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NextGEng

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NextGEng Project

WP3

International team-teaching pilot program

Deliverable 3.5b

Developed course modules C5 and C6

September 2024

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA · jamk · Universidad de Jaén · iSR www.isr.es · Valmet · BOSCH Invented for life

WP3	R3.5b - Developed course modules C5 and C6
Authors	Ciprian Rad
Short Description	This report presents the results of the course upgrading process for courses C5 and C6 within second round of course and laboratory upgrading process in WP3.
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Contributions by:	Ciprian Lapusan
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Final	29.09.2024	Ciprian Rad	Final Version

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1. Introduction

This report presents the outcomes of the course upgrading and team-teaching development carried out within WP3 of the NextGEng project. The implementation process led to the creation of **12 new English-language course modules**, developed across the three partner universities—TUCN, JAMK, and UJA (TUCN: 5 modules; JAMK: 3 modules; UJA: 4 modules). These modules were designed using student-centered and collaborative teaching approaches, integrating blended and digital delivery methods, eco-friendly concepts, and real-life case studies to ensure a modern and practice-oriented learning experience.

The development process was highly collaborative, involving **16 coordination meetings** across the co-teaching teams of courses C5–C6, with the participation of **12 higher-education teachers** and **5 industry experts**. This joint effort ensured alignment of content, consistent implementation across institutions, and the integration of industry-relevant competencies.

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In the next Chapters the produced courses modules are presented.

2. Courses topics

C5 - Computer Aided Design

Module 1 – Simulation of mechanical assemblies

Module 2 – FEA analysis of mechanical parts

Module 3 – Parametric Design with CATIA

Module 4 – 3D-Scanning

Module 5 - Reverse Engineering

Module 6 – Ecodesign

Module 7 - Re-design & Re-Using

C6 - Manufacturing Technology

Module 1 – 3D printing processes

Module 2 – Manufacturing technology of MEMS

Module 3 – Design for Additive Manufacturing (DfAM)

Module 4 – Additive Manufacturing Materials

Module 5 – Sustainable Additive Manufacturing

C5 – Computer Aided Design

M1 - Simulation of mechanical assemblies

CO - Technical University of Cluj-Napoca

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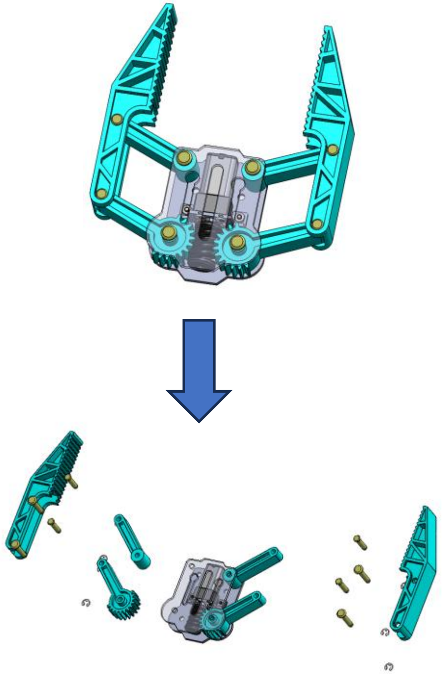
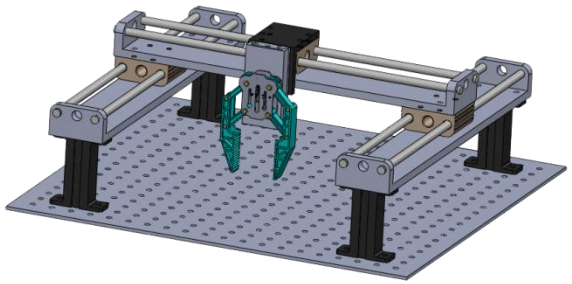
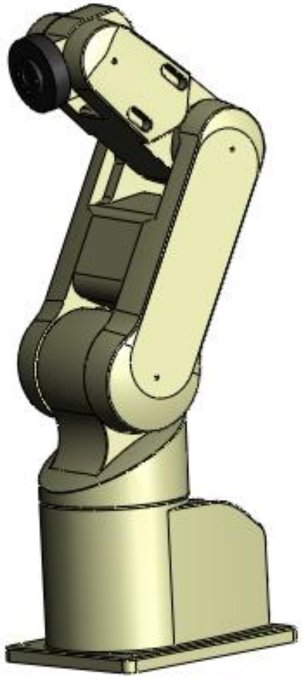
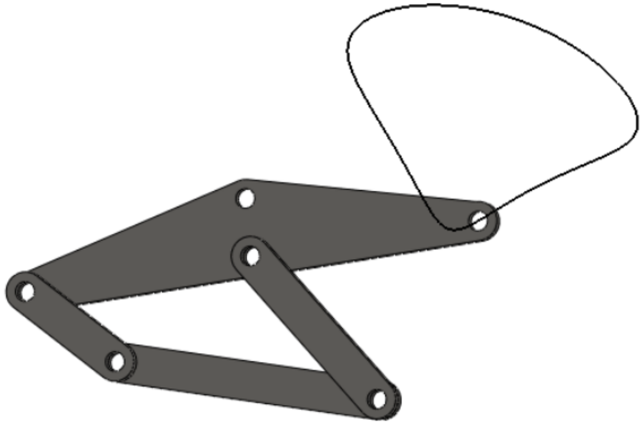
Simulation of mechanical assemblies

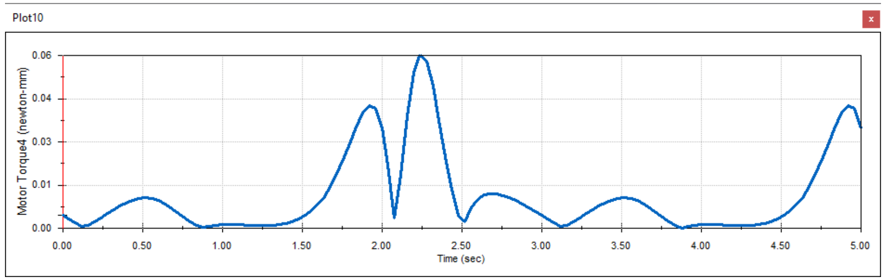
Kinematic simulation of robotic systems











Dynamic simulations

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Simulation of mechanical assemblies

Upon completion of this module, the student will be able to:

1) Create animations of assemblies defined in SolidWorks
2) Create simulations of assemblies defined in SolidWorks
3) Measure the kinematic and dynamic parameters of links during simulations

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Content

- Introduction
- Animations in SolidWorks
- Simulations in SolidWorks
- Results display and analysis

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Introduction

Introduction

The Role of Simulation in Mechatronic Design

- Simulation of mechanical assemblies is essential in mechatronic design, where mechanical, electrical, and control systems must operate in synergy.
- Benefits:
  - Validate designs early, reducing the risk of errors before physical prototyping
  - Optimize performance, motion paths, and energy efficiency
  - Reduce development costs by identifying design flaws early in the process
  - Accelerate time-to-market by enabling faster design iterations
  - Improve sustainability by analyzing friction, material use, and energy consumption

Introduction

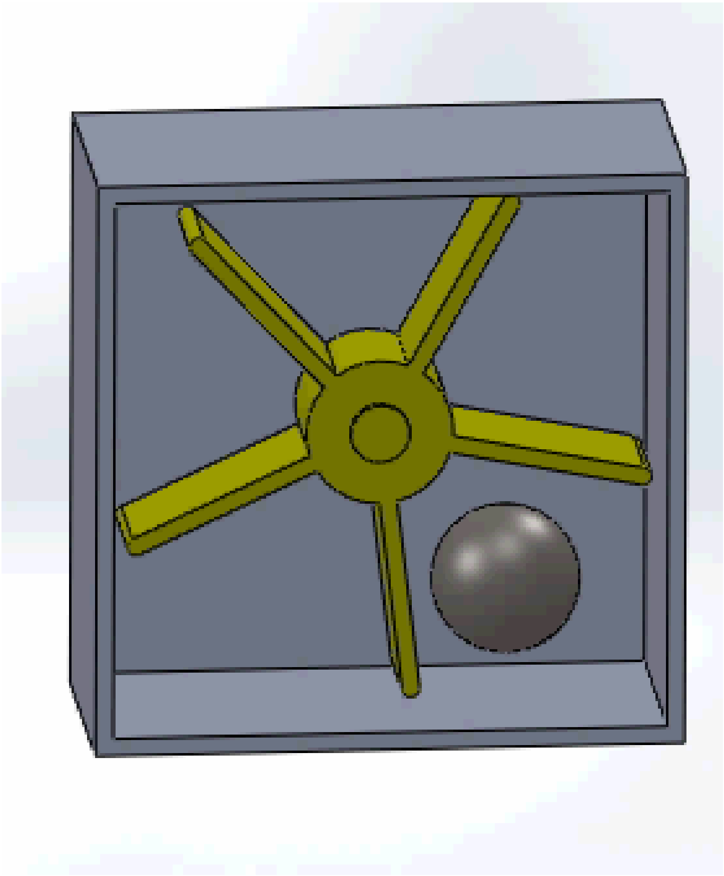
Types of animations/simulations in SolidWorks

- **Kinematic**
- Dynamic
- Free motion

Introduction

Types of animations/simulations in SolidWorks

- Kinematic
- **Dynamic**
- Free motion



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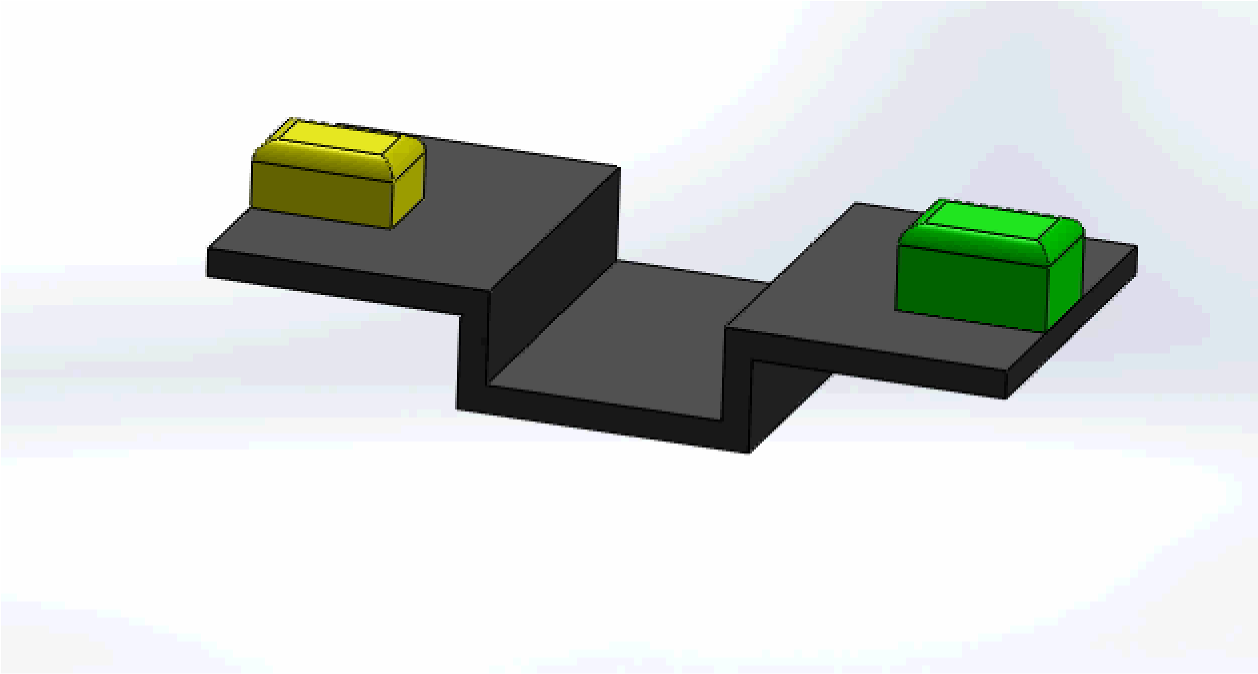
Introduction

Types of animations/simulations in SolidWorks

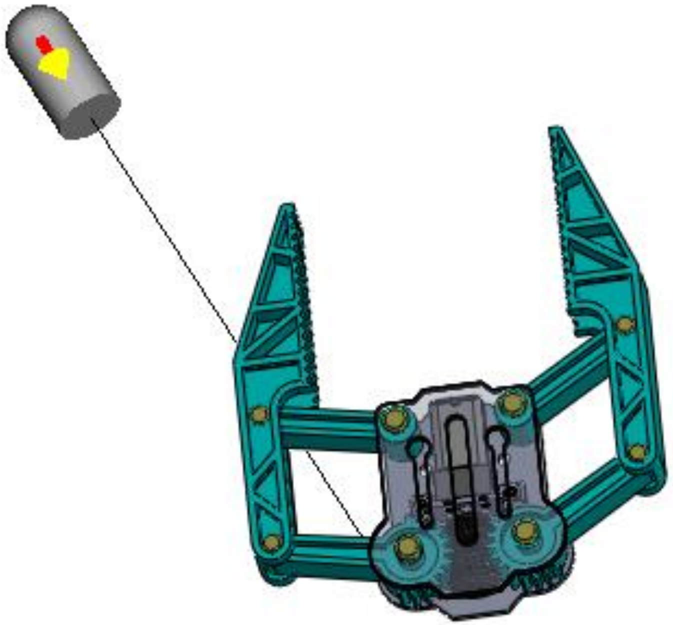
- Kinematic
- Dynamic
- **Free motion**

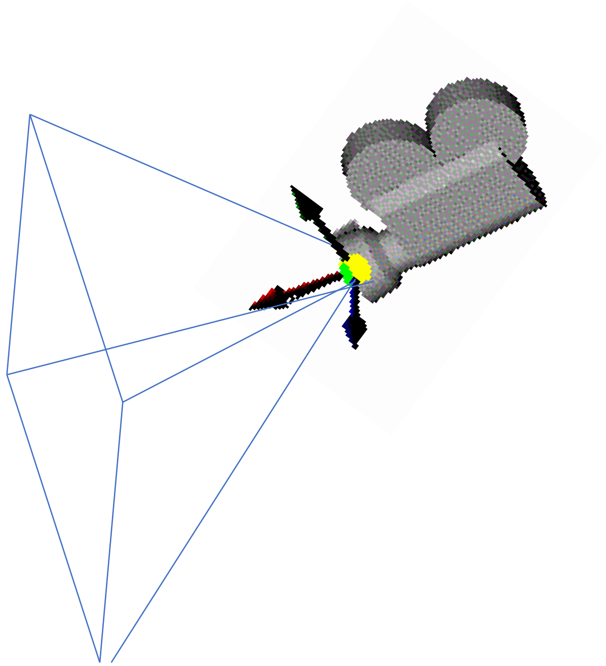


Introduction

What can be animated?

- Componente
- Proprietăți
- Viewpoint





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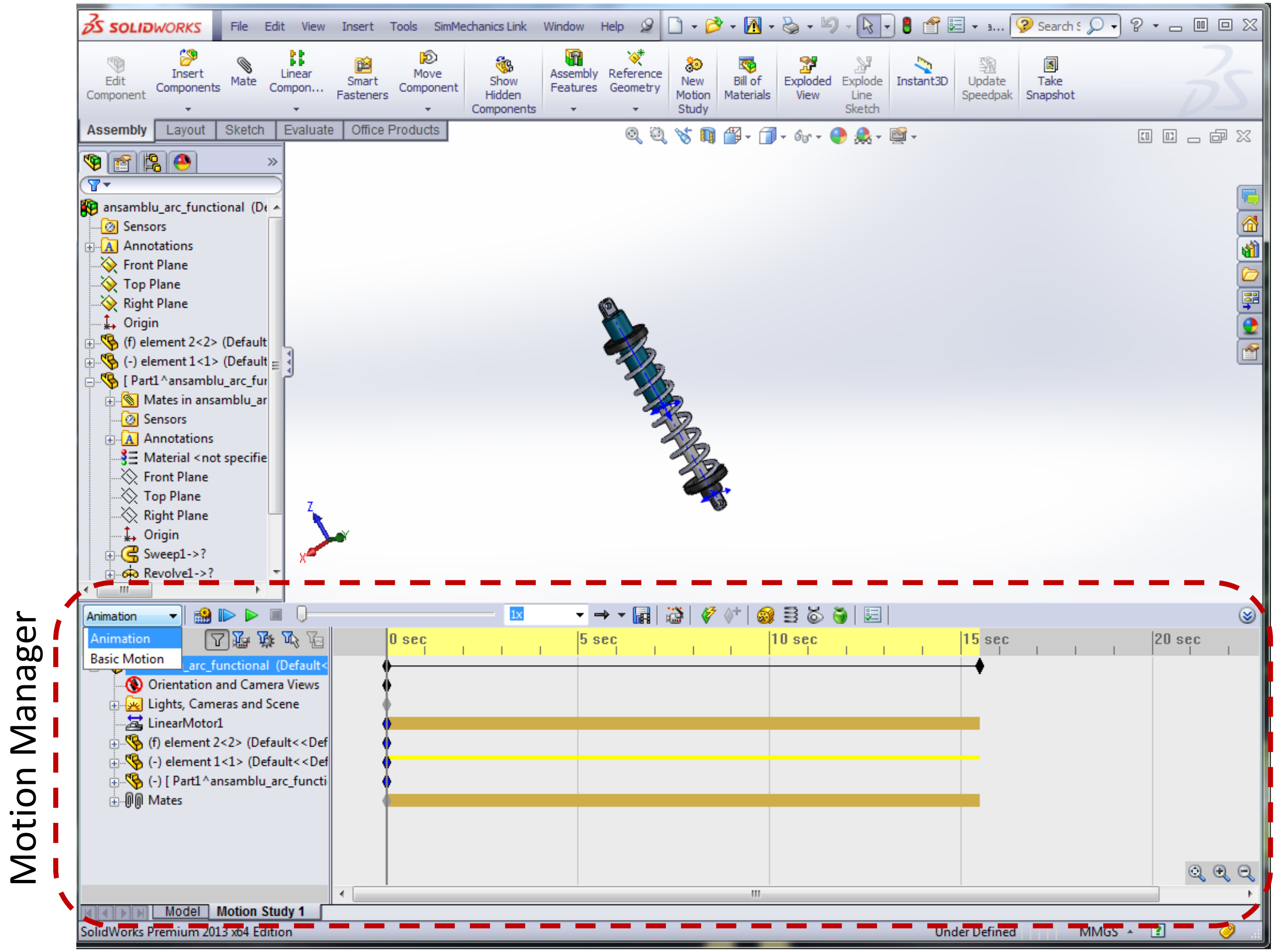
Introduction

Motion Manager

- It is an interface (integrated into SolidWorks) that facilitates the creation of animations and/or motion analyses for assemblies created in SolidWorks.

- Types of analysis:
    - Animations
    - Basic Motions
    - Motion Analysis



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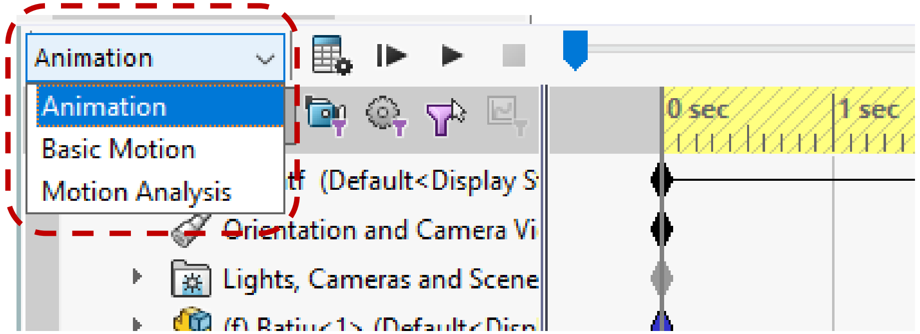
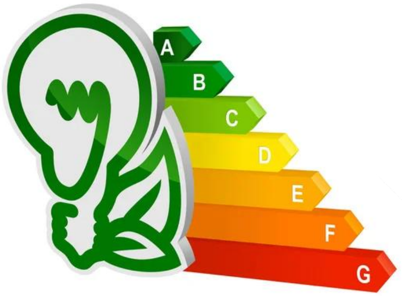
Introduction

Motion Manager

- **Animation** – allows the creation of simple animations using interpolation to define the point-to-point movement of assembly components.
- **Basic Motion** – allows the approximation of the effects of motors, springs, contacts, and gravity on assemblies using physics-based simulations.
    - Takes component mass into account when generating motion
    - Fast computation
- **Motion Analysis** – enables accurate simulations and analysis of an assembly's motion by incorporating the effects of Motion Study elements (including forces, springs, dampers, and friction).
    - Types of analyses: time-based/event-based



Introduction



Designing of eco-friendly and sustainable systems

- **Energy Efficiency in Mechanical Design**
    - Simulation of energy consumption and losses in mechanical systems
    - Optimizing mechanical movements to reduce unnecessary energy waste
    - Using **Motion Analysis** to evaluate friction, damping, and efficiency
- **Environmental Impact of Motion and Kinematics**
    - Evaluating how different motion strategies affect energy consumption
    - Reducing unnecessary accelerations/decelerations in automated systems
    - Applying kinematic simulations to optimize robotic or automated processes for sustainability

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Animations in SolidWorks

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Animations

What is an animation?

- **Animations**
  - allows the creation of simple animations using interpolation to define the point-to-point movement of assembly components.
  - Allows the creation of animations where motion is imposed through motors/mates.

- **When is animation used?**
  - Creating simple animations that define the movement of assembly components through points.
  - Animation is used when physical phenomena such as mass, friction, torque, contact, and gravity are not required.

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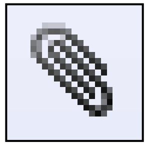
Animations

How SolidWorks calculate the animations?

- At time zero – an image is captured
- Advance the actuating elements by one frame
- Reconstruction
    - Constraint (mates) solving
    - In-context feature solving
- Capturing another frame
- Repeat

Animations

Animation – Motion Drivers

[1] [2]  [3] 

	Key Points	Mates	Inertia	Gravity	Force	Spring	Motor	Contact	Friction	Damping	Event Based	Plots
Animation	X	X					X					
Basic Motion		X	X	X		X	X	X	L	L		
Motion Analysis		X	X	X	X	X	X	X	X	X	X	X

Source: Dassault Systemes

- X – Available Function
- L – Limit Functionality

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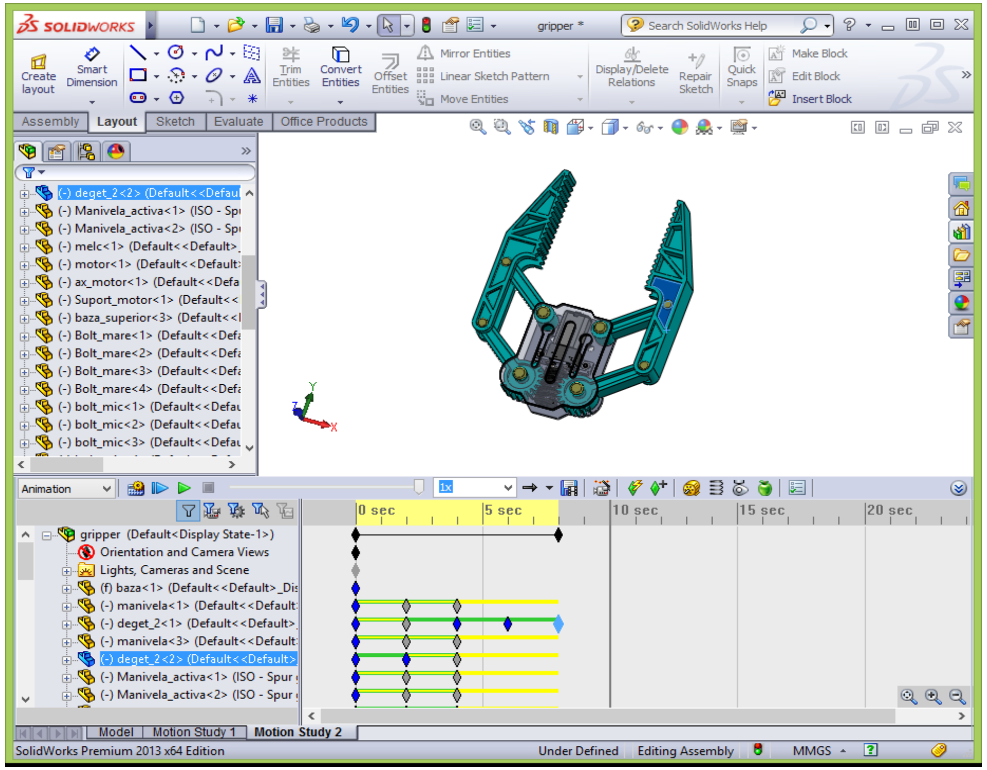
Animations

❑ Keypoint Animations

Basic Workflow

- Positioning the Timebar
- Positioning components
- Positioning the viewpoint
- Adjusting Properties
- Recording Keypoint (automatic or manual)
- Repeat



Autokey On

- Automatically positions key points at the current time bar position
- Calculates the animation so that the components reach the specified position
- Computes the movement of assembly components from the initial to the final position using interpolation functions

Autokey Off

- Key points must be set manually

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Animations

- **Keypoint Animations**

Component actuation

- Components position.
- Actuation using motors.
- Mates actuation

  Distance or *Angle*

Viewpoint position

- Viewpoint orientation andselection of camera views
- Properties : *Light* & *Camera*

Properties

- Hide
- Component Display
  - Wireframe
  - Hidden Lines Visible
  - Hidden Lines Removed
  - Shaded With Edges
  - Shaded
- Appearance
  - color
  - transparency

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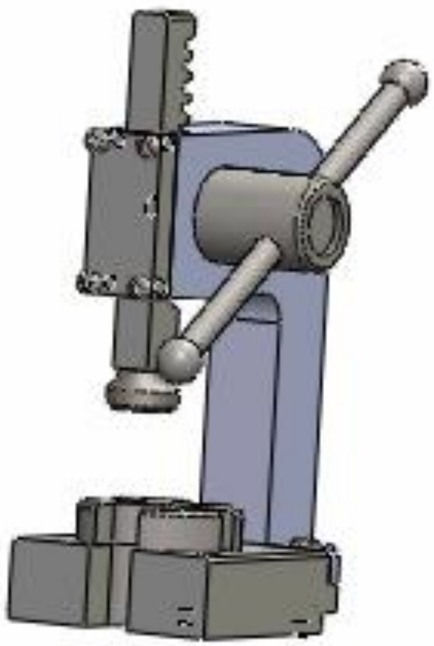
Animations

- **Case study I**

Press - *Animation*

- Change component position
- Change *Viewpoint orientation*
- Change the component properties

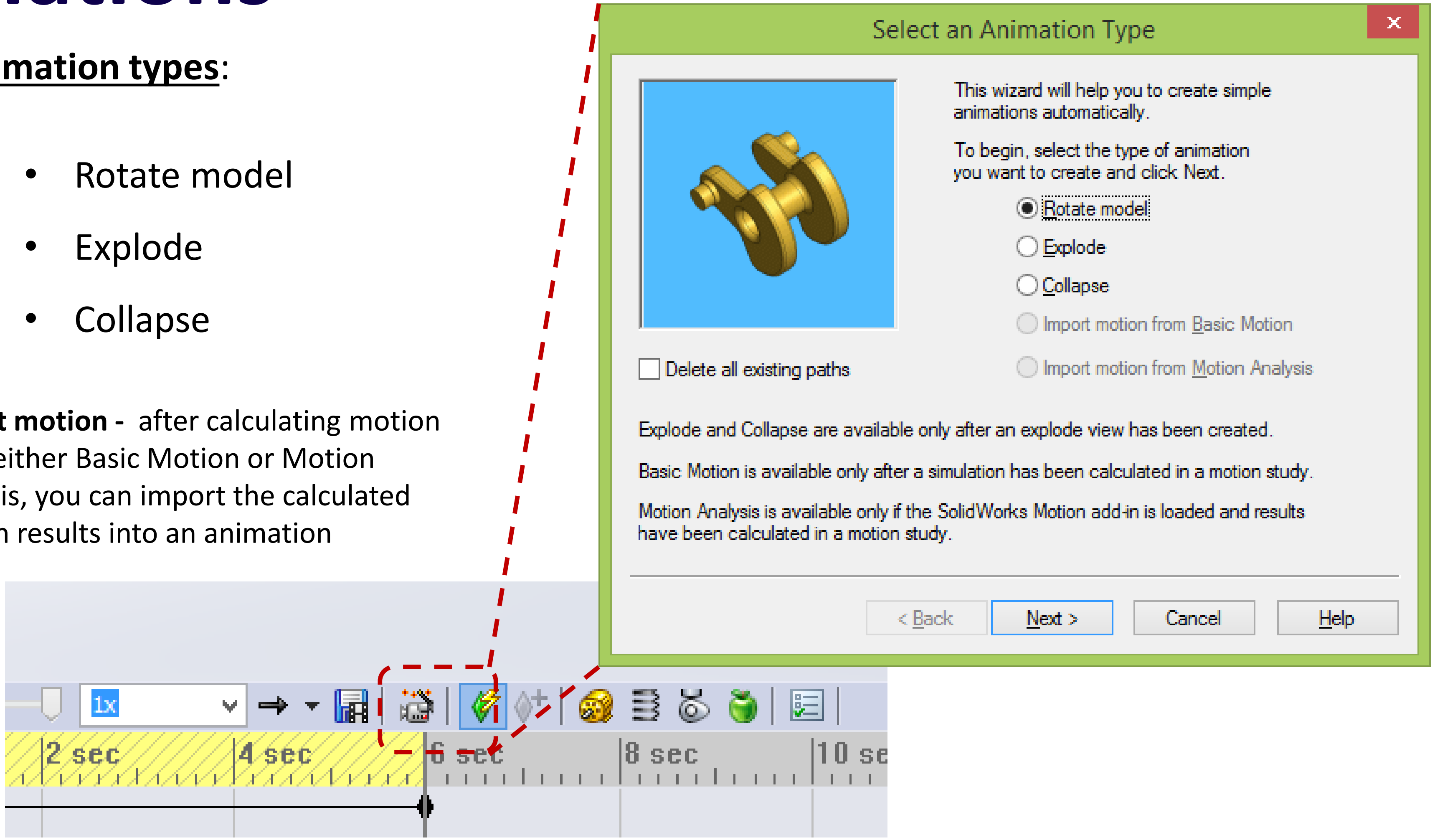


Animations

Animation types:

- Rotate model
- Explode
- Collapse

Import motion - after calculating motion using either Basic Motion or Motion Analysis, you can import the calculated motion results into an animation



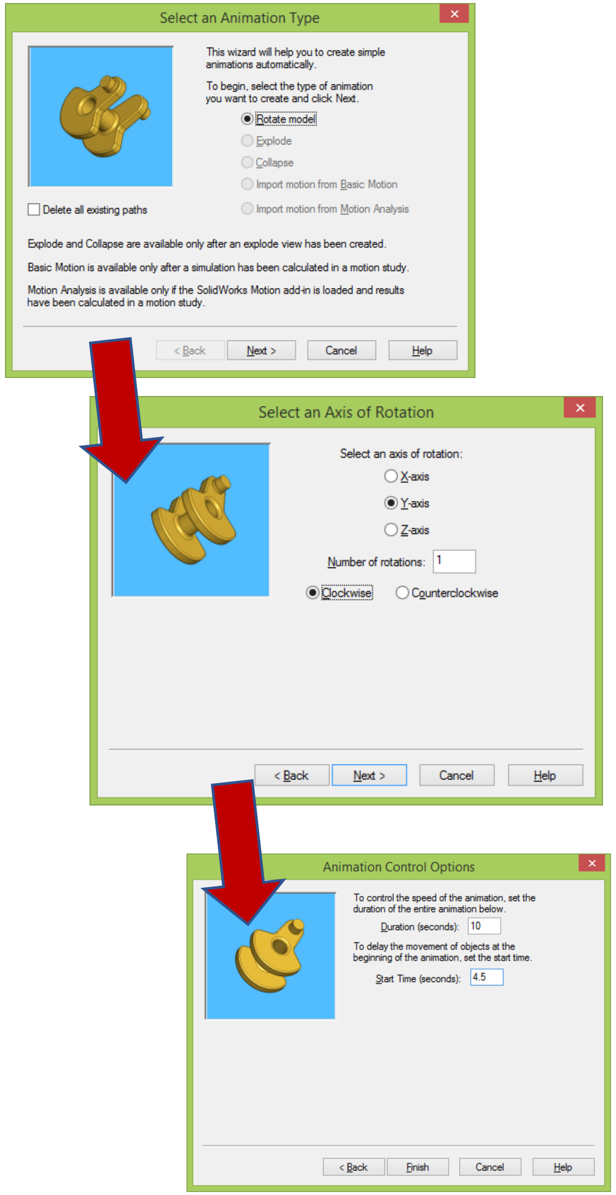
Animations

Rotate model:

1. Click **Animation Wizard** 
2. In the Select an Animation Type dialog box:
   - Select **Rotate model**.
   - Select **Delete all existing paths** if you want to remove any existing animation sequences
   - Click **Next**

3. In the **Select an Axis of Rotation** dialog box
   - Select X-axis, Y-axis, or Z-axis for **Select the axis of rotation**
   - Type a value for the **Number of rotations**
   - Select **Clockwise** or **Counterclockwise**
   - Click Next

4. In the **Animation Control Options** dialog box
   - Type a value for the **Duration** (seconds) of the animation
   - Type a value for the **Start Time** (seconds) of the motion
   - Click **Finish**



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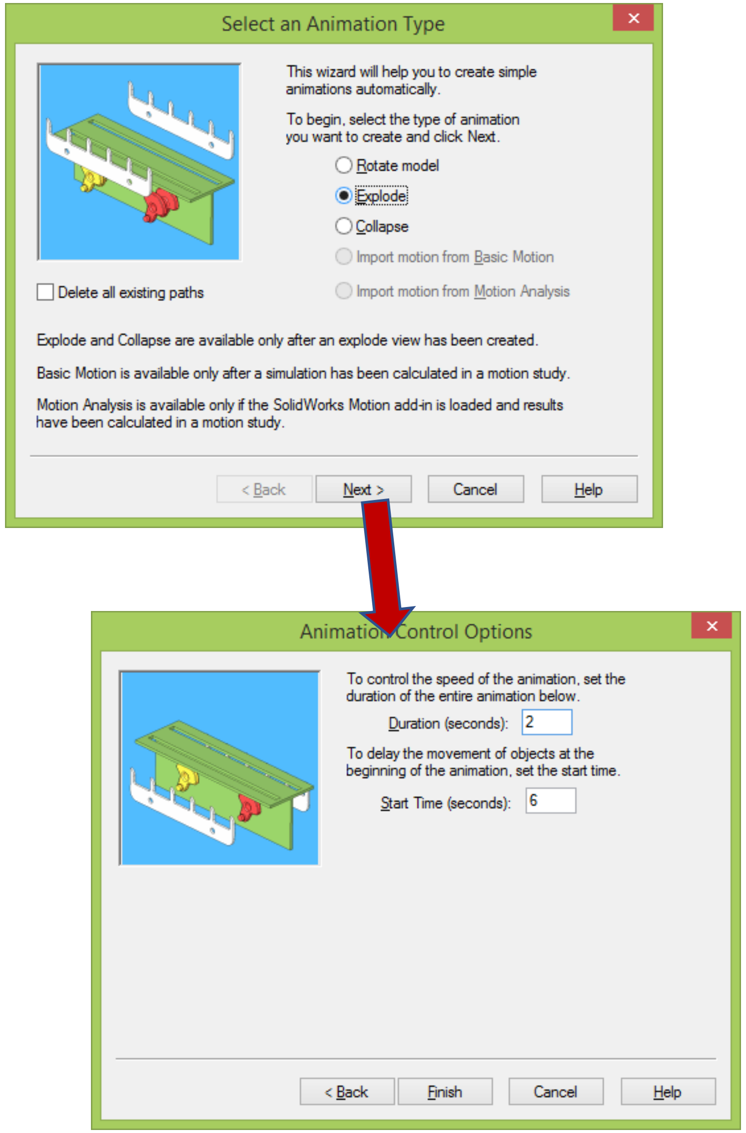
Animations

Explode/Collapse:

1. Click **Animation Wizard** 
2. In the Select an Animation Type dialog box:
   - Select **Explode** or **Collapse**
   - Select **Delete all existing paths** if you want to remove any existing animation sequences
   - Click **Next**

3. In the Animation Control Options dialog box
   - Type the **Duration (seconds)** of the animation in seconds
   - Type a value for the **Start Time (seconds)** of the motion
   - Click **Finish**



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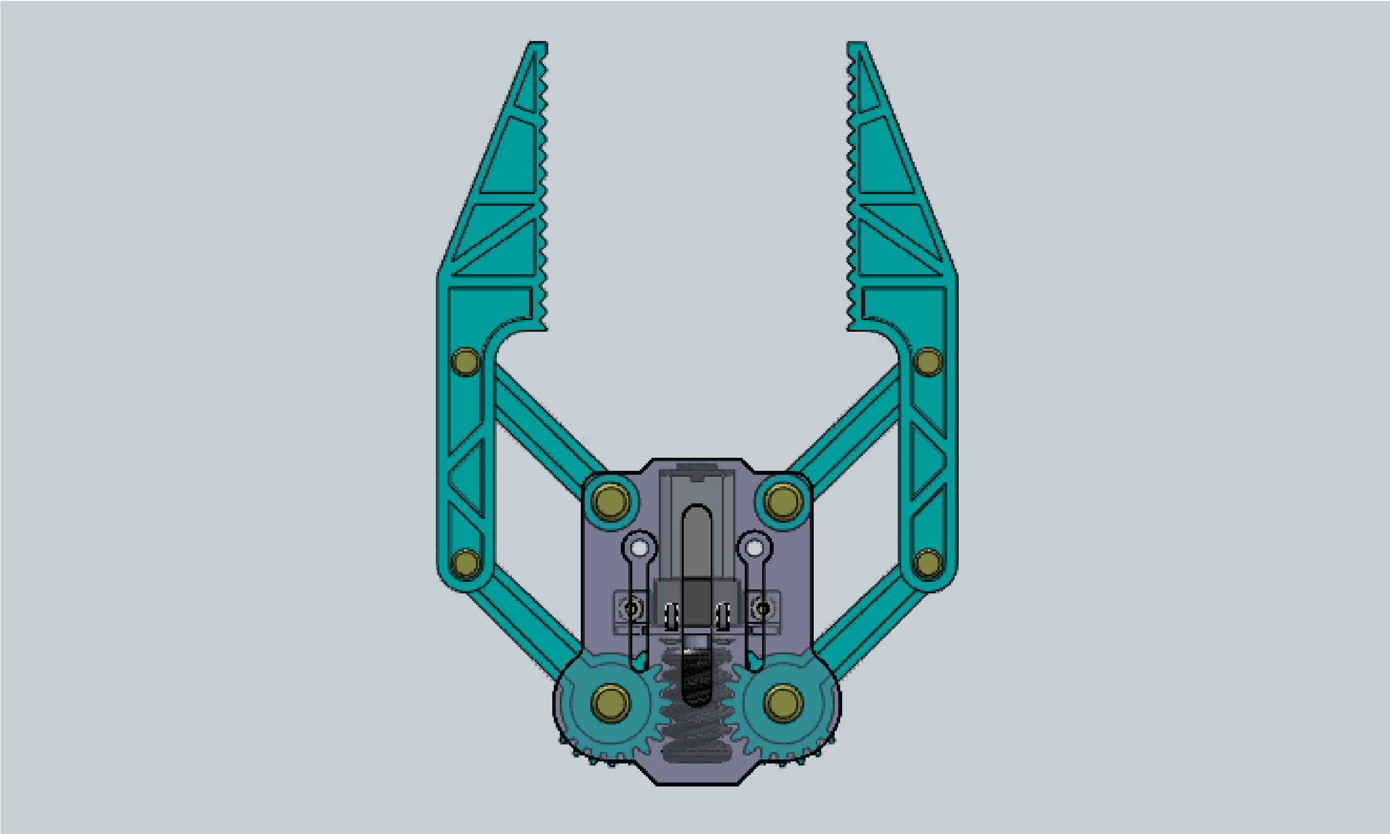
Animations

❑ **Case study II**

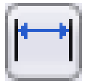
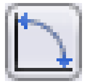
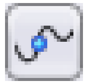
Gripper - Animation

- Rotate model
- Explode
- Collapse



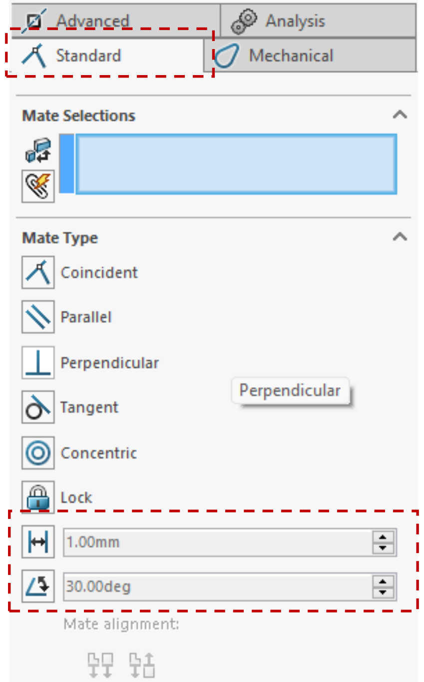
Animations

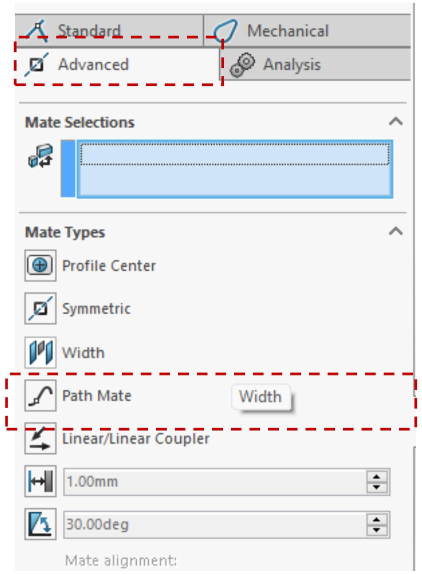
MOTION DRIVERS - MATES

- Mates that produce movement in animation
  - Distance Mate 
  - Angle Mate 
  - Path Mate 

- Driving Mates
  - Standard Mates (cu excepția celor prezentate mai sus)
  - Mechanical Mates

Note–Global Mates vs. Local





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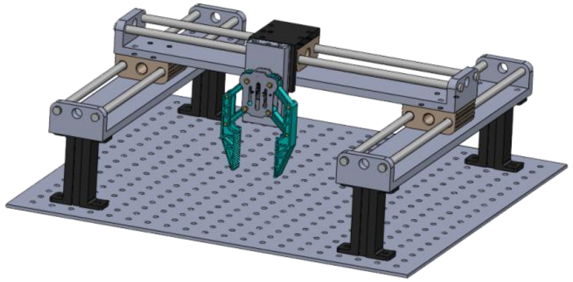
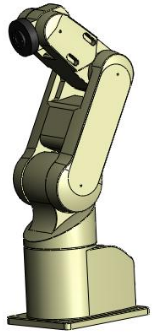
Animations

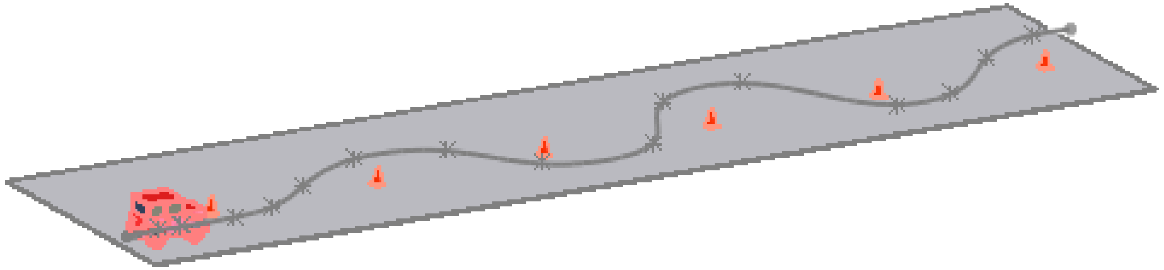
- Distance Mate
  - Values range from 0 to 100,000,000
  - Replace global mates with local mates dedicated to the animation





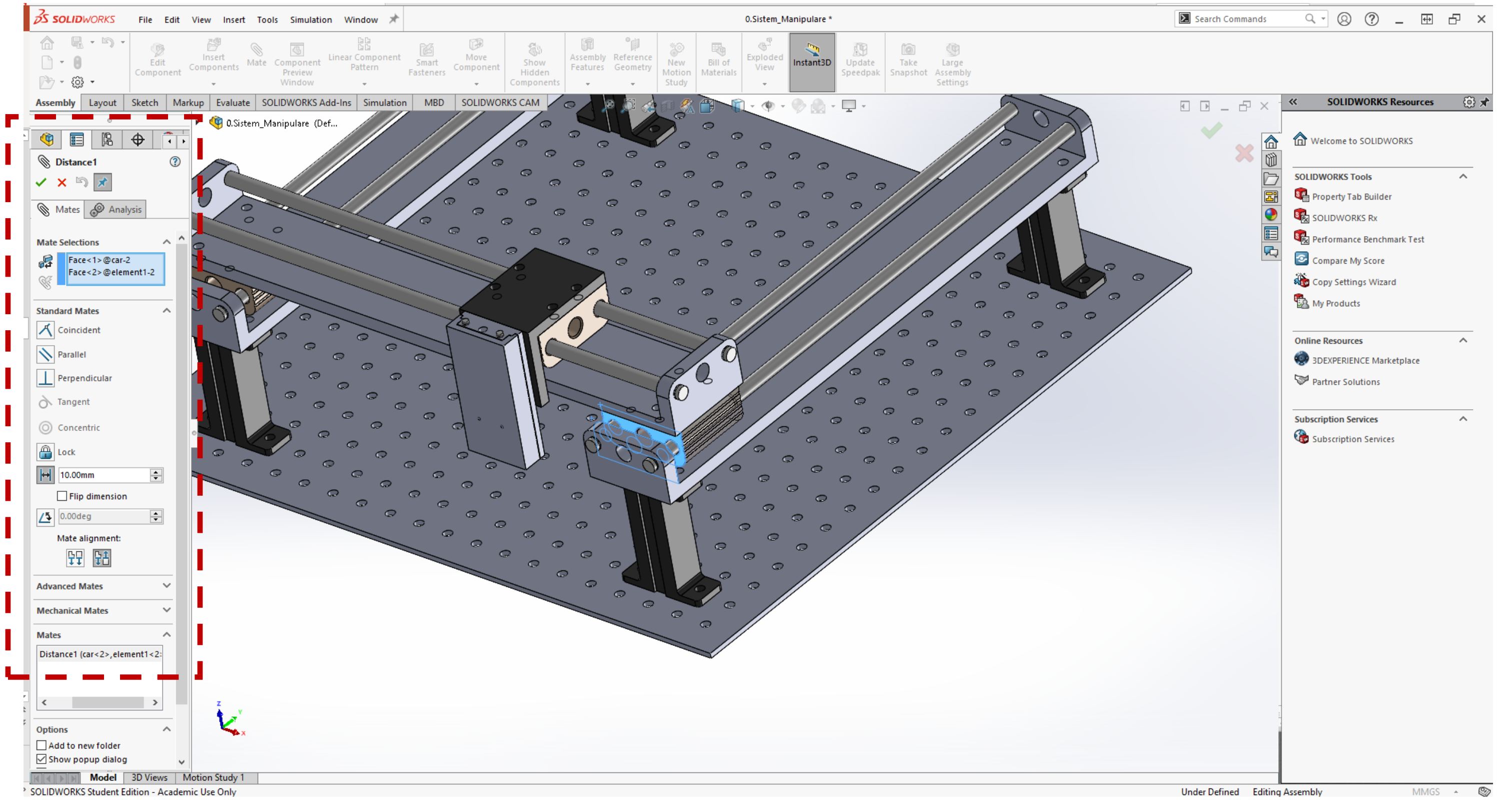
- Angle Mate
  - Values range from 0 to 360 [°].

- Path Mate
  - •Free
  - •Distance
  - •Percent



Animations

- Distance Mate
  - ❑ Define the mate
  - ❑ Change the mate parameter to produce the animation



Animations

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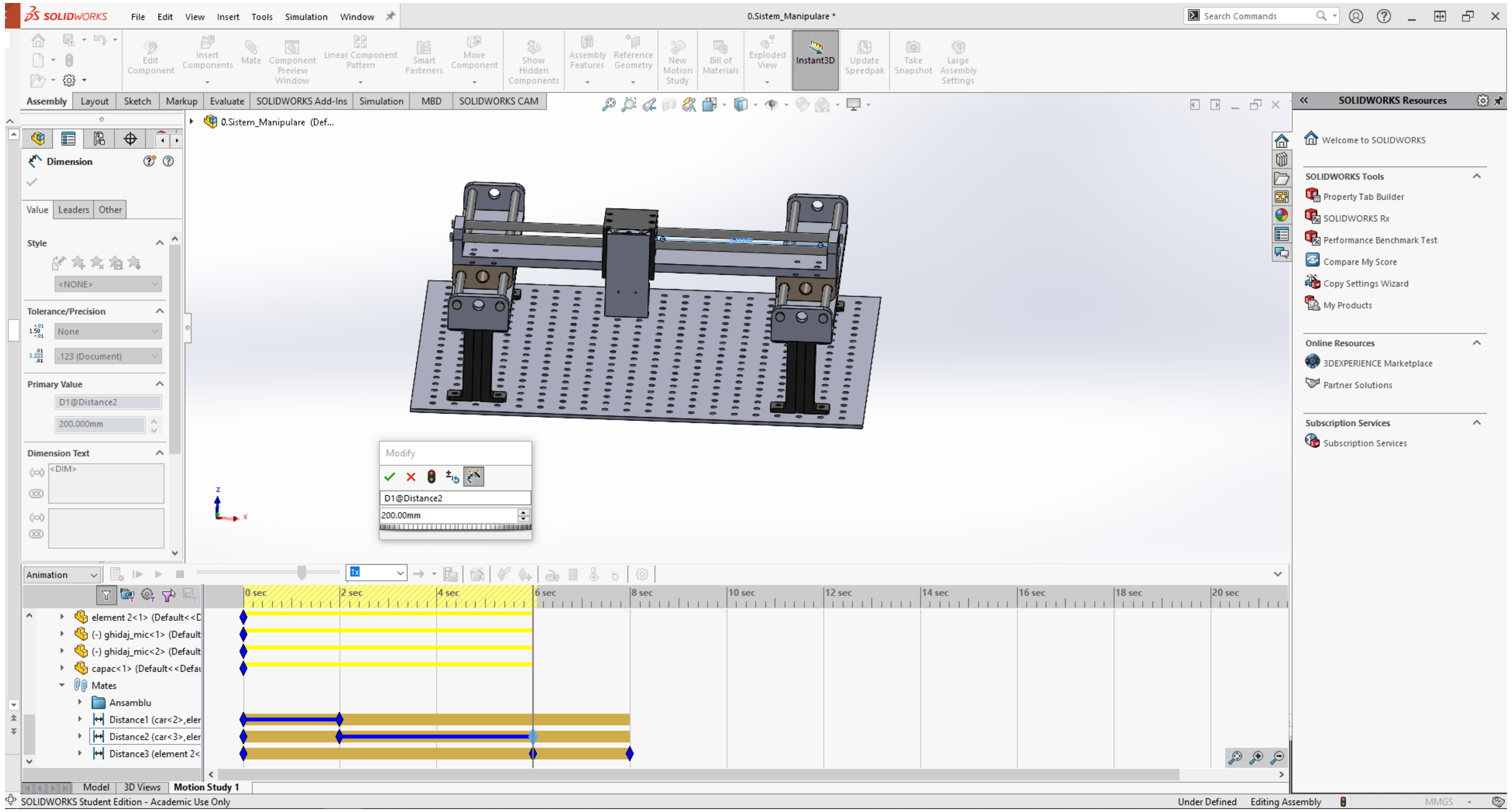

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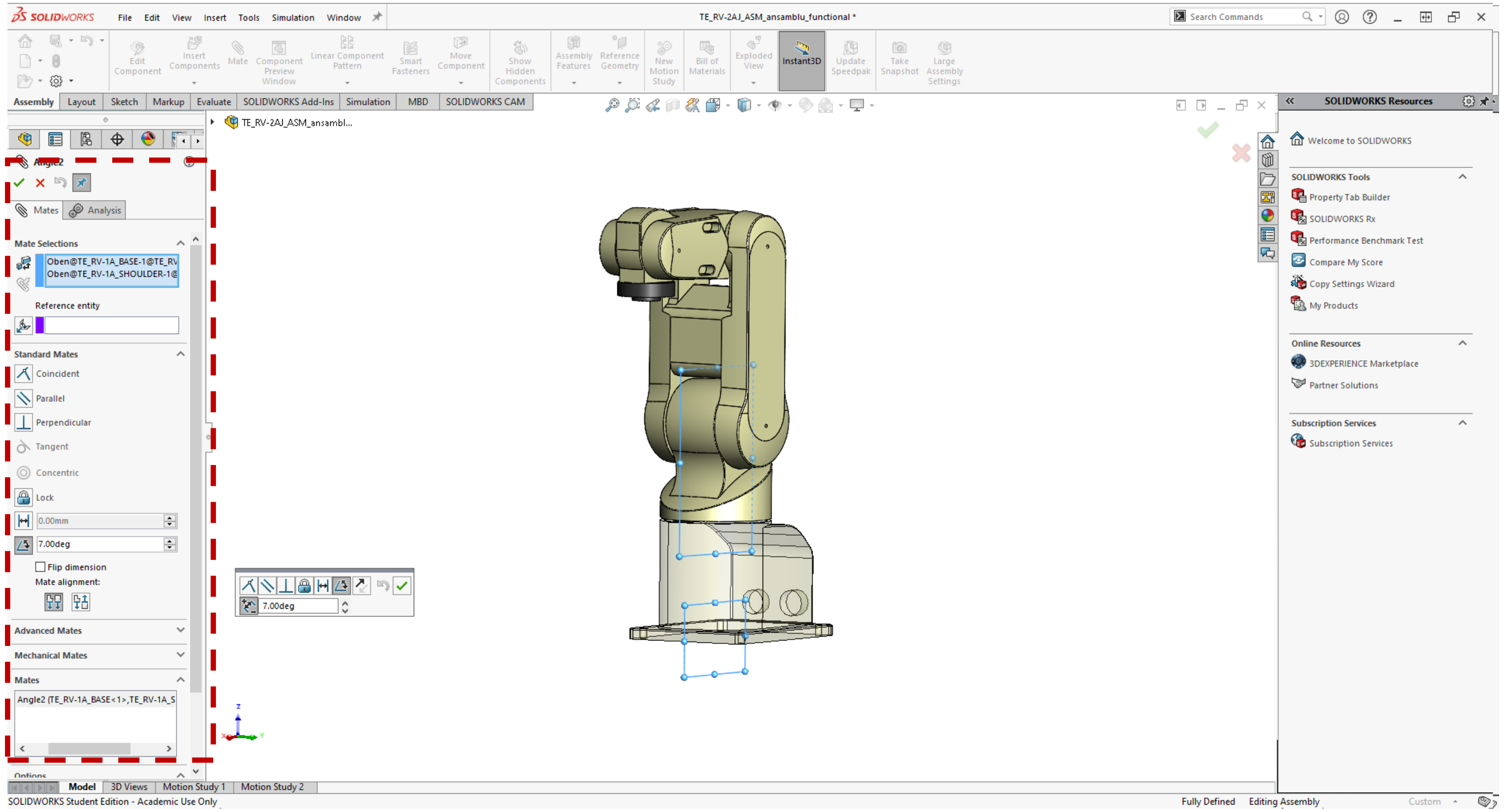

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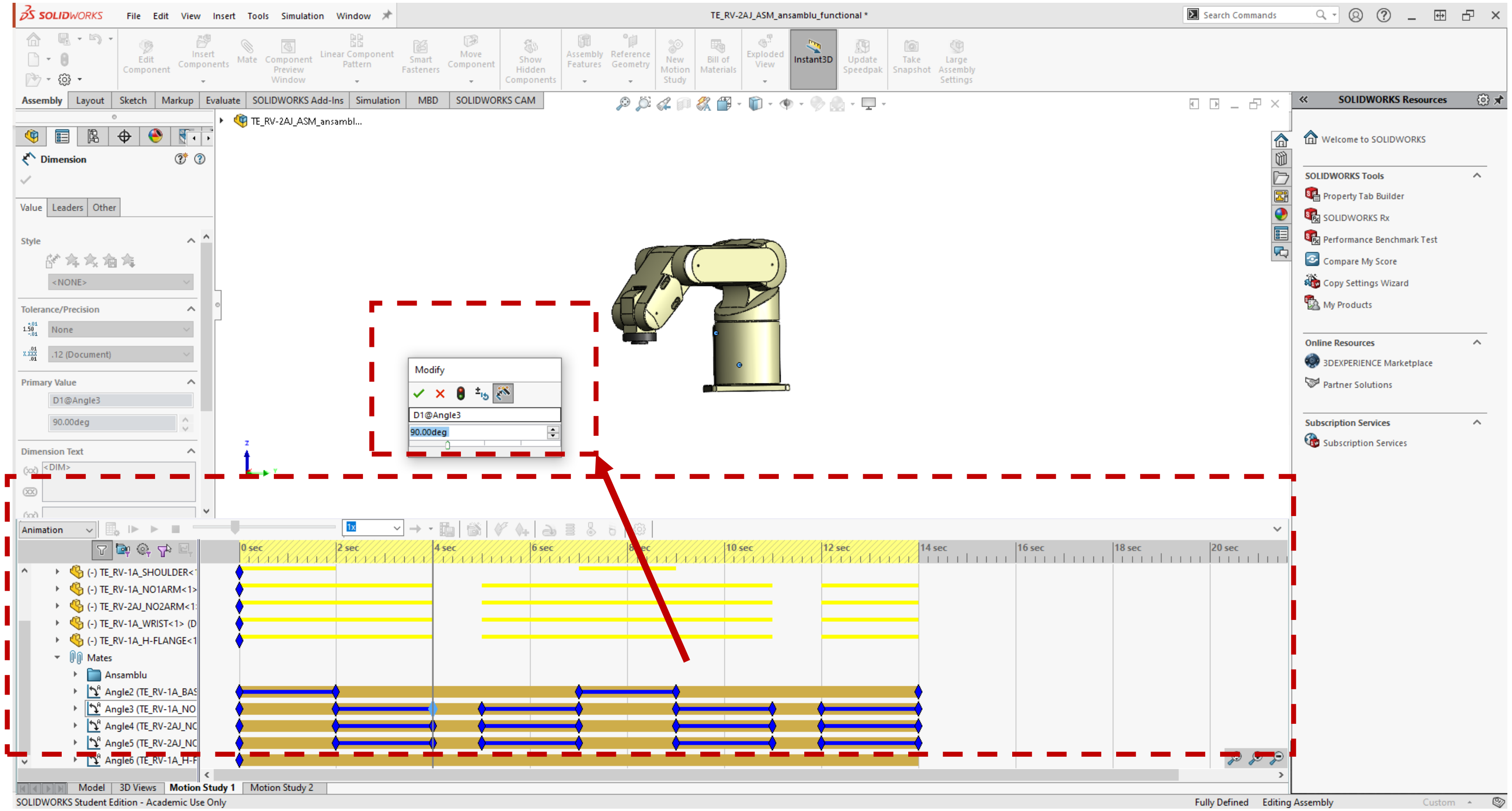
Animations

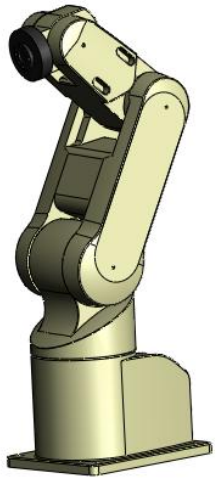
- Angle Mate
  - ❑ Define the mate
  - ❑ Change the mate parameter to produce the animation

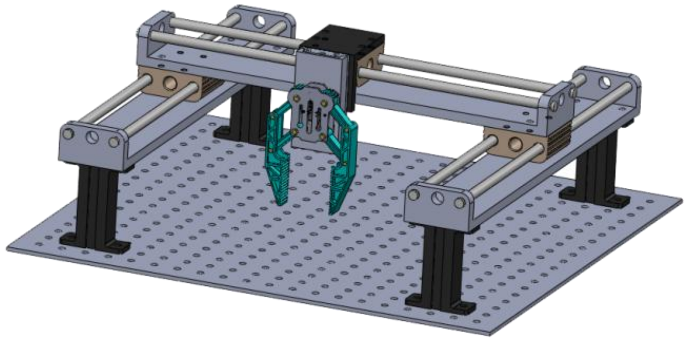


Animations

MOTION DRIVERS - MOTORS

- Type of motors
  - Rotation
  - Linear
- Type of motor movements
  - On/Off
  - Constant Speed
  - Distance
  - Interpolated/data point
  - Segment
  - Expression
  - Oscillating
  - Servo Motor





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Simulations in SolidWorks

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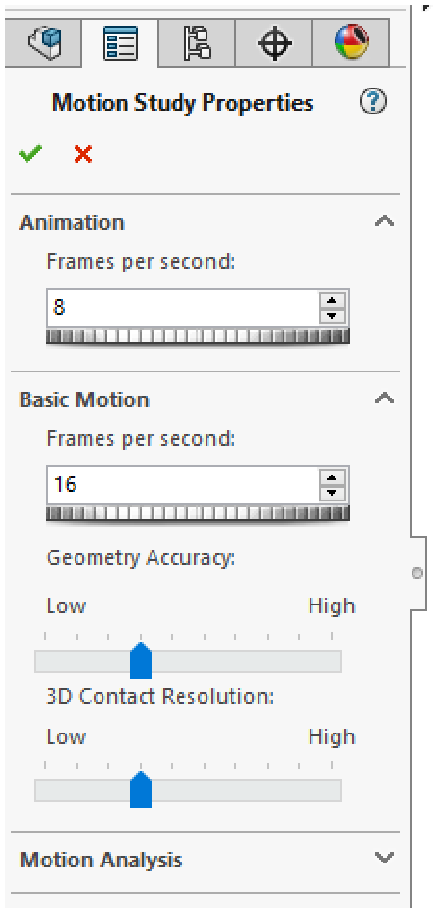
Basic Motion

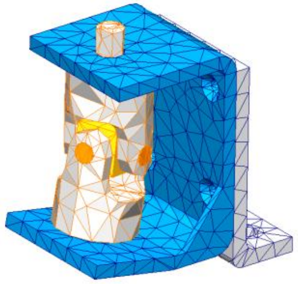
Motion Study Properties

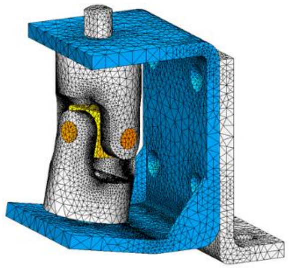
- **Frames per second**. This value, multiplied by the length of the animation, specifies the total number of frames that are captured. This value does not affect the playback speed.

- **Geometry Accuracy**. Basic Motion makes meshes out of curved geometry. The higher the accuracy, the closer to actual geometry the mesh becomes. This makes collision simulation more accurate, but requires more time to compute.

- **3D Contact Resolution**. Controls the allowed amount of penetration within geometric meshes. Lower settings allow more penetration within the mesh. Using solid body **Contact** produces smoother motion, especially in tight-fit situations. For example, you can include solid body







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Basic Motion

Basic Workflow

1. Select **Basic Motion** from the Type of Study list in the MotionManager
2. Select tools in the MotionManager toolbar to include simulation elements.
   See Linear or Rotary Motors, Springs, Solid body contact, and Gravity.
3. Click **Calculate** MotionManager toolbar) to calculate the simulation.
4. Click **Play from Start** (MotionManager toolbar) to play the simulation from the start.

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Basic Motion

Basic Motion – Motion Drivers

	Key Points	Mates	Inertia	Gravity	Force	Spring	Motor	Contact	Friction	Damping	Event Based	Plots
Animation	X	X					X					
Basic Motion		X	X	X		X	X	X	L	L		
Motion Analysis		X	X	X	X	X	X	X	X	X	X	X

Source: Dassault Systemes

- X – Available Function
- L – Limit Functionality

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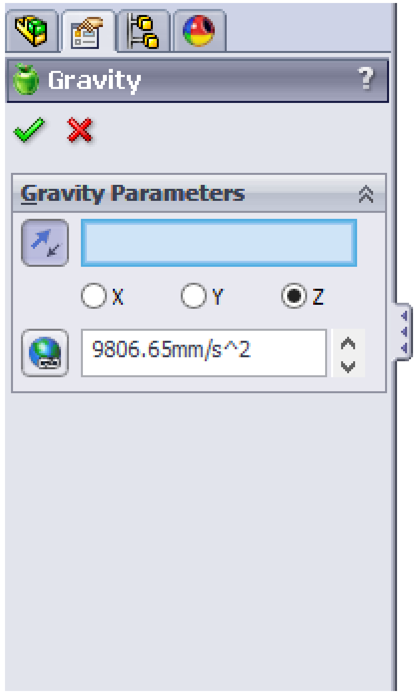
Basic Motion

- **Gravity** is a simulation element that moves components around an assembly by inserting a simulated gravitational force



Gravity Parameters

- **Direction Reference** Set a **Direction Reference** for gravity.
  - a face to orient gravity parallel to the normal
  - an edge to orient gravity parallel to the edge
  - X, Y, or Z to orient gravity in the chosen direction in the assembly reference frame
- **Numeric gravity value -** Set the **Numeric gravity value**. Default is standard gravity

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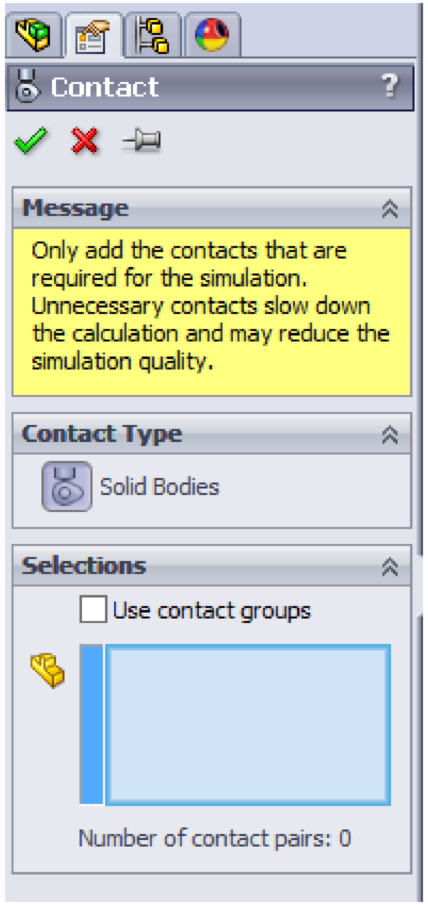
Basic Motion

BASIC MOTION - CONTACT

- Helps to model component contact in a motion study when components ***collide***, ***roll***, or ***slide***
- can also use contact to constrain parts to touch throughout the motion analysis



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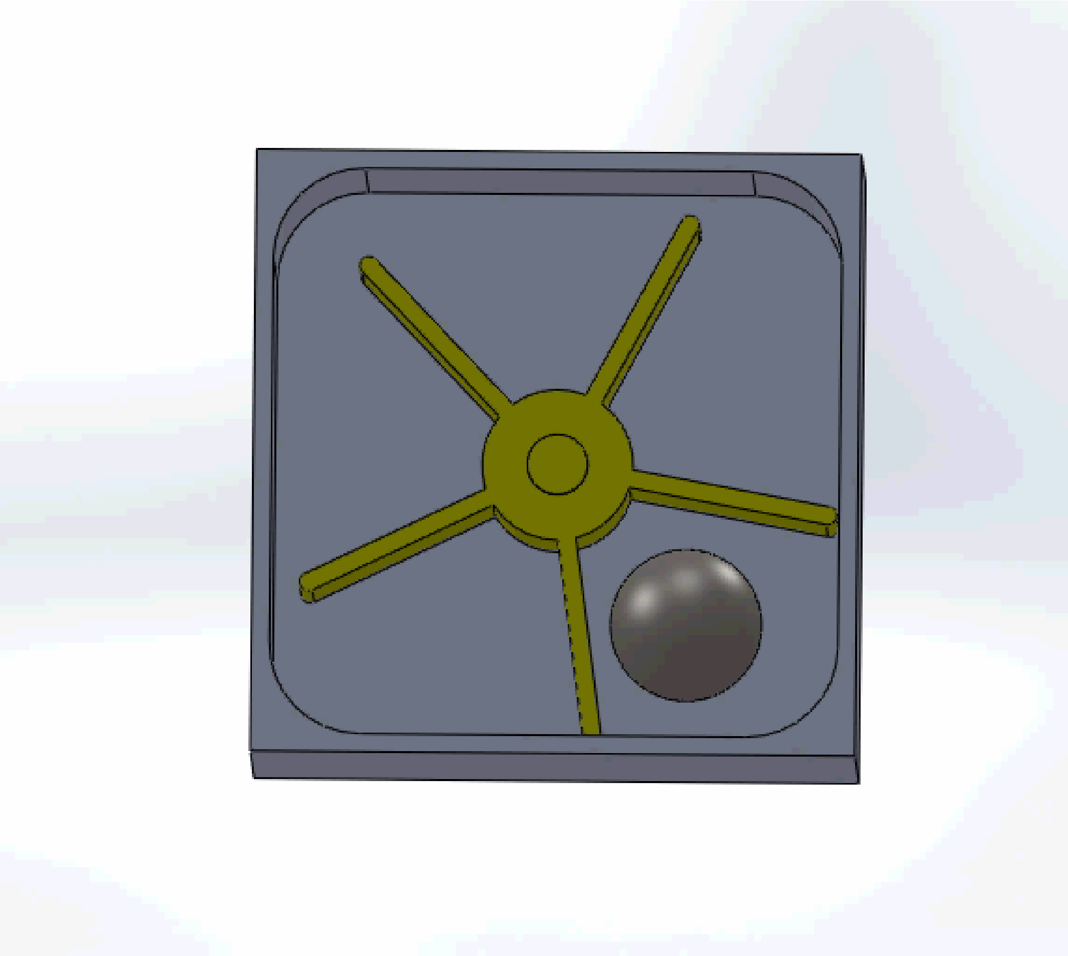
Basic Motion

- Case study III

<u>Contact - Animation</u>



Basic Motion

BASIC MOTION - SPRING

Linear Spring - represents forces acting between two components over a distance and along a particular direction

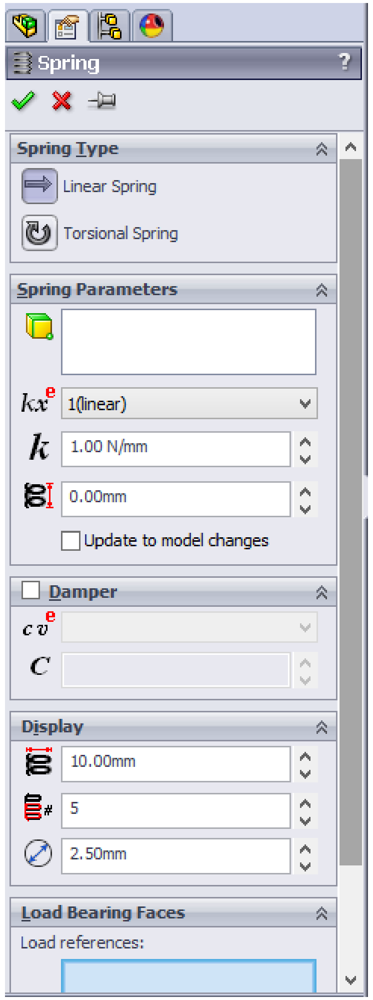
- Calculates the spring forces based on the distance between the locations of the two components
- Applies a force to the first part you select
- Applies an equal and opposite force along the line of sight of the second part you select

Torsional Spring - represents torsional forces acting between two components

- Calculates the spring moments, based on the angle between the two parts about the specified axis
- Applies a moment about the specified axis to the first part you select
- Applies an equal and opposite reaction moment to the second part you select

Note

- Can be used in Basic Motion and Motion Analysis



Basic Motion

BASIC MOTION - SPRING

Spring Constant

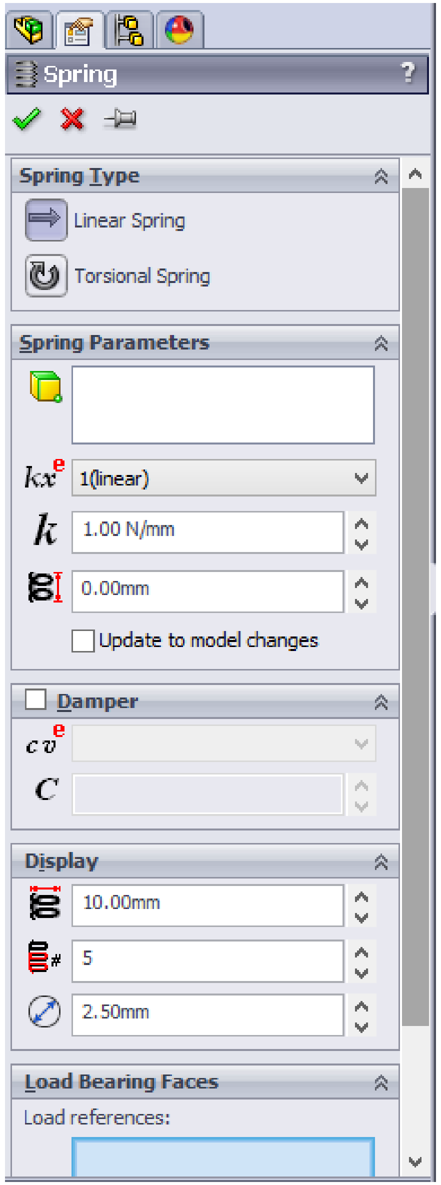
- $F=kx^e$
- Linear only in Basic Motion
- Powers of up to ± 4 in Motion Analysys
- Error in Basic Motion by one order of magnitude

Spring damping

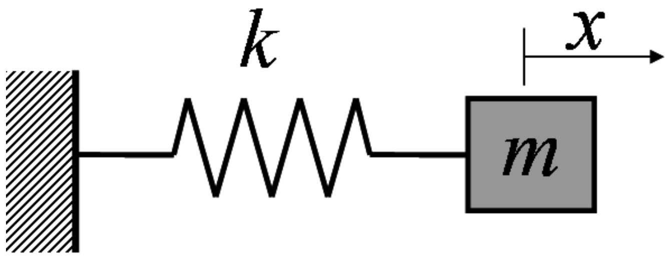
- Global in Basic Motion
- Adjustable in Motion Analysis

Note

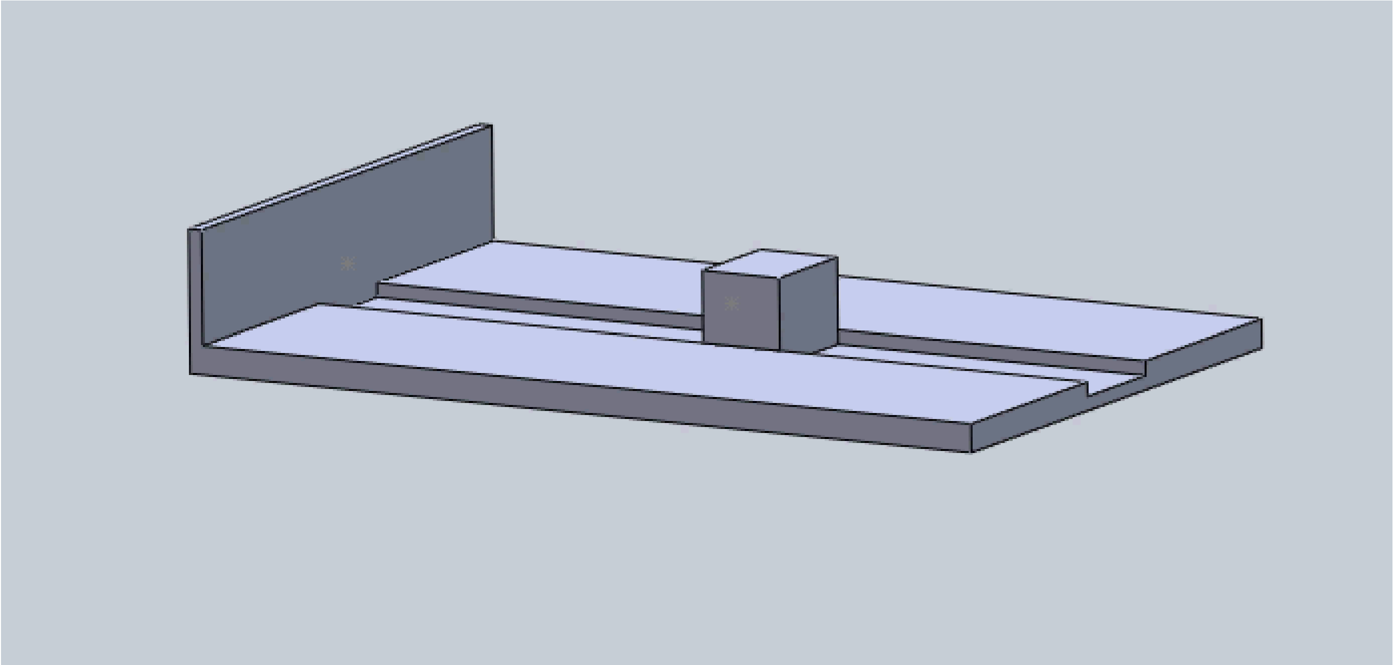
- Can be used in Basic Motion and Motion Analysis
- **Display** - you can view the display values only when the Spring PropertyManager is open, or when you calculate the study



Basic Motion



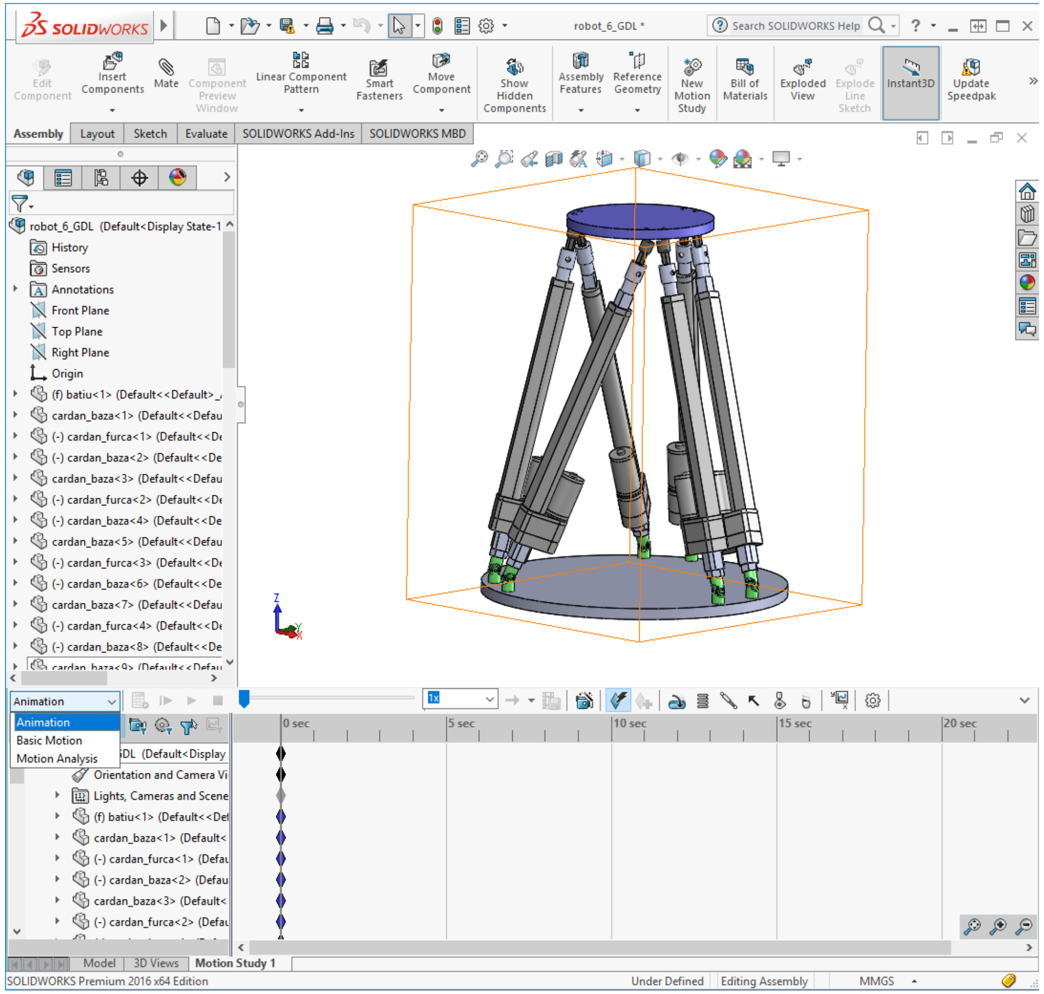
k=0.025 [N/mm]
l=200 [mm]



Motion Analysis

Motion Analysis – allows accurate simulation and analysis of the motion of an assembly by incorporating the effects of elements from the Motion Study (including forces, springs, dampers, and friction).

- Types of analyses
    - time-based
    - event-based.



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NextGEng

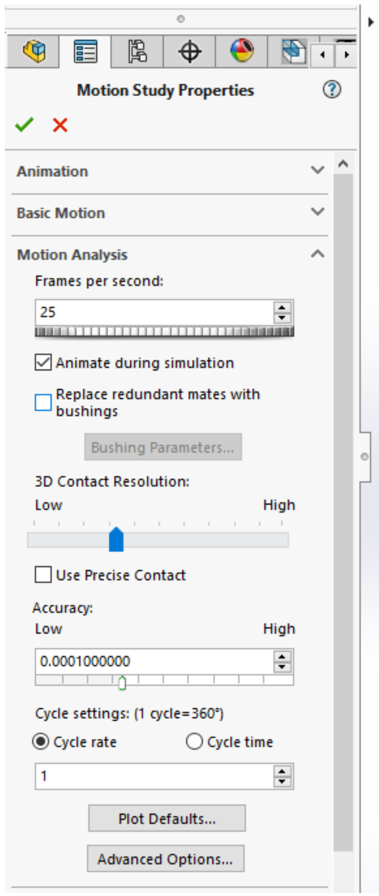
Motion Analysis

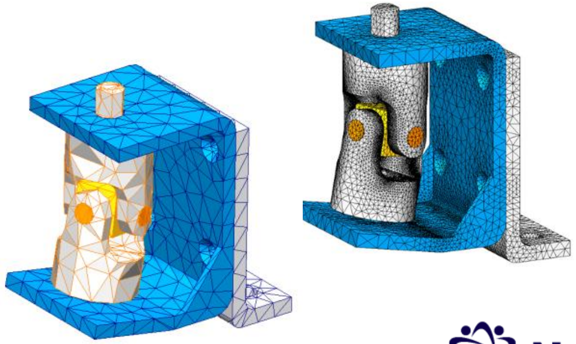
Motion Study Properties

- **Frames per second**. Specifies the total number of frames that are captured when multiplied by the length of the animation. This value does not affect the playback speed.

- **Animate during simulation -** Clearing this option speeds up the calculation time and prevents the graphics from displaying the motion during calculation of the simulation.

- **3D Contact Resolution**. Increases the calculation time when you introduce solid body **Contact**
  - SOLIDWORKS Motion typically represents shapes as many-sided polygons. The higher the number of sides, the more closely SOLIDWORKS Motion approximates the actual geometry.





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NextGEng

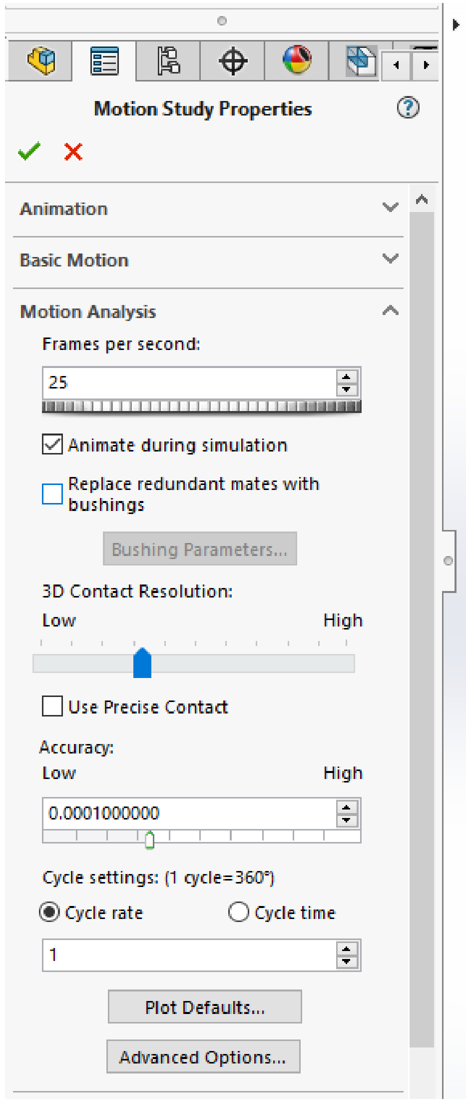
Motion Analysis

Motion Study Properties

- **Use Precise Contact**. Calculates contact by using the equations that represent the solid bodies. Clear to calculate contact approximately using the geometry of many-sided polygons. When you select **Use Precise Contact**, the computed contact is analytically correct, but the computation can take longer than an approximate solution.

- **Accuracy -** Increases the calculation time when higher values are selected.

- **Cycle setting**. Specifies the cycle rate or period. Cycle settings defines the cycle angle used in custom Motor or Force profiles.



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NextGEng

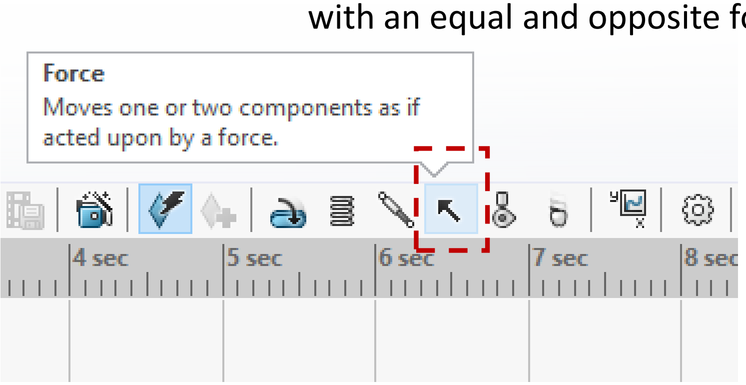
Motion Analysis

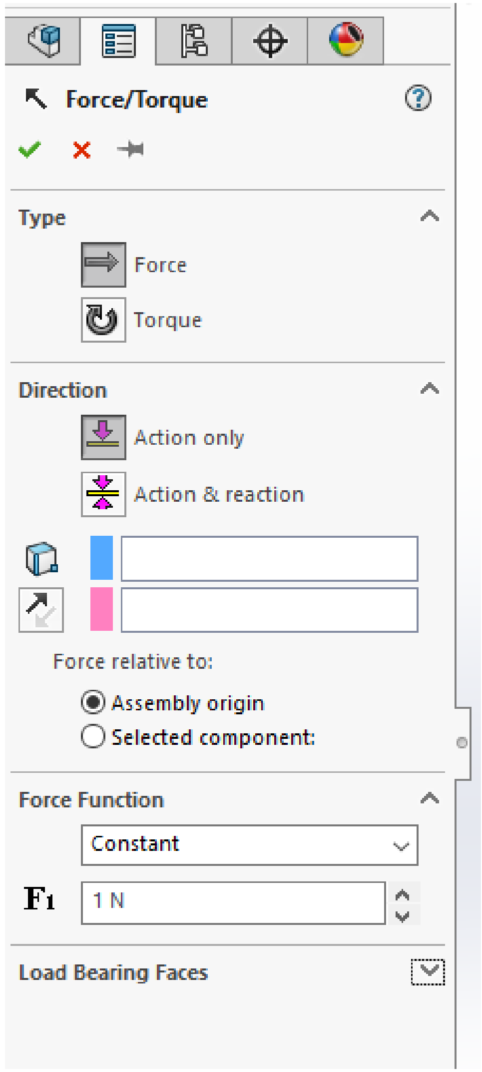
Force/Torque

Torsional Force	Specifies a torque.
Linear Force	Specifies a linear force.

