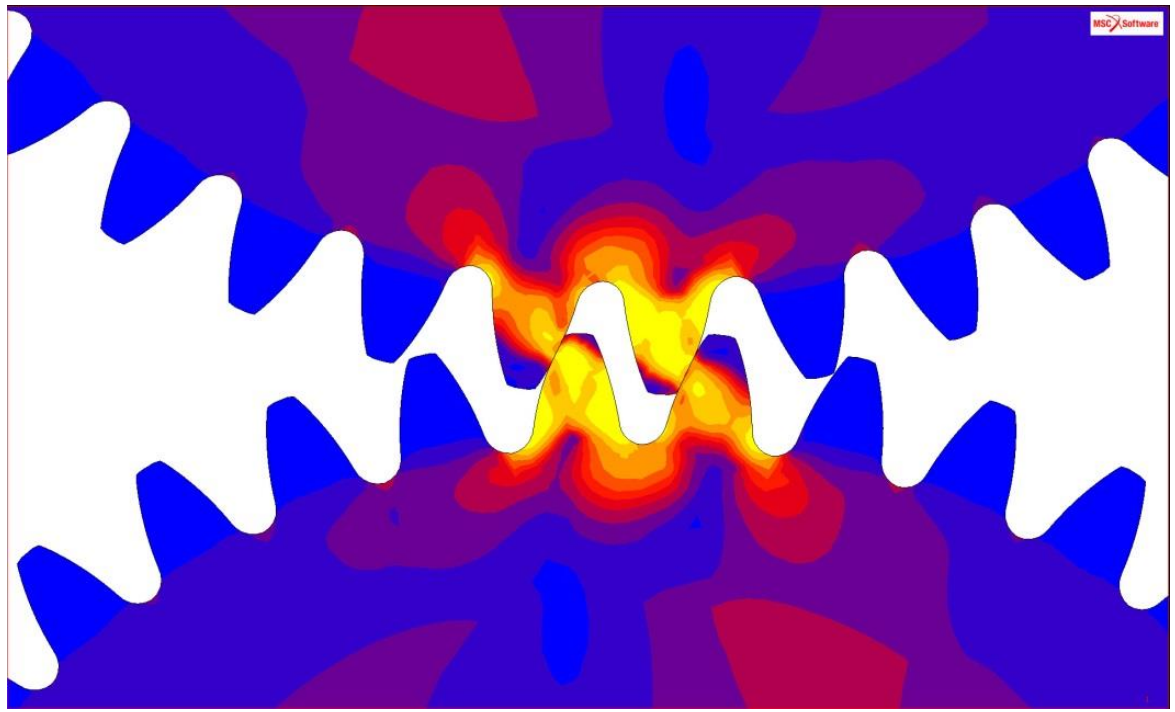
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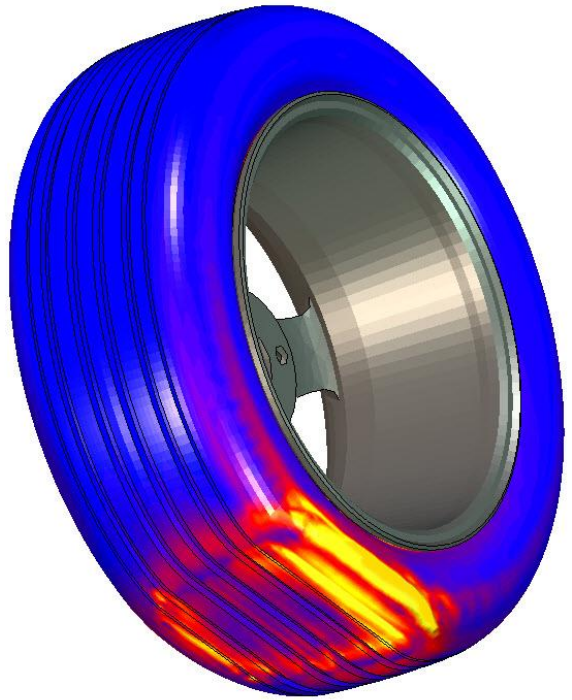
Z. Zhou, S. Xie, and D. Chen, *Fundamentals of Digital Manufacturing Science*. London: Springer London, 2012

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# FINITE ELEMENT MODELLING

- The method approximates the e.g. displacement field in the body with small, finite number volumes (elements). The field is continuous over the elements, and unknown parameters are assigned to finite number of nodes.
- The required quantities (stress, strain, temperature) are determined by the solution of an algebraic equation system.





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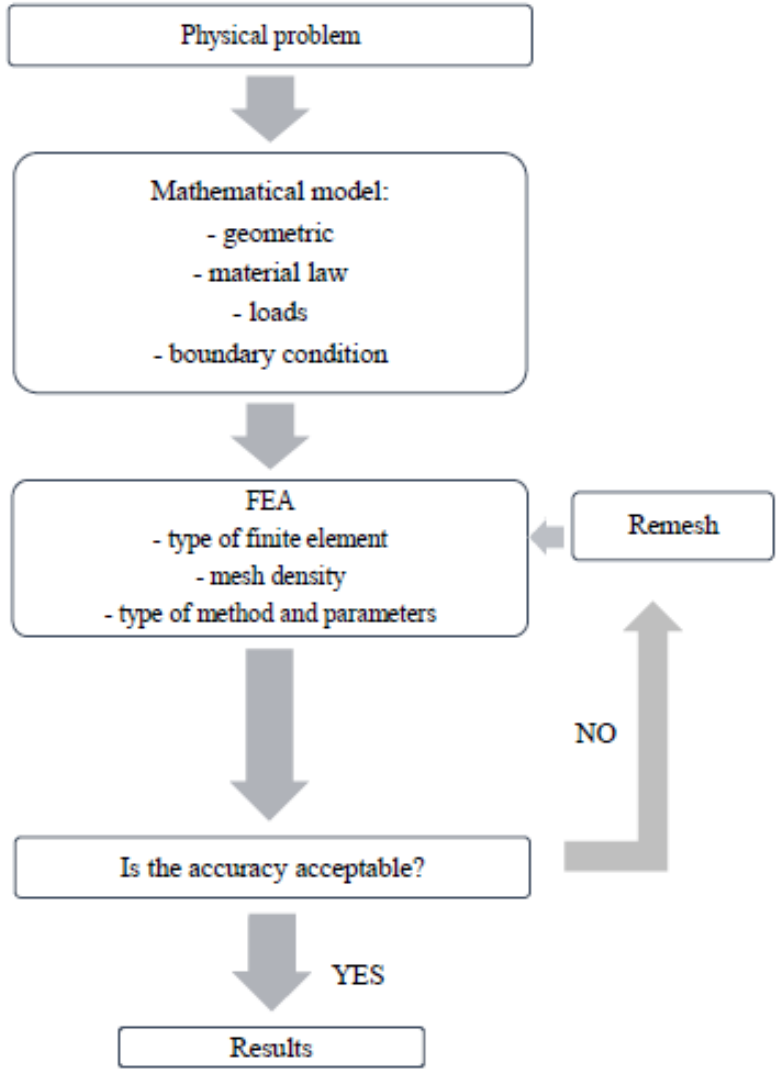
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# FINITE ELEMENT MODELLING - STEPS

- Definition of the problem

- Model building (simplification)
  - defining the problem and element types
  - geometry
  - selection of the material model
  - initial and boundary conditions

- Limitations, dangers
  - computational costs, limit of our computers
  - numerical process (approximation, numerical errors, etc.)
  - skill of the user (not competent person)

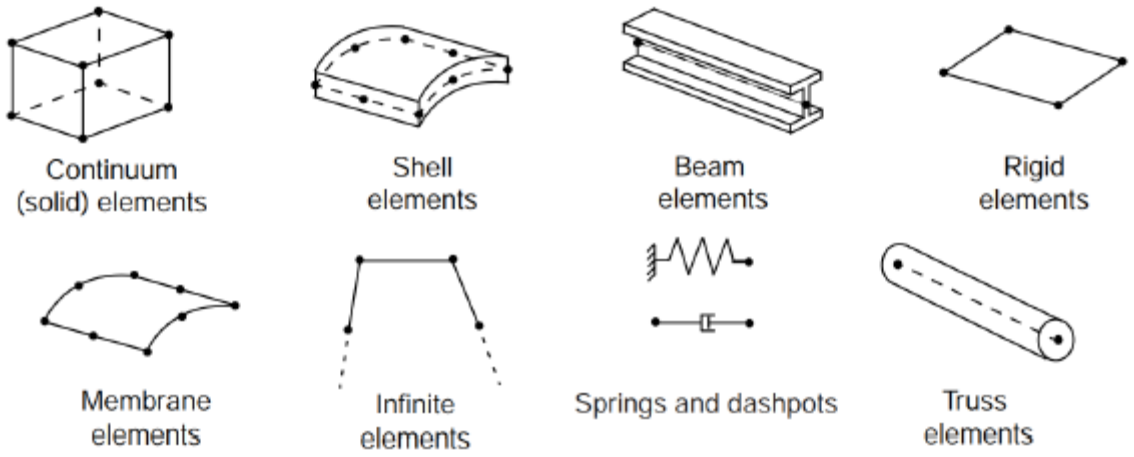


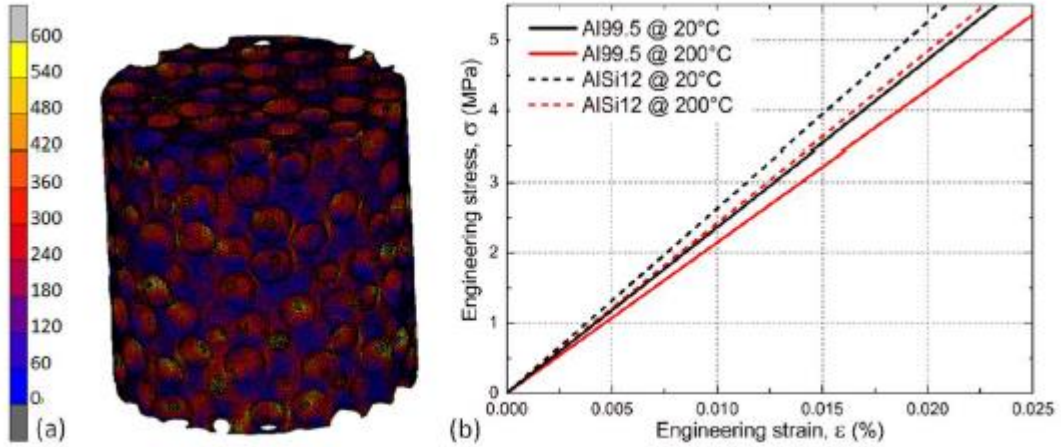

Mankovits, T., & Huri, D. (2015). *Modellezés és szimuláció*. Debreceni Egyetem.

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# MODELL BUILDING FOR SIMULATION




- Finite number of elements
- Rigid or deformable bodies
- Meshing density can be varied for computational challenges and computational time

After the model building

1. Initial conditions must be defined
2. Boundary conditions (mechanics)
3. Loads
4. Simulation
5. Evaluation

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http://130.149.89.49:2080/v6.14/books/gsa/default.htm
https://doi.org/10.1016/j.msea.2018.10.014

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# **Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

## Energy system

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# GOALS AND OBJECTIVES

It is not an obligatory module for the students.
→ Connection to the digital manufacturing: modern energy sytems which can uses digital technologies

It is focuses to:
1. Describe the different renewable energy system
2. Explain the operation and the application

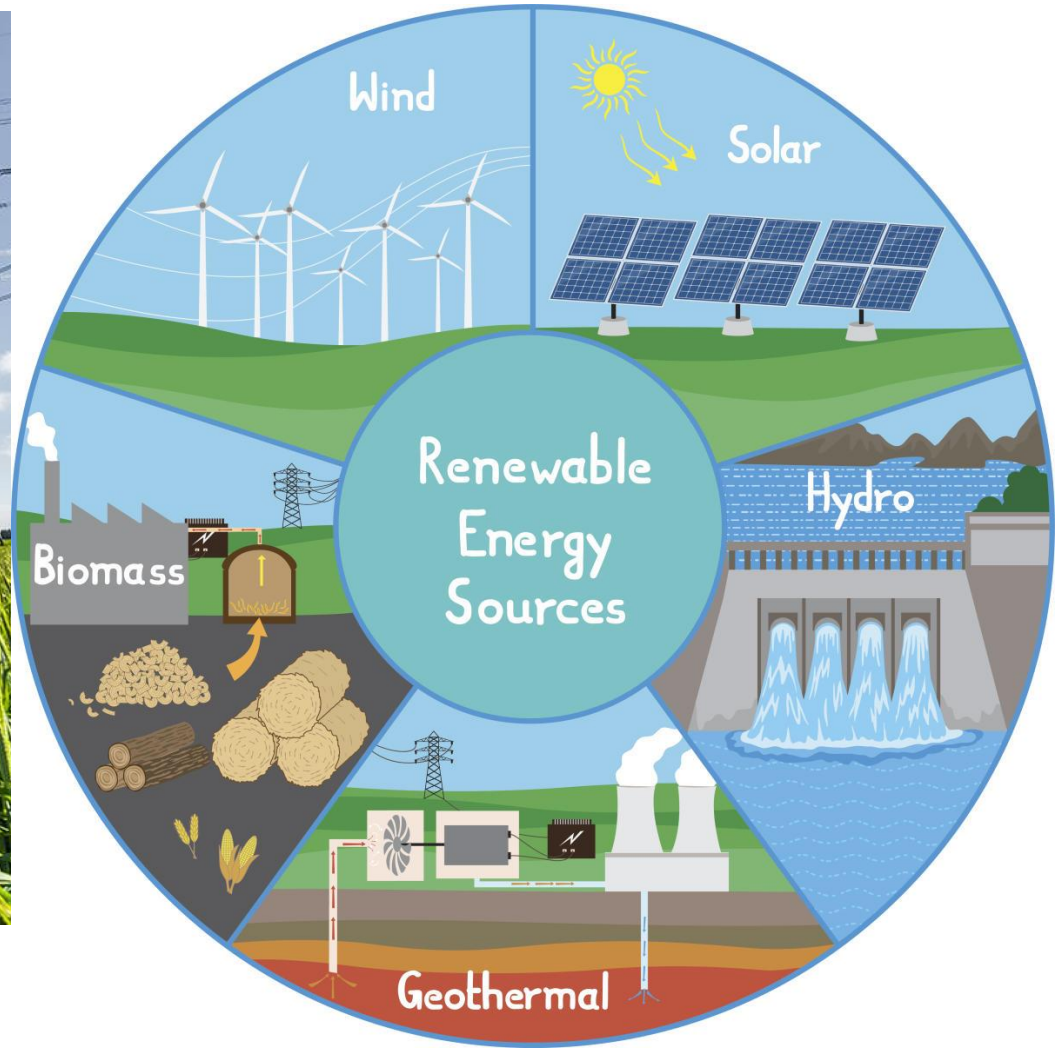
Learning outcomes:
1. Obtain advanced knowledge and critical understanding of the theory, principles and applicability of: Energy systems
2. Describe the different method of produce energy
3. Discuss the different methods that can be used to reduce green house effect
4. Classify the different energy systems

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# RENEWABLE ENERGY






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# HYDROPOWER

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations.

The classification according to size: small scale, large scale

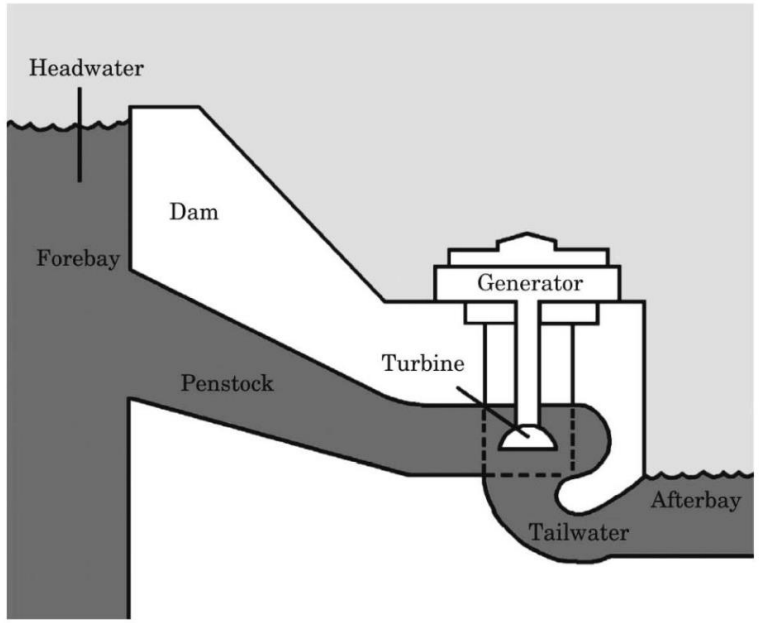



Figure 1. Hydro power plants components (Al-Juboori, n.d.)

Most hydroelectric power is generated by dams across large-flow rivers. A dam built across river creates a reservoir behind it. The height of the water behind the dam is greater than that below the dam, representing stored potential energy.

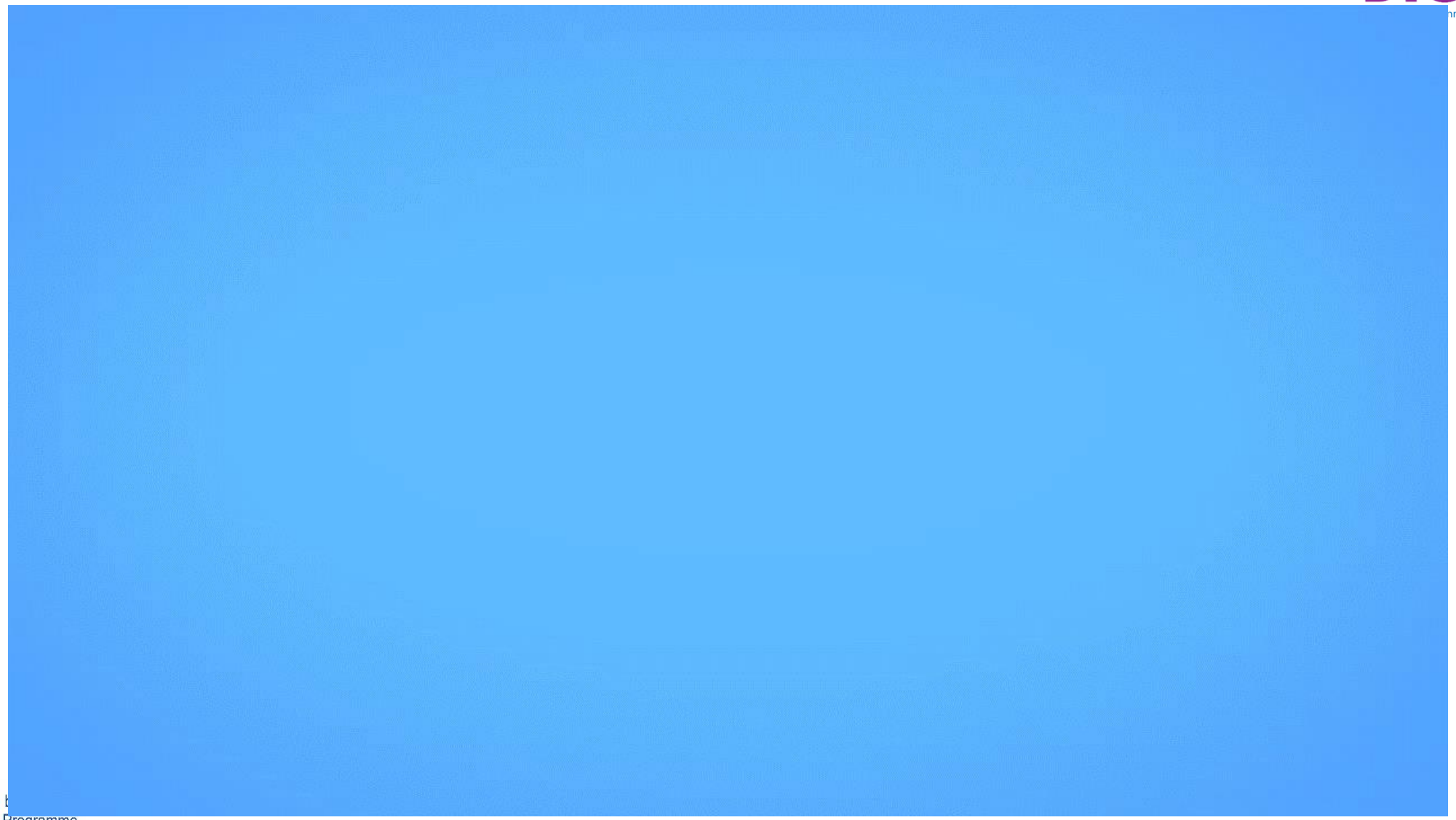
To generate electricity, water must be in motion. This is kinetic (moving) energy. When flowing water turns blades of a turbine, the form of energy is changed to mechanical (machine) energy.

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# HYDROPOWER

Open source:
https://www.youtube.com/watch?v=q8HmRLCgDAI&t=79s



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# SOLAR ENERGY

The Sun is the central star of our solar system. The energy emitted by the sun is called solar energy or solar radiation. When passing through the atmosphere, solar radiation with normal incidence is subject to two sources of attenuation: scattering and absorption.

## Measurement of solar radiation

### Pryanometer



Figure 4. Pryanometer (Hukseflux, 2018)

### Pyrheliometer



Figure 5. Phyrheliometer

## Solar panels

### Solar cell

directly converts the energy in light into electrical energy through the process of photovoltaics

### Solar collectors

special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium.

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# SOLAR ENERGY

Open source:
https://www.youtube.com/watch?v=BtbASIJmsjE&t=11s

DIGIMAN
master programme for digital manufacturing

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# GEOTHERMAL ENERGY

Geothermal heat is constantly produced by the Earth from the decay of radioactive material in the core of the planet. The heat is moved to the surface through conduction and convection.

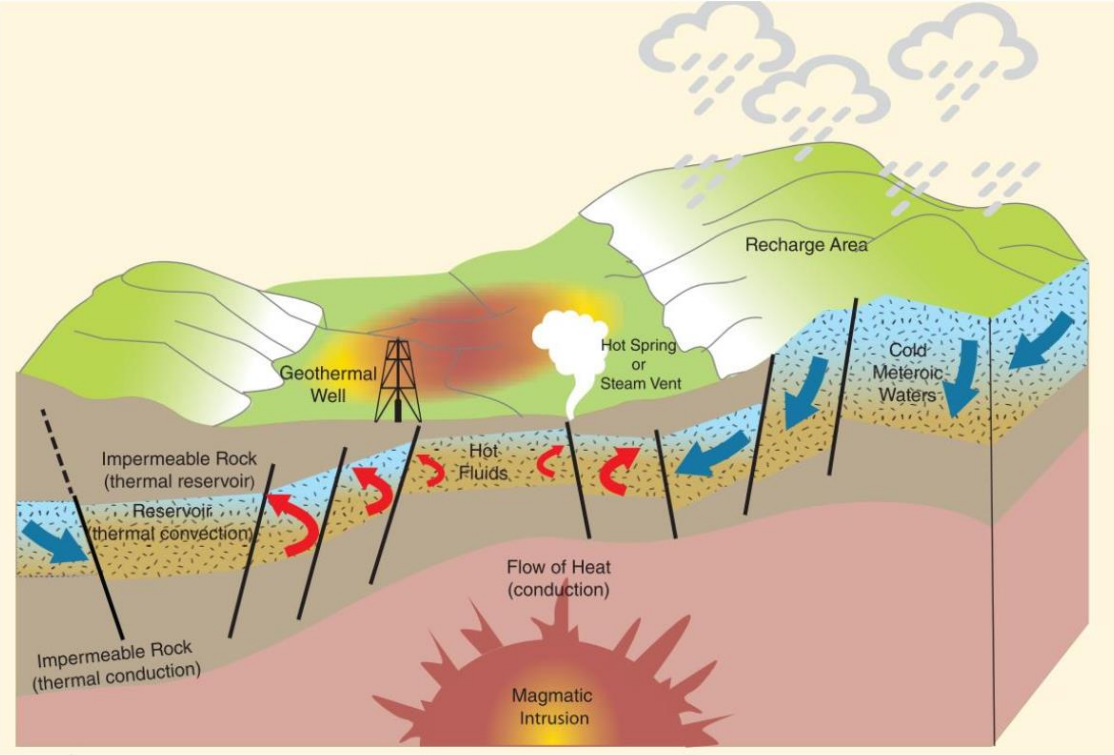



Figure 11. Schematic representation of an ideal geothermal system (Dickson & Fanelli, 2004)

Geothermal power plants mainly come in two groups, namely, steam and binary power cycles. These cycles operate at high geothermal fluid enthalpy.

- Dry steam power plant
- Flash steam power plant
- Double flash steam power plant
- Binary power plant

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# GEOTHERMAL ENERGY

Open source:
https://www.youtube.com/watch?v=DFQrE91kZwk



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# BIOMASS ENERGY

Biomass is the plant material derived from the reaction between CO2 in the air, water and sunlight, via photosynthesis, to produce carbohydrates that form the building blocks of biomass.

Biomass contains varying amounts of cellulose, hemicellulose, lignin and a small amount of other extractives.

- Wood
- Herbaceousnt
- Aquatic plant
- Animal and human waste

**Production of biomass energy**

### Combustion

A biomass combustion system burns renewable biomass fuel (e.g., wood, field crops) to produce heat.

### Gasification

Gasification is a thermo-chemical process that transforms carbonaceous materials such as biomass into usable fuels or chemicals

### Pyrolysis

It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes and occurs naturally in the first two seconds

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# BIOMASS ENERGY

Open source:
https://www.youtube.com/watch?v=yHWcddUZ35s



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# WIND ENERGY

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. Wind varies with the geographical locations, time of day, season, and height above the earth's surface, weather, and local landforms.