Action only — Specifies the reference feature and direction for an action-only force or torque. An action-only force or torque acts on a body, but is not generated from a body.

Action & reaction — Specifies the reference feature and direction for an action-reaction force or torque. The action body generates the action force or torque, while the reaction body responds with an equal and opposite force or torque.





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NextGEng

Results display and analysis

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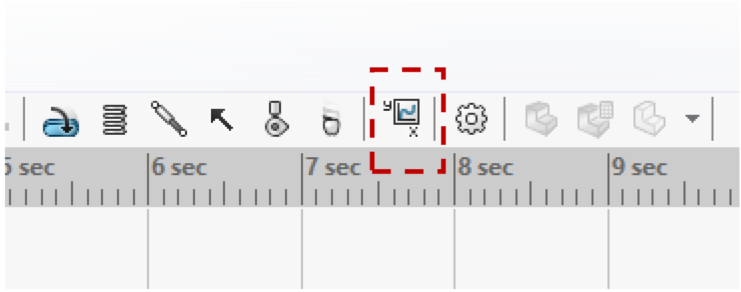
Simulation results

MOTION ANALYSIS - PLOTS

- For Motion Analysis type motion studies, the following plot results obtained from calculated motion can be obtained:
  - **Displacement, Velocity, and Acceleration Type Plots**
    - Trace path
    - Center of mass position
    - Linear Displacement/Velocity/Acceleration
    - Angular Displacement/Velocity/Acceleration
  - Force and Torque Plots
  - Energy and Momentum Type Plots



Simulation results

MOTION ANALYSIS - PLOTS

- For Motion Analysis type motion studies, the following plot results obtained from calculated motion can be obtained:
  - Displacement, Velocity, and Acceleration Type Plots
  - **Force and Torque Plots**
    - Motor force/torque
    - Reaction force/momentum
    - Friction force/momentum
    - Contact force
  - Energy and Momentum Type Plots

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Simulation results

MOTION ANALYSIS - PLOTS

- For Motion Analysis type motion studies, the following plot results obtained from calculated motion can be obtained:
    - Displacement, Velocity, and Acceleration Type Plots
    - Force and Torque Plots
    - **Energy and Momentum Type Plots**
        - Momentum of a Part - Translational/Angular
        - Kinetic Energy of a Part - Translational/Angular
        - Change in Potential Energy of a Part
        - Power Consumption of a Motor

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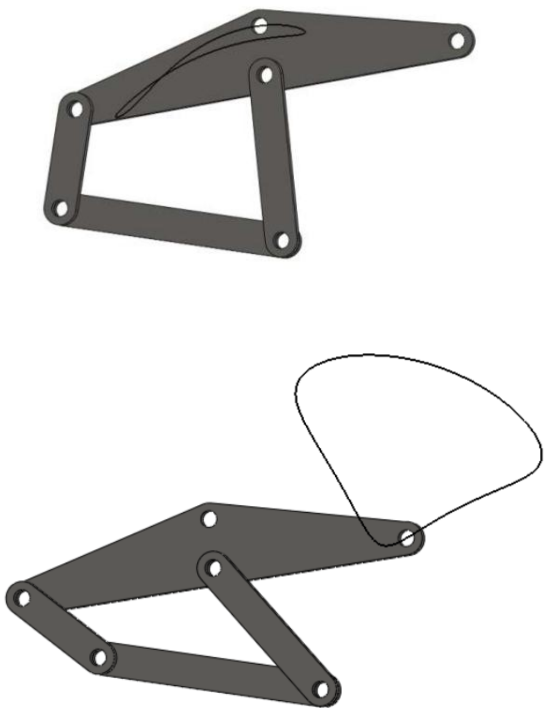
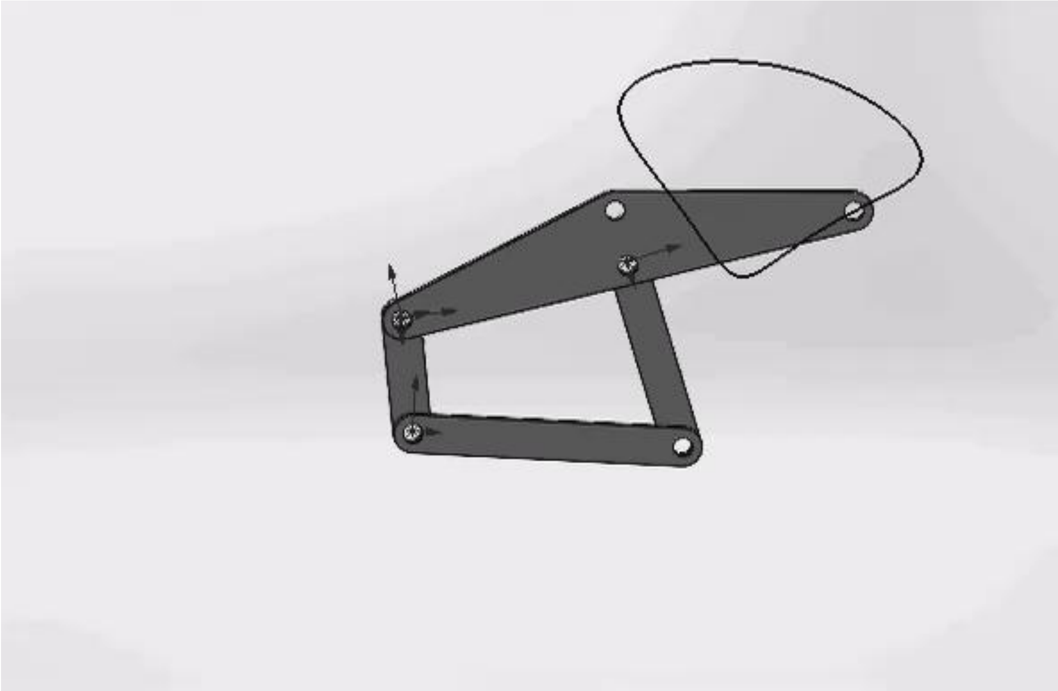
Simulation results

MOTION ANALYSIS - PLOTS





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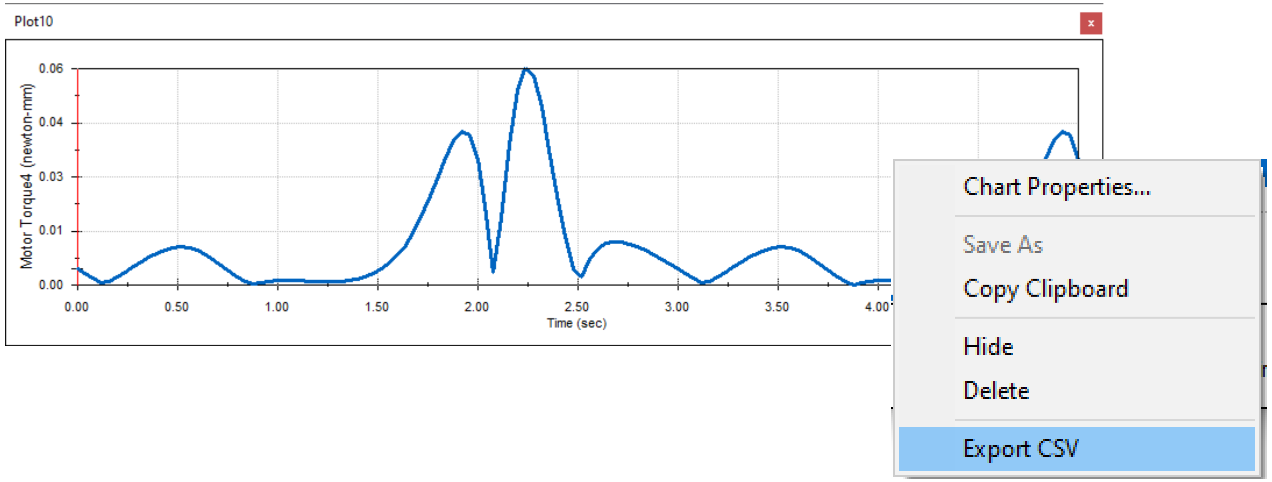
Simulation results

MOTION ANALYSIS - PLOTS

- Exporting data - Right-click in the graph and choose Export CSV. Save the file to a convenient location, and open it in Excel.



Plot10	
Time (sec)	Motor Torque4 (newton-mm)
0	0.004256875
0.04	0.003043093
0.08	0.001811177
0.12	0.00056001
0.16	0.00071145
0.2	0.002001708
0.24	0.003303985
0.28	0.004603099
0.32	0.005872104
0.36	0.007069173
0.4	0.008135789
0.44	0.008997901
0.48	0.009572073
0.52	0.009778175

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C5 – Computer Aided Design

M2 - FEA analysis of mechanical parts

CO - Technical University of Cluj-Napoca

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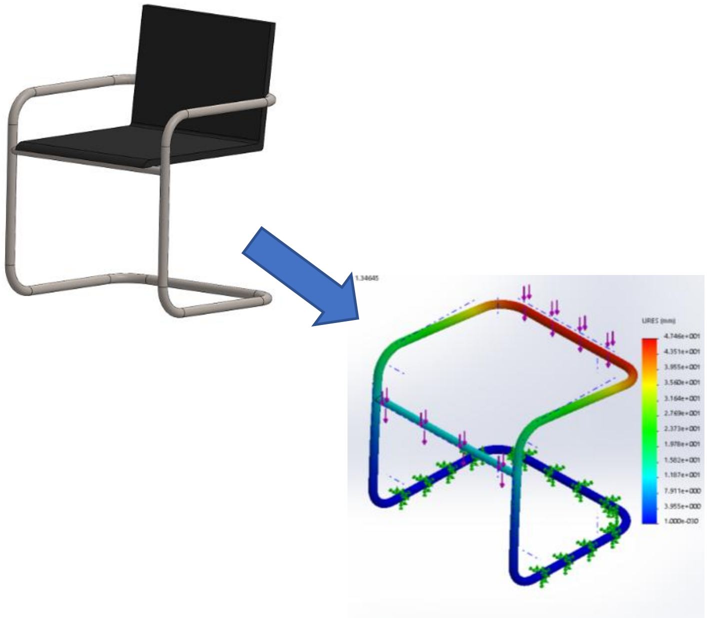
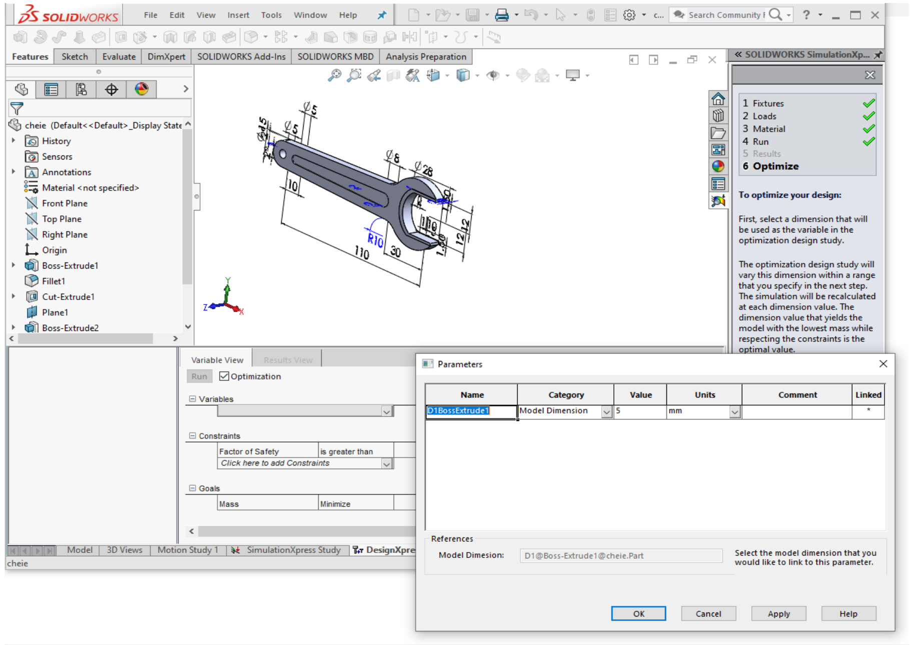
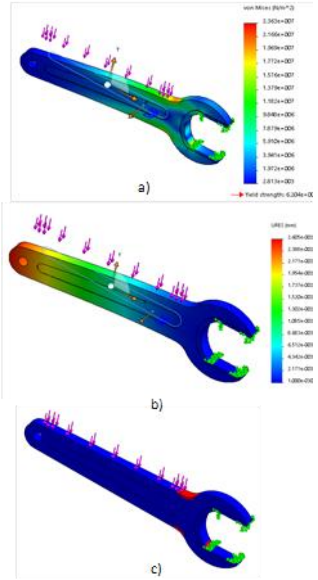
FEA analysis of mechanical parts







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NextGEng

FEA analysis of mechanical parts

Upon completion of this module, the student will be able to:

1) Create a finite element analysis (FEA) for a part in SolidWorks using SimulationXpress
2) Dimensional optimization of a part

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Content

- Introduction
- FEA simulations in SolidWorks
- Part dimensional optimization using FEA
- Summary, Discussions & Feedback

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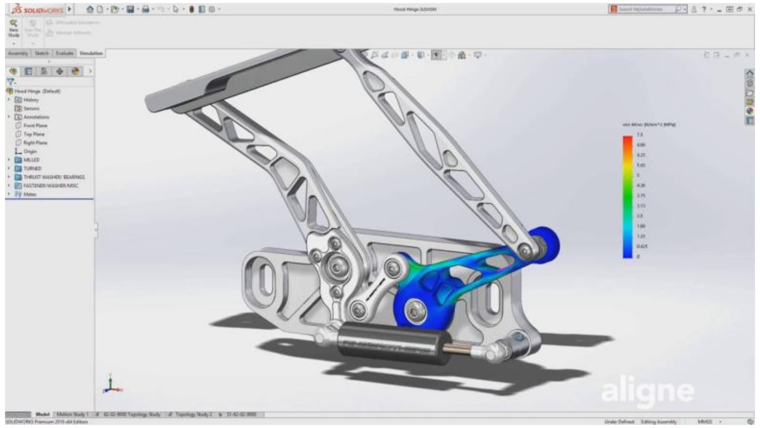
NextGEng

Introduction

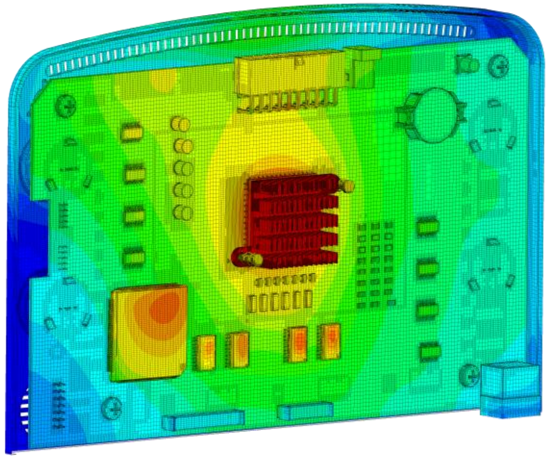
Introduction

What is a FEA simulation?

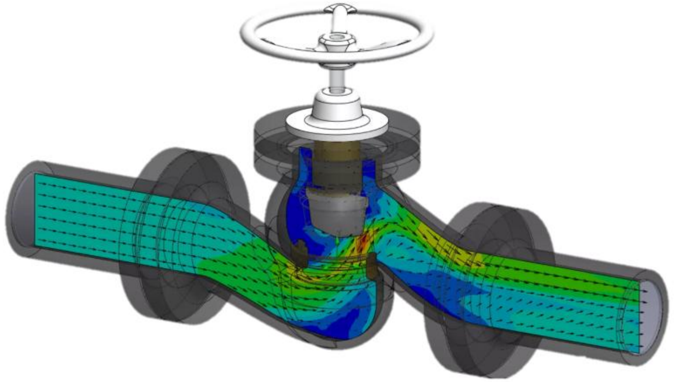
- **Finite Element Analysis (FEA)** is a computational technique used to obtain approximate solutions to complex engineering problems involving physical phenomena such as structural mechanics, heat transfer, fluid dynamics, and electromagnetism.



structural mechanics [Source]



heat transfer [Source]

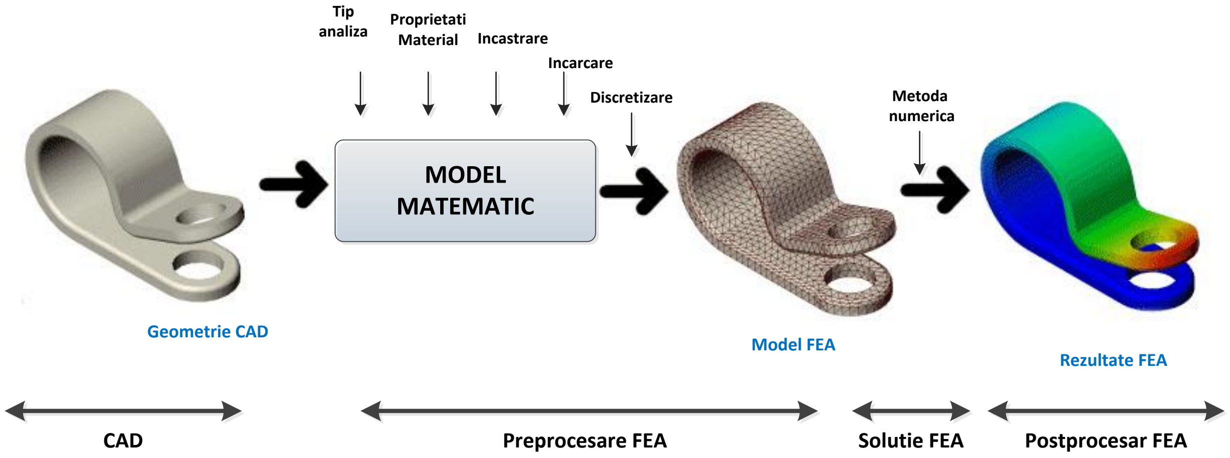


fluid dynamics [Source]

Introduction

How FEA simulation works?

- **Discretization**: The geometry is divided into a mesh of elements.
- **Element Equations**: Each element is governed by simplified physical equations.
- **Assembly**: The system of equations is assembled into a global system.
- **Boundary Conditions**: Loads, supports, and constraints are applied.
- **Solution**: The system is solved to obtain unknowns like displacement, stress, or temperature.
- **Postprocessing**: Results are visualized as plots or animations for interpretation



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NextGEng

Introduction

Advantages of using FEA in the design process

- **Accurate prediction of performance and failure**
  - FEA enables engineers to simulate how a mechanical component or assembly behaves under operational conditions (e.g., static loads, dynamic loads, vibrations, temperature variations)
  - It helps identify **stress concentrations**, **critical failure points**, and **fatigue-prone areas** before physical testing
  - Enables **virtual validation** of designs according to real-world standards (e.g., ISO)

- Reduces the need for physical prototypes
- Supports design optimization
- Saves time and cost during product development

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Introduction

Advantages of using FEA in the design process

- Accurate prediction of performance and failure
- **Reduces the need for physical prototypes**
  - Early design validation with FEA reduces the number of **iterations in physical prototyping**
  - Engineers can test multiple scenarios and **what-if conditions** virtually, which lowers costs and accelerates the R&D process
  - Minimizes **material waste** and production setup costs for prototype fabrication **(**eco-friendly**)**

- Supports design optimization
- Saves time and cost during product development

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Introduction

Advantages of using FEA in the design process

- Accurate prediction of performance and failure
- Reduces the need for physical prototypes
- **Supports design optimization**
  - FEA allows for parametric and topology optimization of components to **maximize strength-to-weight ratios**, **improve stiffness**, or **minimize deformation**
  - Support **designing lighter, more efficient** components—crucial in sectors like automotive, aerospace, and robotics
  - Enables **multi-physics optimization** by considering thermal, structural, and fluid interactions together
- Saves time and cost during product development

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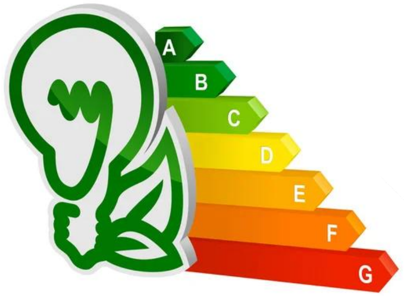
Introduction

Advantages of using FEA in the design process

- Accurate prediction of performance and failure
- Reduces the need for physical prototypes
- Supports design optimization
- **Saves time and cost during product development**
  - Integrating FEA into early design stages shortens the overall **product development lifecycle**
  - Detecting flaws early prevents **costly redesigns** later in manufacturing
  - Reduces dependence on **trial-and-error engineering** approaches and speeds up the **time-to-market**

Introduction

Designing of eco-friendly and sustainable systems



- **Reduced Material Waste**
  - FEA allows precise stress and strain analysis, enabling material minimization without compromising safety
  - Supports lightweight design, especially in automotive and aerospace applications, reducing material usage and carbon footprint
- **Improved Energy Efficiency**
  - Enables optimization of thermal management and mechanical efficiency in components
- **Supports Sustainable Innovation**
  - Empowers engineers to experiment with eco-friendly materials and biomimetic designs in a low-risk digital environment

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FEA simulations in SolidWorks

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FEA simulation

SimulationXpress is a built-in tool available in all versions of SolidWorks, designed for quick and basic linear static analysis on individual parts.

SolidWorks Simulation is a comprehensive FEA suite that supports advanced analysis of both parts and assemblies.

Feature / Criteria	SimulationXpress	SolidWorks Simulation
Included in	All SolidWorks versions (part-only analysis)	Add-in module (Standard, Professional, Premium tiers)
Type of Analysis	Linear static analysis on individual parts	Linear, nonlinear, dynamic, thermal, frequency, fatigue, etc.
Assemblies Support	Not supported	Full support for assemblies
Material Models	Basic (linear, isotropic materials only)	Advanced (nonlinear, orthotropic, plasticity, etc.)
Loading Conditions	Limited to simple forces and fixtures	Full range: forces, torques, pressures, gravity, thermal loads
Meshing Options	Automatic, basic mesh only	Advanced mesh control (manual, curvature-based, refinement)
Contact Simulation	Not available	Supports bonded, no penetration, frictional contacts
Reporting and Postprocessing	Basic result plot (stress, displacement)	Full control: animations, stress plots, safety factor maps

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FEA analysis using SimulationXpress

Steps in Performing an Analysis

❑ **Step 1 – Accessing the *SimulationXpress Module***

- Open the **part** to be analyzed in SolidWorks.
- Go to the **Evaluate** tab and select **SimulationXpress Analysis Wizard**.

SimulationXpress Module

Note - Alternatively, it can be accessed via *Tools > Xpress Products > SimulationXpress*

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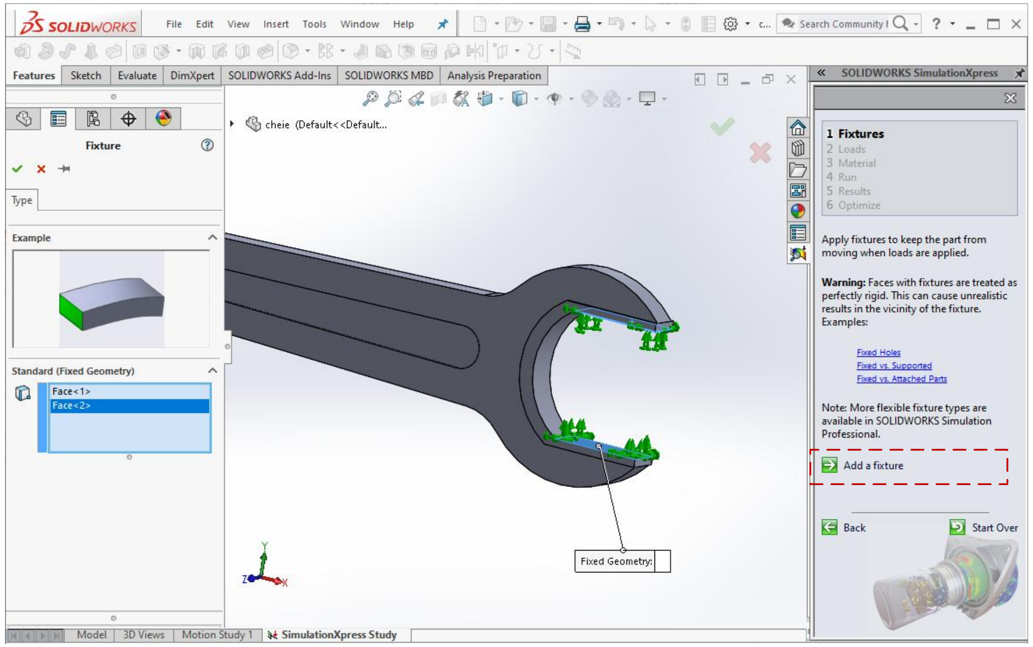
FEA analysis using SimulationXpress

Steps in Performing an Analysis

❑ Step 2 - Define Fixtures (Motion Constraints)

- In the **Fixtures** step of the wizard, click **Add Fixture**.
- Select the face(s) of the part considered fixed (immobile).



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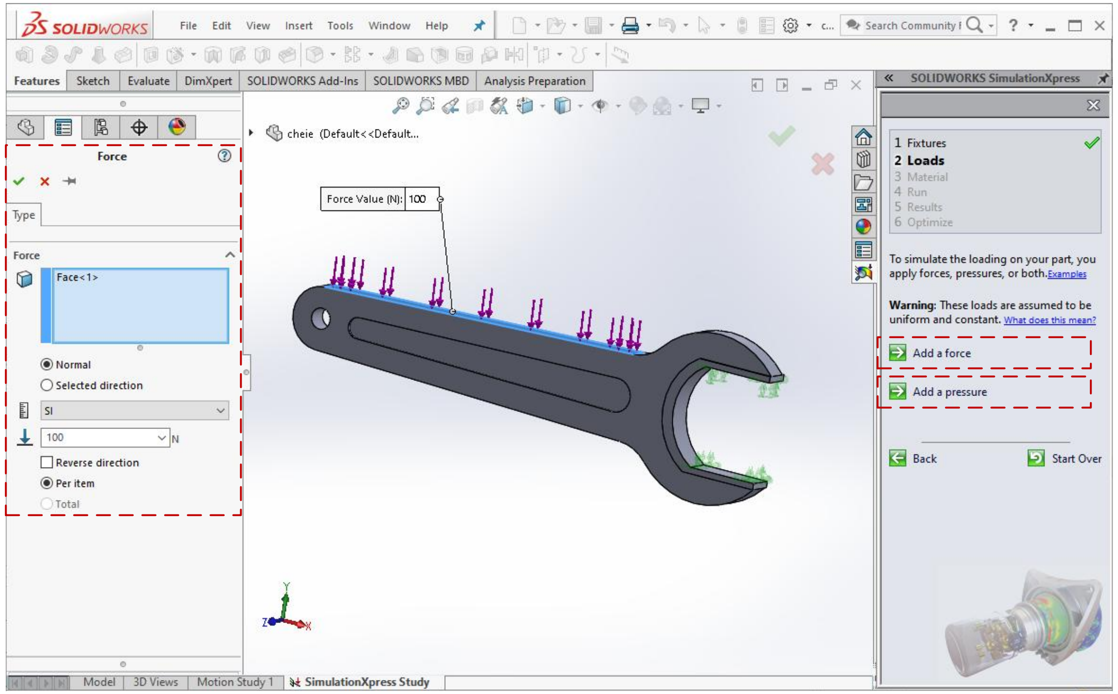
FEA analysis using SimulationXpress

Steps in Performing an Analysis

- ❑ **Step 3 – Define External Loads**

  - Based on the type of loads acting on the part, choose:
    - **Add a Force**
    - **Add a Pressure**

  - Select the regions where the load applies and set its magnitude and direction.



Note - Default load direction is **normal to the surface**.

- For forces: use **Selected Direction** to modify the force direction.
- For pressure: use **Use Reference Geometry** to define the direction relative to planes

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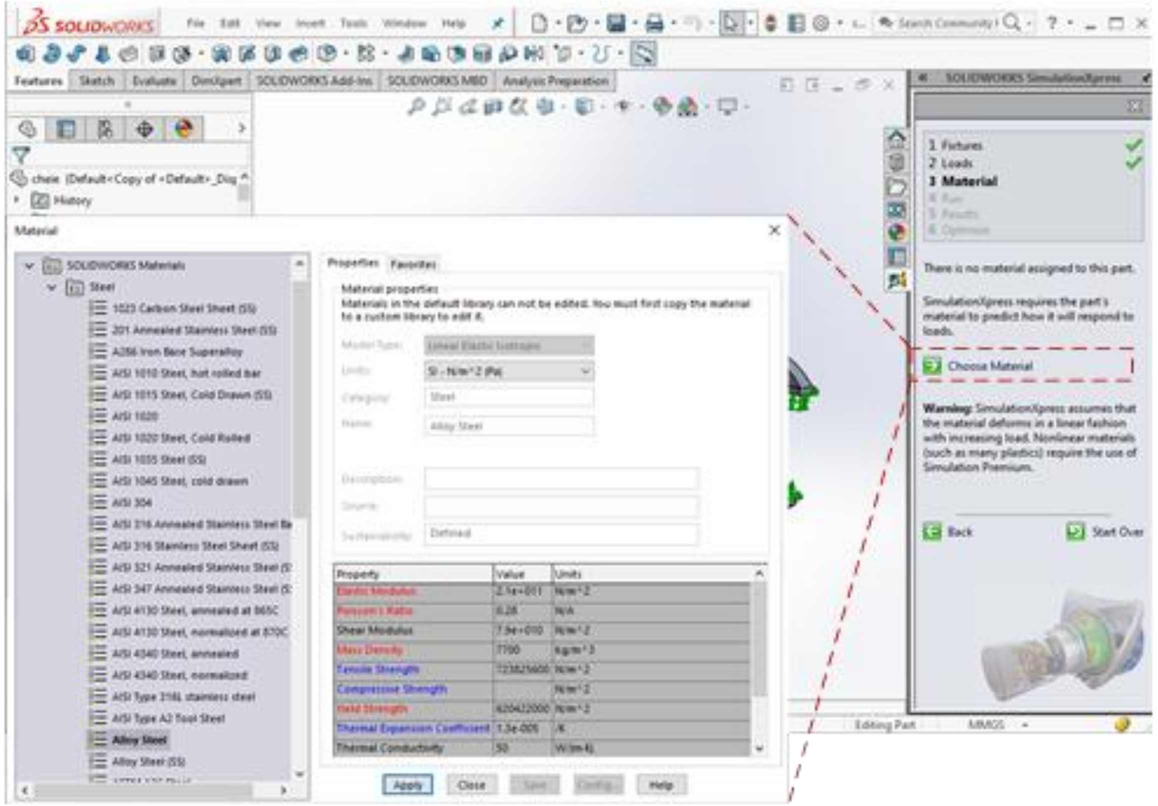
FEA analysis using SimulationXpress

Steps in Performing an Analysis

- ❑ **Step 4 – Assign Material to the Part**

  - Use **Choose Material** option to assign the material to the analyzed part
  - The user can choose from already existing materials from the library or create a custom one

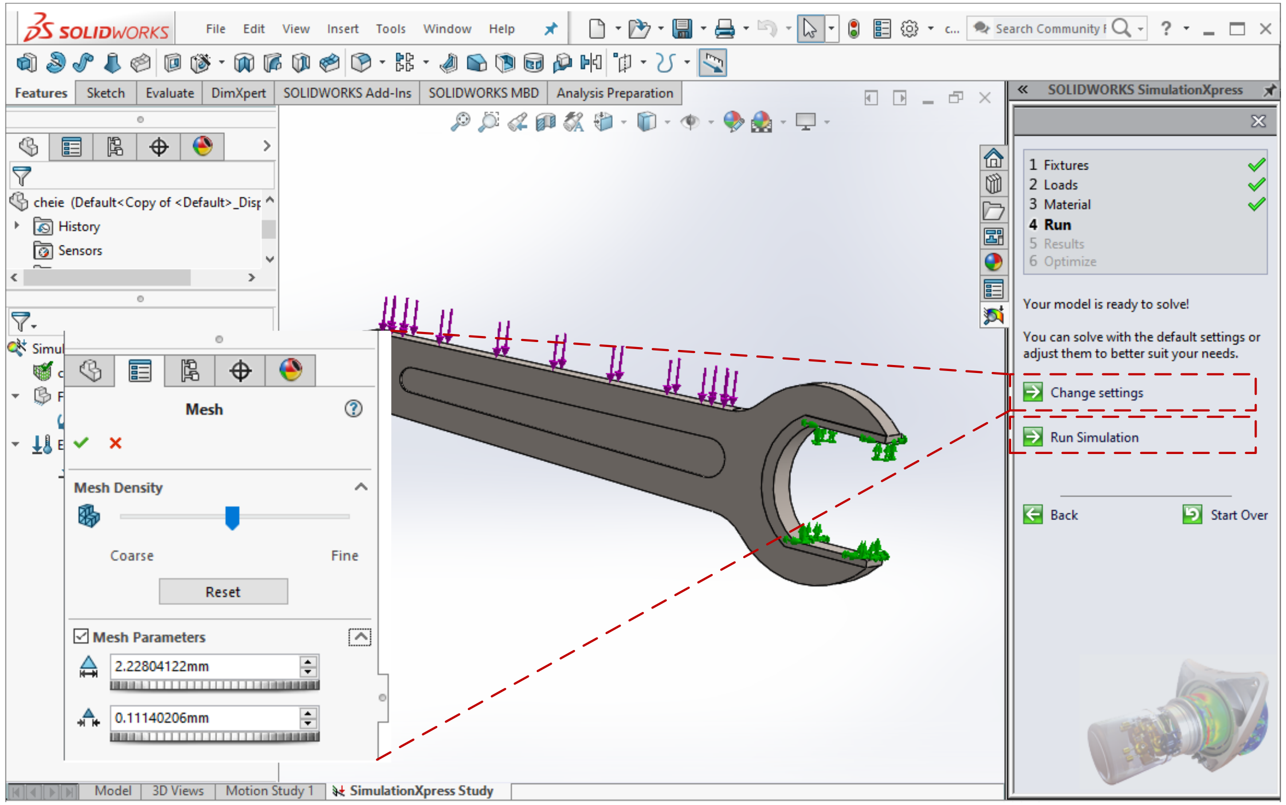


FEA analysis using SimulationXpress

Steps in Performing an Analysis

❑ Step 5 – Configure and Run the Simulation

- Use **Change Settings** to adjust the mesh (finite element grid).
  - a finer mesh increases accuracy but also increases computation time.
- Click **Run Simulation** to start the analysis
  - SolidWorks creates nodes on surfaces and within the volume using tetrahedral elements



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NextGEng

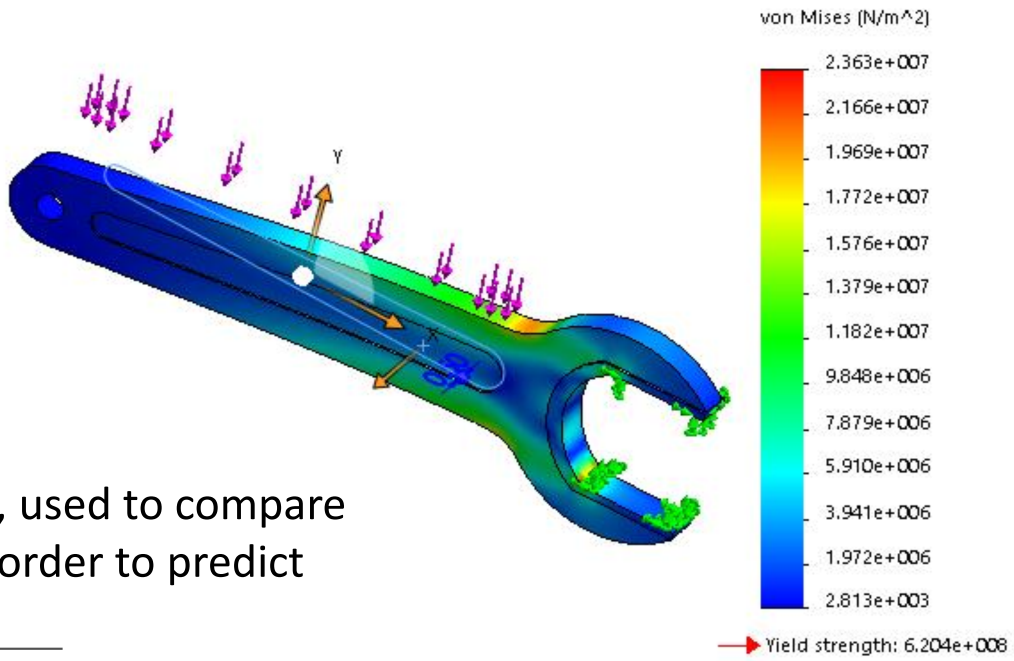
FEA analysis using SimulationXpress

Steps in Performing an Analysis

- **Step 6 – View Results**

  - ***Show von Mises Stress***

    - Displays equivalent von Mises stress due to applied loads.
    - Stress is visualized using a **color scale** (blue = low, red = high).



- **Von Mises stress** is a scalar measure derived from the stress tensor, used to compare a three-dimensional stress state to an equivalent uniaxial stress, in order to predict material yielding

$$\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}$$

Note - Deformations are exaggerated in display for visibility (amplification factor shown on screen).

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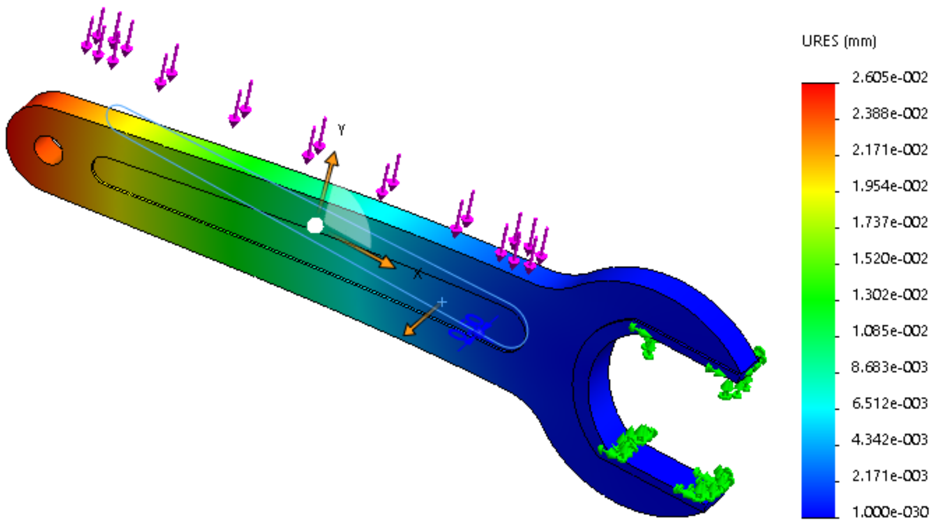
FEA analysis using SimulationXpress

Steps in Performing an Analysis

- Step 6 – View Results

  Show Displacement



- visualizes the part’s displacement due to applied
- uses a **color gradient** (blue = minimal, red = maximal displacement)

Note - Deformations are exaggerated in display for visibility (amplification factor shown on screen).

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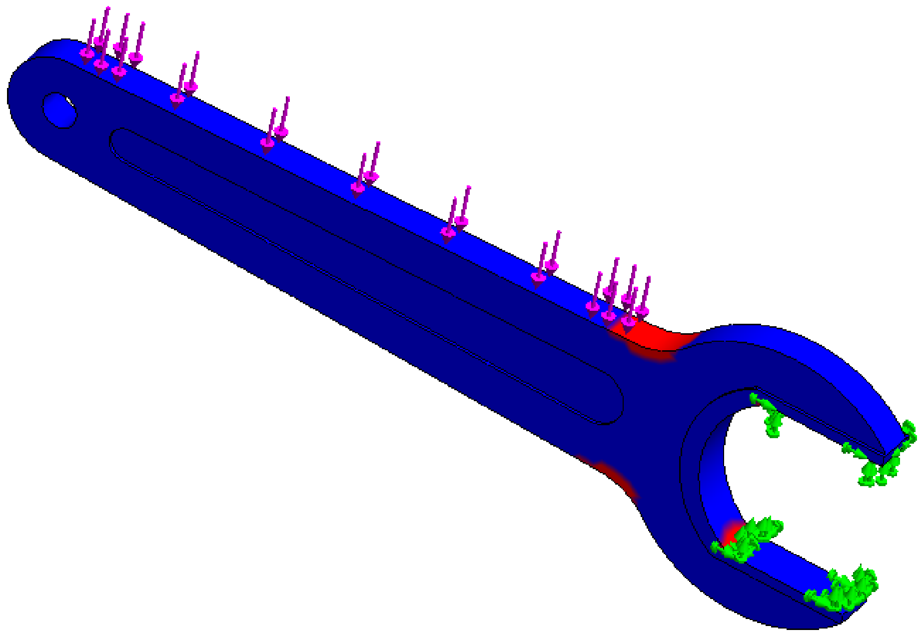
FEA analysis using SimulationXpress

Steps in Performing an Analysis

- **Step 6 – View Results**
  - ***Show where factor of safety (FOS) is below***

- Highlights areas where the FOS is below a user-defined threshold.
- Blue = safe zone, Red = risk zone (FOS below limit).

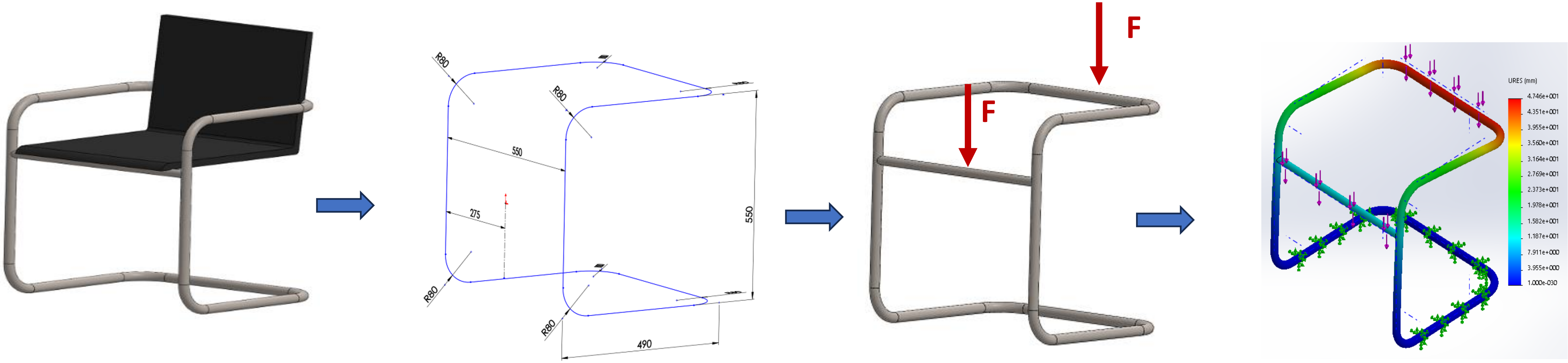


FEA analysis using SimulationXpress

❑ Example

- Task: Determine the displacement and the safety factor of a chair frame for a given imposed weight.

  Input data:
  - Load : A person weighing 122 Kg
  - Material : steel alloy



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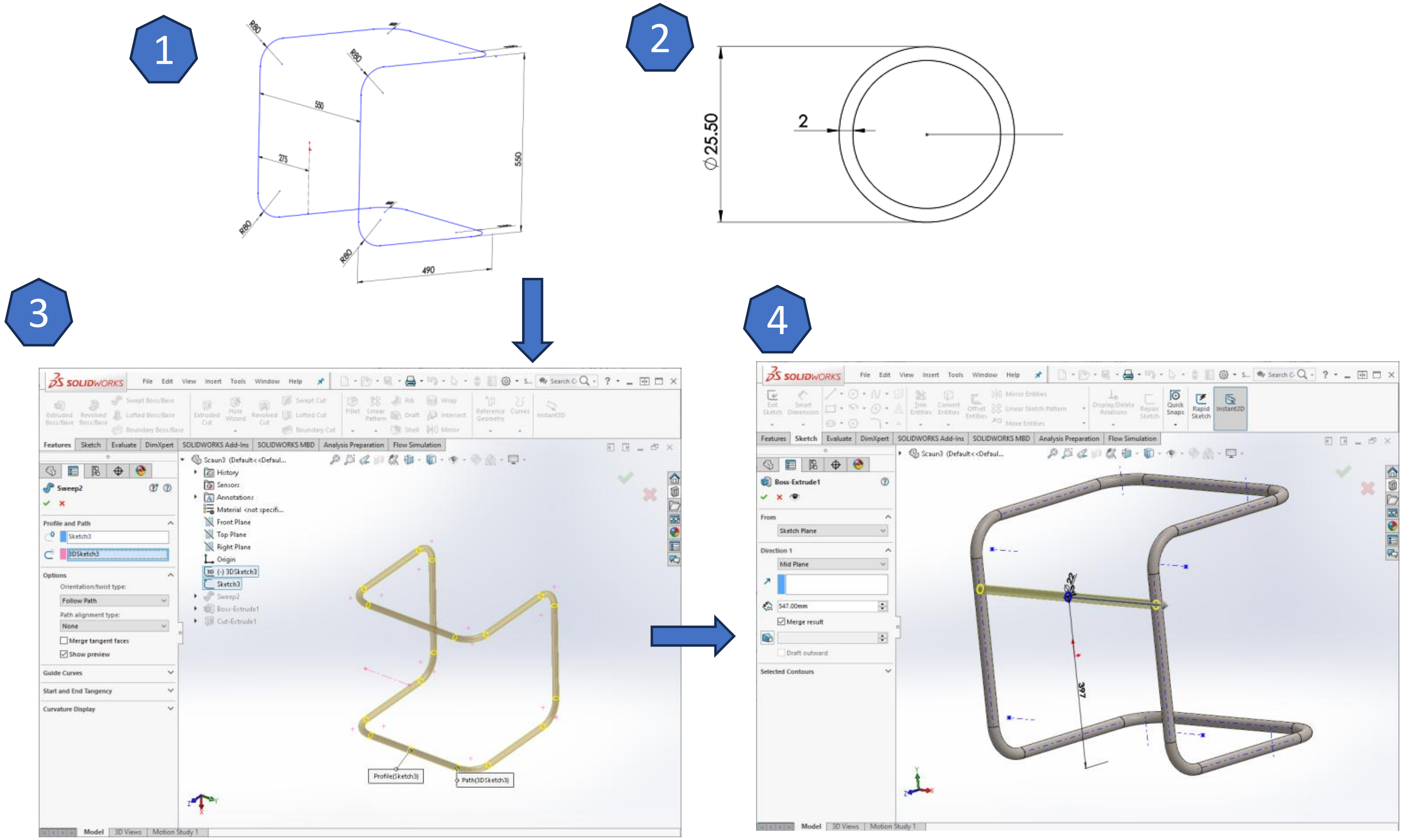
NextGEng

FEA analysis using SimulationXpress

❑ Example

- Development of the chair frame
  - Create a **3D sketch** that define the shape of the chair frame (1)
  - Create a **cross section** of the pipe that forms the frame (2)
  - Use ***Sweep*** command to create the frame (3)
  - Create the transverse bar that supports the seat of the chair (4)



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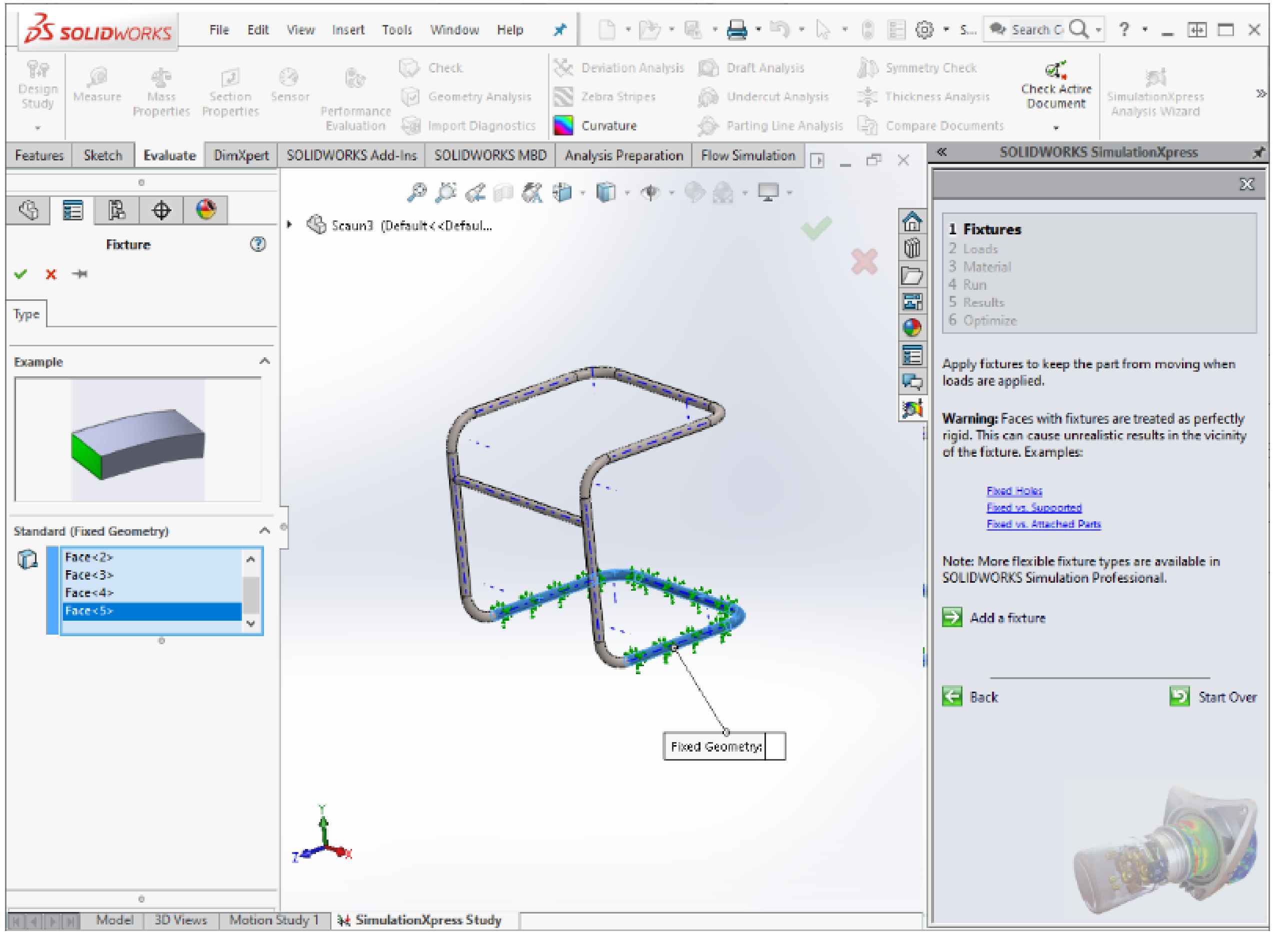
FEA analysis using SimulationXpress

❑ Example

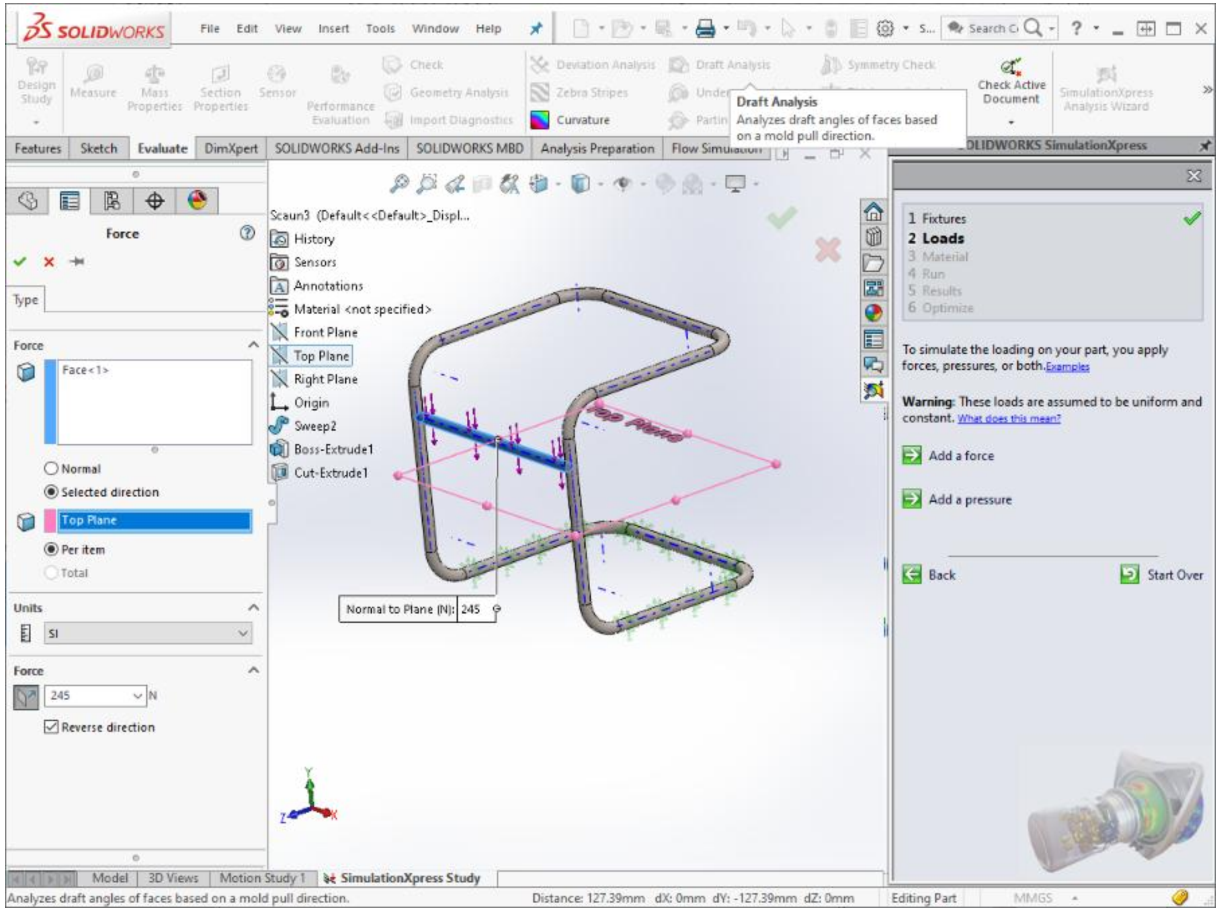
- Defining the fixtures
  - Click **Add a fixture**
  - Select all the surfaces that are in contact with the ground
  - Click the **Ok** button



FEA analysis using SimulationXpress

❑ Example

- Defining the forces that act on the chair
  - Click **Add a force**
  - Add **Force 1** (20% of the person weight)
    - Select the front horizontal bar
    - Introduce a force value of 245 N
    - Click **Select direction** option and choose *Top Plane*
  - Click **Ok** button



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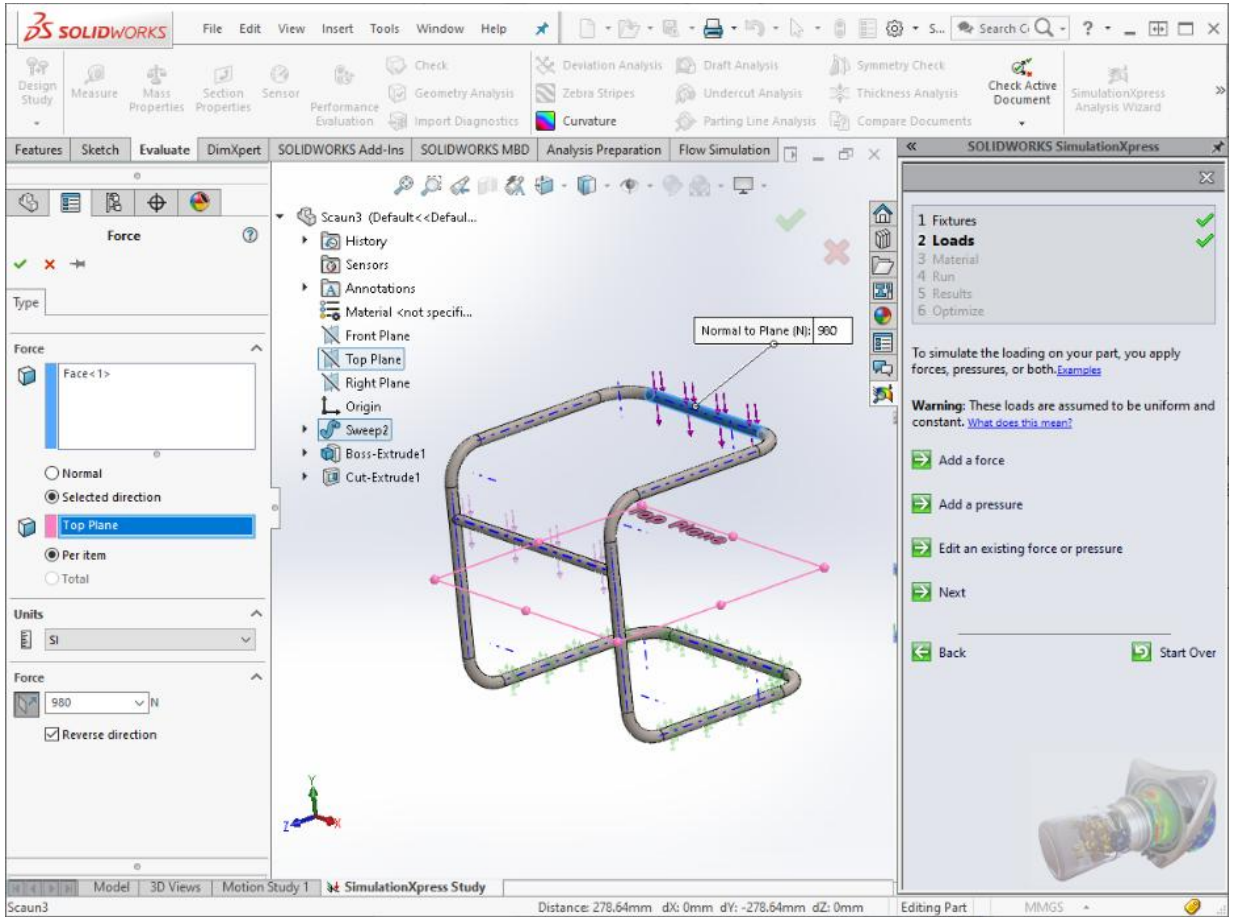
FEA analysis using SimulationXpress

❑ Example

- Defining the forces that act on the chair
  - Click **Add a force**
  - Add **Force 2** (80% of the person weight)
    - Select the front horizontal bar
    - Introduce a force value of 980 N
    - Click **Select direction** option and select *Top Plane*
  - Click **Ok** button



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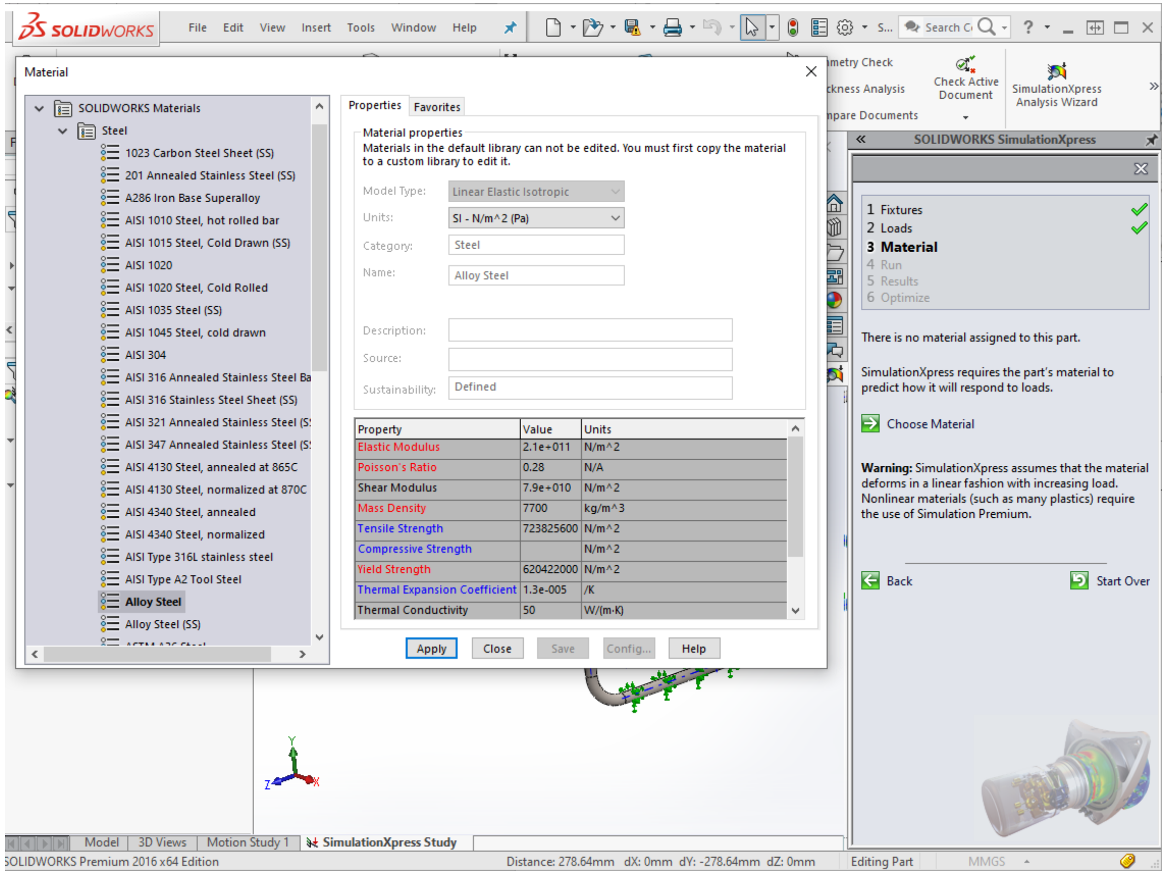
FEA analysis using SimulationXpress

❑ Example

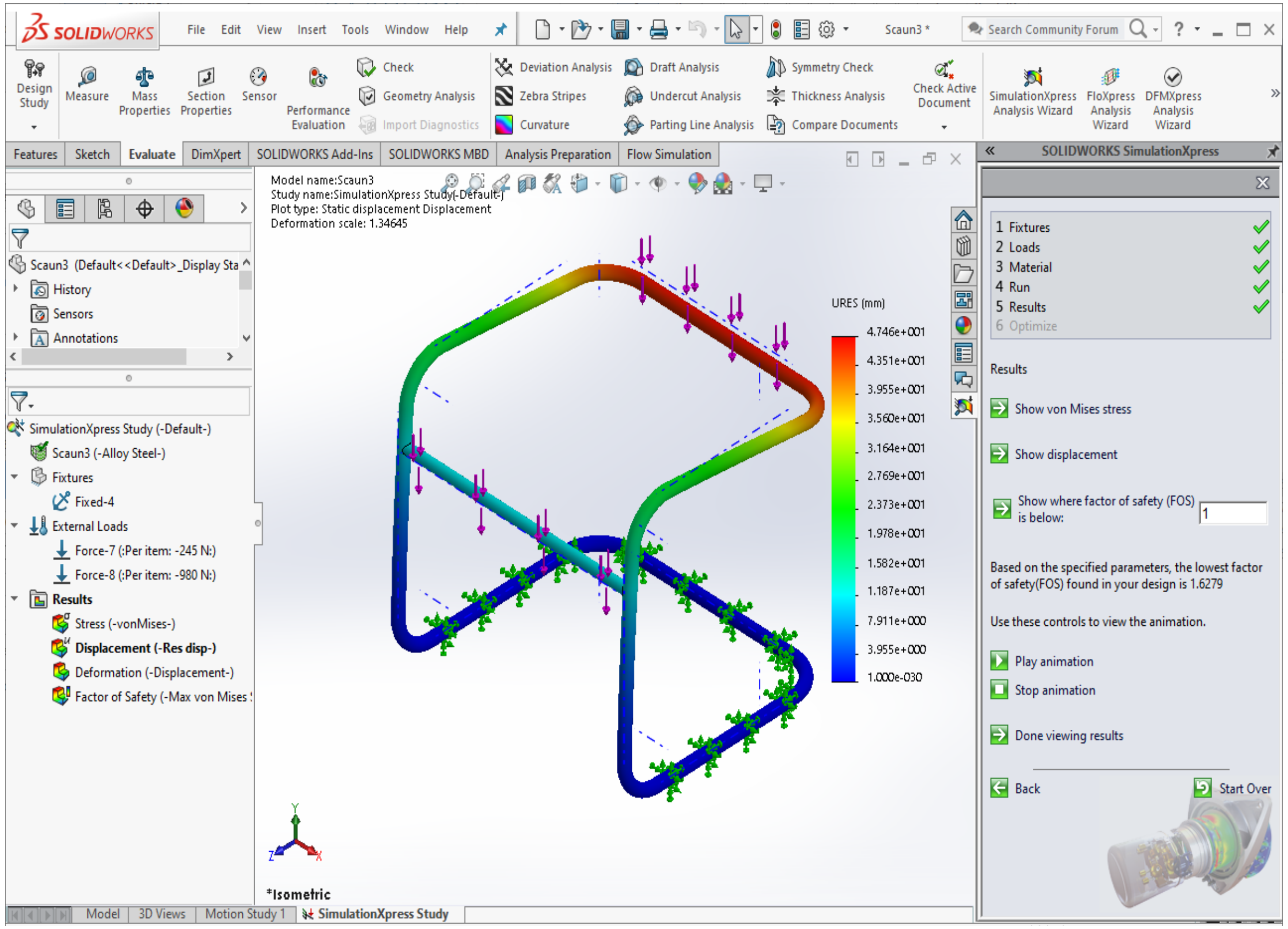
- Defining the frame material
  - Click **Choose material**
  - From the list of predefine materials, select *Alloy Steel*
  - Click **Apply** button



FEA analysis using SimulationXpress

❑ Example

- Simulation results
  - Displacement (max):
    - 47.4 [mm]
  - Factor of safety
    - 1.627



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Part dimensional optimization using FEA

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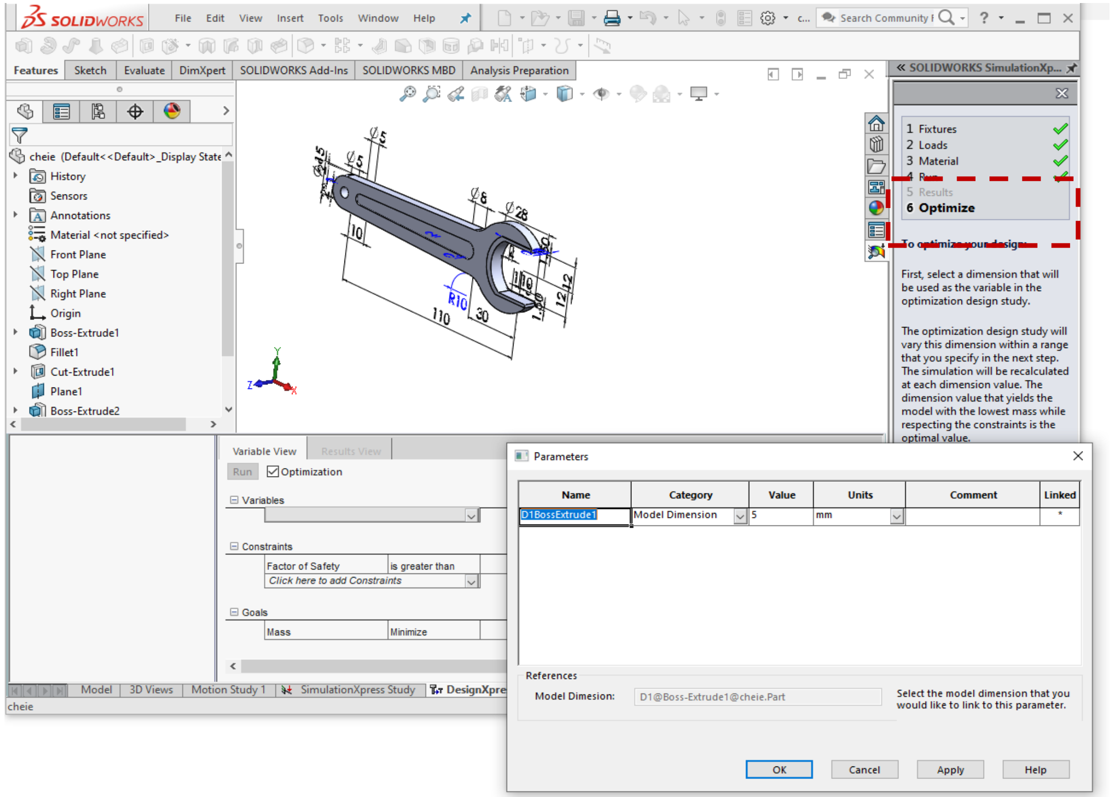
Part dimensional optimization using FEA

- **Optimization criteria:**
  - von Mises stresses
  - displacements
  - safety factor

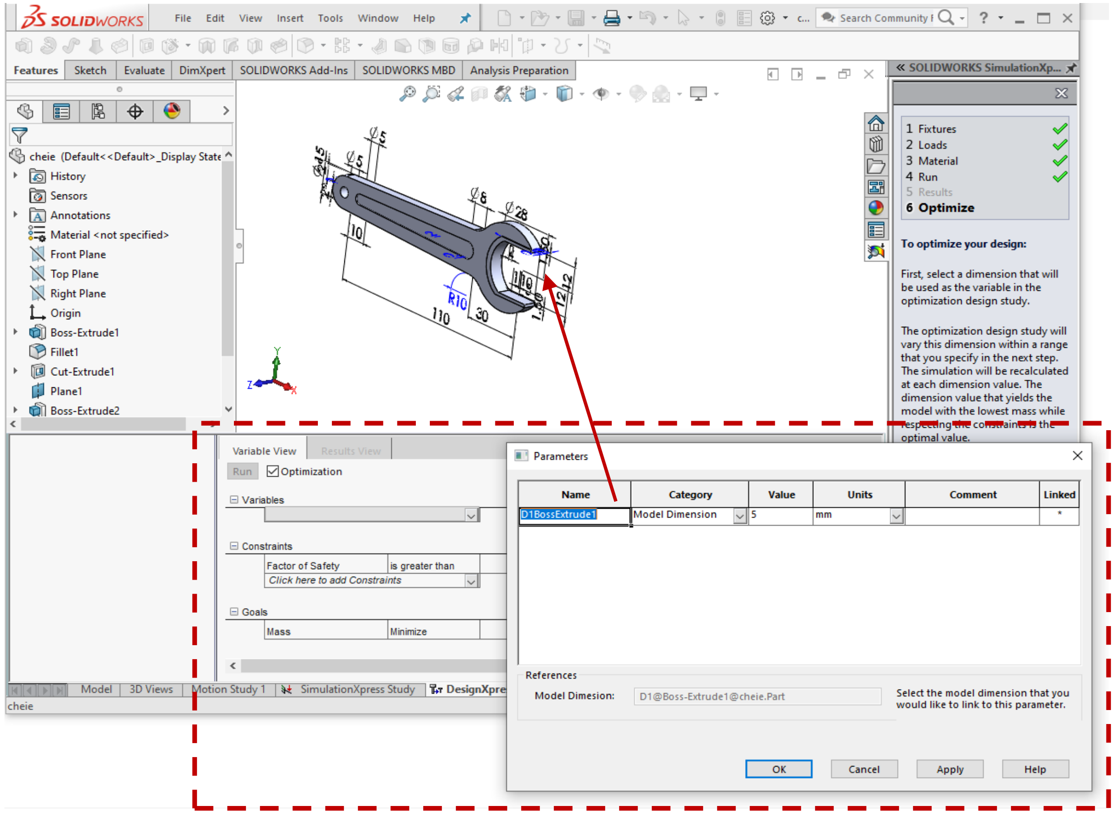


- From the **SimulationXpress Analysis Wizard** dialog window, select the option **"Would you like to optimize your model?"**

Part dimensional optimization using FEA

Steps in Performing the dimensional optimization

- ❑ **Step 1 – Selection of the parameter for optimization**
  - Click **Variables** section in Variable view area
  - In the **Parameters** dialog window select a dimension from the graphics area (part dimensions) or from the FeatureManager design tree



Note -The selected dimension will be varied during the optimization process to meet the chosen goal and constraints.

Part dimensional optimization using FEA

Steps in Performing the dimensional optimization

- **Step 2 – Define the constraint to be evaluated**
  - From the DesignXpress study dialog window, in the Constraints option, select the constraint for which the optimization will be performed:
    - Factor of Safety
    - Max Displacement
    - Max Stress

Note - For the **Factor of Safety** option, the minimum accepted value must be entered.
Note - In the case of the **Max Displacement** or **Max Stress** options, the maximum accepted value must be entered.

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Part dimensional optimization using FEA

Steps in Performing the dimensional optimization

- **Step 3 – Run the optimization**

  - After configuring the optimization parameters, to run the optimization process, select the option from the SimulationXpress Analysis Wizard window:

    Run the optimization

Part dimensional optimization using FEA

Steps in Performing the dimensional optimization

❑ Step 4 – Evaluate the results

- In the **Results View** tab, the initial values and the values obtained after optimization are displayed in tabular form.

Variable View | Results View

	Initial	Optimal
D1BossExtrude1 (0.00277133)	5mm	2.77133mm
Factor of Safety	32.817032	20.298346
Mass	0.0850677 kg	0.0460483 kg

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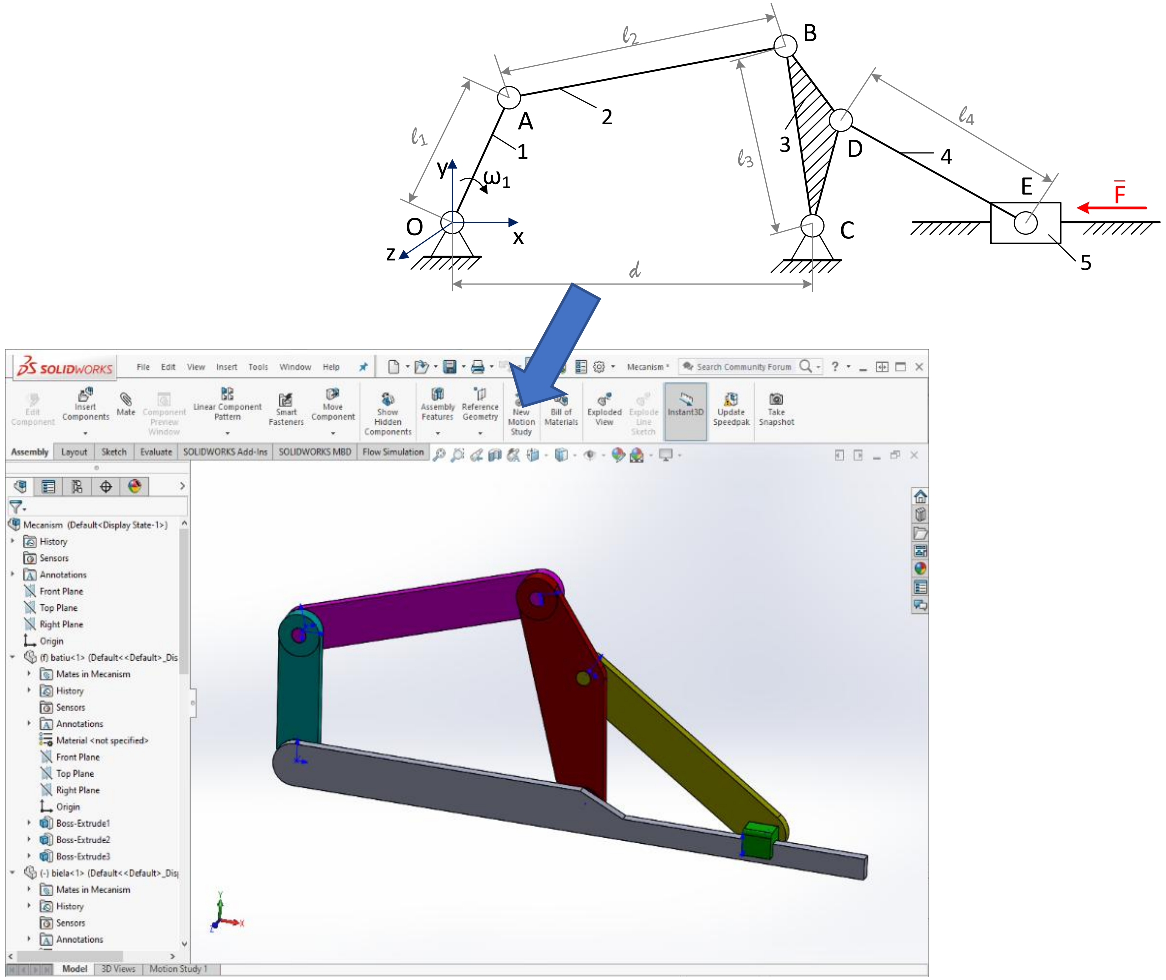
Part dimensional optimization using FEA

❑ **Example**

Tasks:

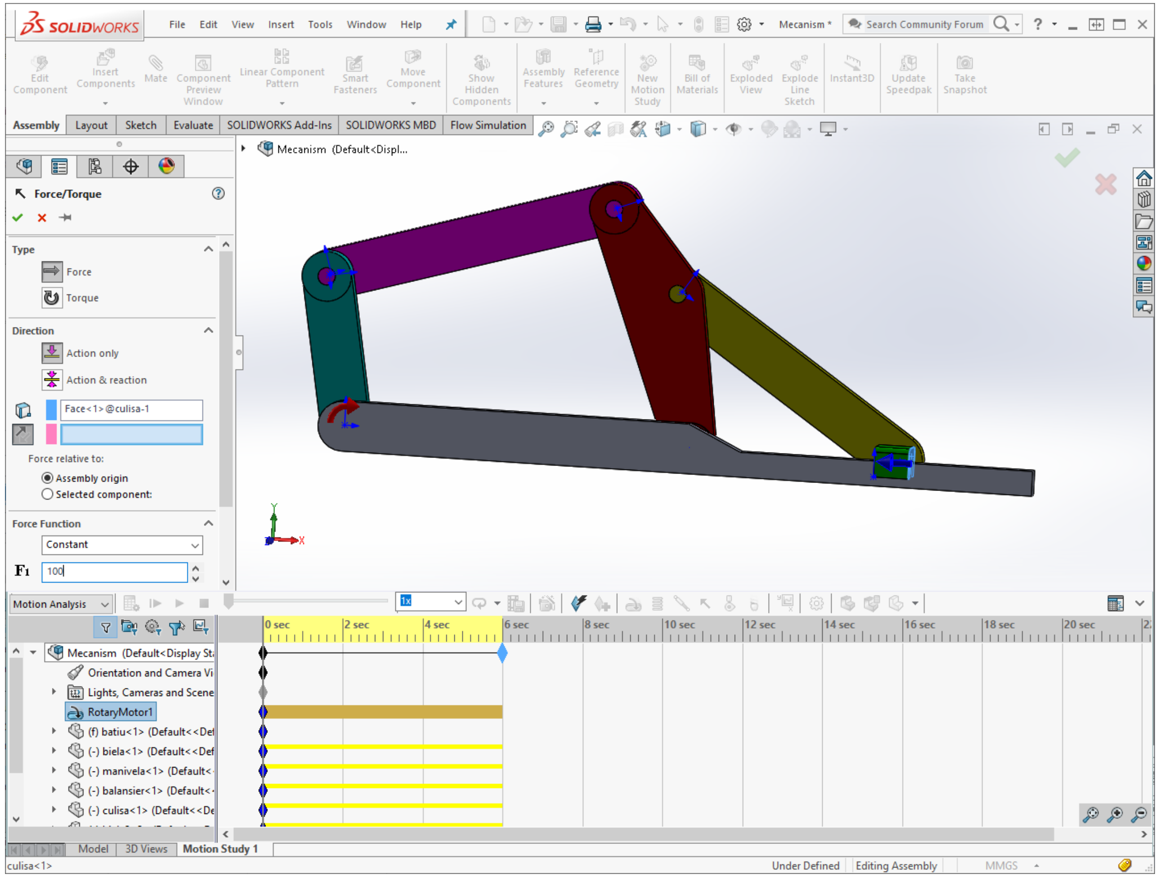
- Determine the reaction force in the kinematic joint A and the driving torque required for a complete operating cycle.
- Determine the deformation and the safety factor for the driving kinematic element (1) (based on the reaction force at pair A).
- Optimize the thickness of the kinematic element 1 so that the minimum safety factor is higher than 2



Part dimensional optimization using FEA

❑ Example

- Create a new animation using the **Motion Analysis** tool
- Insert a **Rotary motor** in joint O that has a rotational velocity of 10 rpm and rotates clockwise
- Apply a **Force** that acts on the kinematic element 5 with a magnitude of 100 N



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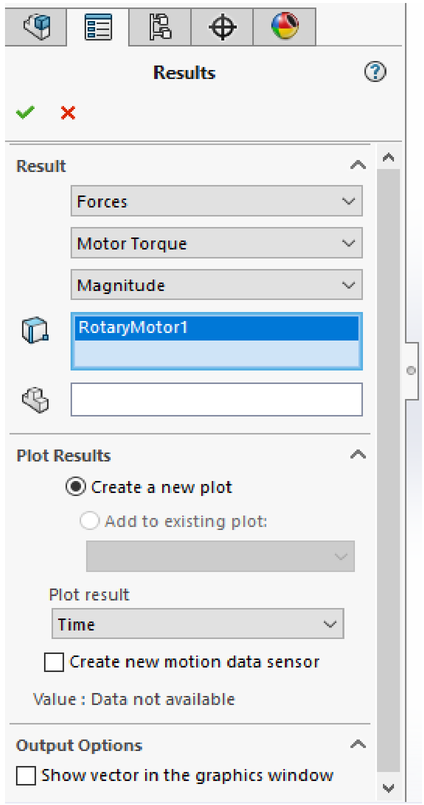
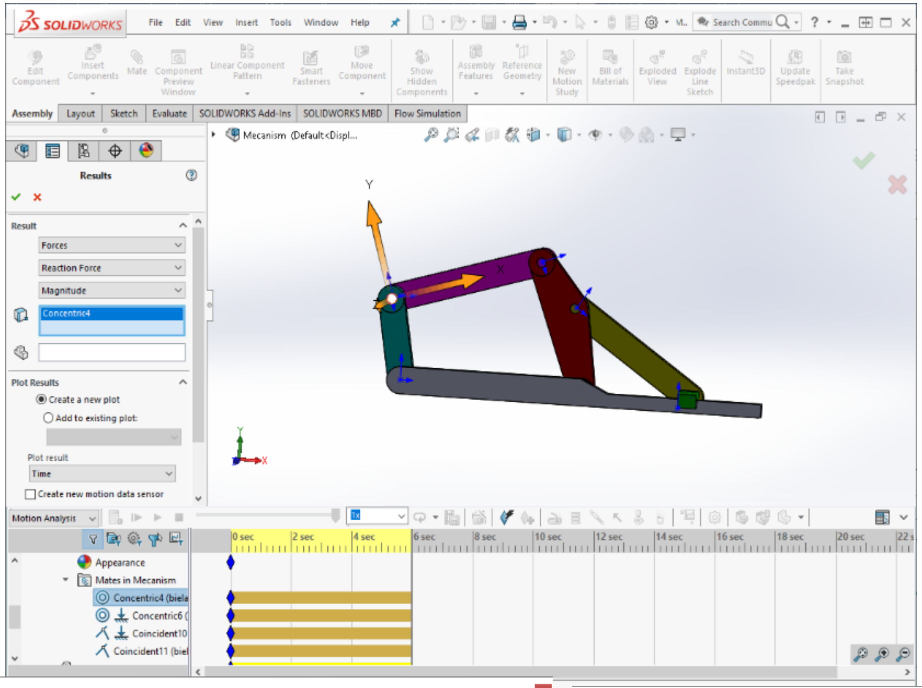
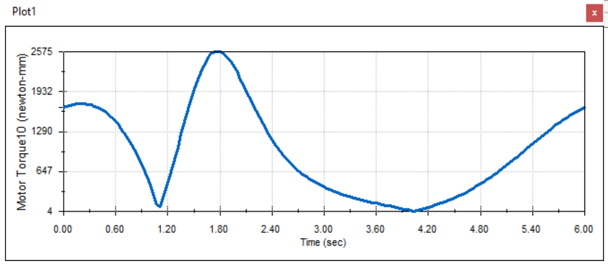
Part dimensional optimization using FEA

❑ Example

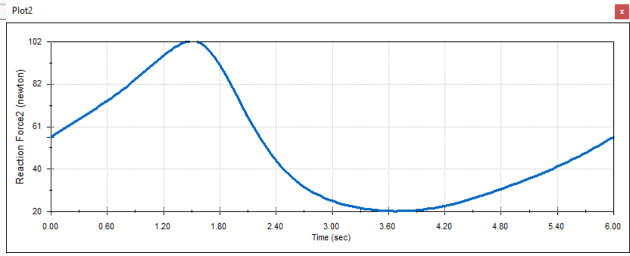
- Use the Plot command to determine:
  - The **Motor torque** required for a full cycle
  - The **Reaction force** at joint A
- Note :
  - Max F_A=102.2 [N]
  - Max N_m=2577.2 [Nmm]







Motor torque

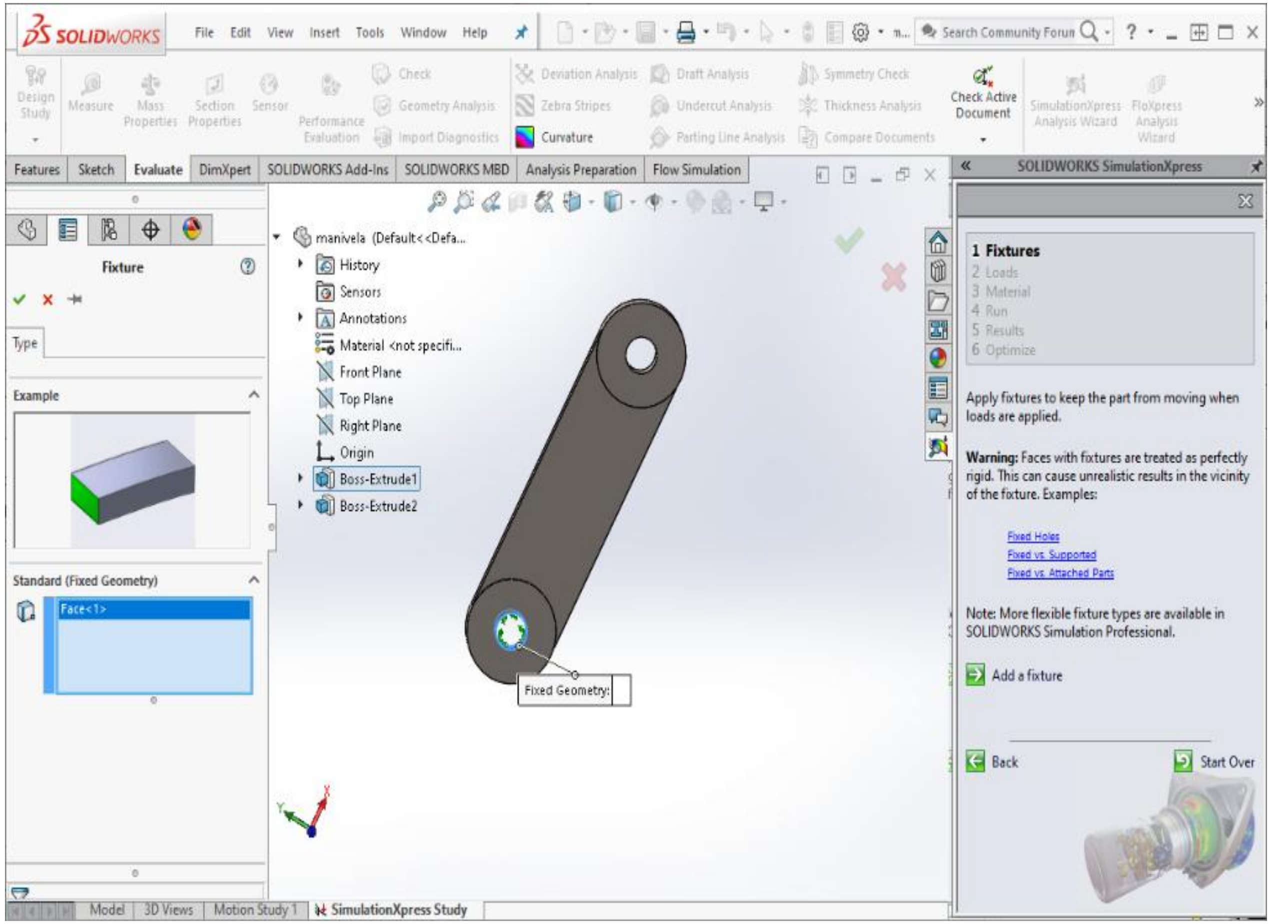


Reaction Force

Part dimensional optimization using FEA

- **Example**

  - **Optimization** of the geometric dimension of kinematic element 1
    - Define the fixtures



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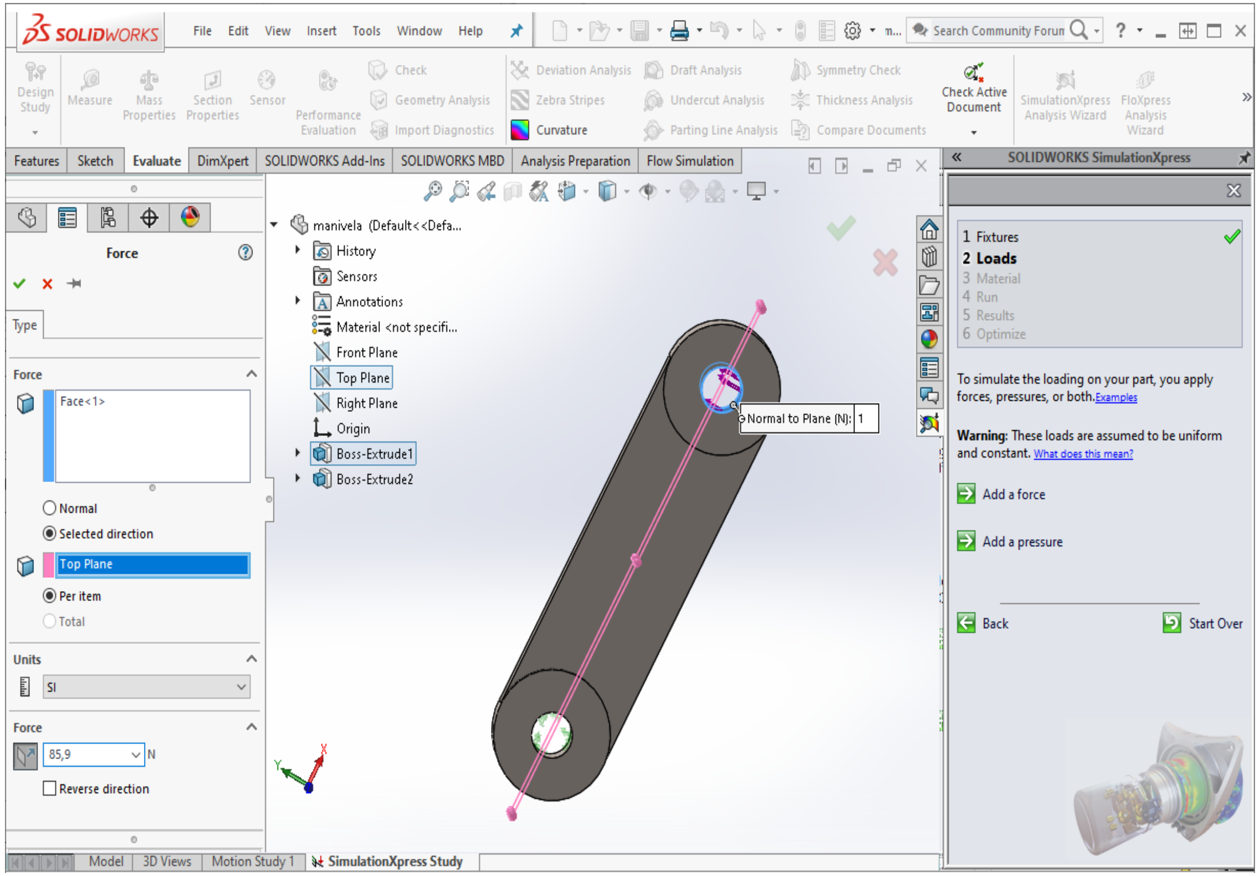
Part dimensional optimization using FEA

❑ Example

- **Optimization** of the geometric dimension of kinematic element 1
  - Define the fixtures
  - Define the Force acting on Joint A
    - Force magnitude F_A=85.9[N].