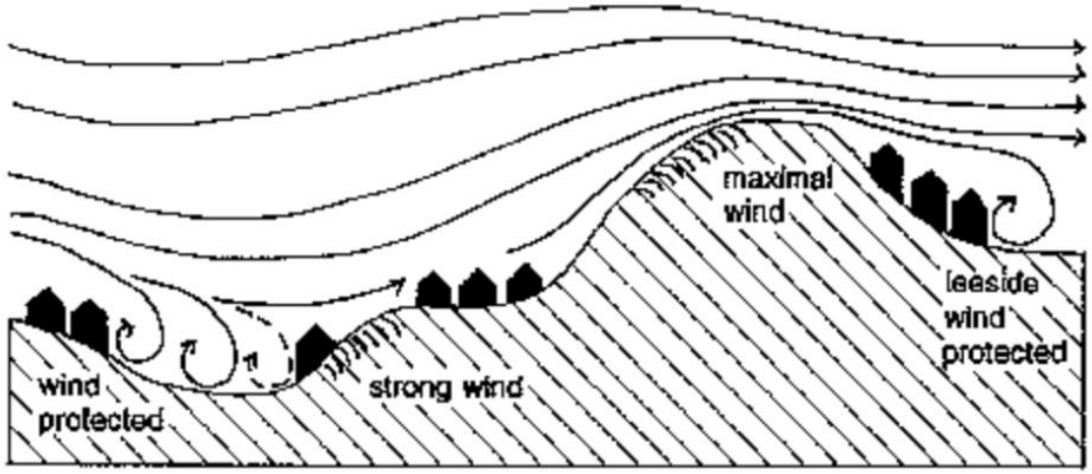



Figure 17. Way of the wind behind the obstacle (Gut, 1993)

As electricity generators, wind turbines are connected to some electrical network. These networks include battery-charging circuits, residential scale power systems, isolated or island networks, and large utility grids.

HAWT – horizontal axis wind turbine
VAWT - vertical axis wind turbine

**Application**

| On-shore | Off-shore |
| --- | --- |
| In land | In bodies of water |

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# WIND ENERGY

Open source:
https://www.youtube.com/watch?v=B-qeeAsm7nc



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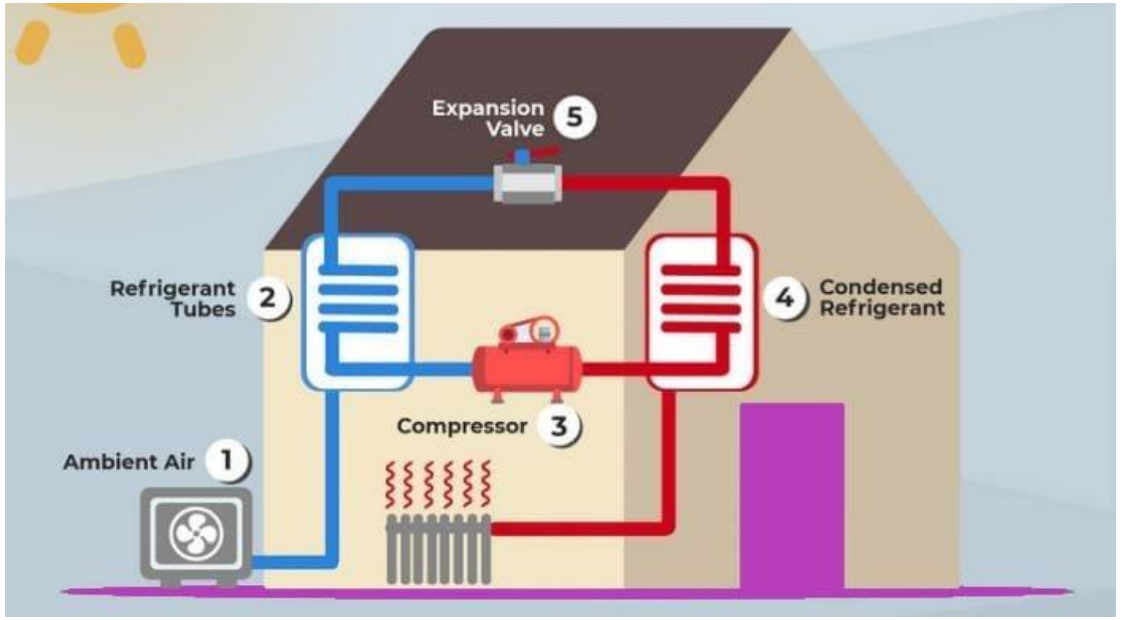
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# HEAT PUMP SYSTEM

A heat pump is a device that extracts thermal energy from a low-temperature source (such as the outside air or ground) and transfers it to a higher-temperature sink (such as the heated indoors of a building). A heat pump usually extracts the energy from the environment. Air, groundwater, the earth or river water are common.

Heat pumps can operate at outdoor temperatures between about -20 to -25 °C and 25 °C.

**Types:** Air source heat pump
Geothermal heat pump




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# HEAT PUMP SYSTEM

Open source:
https://www.youtube.com/watch?v=KH47xAXEEe0

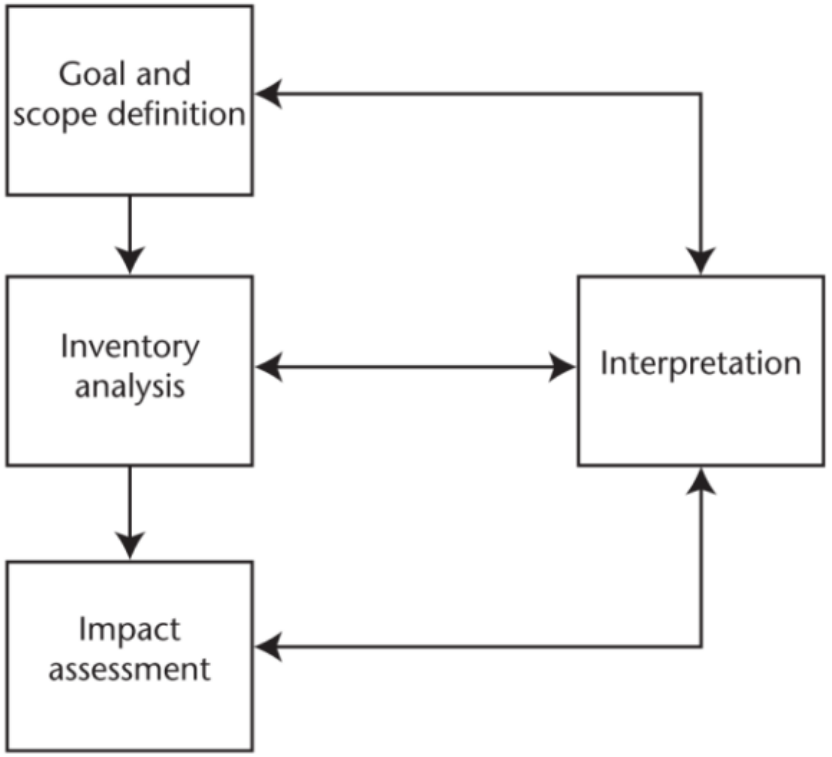


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# LYFE CYCLE ASSESMENT (LCA)

Life cycle assessment (LCA) is the calculation and evaluation of the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service. Environmental inputs and outputs refer to demand for natural resources and to emissions and solid waste.




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# LYFE CYCLE ASSESMENT (LCA)

Open source:
https://www.youtube.com/watch?v=KH47xAXEEe0




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**Digi**tal **Man**ufacturing Master Degree to set specialists for the dawn of the Industry 4.0

# Directed Energy Deposition – Arc (DED-Arc) Manual

# CU 01

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# Directed Energy Deposition – Arc (DED-Arc) Manual

Coverage:

1. Introduction to the Process DED-Arc

2. DED-Arc Manufacturing Strategy
(DED-Arc variants, Fixturing, Positioning and Nesting, Layer Thickness, Interaction of Layers, Gas System, Wire Feeding System, Deposition rate/Production Rate, Hybrid Build Strategies, Parameters adjustments along the layer)

3. DED-Arc associated problems
(Distortion and Residual Stress – Heat related problems, Weld Bead Defects – Porosity, cracks and Delamination)

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# Directed Energy Deposition – Arc (DED-Arc) Manual

Coverage:

4. Post-processing
(Thermal Post-Processing (Post-Heating, Annealing, Hardening, Hot Isostatic Pressure (HIP)), Surface Finishing, Interpass cold rolling, Peening and ultrasonic impact treatment (UIT), Support and substrate removal)

5. DED-Arc build substrate, feedstock and other consumables
(Substrate, Feedstock)

6. DED-arc advantages and disadvantages
(Advantages of DED-Arc, Disadvantages of DED-Arc, Speed of the DED-Arc process, Economics of DED-Arc, Wire vs. Powder, DED-Arc vs. other AM processes, DED-Arc vs. traditional processes, Typical DED applications)

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# Directed Energy Deposition – Arc (DED-Arc) Manual

## CU 01 DED-Arc Process



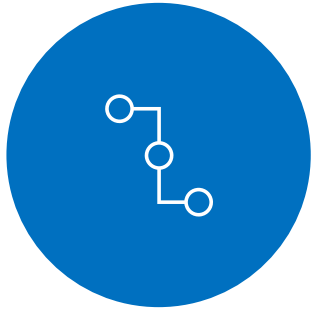
**OBJECTIVES:**



UNDERSTAND THE PRINCIPLES OF DED-ARC PROCESSES



UNDERSTAND DED-ARC PROCESS FEEDSTOCK



UNDERSTAND DED-ARC PROCESS LIMITATIONS

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# Directed Energy Deposition – Arc (DED-Arc) Manual

**On successful completion of this module a student should have knowledge of:**

1. DED–Arc systems
2. Arc physics
3. Processable materials with DED–Arc
4. Processing atmosphere requirements with DED–Arc
5. Sensors and process controls with DED–Arc
6. DED–Arc equipment, accessories, including build platform, feedstock and other consumables
7. DED–Arc process parameters and variables, including post-processing operations

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# Directed Energy Deposition – Arc (DED-Arc) Manual

## INTRODUCTION TO THE PROCESS DED-ARC

Additive processes are a way to manufacture objects obtained from Computer Aided Design (CAD) models. After a creation of a 3D model of the desired geometry, it is necessary to divide the wanted structure in a set of layers, which will then be produced one by one forming the final piece.

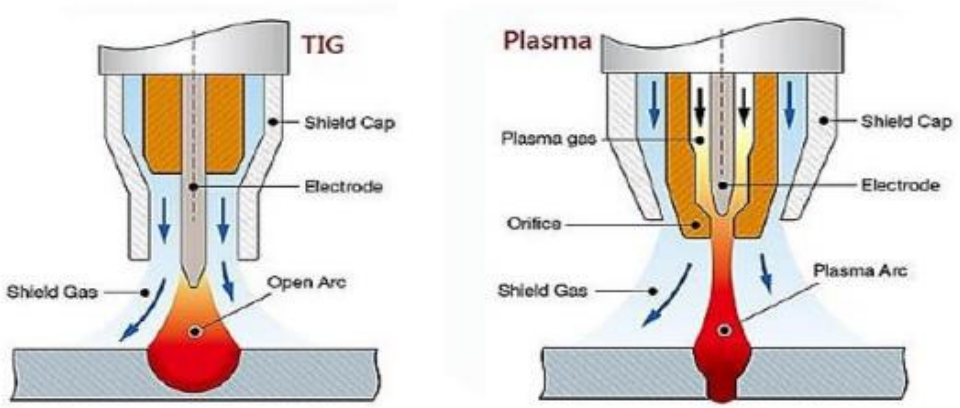
**DED-Arc** can be divided in three main types depending on the welding technology used, TIG, MIG-MAG and Plasma Welding.

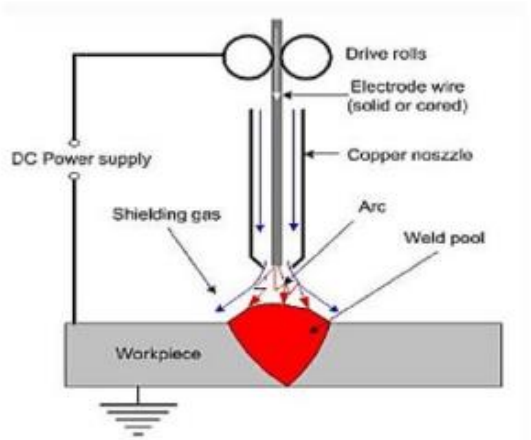
| WAAM | Energy source | Features |
|---|---|---|
| GTAW-based | GTAW | Non-consumable electrode; Separate wire feed process;<br>Typical deposition rate: 1-2 kg/hour;<br>Wire and torch rotation are needed; |
| GMAW-based | GMAW | Consumable wire electrode;<br>Typical deposition rate 3-4 kg/hour;<br>Poor arc stability, spatter; |
| | Cold metal transfer (CMT) | Reciprocating consumable wire electrode;<br>Typical deposition rate: 2-3 kg/hour;<br>Low heat input process with zero spatter, high process tolerance; |
| | Tandem GMAW | Two consumable wires electrodes;<br>Typical deposition: 6-8 kg/hour;<br>Easy mixing to control composition for intermetallic materials manufacturing ; |
| PAW-based | Plasma | Non-consumable electrode; Separate wire feed process;<br>Typical deposition rate 2-4 kg/hour;<br>Wire and torch rotation are needed; |

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## INTRODUCTION TO THE PROCESS DED-ARC




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## Gas System

**Local Shielding –** Used mainly in the production of large components where the quality part can be lower. More economic and practical since it does not need a chamber.

**Inert Chamber –** Creates a high-quality environment in a closed system of inert gas. Has the disadvantage of the high costs that is required to acquire the chamber and the associated components.

**Vacuum -** In this type of environment is where the components formed have the highest quality. Has some disadvantages as the high cost of the vacuum chamber, the energy wasted to generate vacuum and support its forces.



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## DED-Arc associated problems

**Distortion and residual stress –** Occurs due to the excessive heat input and large temperature gradients. Reduces fatigue life and stress corrosion resistance, and higher chances of mechanical failure.

**Porosity** – It is a welding defect that results from contaminations in the molten metal in the weld pool. Inclusions of this contaminations and voids seriously reduce the mechanical strength and the fatigue life of the final piece.

**Cracks –** These can form during the solidification process or in grain boundaries, due to the stress that arise with temperature gradients.

**Delamination –** Occurs due to incomplete melting or insufficient re-melting of the underlying solid between layers. This lack of fusion might be fatal to the workpiece functionally. Post-process generally will not solve the defect.

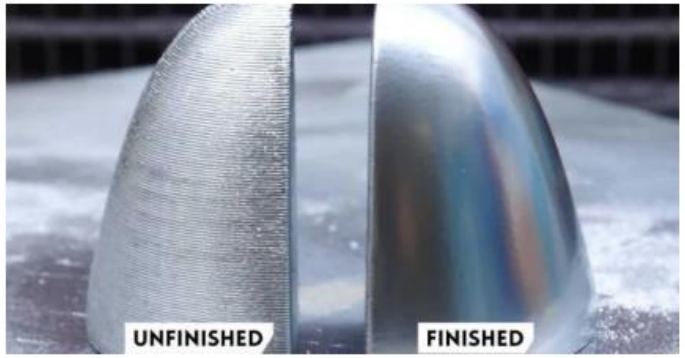
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## Post Processing

**Thermal Post-Processing –** Used to relieve residual stress, close pores and improve the mechanical performance of the material, such as increasing the material strength and making hardness control.

- Post-Heating
- Annealing
- Hardening
- Hot Isostatic Pressure (HIP)




**Surface Finishing -** In simple cases, polishing or grinding can be done with a rotary-tool or a belt sander. In other cases, it can be used chemical polishing.

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## Feedstock

The feedstock is the material that is deposited on the substrate through an arc. The material used in this process comes in wire spools for a high range of alloys.

- Titanium-based alloys
- Nickel-based alloys
- Aluminum alloys
- Magnesium alloys

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# Directed Energy Deposition – Arc (DED-Arc) Manual

## Advantages

- High deposition rates
- High level of automation
- Capability of repair or add material to existing components
- Capable of handling medium and large metal components
- Material waste close to zero

## Disadvantages

- Weak surface finish
- Increased residual stress
- Use of post-processing on the components

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# Directed Energy Deposition – Arc (DED-Arc) Manual

**Checklist – On successful completion of this module a student should be able to:**

- Describe the DED–LB systems, including the components and their functions
- Distinguish different types of feedstock
- Associate the interaction of the process heat source with the feedstock
- Recognise the DED–LB parameters and the influence of their adjustment on the as-built part (e.g., deformation)
- Recognise the characteristics of the DED–LB build platform, feedstock and other consumables
- Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED–LB
- Recognise the basic principles of 3D CAD systems and machine control software

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# Directed Energy Deposition – Arc (DED-Arc) Manual

- Relate the influence of the process parameters, build platform, feedstock and other consumables with the properties of the as-built part
- Implement different methodologies related with to process parameters and deposition strategies for reducing distortion of as-built parts
- Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them
- Select specific materials for different applications to meet part requirements
- Identify specific metallurgical aspects of DED-Arc parts
- Define DED-Arc parameters for manufacturing specific parts
- Adjust process parameters, manufacturing strategy and set up to prevent part defects and process-related issues

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

# CU 08

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

Coverage:

1. Introduction to the Process DED-LB

2. DED-LB Manufacturing Strategy
(Fixturing, Positioning and Nesting, Layer Thickness, Dosing Factor (Powder Capture Efficiency, Powder Optimization), Interaction of Layers, Distortion avoidance, Deposition rate/Production Rate (Deposition Rate, Production Rate), Hybrid Build Strategies, Parameters adjustments along the layer)

3. Equipment and accessories
(Optical System, Powder/wire Feeding System, Gas System, Powder Feeding System (Powder feeding and Conveyance Systems), Deposition Direction (Types of Nozzles), Sieves and Filters (Sieves, Filters)

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

Coverage:

4. DED-LB Build substrate
(Common defects, Influence of Inclined Substrate in DED)

5. Post processing

6. Consumables (Feedstock)

7. Advantages and Limitations

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## CU 08 DED-LB Process



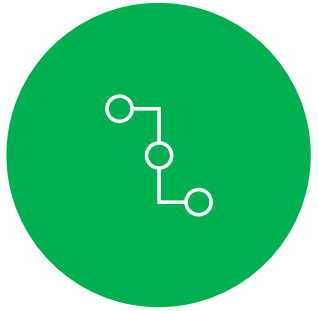
**OBJECTIVES:**



UNDERSTAND THE PRINCIPLES OF DED-LB PROCESSES



UNDERSTAND DED-LB PROCESS FEEDSTOCK



UNDERSTAND DED-LB PROCESS LIMITATIONS

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

**On successful completion of this module a student should have knowledge of:**

1. DED-LB systems
2. Laser characteristics
3. Build platform
4. Powder/wire
5. Gases
6. DED-LB equipment, accessories, including build platform, feedstock and other consumables
7. DED-LB process parameters and variables, including post-processing operation

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## Introduction to the Process DED-LB

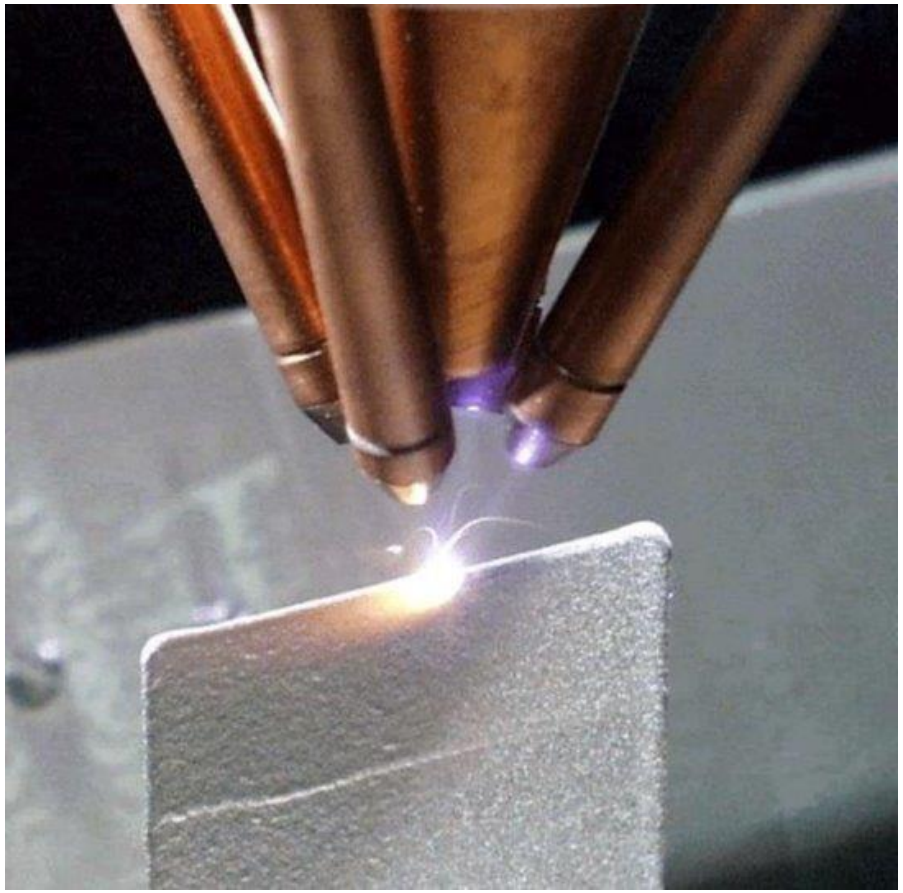
Additive manufacturing (AM) was born as a rapid prototyping technology with the process of joining materials in successive layer by layer to make objects. It allows designers to produce accurate physical prototypes directly from 3-Dimensional Computer-Aided Design (3D-CAD) model in few hours.

**DED-LB** is a technology that works by melting material that is fed to a local site on the build layer, usually occurring within an inert gas atmosphere. While this can be used for nonmetal materials, it is predominately used with metals and metal alloys.

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual



In laser DED, the material in the form of powder or wire is fed into the melt pool. The powder is usually blown coaxially from either a conical nozzle or a multi-nozzle powder delivery system into the processing zone.

In laser DED based on wire feeding, the wire metal is usually fed from one side (mostly from leading edge of melt pool). With the advancement of this technology, new laser heads are capable of feeding wire from center that is being exposed to the coaxially split laser beams.

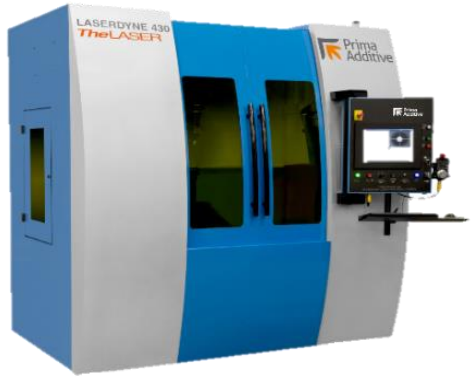
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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Fixturing

- **Control Workstation**
- **Laser Source**
- **Powder feeding system**
- **Multi-axis CNC system**













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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

Configurations that can appear in the machines:

**Fixed Tables**: Fixed tables exploit the very large working envelope to process large parts and provide great accessibility from all sides. The accuracy of the part could be improved by better securing the substrate in the same position.

**Split Cabin**: The Split Cabin configuration allows the working volume to be separated in a removable wall and a sliding roof into two halves, where the parts are alternatively processed or loaded/unloaded in total safety. In this way, machine productivity is increased and, when needed for larger parts, the wall can be removed to restore the entire working envelope.

**Turn Table**: The installation of the turn table has the function of keeping the pool of fusion created in a horizontal plane.

**Automatic Shuttles**: "The Shuttle Tables allow quick and automatic movement of parts and accessories outside the work area from the sides or from the front of the machine". This perfect solution allows large, heavy parts to be handled outside the work area. It is also vital in the case of complex configurations.

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## Layer Thickness

Every part manufactured using a process of AM is built layer to layer. **Layer thickness** is one of the most important aspects to consider as it varies depending on the parameters that the operator inputs into the machine.

The laser generates a small molten pool typically **0.25-1 mm** in diameter and **0.1-0.5 mm** in depth on the substrate, into which feedstock material (wire or powder, or a combination of both) is injected.

The amount of track overlap is typically **25% of the track width**. Results in re-melting of previously deposited material, and typical layer thickness employed are **0.25-0.5 mm**.

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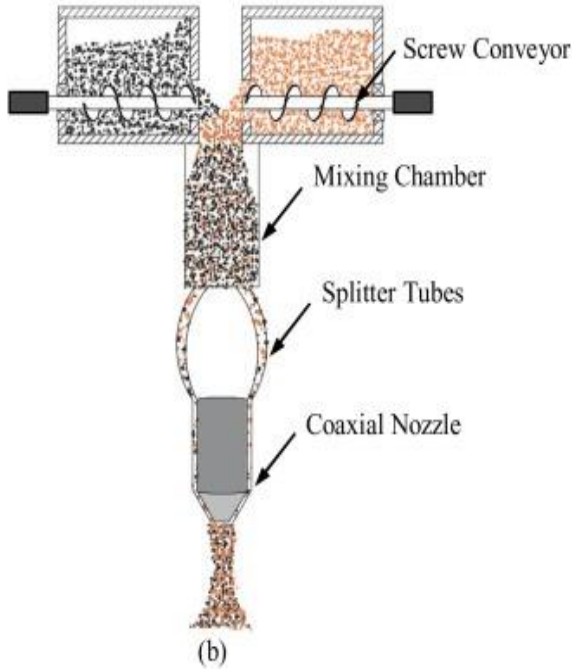
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## Dosing Factor

Amount of powder needed to properly cover the
Exposure area of each layer without over or under dispensing powder.
The quantity of powder can increase or decrease.