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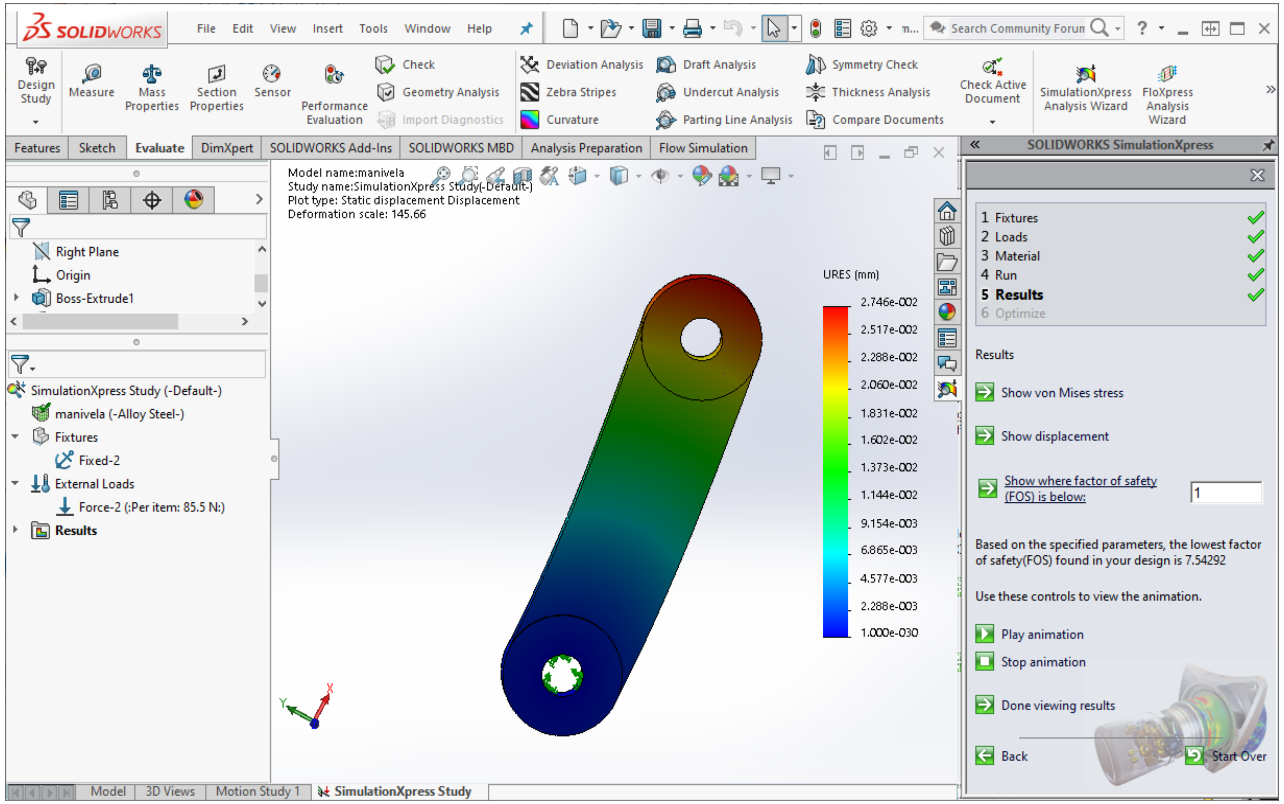
Part dimensional optimization using FEA

❑ Example

- **Optimization** of the geometric dimension of kinematic element 1
  - Define the fixtures
  - Define the Force acting on Joint A
  - FEA analysis
    - Safety factor 7.54
    - Displacement 0,0275 [mm]



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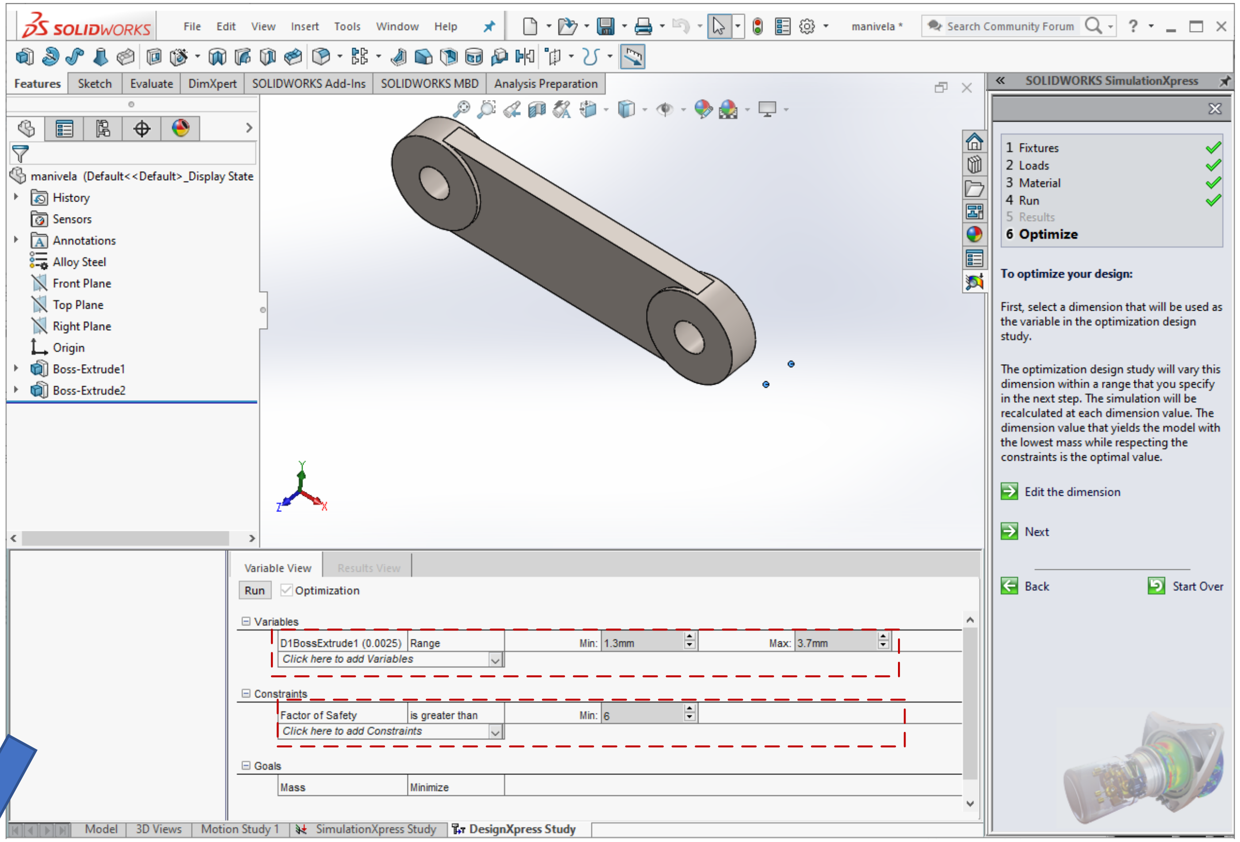
Part dimensional optimization using FEA

❑ Example

- **Optimization** of the geometric dimension of kinematic element 1
  - Define the fixtures
  - Define the Force acting on Joint A
  - FEA analysis
  - Geometric optimization of the element
    - Variable – part width
    - Constraints – safety factor (min): 6



	Initial	Optimal
D1BossExtrude1 (0.00179033)	2.5mm	1.79033mm
Factor of Safety	7.444344	6.013676
Mass	0.00797783 kg	0.00601447 kg

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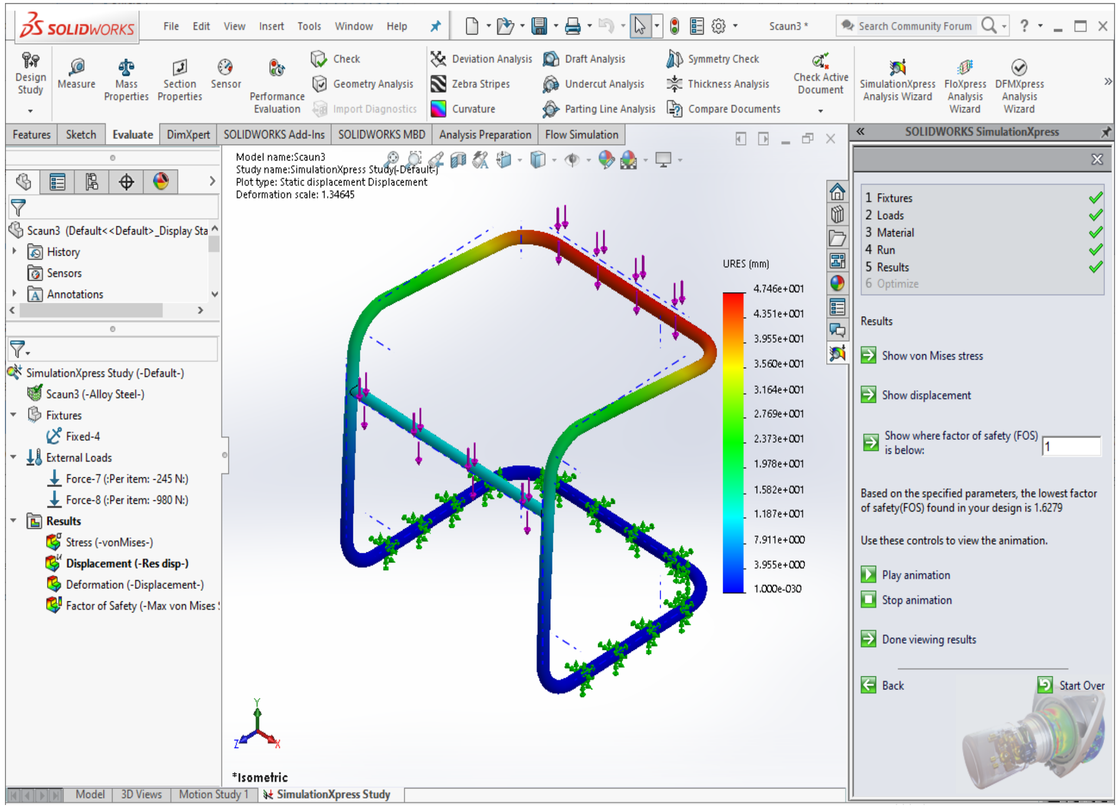
Summary & Discussions

FEA simulations and part optimisation

- ***SimulationXpress Module***
  - Performs linear static analysis using the Finite Element Method for single-body parts.
  - Allows selection of material from the SolidWorks library
  - Applies loads (forces or pressures) on selected faces to simulate operational conditions
  - Displays Von Mises stress, displacement, and factor of safety as color contour plots
  - Provides basic shape optimization tools for a selected dimension



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C5 – Computer Aided Design

M3 - Parametric Design with CATIA

CO - Technical University of Cluj-Napoca

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About NextGEng Project

- Three-year Erasmus+ Cooperation Partnership project that started in October 2022
- International consortium consisting of 3 universities and 3 companies from European countries
- Project co-funded by the European Union and coordinated by Technical University of Cluj-Napoca, Romania

Technical University of Cluj-Napoca

Jamk University of Applied Sciences

University of Jaén

Integracion Sensorial y Robotica

Valmet Technologies Oyj

Rober Bosch SRL

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About NextGEng Project

- **NextGEng Project** aims to create new pedagogical models that promotes international team-teaching with the support of new learning materials for existing courses in the curricula

NextGEng comprises three types of activities

Training

Tailored training program for teachers that sustain the skill improvement of HEI partners staff in new/innovative teaching methods.

International Team-Teaching

international pilot program. Upgrade a set of engineering courses, belonging to the HEI partners curricula, in close collaboration with companies' partners.

CEL Projects

Cases of Experiential Learning projects. Type of projects where students learn by doing in an international and multidisciplinary environment.

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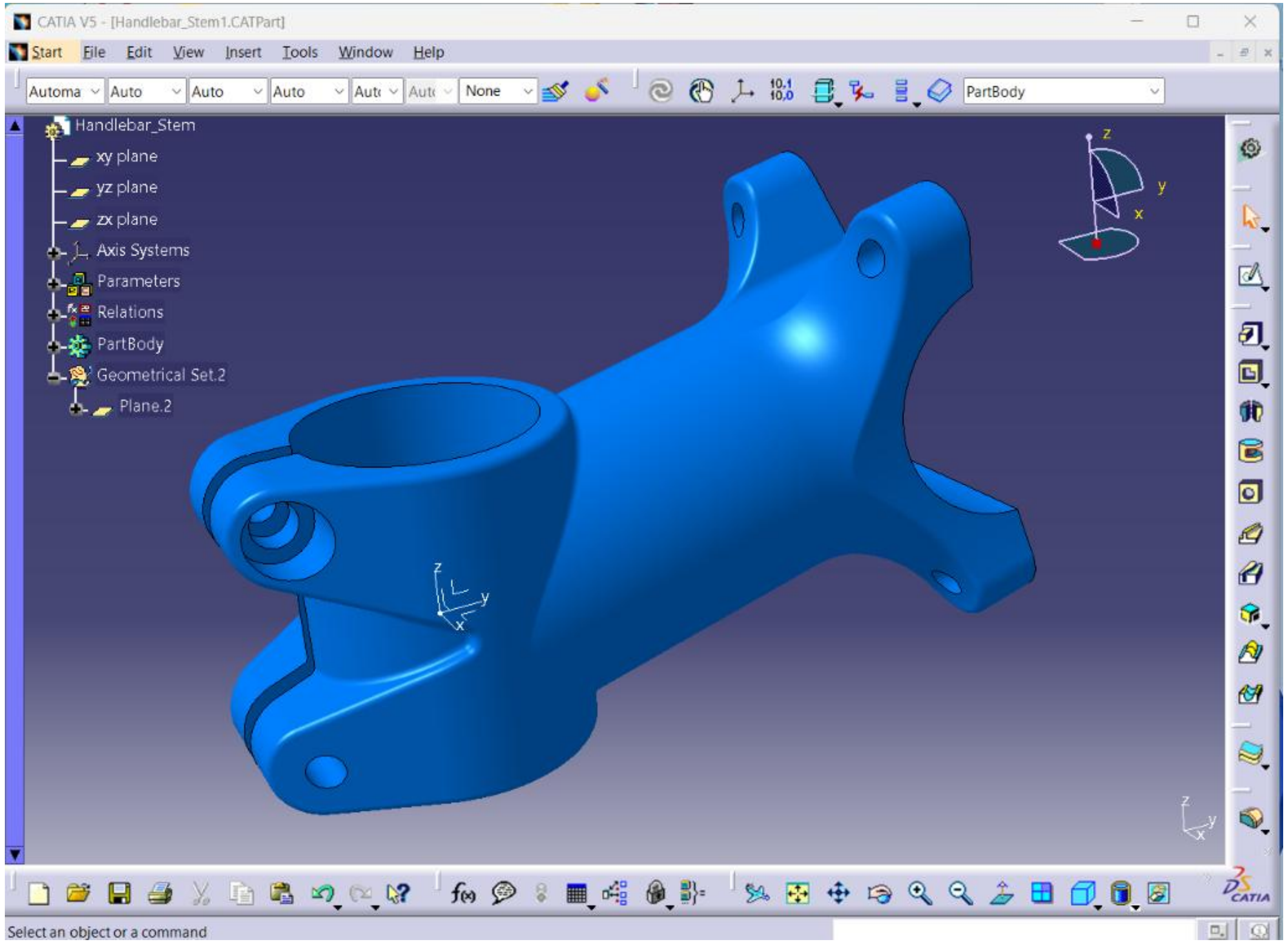
Parametric Design with CATIA

The main objective of this presentation is to introduce and explain the concepts and techniques of parametric design within the context of the CATIA software.



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Parametric Design with CATIA

Upon completion of this module, the student will be able to:

1) Understand CAD parametric design principles and concepts;
2) Capture and utilize engineering knowledge in CAD environments;
3) Gain insight into CATIA functionalities, particularly in parametric modeling;
4) Develop awareness of eco-friendly engineering concepts and their importance in modern product design;

Content

- Introduction
- Relations and Parameters in CATIA
- Case Study: Parametric Design of a Bike Handlebar Stem
- Knowledge-Based Engineering (KBE) in CATIA
- Eco-Friendly Engineering through Parametric Design

Introduction

Introduction

What is Parametric Design?

- Parametric design is a method of creating 3D models using computer-aided design (CAD) software where the geometry is defined by parameters and relationships rather than fixed dimensions.
- The design automation capabilities of parametric modeling software mean that designers do not have to redraw a design each time the dimensions of a model change
- Parametric design empowers designers to focus on the design intent rather than the manual creation of shapes.

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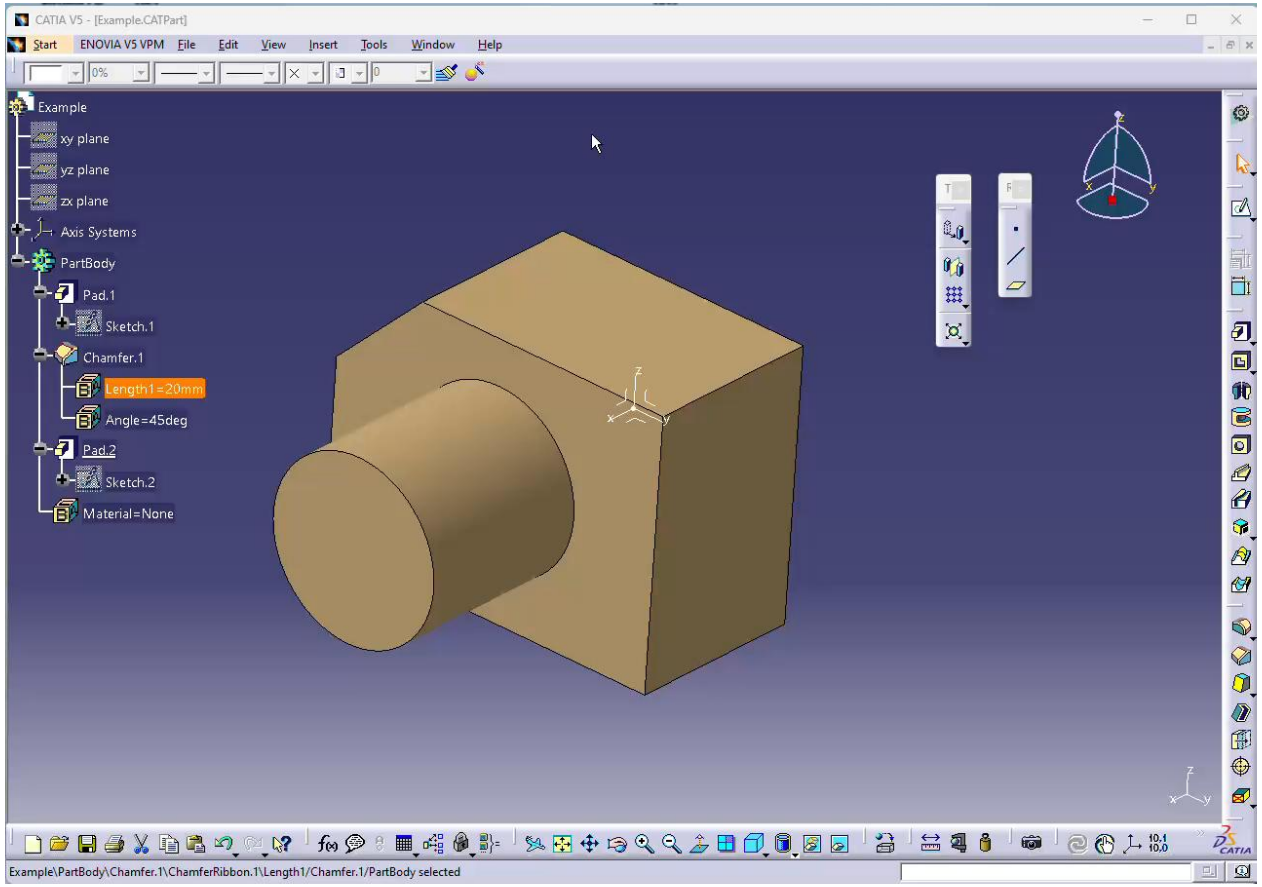
How it works?



- **Fixed dimensions:** Geometries are created with specific, fixed dimensions rather than variable parameters.
- **Direct manipulation:** Users directly modify the geometry by selecting and editing faces, edges, or vertices.
- **Independent elements:** Parts of the model are generally not relationally linked, so changes to one element don't automatically update others
- **Limited flexibility:** More challenging to make sweeping changes or create design variations

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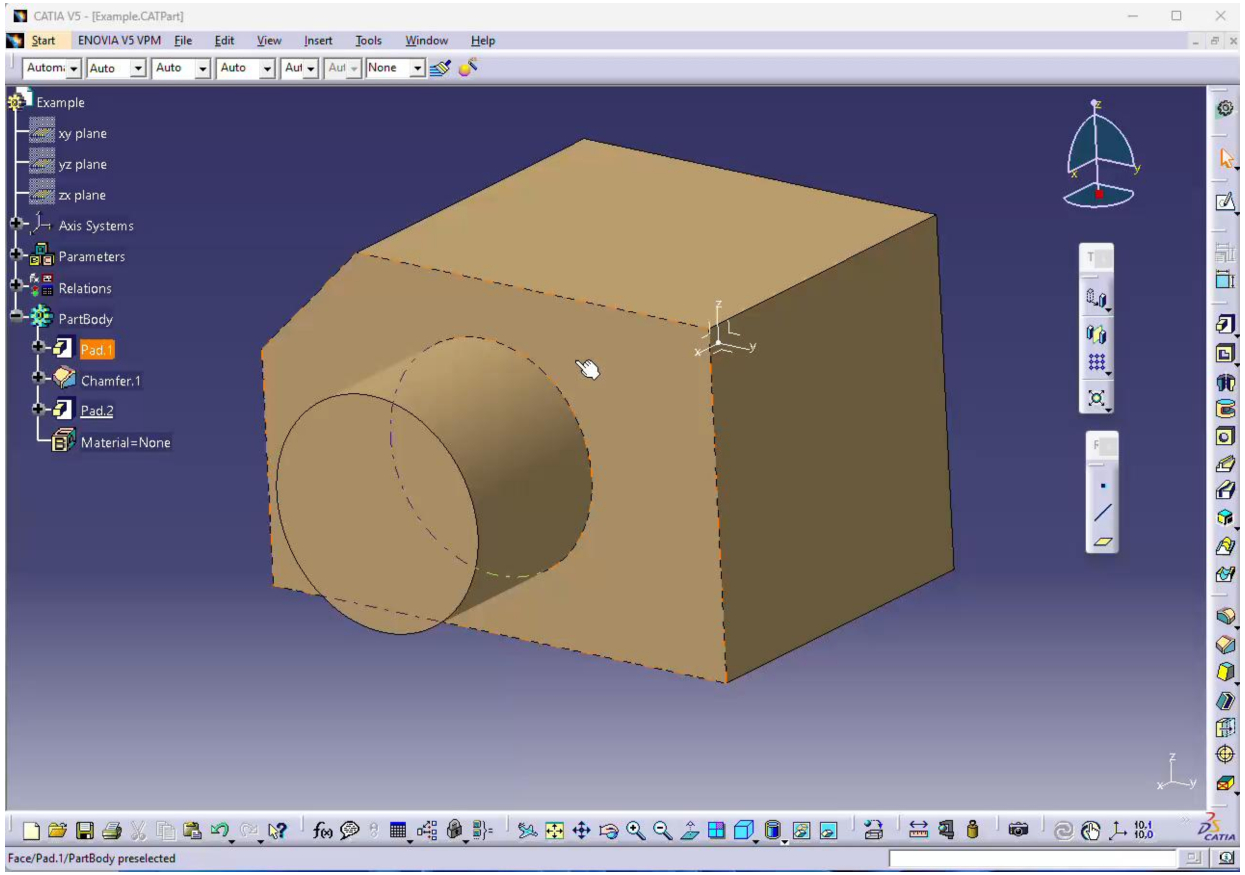
How it works?



- **Parameters:** These are the variables that define the design, such as dimensions and sometimes relationships between elements.
- **Rules:** These are the constraints or equations that govern how the parameters interact and influence the overall model.
- **Algorithms:** The CAD software uses these parameters and rules to generate the 3D model.

Benefits of Parametric Design

This approach offers several advantages over traditional CAD methods, including:

- **Efficiency:** Quickly modify designs by changing parameters, without having to redraw everything.
- **Consistency:** Ensures that design intent is maintained throughout the modification process
- **Relational modeling:** Elements of the design are related to each other, so changes in one part can automatically update connected parts.
- **Automation**: Repetitive design tasks can be automated, saving time and reducing errors.
- **Design exploration:** Easily create multiple design variations by adjusting parameters

Traditional Design vs. Parametric Design

	Traditional Design	Parametric Design
1. Design philosophy:	Direct manipulation of geometry	Design driven by parameters and relationships
2. Flexibility:	Less flexible; major changes often require rebuilding	Highly flexible; easy to modify designs by adjusting parameters
3. Design intent:	Design intent not explicitly captured	Design intent is built into the model
4. Speed:	Often faster for simple designs	Slower for simple tasks due to setup time
5. Learning curve:	Generally easier to learn initially	Steeper learning curve, but more powerful after mastering it
6. Industry usage:	Still common, especially for simpler parts	Widely adopted in complex products or frequent design changes

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CAD software packages

	Stand-alone	Cloud based
DASSAULT SYSTEMES	CATIA V5, CATIA V5-6 SolidWorks	CATIA V6 (3DExperience)
AUTODESK	Inventor	Fusion 360
ptc	Creo (formerly Pro/ENGINEER)	Onshape
SIEMENS	NX (formerly Unigraphics) SolidEdge	-

Parametric design capabilities in CATIA

- The 2D sketching tool is fully parametric, allowing for the creation of constrained, dimension-driven sketches
- CATIA's Part Design workbench allows for the creation of fully parametric 3D models. Features can be defined using parameters, formulas, and rules.
- Users can create reusable design templates that capture design intent and engineering knowledge
- Parts can be related to each other, so changes in one part can drive changes in others.
- Product Engineering Optimizer enables optimization of designs based on defined parameters and constraints.
- CATIA supports various programming languages for automating parametric design tasks
- Parametric models in CATIA can be integrated with PLM (Product Lifecycle Management) systems for comprehensive product development

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Relations and Parameters in CATIA

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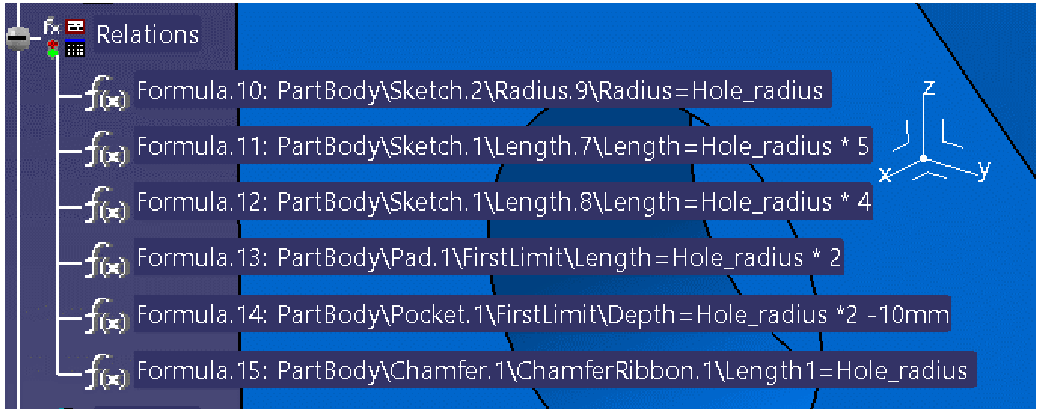
Relations and Parameters in CATIA



Formulas and Relations are essential tools in CATIA for defining relationships between geometric elements, parameters, or dimensions. Despite their apparent similarities, they have different functions

Formulas:

- are used to calculate values based on existing data
- typically involves mathematical expressions using operators like +, -, *, /, and functions (e.g., SIN, COS, TAN, etc.).

Relations:

- are used to define and maintain geometric relationships between elements
- can include conditional statements (e.g., IF-THEN-ELSE) to perform different calculations based on specific conditions

Relations and Parameters in CATIA

Parameters: are variables that can be modified to change the geometry or behavior of a design.

Key characteristics:

- can be assigned different values, allowing for variations in the design
- can be related to each other using formulas or relations, creating dependencies between design elements
- used to capture the design intent, making it easier to understand and modify the model
- can be used to automate design processes, such as creating a series of parts with varying dimensions.

Design intent

The key to building parametric, feature-based, solid models is to ensure that they have a flexible and predictable behavior. This process is known as capturing ***design intent.***

Key aspects:

- **Purpose:** The overall goal or objective of the design.
- **Relationships:** The relationships between different design elements and how they contribute to the overall functionality.
- **Constraints:** The limitations or restrictions that must be considered during the design process.
- **Design logic:** The underlying principles or rules that govern the design

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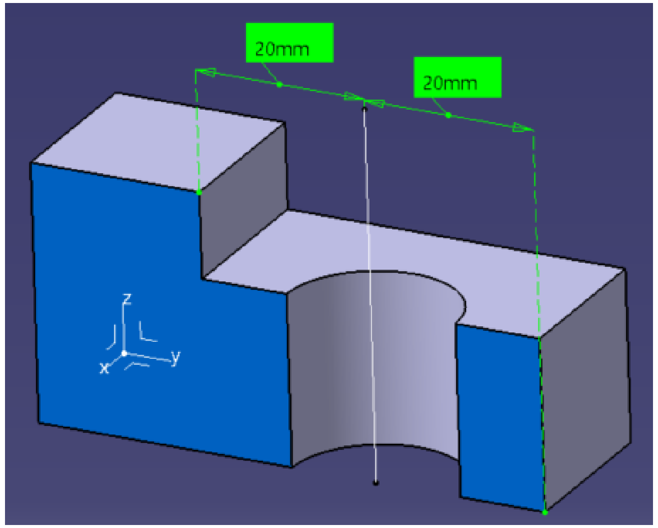
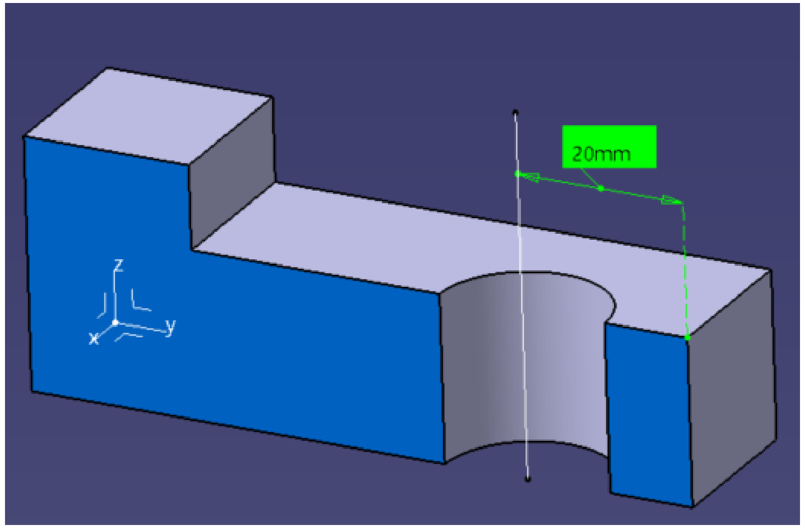
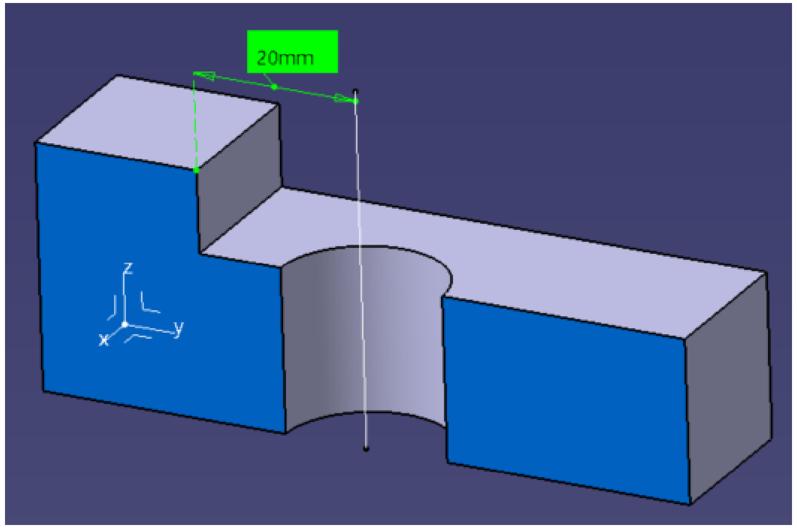
Design intent

Example: Part with a hole.

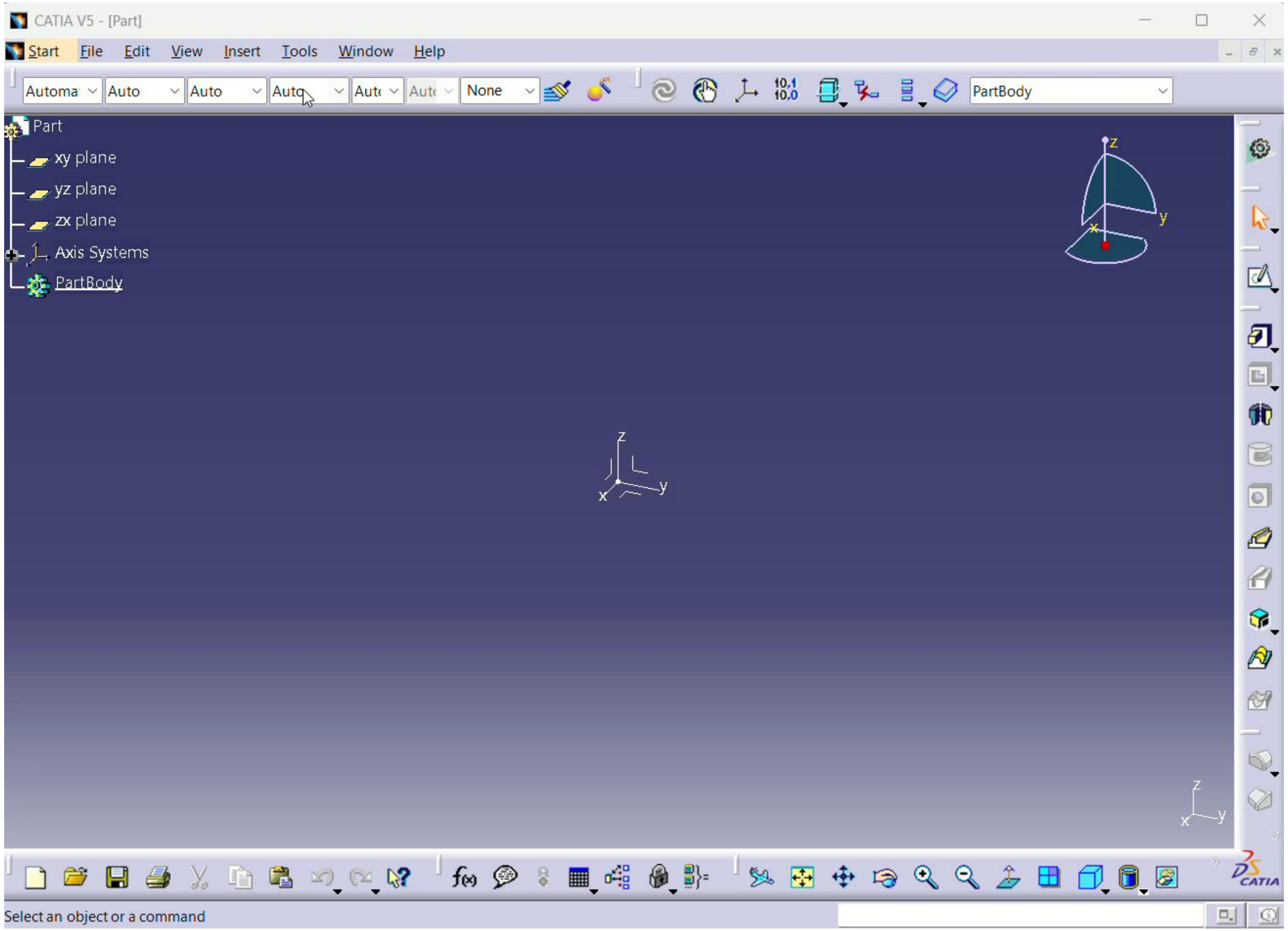
When part's length increases the design intent of the hole determines how it behaves







Tree visualization:

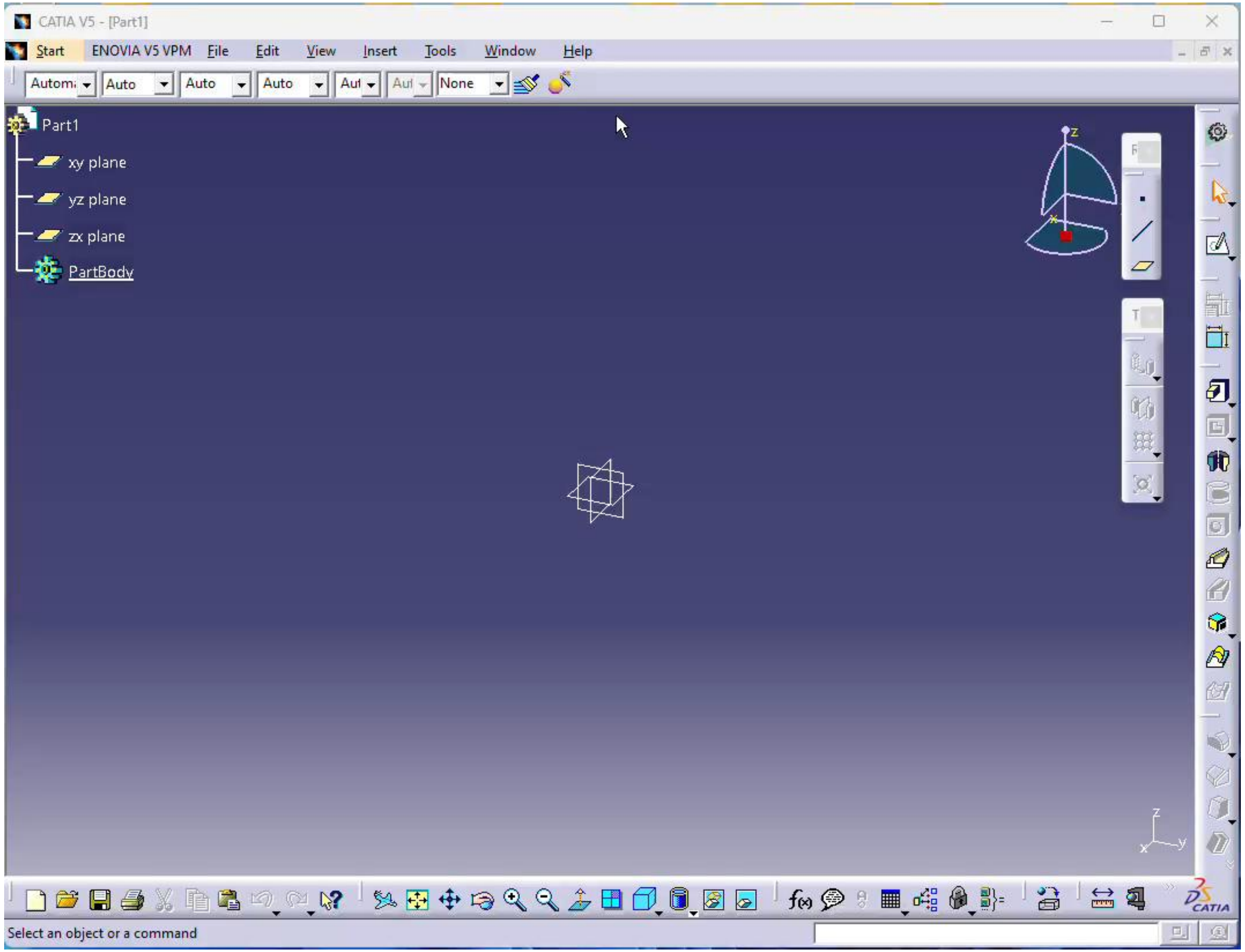


Tools -> Options:

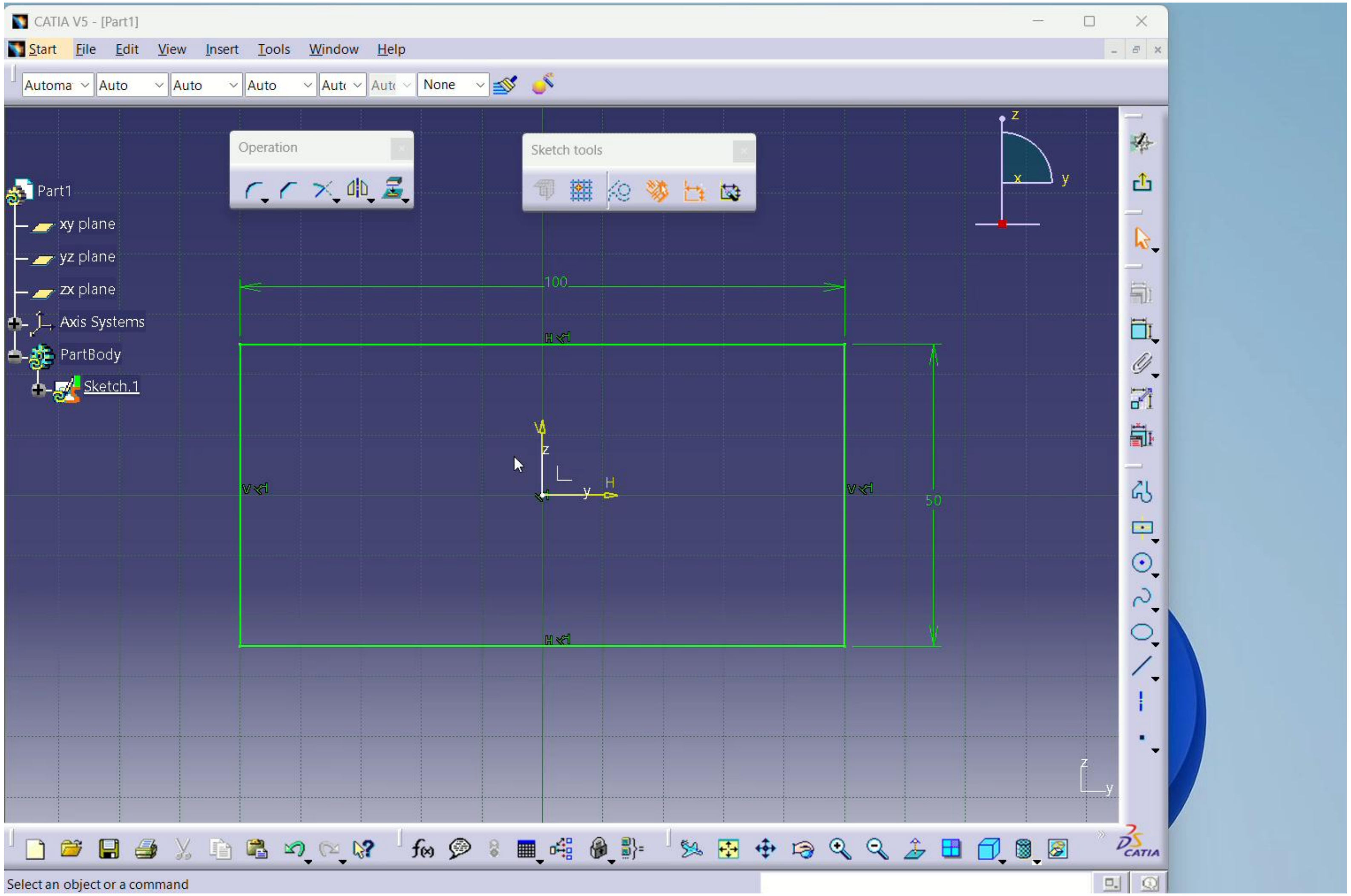
- General-> Parameters and Measure-> Knowledge: Parameter Tree View
- Infrastructure-> Part Infrastructure-> Display: Display in Specification Tree

Types of Parameters:

- **Numeric parameters (Real or Integer):** such as length, width, height, angle, or radius.
- **Text parameters (String):** such as material names, part numbers, or descriptions.
- **Boolean parameters:** boolean values (true or false), which can be used to control the visibility of elements or activate certain design features.
- **Date/time parameters:**
- **Custom parameters:** are specific data types and properties to suit your design needs

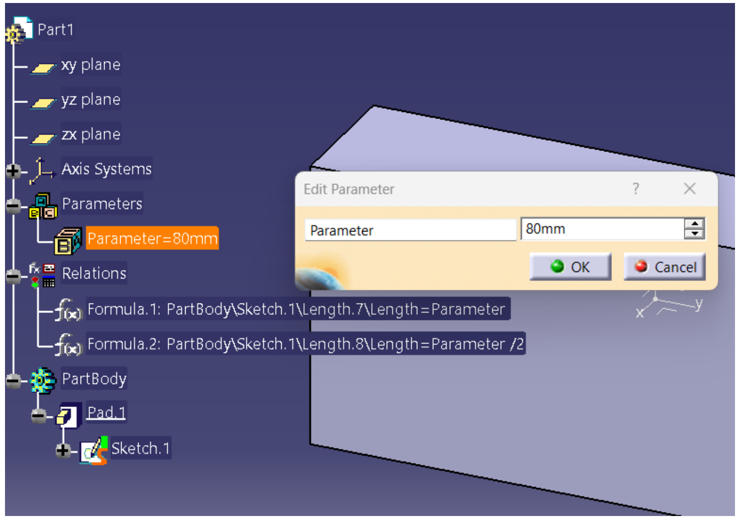


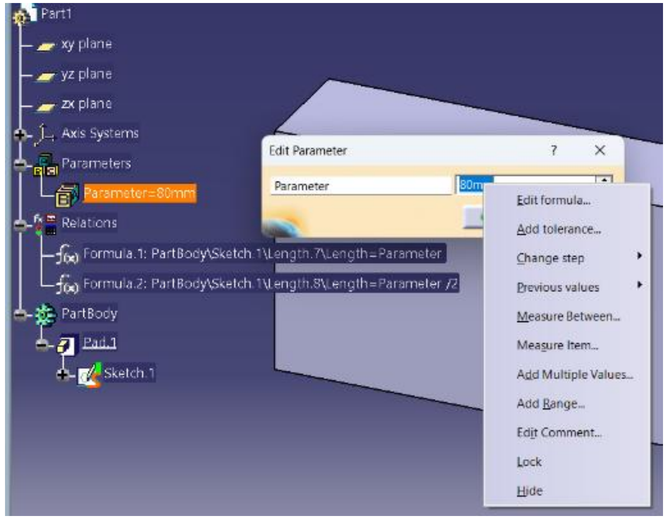
Define parameters and formulas

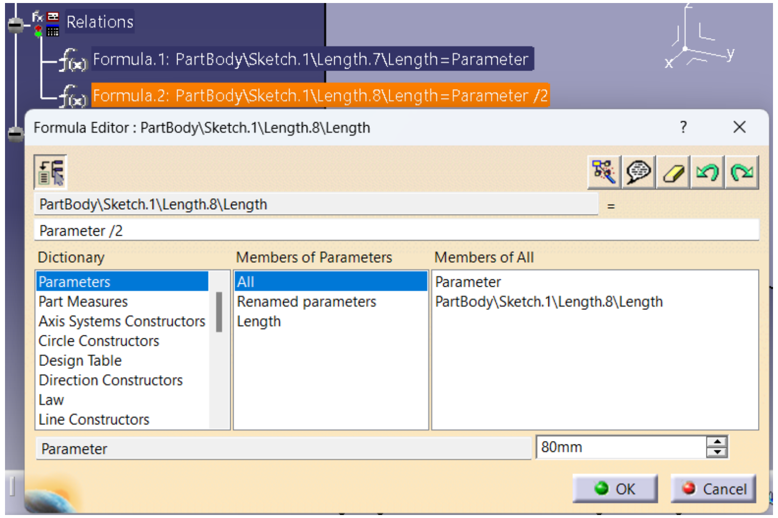


Edit parameters and formulas

- Double-click the parameter in the specification tree. The Edit Parameter window is displayed
- Right-click the value field and select one of the options available
- Double-click the formula in the specification tree. The Formula Editor window is displayed







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Adding parameters and relations to a 3D Model

Objective: Change the part dimensions according to the central hole radius

Parameter [Length] : Hole_radius

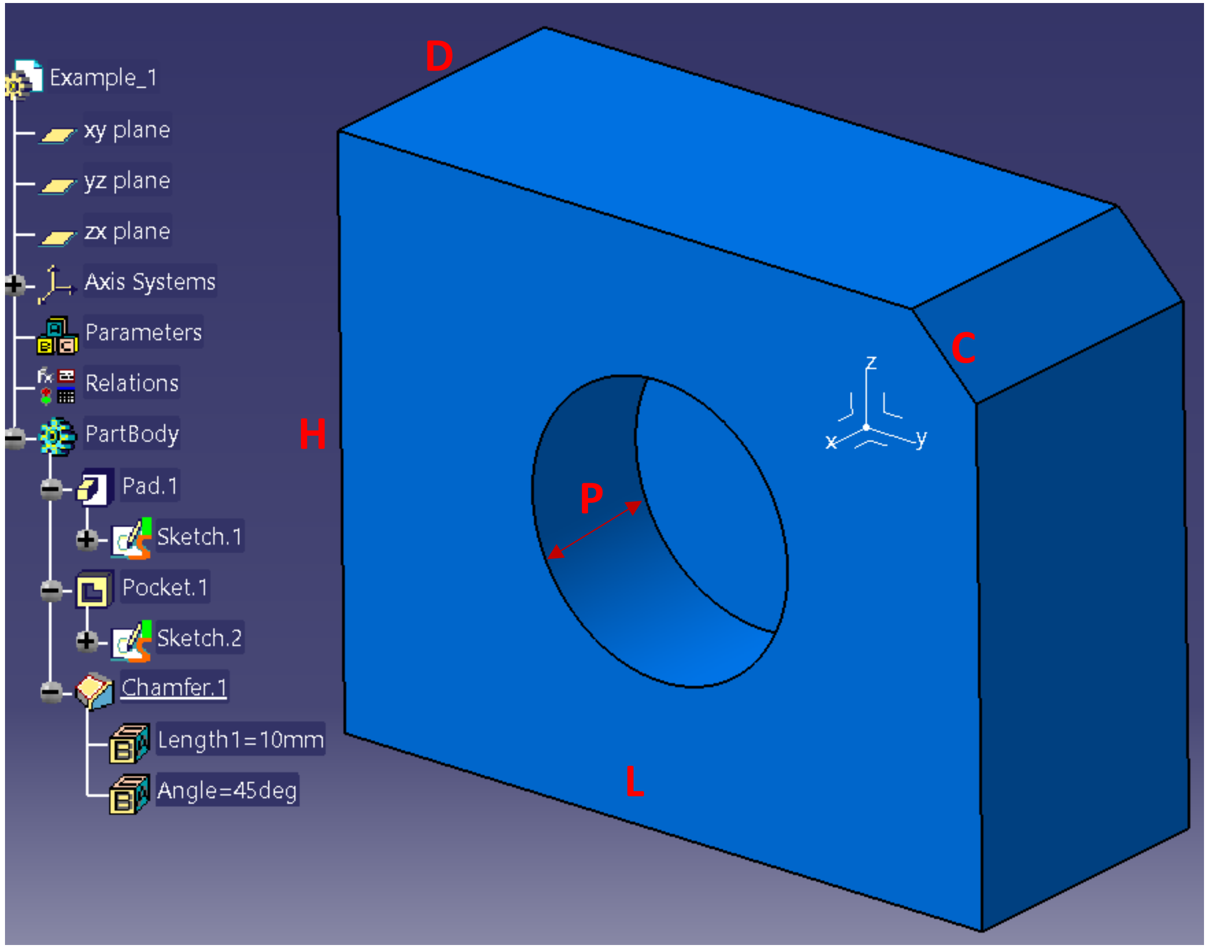
Formulas: H = Hole_radius * 4

L = Hole_radius * 5

D = Hole_radius * 2

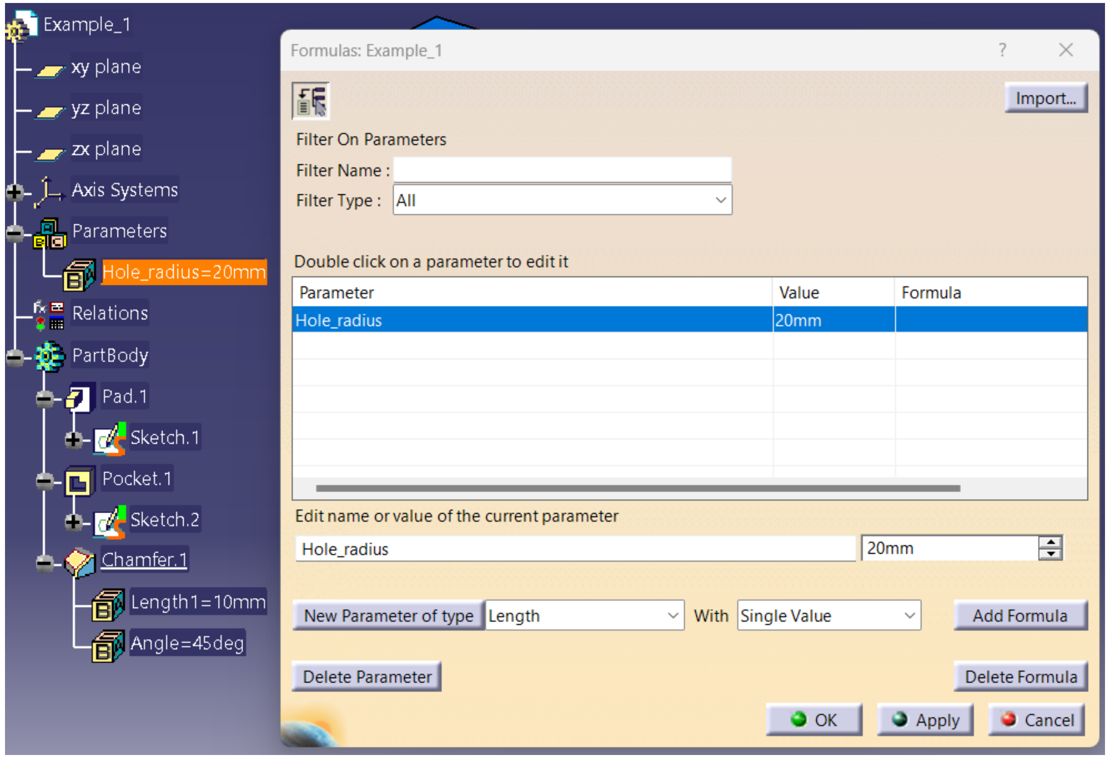
C = Hole_radius

P = Hole_radius * 2 – 10 mm

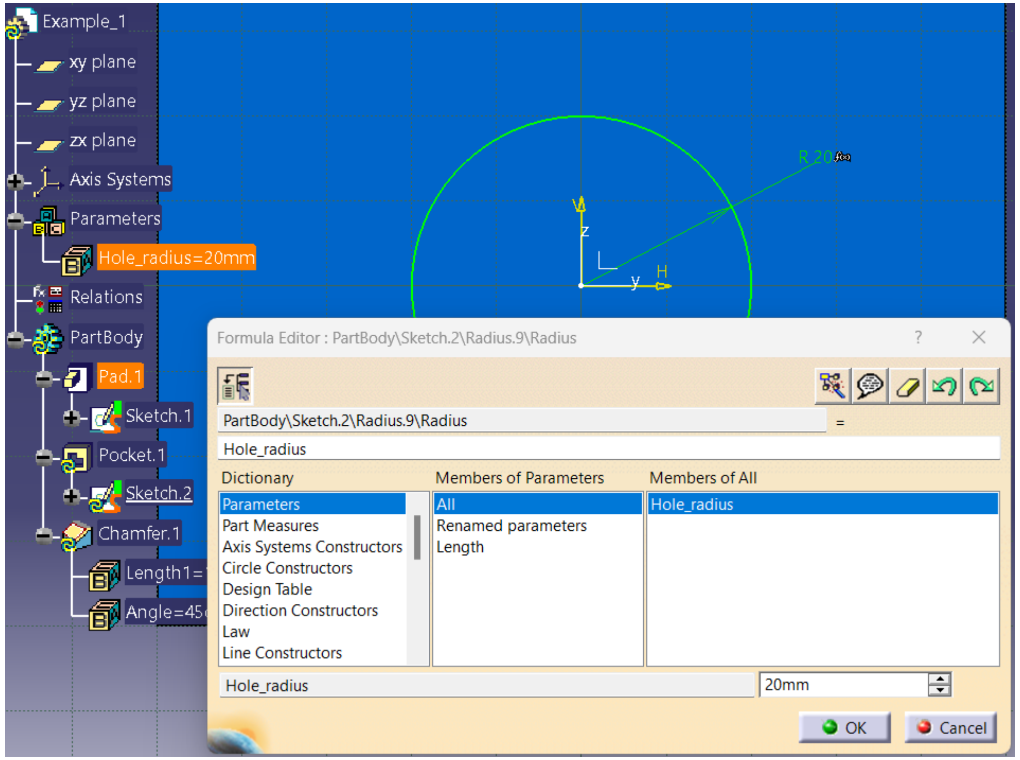


Adding parameters and relations to a 3D Model

The Length parameter named Hole_radius is created. An initial value of 20 mm is assigned to it

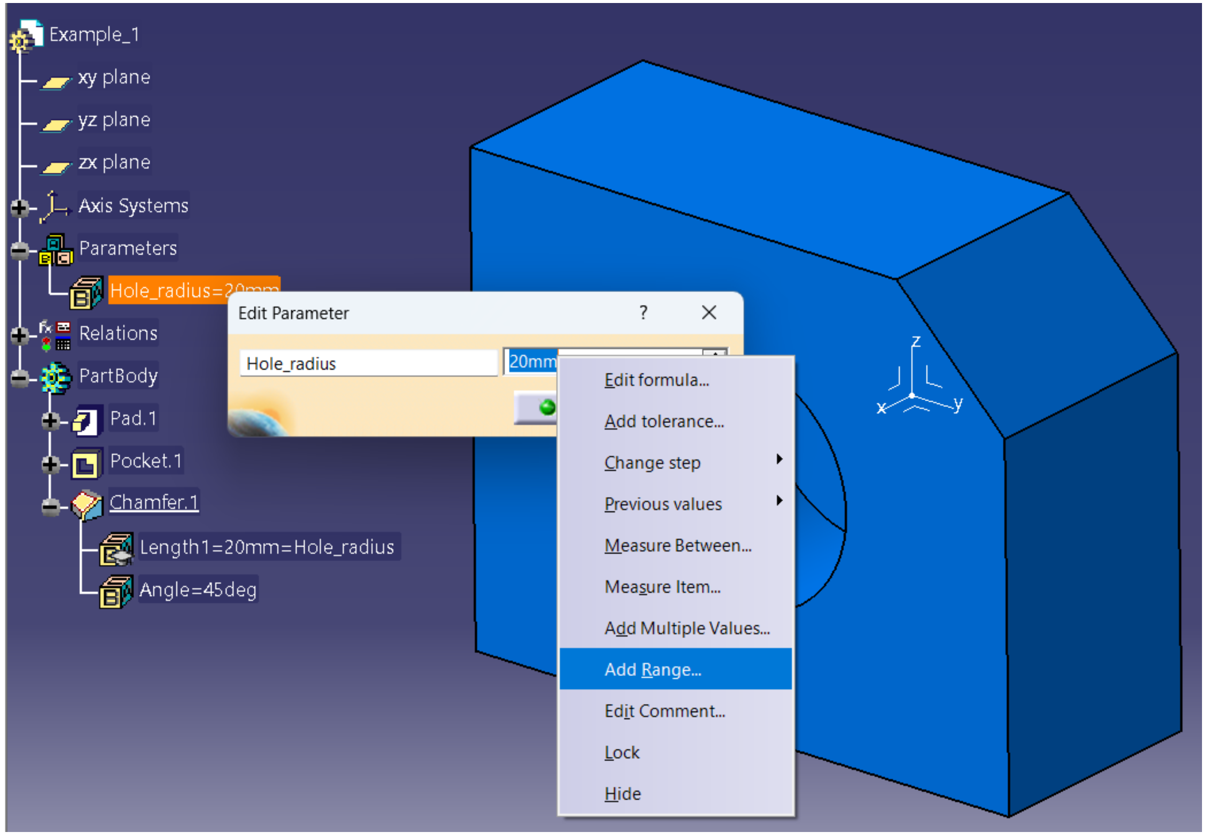


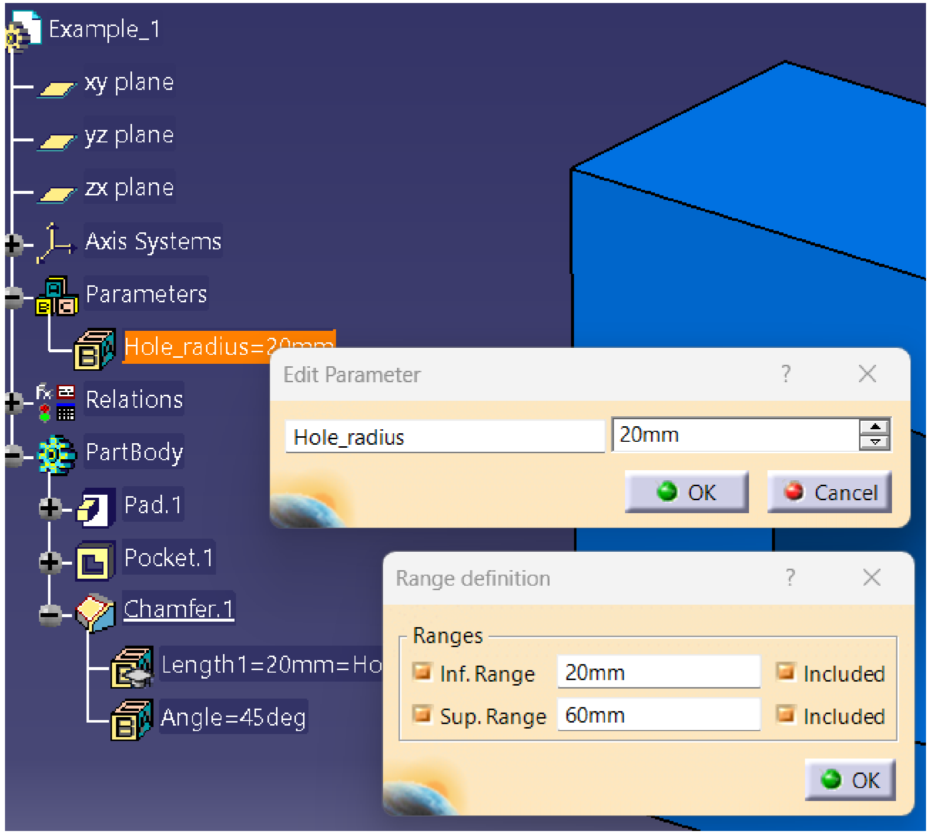
The hole radius becomes equal to the value of the previously created parameter



Adding parameters and relations to a 3D Model

We edit the parameter value to define the range of possible values (e.g. between 20 and 60 mm)





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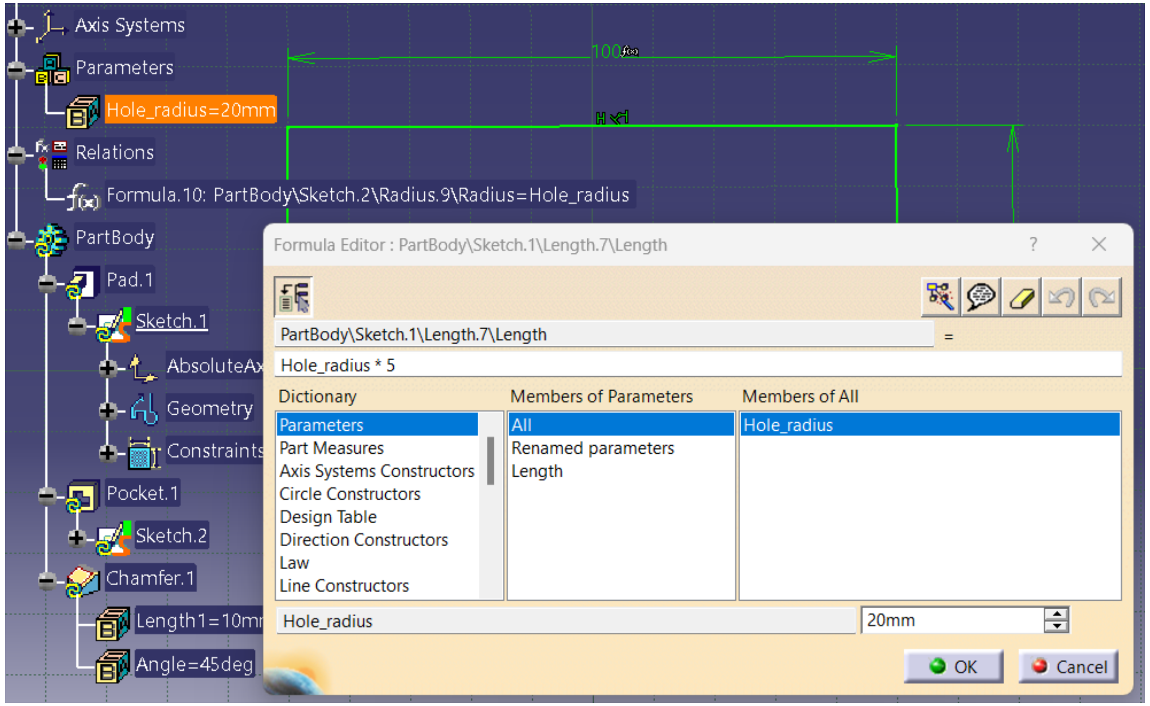
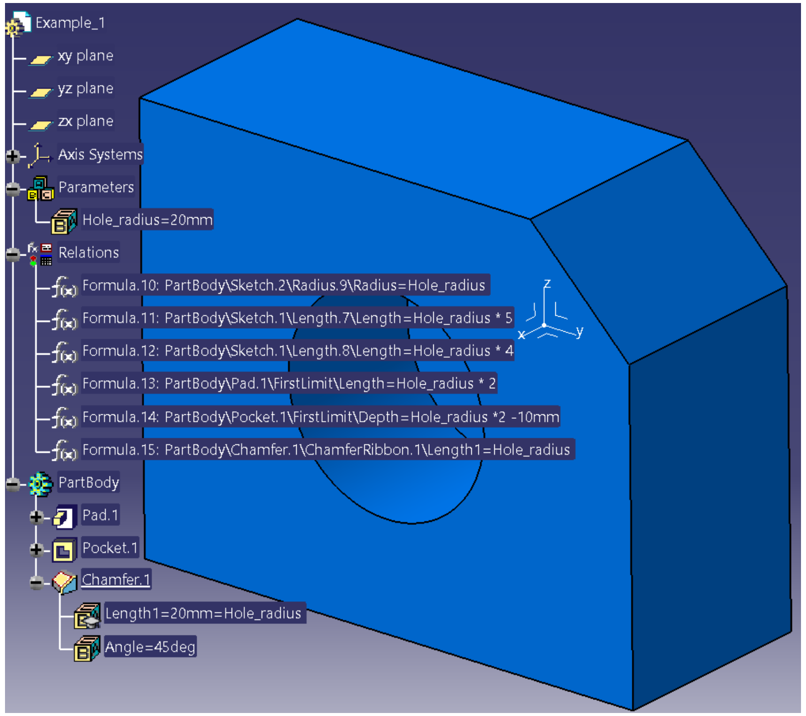
NextGEng

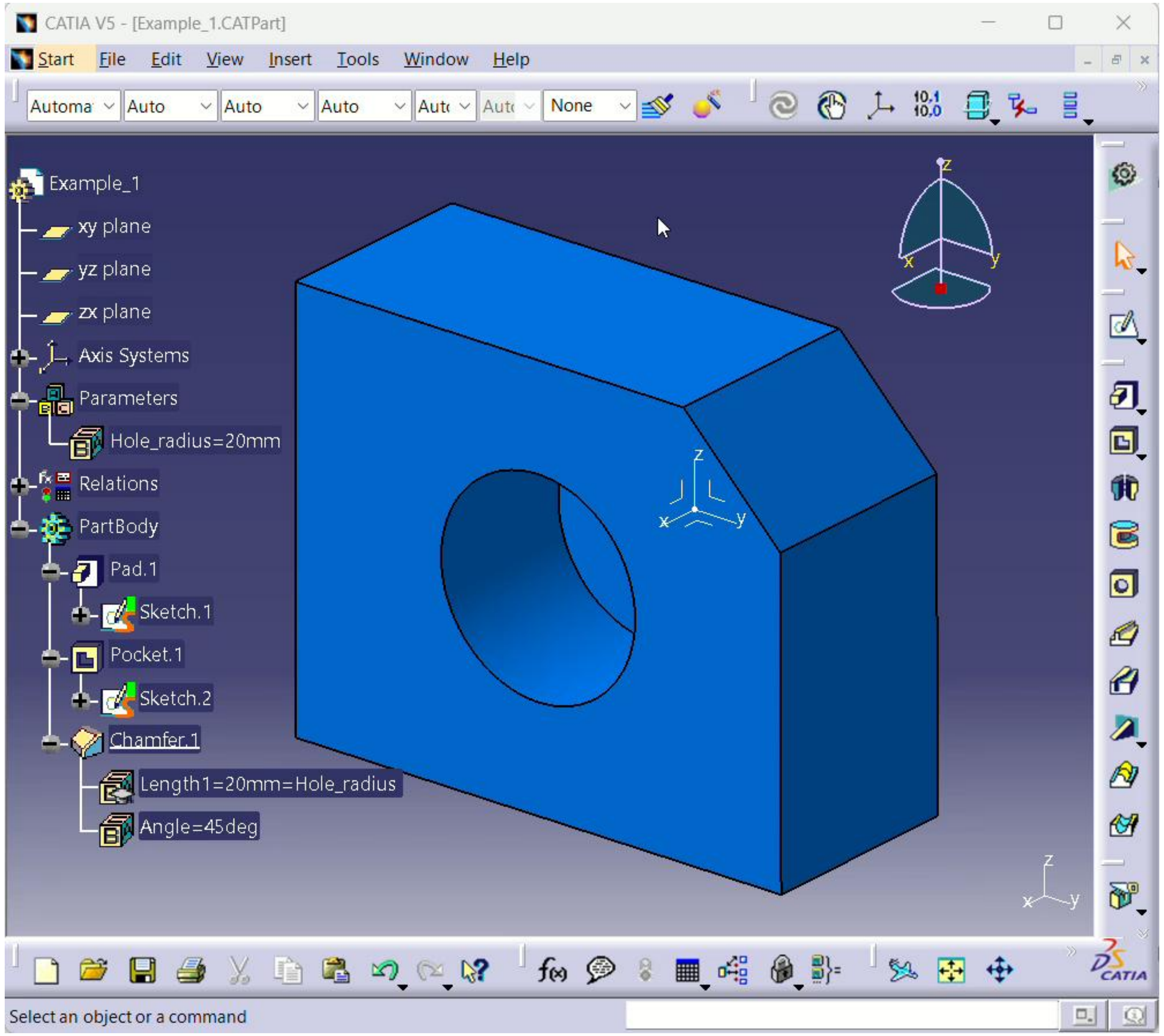
Adding parameters and relations to a 3D Model

Using the Formula Editor the Relations are defined for all model dimensions





Adding parameters and relations to a 3D Model



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NextGEng

Adding conditional statements to a 3D Model

Conditional Statements (If-Else) in CATIA allow you to control the behavior of design elements based on specific conditions. Those can be implemented using CATIA V5's **Knowledge Advisor** workbench, which includes the Rule Editor.

Types of Conditional Statements in CATIA:

Basic:

```
IF condition
  {
      Action1
  }
ELSE
  {
     Action2
  }
```

Nested:

```
IF condition1
  {
      Action1
  }
ELSE IF condition2
  {
     Action2
  }
ELSE
 {
     Action3
  }
```

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Adding conditional statements to a 3D Model

Objective: Change the flange dimensions and number of holes according to the bore radius (R).