- **Gravity powder conveyance system**
- **Screw for powder metering**

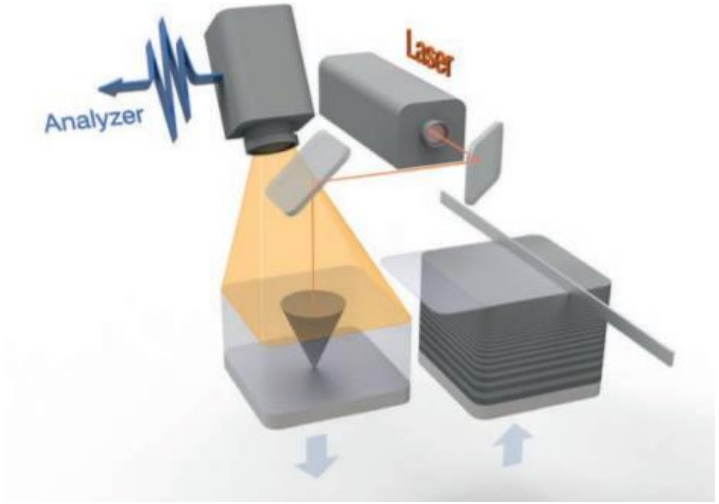



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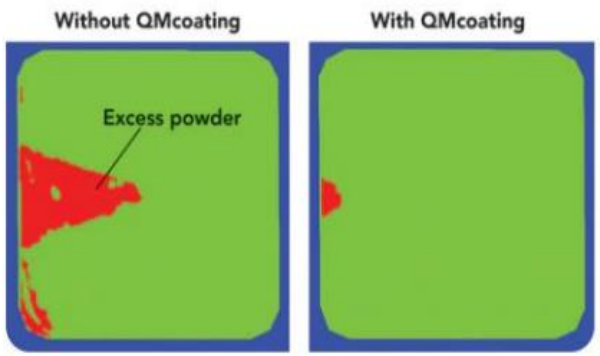
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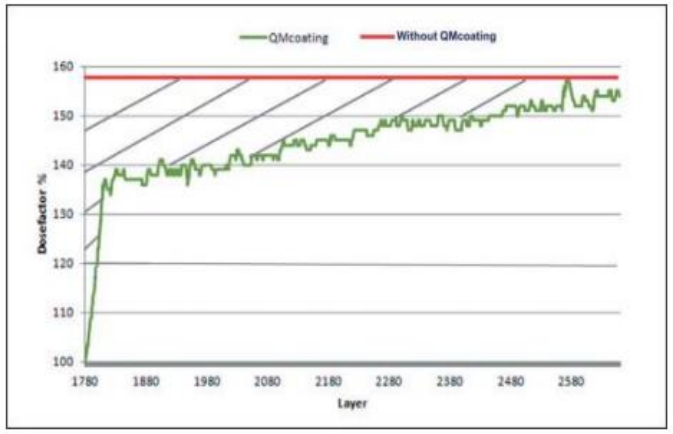
## Dosing Factor – Powder Optimization




QM Coating advantages:

- The real-time monitoring of the dosing factor;
- The reduction of setup times;
- The powder savings;
- The guarantee of an optimal coating throughout the entire build process.



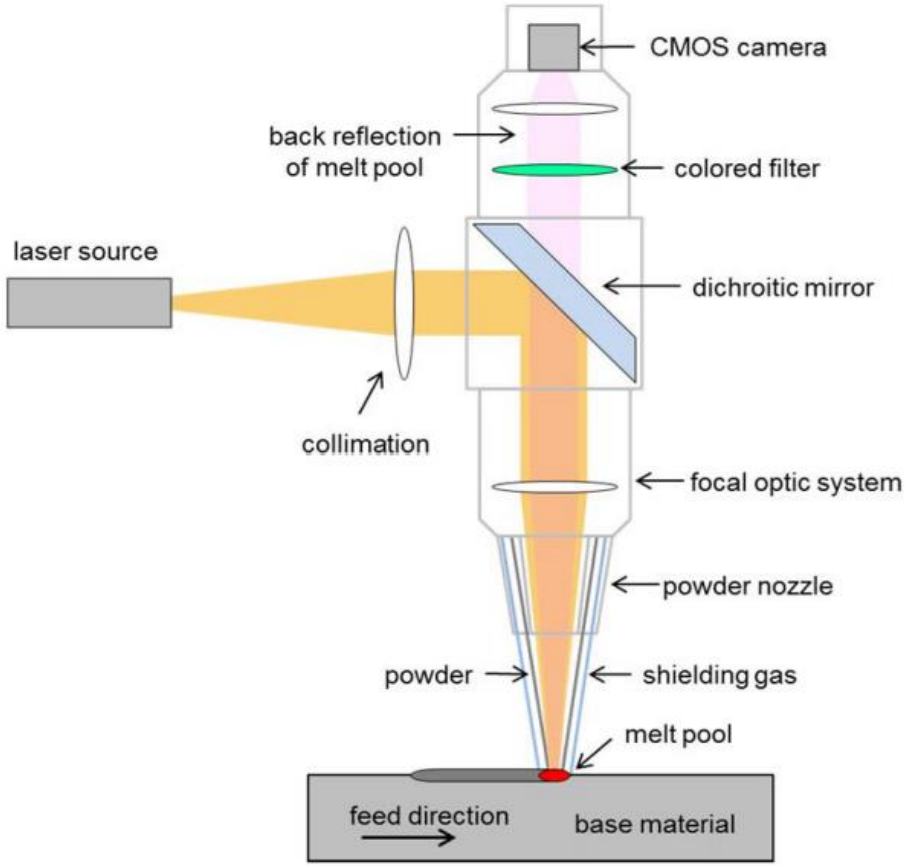




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Optical System



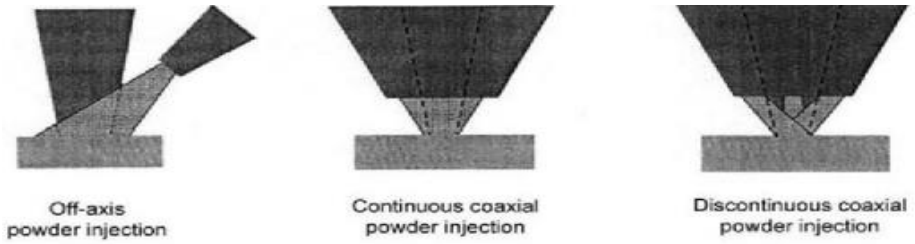

- **Laser source** – is responsible for providing the laser beam for the process. There are different types of laser sources currently available (typically between 500 W and 6000 W), each with diverse functional characteristics.
- **Chiller** – normally attached to the laser system, responsible not only for cooling it, but also for cooling other machine components. Deionized water is commonly used as a coolant, and it must be adjusted to circulation system materials, since it can be highly aggressive with some material (ex. Copper).
- **Collimator** – attached to the lased head, responsible for receiving the diverging light from the optical path, and producing a parallel beam, increasing its output quality.

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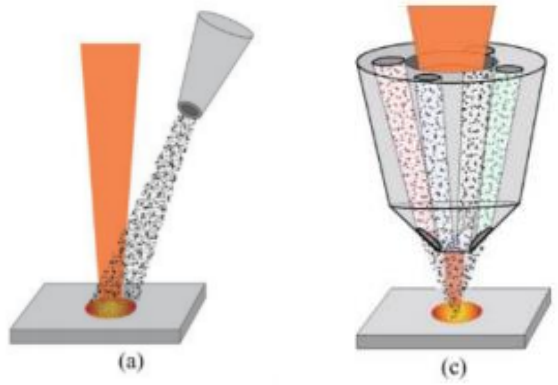
# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Powder/Wire Feeding System




Powder injection can be done using 3 methods:

- Off-axis powder injection (there is only a single powder stream fed laterally into the laser beam);
- Coaxial continuous powder injection (the powder stream cone is produced and encloses the laser beam);
- Discontinuous coaxial powder injection (the laser beam is fed coaxially by three or more streams of powder).




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Powder/Wire Feeding System

| Powder feeding arrangement | Advantages | Disadvantages | Suitable for |
|---|---|---|---|
| Lateral or off-axis  | • Part accessibility<br>• Width of deposited track: 0.5–25 mm<br>• Laser power up to 20 kW maximum | • Directional deposition<br>• Less powder efficiency<br>• Alignment between powder and laser beam<br>• No integrated protective gas feeding | • Directional deposition<br>• Specific requirements in terms of part accessibility |
| Continuous coaxial  | • Unidirectional deposition<br>• Width of deposited track: 0.3–5 mm<br>• Applied laser power: up to 3 kW maximum<br>• Powder efficiency: maximum 90% (diameter of powder-gas jet in the focus: minimum 400 µm)<br>• Integrated protective gas feeding | • Restricted part accessibility<br>• Gravity influence, no deposition for tilting angles >20 degrees because of inhomogeneous powder density distribution | • 3D deposition up to tilting angles of approximately 20 degrees<br>• Largest effect from integrated protective gas feeding |
| Discontinuous coaxial  | • Unidirectional deposition<br>• Width of deposited track: 2–7 mm<br>• Applied laser power up to 5 kW maximum<br>• Unrestricted 3D functionality<br>• Integrated protective gas feeding | • Restricted part accessibility<br>• Low powder efficiency (diameter of powder-gas jet in the focus: minimum 2.5 mm) | • 3D deposition up to tilting angles of 180 degrees (overhead processing is feasible) |

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

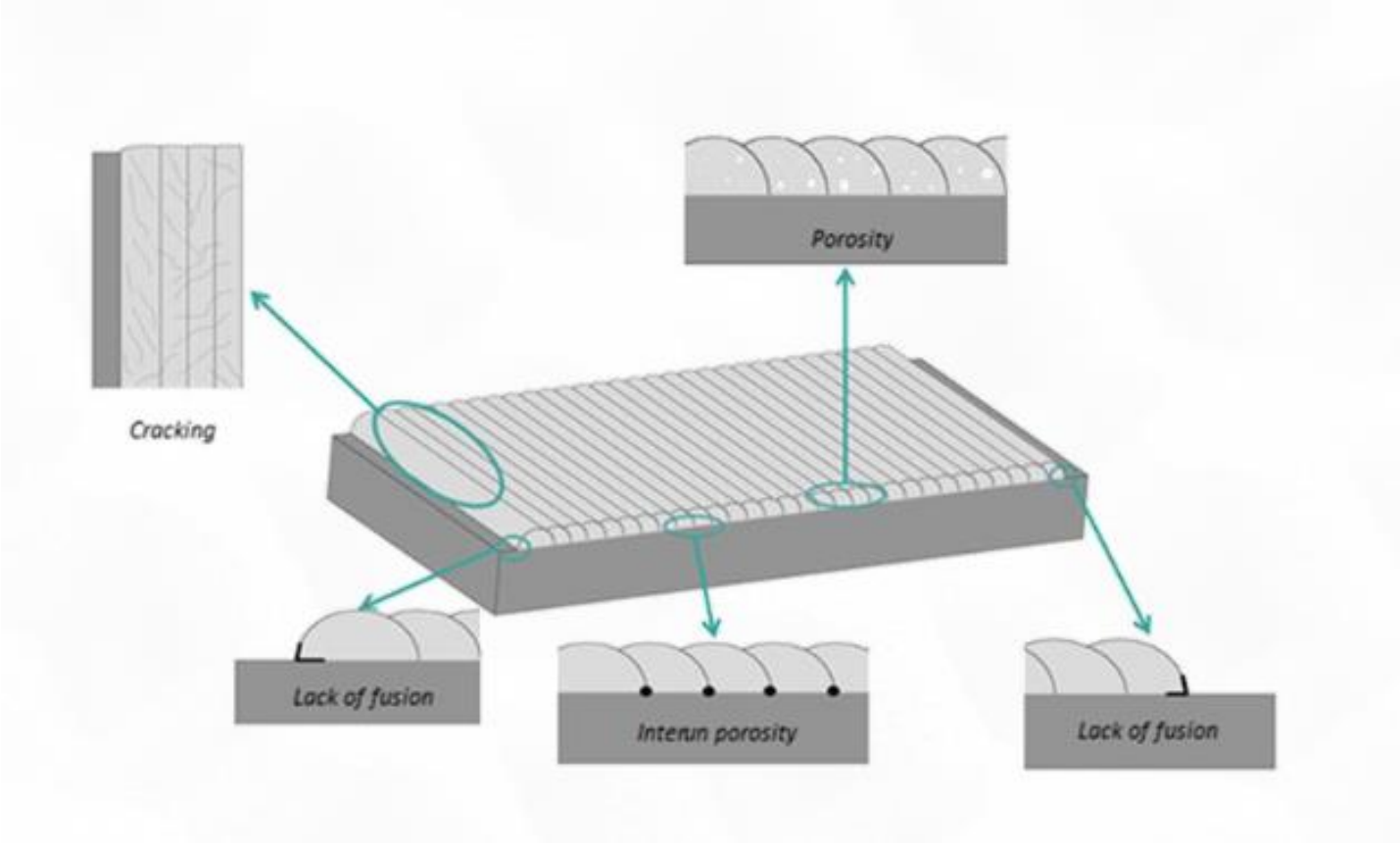
## Defects

During deposition a range of defects may occur:

- Porosity
- Lack of Fusion (LoF)
- Cracking
- Residual stress

Some may be mitigated during pre or post-process:

- Parameter/process optimisation
- Post processing




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Defects – Porosity

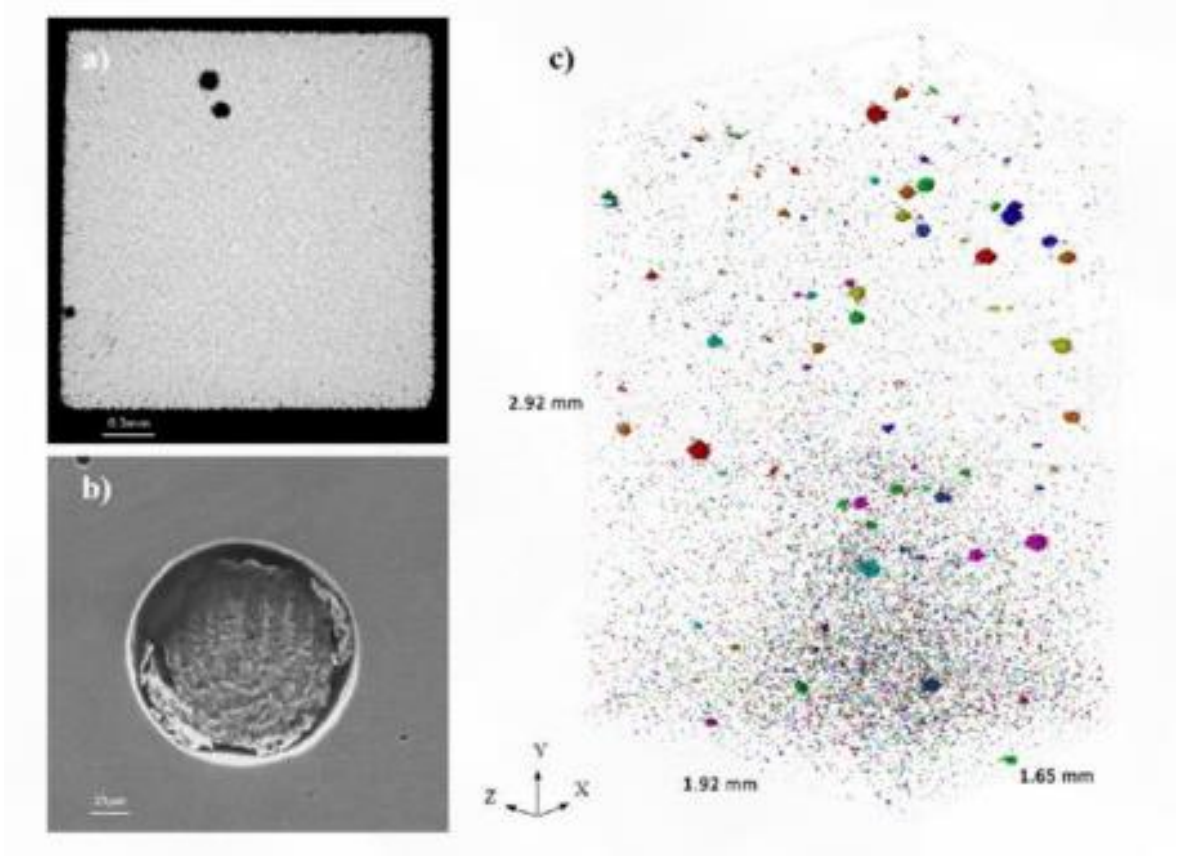
Typically, spherical
Can occur throughout the component

Why does it occur?

- Incorporation of gas contained powder particles
- Over-melting
- Incorporation of process gases
- Poor track stitching

How can we avoid?

- Good quality powder
- Optimisation of parameters
- Melting
- Shielding and delivery gases




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Defects – Lack of Fusion

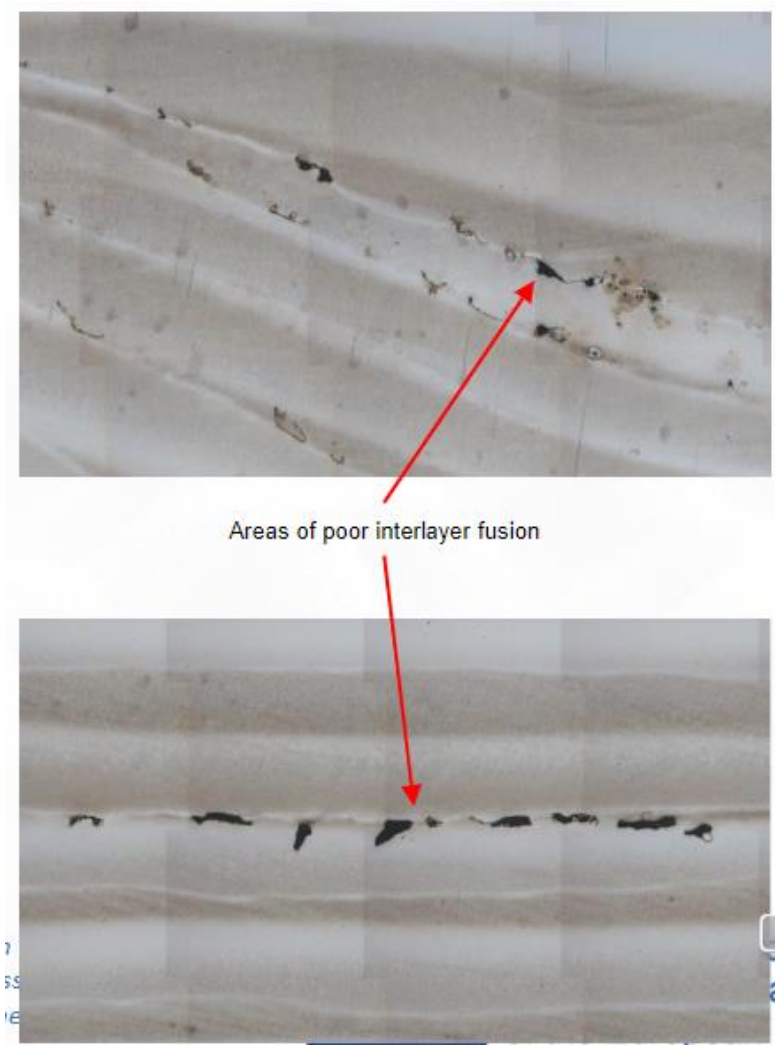
Typically, irregular and non spherical
Occurs between layers or coating substrate interface

Why does it occur?

- Due to insufficient melting of substrate or previous layers
- Oxides can also inhibit fusion (Aluminiumoxides especially)

How can we avoid?

- Increase re-melting depth
- Optimisation of parameters




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Defects – Cracking

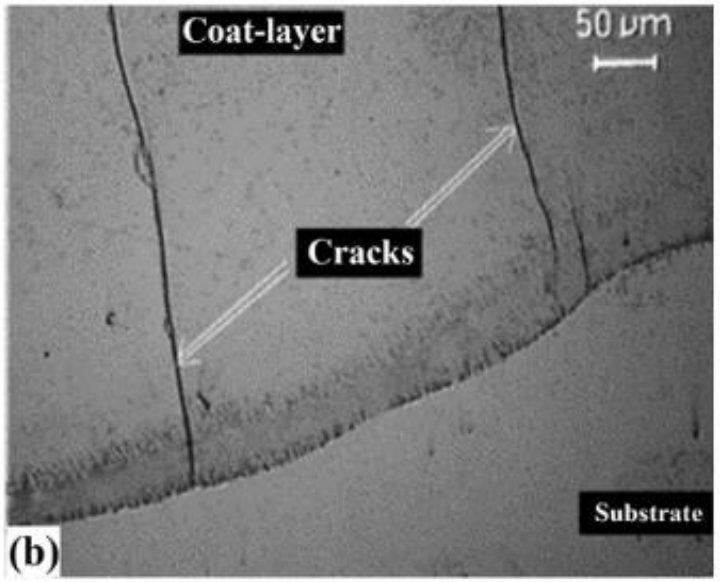
Macro and microscale cracking

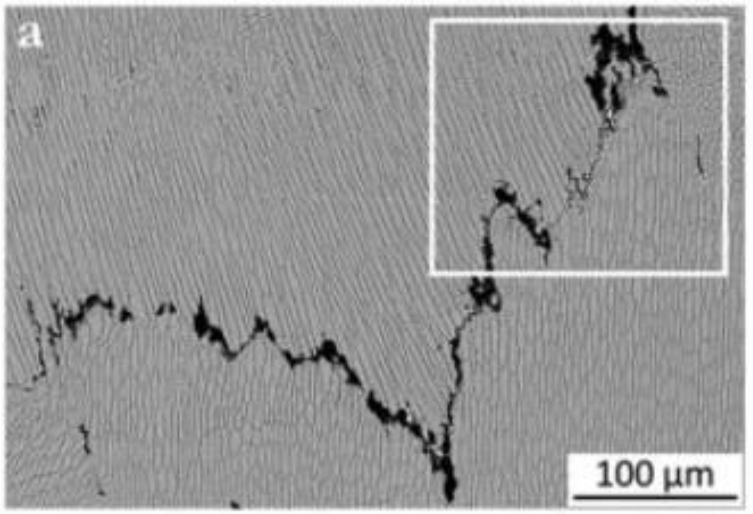
Why does it occur?

- Hot tearing
- Liquation cracking
- Differential thermal contractions

How can we avoid?

- Parameter optimisation-aimed at reducing cooling rates
- Pre-heating -aimed at reducing residual stresses
- Buffer layers for thermal property gradation
- Material selection




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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

## Advantages

- High productivity;
- Capability of manufacturing parts with complex geometries
- Capability of creating a surface layer to improve the surface's properties
- Wide range of alloys that can be used
- Low impact on substrate's properties

## Disadvantages

- High cost of the necessary equipment;
- Powder material is expensive;
- Design freedom more limited than Powder Bed Fusion;
- The need to have post-processing steps to obtain good surface rectilinearity

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

**Checklist – On successful completion of this module a student should be able to:**

- Describe the DED–LB systems, including the components and their functions
- Distinguish different types of feedstock
- Associate the interaction of the process heat source with the feedstock
- Recognise the DED–LB parameters and the influence of their adjustment on the as-built part (e.g., deformation)
- Recognise the characteristics of the DED–LB build platform, feedstock and other consumables
- Identify the problems associated with inadequate preparation and set-up of the build platform, handling and storage of feedstock and application of the gases used in DED–LB
- Recognise the basic principles of 3D CAD systems and machine control software

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

- Explain how the DED-LB process works
- Explain the influence of modifying process parameters on the as-built part
- Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing
- Identify areas that will need thermal compensation
- Identify the cause of defects and propose methods for their mitigation
- Discuss the adequacy of selected equipment and accessories on the part manufacturing
- Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them

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# Directed Energy Deposition – Laser Beam (DED-LB) Manual

- Select specific materials for different applications to meet part requirements
- Identify specific metallurgical aspects of DED-LB parts
- Identify the variables used to define the DED-LB manufacturing strategy

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

# CU 15, CU 00

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# Power Bed Fusion – Laser Beam (PBF-LB) Manual

Coverage:

1. Introduction to the Process PBF-LB
(General Introduction to PBF, and PBF-LB Specifically, Classification, Advantages and Disadvantages, Process Mechanics)

2. PBF-LB Manufacturing Strategy
(Fixturing, Positioning and Nesting, Layer Thickness, Dosing Factor, Interaction of Layers (Effect of spatter on powder layer height, Effect of denudation on powder layer height), Distortion avoidance (Evolution along the building process, Thermal Conductivity of Metal Powder and Surrounding Gas Effect, Cooling Rate, Thermal Stresses, Solutions), Deposition rate/Production Rate, Hybrid Build Strategies, Parameters adjustments along the layer, Scanning Strategy)

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# Power Bed Fusion – Laser Beam (PBF-LB) Manual

Coverage:

3. Equipment and accessories
(Optical System, Powder Feeding System, Powder Handling System, Gas System, Deposition Direction, Sieves and Filters)

4.Defects
(Sources of Defects, Defect Control)