Rules:

R < 30 mm -> 4 holes

30 < R < 60 mm -> 6 holes

60 < R < 80 mm -> 8 holes

Parameters [Length] : Bore_radius

[Integer] : Holes

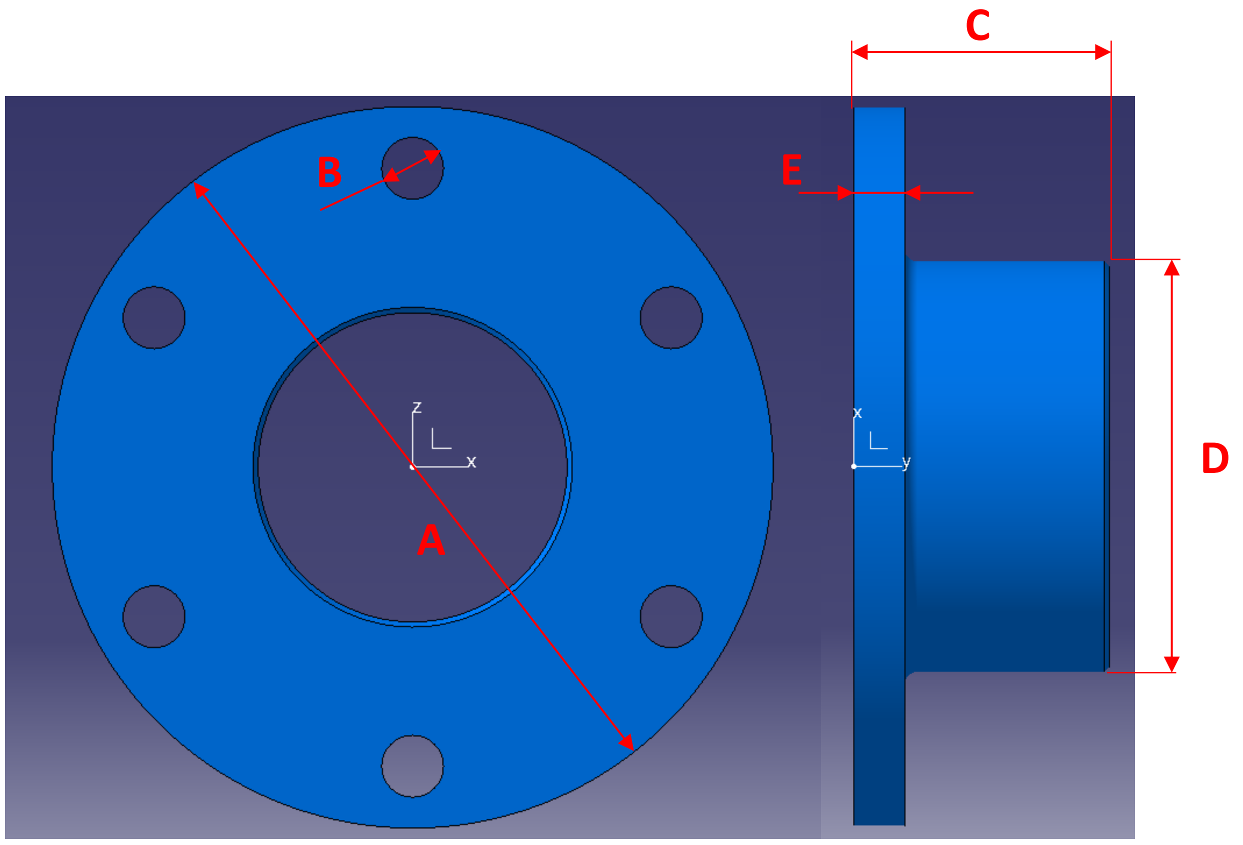
Formulas: A/2 = Bore_radius * 2.5

B/2 = Bore_radius / 5

D/2 = Bore_radius + Bore_radius / 2.5

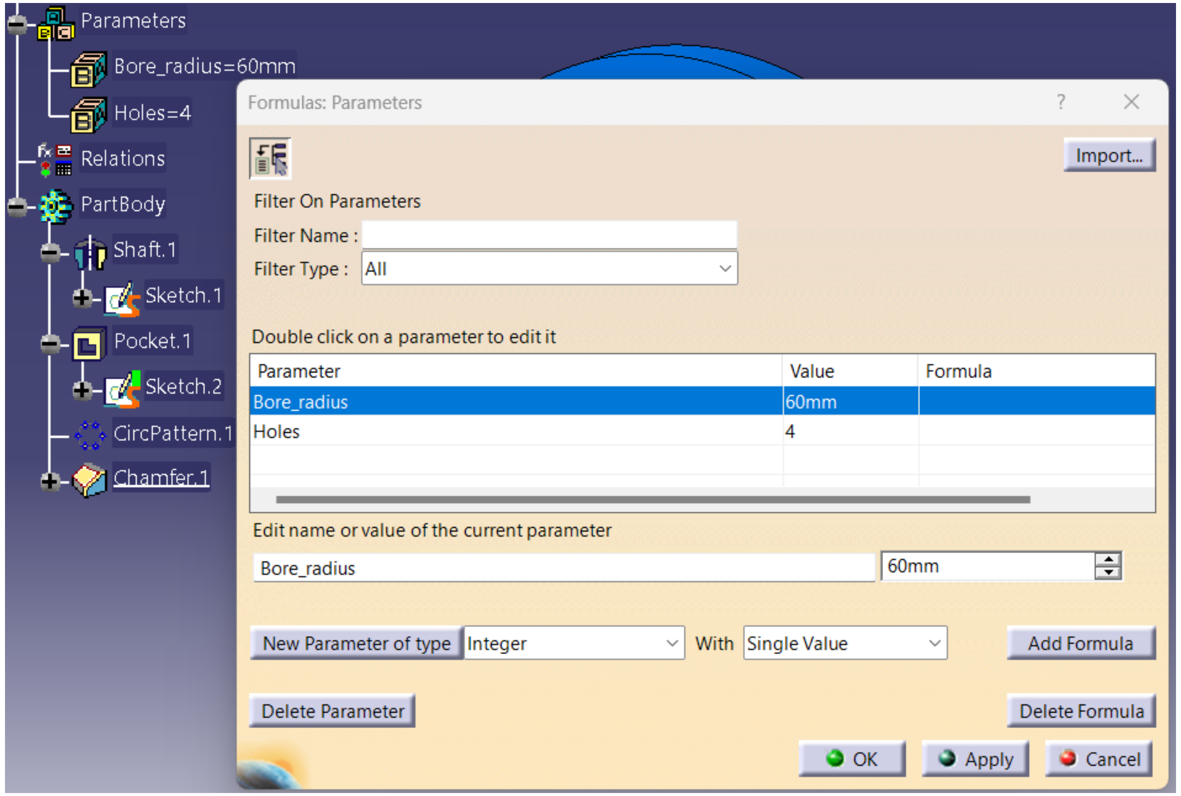
C = D/2 + 20mm

E = Bore_radius / 2.5

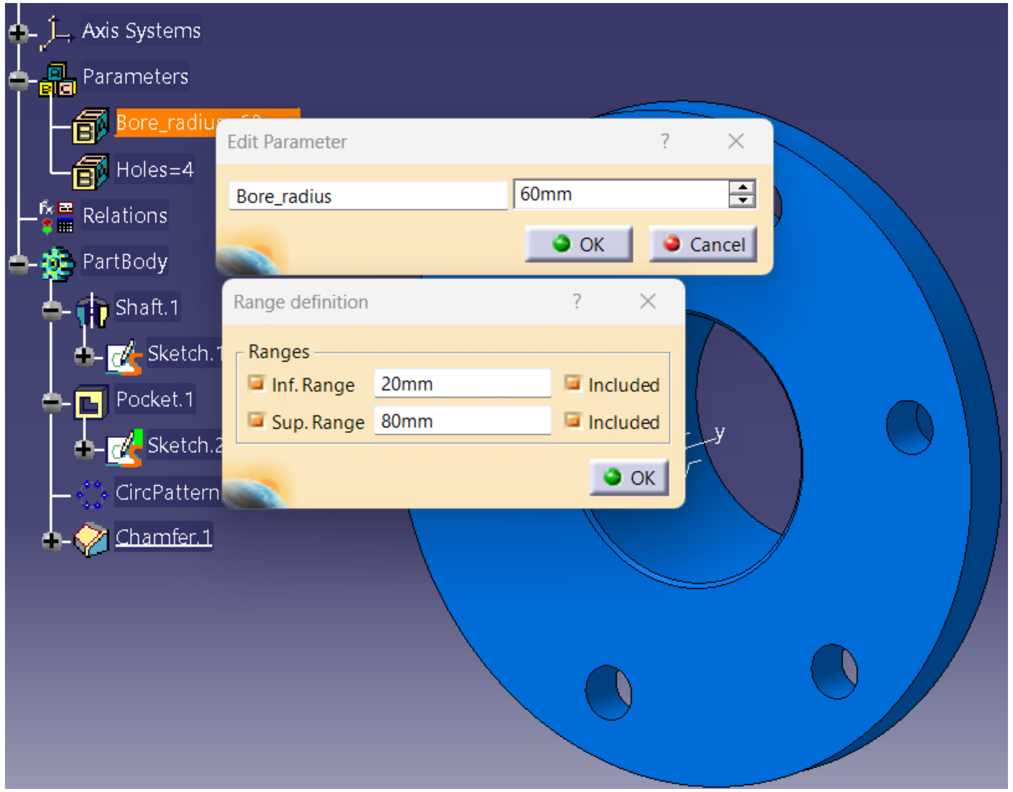


Adding conditional statements to a 3D Model

The two necessary parameters are created. One of type **Length** and the other of type **Integer**



We edit the parameter value to define the range of possible values (e.g. between 20 and 80 mm)



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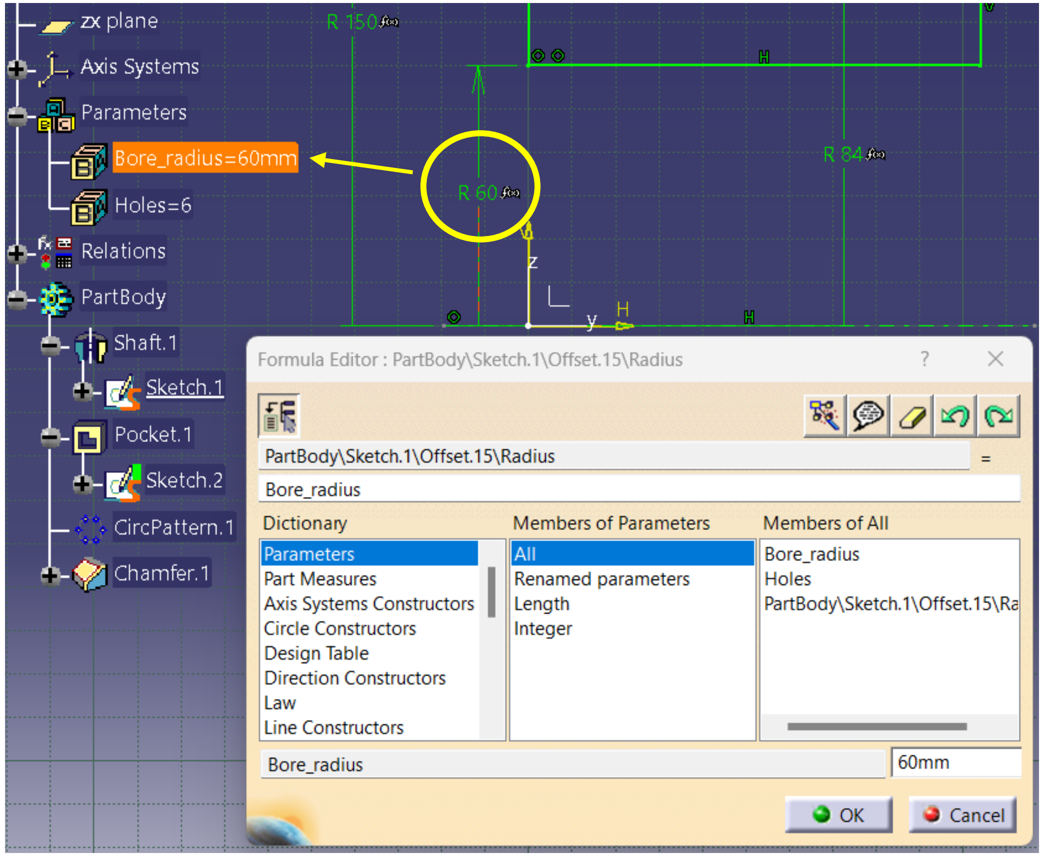
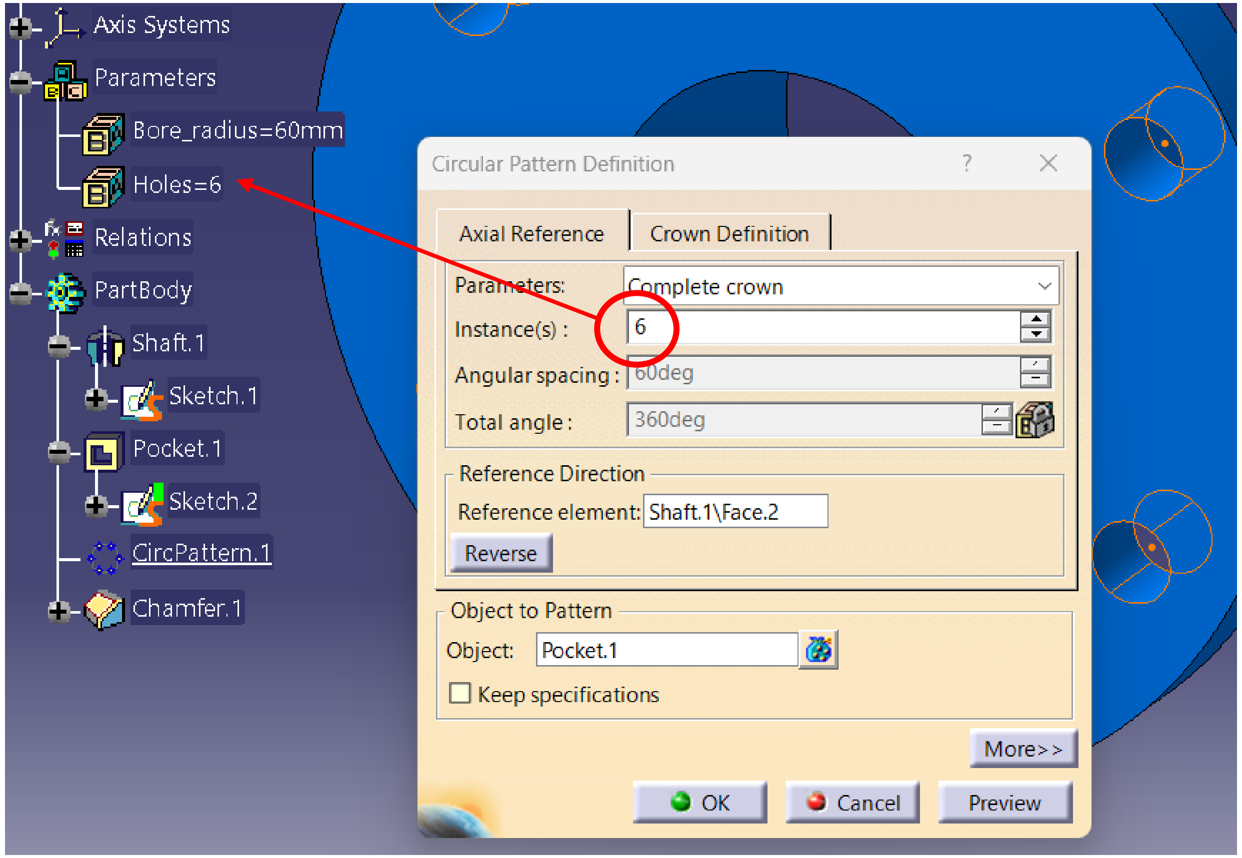
Adding conditional statements to a 3D Model

The bore radius becomes equal to the value of the **Bore_radius** parameter

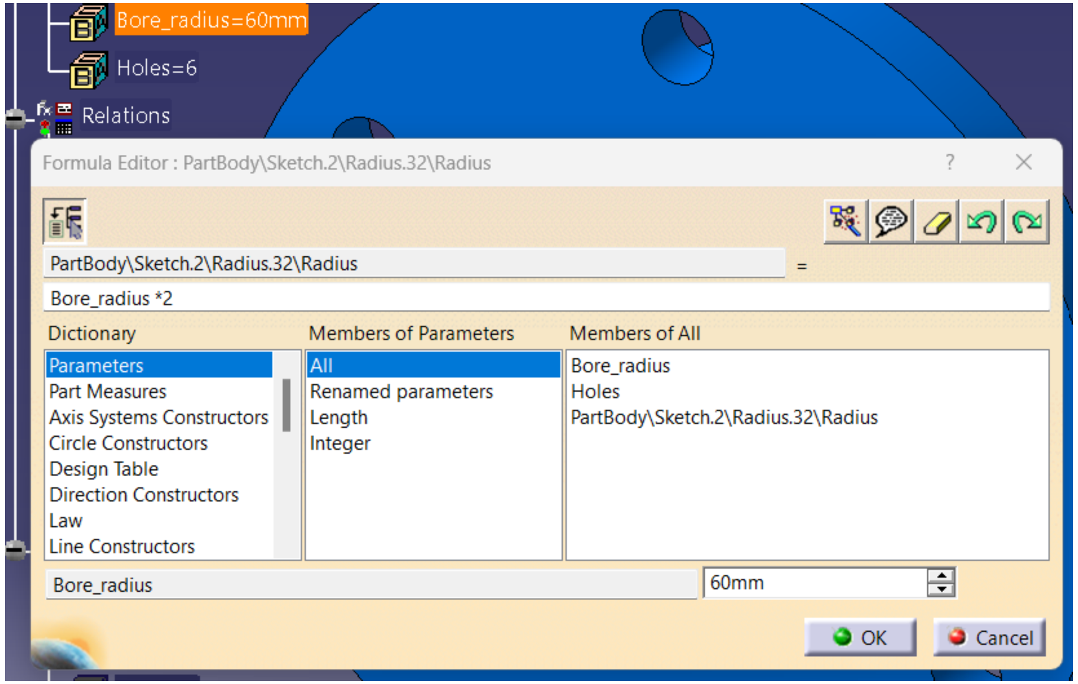


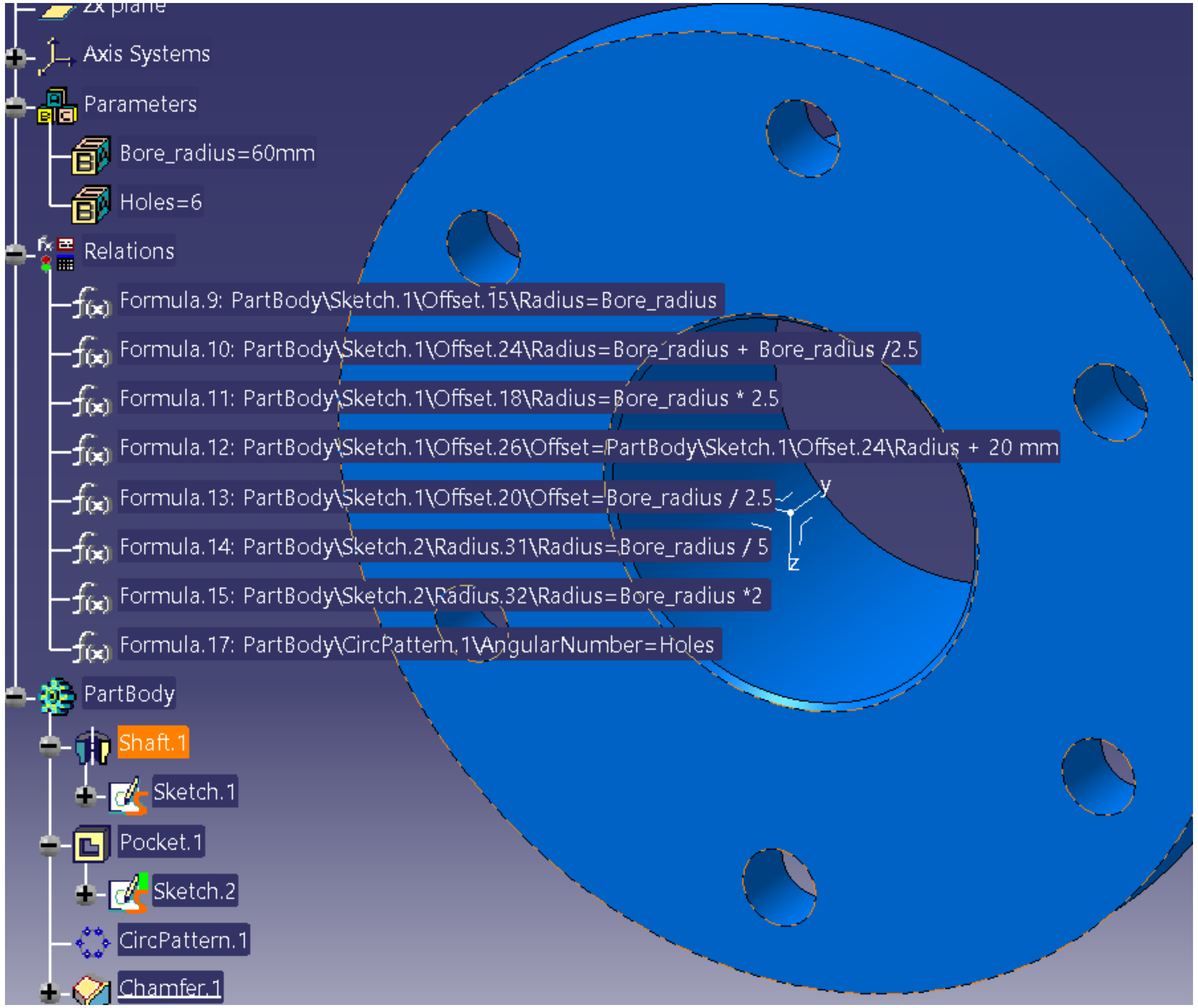
The number of the Instances becomes equal to the value of the **Holes** parameter



Adding conditional statements to a 3D Model

Using the Formula Editor the Relations are defined for all model dimensions and features





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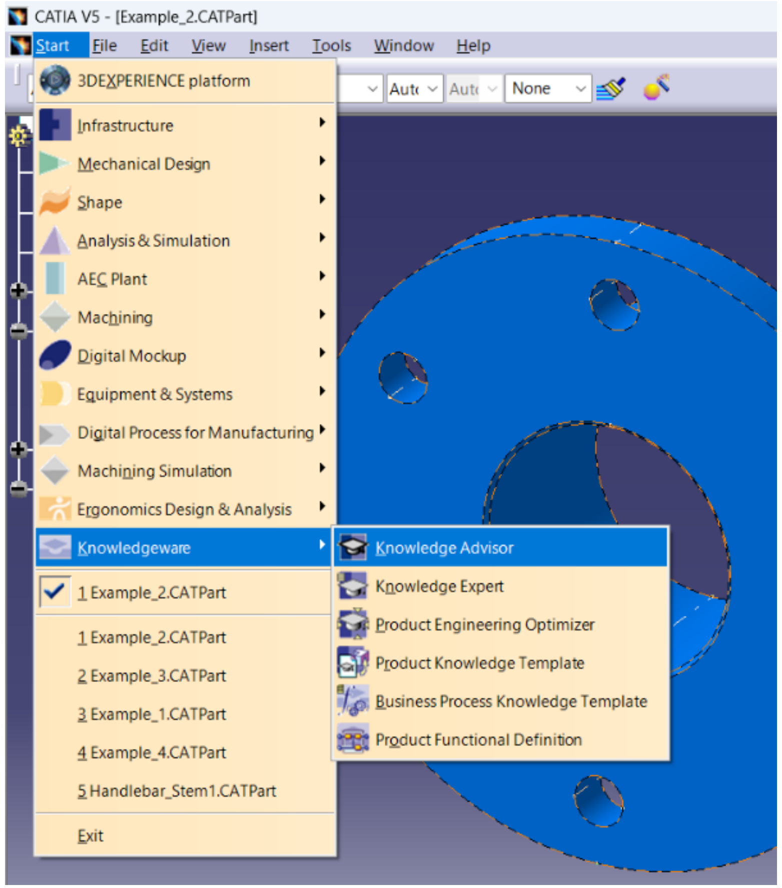
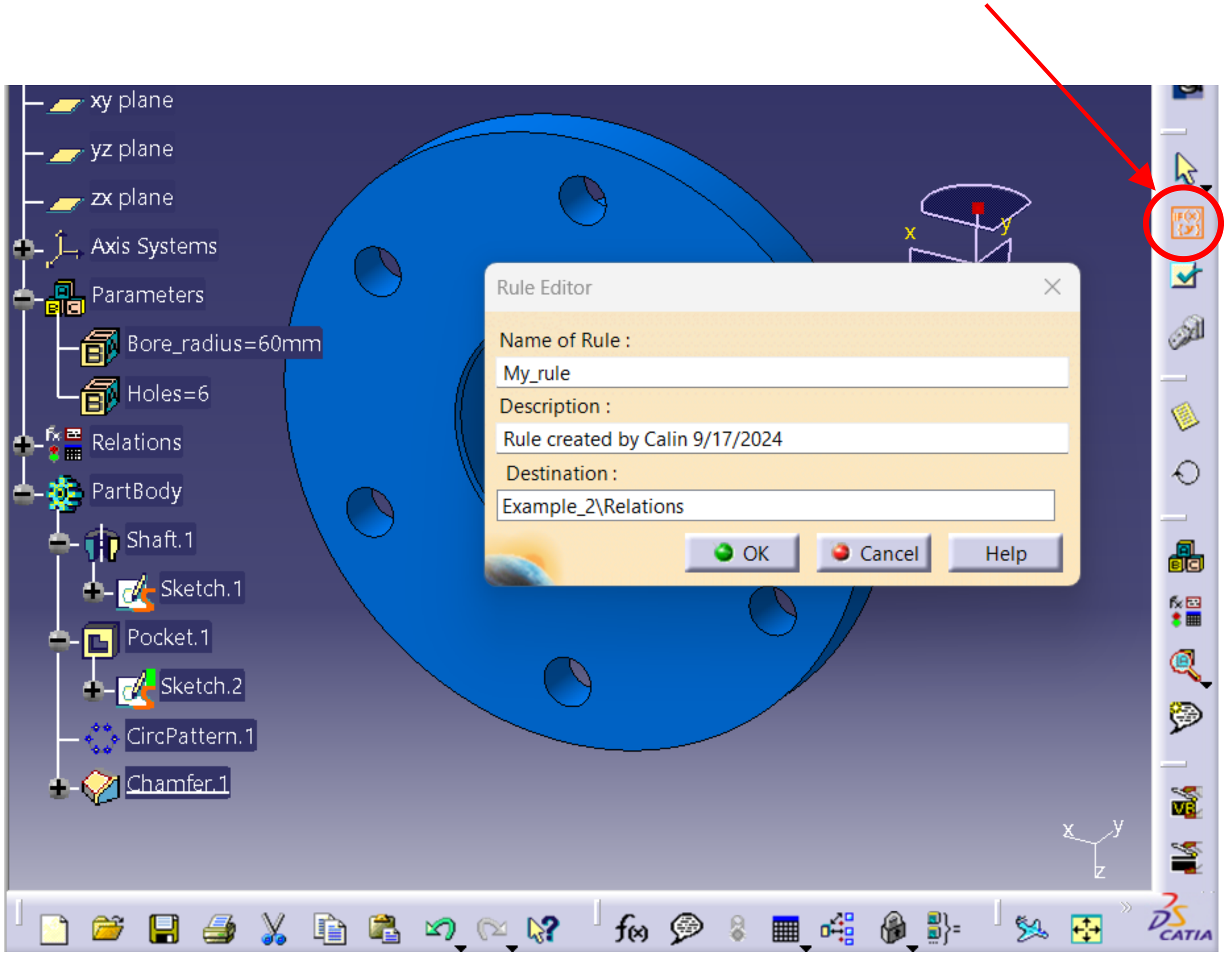
Adding conditional statements to a 3D Model

To implement our conditional statements, we must access **Knowledge Advisor** workbench and **Rule Editor**





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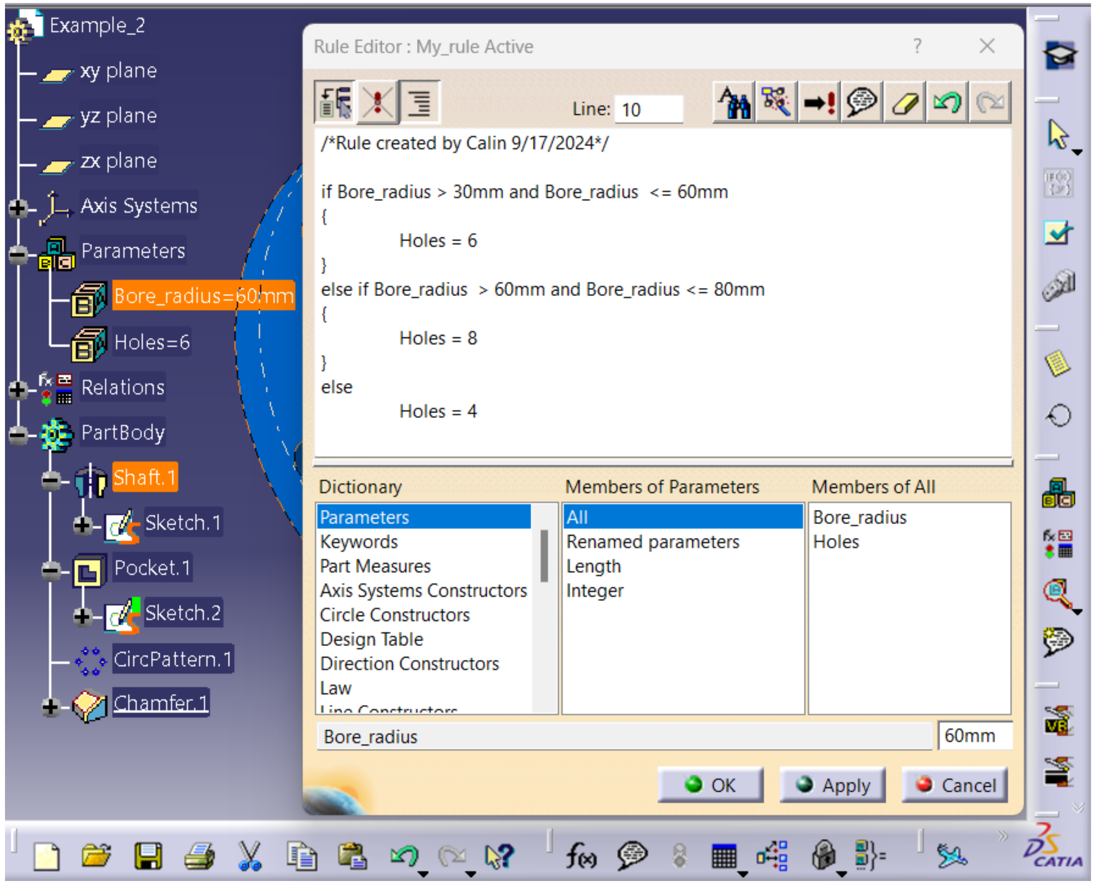
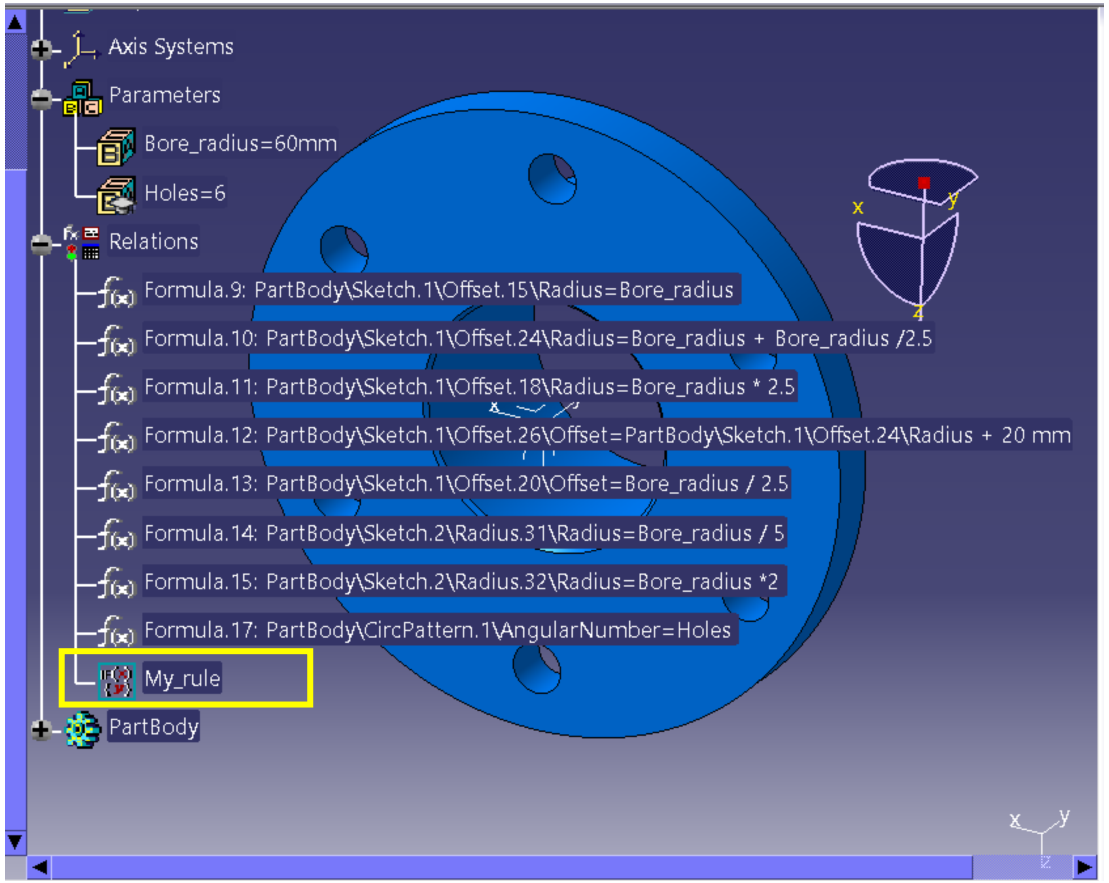
Adding conditional statements to a 3D Model

In the newly opened window, we can implement our rule



In the specification tree, the rule is displayed as a relation that can be activated or deactivated



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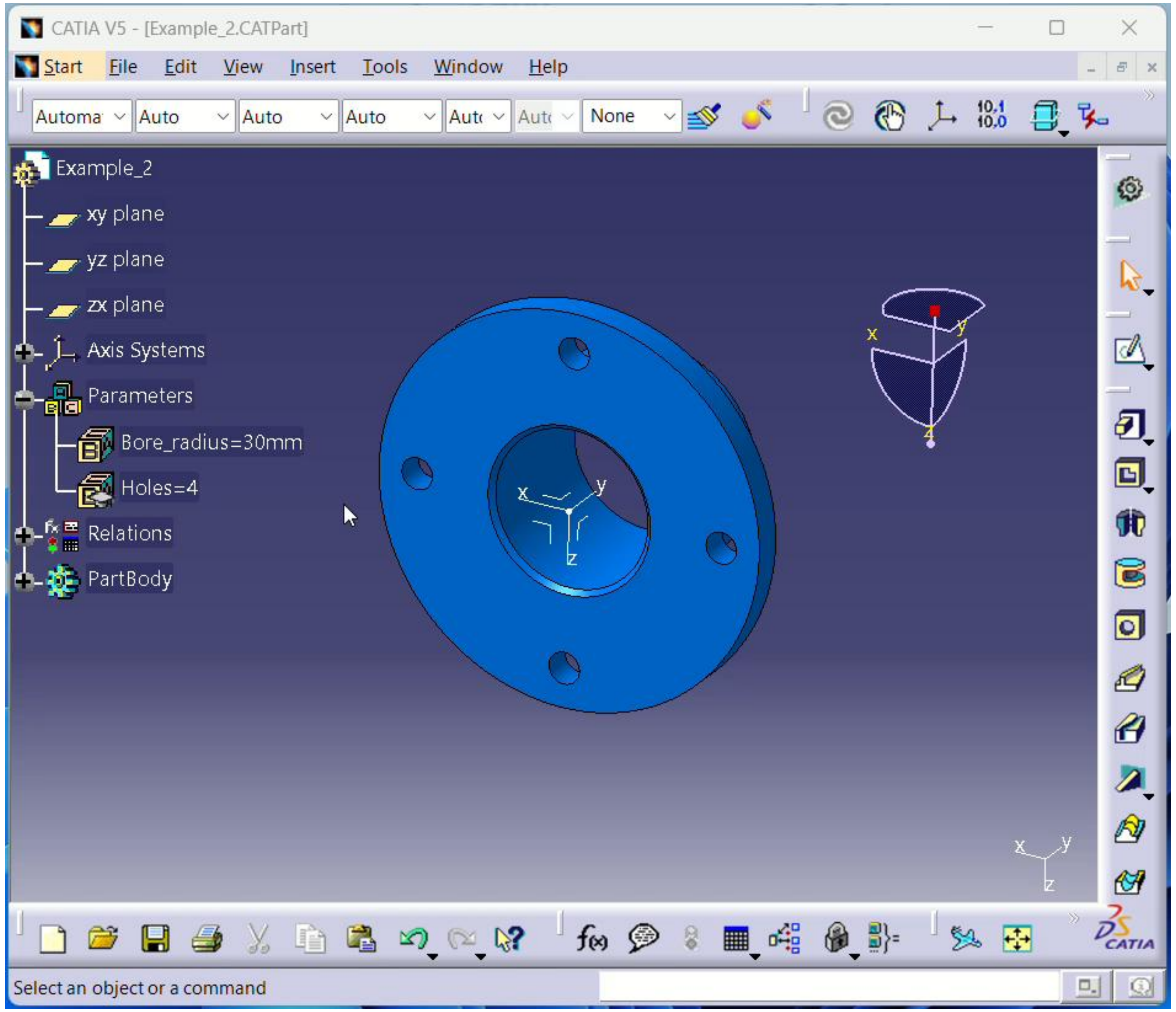
Adding conditional statements to a 3D Model



Parametric design using Design Tables

Objective: Change the diameter of the holes (D) and the distance between them (A) depending on the part dimensions.

Rules:

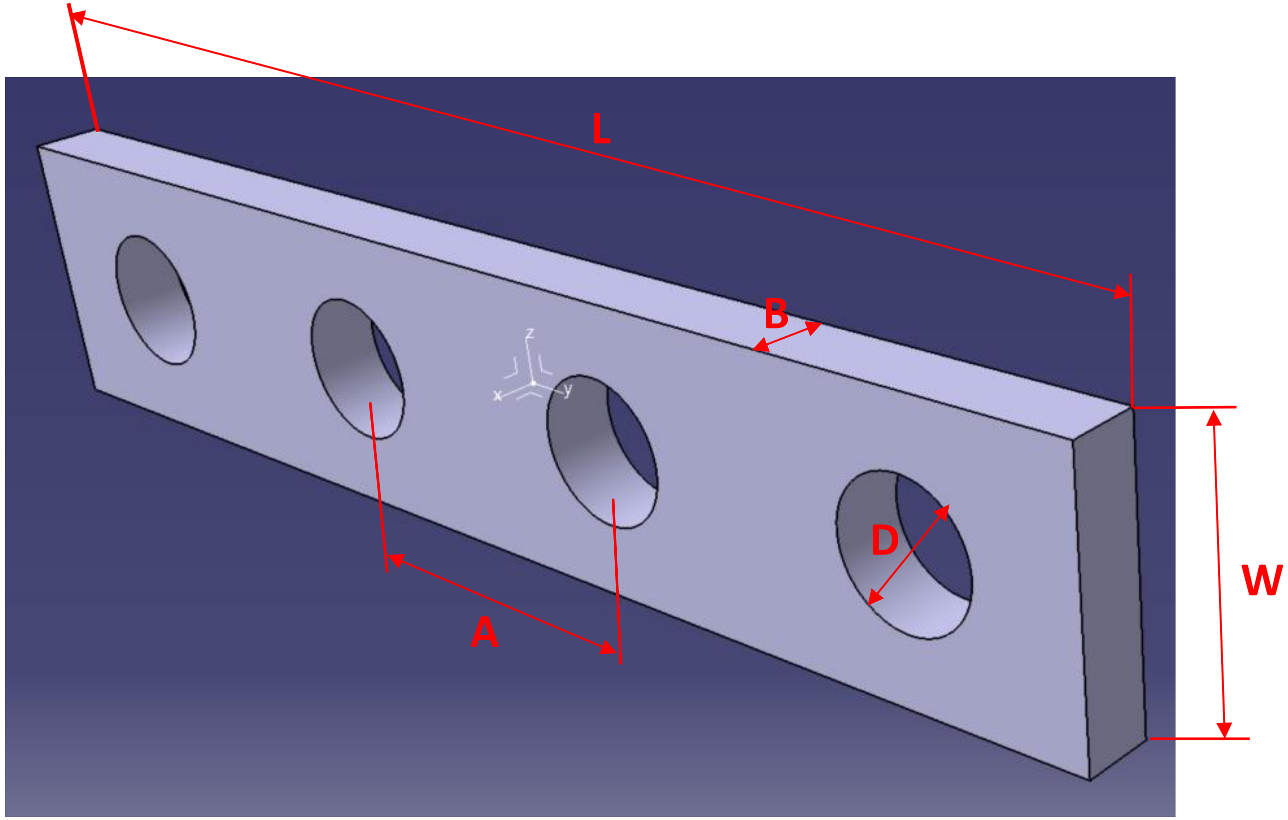
D = W / 2

A = L / 4

Parameters [Length] : L

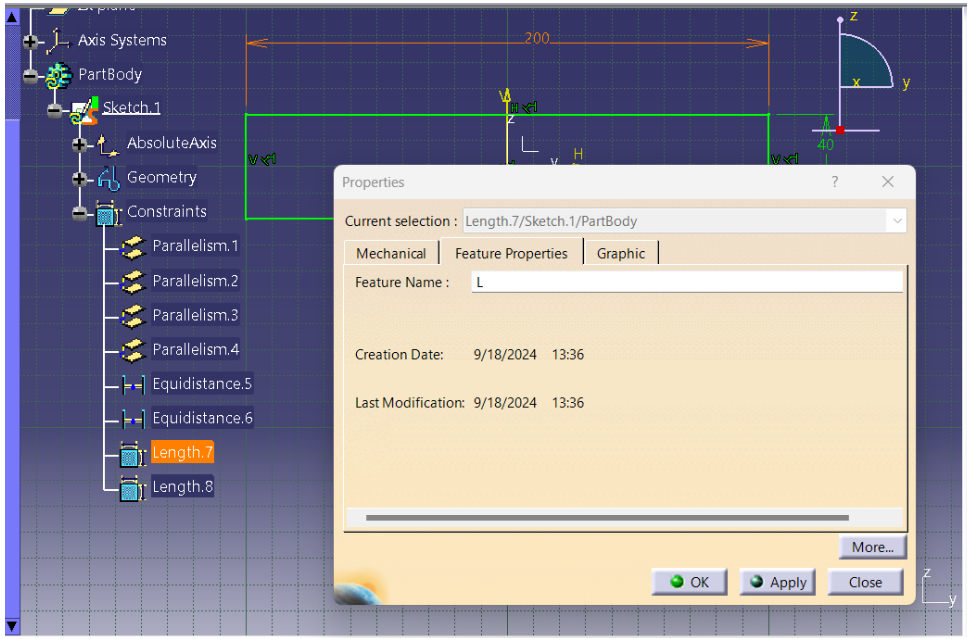
[Length] : W

[Length] : B



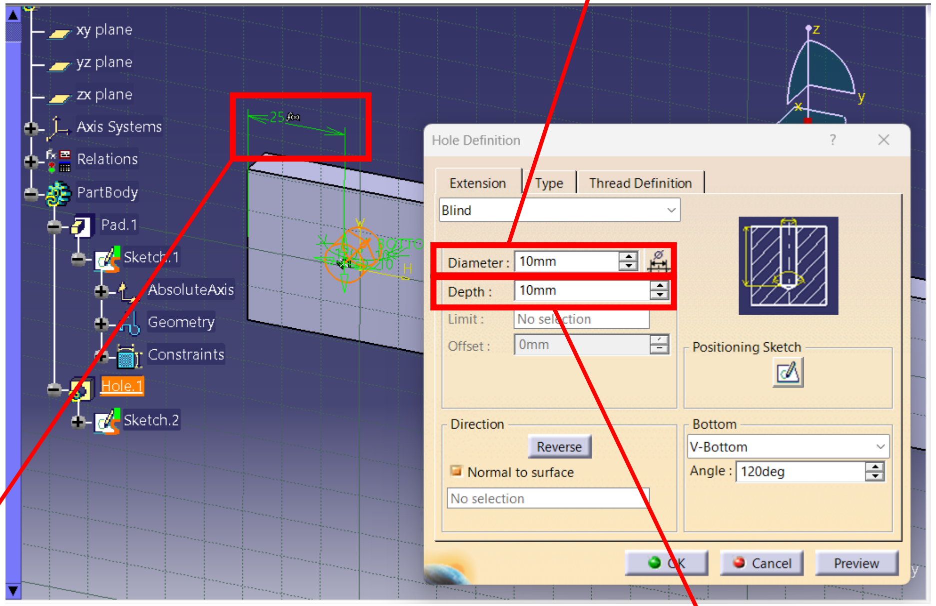
Parametric design using Design Tables

Initially, the names used to describe the part's length and width are changed to **L** and **W**.



The relationships between the diameter, depth and the initial position of the hole, and the overall dimensions of the part are defined

PartBody\Sketch.1\W\Length /2



PartBody\Sketch.1\L\Length /8 PartBody\Pad.1\FirstLimit\Length

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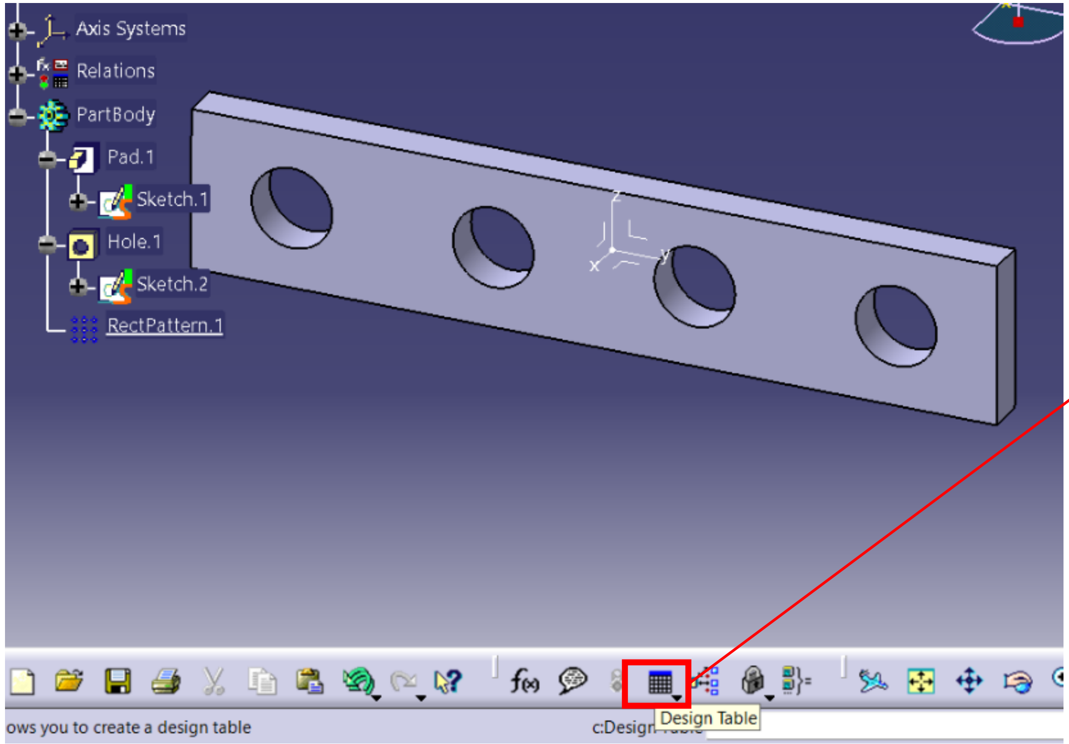
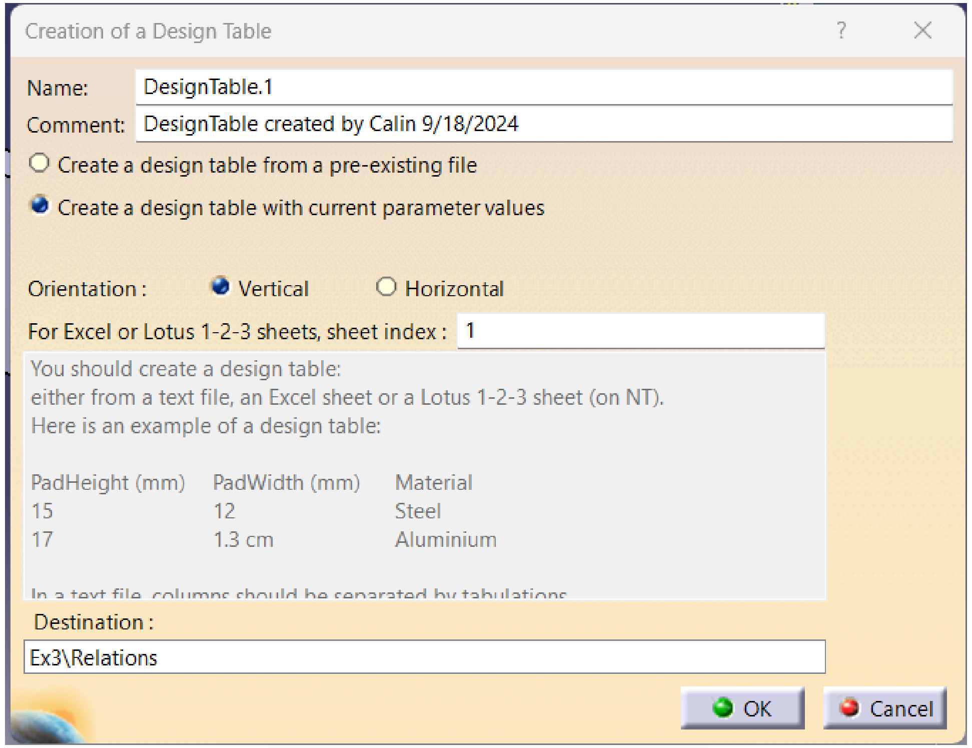
NextGEng

Parametric design using Design Tables

- Click the *Design Table* icon and the *Creation of a Design Table* window is displayed

In the newly opened window, we can enter a specific name for our Design Table and specify its orientation. Then click OK





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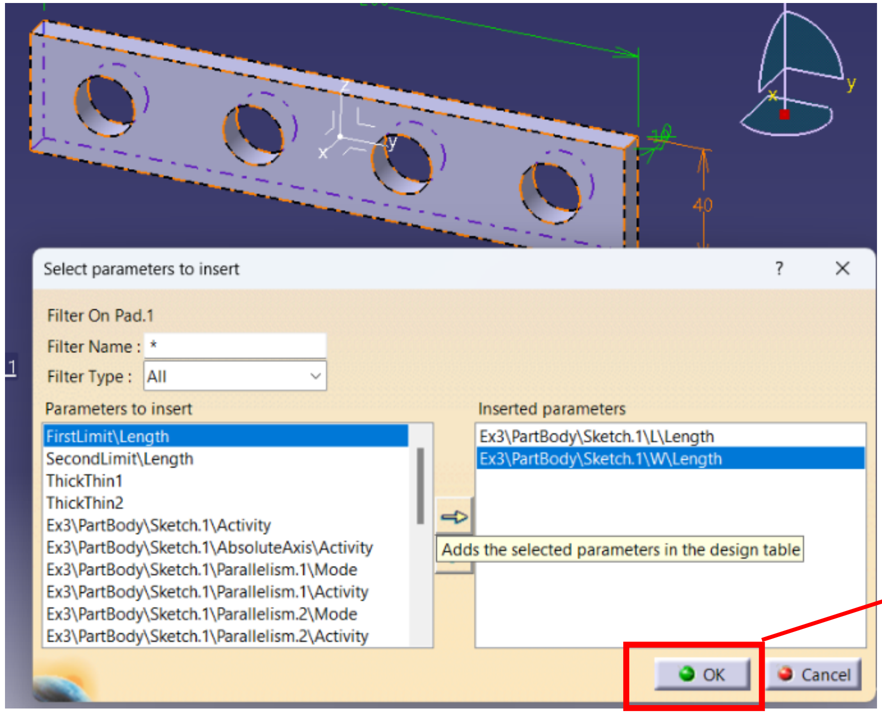
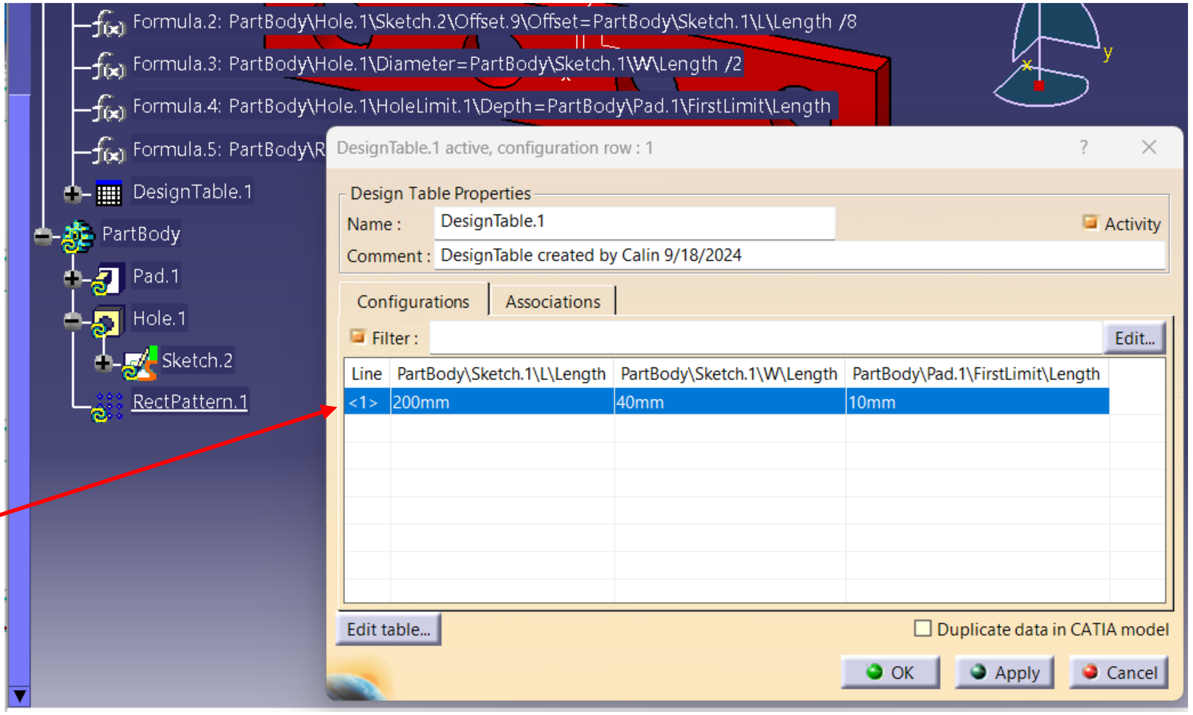
Parametric design using Design Tables

Next, we need to add parameters to our Design Table. After entering all the desired parameters, click OK



In the new window we find a preview of the Design Table currently with only one row.

If we want to add new rows (new part configurations) we have to click on Edit Table



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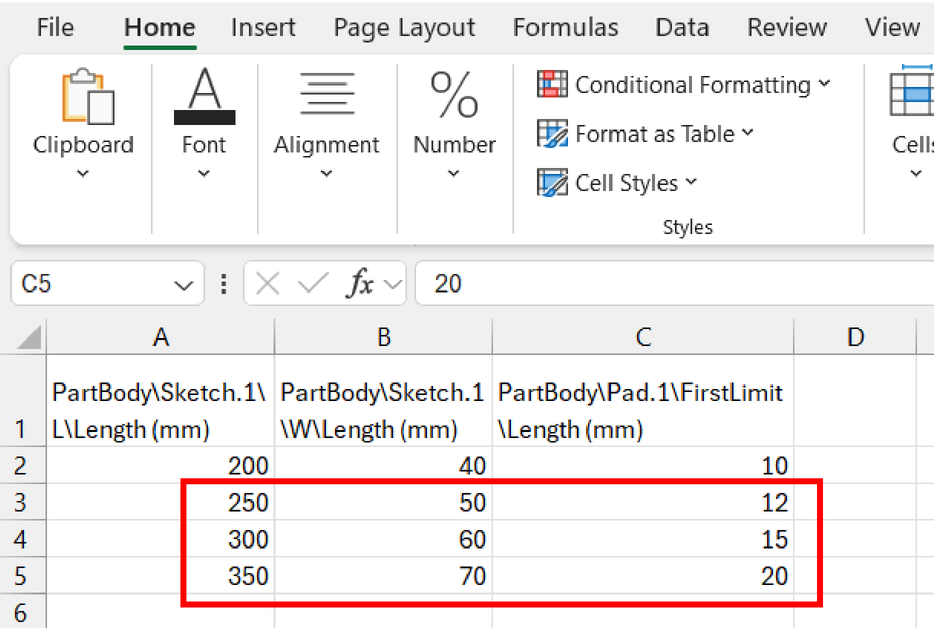
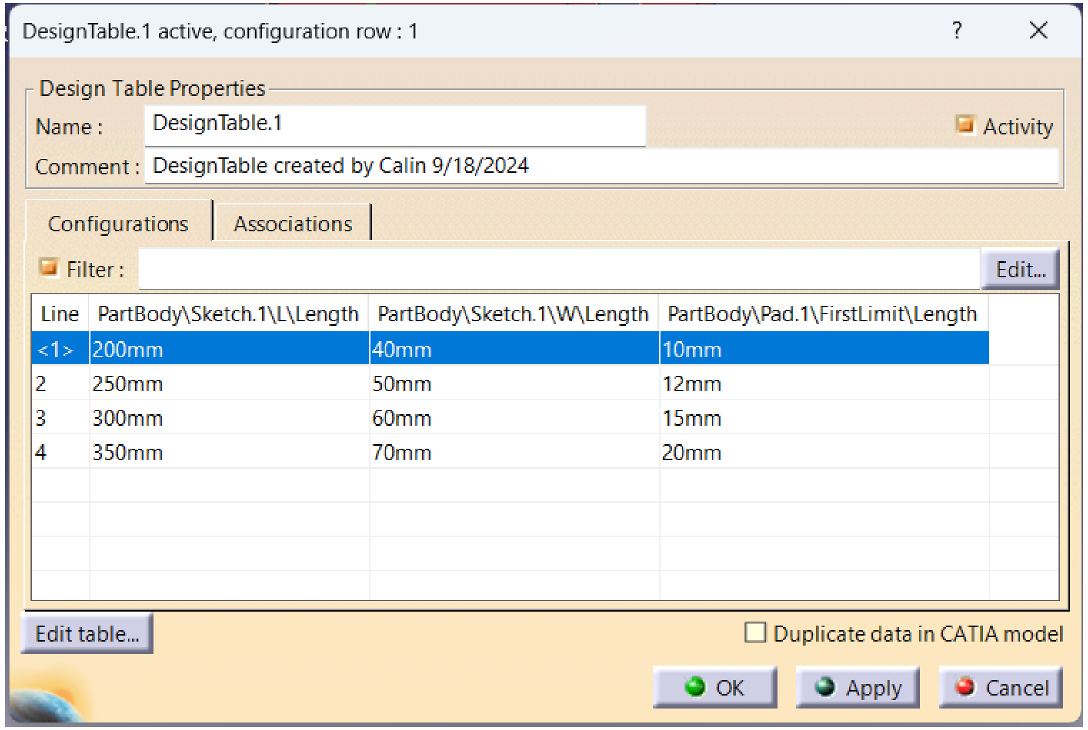
Parametric design using Design Tables

This time, our table will open in Excel, where we can edit and add the desired values.



After saving the table in Excel, it will be automatically updated in CATIA



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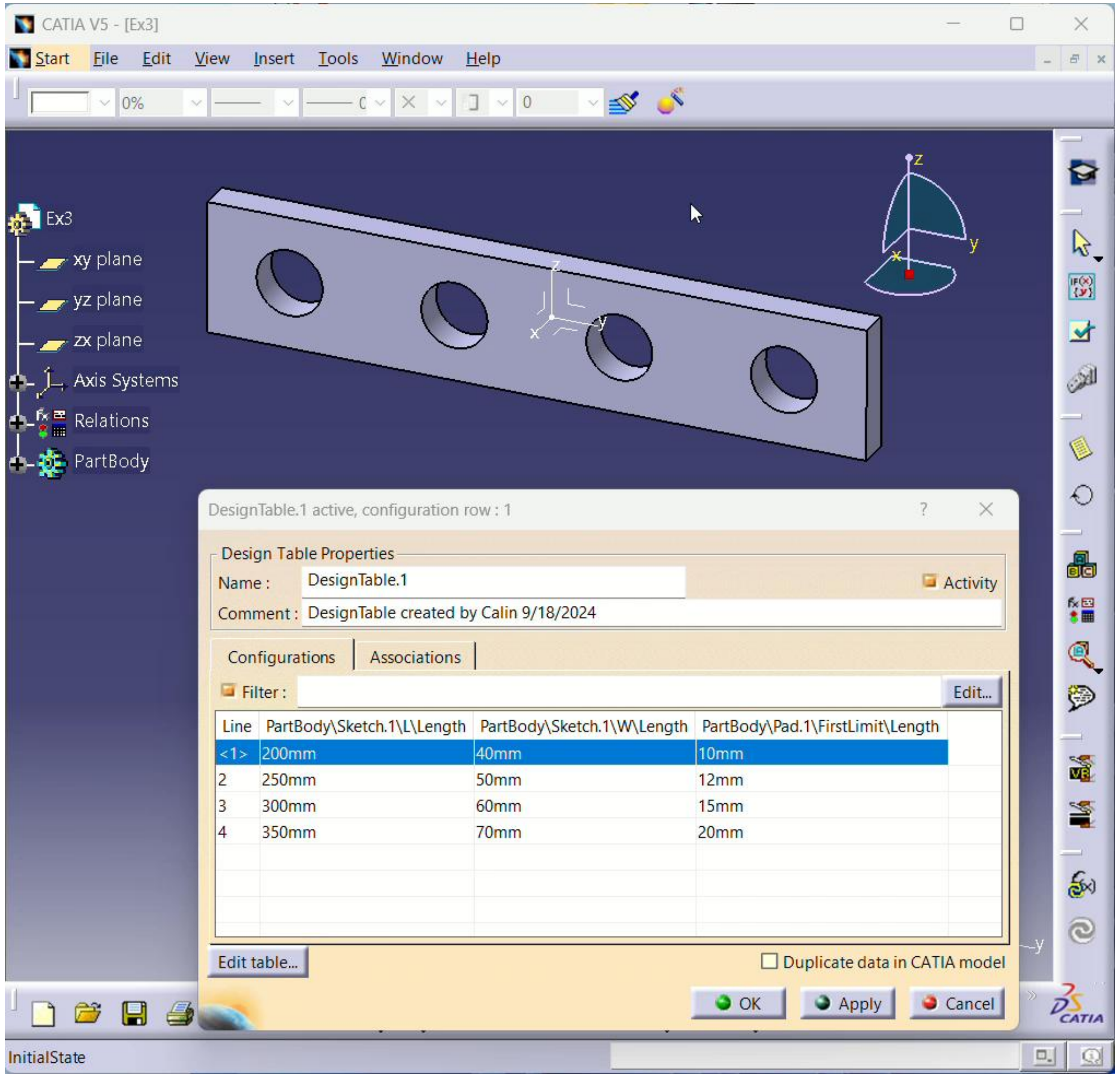
Parametric design using Design Tables



Case Study: Parametric Design of a Bike Handlebar Stem

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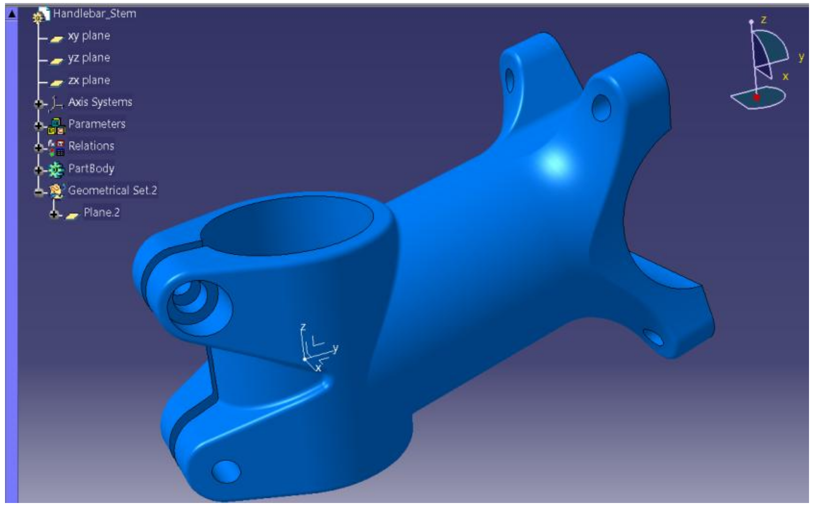
Case Study: Parametric Design of a Bike Handlebar Stem

Objective: Parameterized design of a handlebar stem

Parameters [Length] : LENGTH
[Angle] : ANGLE
[Length] : THICKNESS
[Length] : HANDLEBAR_DIAM
[Length] : STEERER_TUBE



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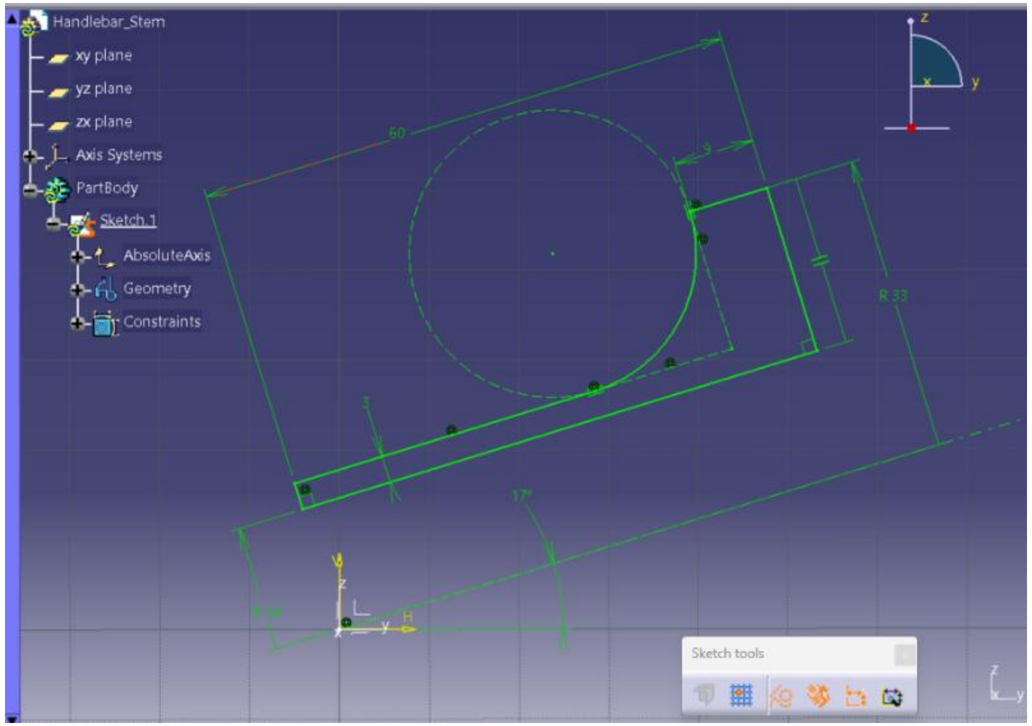
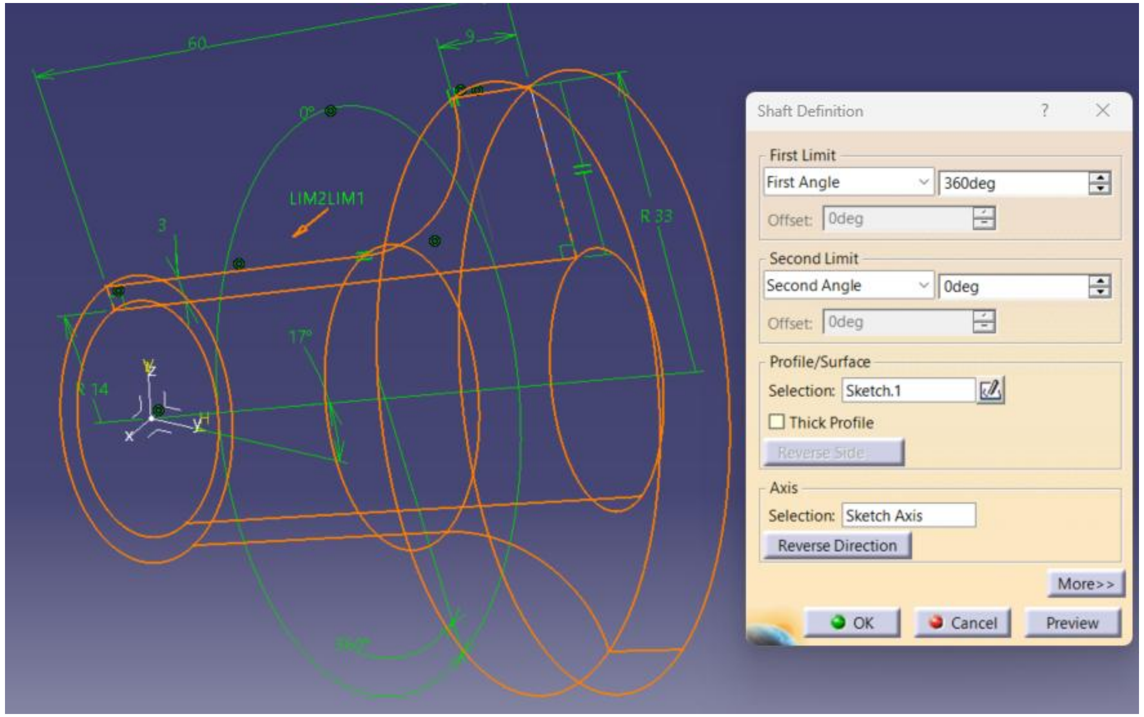
Case Study: Parametric Design of a Bike Handlebar Stem

- It starts from a fully defined sketch that contains an inclined symmetry axis.
- The tilt angle will become one of the parameters that will determine the geometry of the piece.
- Using the ***Shaft*** command, we can generate the main body shape for the handlebar stem





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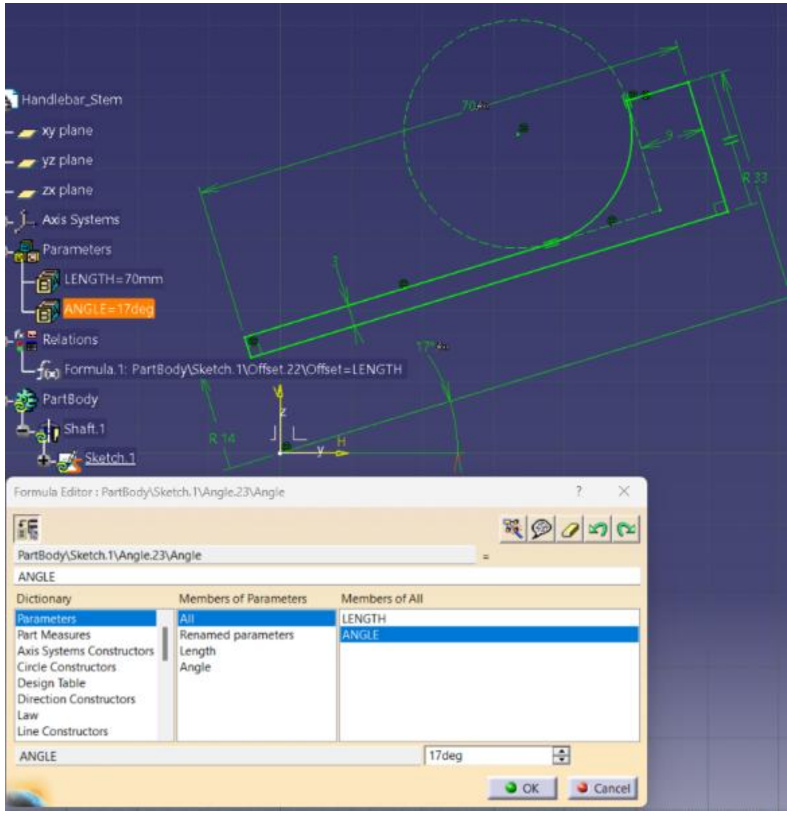
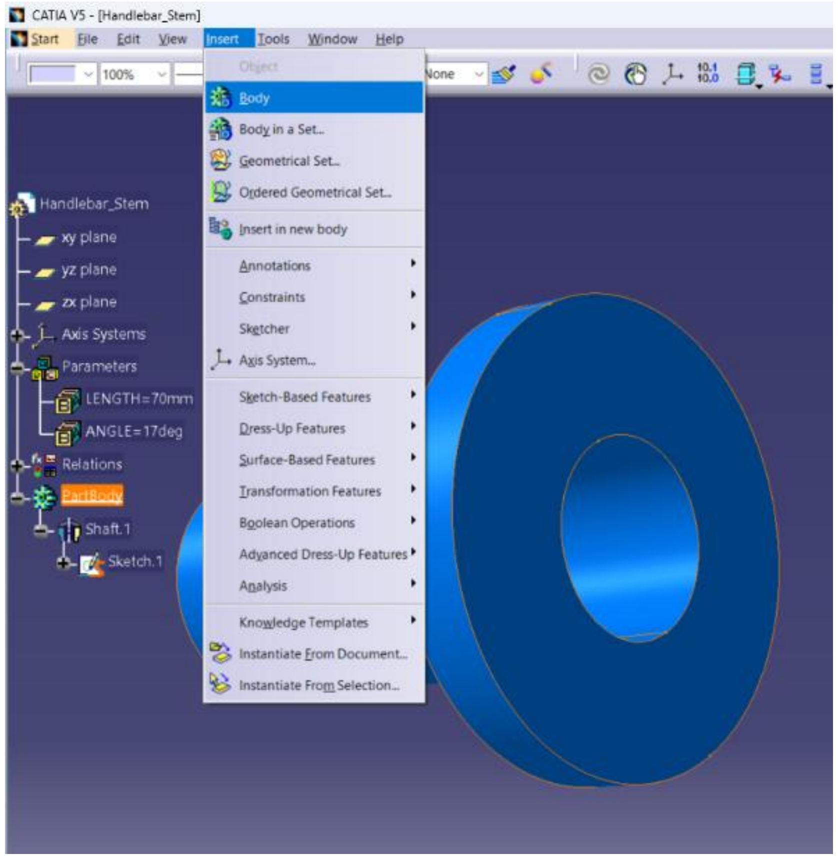
Case Study: Parametric Design of a Bike Handlebar Stem

We create the first two parameters (LENGTH and ANGLE) and link them to the corresponding dimensions in the sketch

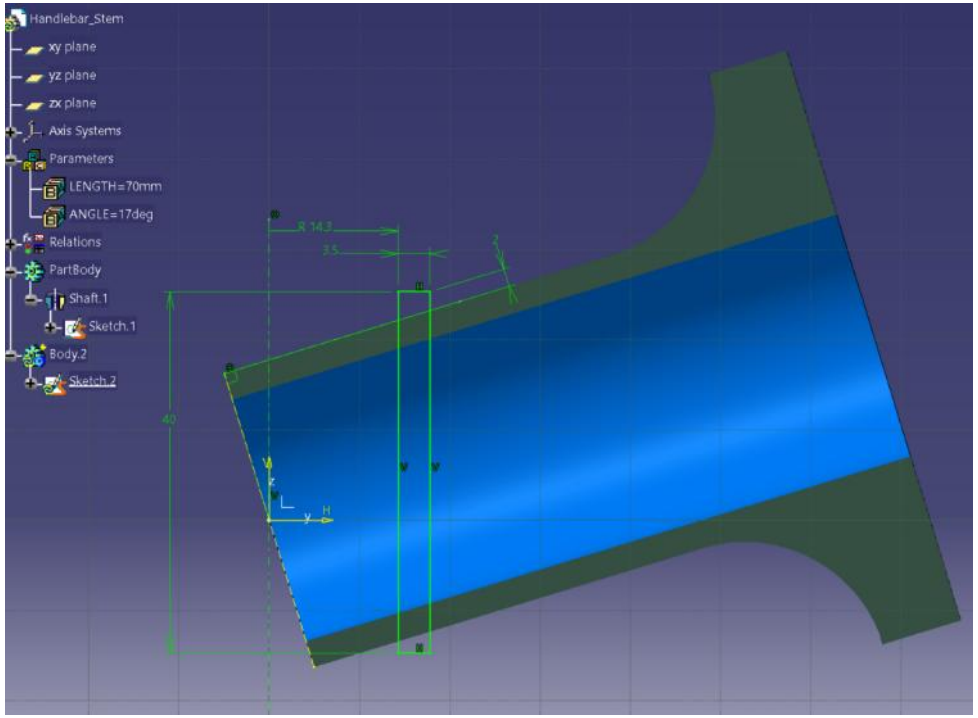


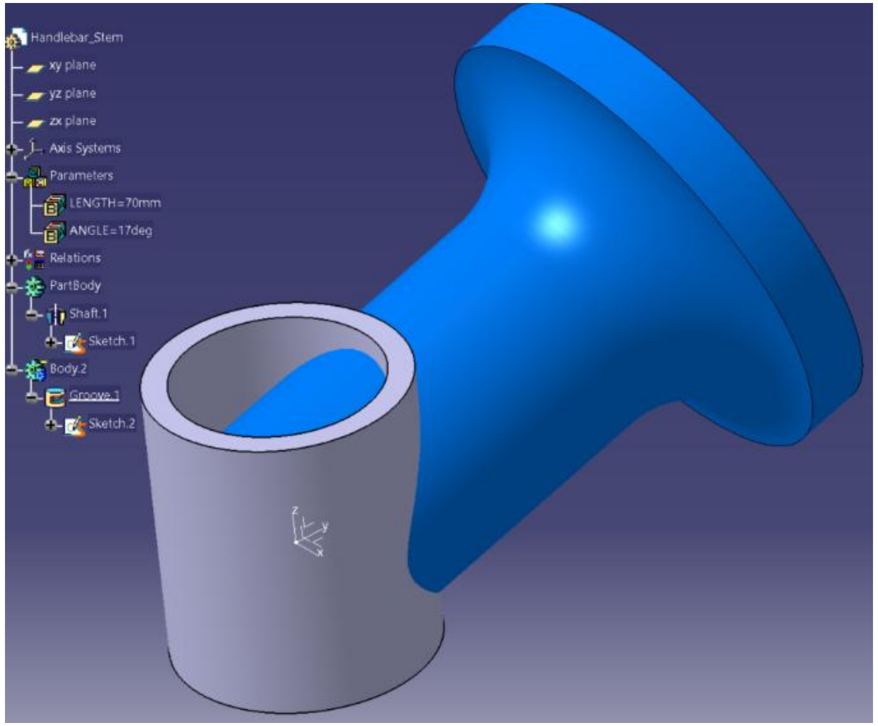
To create the clamp for the steerer tube we need to insert a new ***Body*** in our part



Case Study: Parametric Design of a Bike Handlebar Stem

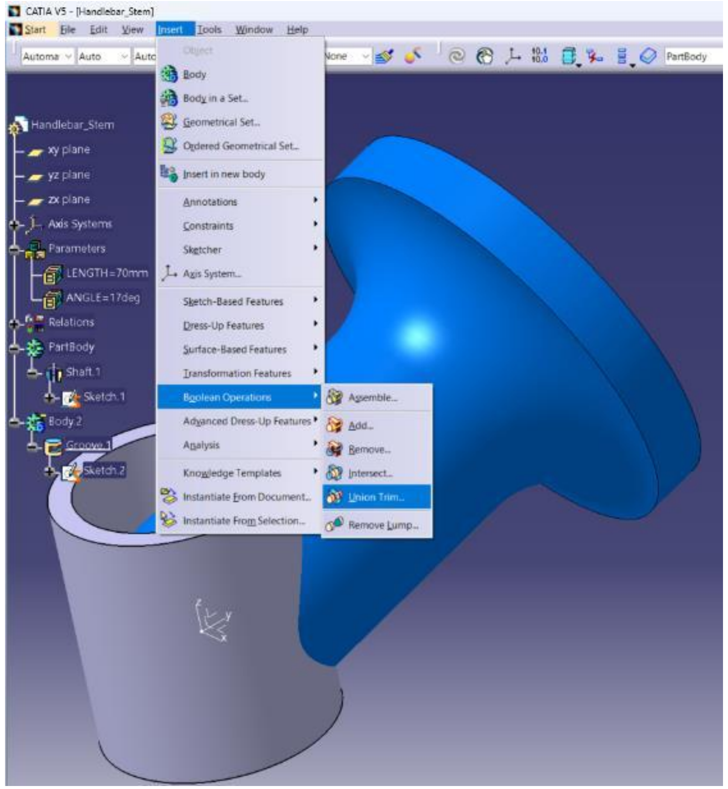
- We draw here a new sketch, which will form the basis for the cylindrical part of the clamp.
- It is important to position the sketch a few mm above the cylindrical part of the main body.
- This distance will remain the same regardless of the angle of inclination of the main body in relation to the clamp

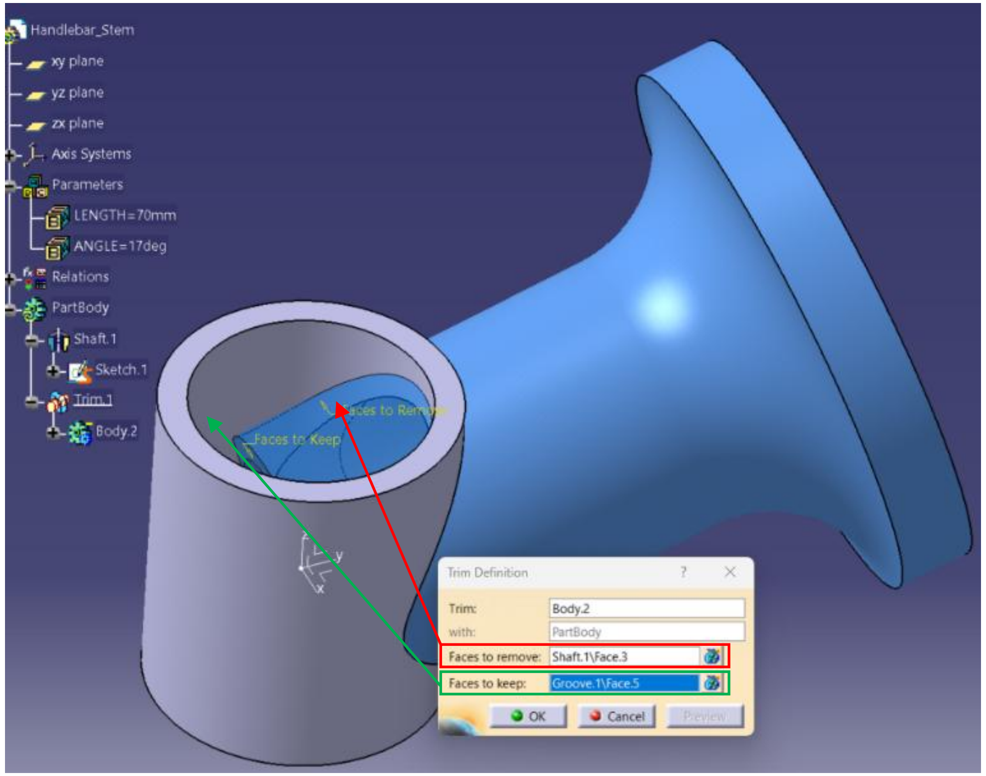




Case Study: Parametric Design of a Bike Handlebar Stem

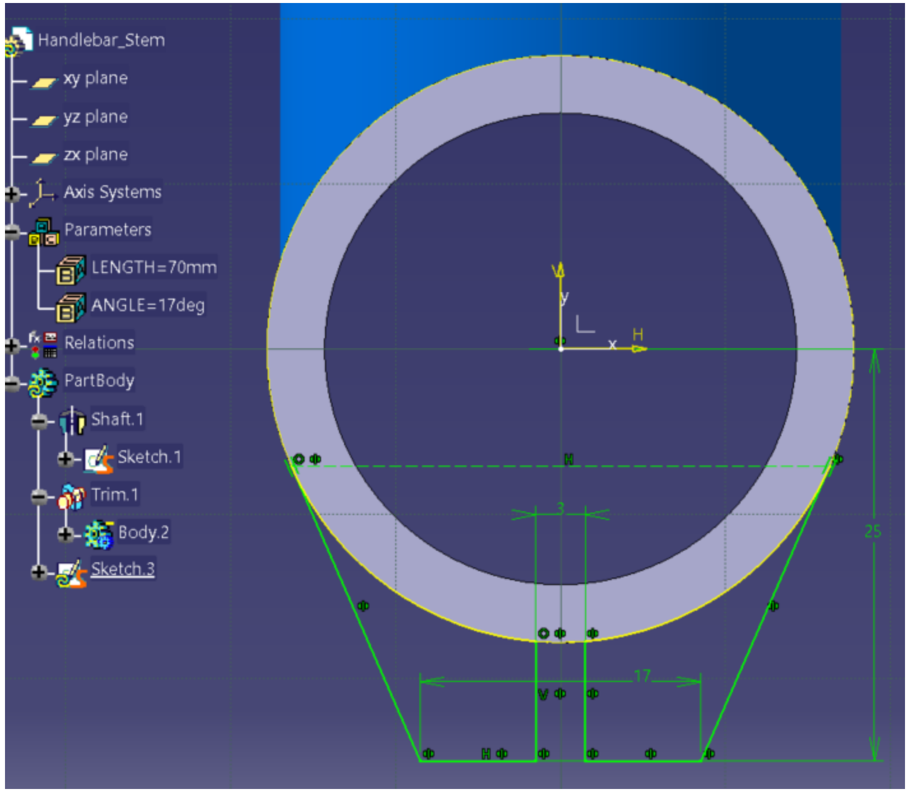
- Now we have to remove the part of the main body that is inside the clamp bore
- This can be done with the ***Union Trim*** command

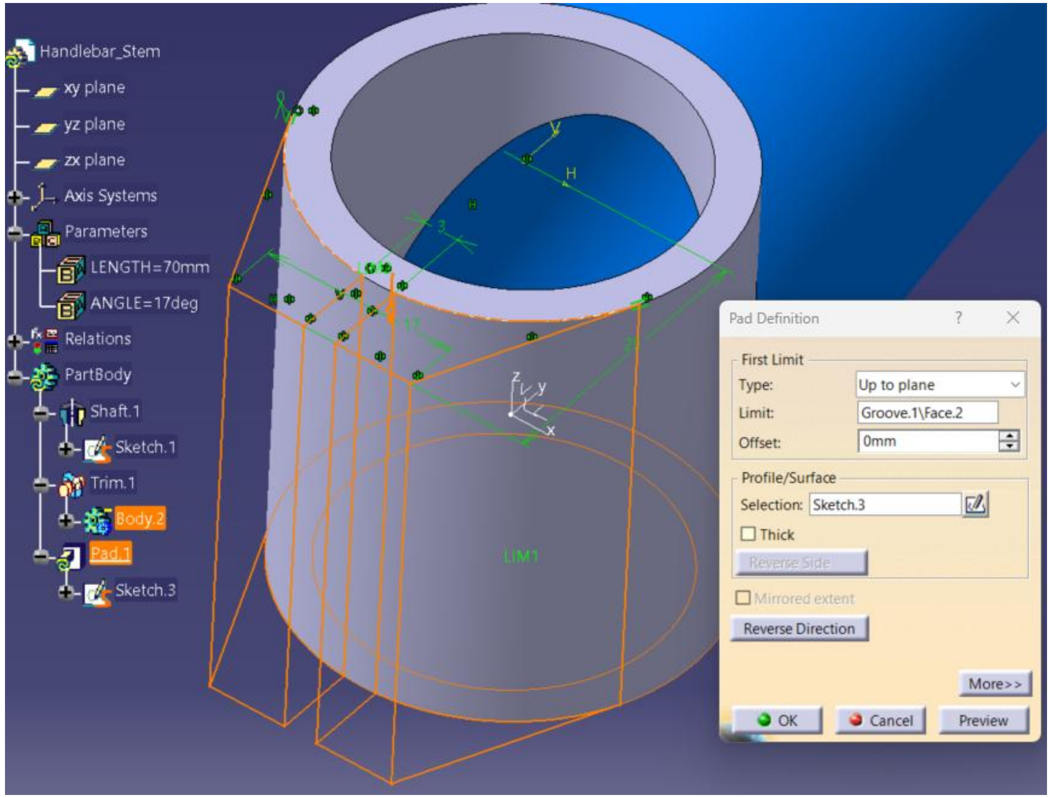




Case Study: Parametric Design of a Bike Handlebar Stem

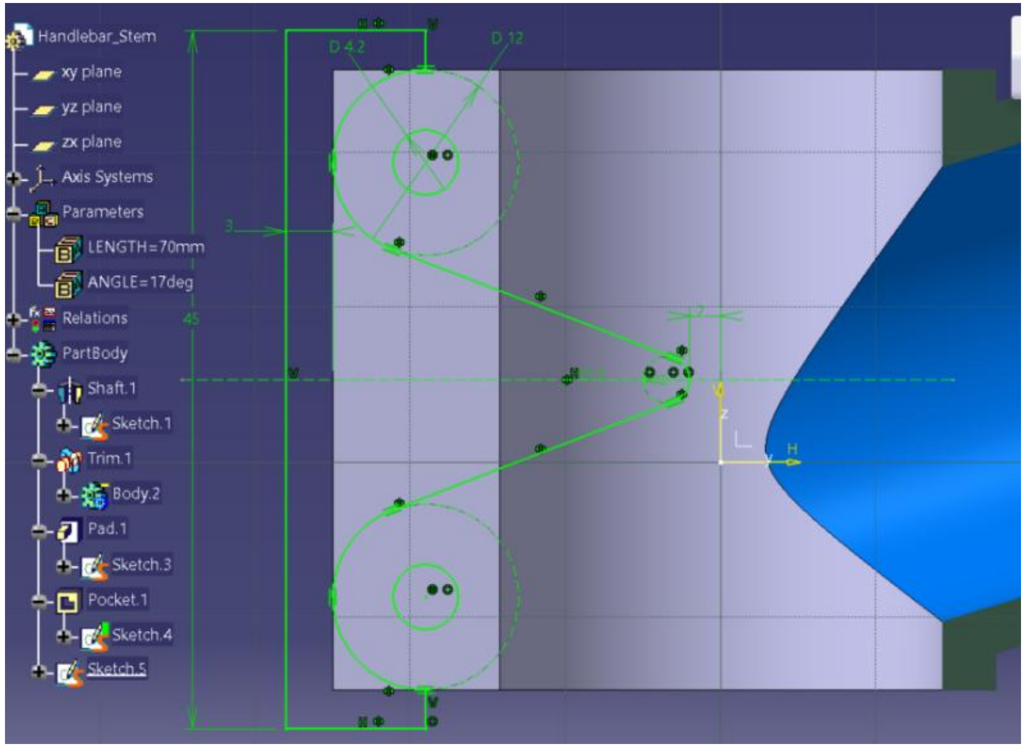
Now we can add the side parts that will contain the holes for the clamp tightening screws
When using the **Pad** command, it is recommended that you use one of the options "*Up to plane*" or "*Up to next*"





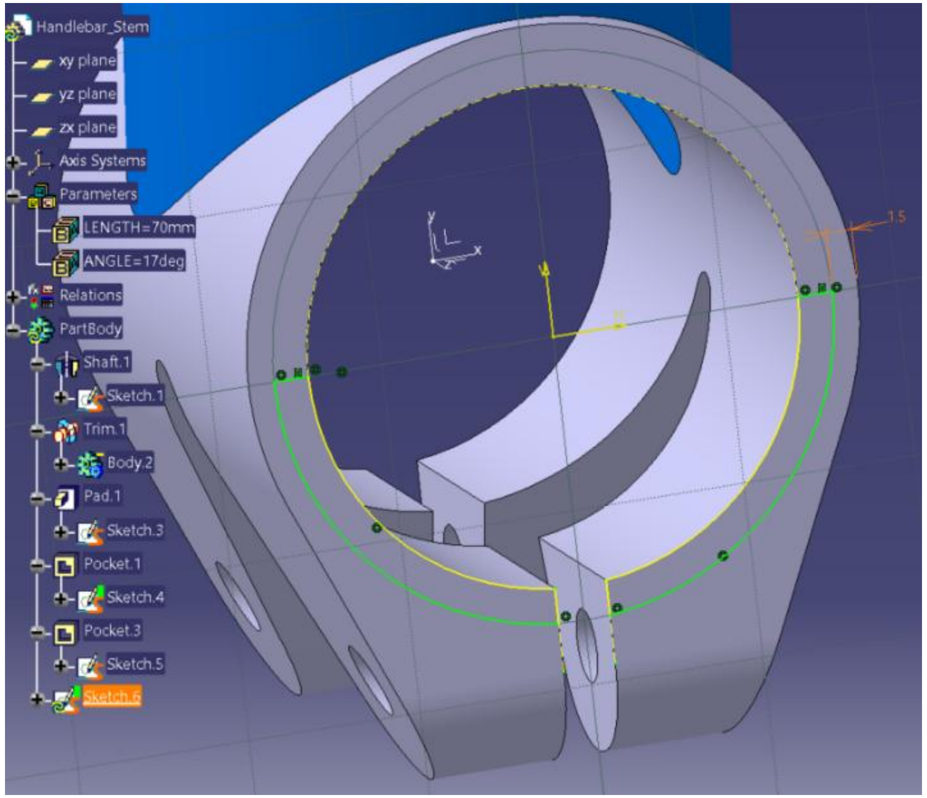
Case Study: Parametric Design of a Bike Handlebar Stem

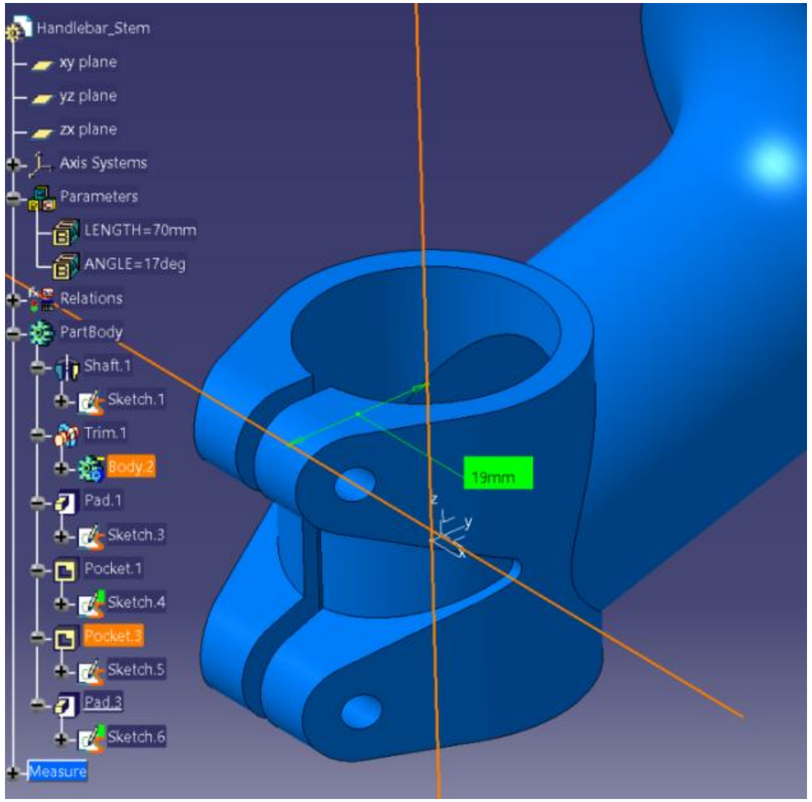
We continue the construction of the clamp shape and add the holes for the tightening screws



Case Study: Parametric Design of a Bike Handlebar Stem

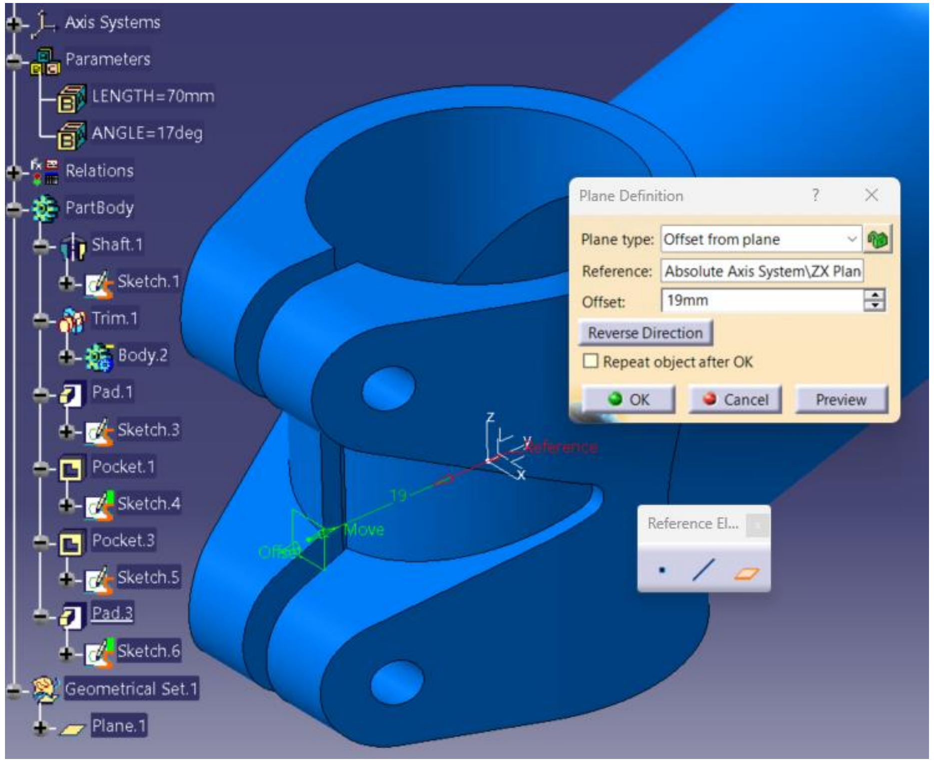
- Now we restore the lateral side of the bore, partially removed in the previous operation
- It is necessary to measure the distance from the axis of the screw holes to the axis of the clamp

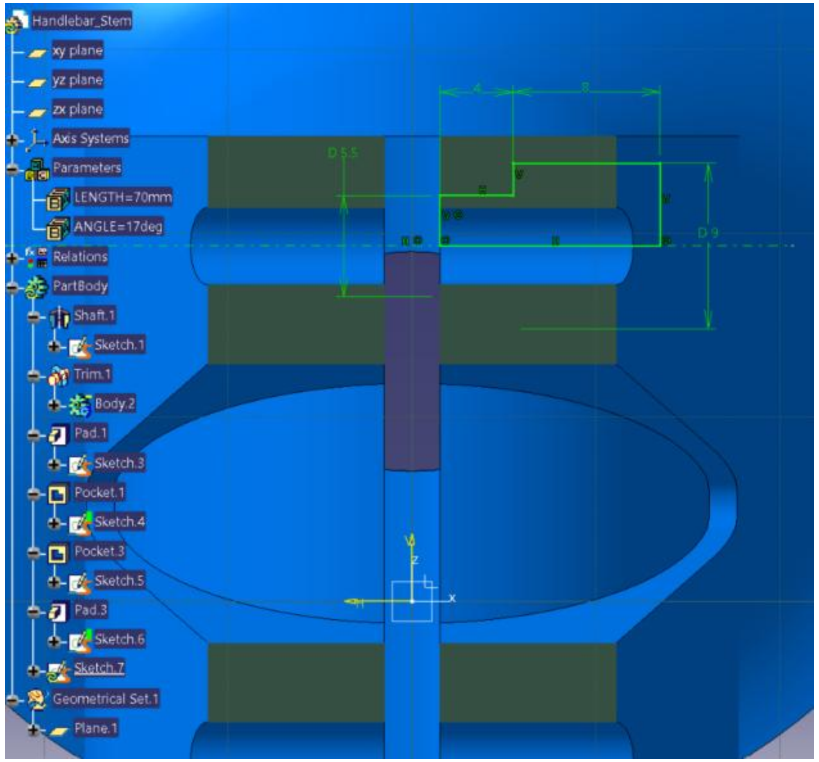




Case Study: Parametric Design of a Bike Handlebar Stem

- We will create a plane at the previously determined distance
- On this plan we will draw the cross section of two counterbored holes
- These will be the through holes for the clamp set screws





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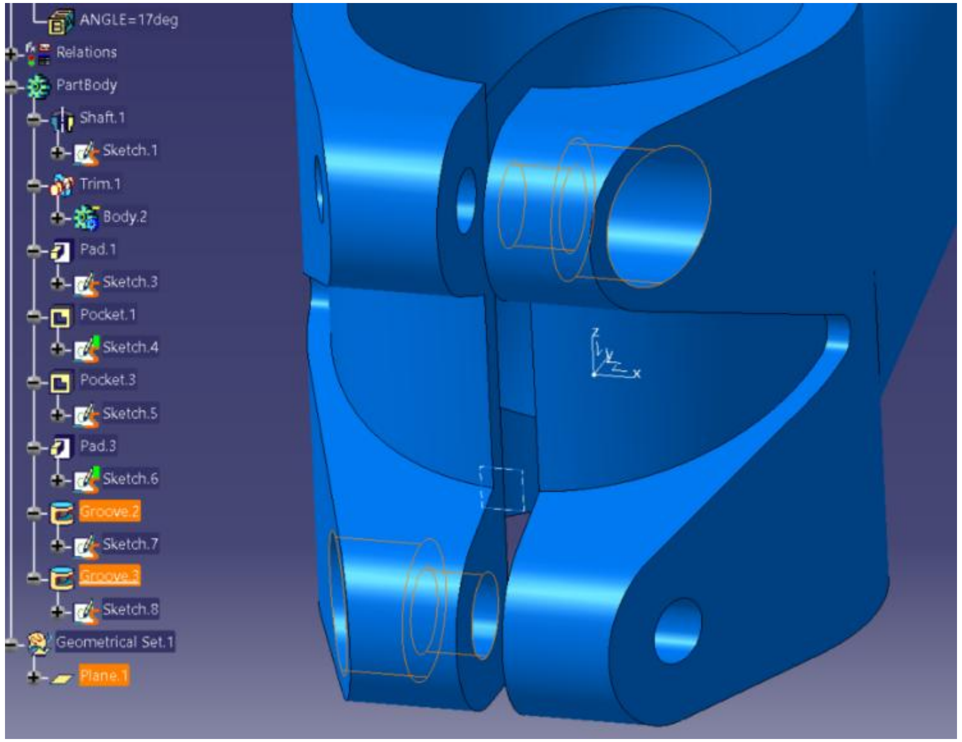
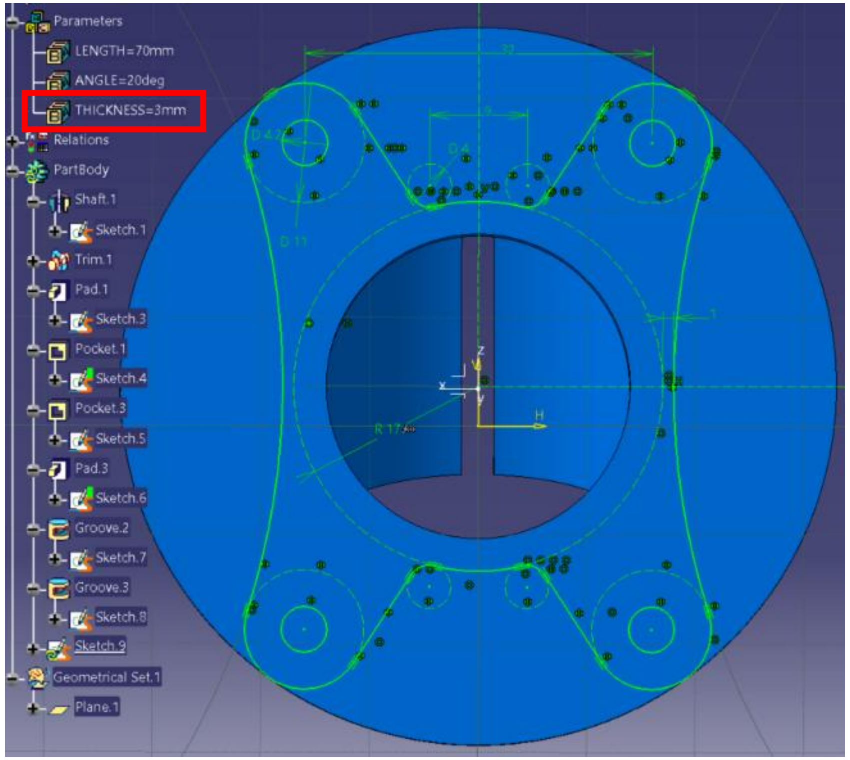
Case Study: Parametric Design of a Bike Handlebar Stem

Based on the previous sketches, we can obtain the two holes using the **Groove** command

- Next, we deal with the handlebar fixing clamp
- Here we have to add another parameter to modify this part of the stem depending on the handlebar diameter





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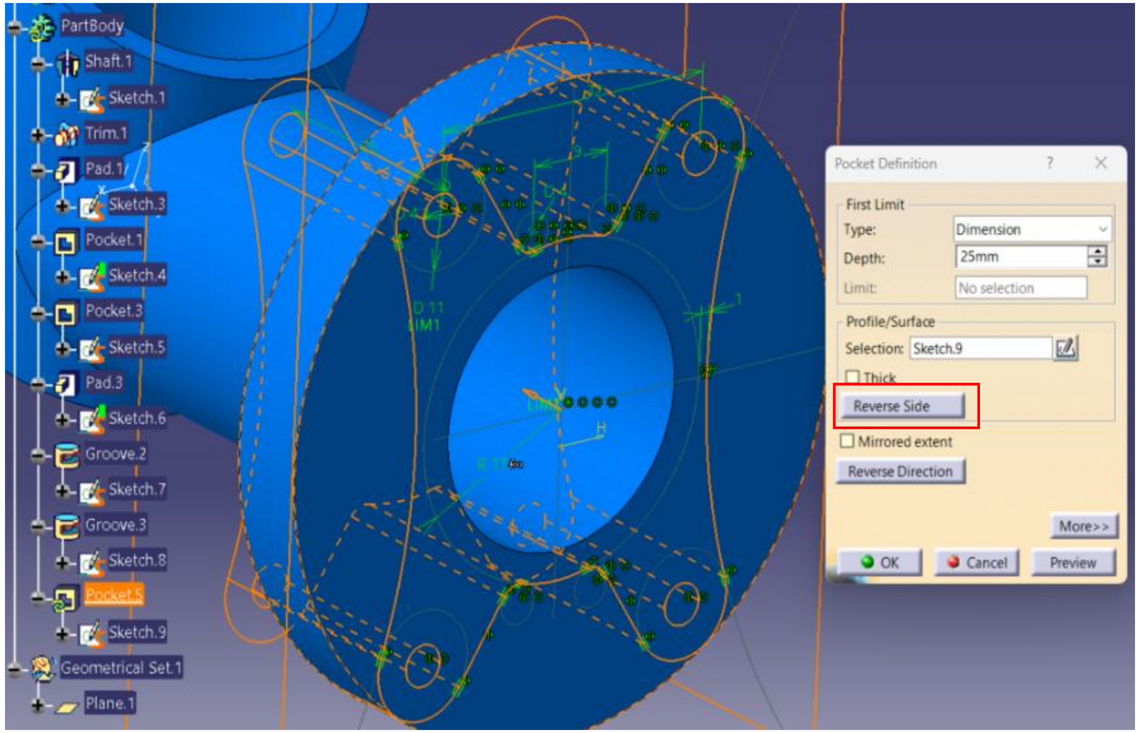
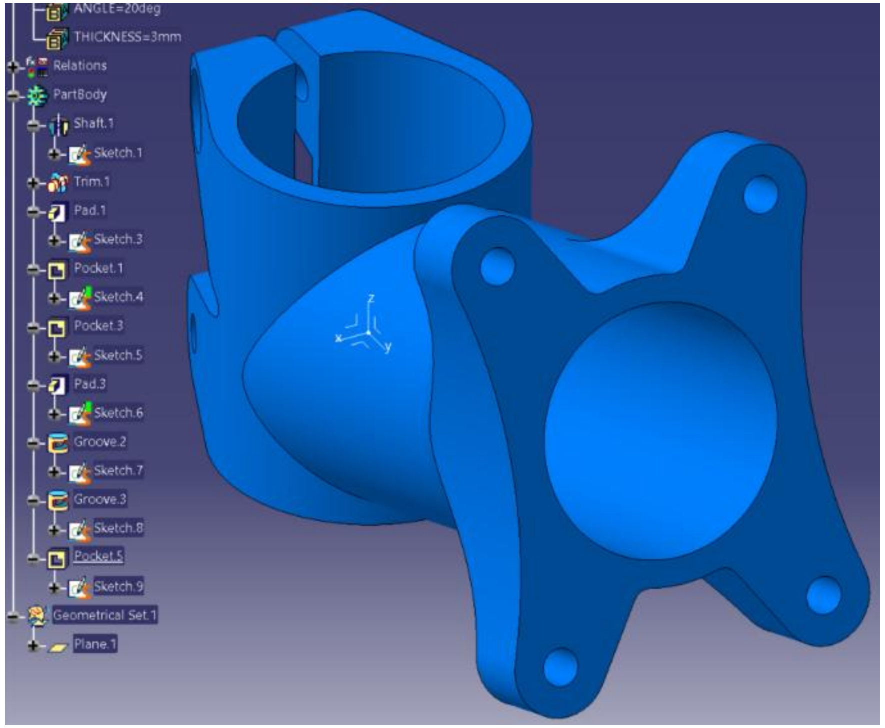
Case Study: Parametric Design of a Bike Handlebar Stem

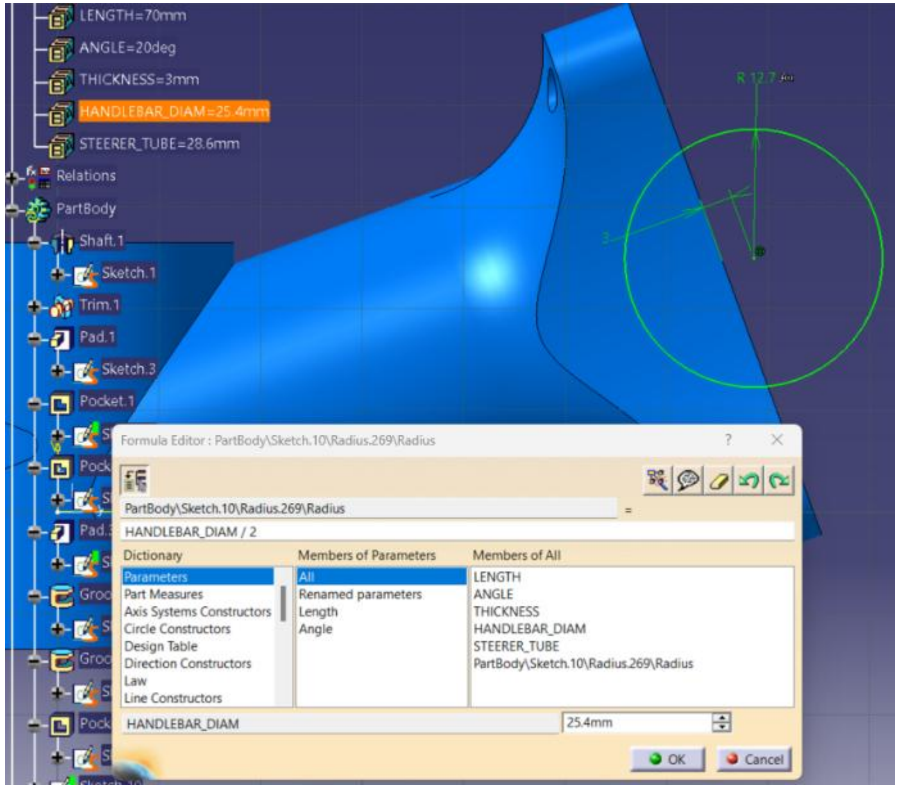
- Using the previously created sketch we can obtain the basic shape of the handlebar clamp using the **Pocket** command with **Reverse Side** option

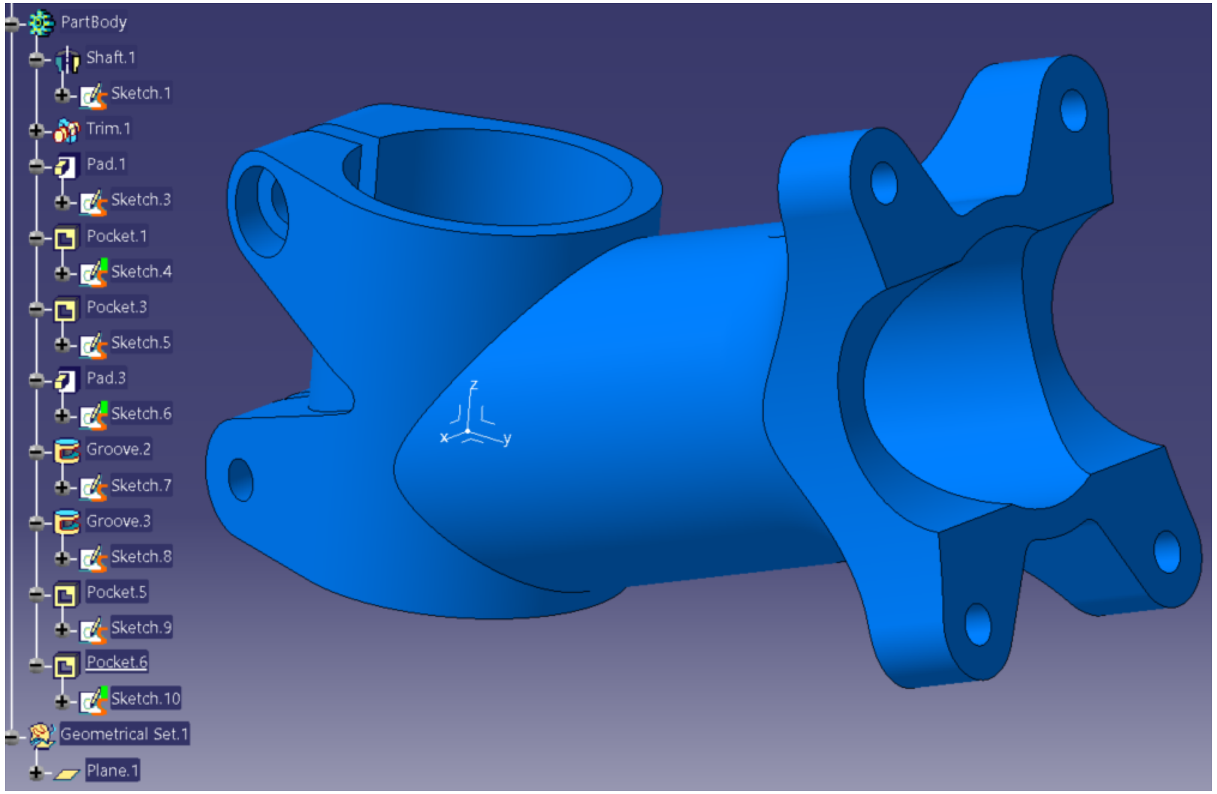




Case Study: Parametric Design of a Bike Handlebar Stem

At the end we draw a circle in a median plane. Its radius will be equal to half of the **HANDLEBAR_DIAM** parameter value





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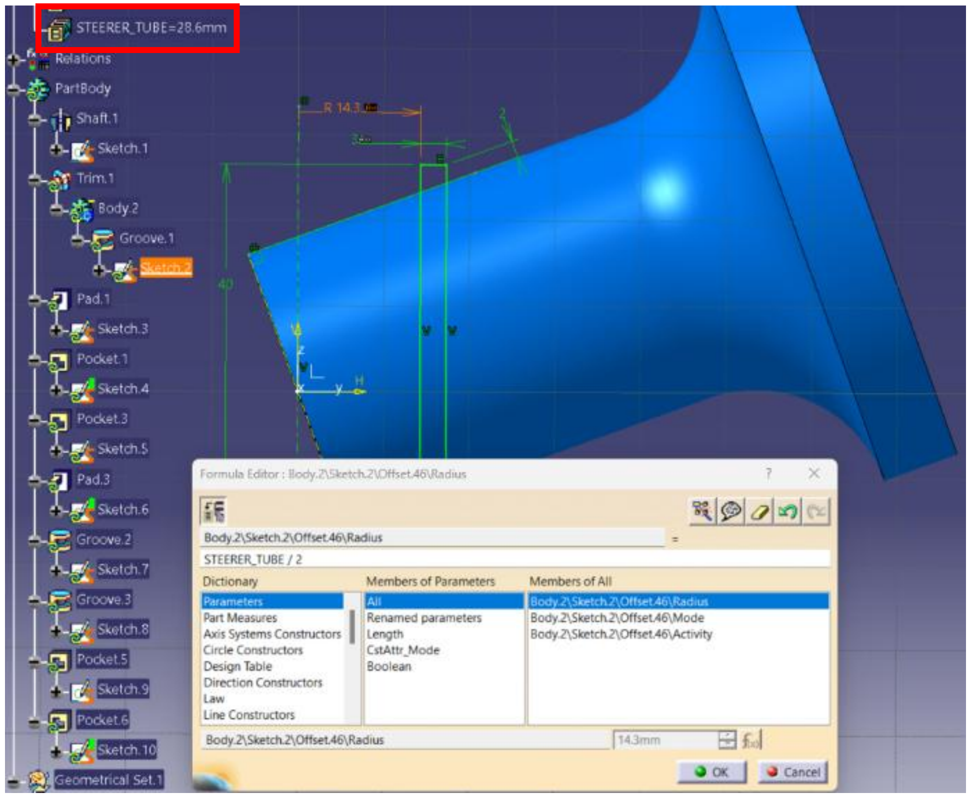
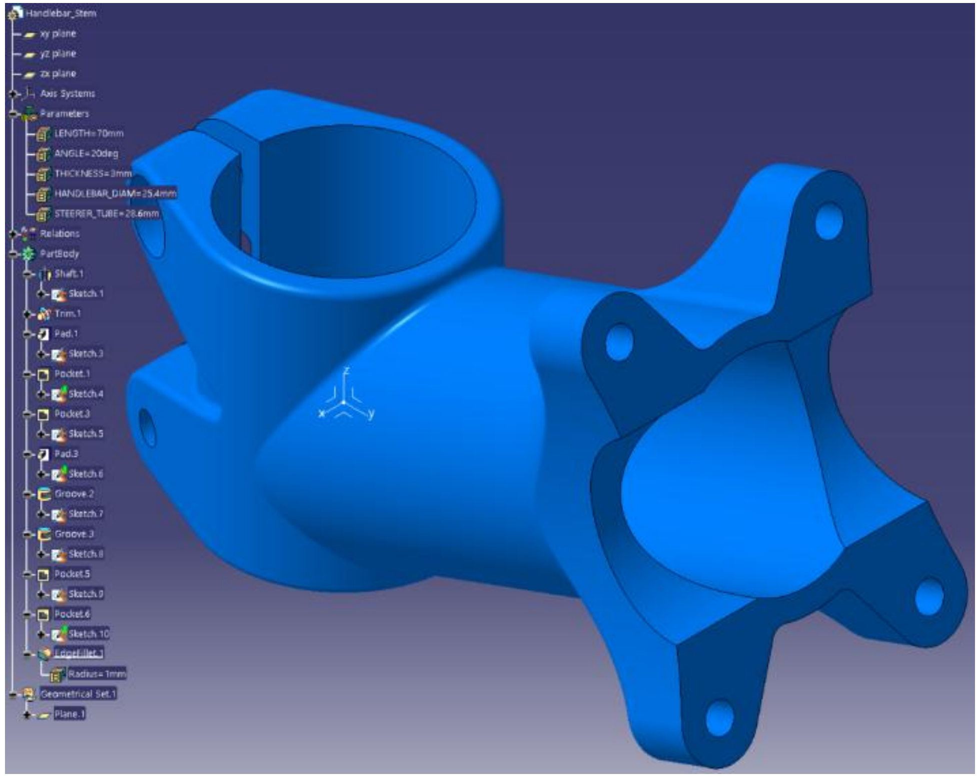
Case Study: Parametric Design of a Bike Handlebar Stem

We define another parameter, to be able to change the shape of the stem for different diameters of the steerer tube.



Finally, we round the outer edges of the part with a radius of 1 mm



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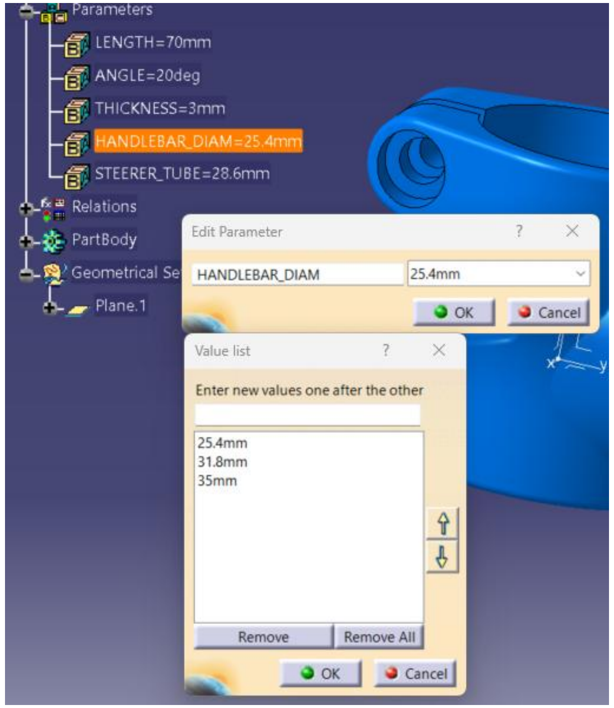
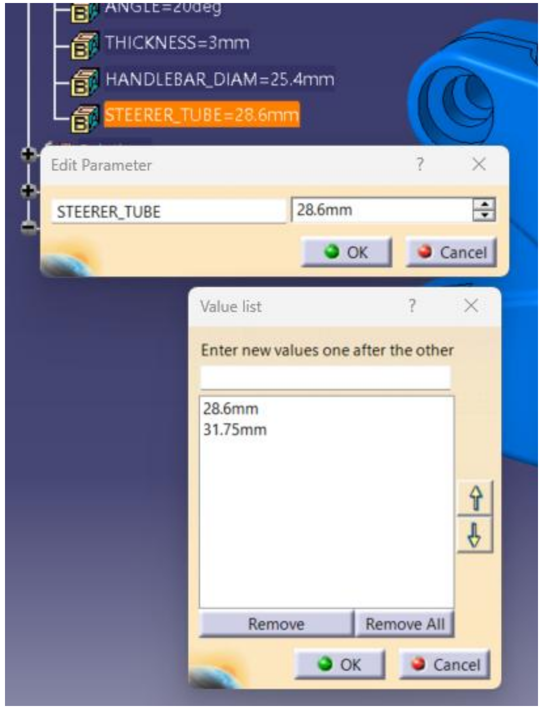
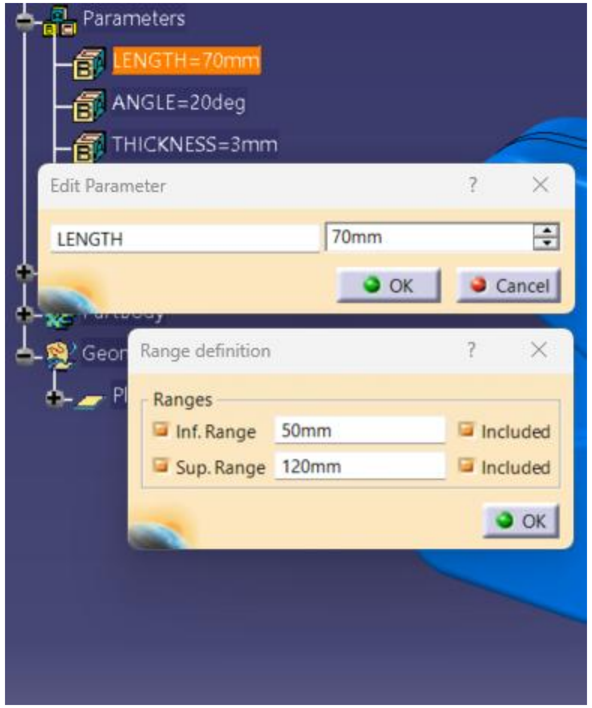
Case Study: Parametric Design of a Bike Handlebar Stem

The usual values for the handlebar and steerer tube diameters are defined, as well as the limits of the values for the tilt angle and the total length.



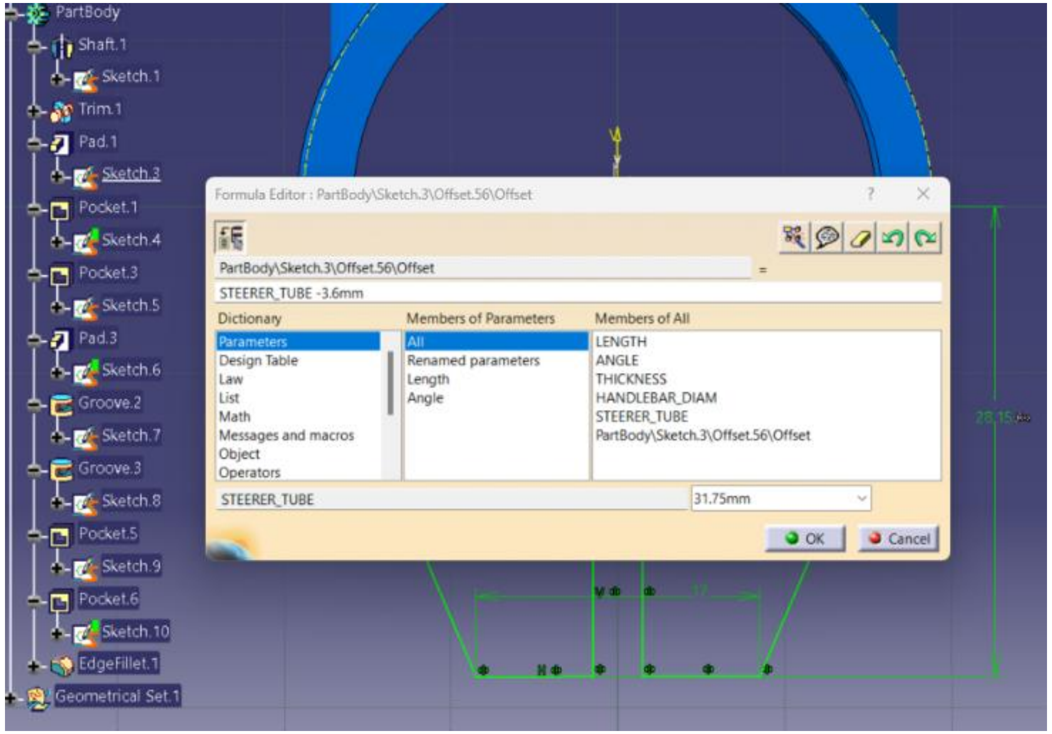


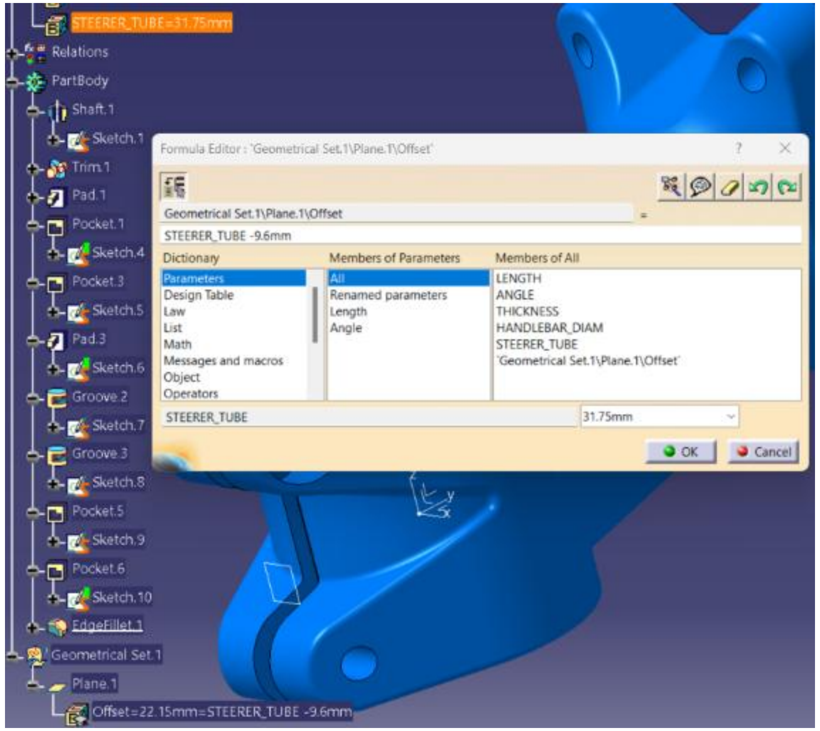


Case Study: Parametric Design of a Bike Handlebar Stem

To be sure that the stem keeps its shape, we need to additionally edit the relations for:

- length of the side parts that will contain the holes
- the position of the median plane for the through holes

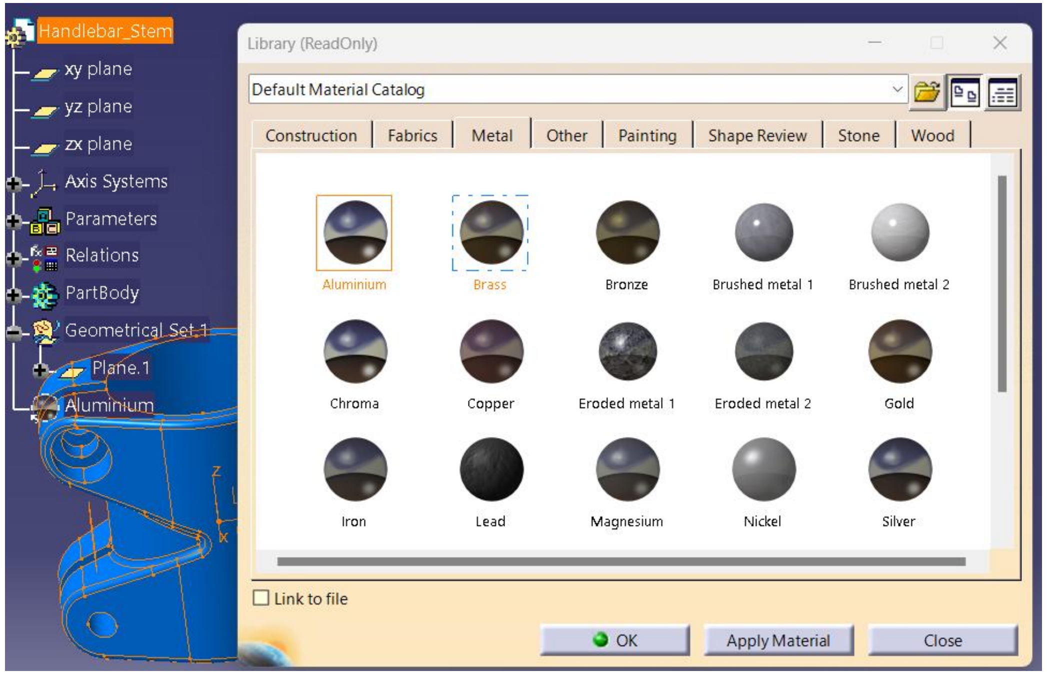


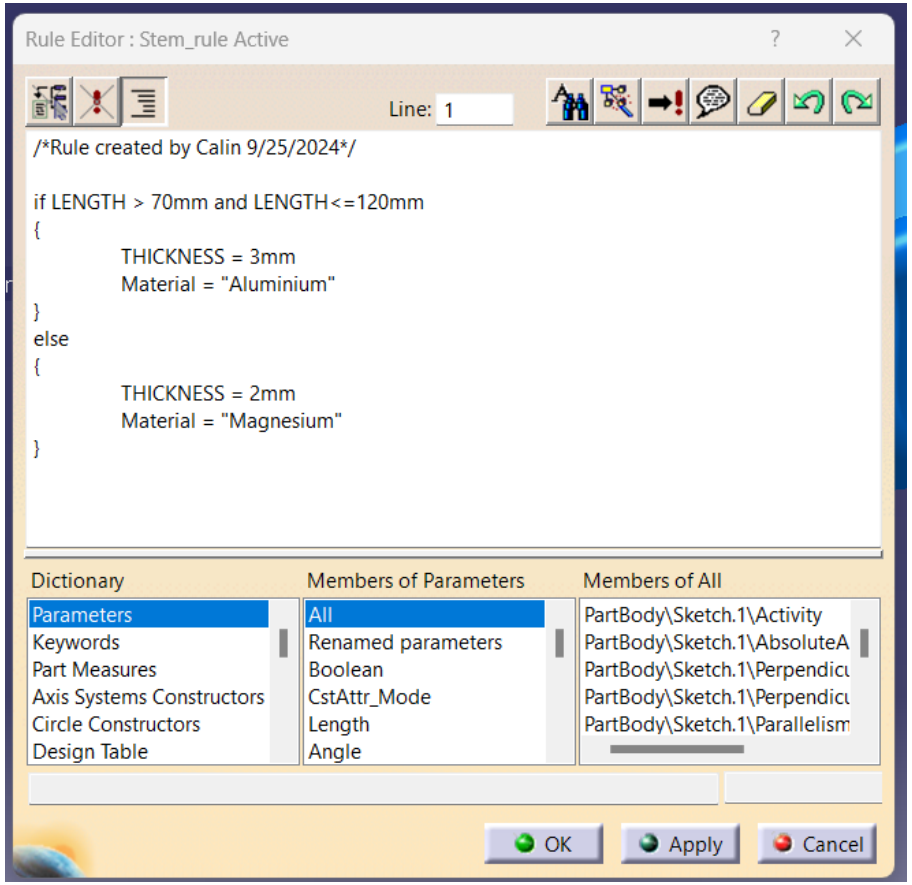


Case Study: Parametric Design of a Bike Handlebar Stem

- Now we can define the stem material, for example Aluminum
- We establish the following rule:

If the total length is between 70 and 120 mm, then Aluminum is used as material, and the wall thickness is 3 mm. Otherwise, the material is Magnesium, and the thickness will be 2 mm





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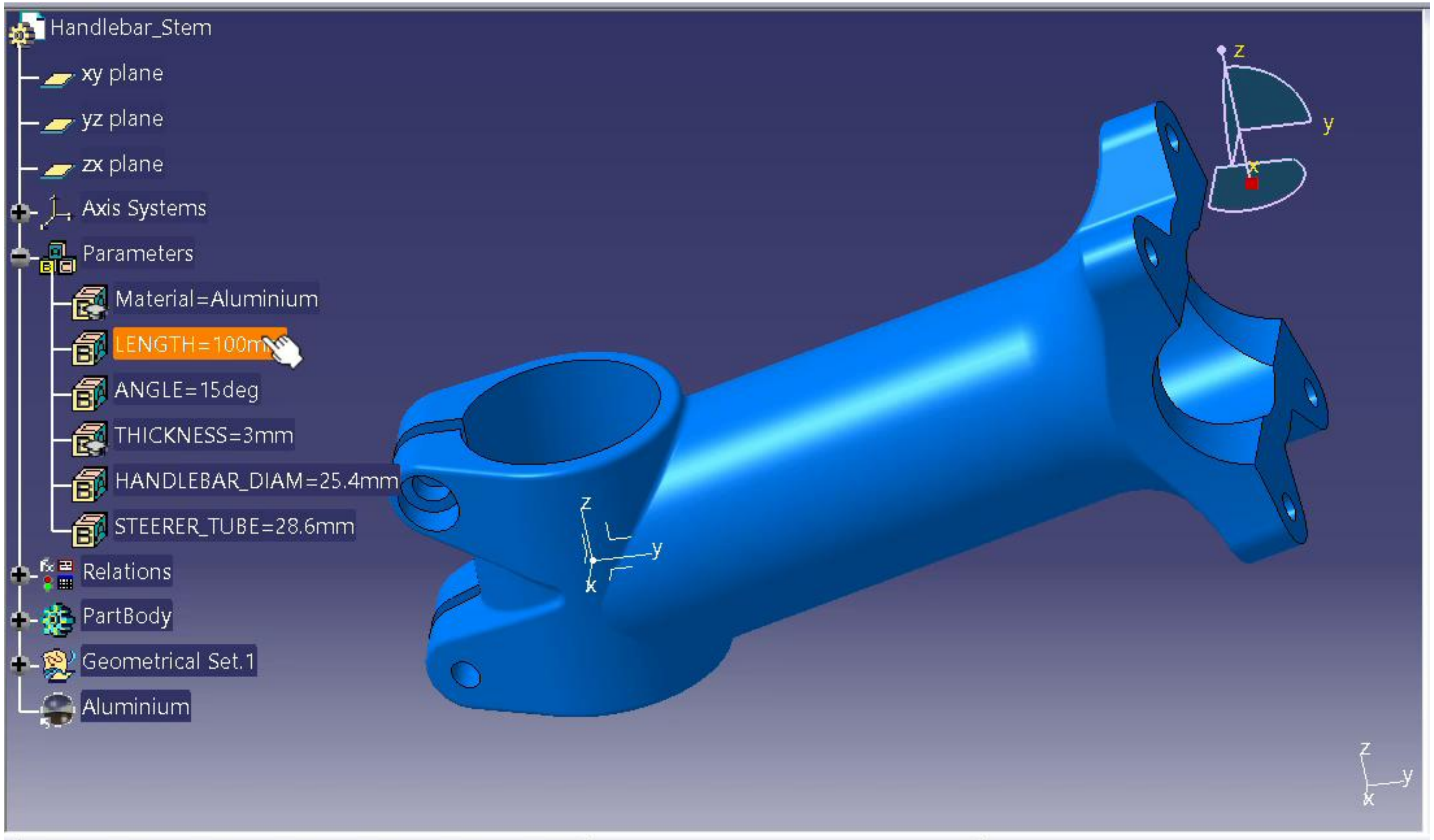
Case Study: Parametric Design of a Bike Handlebar Stem



Knowledge-Based Engineering (KBE) in CATIA

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Knowledge-Based Engineering (KBE) in CATIA

Knowledge-Based Engineering:

- is an engineering approach that captures and reuses product and process engineering knowledge to automate design tasks.
- combines object-oriented programming, artificial intelligence, and computer-aided design to create intelligent CAD models

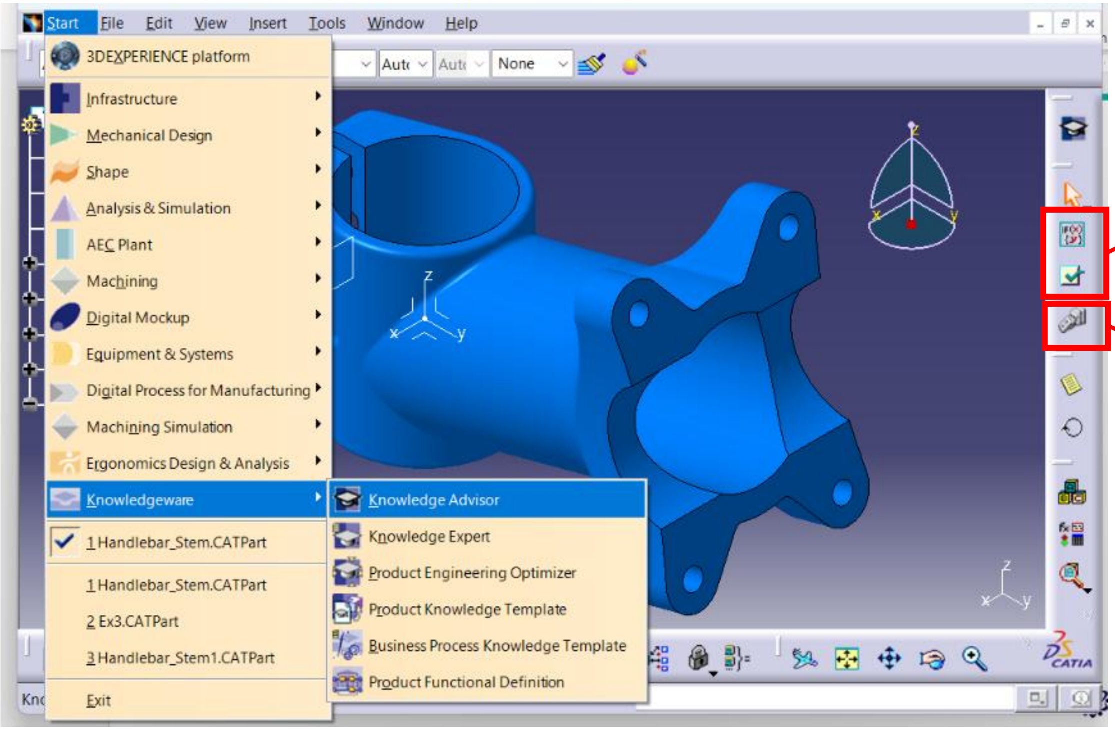
How KBE captures and reuses engineering knowledge:

- Parametric modeling: Creating flexible, rule-driven geometric models
- Design rules and constraints: Encoding engineering best practices and limitations
- Knowledge patterns: Reusable templates for common design scenarios
- Automation scripts: Programs that execute complex design tasks based on inputs

CATIA's Knowledge Advisor

Overview of the tool:

- Designed for creating and managing rules and checks within a single design document
- Defines rules and checks to ensure compliance with design standards.
- Provide visual feedback on rule violation



Rules embedded in the design that reacts to parameter changes

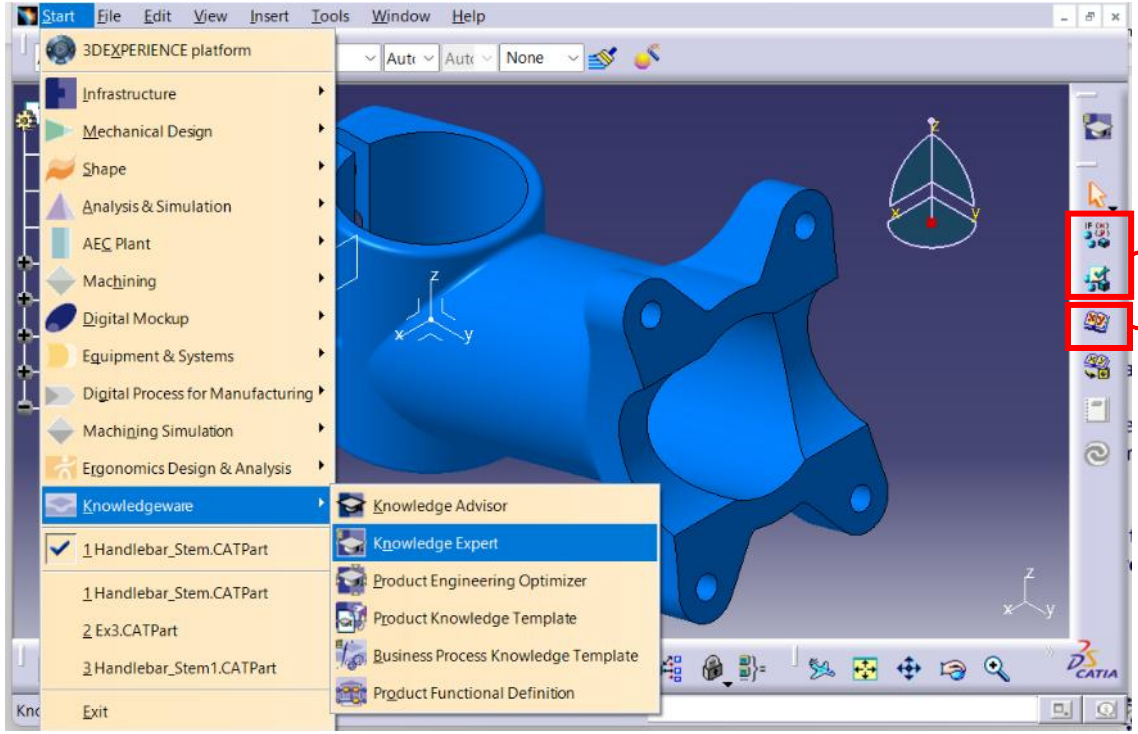
Check embedded in the design that inform the user in case of violation

Reaction feature that reacts to specific events and propagates any type of modifications

CATIA's Knowledge Expert

Overview of the tool:

- A more comprehensive tool for building and managing knowledge bases across multiple projects
- Create and manages generic rules and checks that can be applied to multiple design documents
- Allows for the creation of rule sets to structure the knowledge base



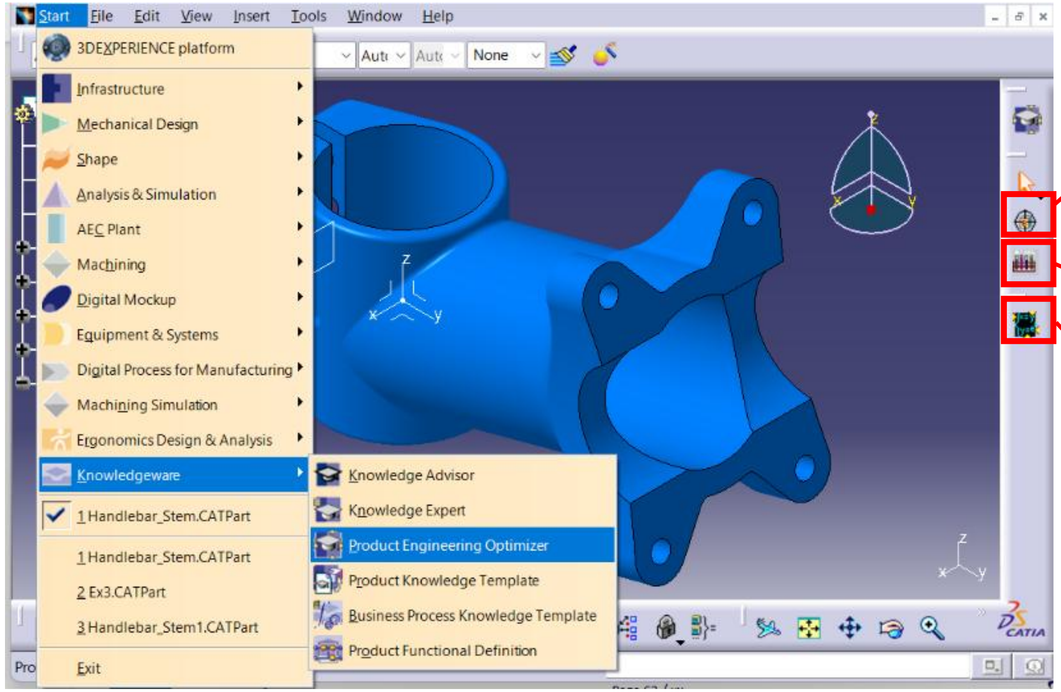
For creating and managing Expert Rules and Checks

Expert Rule Set: a group of expert rules or checks

CATIA's Product Engineering Optimizer

Overview of the tool:

- The Product Engineering Optimizer is the Catia's answer to optimization
- It provides engineers with an easy to use tool based on iterative methods
- Can operate with Local algorithms (*Conjugate gradient*) and Global algorithms (*Simulated Annealing*) to run an optimization depending on the function to analyze



Optimization: Formulates the objective to find the best of all possible values of a function with respect to come constraints

Design of Experiments: Perform virtual experiments considering as many parameters as needed

Constraint Satisfaction: define and manage constraints between geometric elements in a model

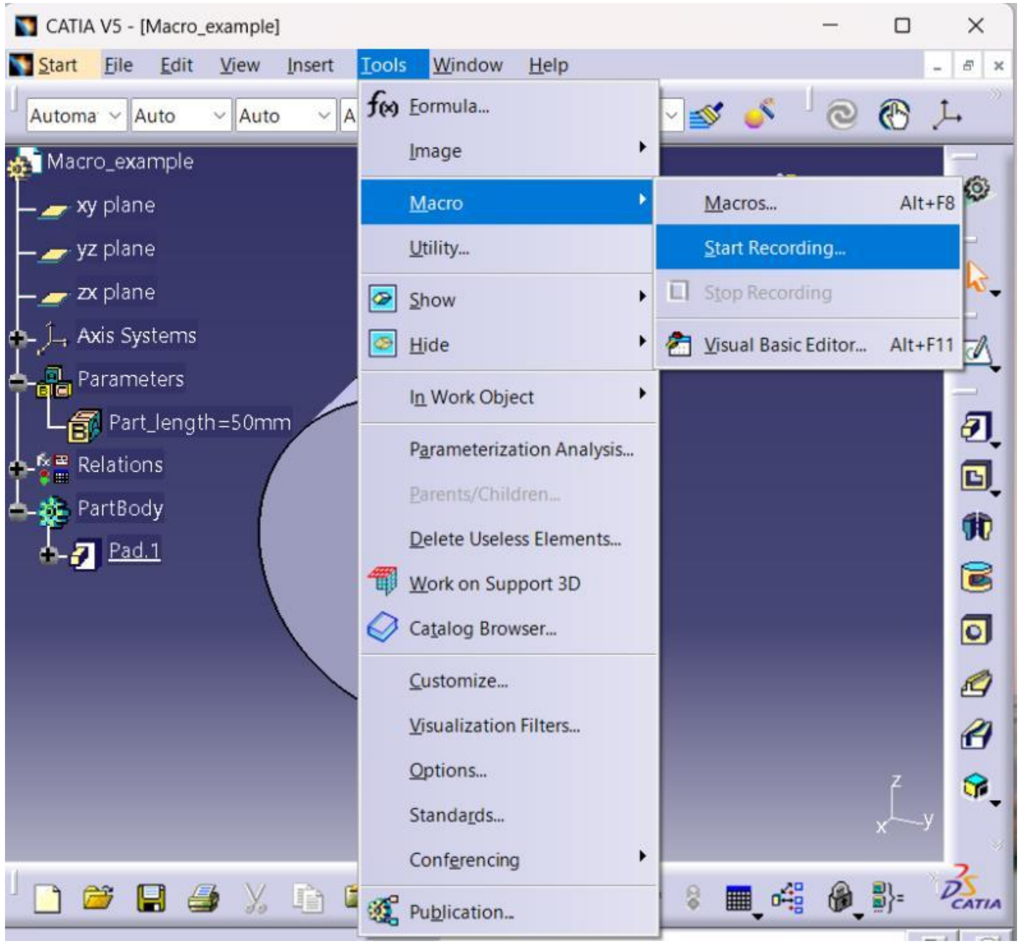
Macros and Scripts in CATIA

Macros:

- Recorded sequences of commands or custom scripts written in Visual Basic for Applications (VBA) that automate repetitive tasks, complex operations, or customized functionalities within the CATIA environment.
- Can interact with CATIA's object model to manipulate parts, assemblies, drawings, and other CATIA elements

Creation methods:

- Recording user actions directly in CATIA
- Writing code manually in the Visual Basic Editor



Macros and Scripts in CATIA

Scripts: key component in automating design processes and embedding engineering knowledge into CAD models.

Types of scripting in CATIA :

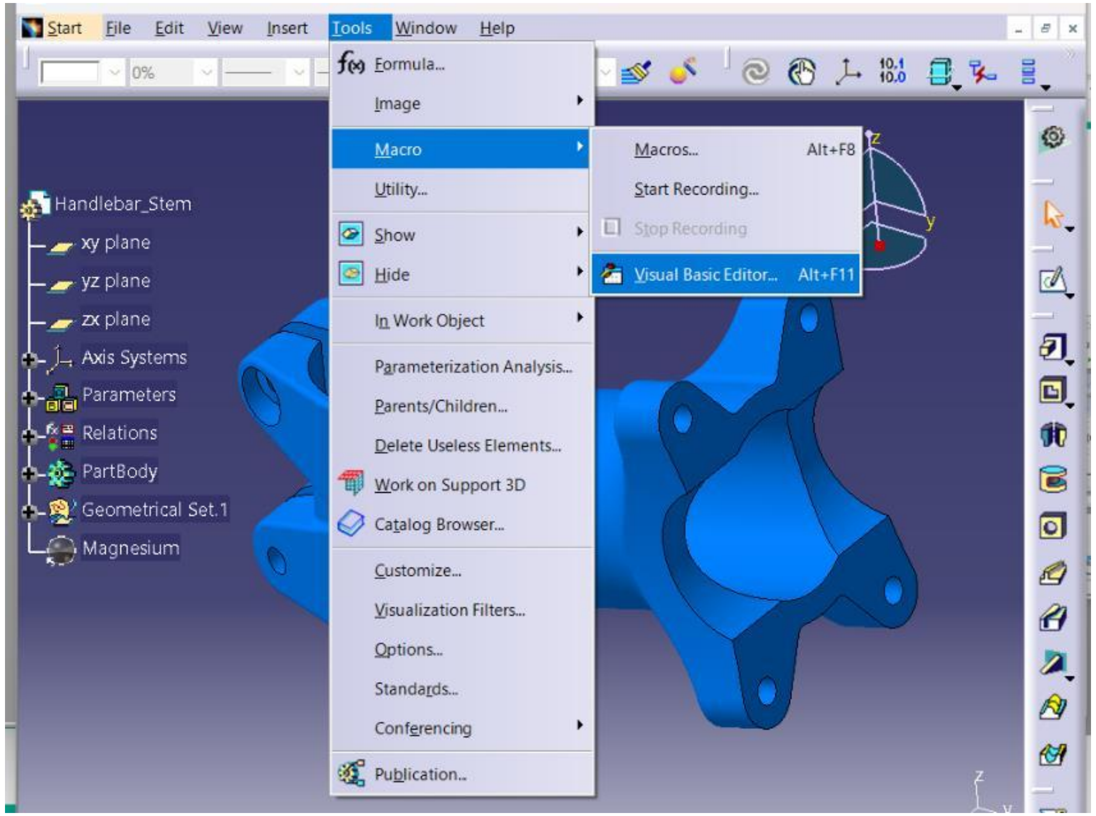
- Knowledge Expert: A CATIA workbench that allows creation of rules and checks without traditional programming.
- VBA (Visual Basic for Applications): The most common scripting language in CATIA.
- CAA (Component Application Architecture): For more advanced C++ based development
- Python: Available in some CATIA environments, especially with newer versions

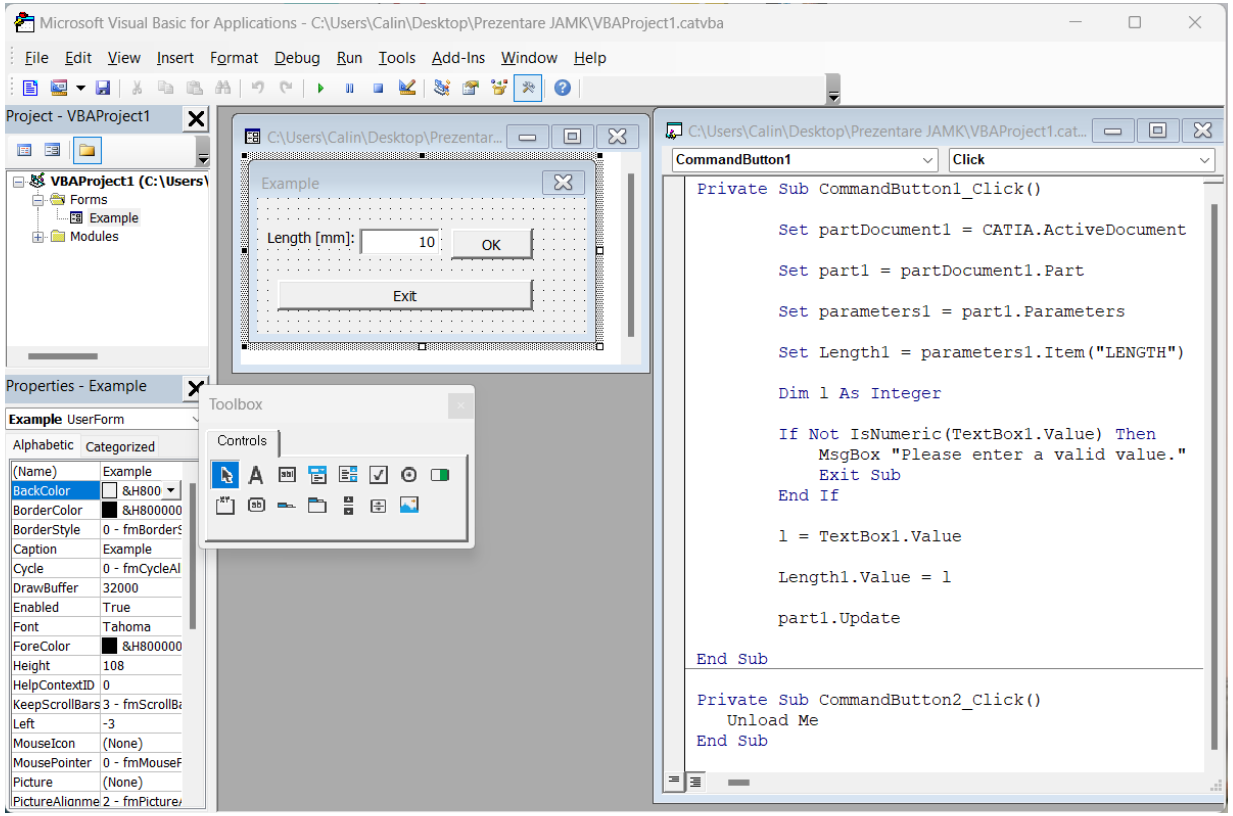
Advantages over recorded macros:

- More flexible and powerful
- Can include complex logic and error handling
- Able to interact with other applications or data sources
- Can be more easily maintained and version-controlled

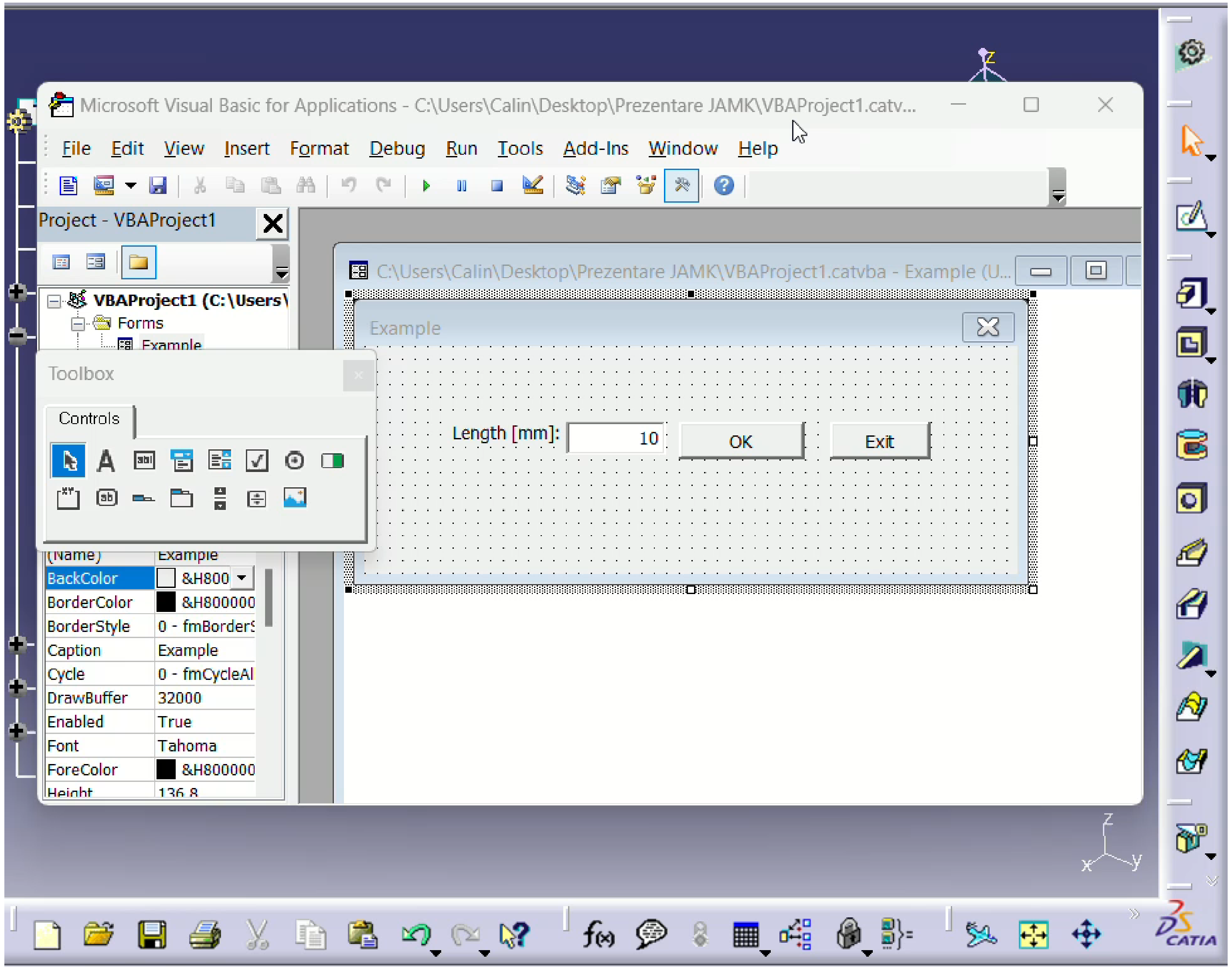
CATIA’s VBA interface

Objective: Create a VBA script for CATIA that allows you to enter a value in a dialog box and change a part dimension accordingly





CATIA's VBA interface



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Eco-Friendly Engineering through Parametric Design

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Eco-Friendly Engineering through Parametric Design

Eco-friendly engineering also known as *sustainable engineering* or *green engineering*, is the practice of developing products, that are environmentally responsible and resource-efficient throughout their entire life cycle, from raw material extraction to end-of-life disposal or recycling.

Focus Areas:

1. Material Optimization:
   - Material selection
   - Material usage optimization
2. Weight Reduction Strategies:
   - Structural optimization
   - Lightweight materials
3. Design for Disassembly (DfD):
   - Modular design
   - Recycling considerations

Source: https://convercon.com/embracing-a-sustainable-future-green-engineering-in-product-design/

Material Optimization

A bike handlebar stem must be:

- **Strong:** Able to withstand the forces exerted by the rider and the handlebars.
- **Lightweight:** To improve bike performance and handling.
- **Durable:** Resistant to corrosion, fatigue, and impact.
- **Aesthetically pleasing:** Align with the overall design of the bike.

Strategies :

- **Consider candidate materials:** Based on the requirements, explore materials like aluminum alloys, steel, carbon fiber, and titanium.
- **Perform structural analysis:** Use Catia's simulation tools to analyze the stem's stress distribution and deflection under various loading conditions (e.g., rider weight, handlebar forces).
- **Evaluate material performance:** Compare the performance of different materials based on factors like stress levels, weight, and cost.
- **Optimize material usage:** Use parametric design to explore different stem geometries and material combinations to find the optimal solution.

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Weight Reduction Strategies

Reducing the weight of a bike handlebar stem can improve handling, acceleration, and overall performance

Example of Weight Reduction in CATIA:

- Create a parametric model of the stem, including dimensions and material properties.
- Perform a structural analysis to determine the critical areas of the stem.
- Use topology optimization or generative design to identify areas where material can be removed.
- Modify the stem's geometry based on the optimization results.
- Perform another structural analysis to ensure that the modified design meets performance requirements.
- Compare the weight of the original and modified designs to assess the weight reduction achieved

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Design for Disassembly

Design for Disassembly (DfD) involves designing products to make them easier to disassemble and recycle at the end of their useful life. This reduces waste and promotes a circular economy

DfD Strategies for a Bike Handlebar Stem:

- **Parametric design**: Use Catia's parametric modeling capabilities to create modular designs that can be easily modified and adapted.
- **Separate components**: Design the stem as an assembly of separate components, such as the stem body, handlebar clamp, and spacers.
- **Quick-release mechanisms**: Use quick-release mechanisms or fasteners to simplify disassembly.
- **Avoid welding:** Use mechanical fasteners or adhesives that can be easily removed.
- **Recyclable materials:** Choose materials that are easily recyclable, such as aluminum or steel.

THANK YOU

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C5 – Computer Aided Design

M4 – 3D-Scanning

P1 – JAMK University of Applied Sciences

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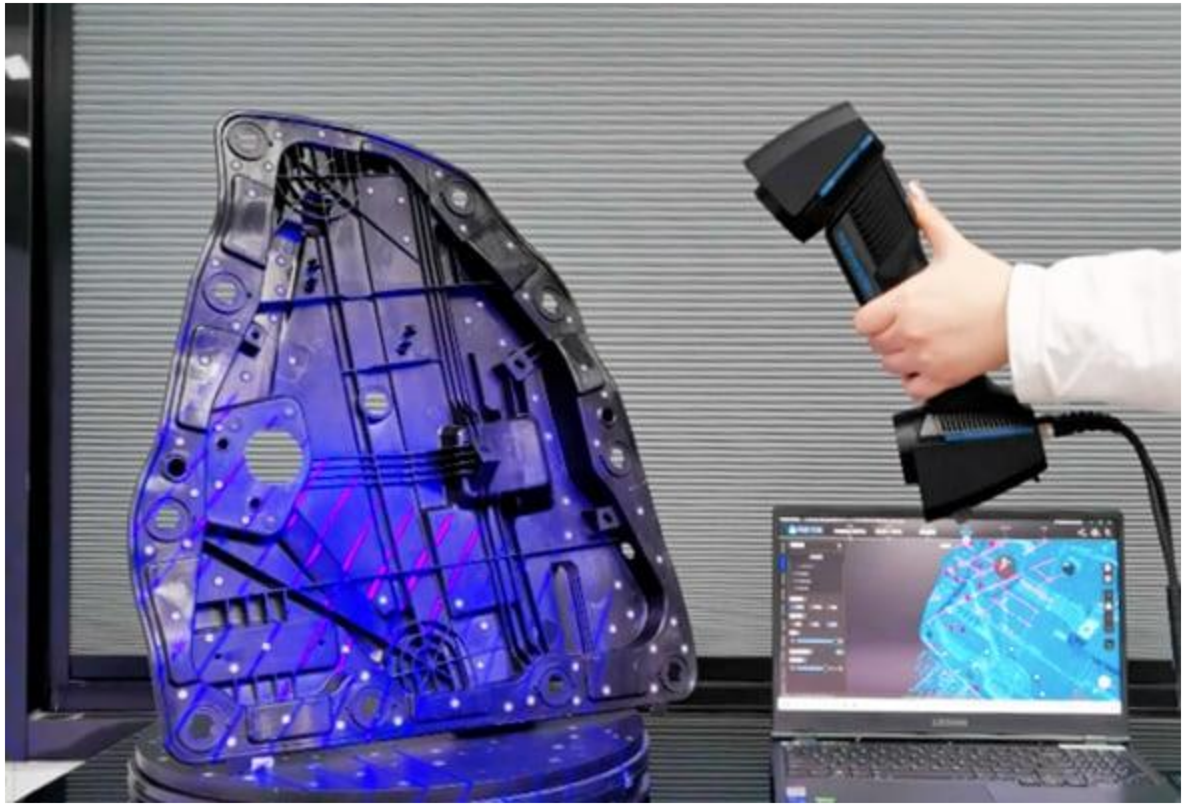
3D-scanning

Principle

- Laser- and/or light-based 3D-measuring
- Based on processing Point Clouds and Triangular meshes formed by millions of measured 3D-coordinate points
- 3D-Scans always require post-processing



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3D-scanning

Principle

- Scanners of different types and sizes
  - Handheld
  - 360 deg
  - Fixed installations
  - Mobile (eg. Drones)

[EngineersGarage, Artec]

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3D-scanning

Scanner types

- Desktop scanners are designed for scanning small to medium-sized objects. They often use structured light or laser triangulation technology and are ideal for applications requiring high precision, such as jewelry or dental work.
- Handheld scanners are portable and easy to use. They can be laser-based or structured light-based and are ideal for scanning medium-sized objects in situ or in difficult-to-reach places. They offer flexibility and convenience for various applications.
- Tripod-mounted scanners are portable scanners intended for scanning buildings, industrial sites or other large areas. The scanner is stationary during the measurements and automatically measures 360 degree bubble around the location.

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3D-scanning

Scanner types – Laser Scanners

Laser scanners emit laser beams to measure distances and create precise 3D models. They are known for their accuracy and ability to scan complex surfaces, including shiny or dark finishes. Common types include:

- Laser Triangulation Scanners: Use a laser beam and a camera to triangulate the position of points on an object's surface.
- Time-of-Flight Scanners: Measure the time it takes for a laser pulse to travel to the object and back, ideal for scanning large objects or environments.

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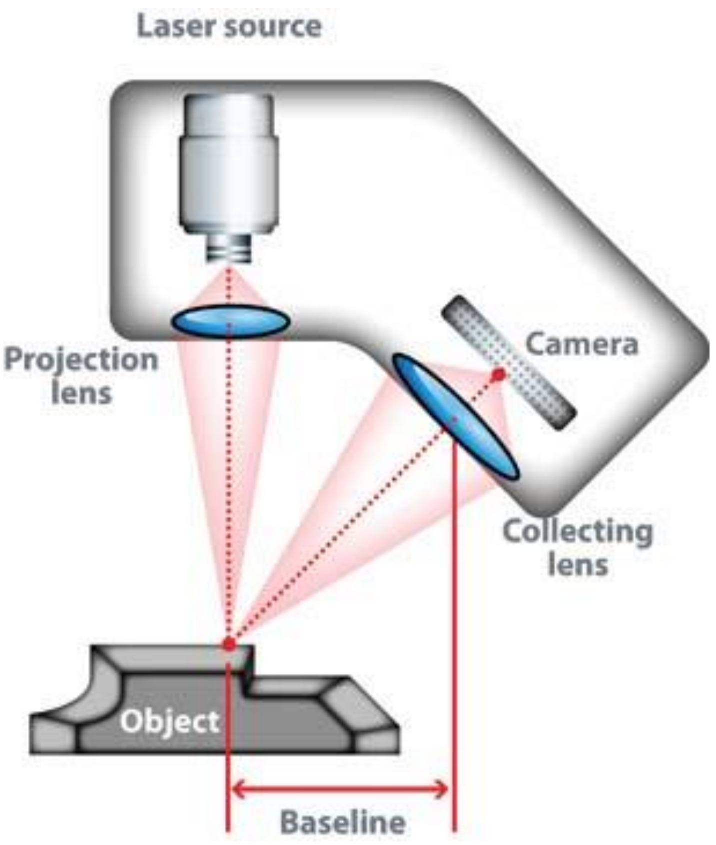
3D-scanning

Scanner types – Laser Triangulation Scanners

- Essentially automatized laser-based distance measuring
- Object is scanned with the laser (or another type of light source)
- The camera in the scanner measures the reflections based on triangulation of the beam
- Millions of points are measured in order to determine the geometry of the part



[DigitalEngineering]

3D-scanning

Scanner types - Structured Light Scanners

Structured light scanners project patterns of light (such as grids or stripes) onto the object.

- Sensors capture the deformation of these patterns to determine the object's shape.
- Fast and can capture high-resolution data, making them suitable for scanning large areas quickly.

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3D-scanning

Scanner types – Other Scanners

- Photogrammetry involves taking multiple photographs of an object from different angles and using software to stitch these images together into a 3D model. This method is highly versatile and can be used with standard cameras. It's particularly useful for capturing detailed textures and is often used in cultural heritage preservation. Dimensions of the object are based on reference measurements and are generally not accurate enough for precise engineering purposes.
- 3D scanning apps are available for smartphones and tablets. These apps use the device's camera to capture images and create 3D models. While not as accurate as dedicated scanners, they offer a convenient and accessible way to perform basic 3D scanning.

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3D-scanning

Scanner types – Other Scanners

- Computed Tomography (CT) Scanners use X-rays to capture detailed internal and external structures of an object. They are commonly used in medical imaging and industrial inspections to create highly accurate 3D models.
- Contact scanners physically touch the object to measure its dimensions. A probe moves across the surface, recording data points. While highly accurate, this method is slower and less suitable for delicate or soft objects.

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3D-scanning

Scanner types – Software Tools

- Point Cloud Processing Software: Proprietary software from the scanner supplier or general point cloud processing software like CloudCompare or Geomagic are used to process and clean up point cloud data.
- Mesh processing and other 3D Modeling Softwares: Tools like Blender, MeshLab, and Autodesk Maya can be used to refine and manipulate mesh-based 3D models.
- CAD Software: Used for creating detailed digital solid or surface models from scanned data.

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3D-scanning

Process – Preparation

- Choosing the Scanner: Appropriate type of 3D-scanner is chosen based on the object's size, material, and required detail (e.g., laser scanner, structured light scanner, photogrammetry).
- Cleaning the Object: Ensure the object is clean and free from dust or debris that could interfere with the scanning process.
- Positioning: Object is generally placed in a stable and accessible position.

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3D-scanning

Process – Scanning

- Capturing Data: The scanner projects light or lasers onto the object and captures the reflected data. This process involves moving the scanner around the object or rotating the object to capture all angles.
- Point Cloud Generation: The scanner generates a point cloud, which is a collection of data points representing the object's surface.
- Multiple Scans: For complex objects, multiple scans from different angles are often necessary to capture all details.

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3D-scanning

Process – Scanning

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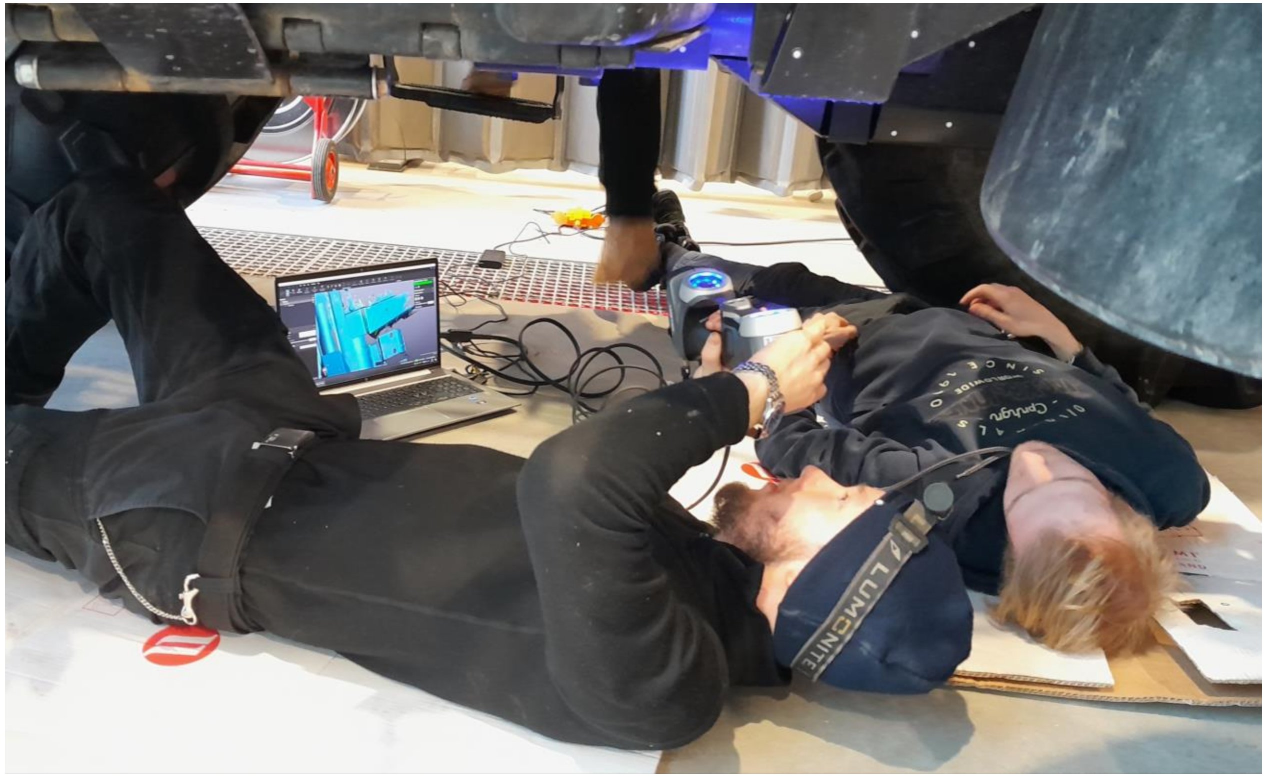
- https://panopto.jamk.fi/Panopto/Pages/Viewer.aspx?id=29e5b9de-ccb7-443a-bd03-b2cf00dd22ab



3D-scanning

Process – Scan Data Processing & Model Creation

- Cleaning Up: Any noise or unwanted data points are removed from the scan.
- Alignment: Multiple scans are combined into a single coordinate system. This step, known as registration, ensures that all scans align correctly.
- Meshing: The point cloud is converted into a mesh, which consists of vertices, edges, and faces that define the object's shape. This step creates a continuous surface from the discrete points.
- Texturing: If color and texture data were captured, this information is applied to the mesh to create a photorealistic 3D model.

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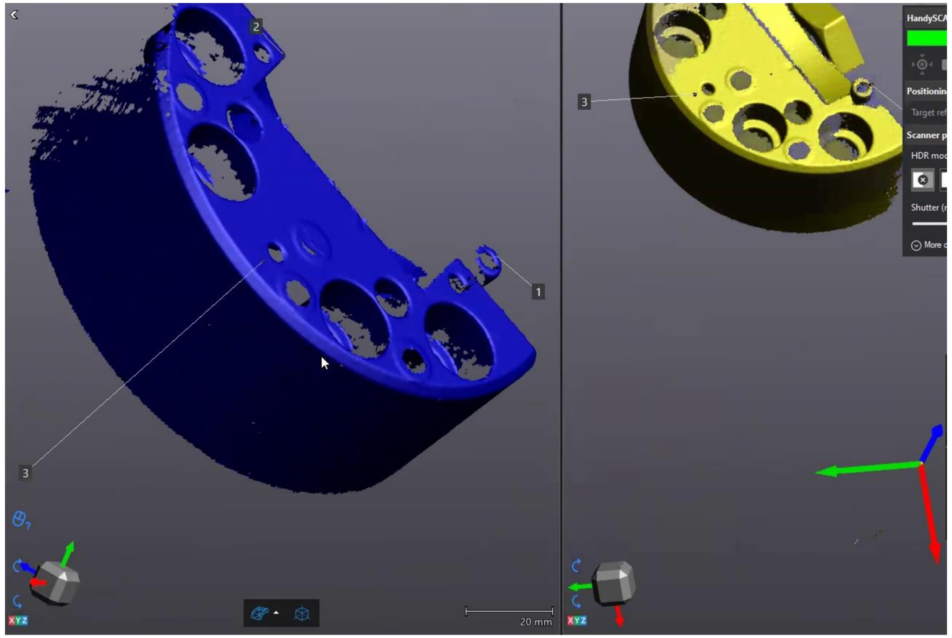
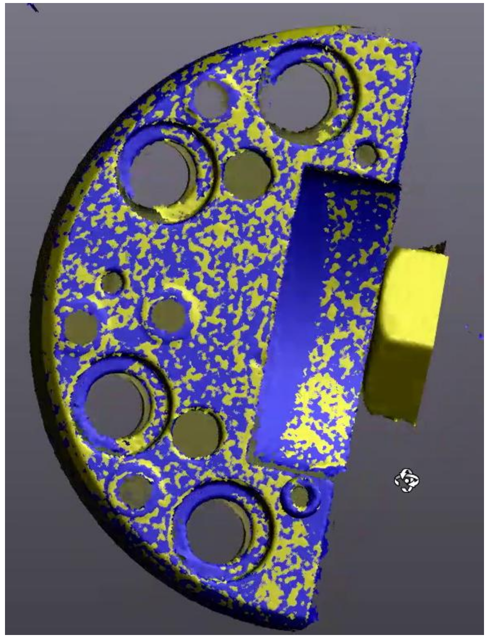
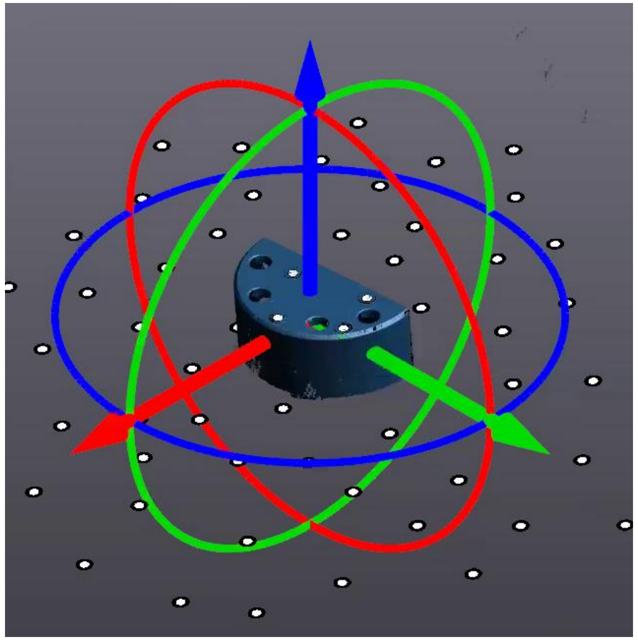
3D-scanning

Process – Scan Data Processing & Model Creation



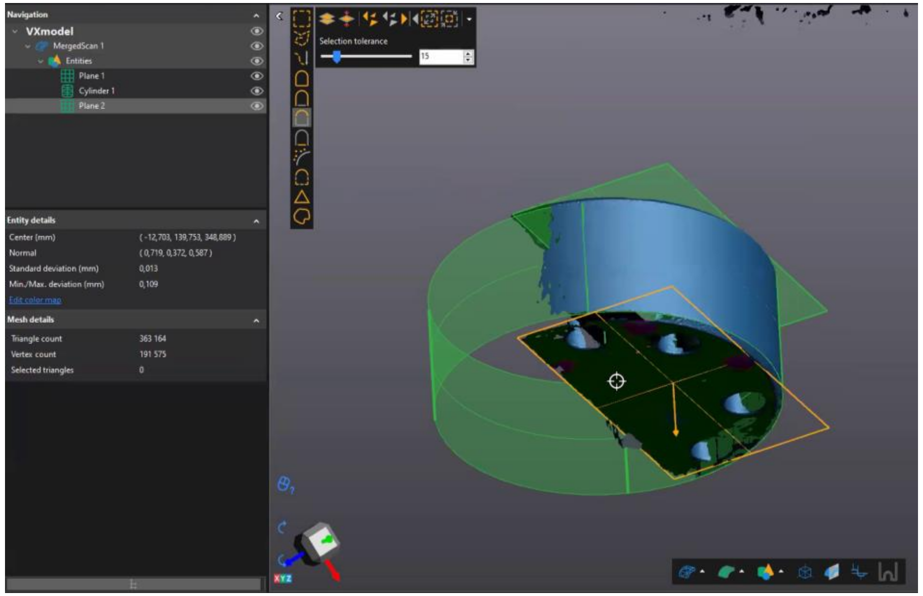




3D-scanning

Process – Scan Data Processing & Model Creation

- Smoothing and Detailing: The mesh is refined to improve accuracy and detail. This may involve smoothing surfaces or adding finer details.
- Feature generation: The whole object or parts of the model can be detected as mathematically defined planes, points, or other geometrical features.



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3D-scanning

Process – Scan Data Processing & Model Creation

- Exporting the Model: The final 3D model and possible detected features is exported in the desired file format (e.g., STL, OBJ, PLY) for use in various applications such as 3D printing, CAD, or virtual reality.