5. Post processing

6. Consumables
(Feedstock, Process Gas and Gas System)

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

## CU 00 Additive Manufacturing Process Overview







**OBJECTIVES:**

UNDERSTAND THE HISTORY OF ADDITIVE MANUFACTURING TECHNOLOGIES

UNDERSTAND AND DISTINGUISH THE MAIN ADDITIVE MANUFACTURING PROCESSES

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

## CU 15 PBF-LB Process



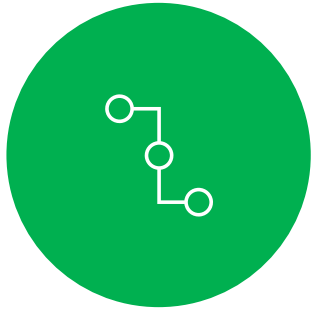
**OBJECTIVES:**



UNDERSTAND THE PRINCIPLES OF PBF-LB PROCESSES



UNDERSTAND PBF-LB PROCESS FEEDSTOCK



UNDERSTAND PBF-LB PROCESS LIMITATIONS

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

**On successful completion of this module a student should have knowledge of:**

1. PBF-LB systems
2. Laser characteristics
3. Build platform
4. Powder
5. Gases
6. Processable materials with PBF
7. PBF-LB equipment, accessories, including build platform, feedstock and other consumables
8. PBF-LB process parameters and variables, including post-processing operation

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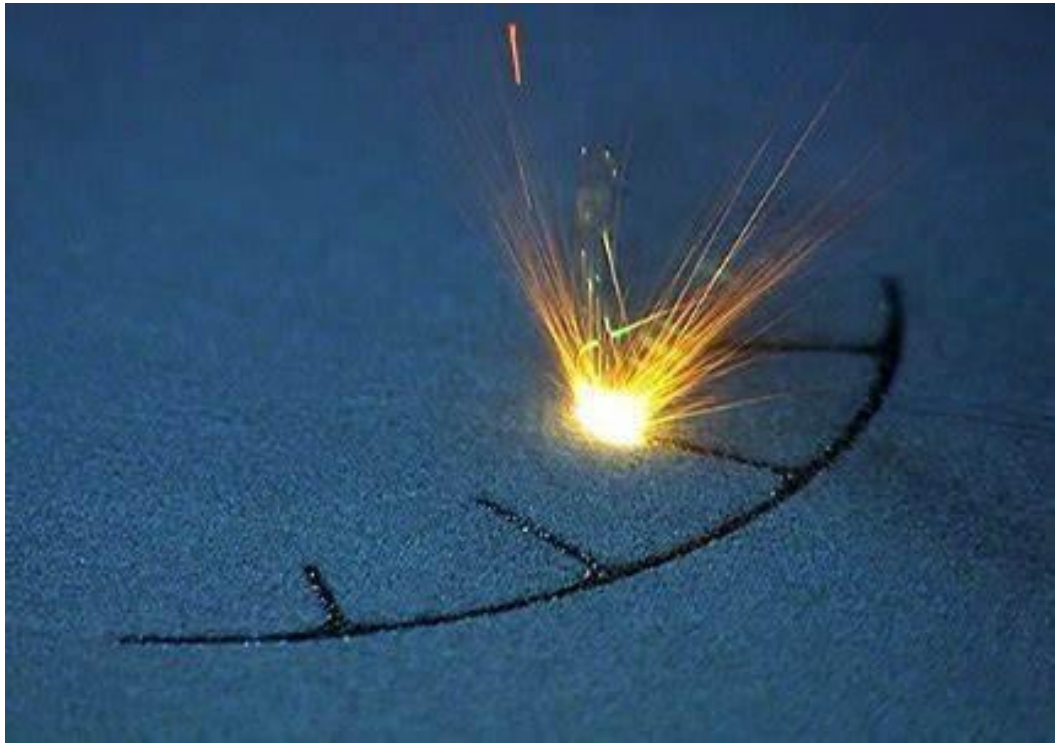
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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

## Introduction to the Process PBF-LB

Powder Bed Fusion is a manufacturing process steadily improving to directly produce net-shape or net-shape metal tools or functional products. PBF presents an unlimited drawing freedom: complex shapes with a rapid, flexible and economical way, where the traditional techniques show their limits.

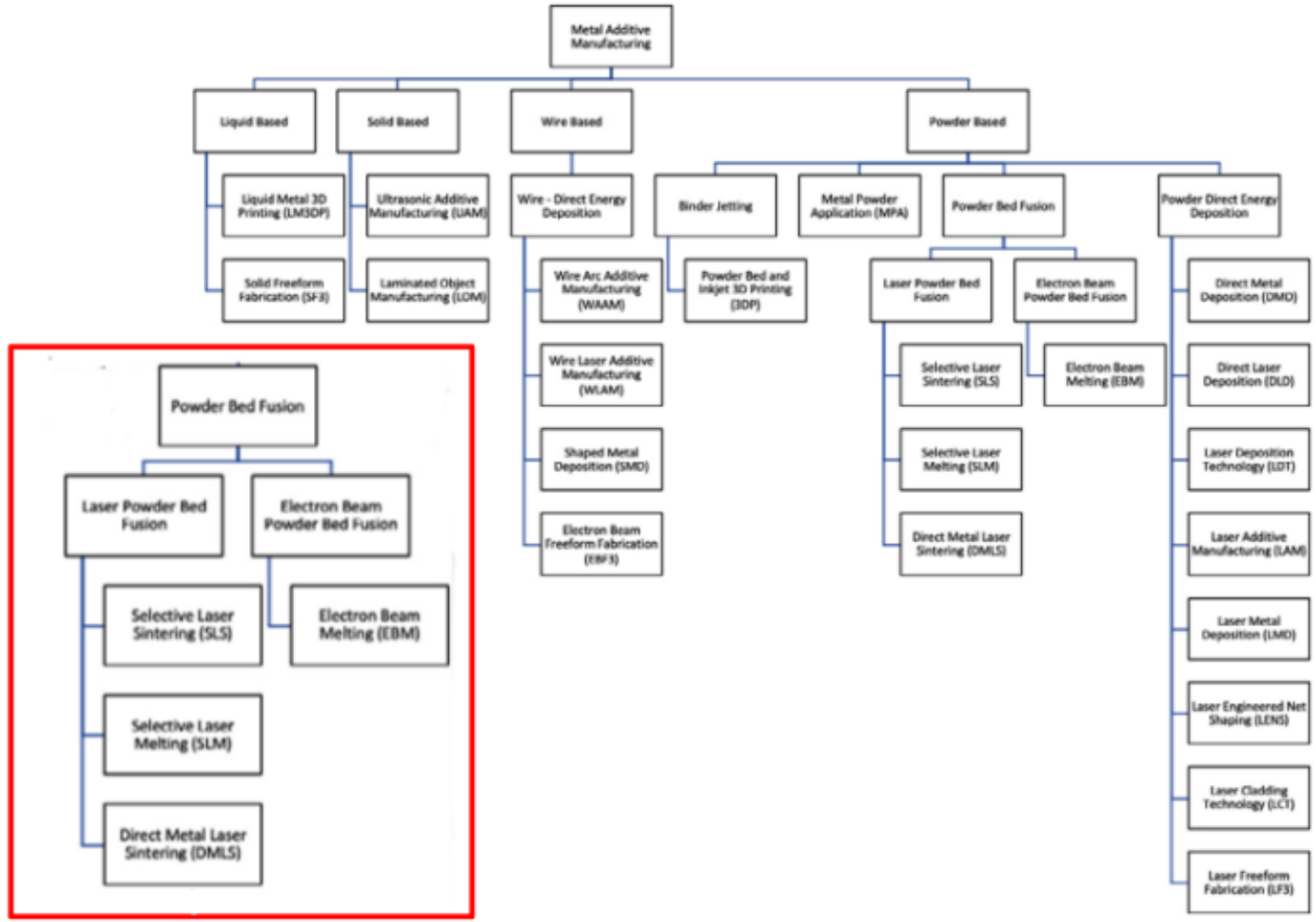
**PBF-LB** begins with the creation of a 3D CAD model, which is numerically sliced into a number of finite layers.



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**Selective Laser Sintering (SLS) -** SLS is a process that applies the same scheme of the general PBF process but without complete melting of the powder. It only applies a densification of the powders by sintering, so by the application of heat and pressure on the piece in order to be able to decrease the number of voids that are present in the initial powder structure and doing so increases the density and consequently the mechanical properties of the final object.

**Selective Laser Melting (SLM) -** Compared to SLS, this technique ,SLM, is faster but requires inert gases protection to avoid oxidation. In fact, in this method, powder is melted rather than sintered. It is currently a very popular method for fabrication of metal parts. Recently, high power lasers with the development of fibre optics are also added in SLM to process different types of metallic materials such as tungsten, copper & aluminium.

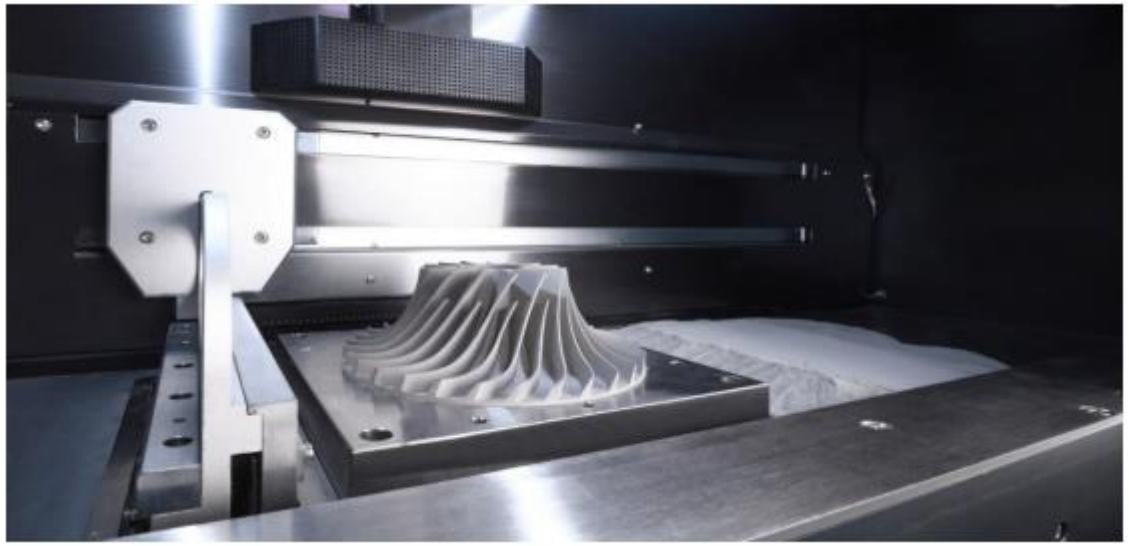
**Direct Laser Metal Sintering (DLMS) –** DMLS is a laser-based AM technique, in which an object is developed with the use of metal (not plastic) powders. Similar to SLS, it is a layer by layer process with computer controlled laser technique. With the support of DMLS, it is possible to control the porosity of each layer, but not eliminate it completely. DMLS titanium implants are probably the most widely spread type of production of this kind.

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## Fixturing

A fixture is a work-holding or support device used in the manufacturing industry. Fixtures are used to securely locate (position in a specific location or orientation) and support the work, ensuring that all parts produced using the fixture will maintain conformity and interchangeability.
A fixture differs from a jig in that, when a fixture is used, the tool must move relative to the workpiece, when a jig is used, it moves the piece while the tool remains stationary.



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## Fixturing

Regarding the support, we can consider that the initial support is given by the metallic plate in which the first layer is deposited, and the any additional support needed can be built up together with the piece. With additive manufacturing the problem of complex supports is easily resolved by simply building up the support with the piece itself.



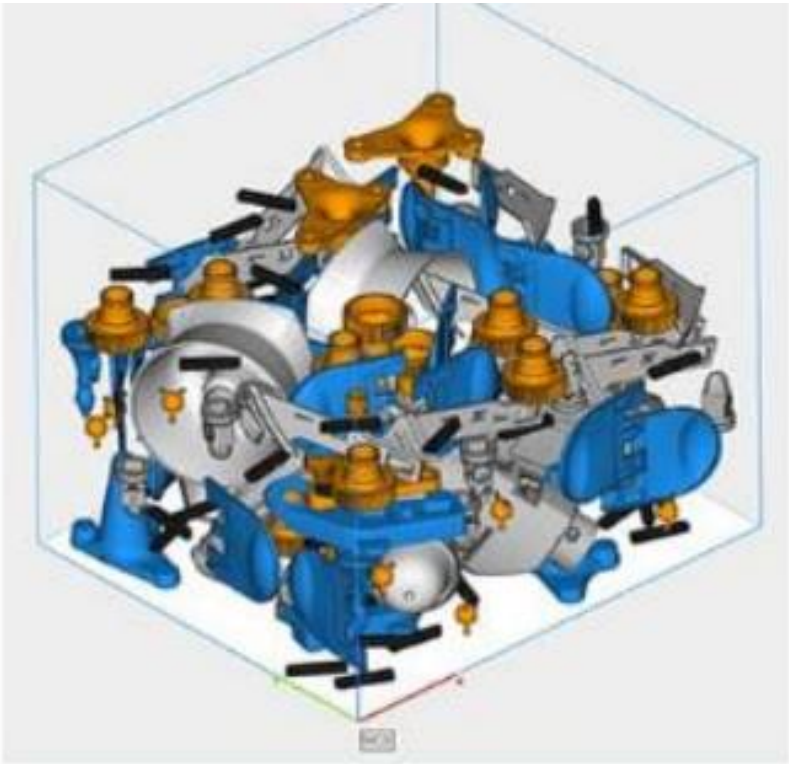
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## Positioning and Nesting

To have an efficient PBF process, it is important to plan correctly how many parts can be built in each batch. The machine can build several parts at the same time, which allows for more efficient production and less powder waste and energy spending.