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3D-scanning

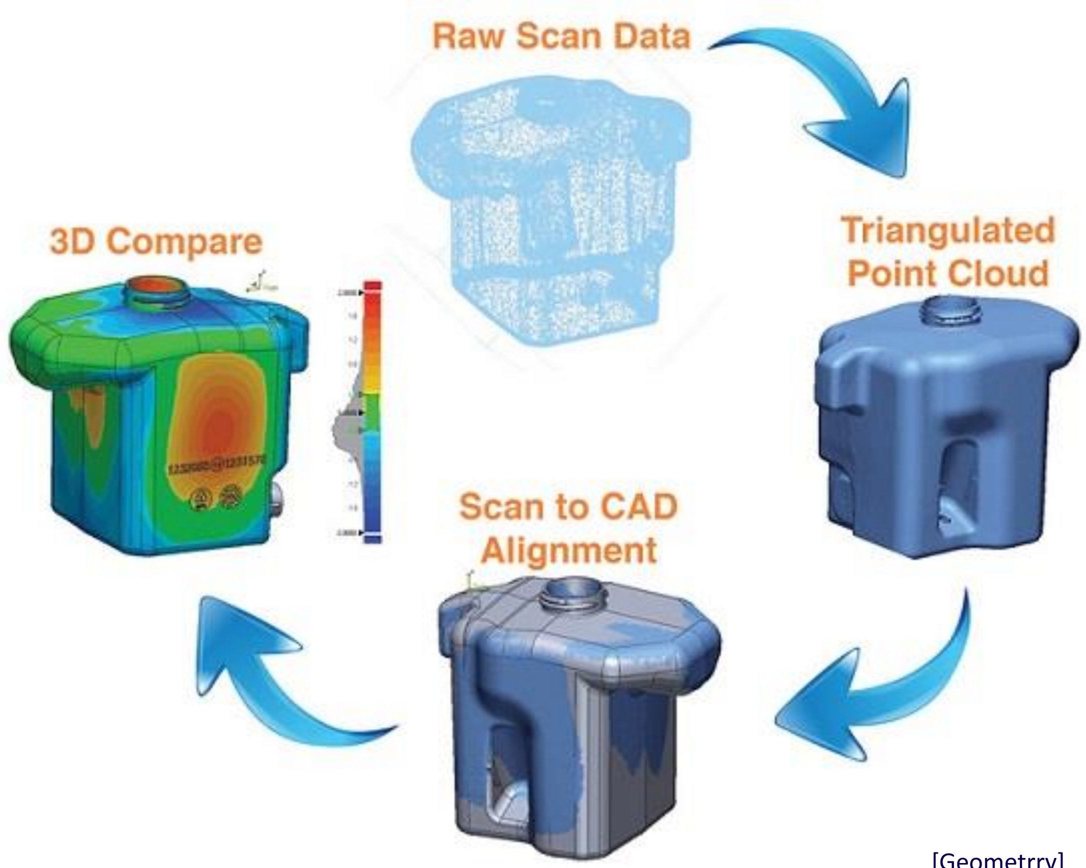
Applications – Engineering

- Reverse Engineering: 3D scanning is employed to digitize existing products or parts, enabling designers to analyze and improve upon them. This is particularly useful for creating custom or replacement parts.
- Customization: In industries like medical device manufacturing, 3D scanning is used to create custom prosthetics and orthotics that fit perfectly to the patient's body.

3D-scanning

Applications – Engineering

- Quality Control and Inspection: 3D scanning is used to inspect manufactured parts and products to ensure that they are built according to design specifications. Scanning can help in identifying defects and discrepancies early, reducing costly rework or enabling fixing the problems before moving forward with the production or delivery.



[Geometrry]

3D-scanning

Applications – Engineering

- Rapid Prototyping: Designers use 3D scanning to create digital models of their concepts, allowing for quick prototyping and testing. This accelerates the design process and helps in refining ideas efficiently.

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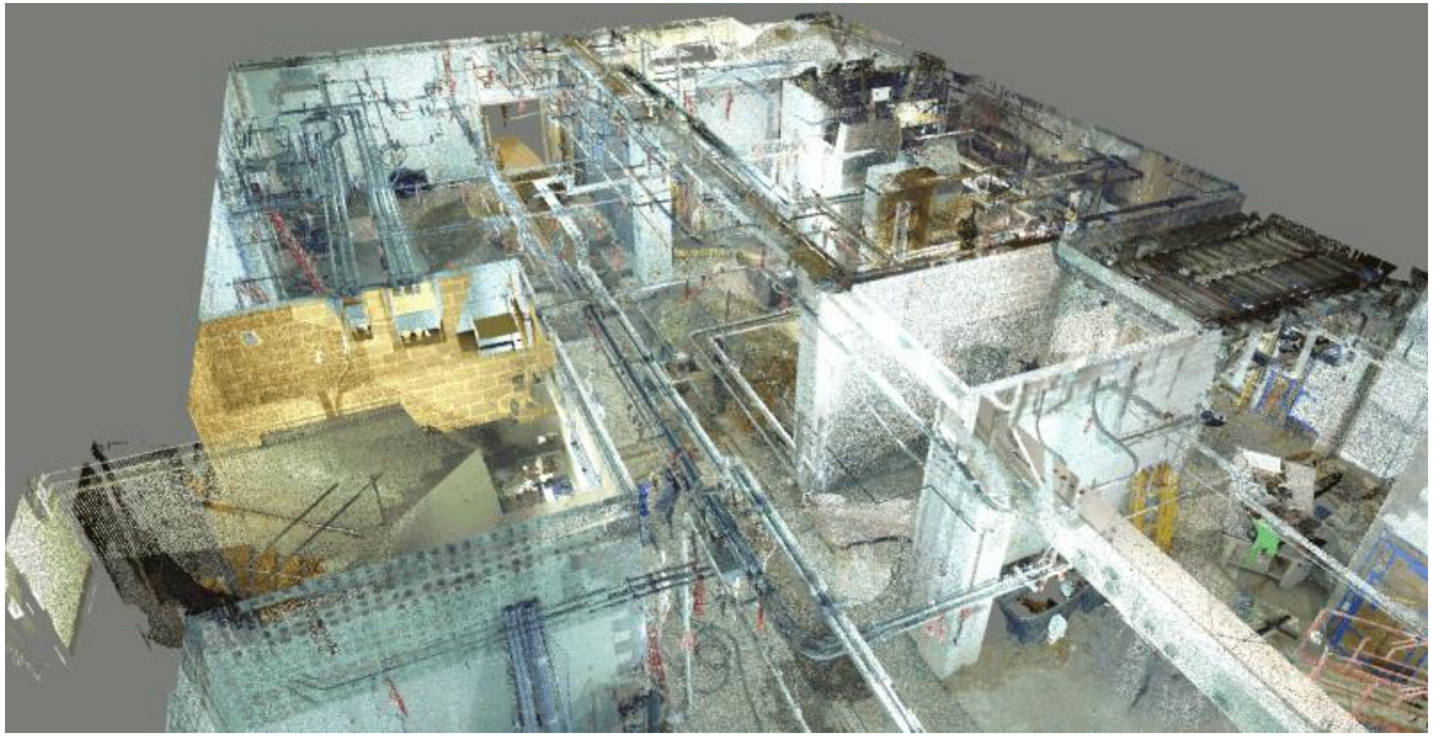
3D-scanning

Applications – Construction

- Quality Control and Inspection: 3D scanning is used to monitor construction progress and ensure that structures are built according to specifications. It helps in identifying discrepancies early, reducing costly rework.
- Safety: By providing detailed scans of construction sites, 3D scanning enhances safety by identifying potential hazards and ensuring compliance with safety standards.
- Topographic Surveys: 3D scanning captures detailed information about the terrain and features of a construction site, facilitating site planning and grading activities.

3D-scanning

Applications – Construction



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3D-scanning

Applications - Architecture

- As-Built Documentation: 3D scanning captures the exact dimensions and details of existing structures, creating accurate as-built models. These models are crucial for renovation projects, ensuring that new designs fit perfectly with existing conditions.
- Design and Visualization: Architects use 3D scans to create detailed visualizations of their designs. This helps in presenting concepts to clients and stakeholders, providing a realistic view of the final product.
- Restoration and Preservation: Historical buildings and monuments can be scanned to create precise digital replicas in order to aid in restoration efforts or preserve the architectural heritage.

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3D-scanning

Applications - Architecture

[Globalsurvey]

3D-scanning

Other Applications

- Entertainment: In the movie, television, and video game industries, 3D scanning is used to create detailed 3D models of characters, props, and environments. This helps in creating realistic animations and special effects.
- Medicine: 3D scanning is increasingly important in the medical field for creating accurate models of body parts. These models can be used for surgical planning, custom prosthetics, and even for educational purposes.

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3D-scanning

Other Applications

- Cultural Heritage Preservation: Museums and historians use 3D scanning to document and preserve artifacts, sculptures, and historical sites. This creates digital records that can be studied and shared globally, and helps in restoration efforts.
- Forensics: In forensic science, 3D scanning is used to document crime scenes, analyze evidence, and recreate accidents. This technology provides detailed and accurate data that can be crucial in investigations.

3D-scanning

Benefits

- High Precision and Accuracy: 3D scanners can capture detailed and accurate measurements, which is crucial for engineering and construction.
- Time Efficiency: Traditional measurement methods can be time-consuming. 3D scanning drastically reduces the time required to capture complex geometries and environments. Especially combined with Additive Manufacturing 3D-scanning can e.g. expedite cases where spare parts are urgently needed.
- Comprehensive Data Collection: A single scan can capture millions of data points, providing a complete and detailed representation of the scanned object or environment. This is beneficial for creating detailed models and conducting thorough analyses.

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3D-scanning

Benefits

- Non-Contact Measurements: 3D scanners use contact-free technology, meaning they can capture data without physically touching the object. This is advantageous for scanning delicate or hazardous objects, as it eliminates the risk of damage or contamination.
- Versatility and Flexibility: 3D scanners are versatile tools that can be used in a variety of applications, from industrial inspections and reverse engineering to cultural heritage preservation and medical imaging.
- Cost Savings: By reducing the time and labor required for measurements and inspections, 3D scanning can lead to significant cost savings in various projects.

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3D-scanning

Challenges

- Technical Complexity: Operating 3D scanners and processing the data requires specialized knowledge and skills, and usually plenty of processing power from the computers.
- Data Accuracy: While 3D scanners are generally accurate, certain factors like surface reflectivity, ambient light, and scanner calibration can affect the accuracy of the data.
- High Initial Costs: The initial investment in 3D scanning equipment and software can be high. This includes the cost of the scanner, software licenses, and potentially powerful computers for data processing.

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3D-scanning

Challenges

- Data Processing Time: Although scanning itself is fast, processing the data to create usable 3D models can be time-consuming, especially for large or complex objects.
- Environmental Sensitivity: Some 3D scanners are sensitive to environmental conditions such as lighting, temperature, and vibrations, which can affect the quality of the scans.
- Intellectual Property Issues: Reverse engineering through 3D scanning can raise intellectual property concerns, especially if the scanned object is protected by patents or copyrights.

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3D-scanning

Trends and future outlook

- AI-Driven 3D Scanning: Artificial intelligence (AI) is increasingly being integrated into 3D scanning technologies. AI can enhance the accuracy and speed of data capture, automate data processing, and improve the overall quality of 3D models. AI-driven 3D scanning can also help in real-time data interpretation and error correction.
- Cloud-Based 3D Data Processing: Cloud computing is transforming how 3D scan data is processed and stored. Cloud-based solutions allow for faster processing, easier collaboration, and more efficient data management. This trend is particularly beneficial for large-scale projects that require significant computational power.

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3D-scanning

Trends and future outlook

- Mobile 3D Scanning: Advancements in mobile technology are making 3D scanning more accessible. Smartphones and tablets equipped with advanced cameras and sensors can now perform basic 3D scans. This trend is democratizing 3D scanning, making it available to a broader audience.
- Drone-Based 3D Scanning: Drones equipped with 3D scanning technology are being used for aerial surveys and mapping. This approach is particularly useful for large-scale projects, such as construction site monitoring, environmental studies, and agricultural assessments.

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3D-scanning

Trends and future outlook

- AR and VR Integration: Augmented Reality (AR) and Virtual Reality (VR) are being integrated with 3D scanning to create immersive experiences. This integration allows users to interact with 3D models in real-time, enhancing applications in fields like education, training, and design.
- BIM and Digital Twin Integration: Building Information Modeling (BIM) and digital twins are becoming integral to 3D scanning. These technologies allow for the creation of detailed digital replicas of physical structures, which can be used for maintenance, planning, and simulation purposes.

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3D-scanning

Trends and future outlook

- Enhanced Accuracy and Resolution: The relentless pursuit of higher accuracy and resolution continues to drive innovation. New hardware solutions, refined algorithms, and AI-powered models are pushing the boundaries of what 3D scanners can achieve, aiming for sub-micron accuracy.
- Portability and Miniaturization: Improvements in sensor technology and processing power are leading to smaller, more portable 3D scanners. These portable devices are easier to use in the field and can capture high-quality data without the need for bulky equipment.
- 3D Scanning Automation: Automation is simplifying the scanning process, reducing manual labor, and increasing productivity. Automated systems can handle tasks like point cloud conversion and data cleaning, making the entire workflow more efficient.

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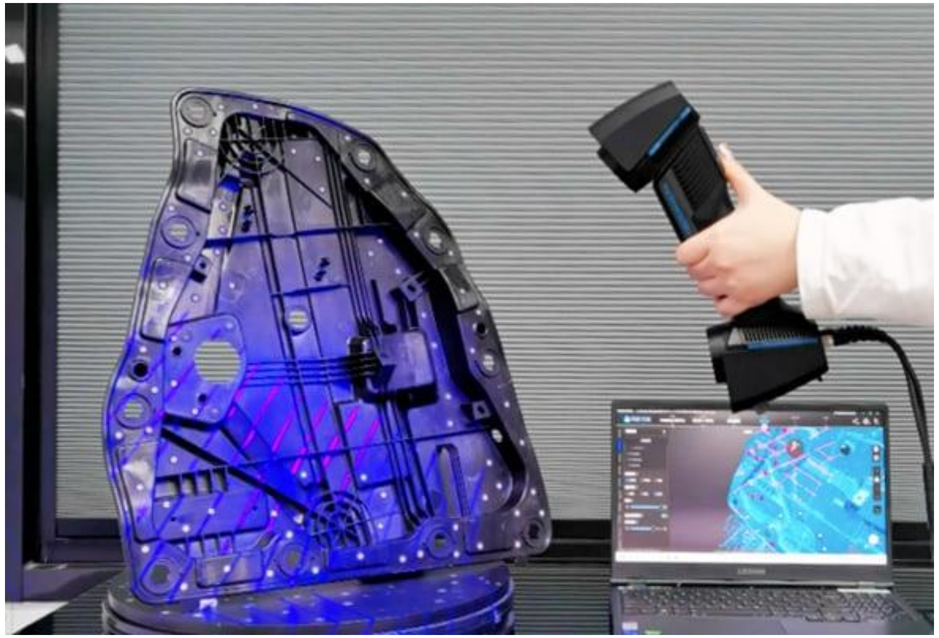
Reverse Engineering

Definition

- Reverse engineering involves deconstructing an object, device, system, or software to understand its design, structure, and functionality.
- Allows engineers and developers to reconstruct, repair, remanufacture and/or improve existing products by identifying flaws, optimizing performance, or repurposing technologies



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Reverse Engineering

Definition

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Reverse Engineering

Process

Obtaining the Object, Disassembly or Deconstruction

- The first step is to acquire the object or system you want to reverse engineer. This could be a physical device, a mechanical part, an electronic circuit, or software code.
- The object is disassembled to access its individual components and internal structure. For physical objects, this might involve taking apart mechanical parts or electronic devices.

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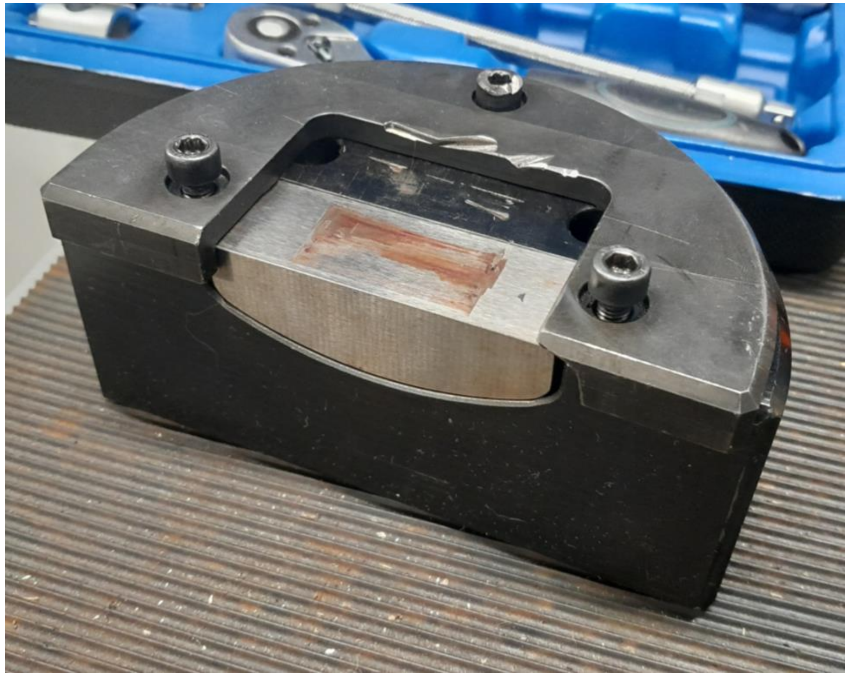
Reverse Engineering

Process



Reverse Engineering

Process

Analysis and Documentation

- Measuring Dimensions: Using tools like calipers or 3D-scanners to capture precise measurements.
- Material Analysis: Identifying the materials used in the components.
- Functional Analysis: Understanding how each part functions within the system.
- Documentation: Recording all findings in detailed diagrams, notes, and models.

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Reverse Engineering

Process

Understanding Design and Functionality

- Deeper analysis to understand the design principles, engineering choices, manufacturing considerations and overall functionality of the object.
- Interaction Analysis: Examining how different components interact and contribute to the system's operation.
- Design Rationale: Understanding why certain design choices were made.

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Reverse Engineering

Process

Understanding Design and Functionality

- Simply copying a part usually gives you a carbon copy of a broken, worn out or defective part with the same design flaws as the original

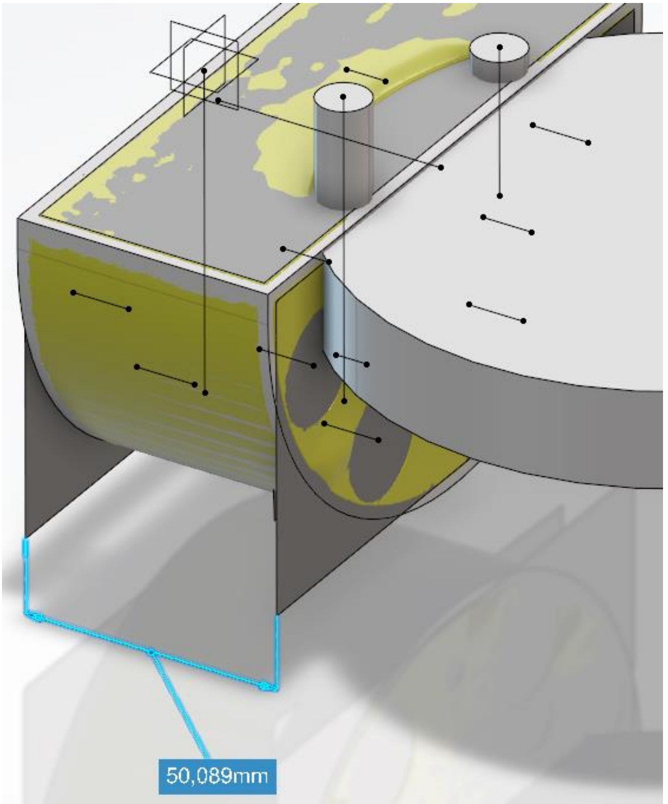
[Dreamstime]

Reverse Engineering

Process

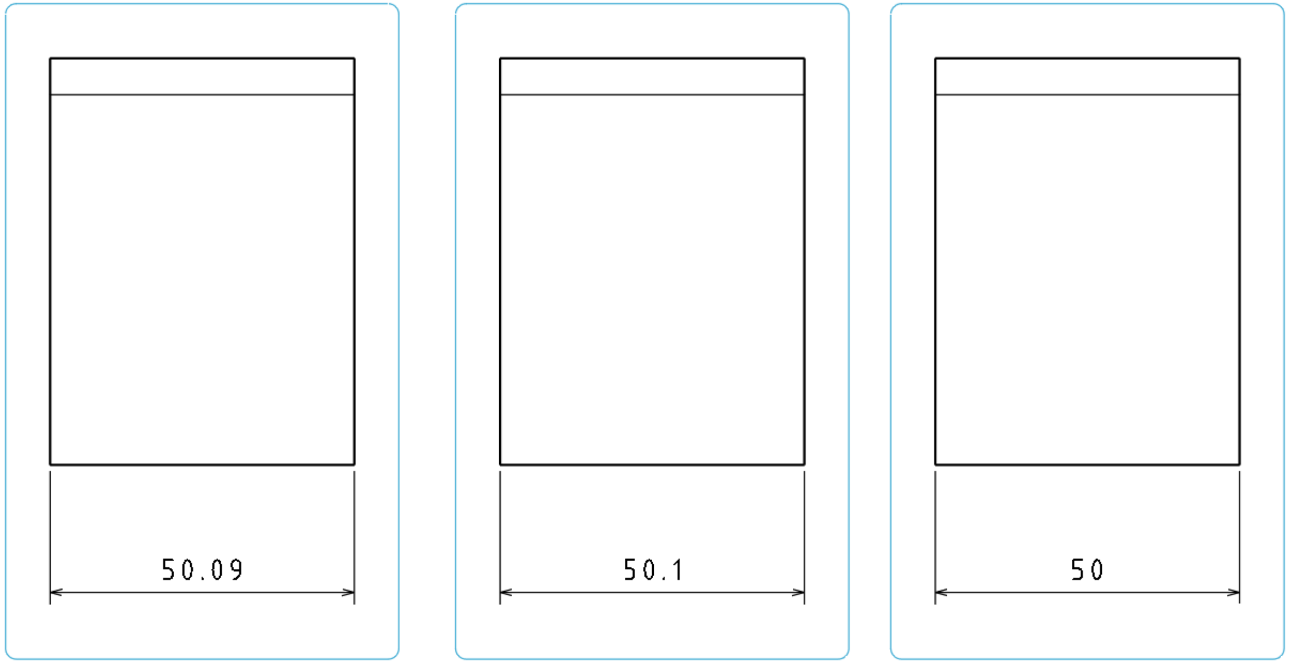
Understanding Design and Functionality

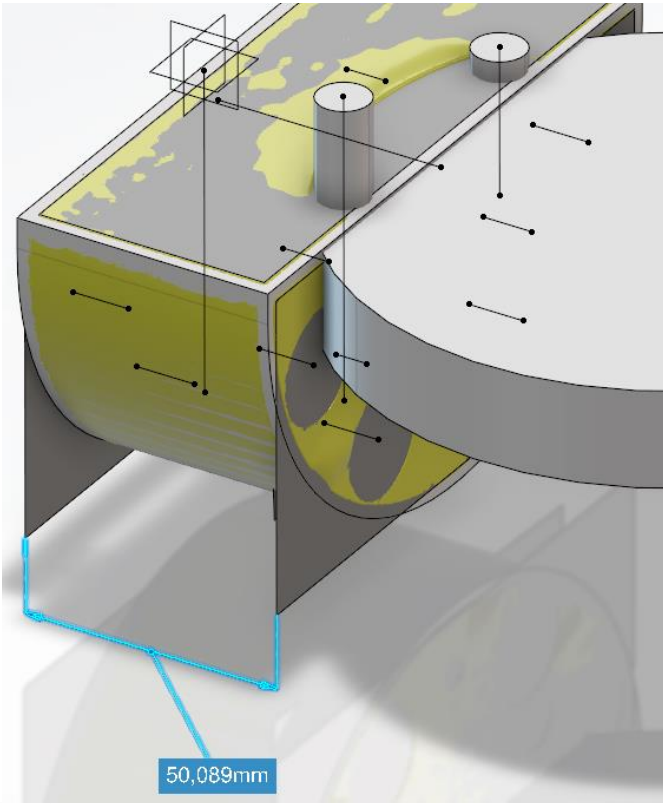
- Why are the measured dimensions as they are?
    - Intent of design
    - Effects of wear and tear
    - Manufacturing inaccuracies



Reverse Engineering

Process





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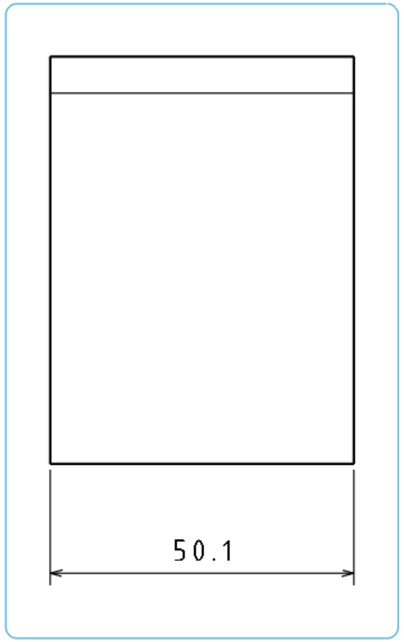
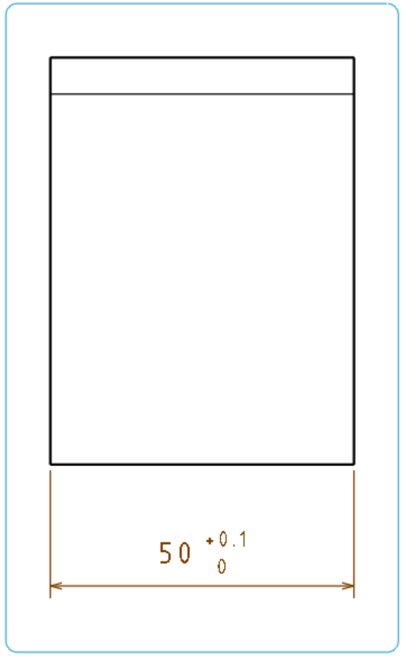
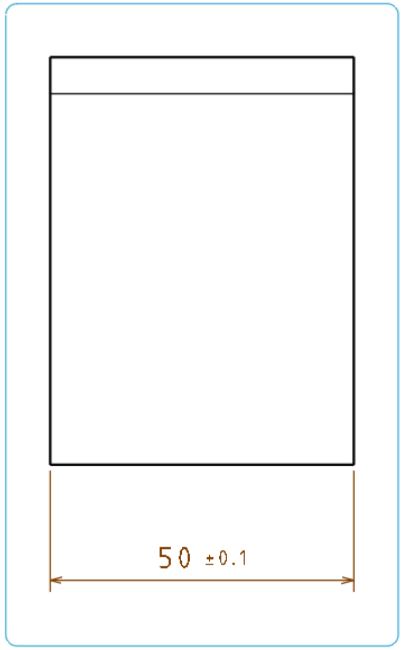
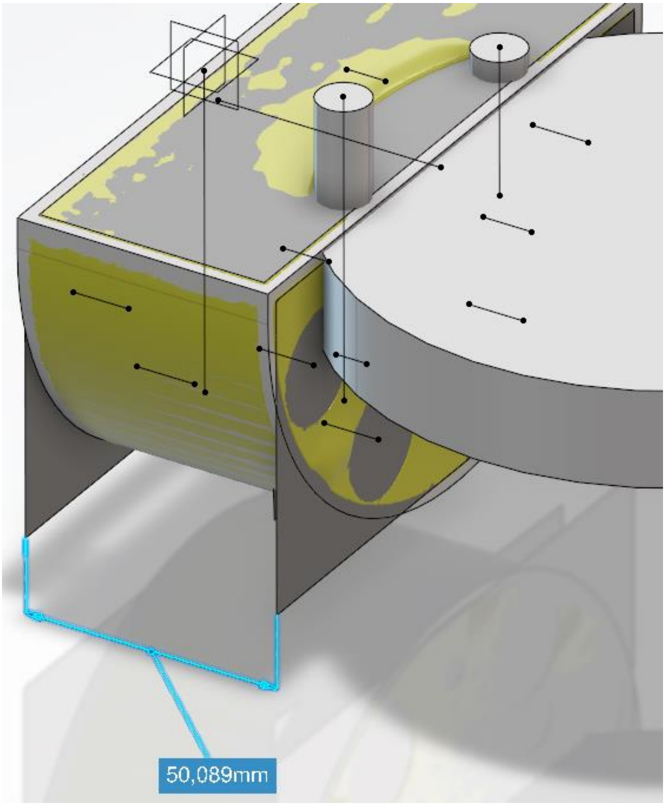
Reverse Engineering

Process









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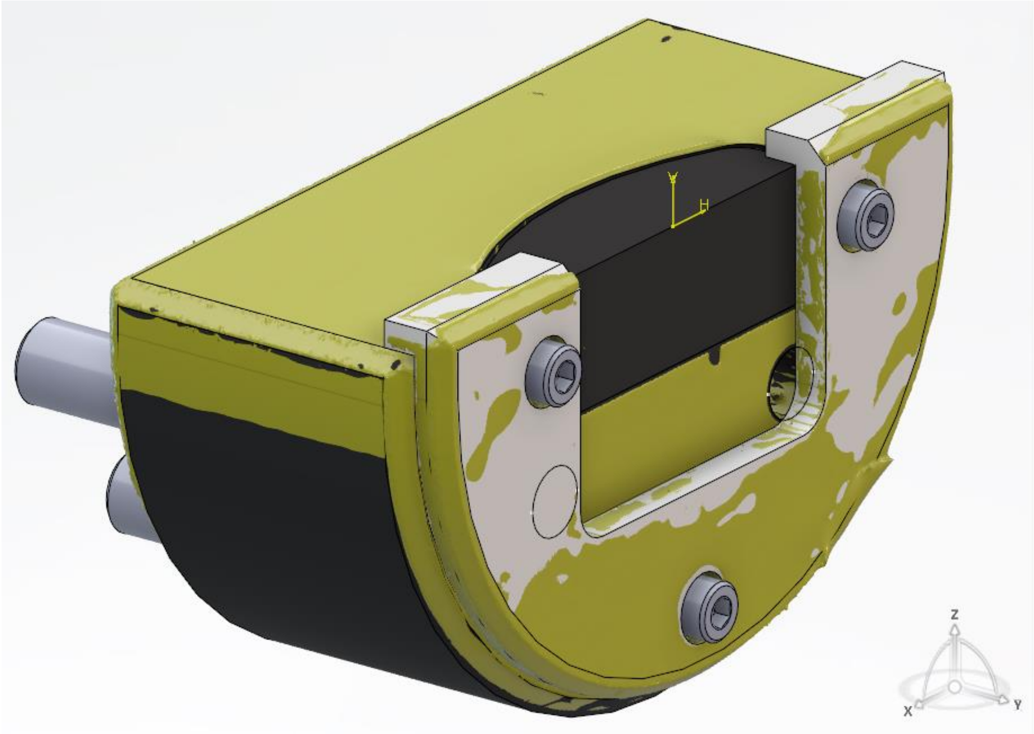
Reverse Engineering

Process

Reconstruction or Replication

- CAD Software: To create detailed digital models.
- 3D Printing: To produce physical prototypes.
- Circuit Design Tools: For electronic components.
- Alternative Manufacturing Methods and materials: Depending on the nature of the object.



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Reverse Engineering

Process

Testing and Validation

- The reconstructed object or system is tested to ensure it functions as intended.
- Performance Testing: Checking if the object meets the required specifications.
- Functional Testing: Ensuring all components work together correctly.
- Iterative Refinement: Making adjustments based on test results to improve accuracy and performance.

Reverse Engineering

Process

Final Documentation

- The final step is to compile all the information, including detailed diagrams, models, and test results, into comprehensive documentation. This serves as a reference for future use and ensures that the reverse-engineered object can be reproduced accurately.

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Reverse Engineering

Benefits of Reverse Engineering

- Innovation: By understanding existing products, improved versions can be created
- Cost Savings: Recreating legacy parts or optimizing existing designs can save costs in production and maintenance.
- Competitive Advantage: Analyzing competitors' products can provide valuable insights for differentiation and improvement.

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Reverse Engineering

Applications of Reverse Engineering

Manufacturing and Product Design

- Recreating Legacy Parts: Many industries rely on legacy equipment that is no longer in production. Reverse engineering helps recreate these components by digitizing their designs for modern manufacturing methods like 3D printing or CNC machining.
- Aftermarket Solutions: Companies can reverse-engineer OEM parts to create cost-effective aftermarket replacements.

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Reverse Engineering

Applications of Reverse Engineering

Manufacturing and Product Design

- Optimizing Performance: By analyzing the weaknesses of existing designs introduce enhancements can be introduced that improve durability, efficiency, and performance or the product. Manufacturers can reverse-engineer parts to develop lighter, more durable, and energy-efficient components.
- Competitor Analysis: Understanding how competitors' products are designed and manufactured offers insights that can drive innovation and differentiation in your own products.

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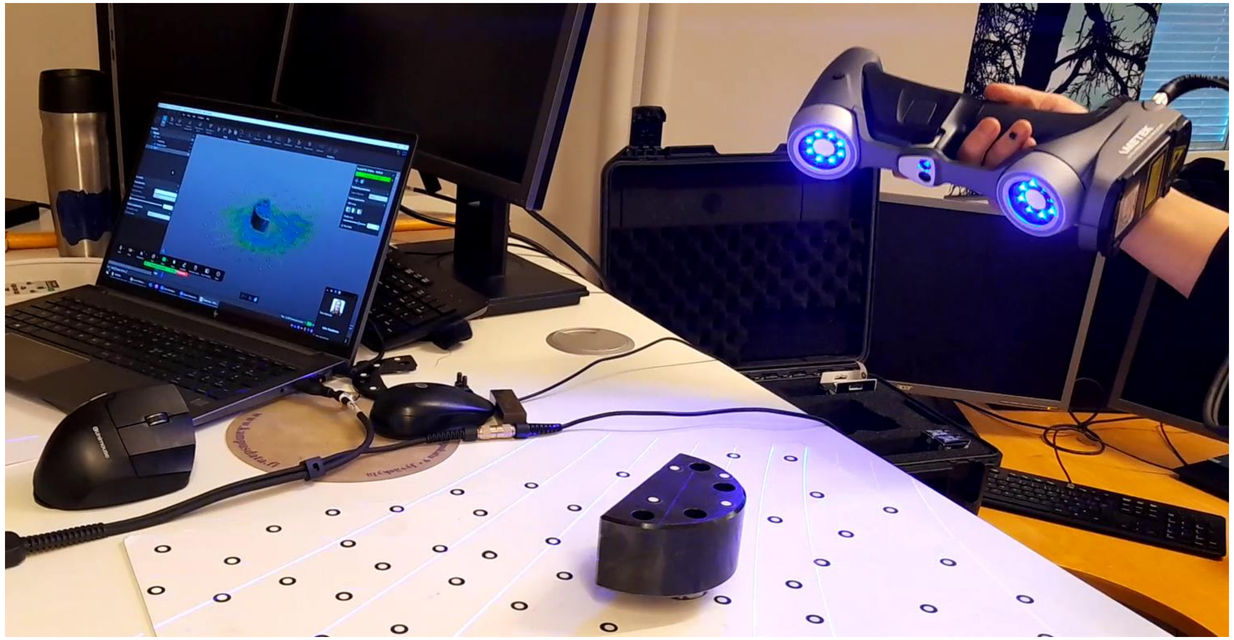
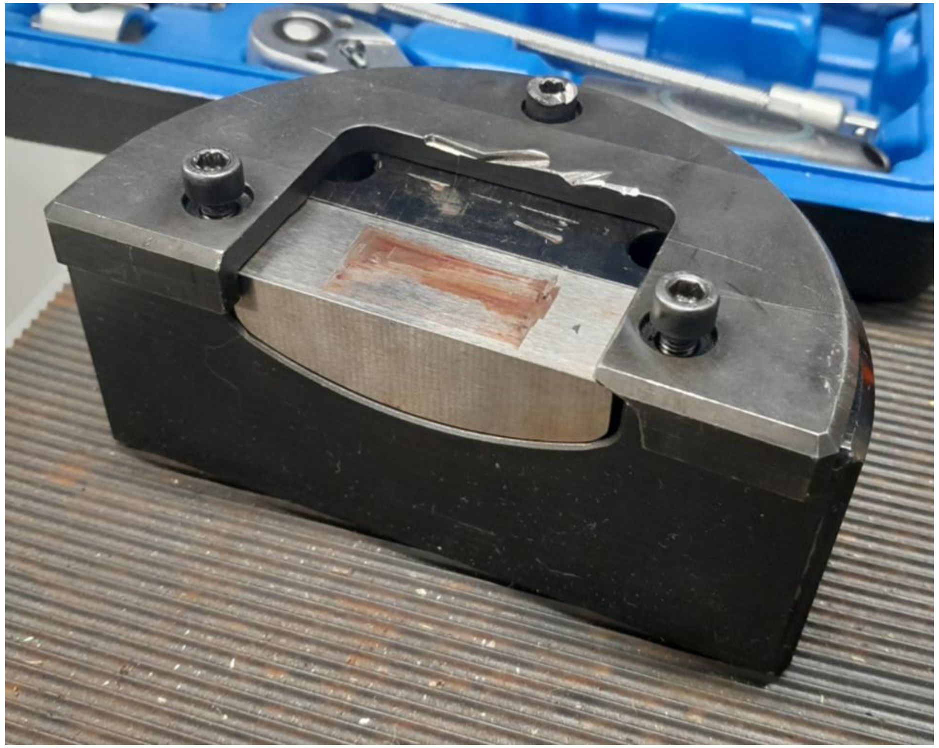
EX: Reverse Engineering

Exercise: Spare part design





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EX: Reverse Engineering

Task

- Make 3D-models and proper manufacturing drawings for spare parts using the 3D-scanning data and additional information provided in these instructions
- Use bolt dimensions provided to find fitting parts from online part libraries (e.g. part supply - download and import .stp files) and to correctly dimension the bolt holes
- Use your own judgment for dimensioning, geometrical tolerances and surface roughness
- Files to submit:
    - Screenshot of the Assembly, with modeled parts, 3D-scan mesh and scanned surfaces visible
    - Manufacturing drawings of the parts

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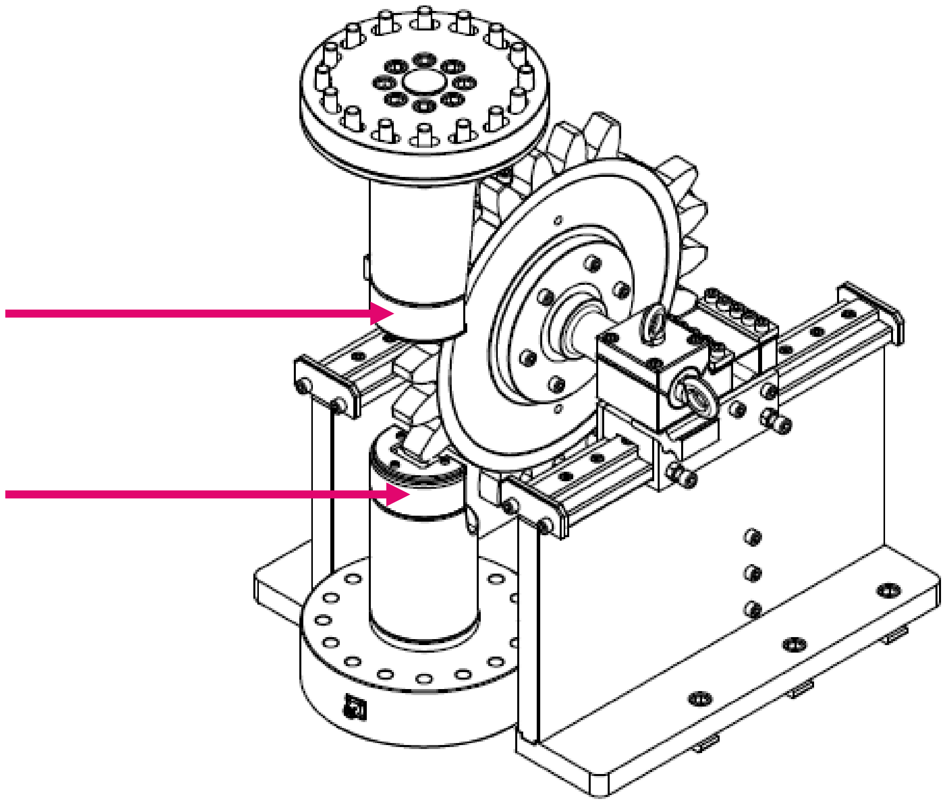
EX: Reverse Engineering

Assembled product

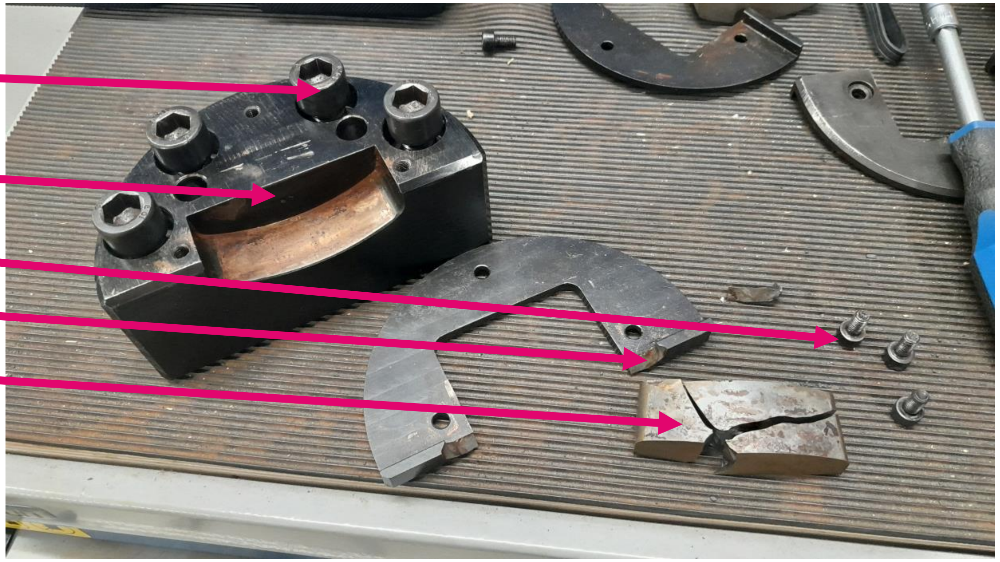
- Calotte holders in fatigue testing rig



EX: Reverse Engineering

Parts of the Assembly

- Calotte holder assembly with broken parts
  - Body connecting bolts
  - Buckled body
  - Bracket screws
  - Fractured bracket
  - Shattered calotte



EX: Reverse Engineering

Broken parts – Body

- Material: AISI 1045 S45C

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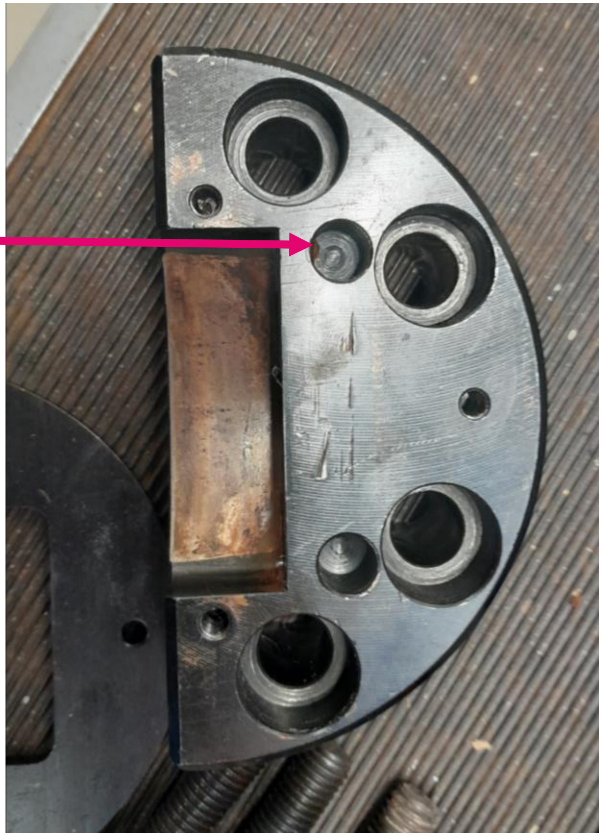
EX: Reverse Engineering

Broken parts – Body

- Alignment pin holes
- V-bottom



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EX: Reverse Engineering

Broken parts – Bracket

- Material: S355JR

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EX: Reverse Engineering

Broken parts – Calotte

- Material: AISI 1045 S45C

EX: Reverse Engineering

Broken parts – Body Bolts

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EX: Reverse Engineering

Broken parts – Bracket screws

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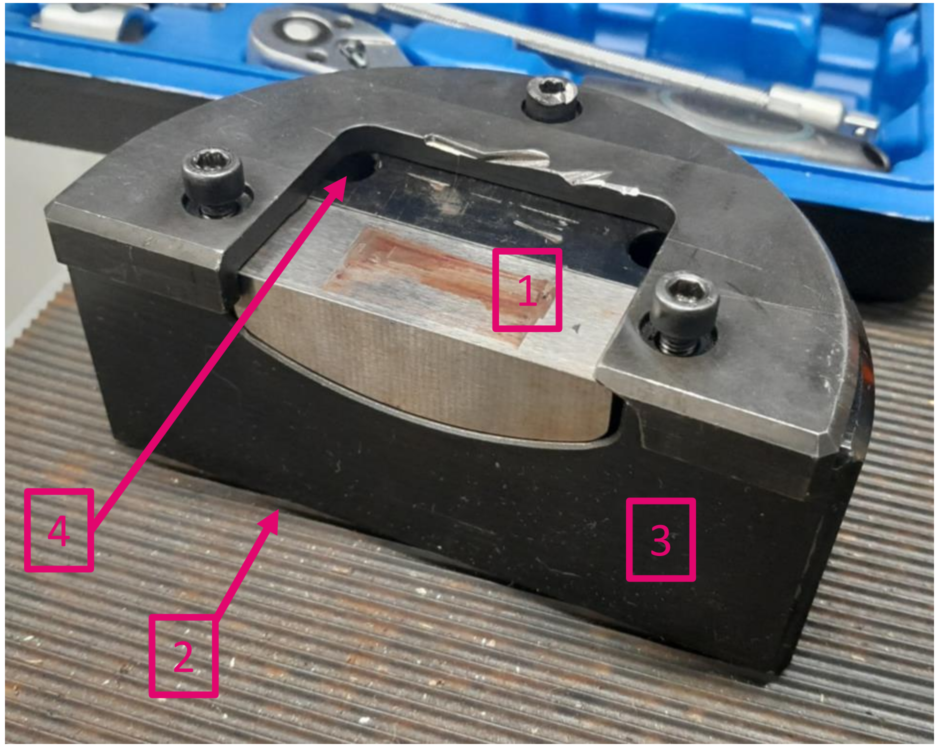
EX: Reverse Engineering

Assembled product & requirements

- Top surface (1) of the calotte must be parallel to the bottom surface of the body (2)
- Front surface (3) of the body should be perpendicular to the bottom of the body (2)
- ISO-tol for the alignment pins? (4)



Reverse Engineering

Sources and pictures

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C5 – Computer Aided Design

M6 – Ecodesign

P2 – University of Jaén

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About NextGEng Project

- Three-year Erasmus+ Cooperation Partnership project that started in October 2022
- International consortium consisting of 3 universities and 3 companies from European countries
- Project co-funded by the European Union and coordinated by Technical University of Cluj-Napoca, Romania

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jamk	**Jamk University of Applied Sciences**	Valmet	**Valmet Technologies Oyj**
Universidad de Jaén	**University of Jaén**	BOSCH Invented for life	**Rober Bosch SRL**

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About NextGEng Project

- **NextGEng Project** aims to create new pedagogical models that promotes international team-teaching with the support of new learning materials for existing courses in the curricula

Ecodesign

Upon completion of this module, the student will be able to:

1) Integrate sustainability principles into the design process, ensuring that products have a minimal environmental impact throughout their lifecycle.
2) Apply ecodesign strategies to develop innovative and sustainable product solutions that meet both technical and environmental standards.
3) Select the most eco-friendly options for industrial design components.
4) Collaborate effectively in multidisciplinary teams to create sustainable product designs

Ecodesign

Today's class will be divided into three blocks:

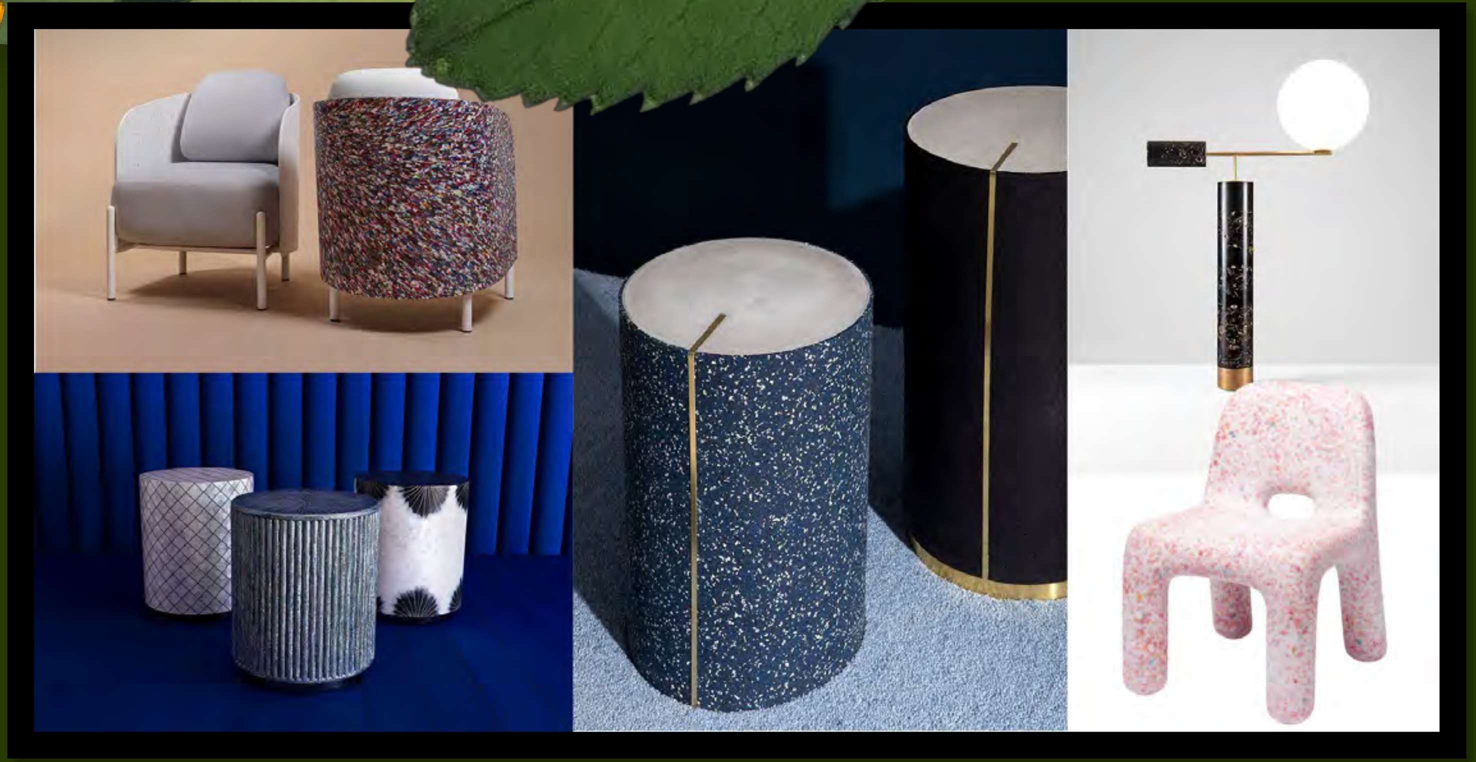
- Theoretical presentation on the use of eco-design strategies
- Presentation of successful case studies applying eco-design criteria
- Resolution of a practical case in groups

Ecodesign

Jaén University

Cristina Martin Doñate
Jorge Mercado Colmenero

Introduction



Introduction

Introduction

Introduction

Introduction

Introduction

Introduction

What benefits do we get from using ecodesign?

- **Optimization of the use of resources:** **Through the choice of sustainable materials, ecodesign seeks to use resources efficiently, favoring those that are recycled or come from renewable sources**

Benefits

Benefits

- **Optimization of the use of resources:** Through the choice of sustainable materials, ecodesign seeks to use resources efficiently, favoring those that are recycled or come from renewable sources

- **Waste minimization:** Favor the design for disassembly, facilitating the recycling or reuse of product parts once it has reached the end of its useful life

Benefits

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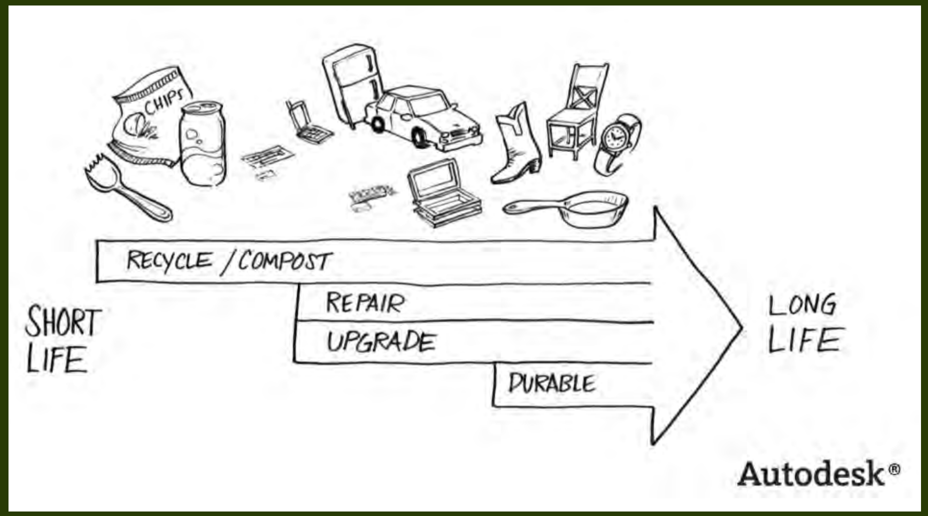
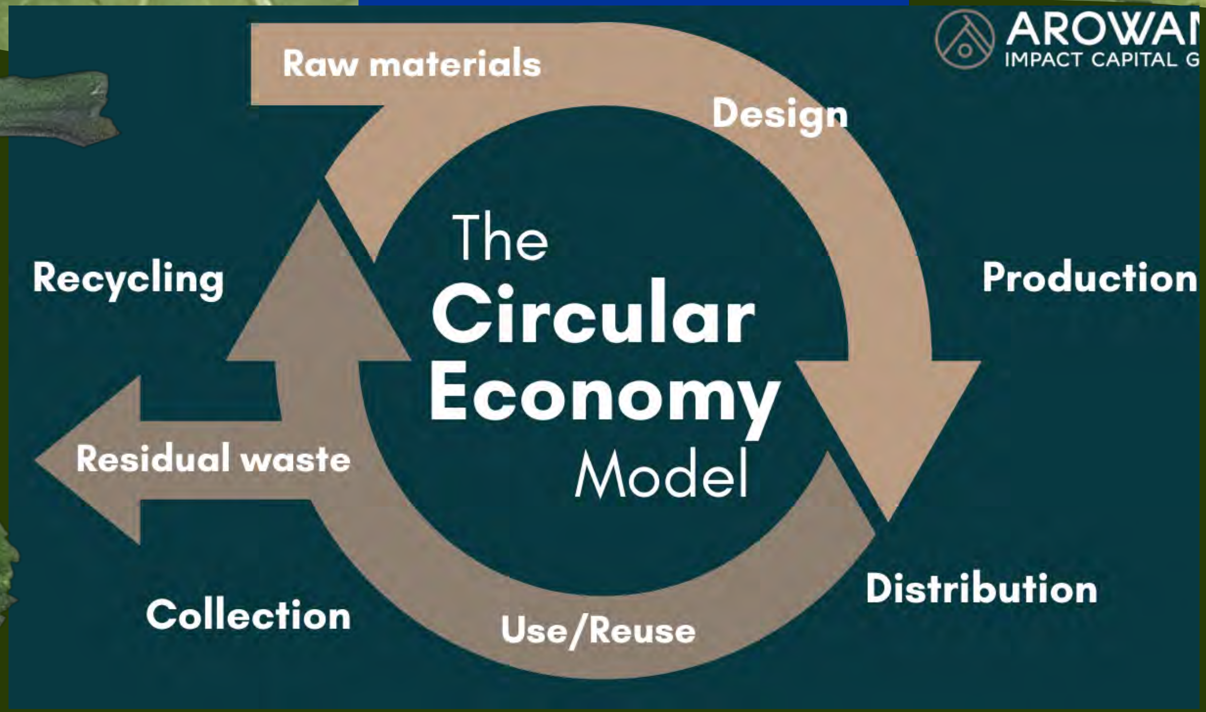


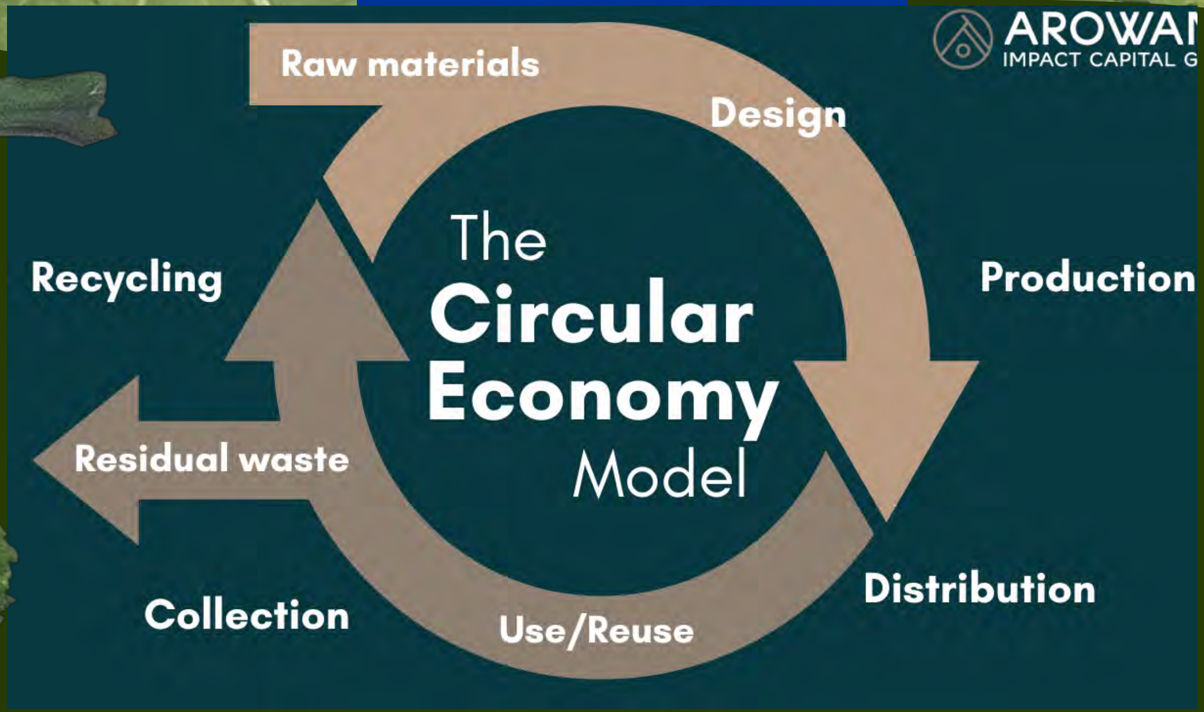
- **Lifecycle extension:** Design durable, modular products that can be easily repaired or upgraded to extend their useful life

Why use ecodesign?

Ecodesign Normative



Ecodesign Normative



Ecodesign Normative


GOBIERNO DE ESPAÑA
MINISTERIO DE LA PRESIDENCIA, JUSTICIA Y RELACIONES CON LAS CORTES
Agencia Estatal Boletín Oficial del Estado

Castellano Buscar Mi BOE Menú

Está Vd. en > Inicio > Buscar > Documento DOUE-L-2024-80992

Reglamento (UE) 2024/1781 del Parlamento Europeo y del Consejo, de 13 de junio de 2024, por el que se instaura un marco para el establecimiento de requisitos de diseño ecológico aplicables a los productos sostenibles, se modifican la Directiva (UE) 2020/1828 y el Reglamento (UE) 2023/1542 y se deroga la Directiva 2009/125/CE.

Publicado en:	«DOUE» núm. 1781, de 28 de junio de 2024, páginas 1 a 89 (89 págs.)
Departamento:	Unión Europea
Referencia:	DOUE-L-2024-80992

Ecodesign Normative

“**EU Regulation 2024/1781**

It should provide for the establishment of new ecodesign requirements to improve the durability, reliability, reparability, upgradeability, reusability and recyclability, improving the reconditioning and maintenance possibilities of products”

Ecodesign Strategies

And what strategies are we going to use to achieve these objectives?

Ecodesign Strategies

- **Choose the Right Materials:** Use recycled or renewable materials that have less impact on the environment.
- **Design for Durability:** Make sure your product lasts longer, which means fewer replacements and less waste over time.
- **Make It Easy to Repair:** Design products so they can be easily fixed. This helps extend their life and reduces the need for new products.

Ecodesign Strategies

- **Plan for Recycling:** Think about how the product can be taken apart and recycled at the end of its life.
- **Use Energy Wisely:** Opt for energy-efficient processes during manufacturing and aim to reduce energy use while the product is in use.

Ecodesign Strategies

Substitution of materials

PLASTIC

PLASTIC

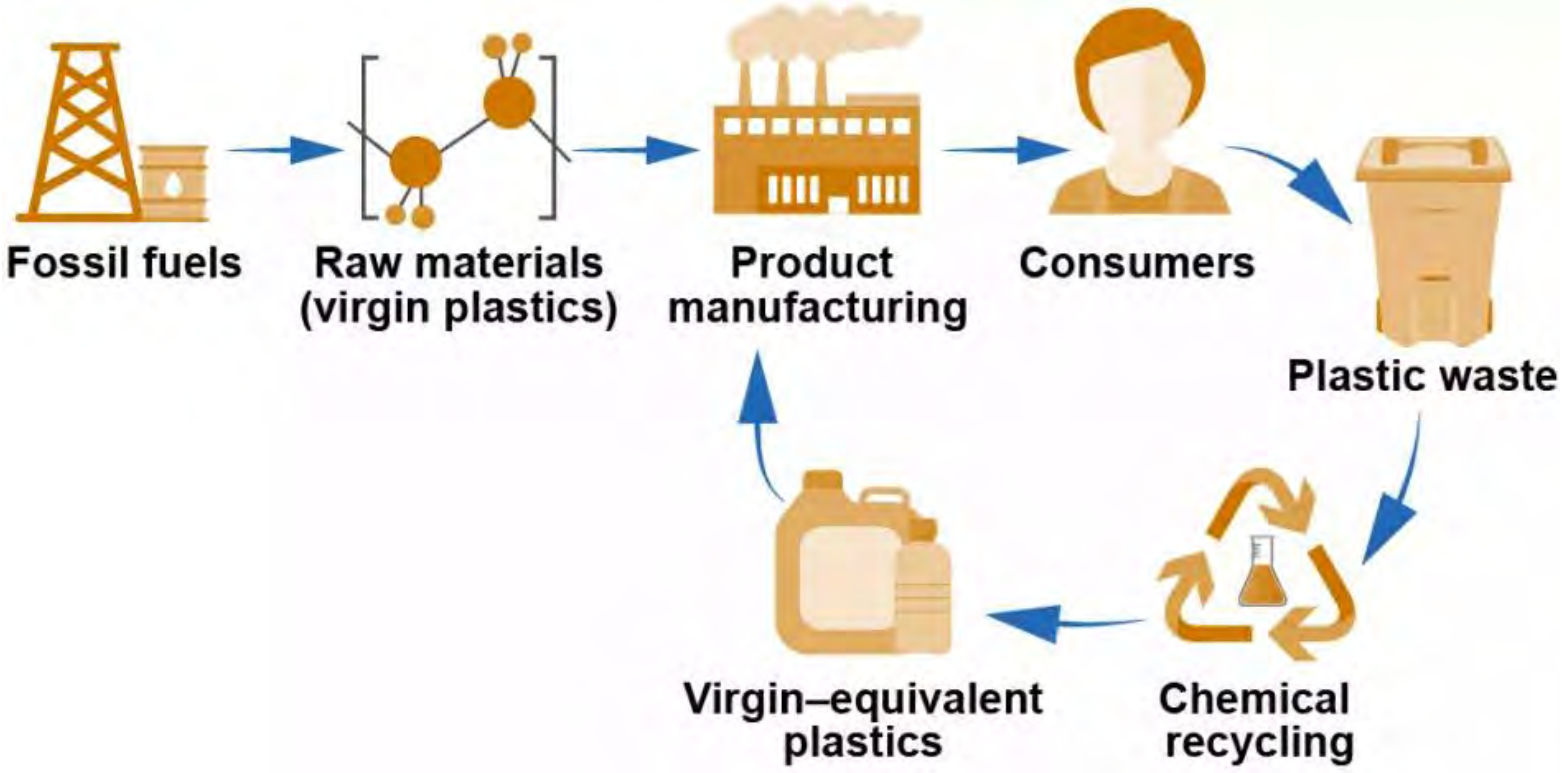

ПЛАСТИК
хартия
СТЕКЛО
хартия
БУМАГА
хартия
МЕТАЛЛ
хартия

CHEMICAL

MECHANICAL

RECYCLING

Chemical Recycling



Chemical Recycling

SABIC Uses Chemical Recycling to Convert Mixed Plastics Waste Into Polycarbonate | Plastics...

Published 9/1/2021

Chemical Recycling Poised to Take Off

Investments in chemical-recycling facilities abound as the industry moves closer to the Circular Economy model, accompanied by plenty of new rollouts of packaging made from chemical recycling.

ECONOMICS | RECYCLED MATERIALS | RECYCLING | SUSTAINABILITY | POSTCONSUMER

Sreeparna Das, independent consultant

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SUSTAINABILITY

Henkel, BASF Collaborate on Chemical Recycling

SUSTAINABILITY

unches Chemical
nnovation for
astic Waste

Remondis Partner
l Recycling

Unilever's Magnum ice cream tubs made from chemically recycled PP from SABIC are being rolled out commercially on a global basis.

Sabic, Mars and Landbell announce chemical recycling "breakthrough"

Recycled PP to be used in wrapper for Kind snack bar from Mars

EUWID + 10 November 2022 | Stefan Lang | ~ 2 min Bookmark

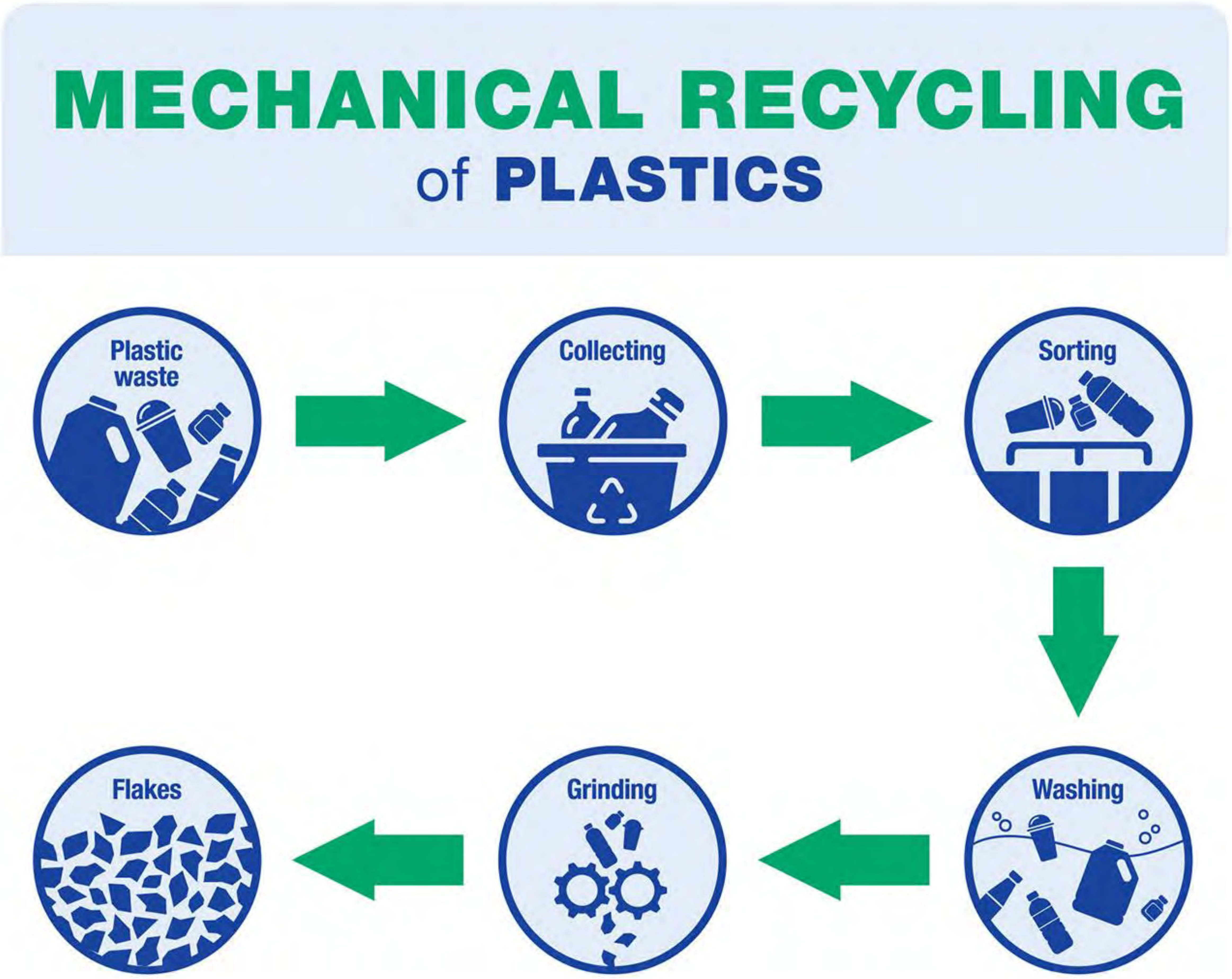
Chemical recycling process turns post consumer PP packaging waste into

The German company Landbell AG is partnering with Sabic and Mars to advance the chemical recycling of

Mars relies on recycled material from chemical recycling. Is this the silver bullet?

THOMAS REINER
02. MAY 2023

Mechanical Recycling



Mechanical Recycling

Ecodesign Strategies

Eco manufacturing processes

MEX PROCESS

Real life cases
Success stories
ecodesign

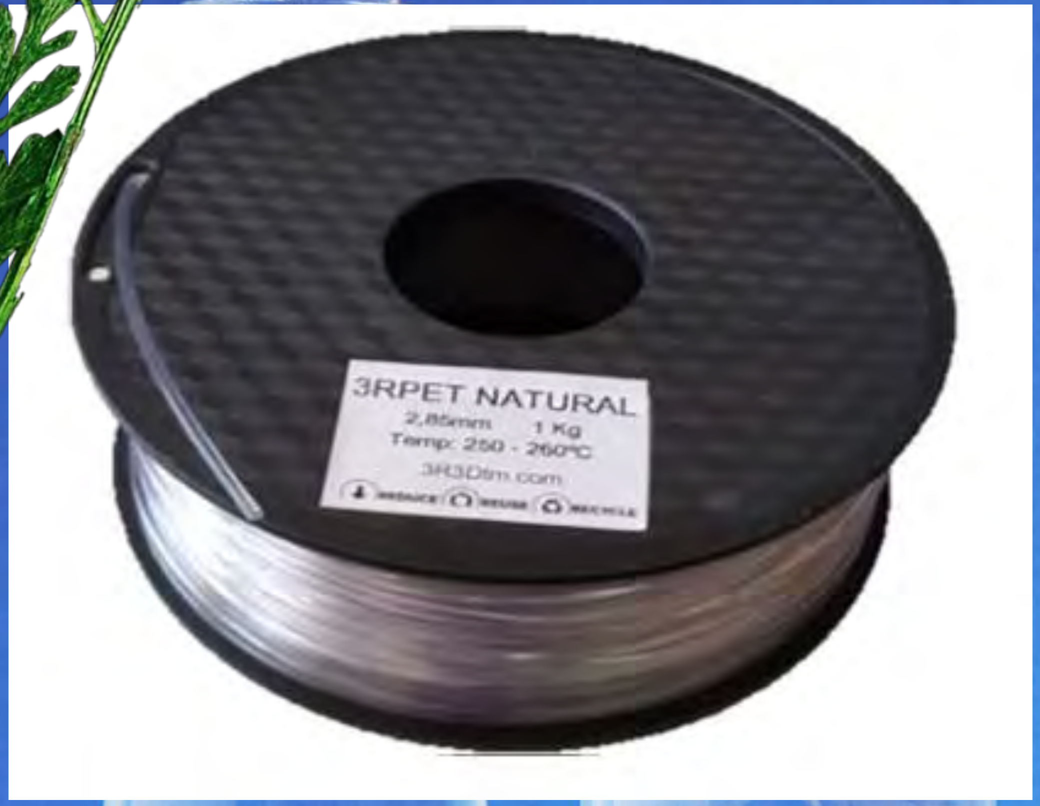
Ecodesign

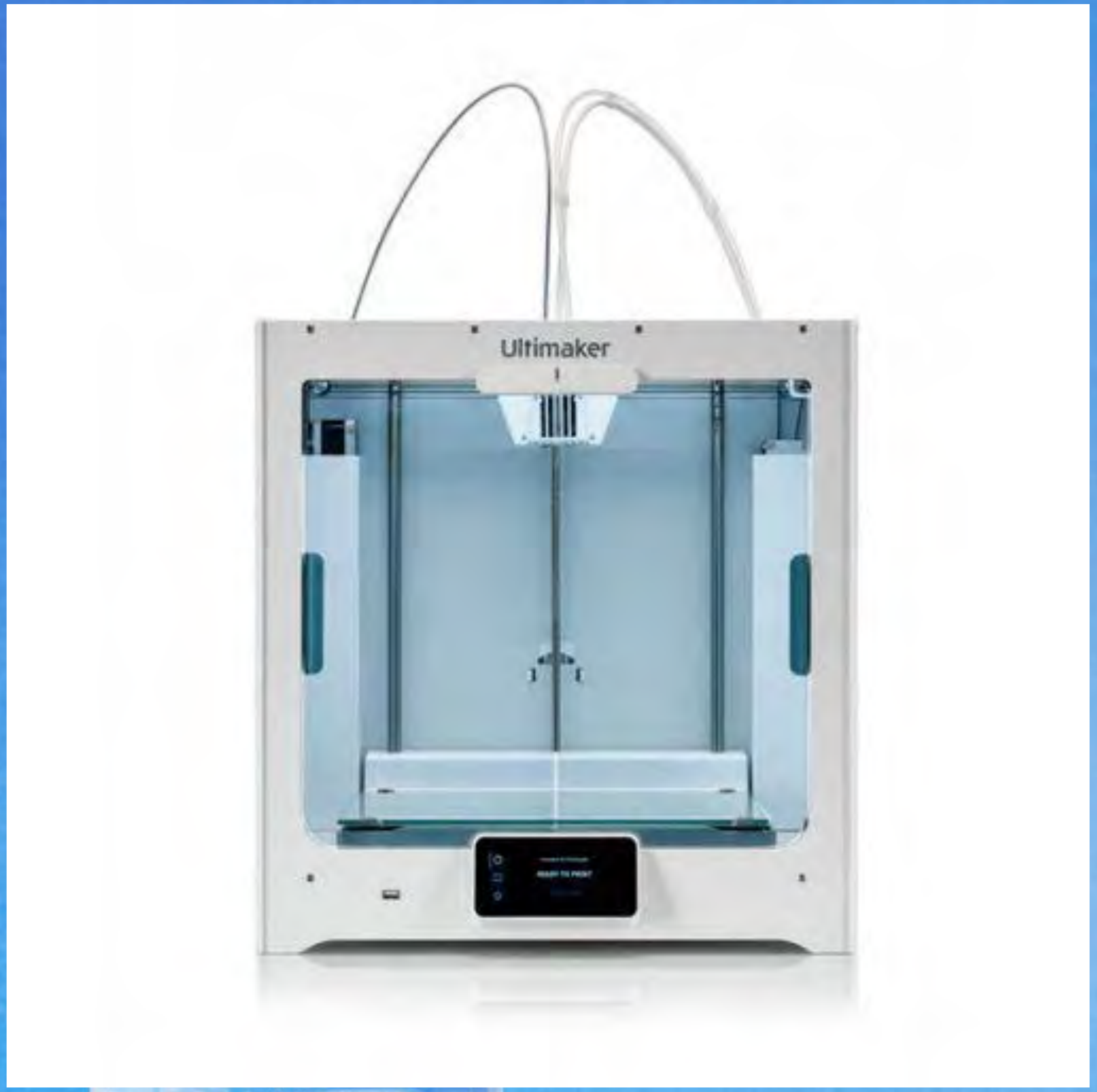
Recycled Plastic Material +MEX

Ecodesign

Recycled Plastic Material +MEX

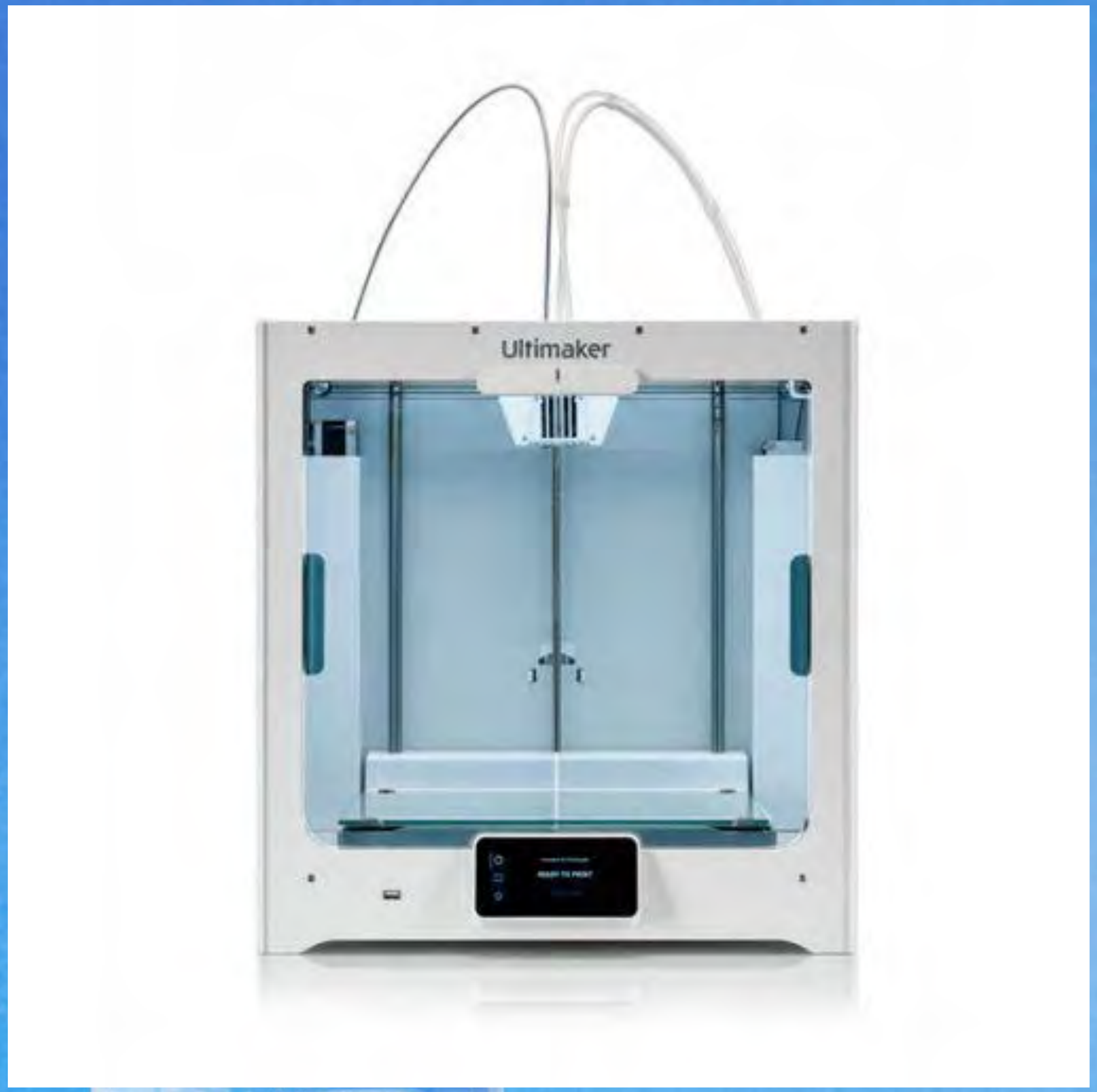
MEX PROCESS


3RPET NATURAL
2,85mm 1 Kg
Temp: 250 - 260ºC
3R3Dtm.com


Ultimaker

MEX PROCESS


3RPET NATURAL
2,85mm 1 Kg
Temp: 250 - 260ºC
3R3Dtm.com


Ultimaker

MEX PROCESS


3RPET NATURAL
2,85mm 1 Kg
Temp: 250 - 260ºC
3R3Dtm.com
Ultimaker

Aesthetic requirements

Design device case study

Design emplacement

Organic shape

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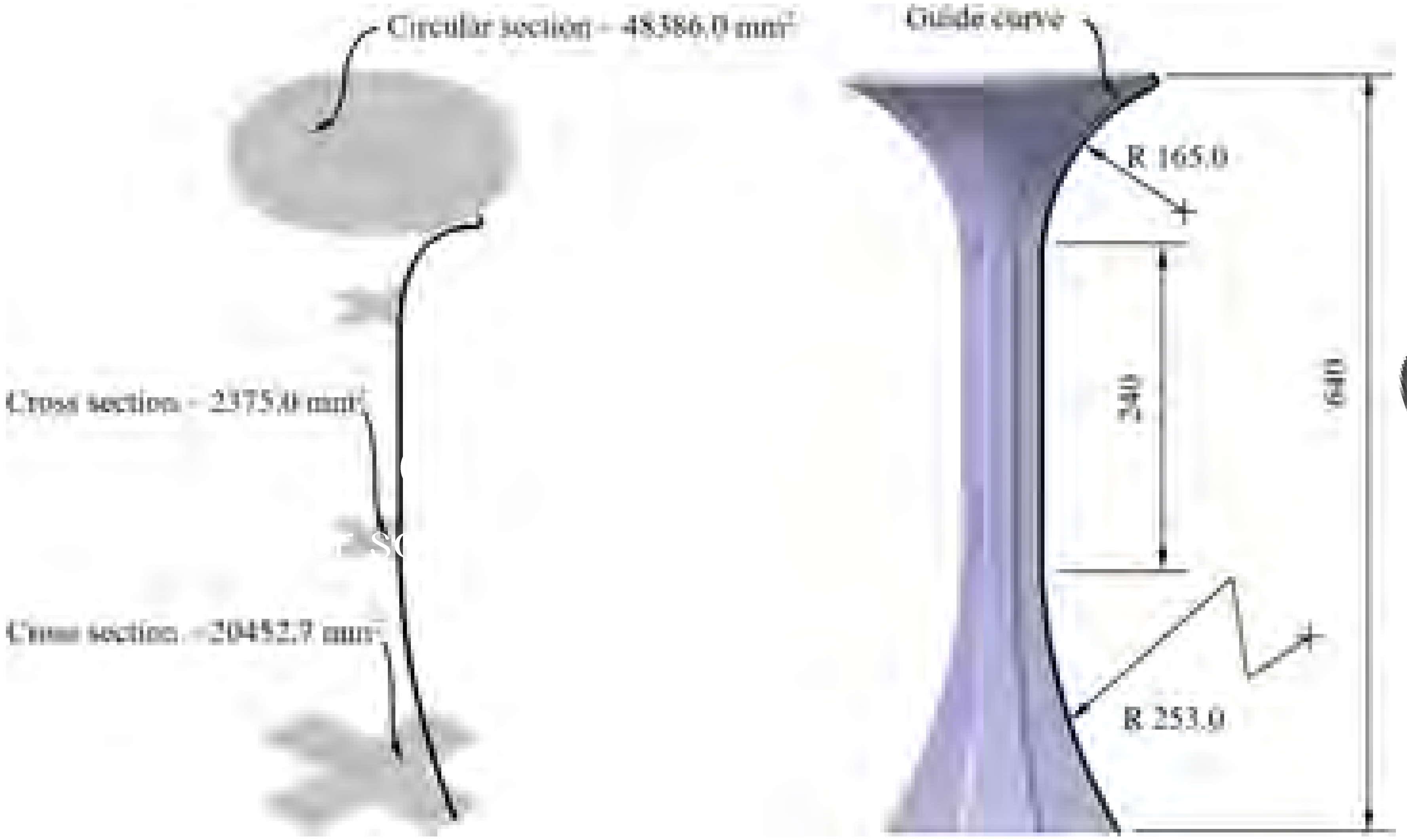
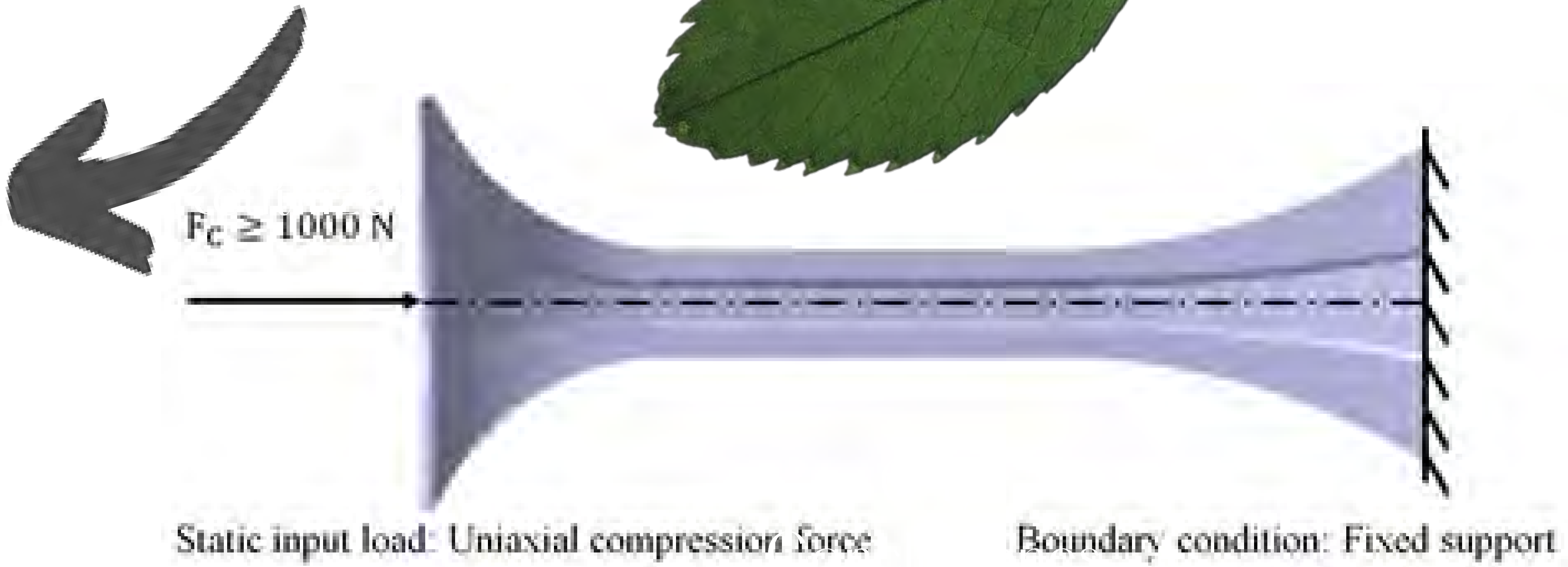
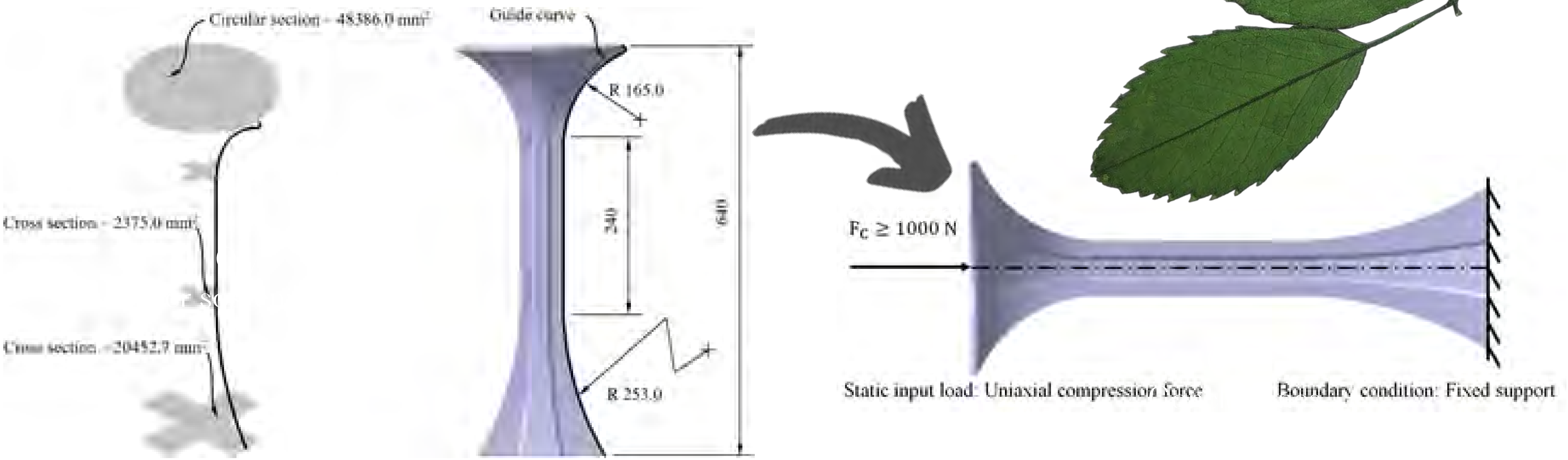