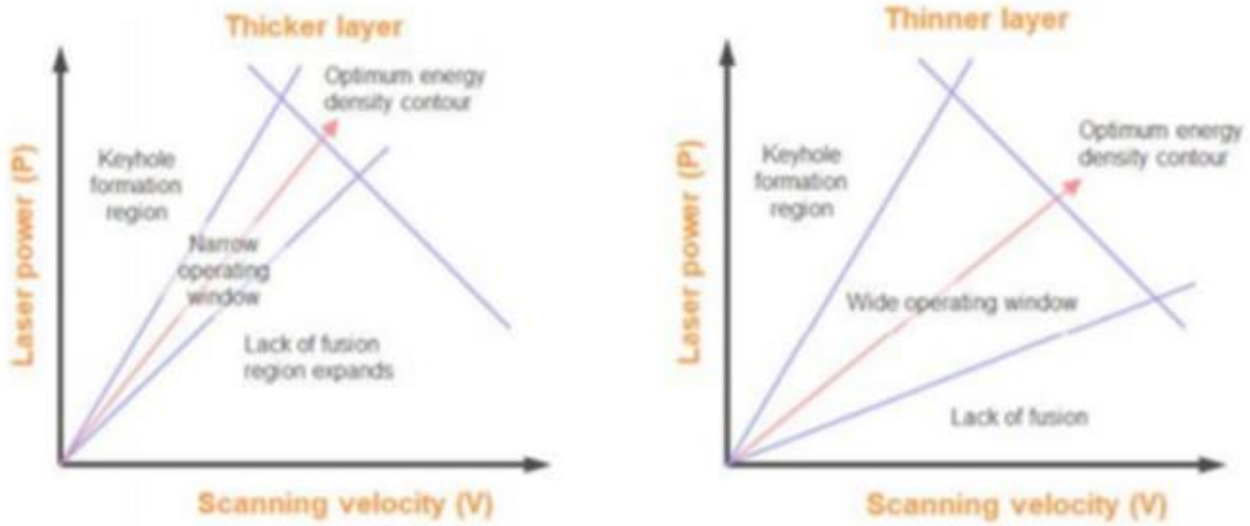
Nesting is the process of correctly positioning and fitting as many parts as possible in the powder bed.



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## Layer Thickness



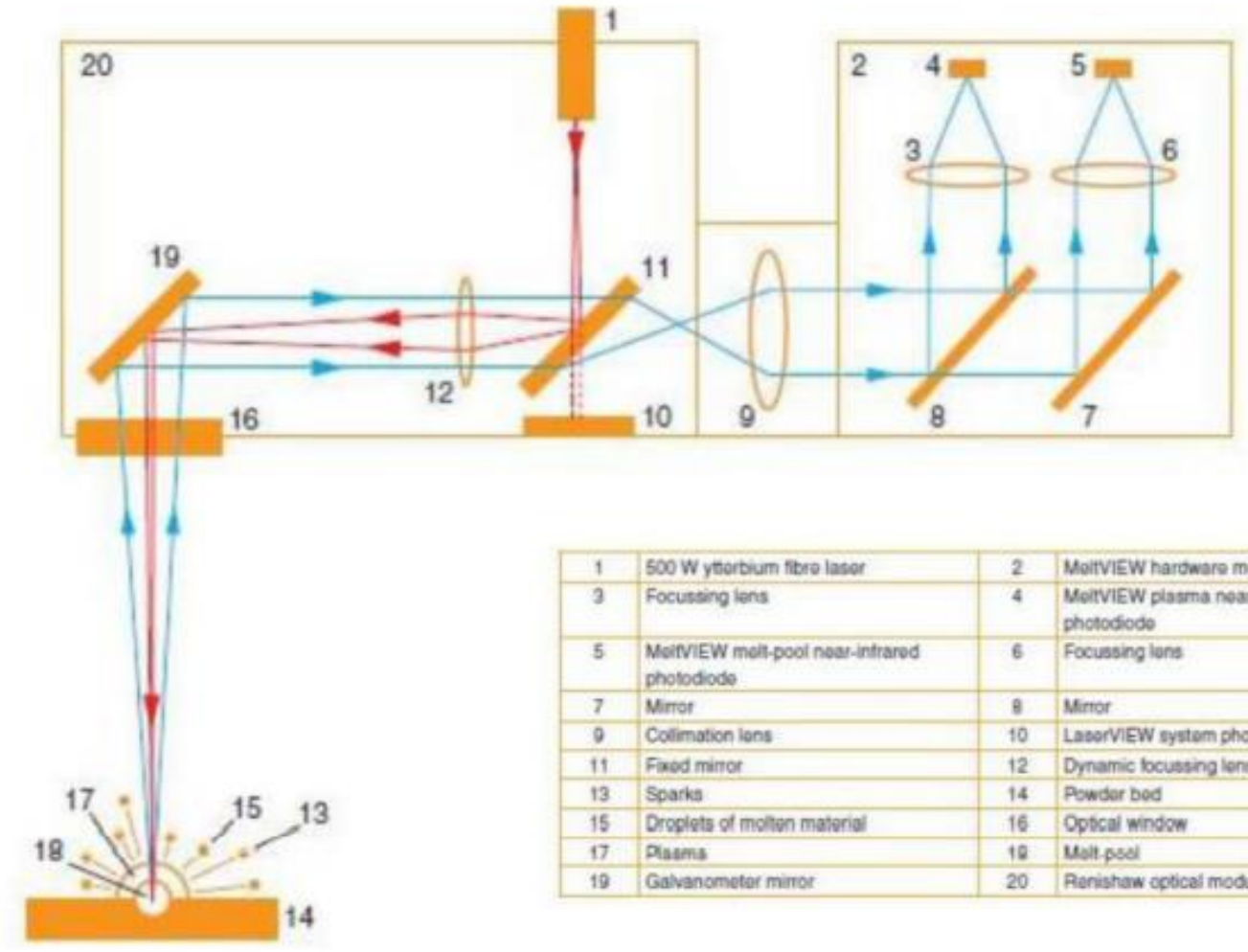

- Lower powder layer thickness results in better surface finish.
- Porosity level slightly increases with the increase in the powder layer thickness.

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

## Optical System

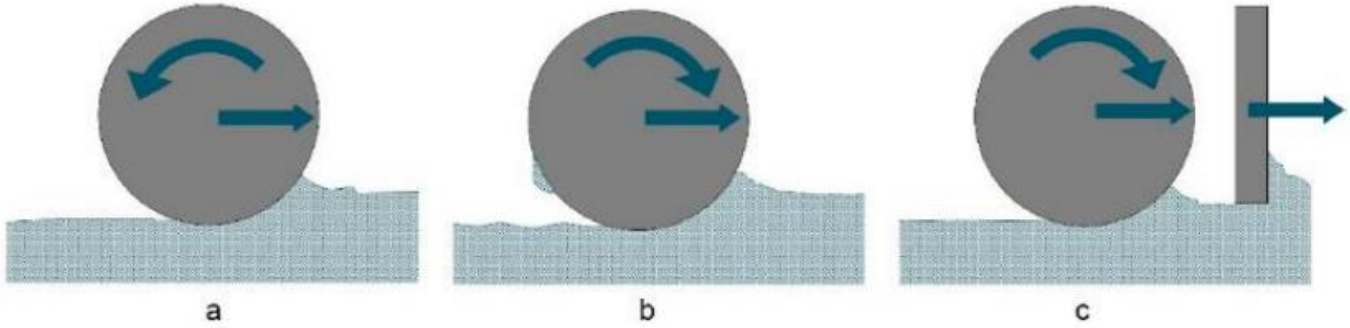


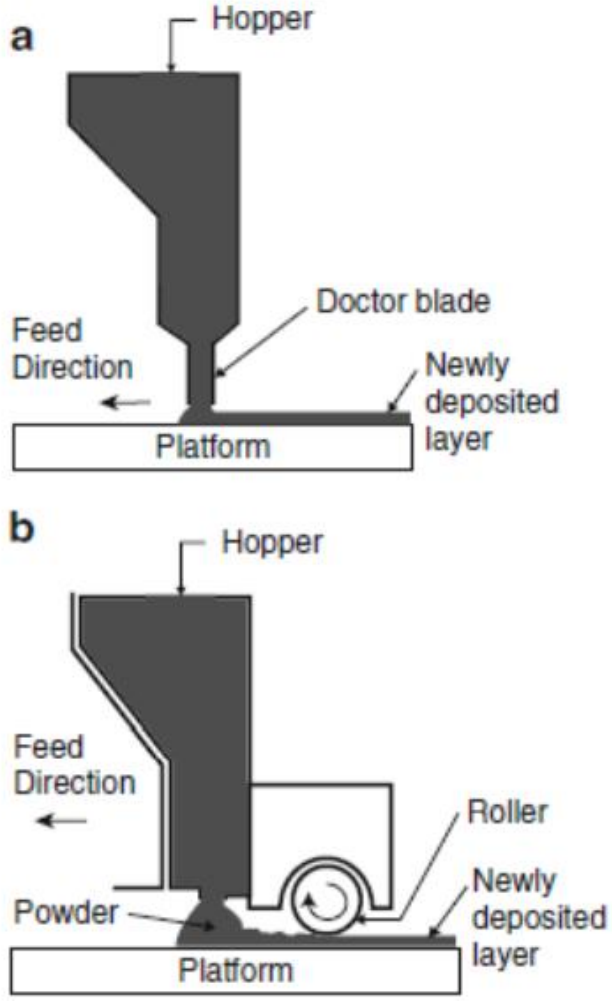

| | | | |
|---|---|---|---|
| 1 | 500 W ytterbium fibre laser | 2 | MeltVIEW hardware module |
| 3 | Focussing lens | 4 | MeltVIEW plasma near-infrared photodiode |
| 5 | MeltVIEW melt-pool near-infrared photodiode | 6 | Focussing lens |
| 7 | Mirror | 8 | Mirror |
| 9 | Collimation lens | 10 | LaserVIEW system photodiode |
| 11 | Fixed mirror | 12 | Dynamic focussing lens |
| 13 | Sparks | 14 | Powder bed |
| 15 | Droplets of molten material | 16 | Optical window |
| 17 | Plasma | 19 | Melt pool |
| 19 | Galvanometer mirror | 20 | Renishaw optical module |

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## Deposition Direction




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## Defects

**Feedstock Material** – can be the first source of defect formation based on its atomization process and whether it carries a high amount of entrapped gas.

**Energy Input –** Insufficient energy will cause compromised bonding between layers and create LoF defects. Excess energy will cause violent convection currents and significant vapor recoil forces.

**LoF (Lack of Fusion) –** These defects usually have sharp edges and are elongated between the layers and also laser tracks. Generally, large LoF defects are formed around and contain unmelted powder particles.

**Void and Gas Bubbles –** Common when the heat input is too high and occurs mainly in the melt pool.

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## Post Processing

**Solution, Quench, Age and Temper heat Treatments –** These steps are required, where the processing of material does not result in an optimum structure for meeting the requirements for the part which is in use. These processes tend to be alloy specific

**Hot Isostatic Press (HIP) –** This method is used to close down the pores and cracks developed in the material. Pressure and high temperatures both work simultaneously and engage in heat treatment of AM parts to close the defects than can lead to poorer tensile and fatigue performance.

**Stress Relief -** Recovery of material at an elevated temperature. As it is not possible to remove the part from the build platform without any distortion, a stress relief is necessary to equalize the stress gradients that are caused by the process, to enable the removal of the part without any distorted shape or part cracking.

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# Powder Bed Fusion – Laser Beam (PBF-LB) Manual

## Advantages

- Design freedom
- High resolution and geometrical accuracy
- Allows for fully customised parts to suit individual requirements
- Unused powder can be recycled and reused in some applications
- Weight savings through using material only where needed

## Disadvantages

- Need for post-processing
- Limited space which limits the part dimensions
- Relatively slow process – not ideal for production in series

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**Checklist – On successful completion of this module a student should be able to:**

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- Recognise the interaction of the process heat source with the feedstock
- Identify the problems associated with inadequate preparation and setup of the build platform, handling and storage of feedstock and application of the gases used in PBF-LB
- Explain how the PBF-LB process works
- Explain the influence of modifying process parameters on the as-built part

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# Power Bed Fusion – Laser Beam (PBF-LB) Manual

- Discuss the influence of build platform, feedstock and other consumables characteristics on part manufacturing
- Identify areas that will need thermal compensation
- Identify the cause of defects and propose methods for their mitigation
- Discuss the adequacy of selected equipment and accessories on the part manufacturing
- Distinguish the different regimes and processes of failure and describe the factors controlling them and the boundaries and limits between them
- Select specific materials for different applications to meet part requirements
- Identify specific metallurgical aspects of PBF-LB parts

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# Power Bed Fusion – Laser Beam (PBF-LB) Manual



Identify the variables used to define the PBF-LB manufacturing strategy

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