Circular section - 48386.0 mm²
Guide curve
R 165.0
240
640
Cross section - 2375.0 mm²
Cross section - 20452.7 mm²
R 253.0



Fc ≥ 1000 N
Static input load: Uniaxial compression force
Boundary condition: Fixed support



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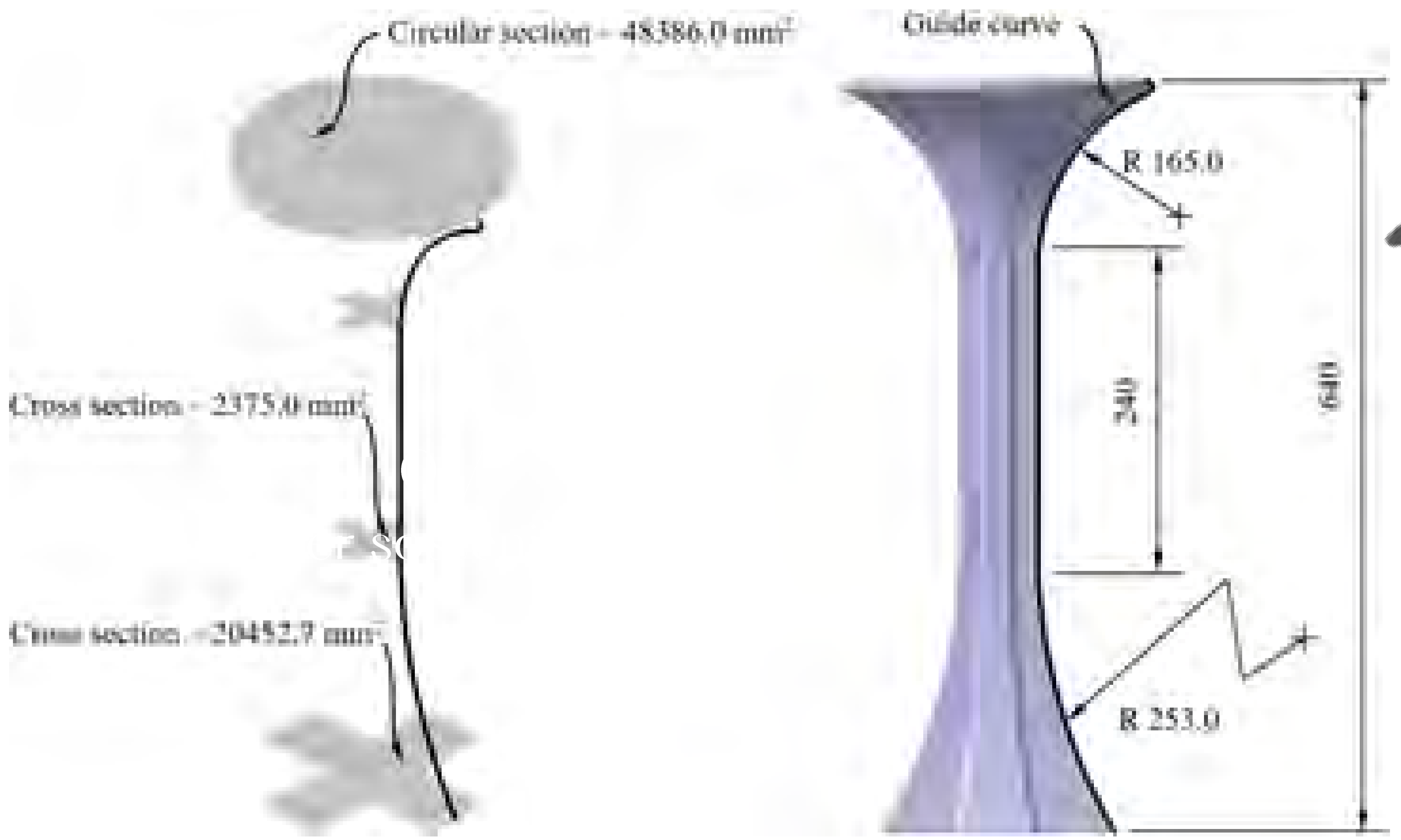
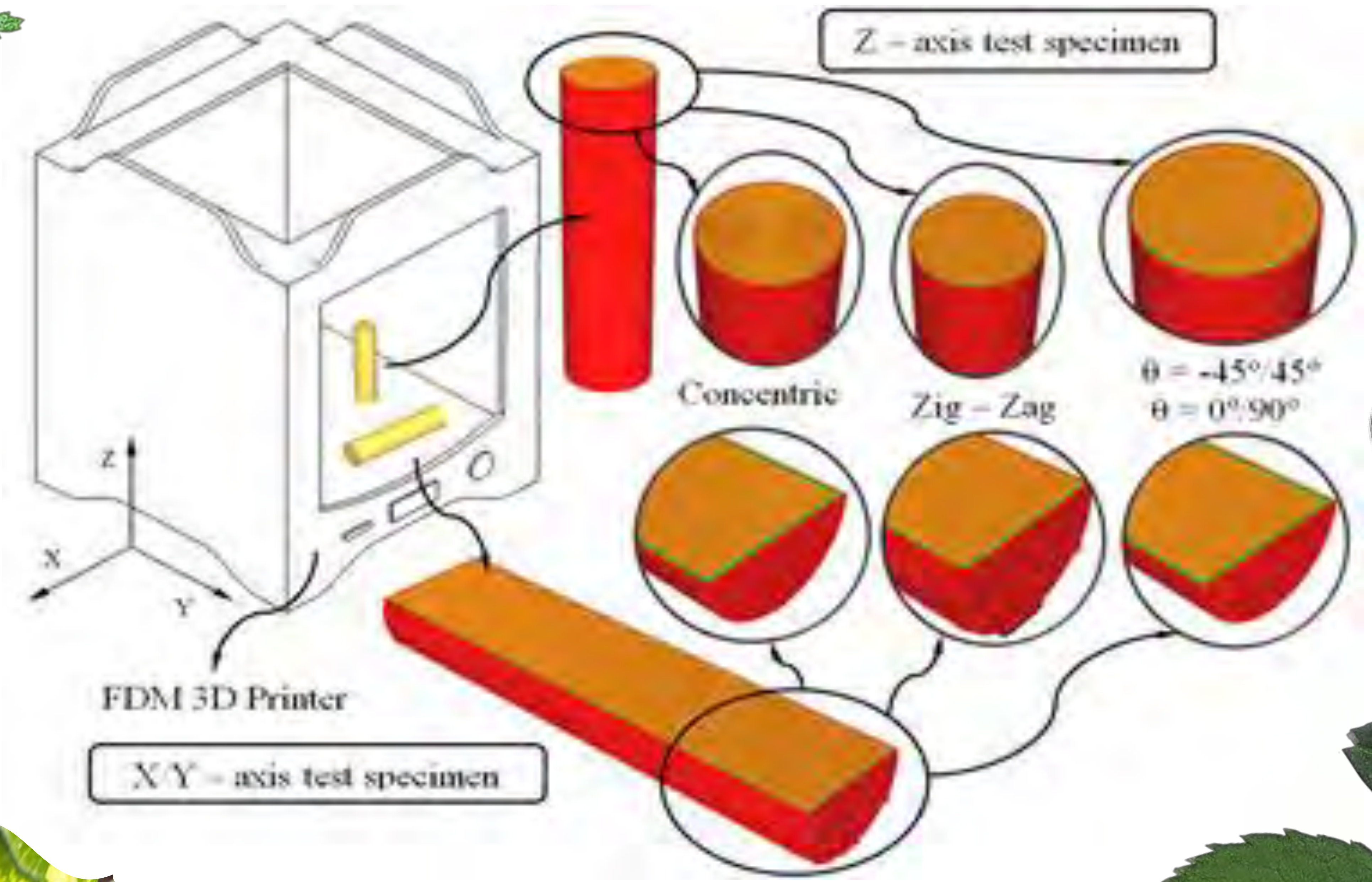

Circular section - 48386.0 mm²
Guide curve
R 165.0
Cross section - 2375.0 mm²
240
640
Cross section - 20452.7 mm²
R 253.0


Fc ≥ 1000 N
Static input load: Uniaxial compression force
Boundary dition: Fixed support

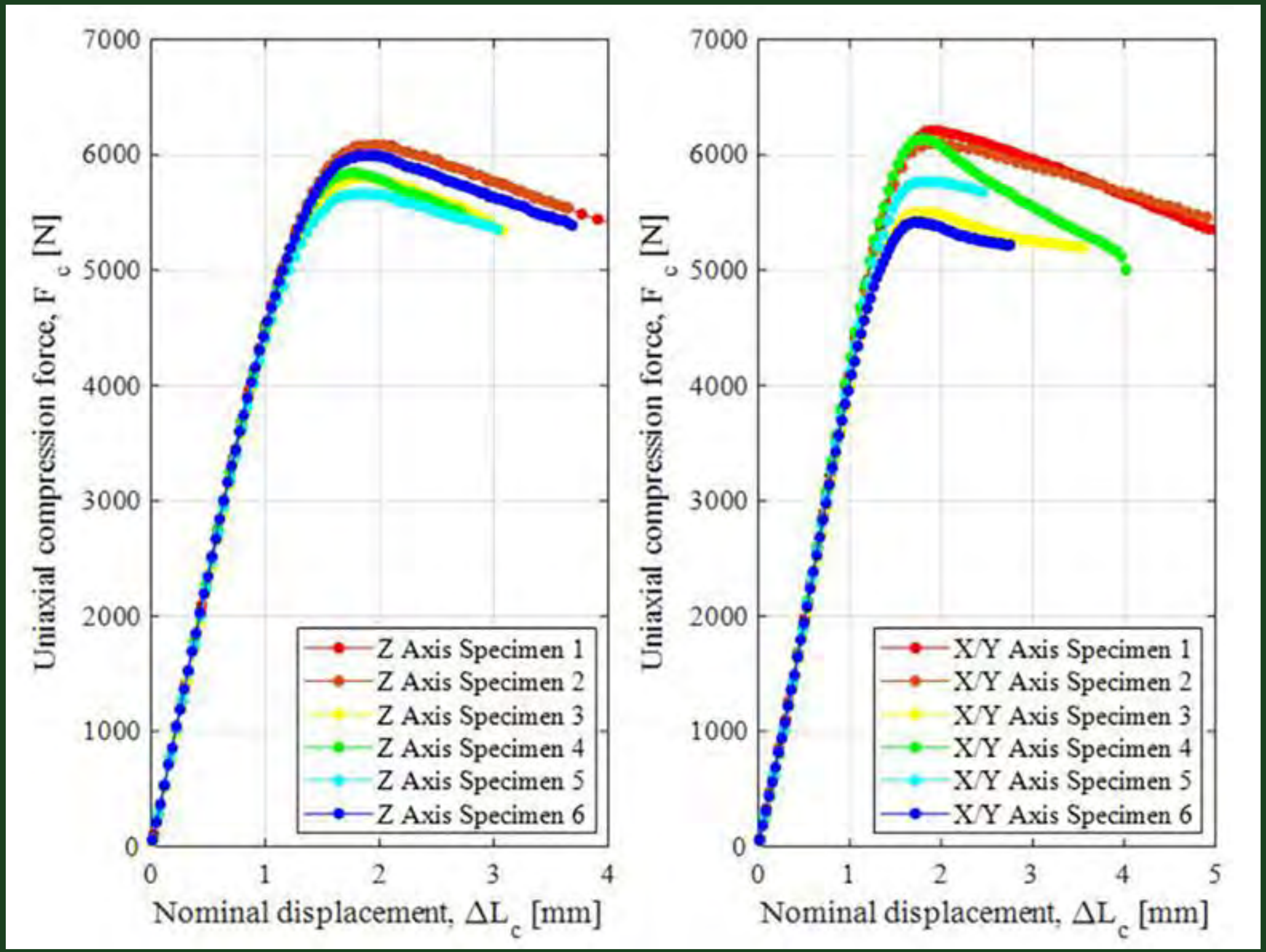
Anisotrophy

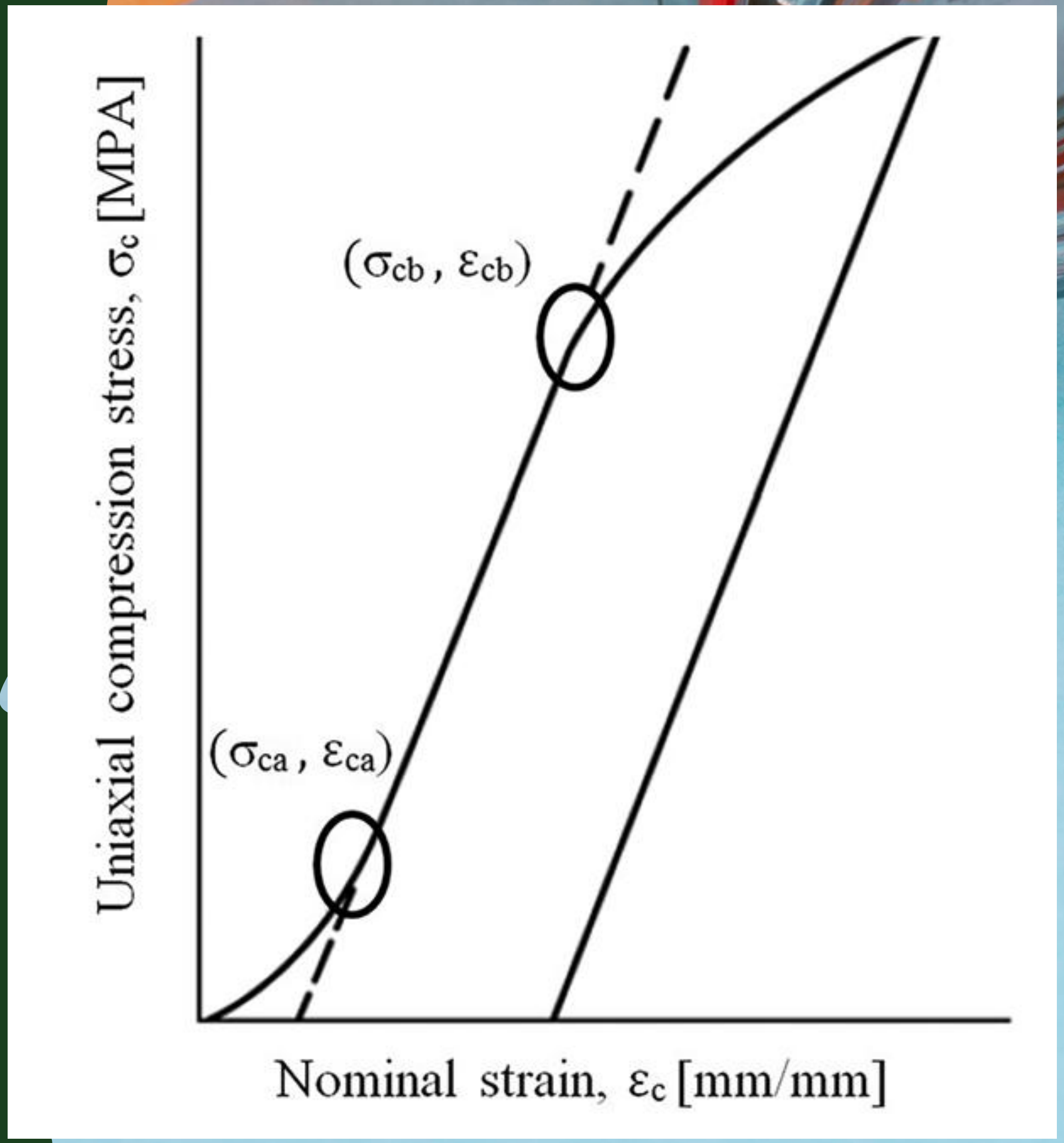
NextGEng

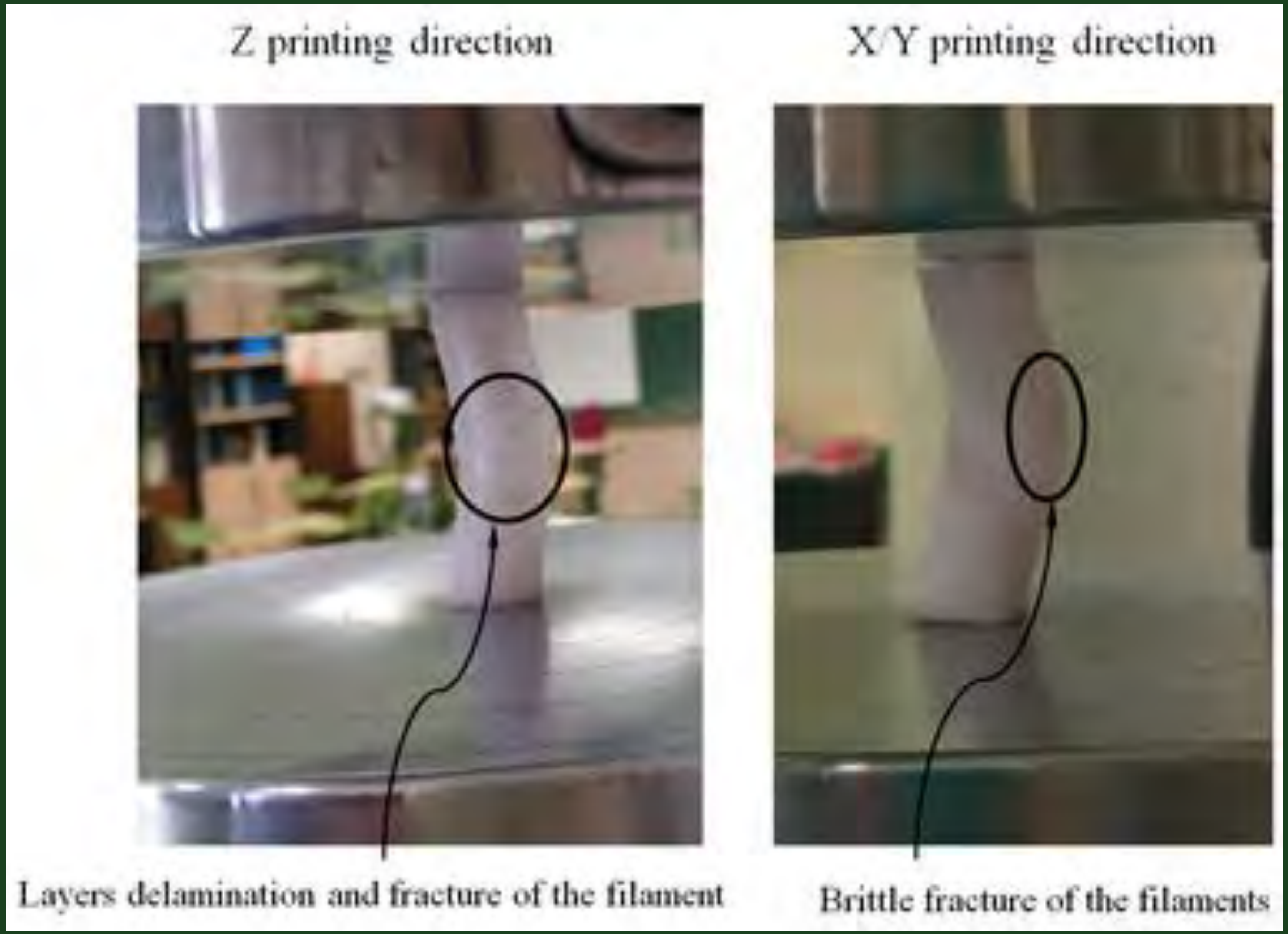
Anisotrophy

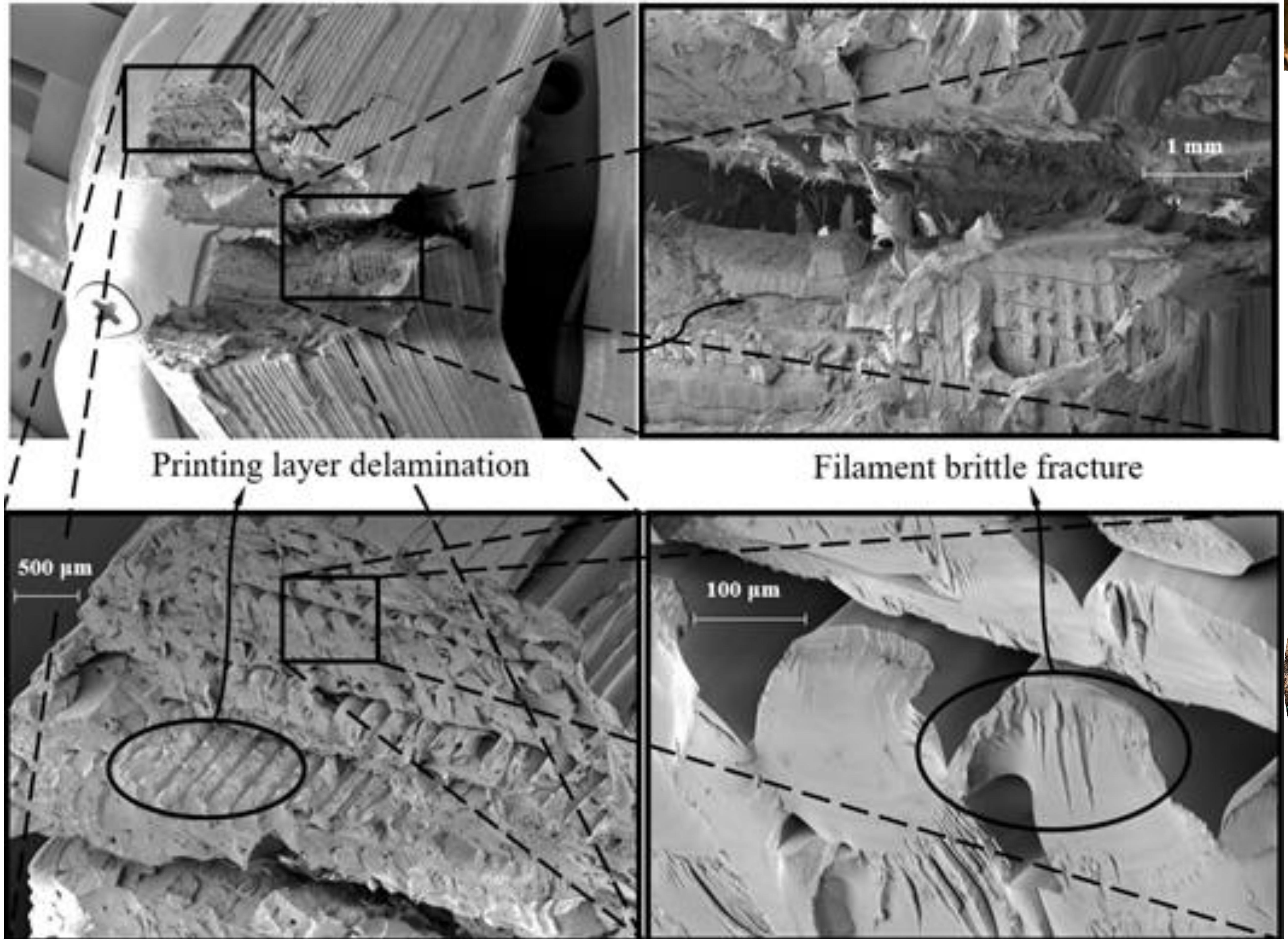


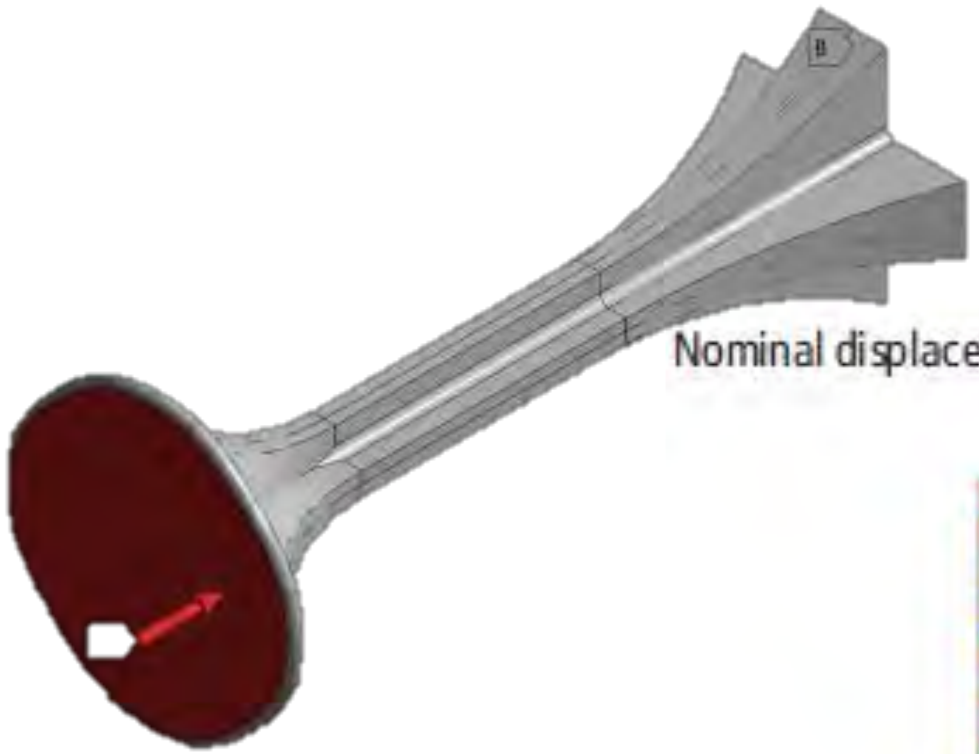

Compression test machine
Cylindrical specimen


7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
Uniaxial compression force, F c [N]
Nominal displacement, ΔL c [mm]
Z Axis Specimen 1
Z Axis Specimen 2
Z Axis Specimen 3
Z Axis Specimen 4
Z Axis Specimen 5
Z Axis Specimen 6
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
Uniaxial compression force, F c [N]
Nominal displacement, ΔL c [mm]
X/Y Axis Specimen 1
X/Y Axis Specimen 2
X/Y Axis Specimen 3
X/Y Axis Specimen 4
X/Y Axis Specimen 5
X/Y Axis Specimen 6

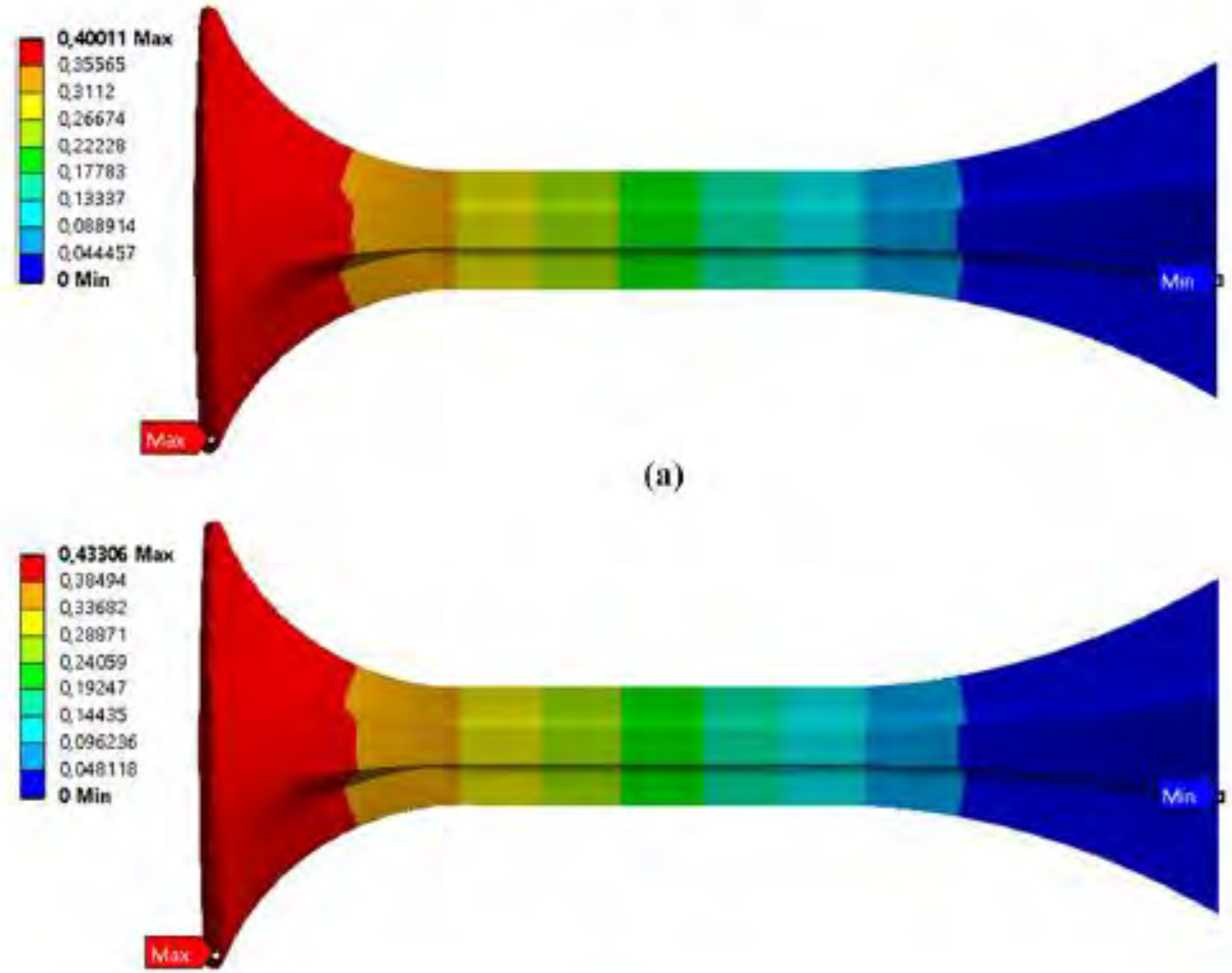

Uniaxial compression stress, σc [MPA]
(σcb , εcb)
(σca , εca)
Nominal strain, εc [mm/mm]

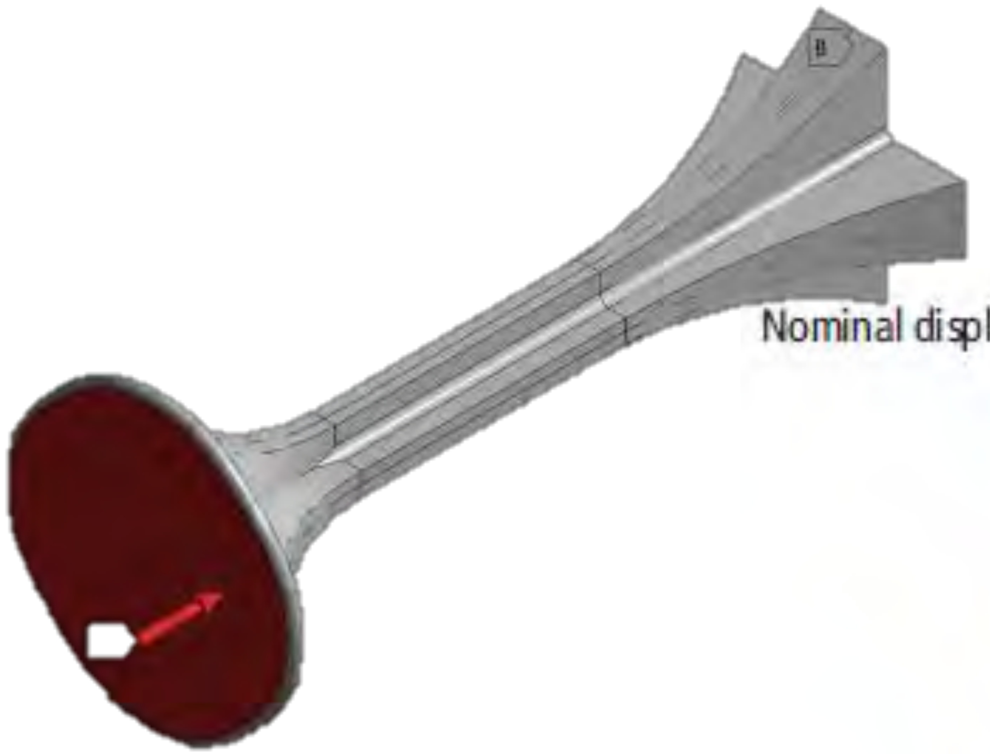

Z printing direction
X/Y printing direction
Layers delamination and fracture of the filament
Brittle fracture of the filaments


1 mm
Printing layer delamination
Filament brittle fracture
500 μm
100 μm

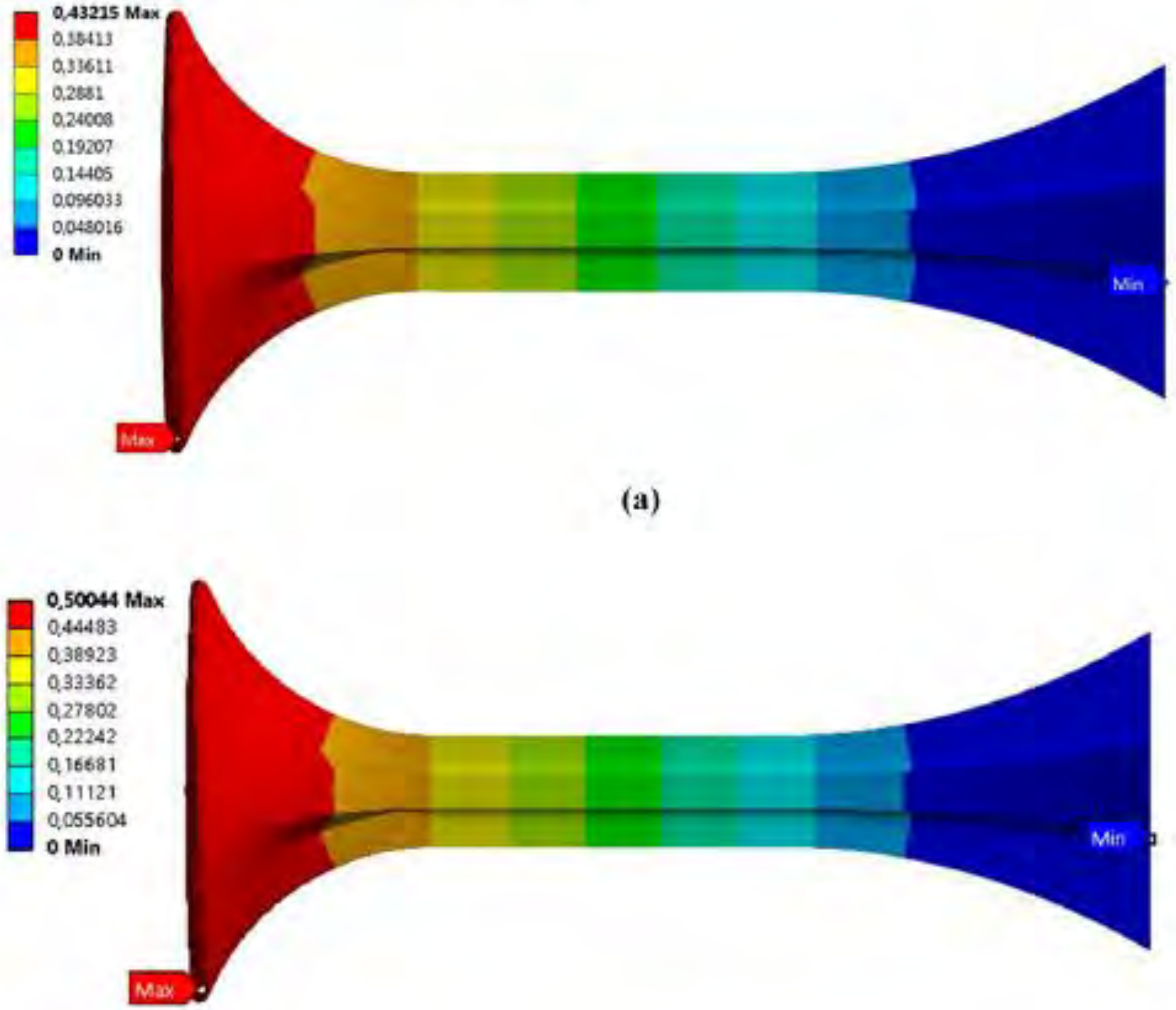


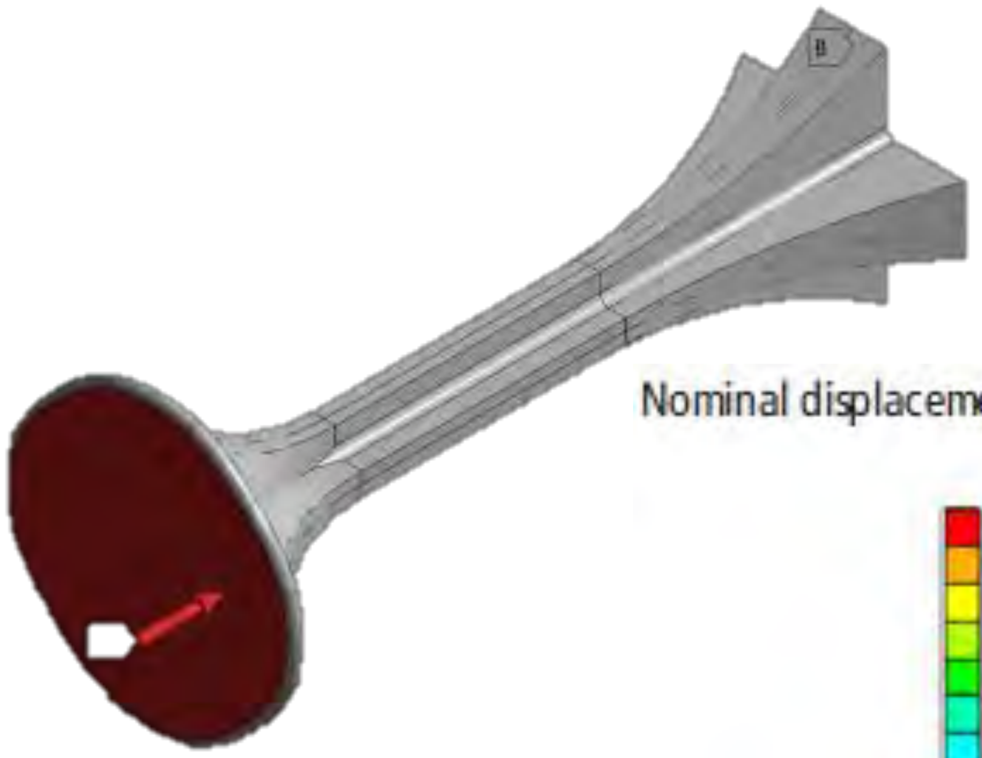
Nominal displacement [mm]: a) Concentric Z-axis: b) Concentric X/Y-axis



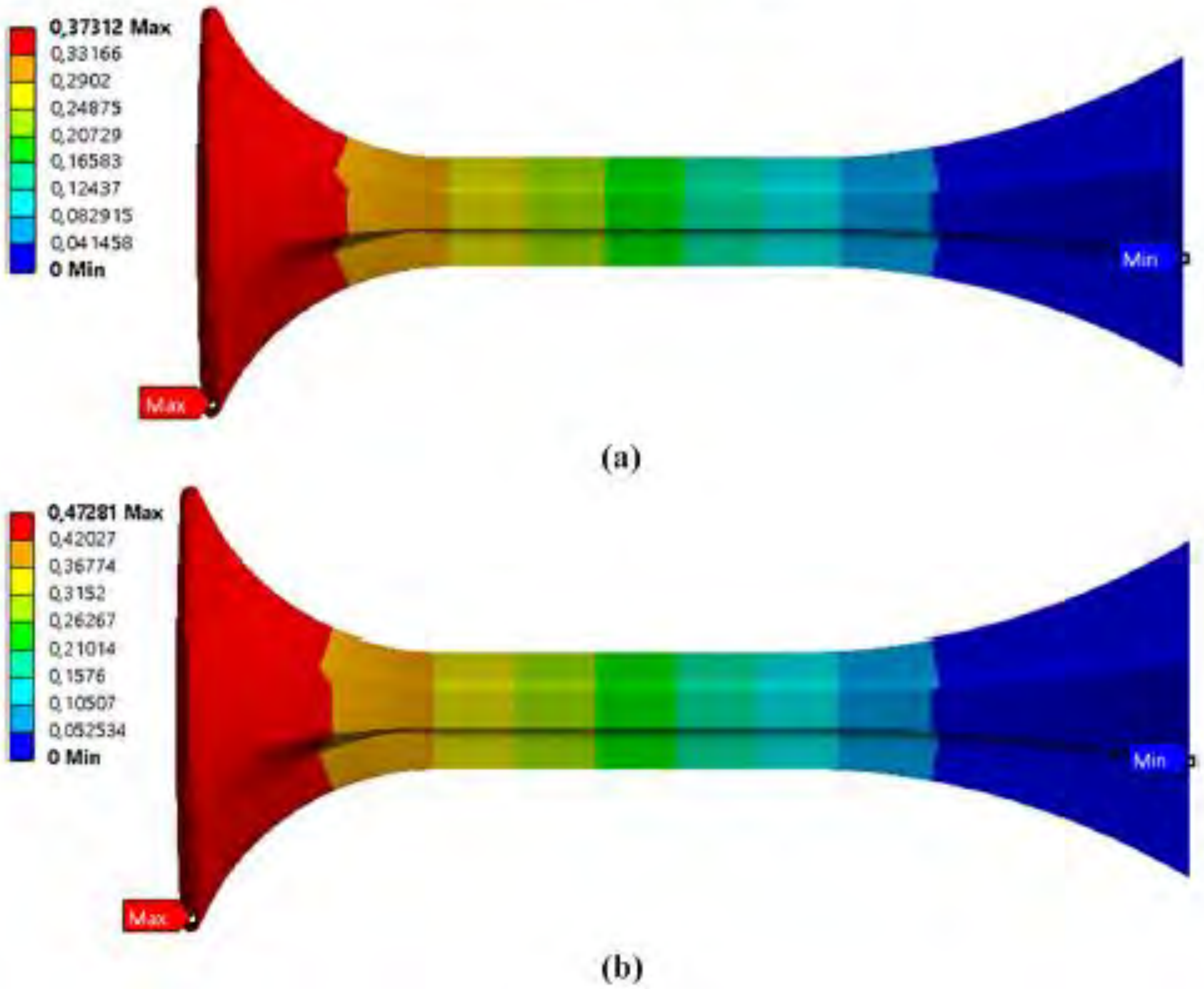


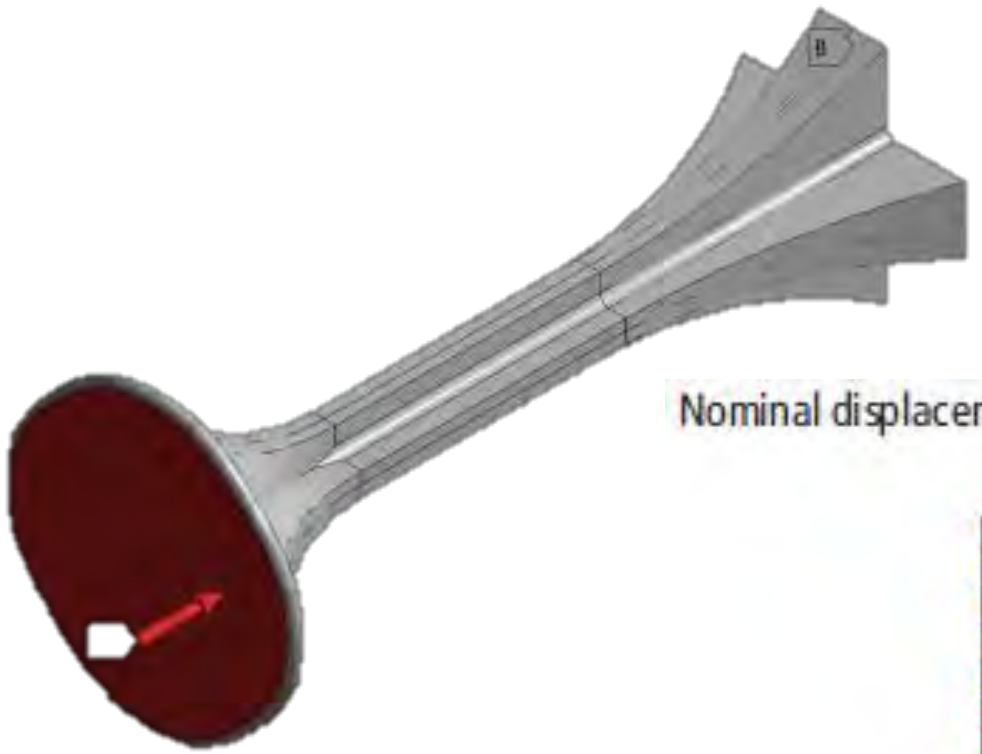
Nominal displacement [mm]: a) Zig–zag Z-axis: b) Zig–zag X/Y-axis



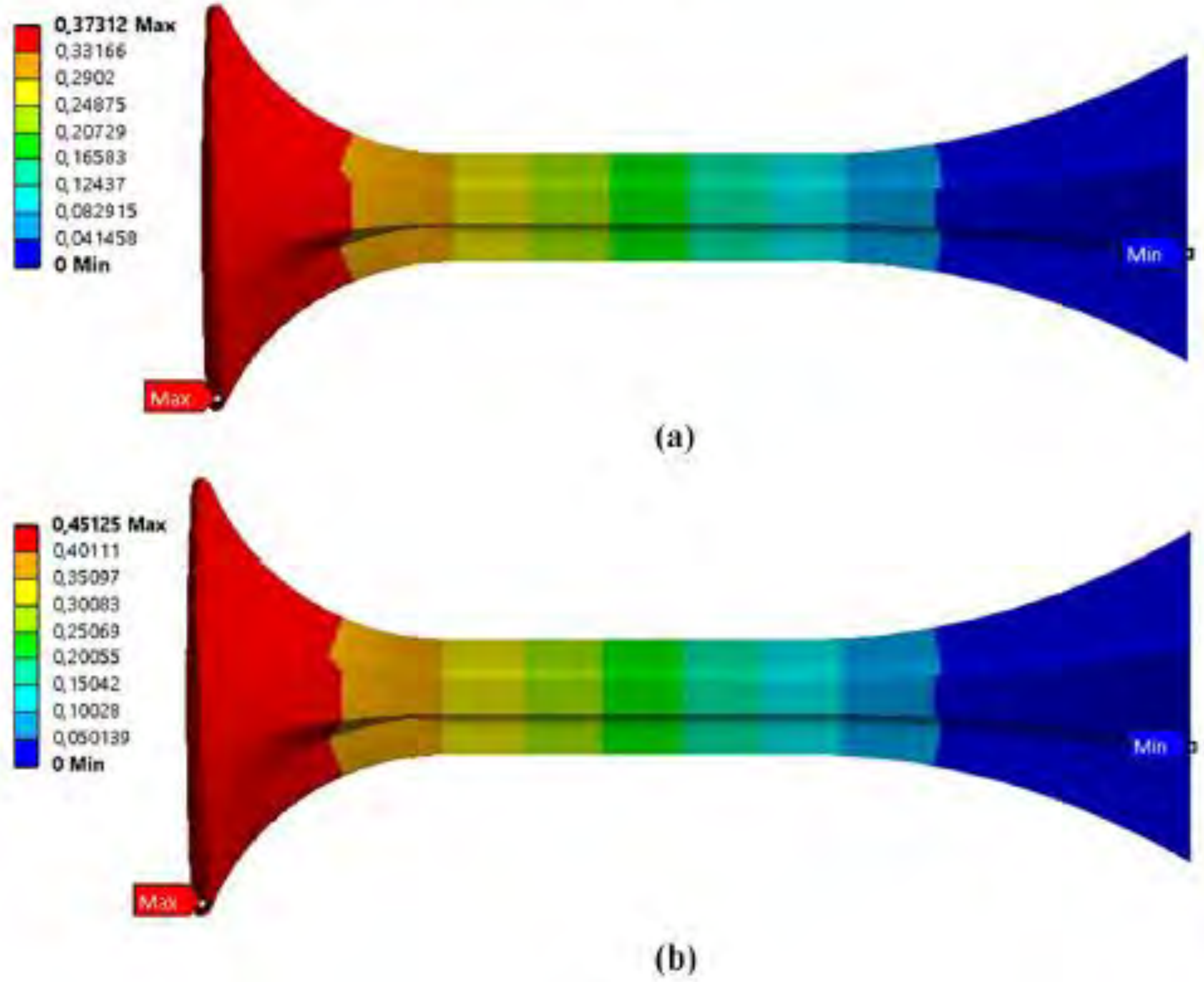


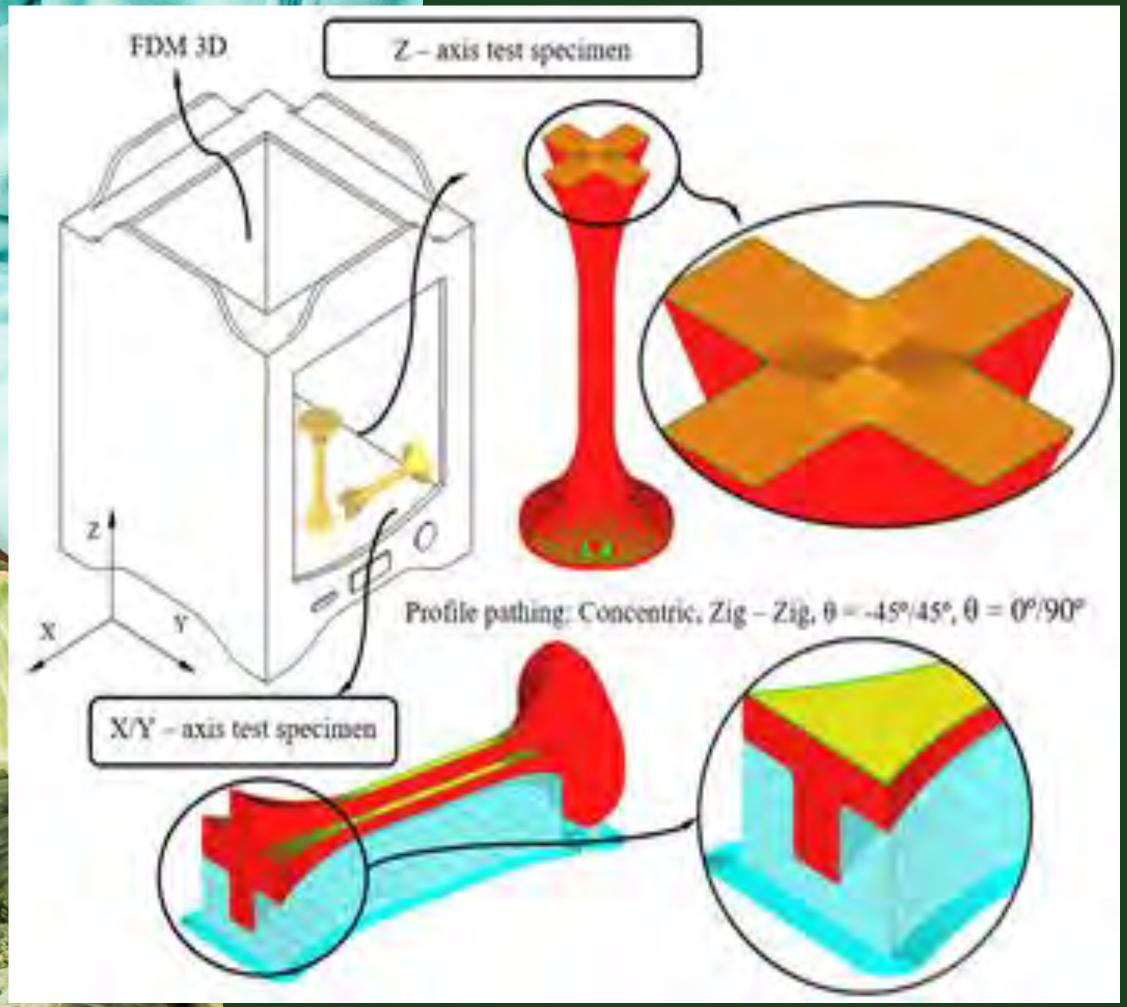
Nominal displacement [mm]: a) $\theta = -45°/45°$ Z-axis: b) $\theta = -45°/45°$ X/Y-axis





Nominal displacement [mm]: a) $\theta = 0°/90°$ Z-axis: b) $\theta = 0°/90°$ X/Y-axis



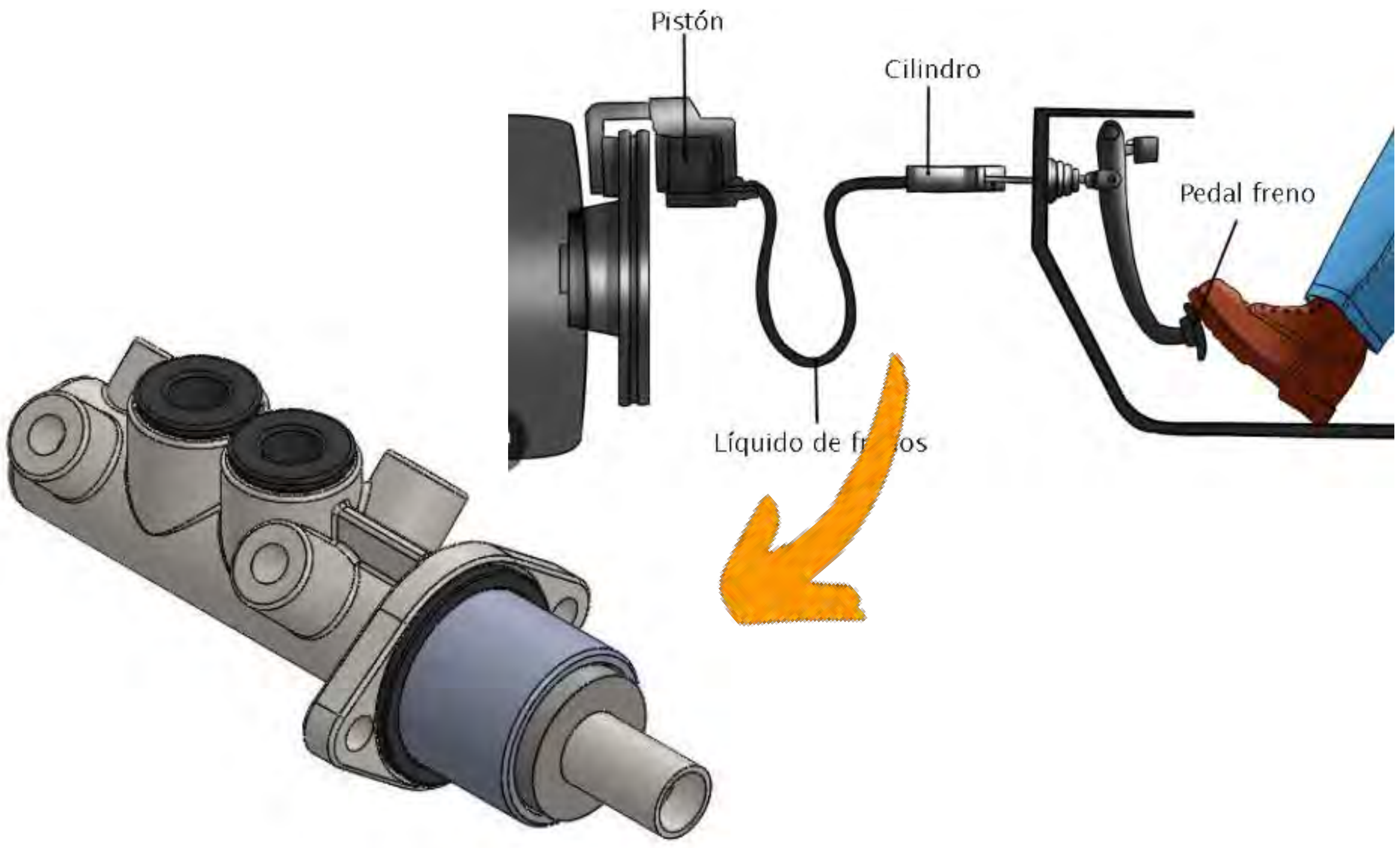


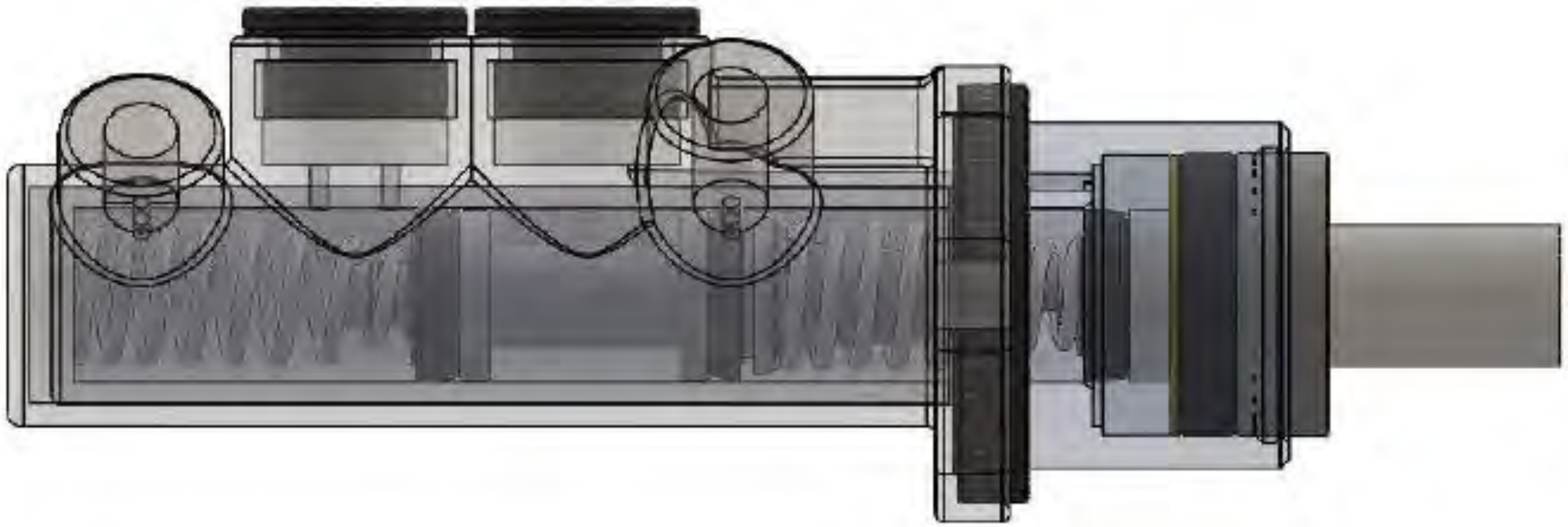
FDM 3D
Z – axis test specimen
Profile pathing: Concentric, Zig – Zig, θ = -45°/45°, θ = 0°/90°
X/Y – axis test specimen

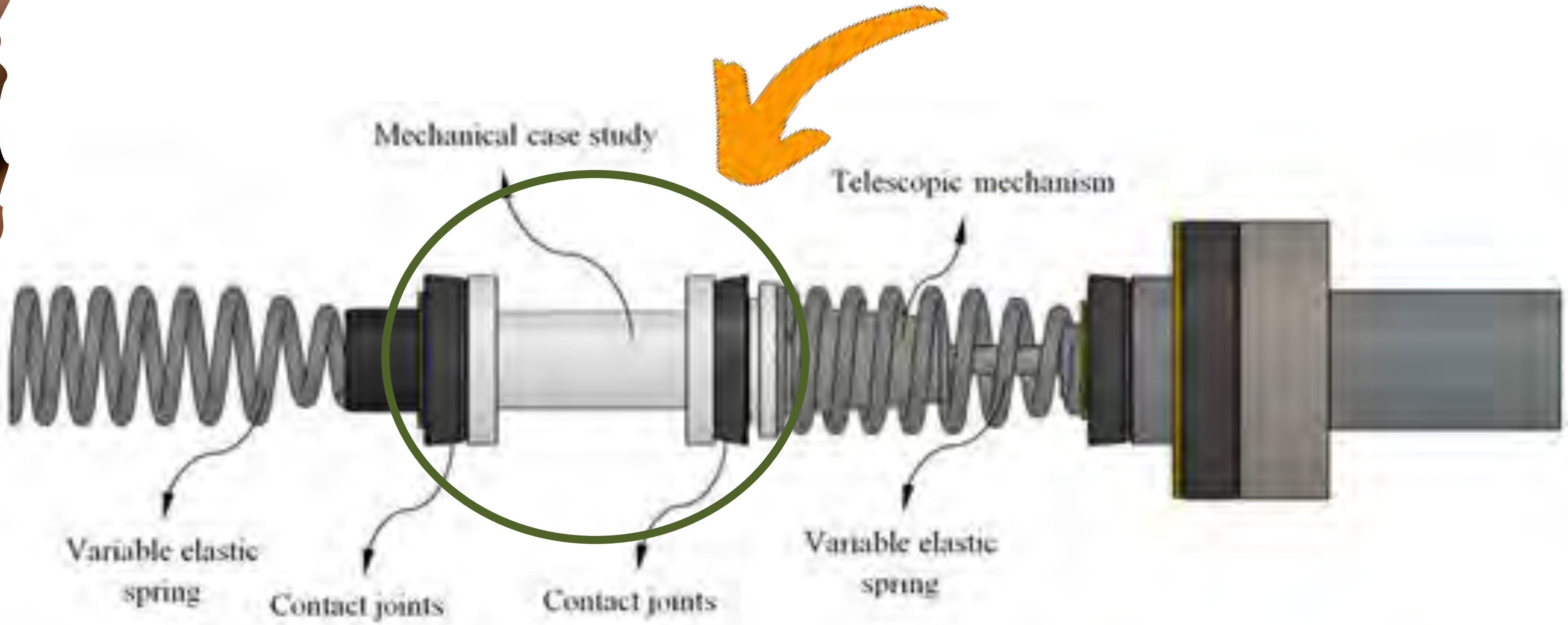
Ultimaker
Ultimaker

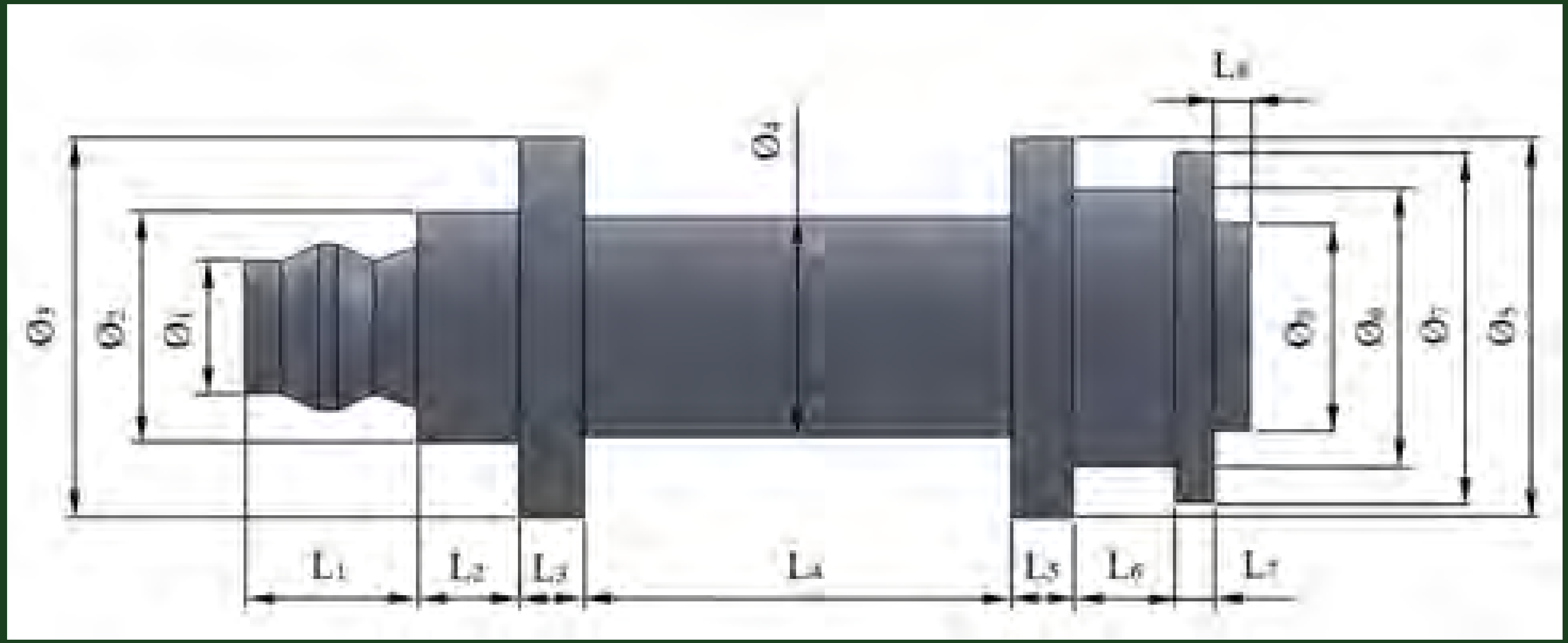
Ecodesign

Reusing


Pistón
Cilindro
Pedal freno
Líquido de fr os




Mechanical case study
Telescopic mechanism
Variable elastic spring
Contact joints
Contact joints
Variable elastic spring


L8
Ø4
Ø3
Ø2
Ø1
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L1
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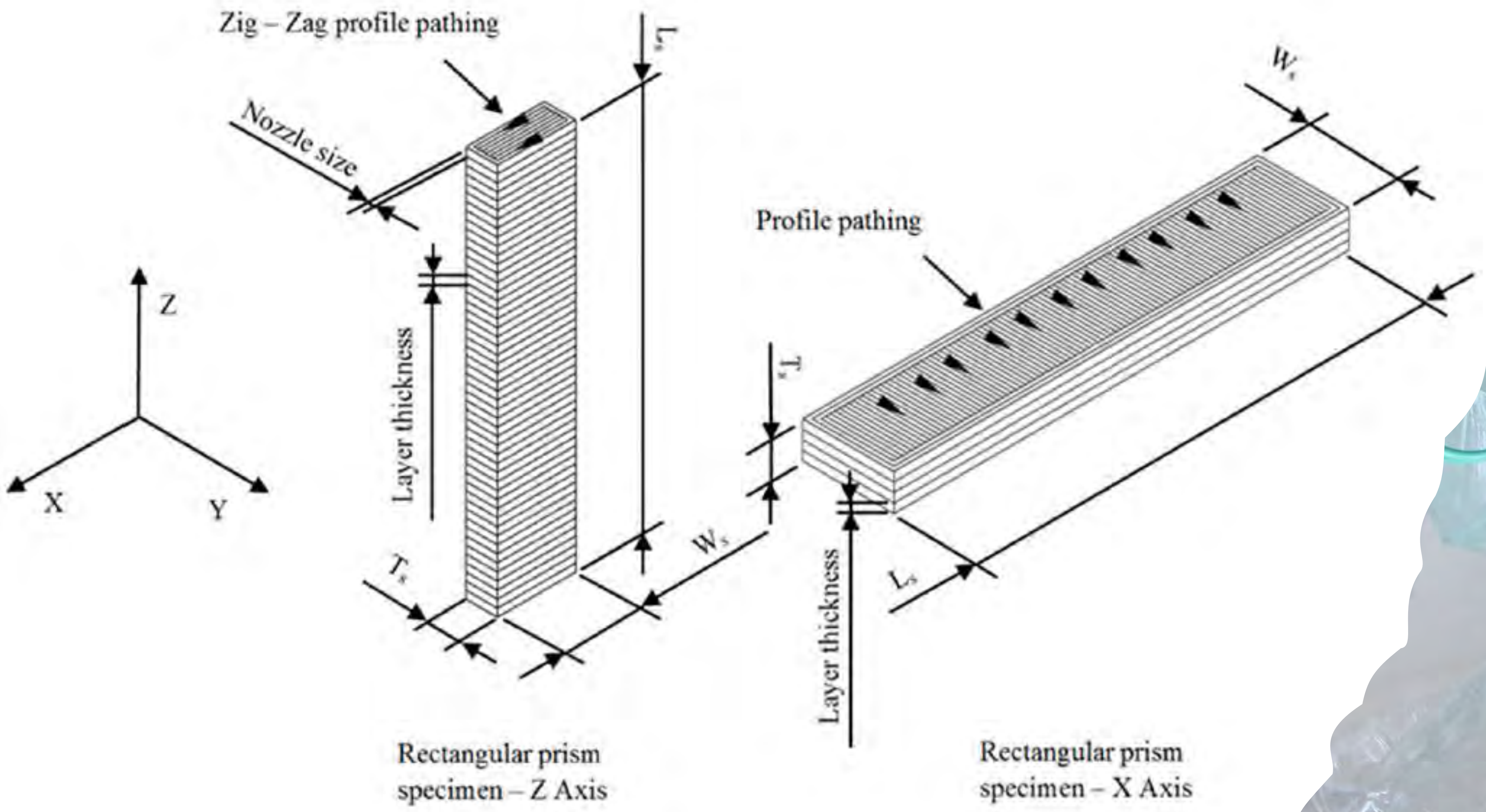
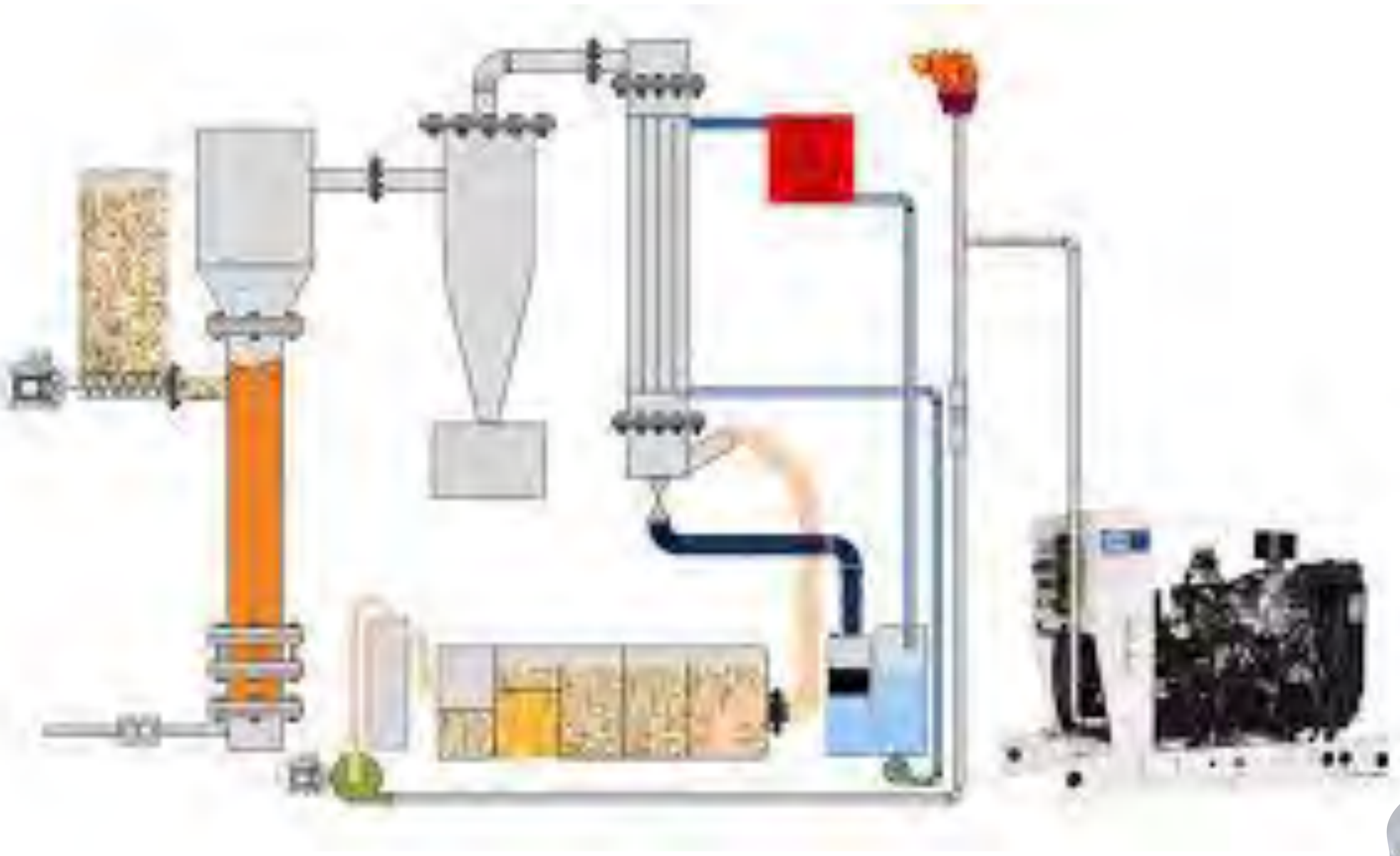
L3
L4
L5
L6
L7

Co-funded by
the European Union



Co-funded by the European Union



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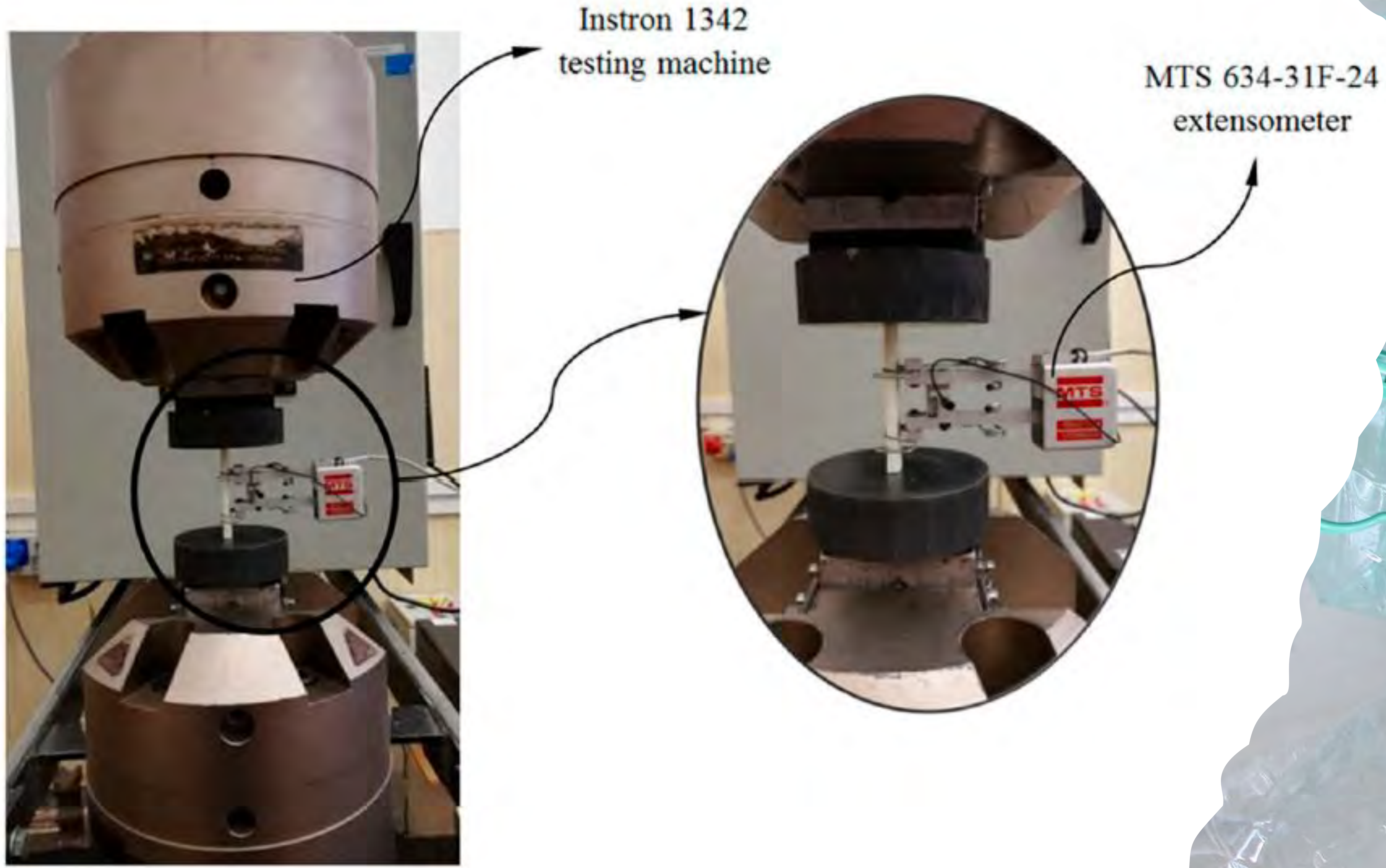
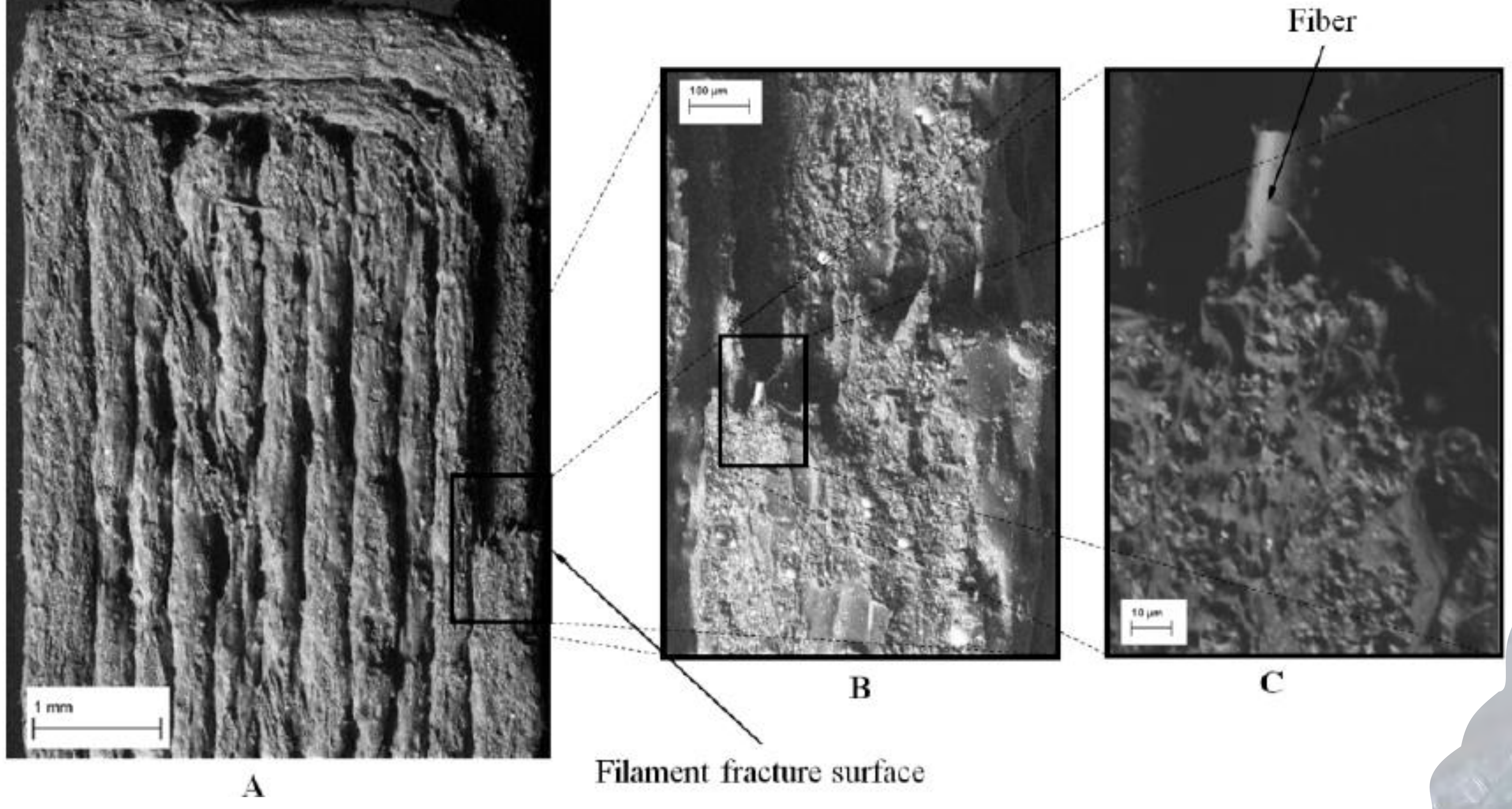
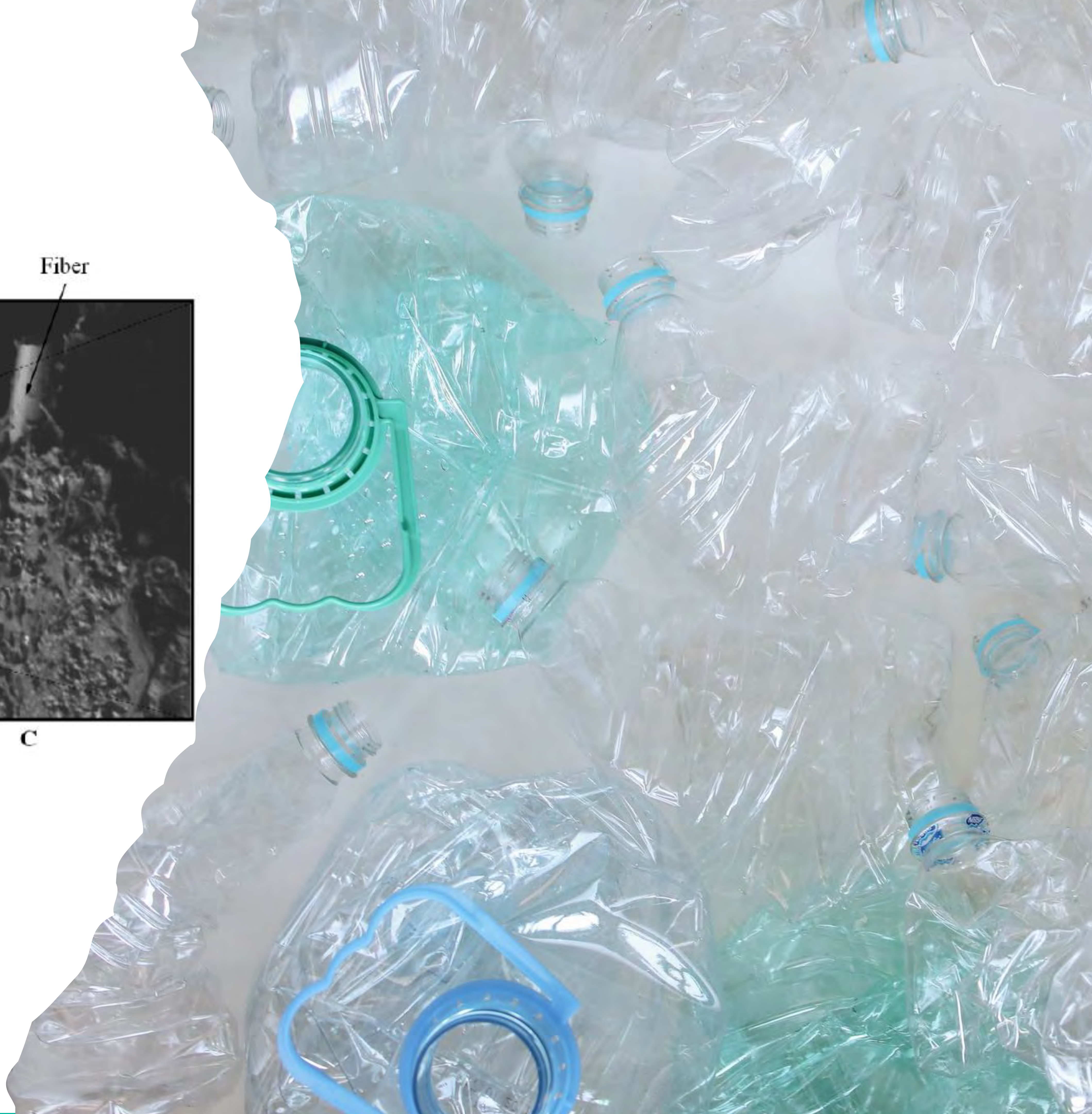
the European Union

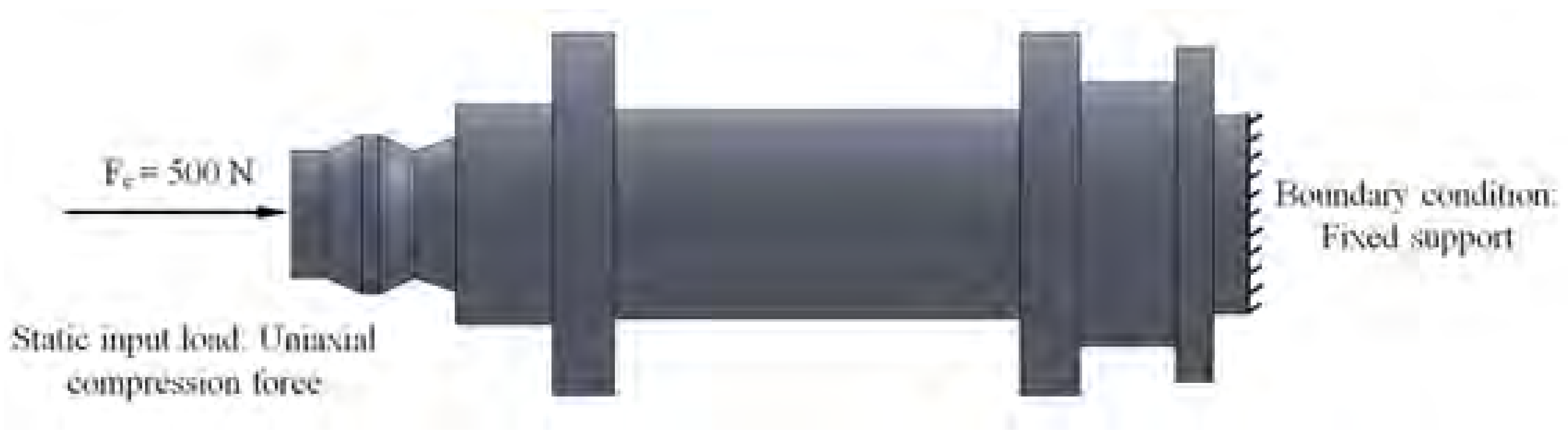


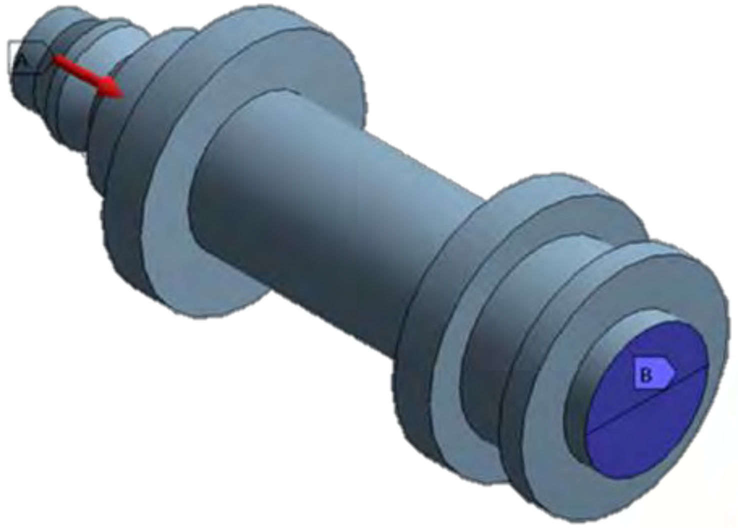
Co-funded by
the European Union



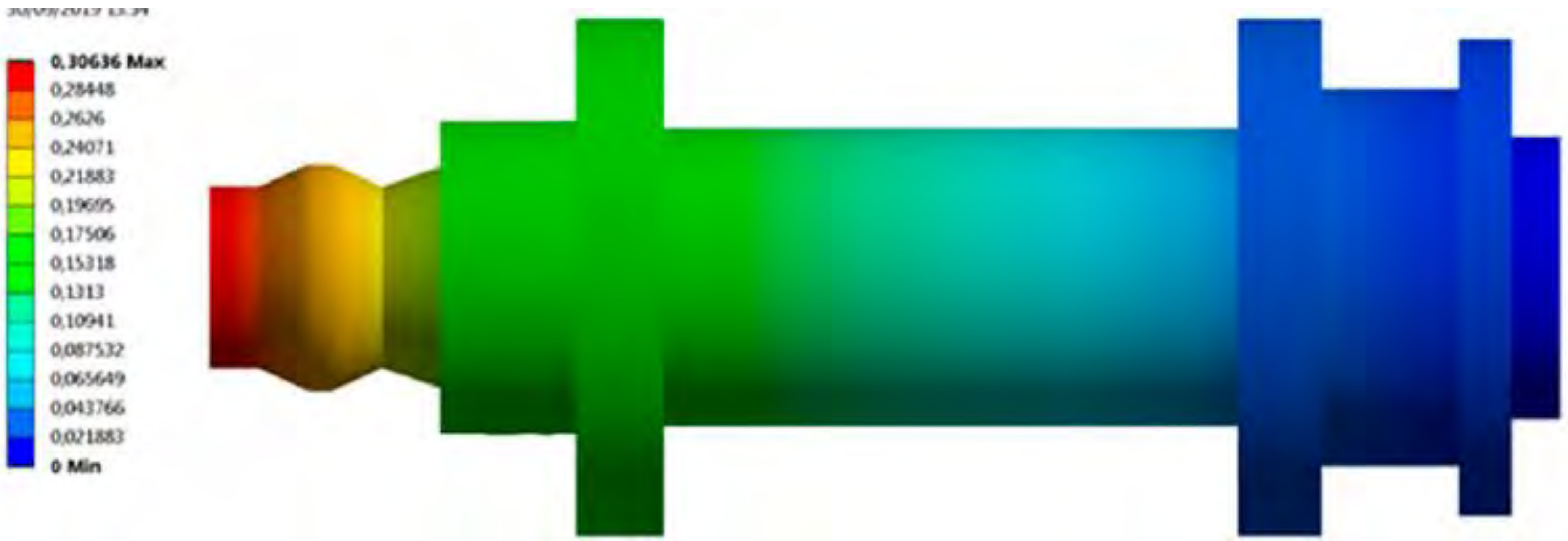


Co-funded by
the European Union


F_c = 500 N
Static input load: Uniaxial compression force
Boundary condition: Fixed support

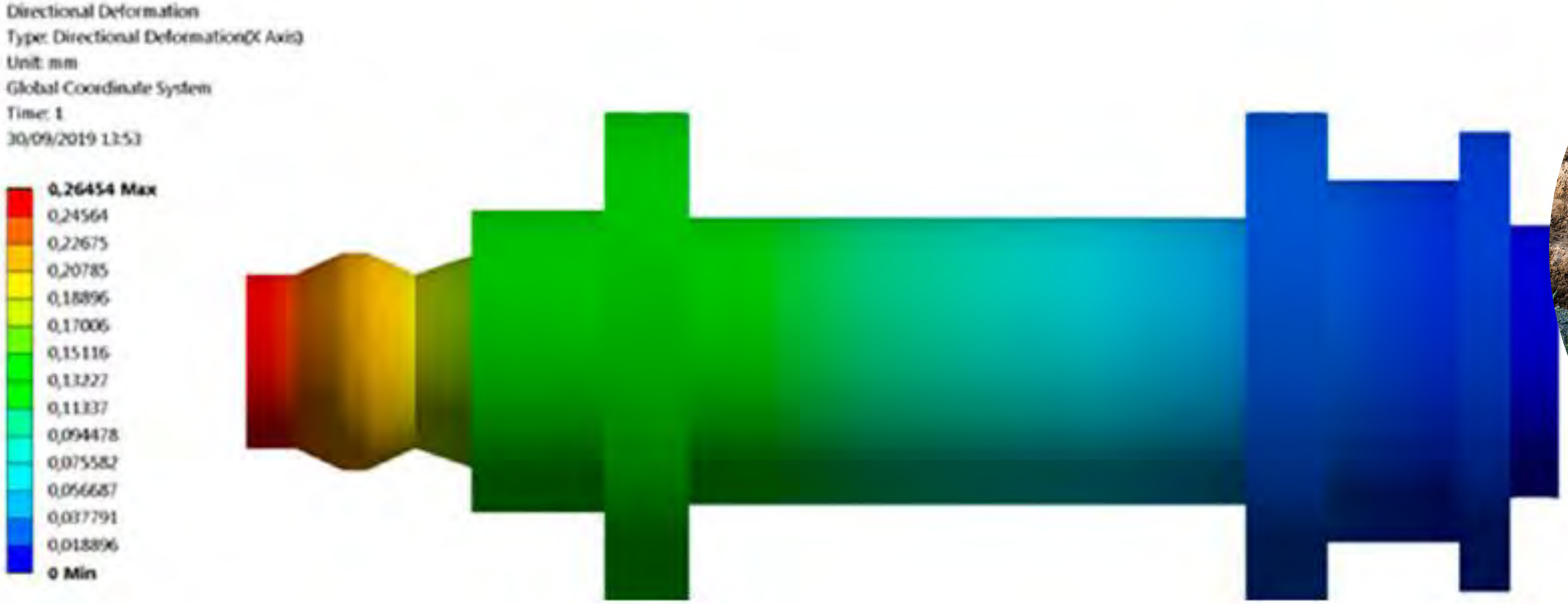


A

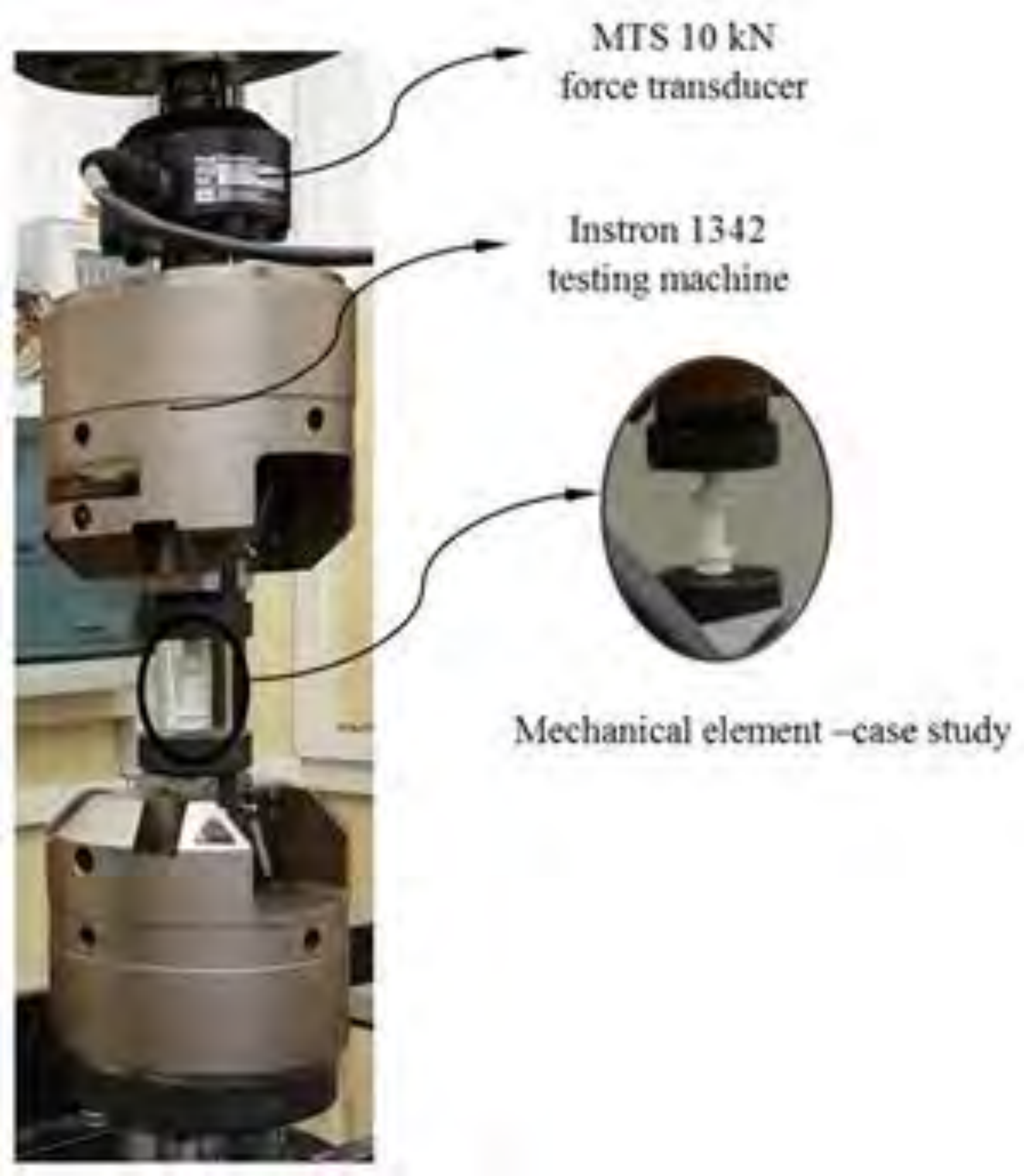


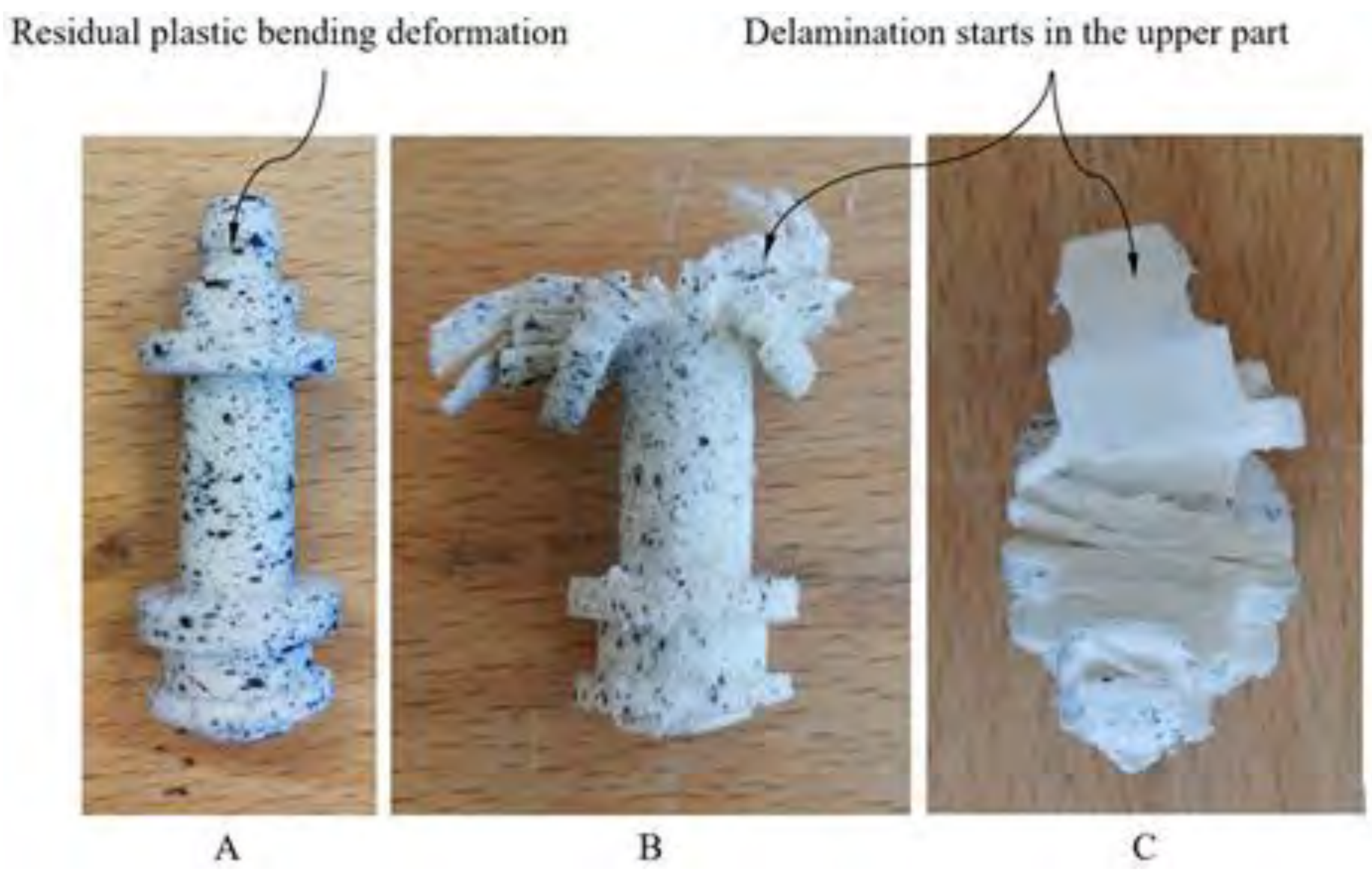
0,30636 Max
0,28448
0,2626
0,24071
0,21883
0,19695
0,17506
0,15318
0,1313
0,10941
0,087532
0,065649
0,043766
0,021883
0 Min

B



Directional Deformation
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1
30/09/2019 13:53
0,26454 Max
0,24564
0,22675
0,20785
0,18896
0,17006
0,15116
0,13227
0,11337
0,094478
0,075582
0,056687
0,037791
0,018896
0 Min


MTS 10 kN
force transducer
Instron 1342
testing machine
Mechanical element –case study


Residual plastic bending deformation
Delamination starts in the upper part
A
B
C

Practical exercise

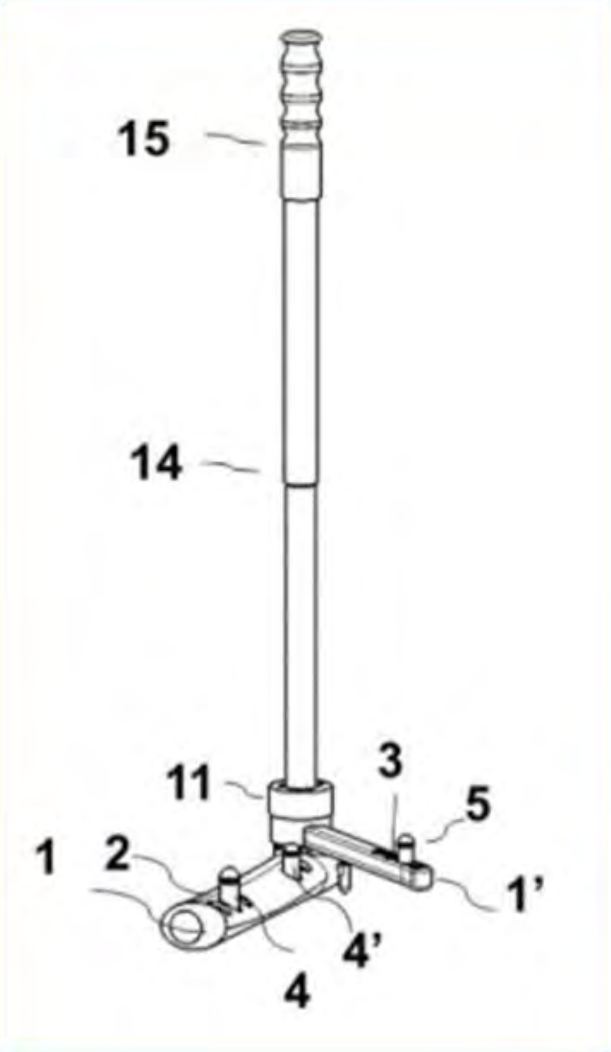
Practical Case

Product Context

Practical Case

Practical Case

Dispositivo para la colocación y retirada de calcetines y medias Número de patente ES 2 605 836 B2



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ESPAÑA

(11) Número de publicación: **2 605 836**

(21) Número de solicitud: 201730135

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A47G 25/90 (2006.01)

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(72) Inventor/es:

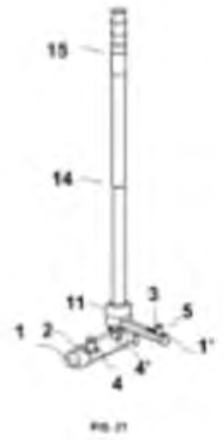
MARTÍN DOÑATE, Cristina y
TORRES SAAVEDRA, Antonio

(54) Título: **Dispositivo para la colocación y retirada de calcetines y medias**

(57) Resumen:

Dispositivo para la colocación y retirada de calcetines y medias.

La invención describe un dispositivo para la colocación y retirada de calcetines y medias que comprende un cuerpo base (1, 1') formado por un elemento guía del pie (1), un elemento soporte superior (1') conectado a un lateral del elemento guía del pie, un sistema de fijación (7) configurado para fijar la posición relativa entre ambos elementos (1, 1'), una pluralidad de casquillos (2, 3) y tetones de sujeción (4, 4', 5) del calcetín conectados con el elemento guía del pie (1) y el soporte superior (1') con posicionamiento variable entre ambos elementos tal que el movimiento de rotación del cuerpo base (1, 1') provoca el posicionamiento y elevación del pie para la colocación precisa del calcetín sobre el pie y el movimiento de traslación del cuerpo base (1, 1') ayuda a la colocación del calcetín de forma completa sobre la extremidad inferior, estando ambos movimientos guiados por el mango extensible (13).



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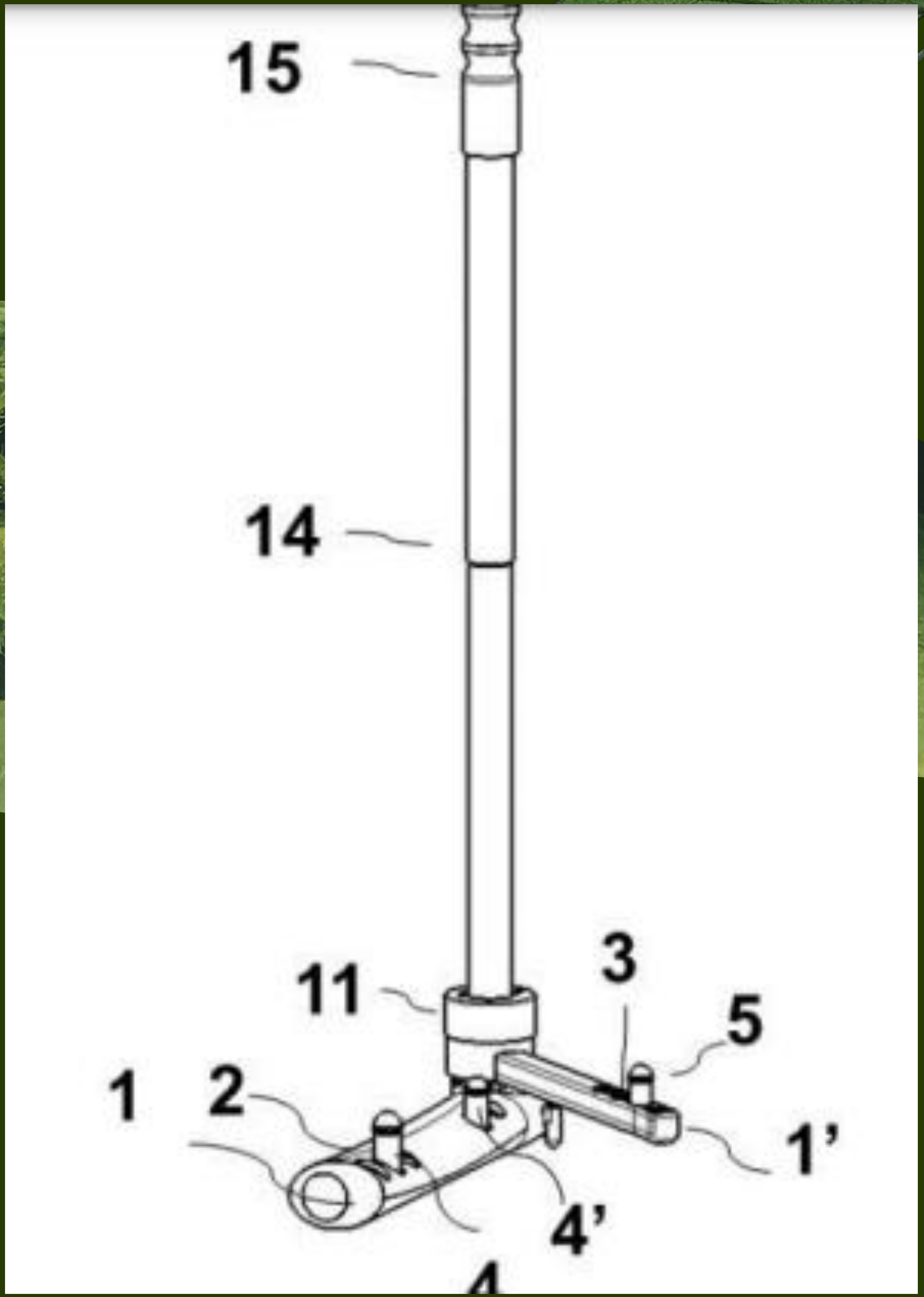

15
14
11
3
5
1
2
1’
4’
4

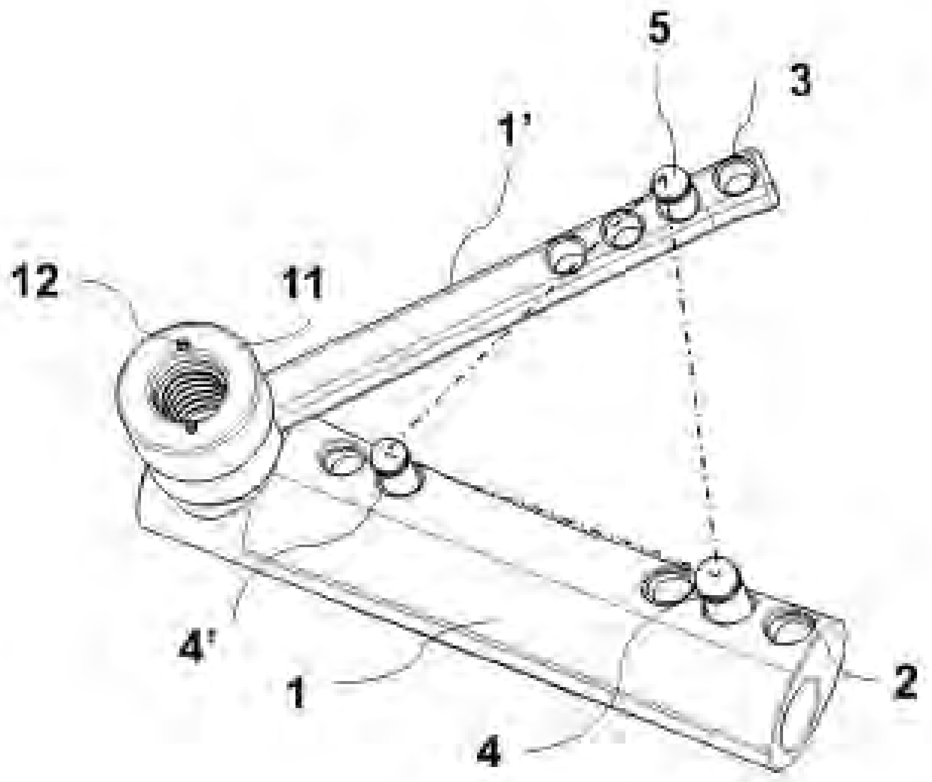
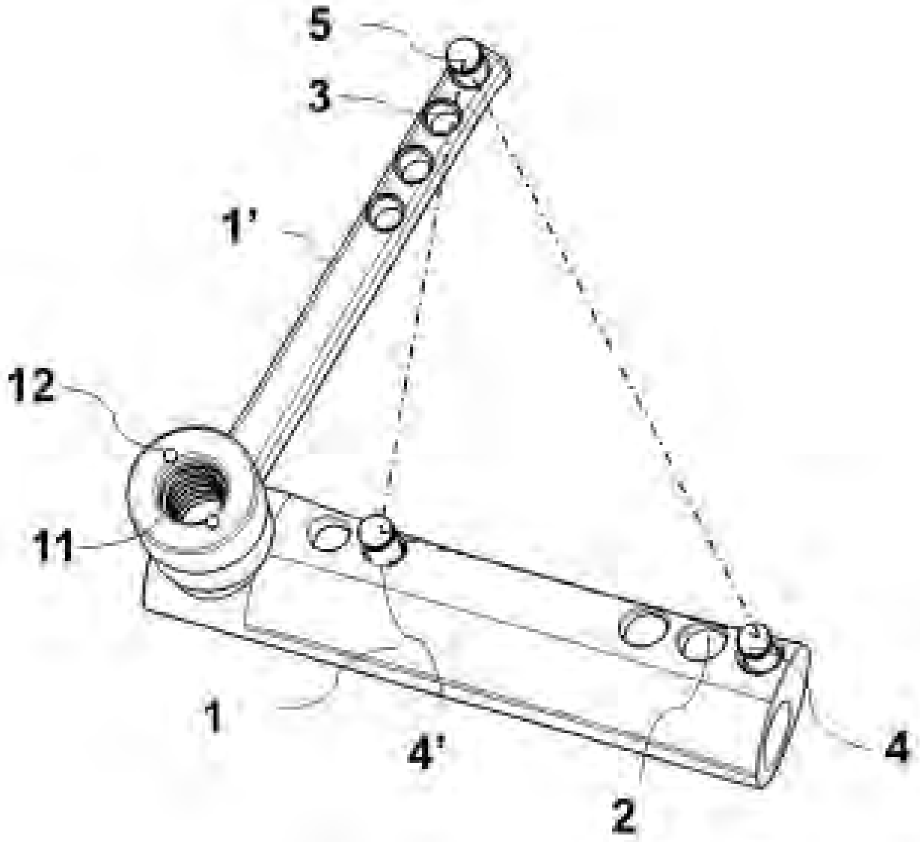


FIG. 15a



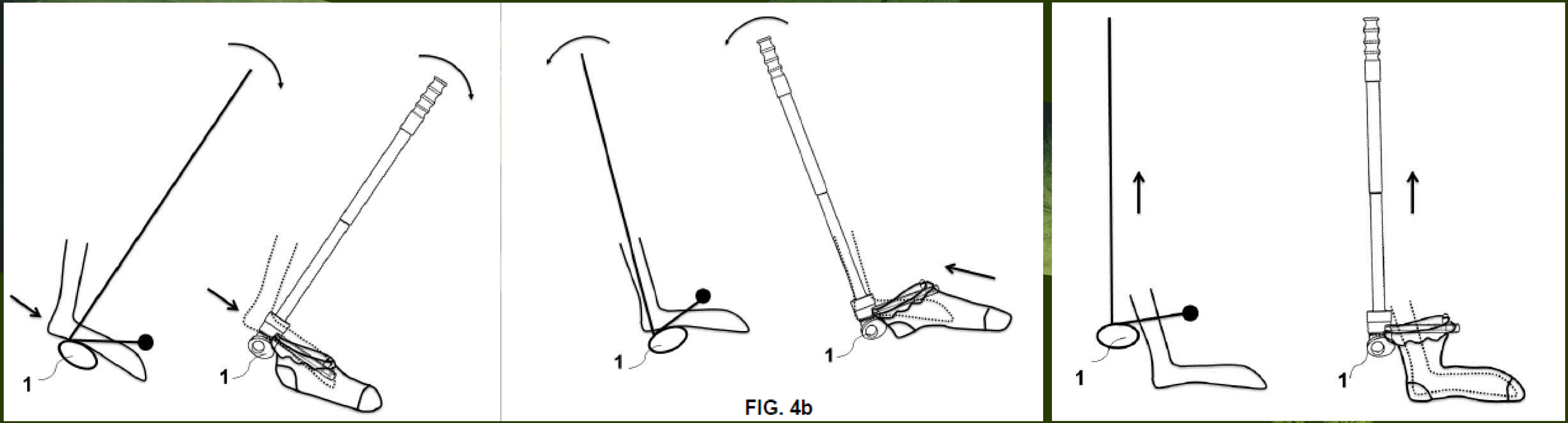


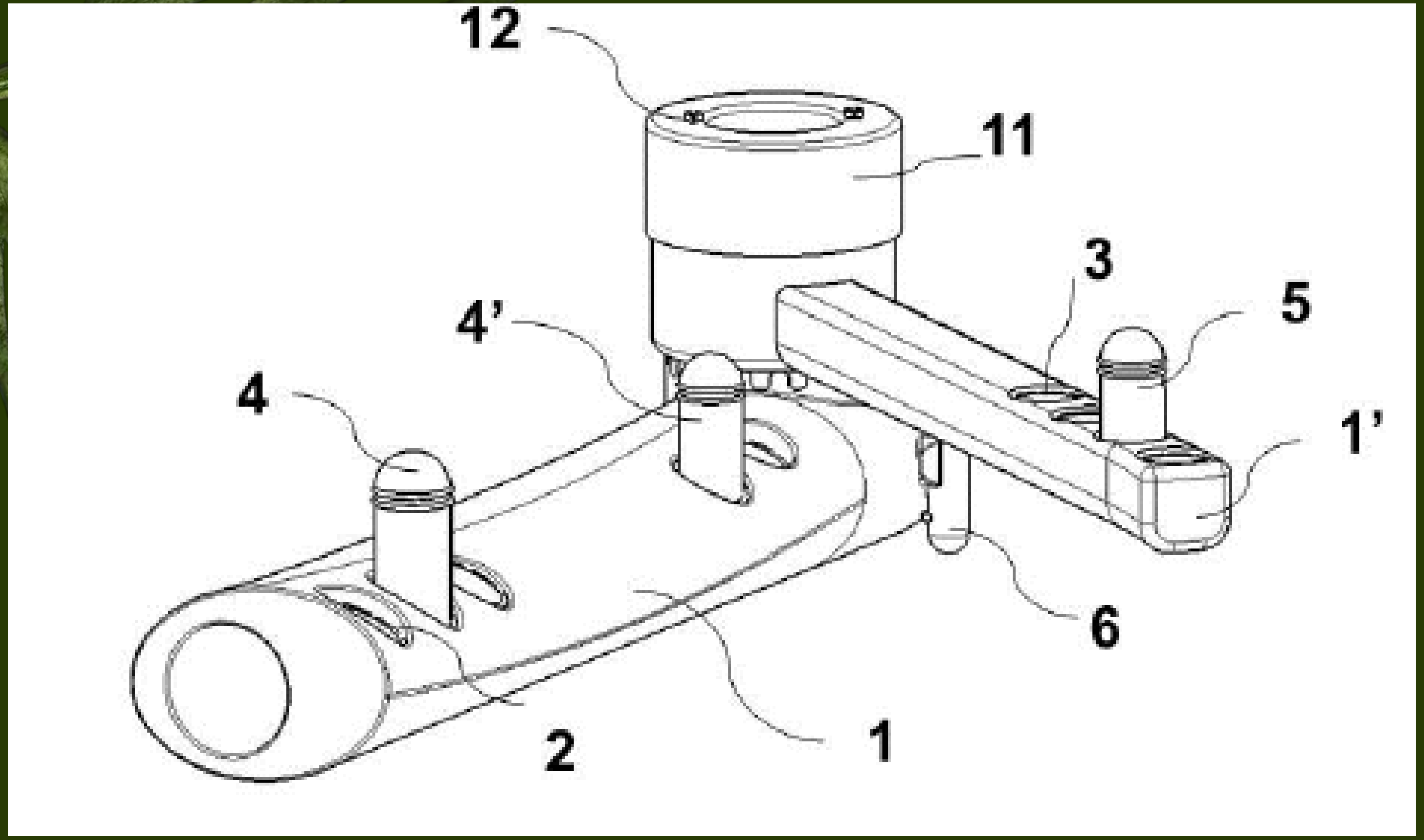
FIG. 4b

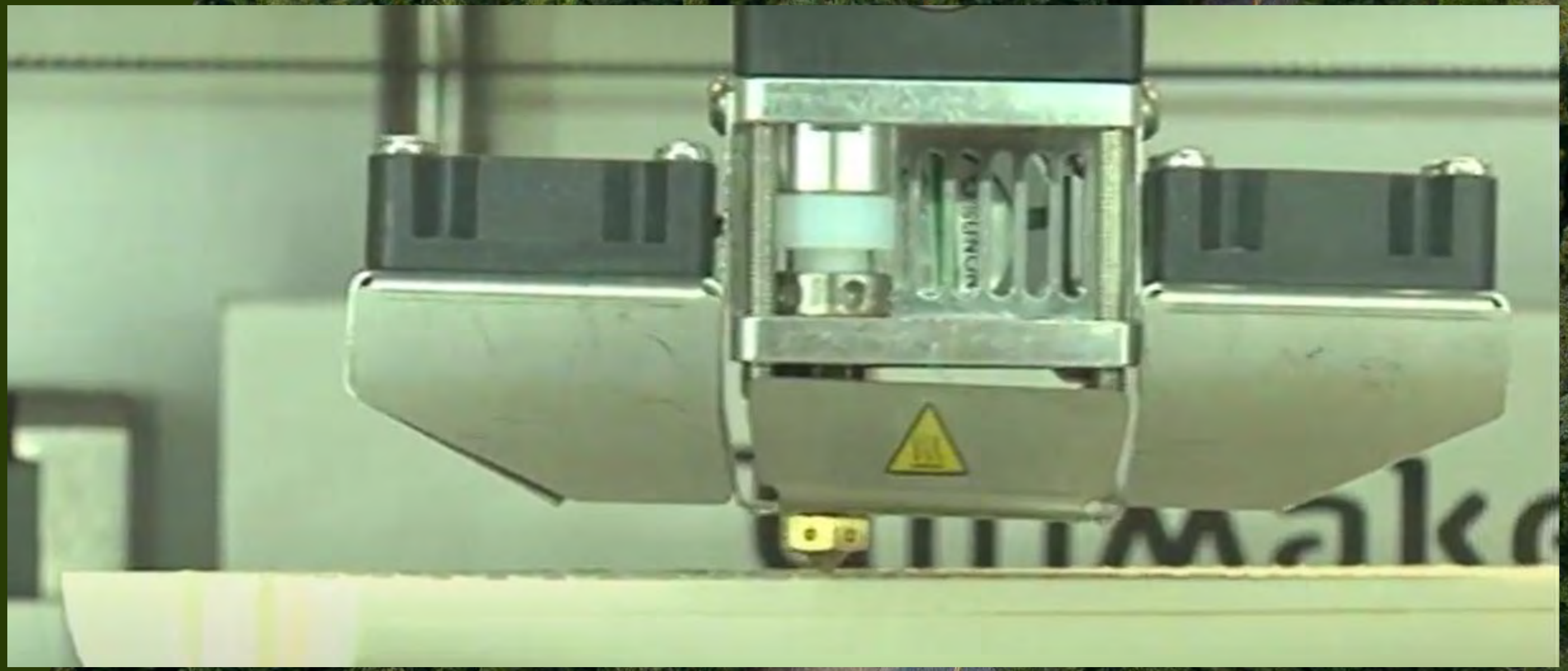
https://www.youtube.com/watch?v=6Q1KPc1V9jk

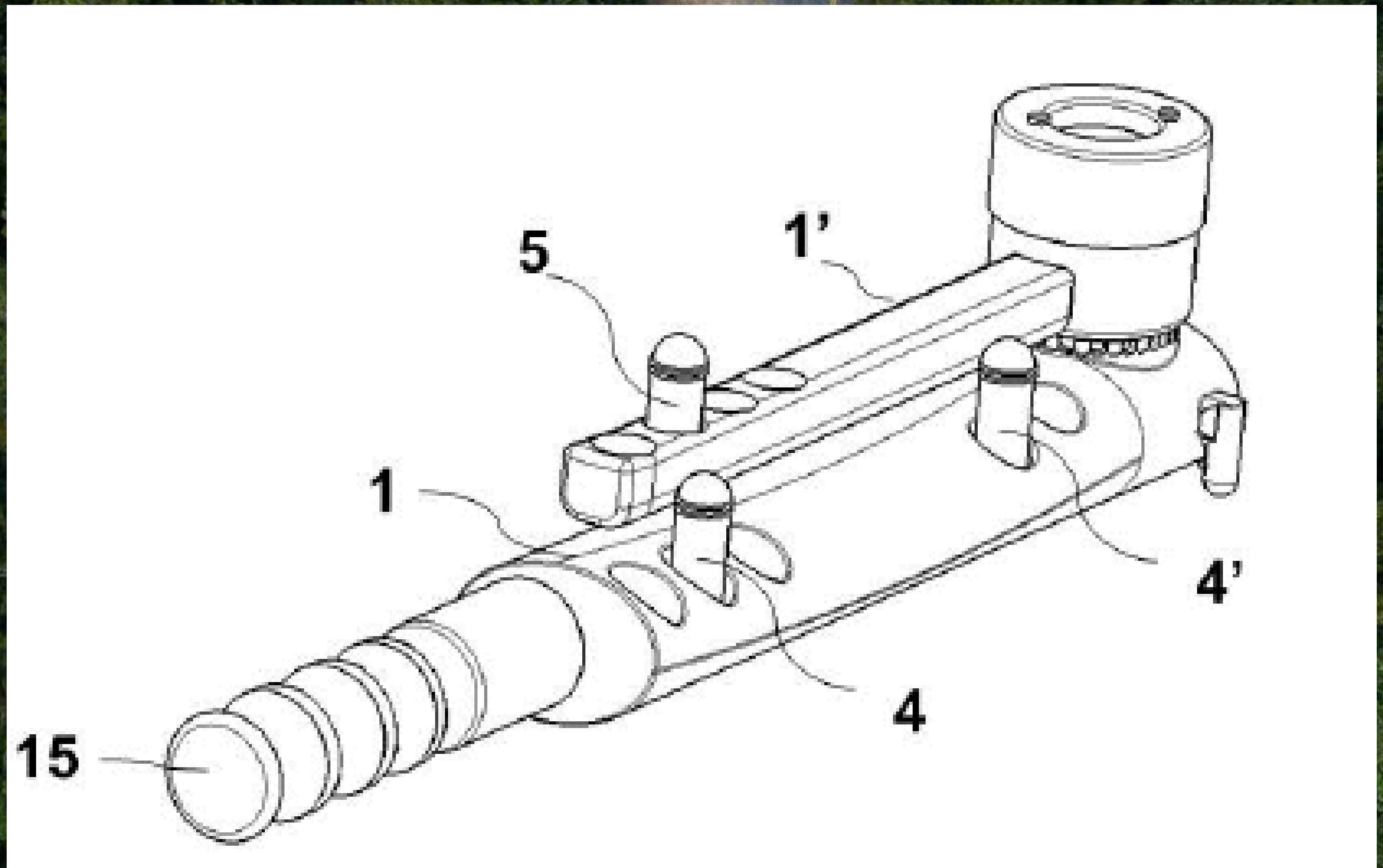
Team work
45 min

- **Choose the Right Materials:** Use recycled or renewable materials that have less impact on the environment.
- **Design for Durability:** Make sure your product lasts longer, which means fewer replacements and less waste over time.
- **Make It Easy to Repair:** Design products so they can be easily fixed. This helps extend their life and reduces the need for new products.
- **Plan for Recycling:** Think about how the product can be taken apart and recycled at the end of its life.
- **Use Energy Wisely:** Opt for energy-efficient processes during manufacturing and aim to reduce energy use while the product is in use.

- **Choose the Right Materials:** The device was made with **PLA** material.
- **Design for Durability:** A **simple** design is created according to the client's requirements, which will not include any sensors that could fail.
- **Make It Easy to Repair:** The product that can be repaired in parts; they could be supplied to the customer, or the **customer could make them himself**. The handle can be used from other products
- **Plan for Recycling:** Biodegradable material like PLA
- **Use Energy Wisely:** Manufactured with additive technology for most of the components, it is supplied folded to reduce transportation and packaging costs


12
11
3
5
4’
4
1’
6
2
1




5
1’
1
4’
4
15

Thank you!!

Mx - Ecodesign

HEI name

Cristina Martin Doñate : cdonate@ujaen.es
Jorge Mercado Colmenero: jmercado@ujaen.es

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C5 – Computer Aided Design

M7 – Re-design & Re-Using

P2 – University of Jaén

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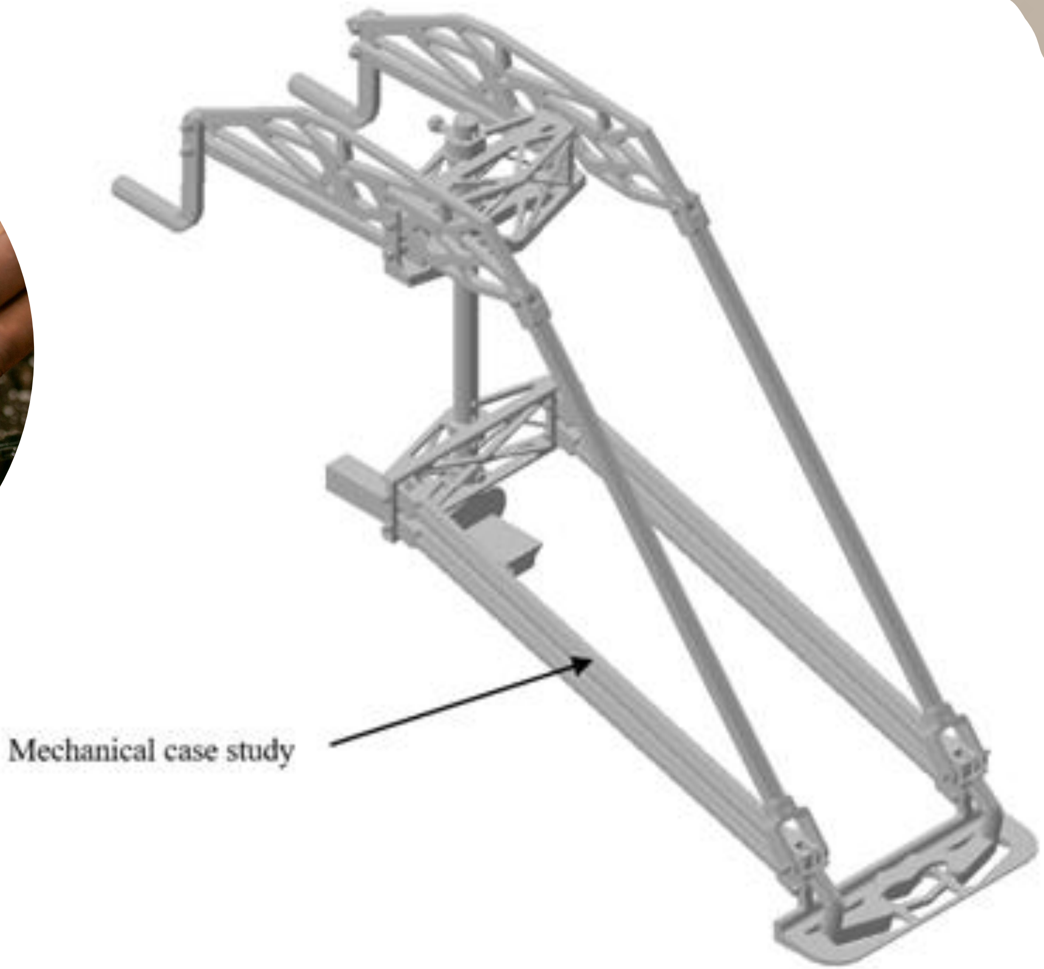
Ecodesign

Re-design & Re - Using

Agriculture application: Olive Harvest

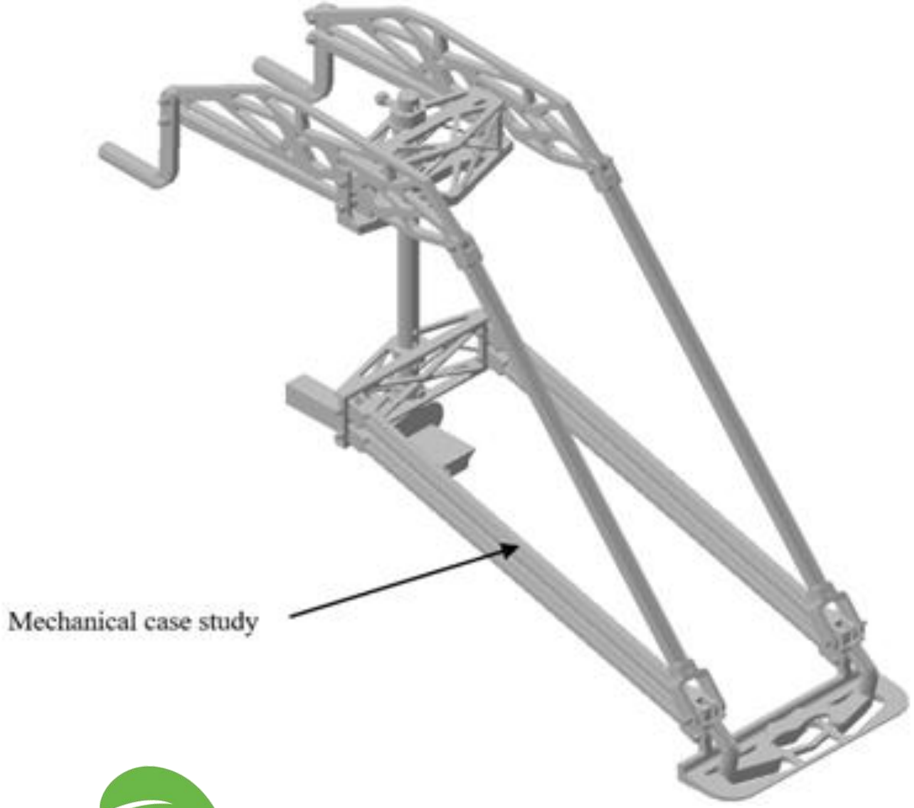
Traditionally, the olive harvesting process has been done manually. This manual process required a lot of labor and time.

Recently, new systems and assemblies have been designed which, with the help of tractions, reduce the effort, time and labor used during the olive harvesting process.



Redesign of the mechanisms, coupled to the tractors, to collect and hold the tarps/umbrellas used to collect the olives.

3D additive manufacturing



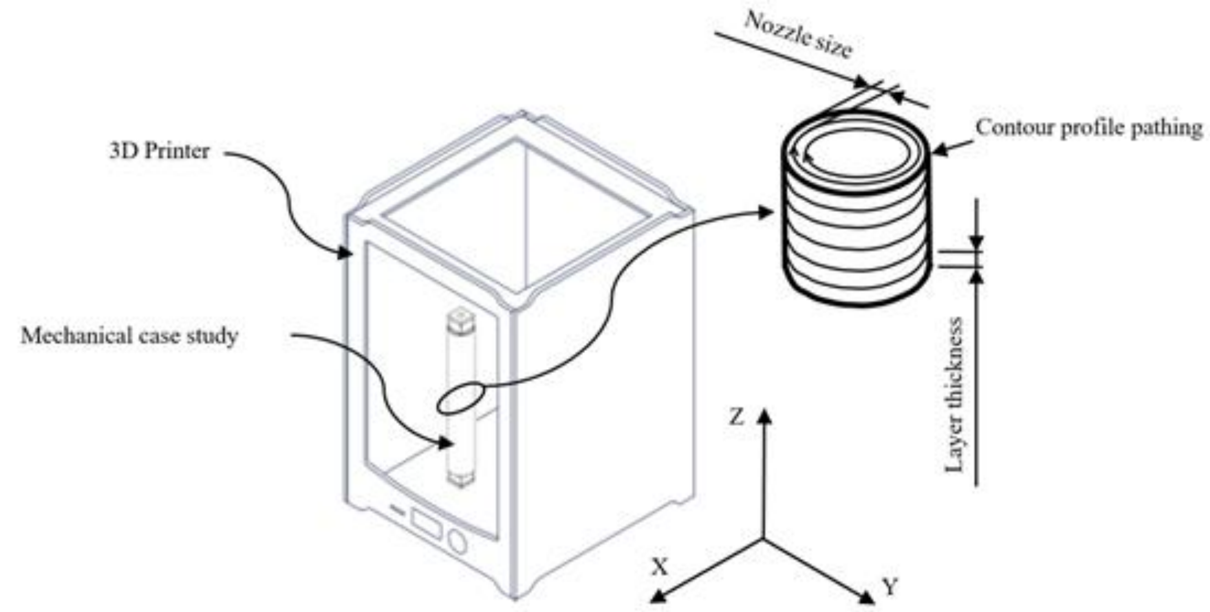
Sustainable (Plastic material)

Reduce Weight

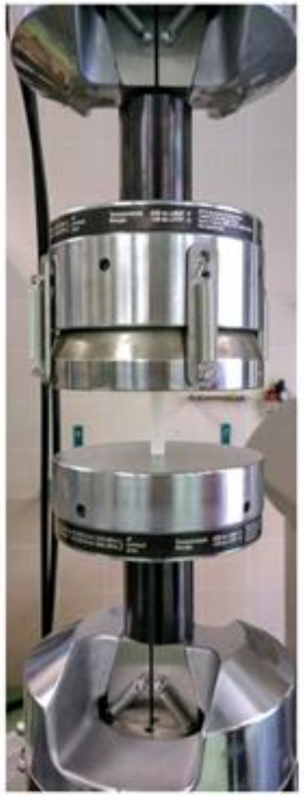
Optimize process


Boundary condition: Fixed support
Static input load: Uniaxial compression force
$F_c = 900N$

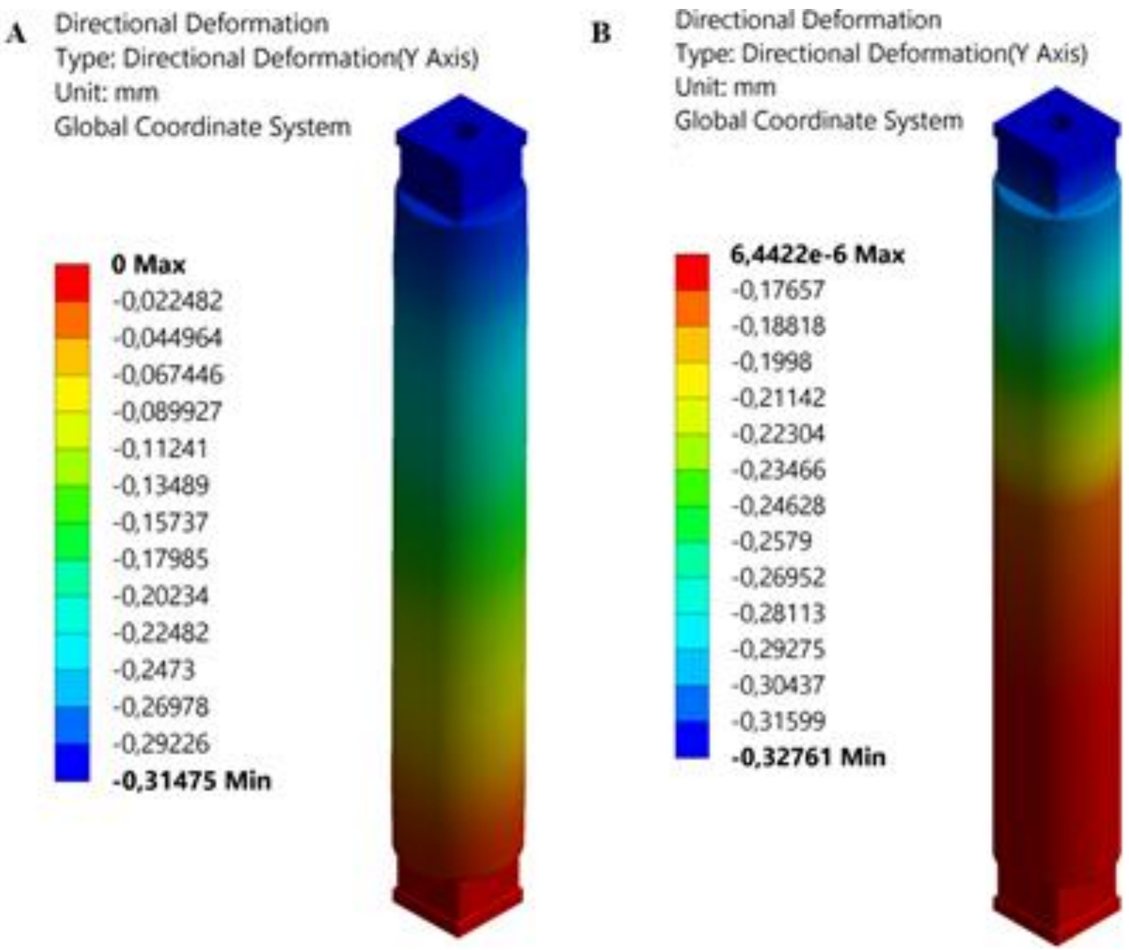
Plastic Material Mechanical Characterization



Pure Unixial Compression Stress State



Numerical & Experimental Validation



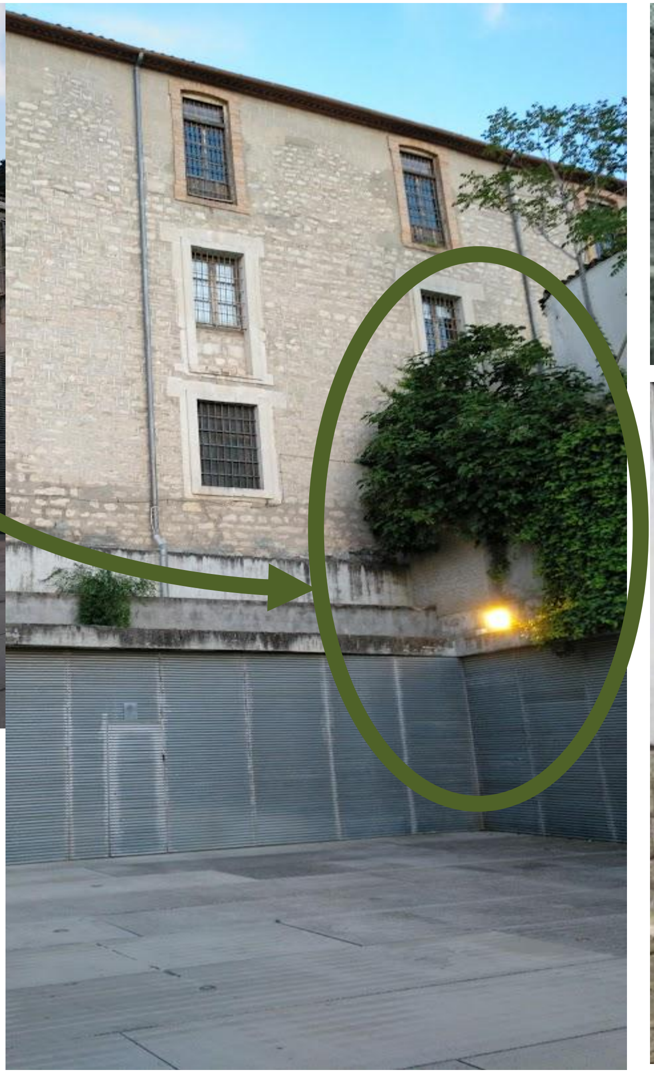
Ecodesign

Accessibility & Sustainability

Architectural Application

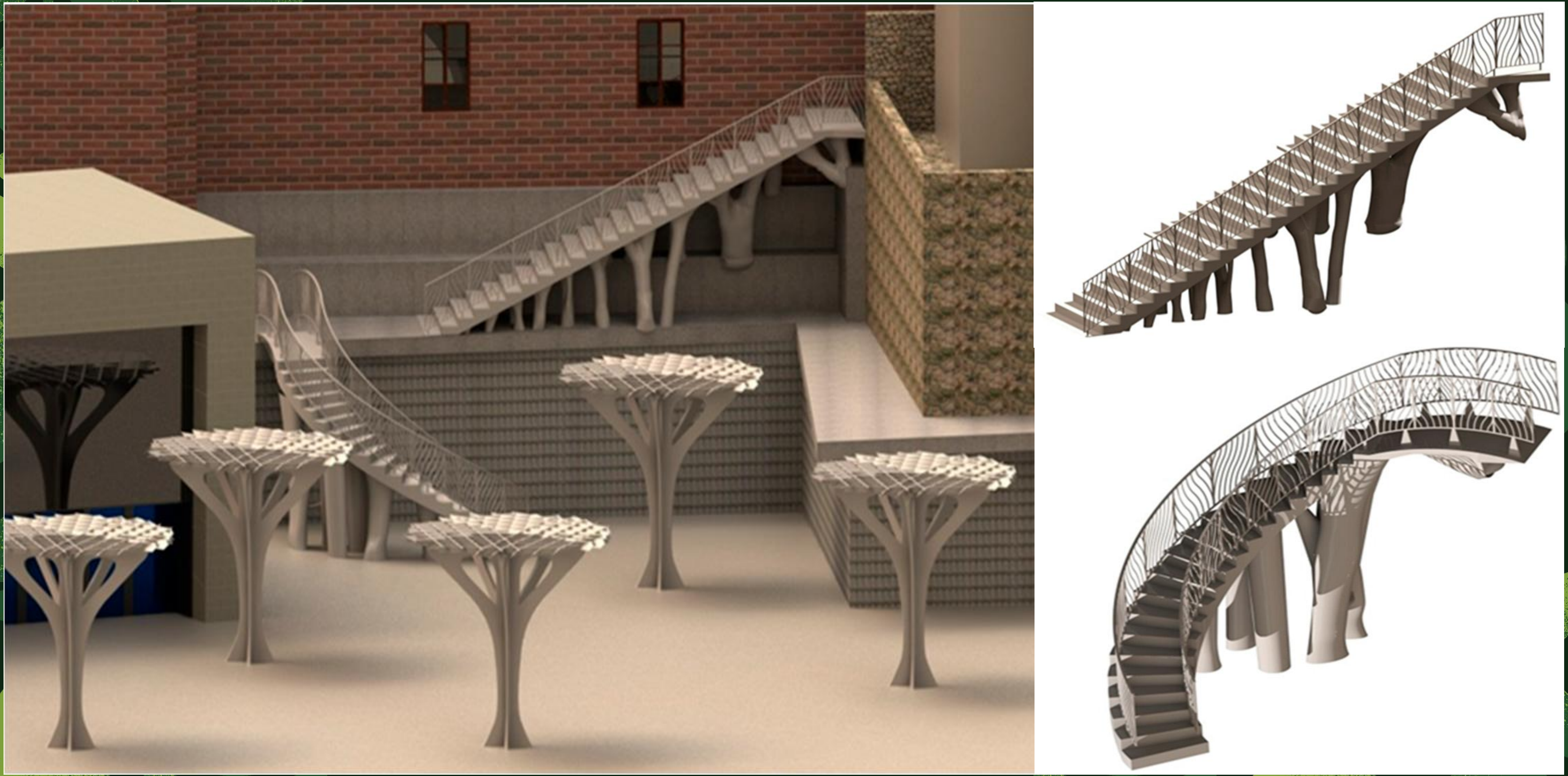
Jaén, Andalucía. Spain

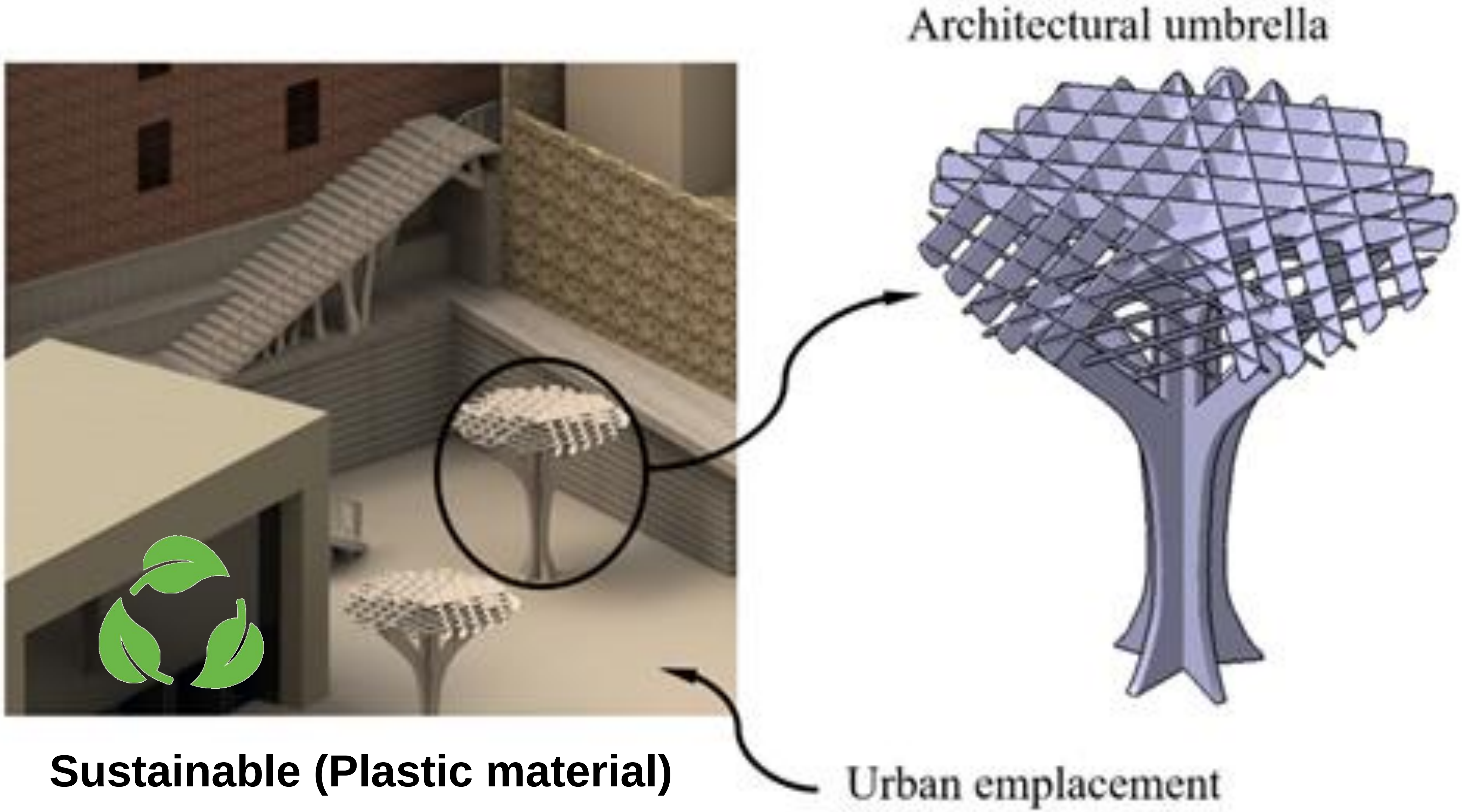
Museum Square



Through the design of new architectural elements, we seek to provide accessibility to the street over the square and create sunshades to encourage public use of the museum square.

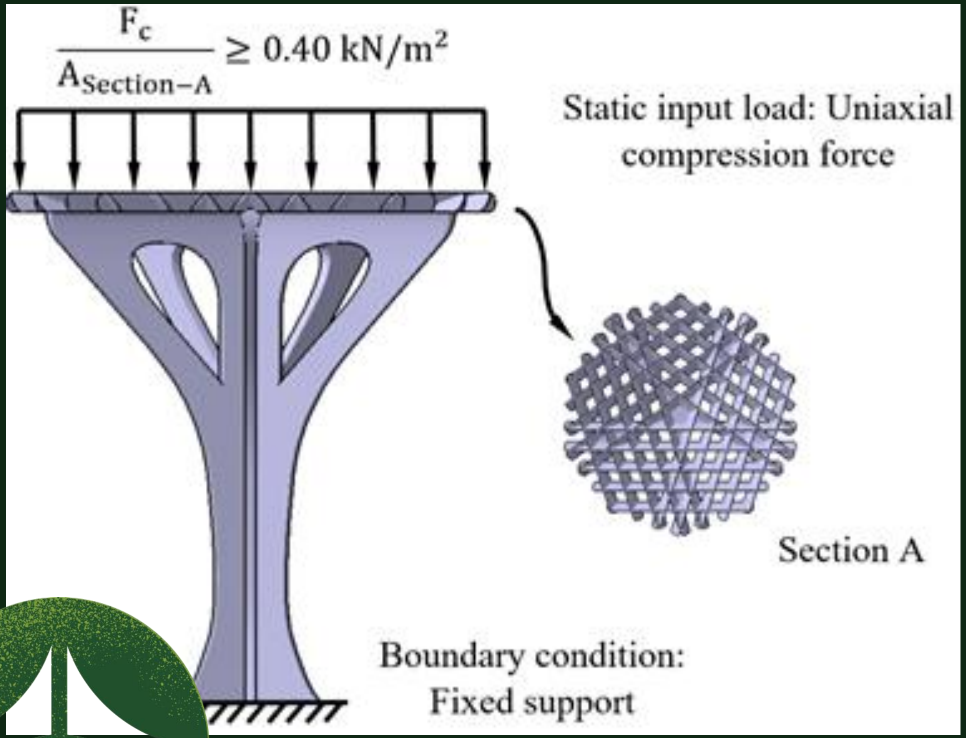
Street without square access

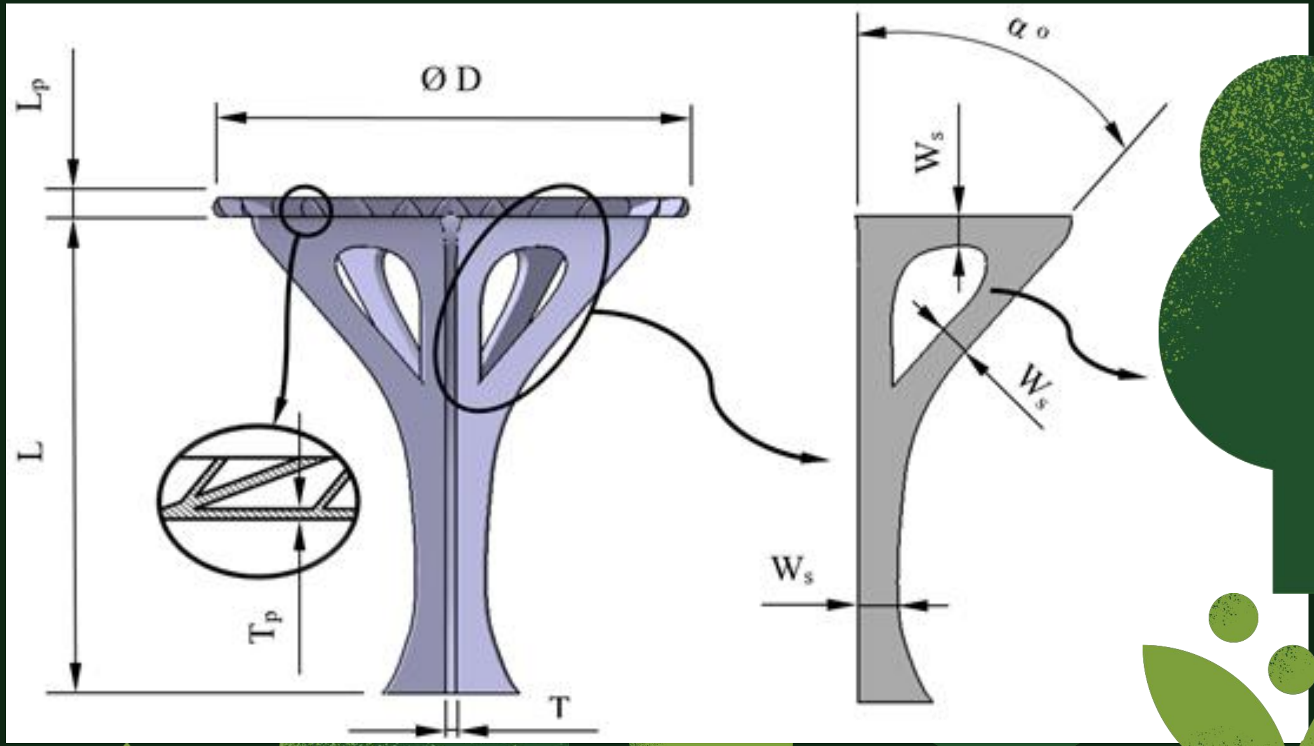




Sustainable (Plastic material)

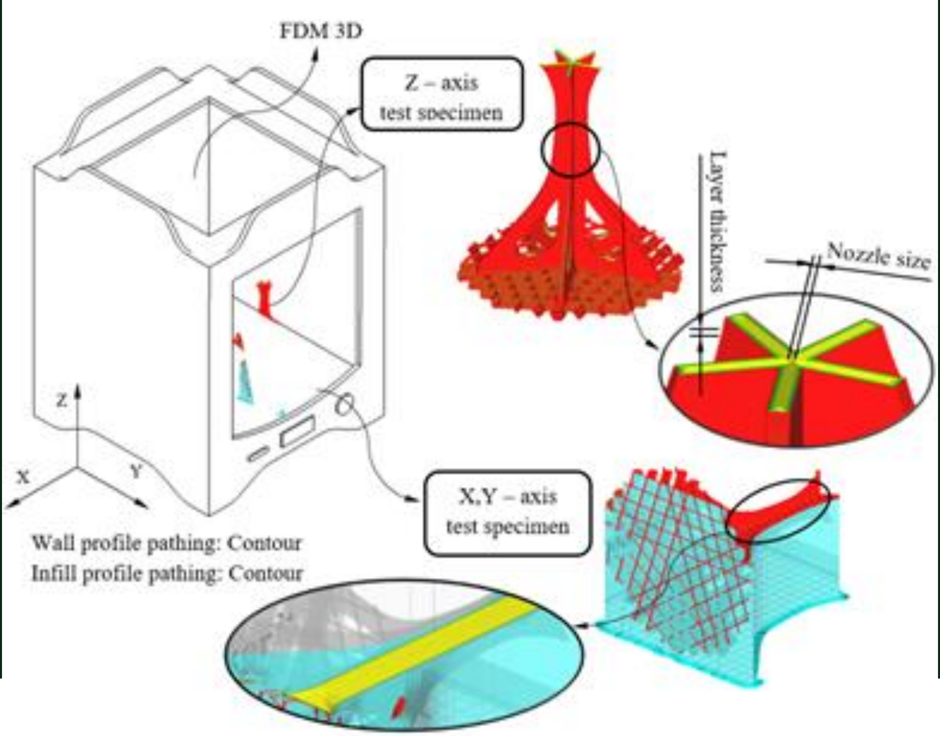
Pure Unixial Compression Stress State

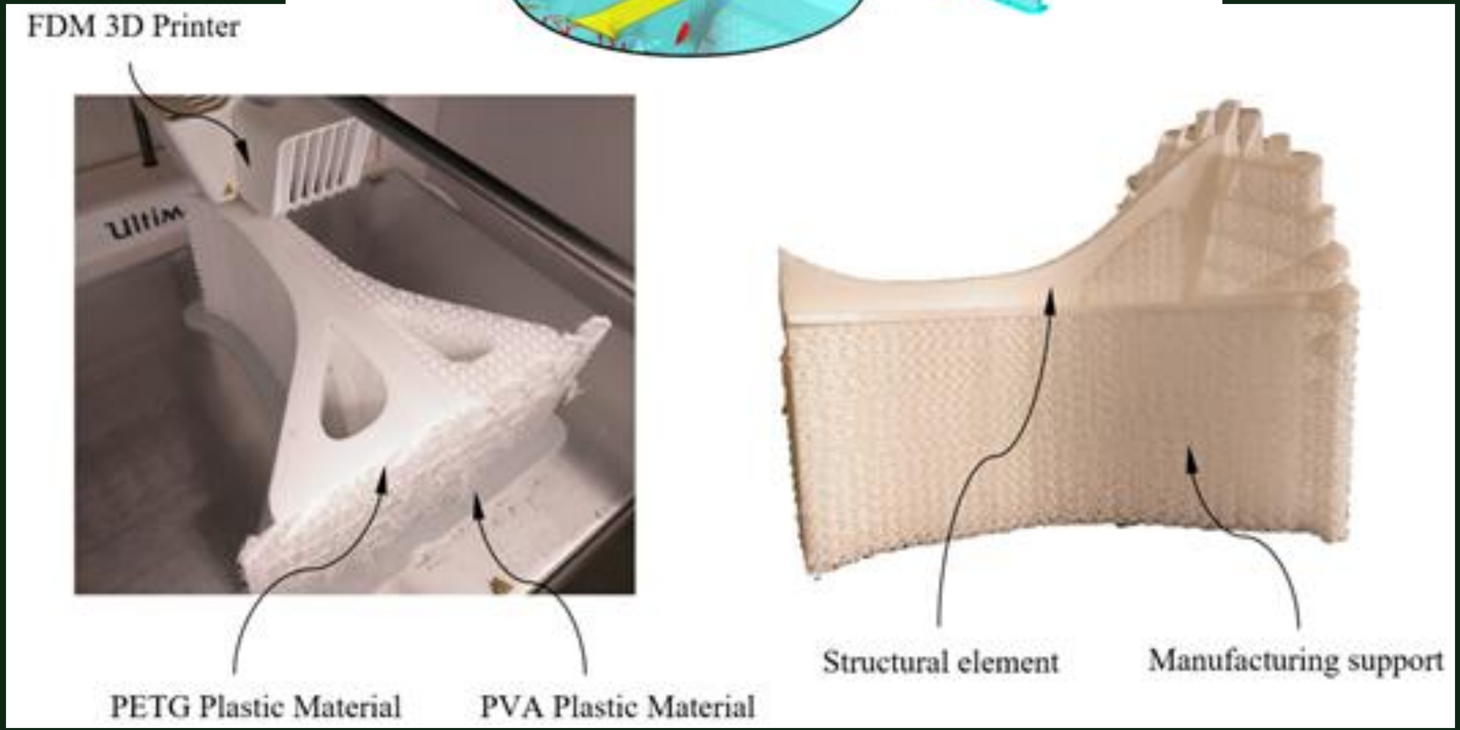




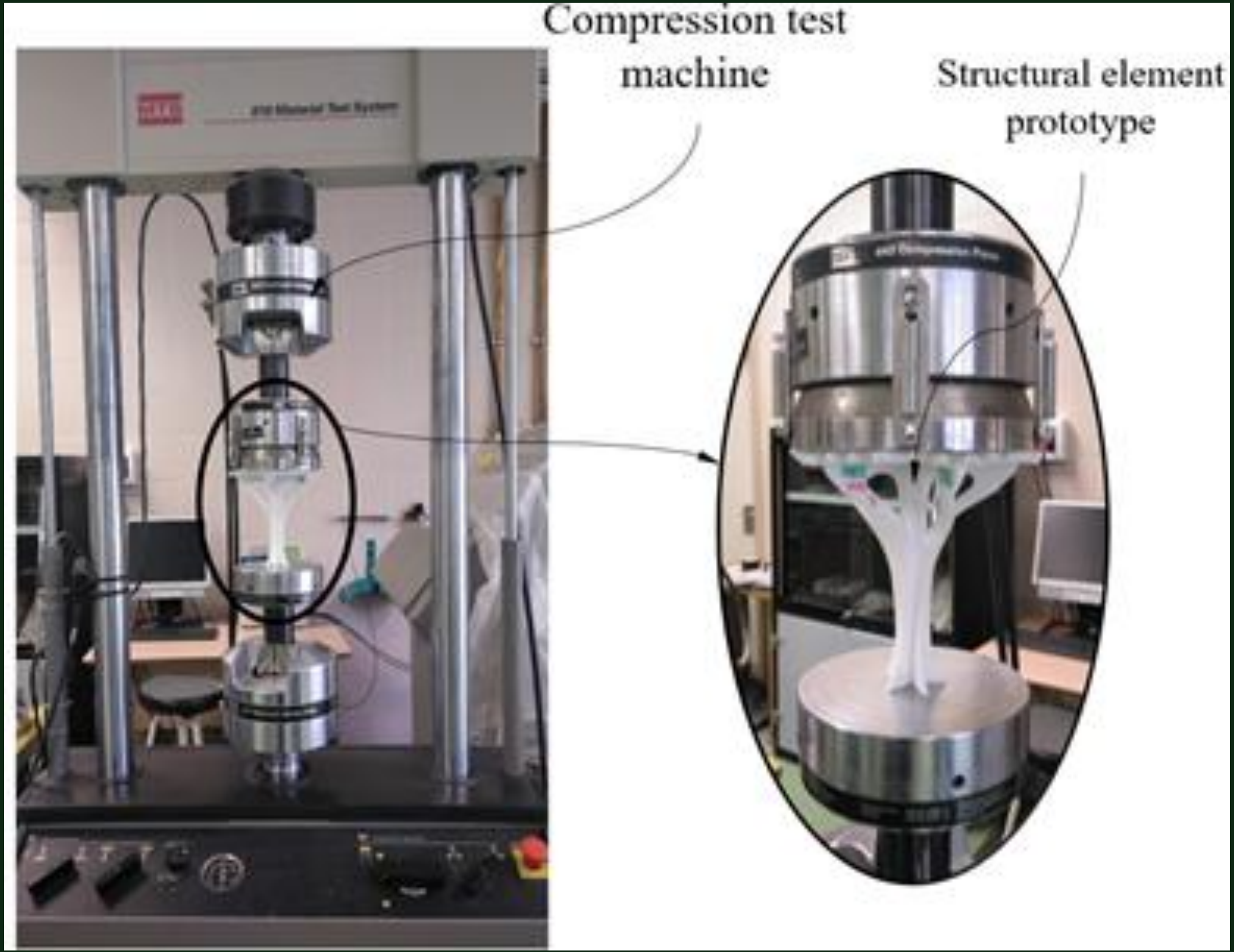
Co-funded by the European Union

Manufacturing of the parasol prototype on a scale using 3D additive manufacturing and sustainable plastic material

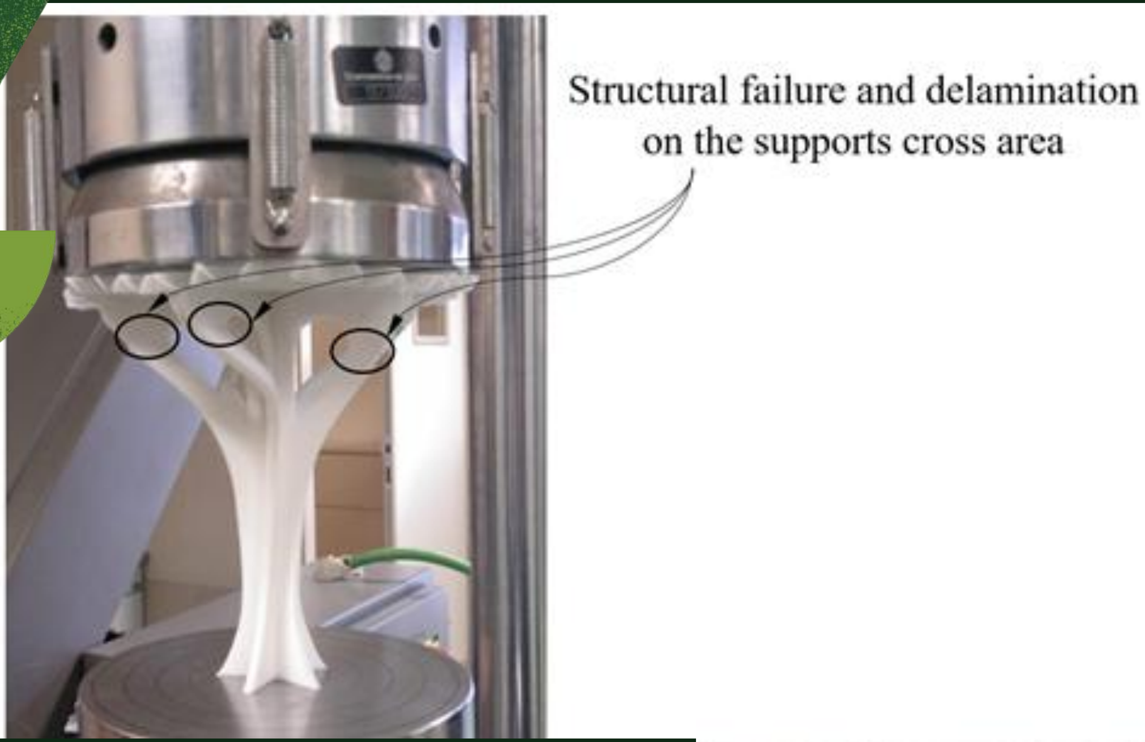


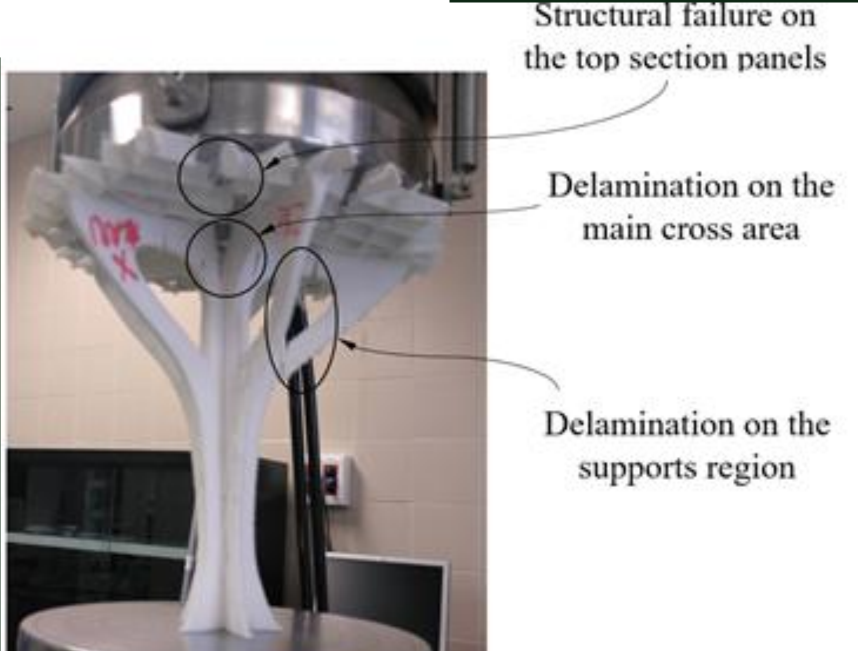


Experimental & Numerical Validation

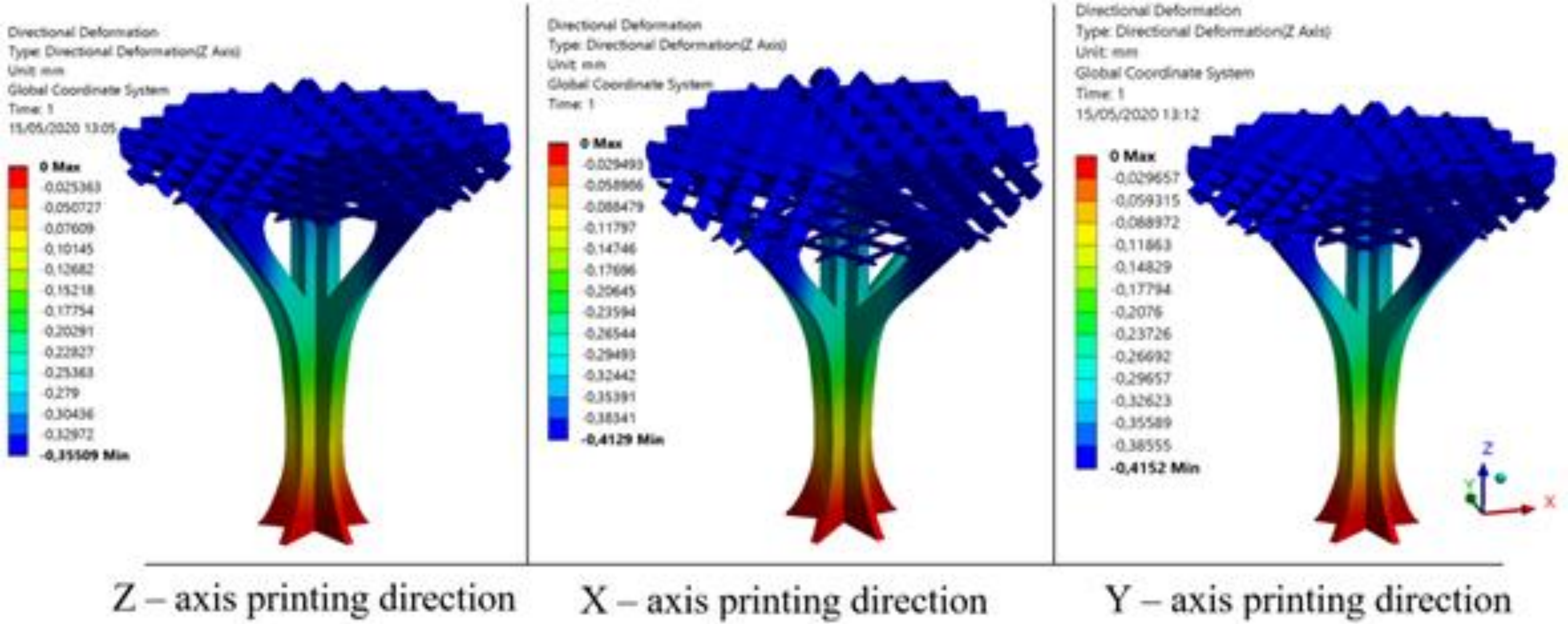


Experimental & Numerical Validation



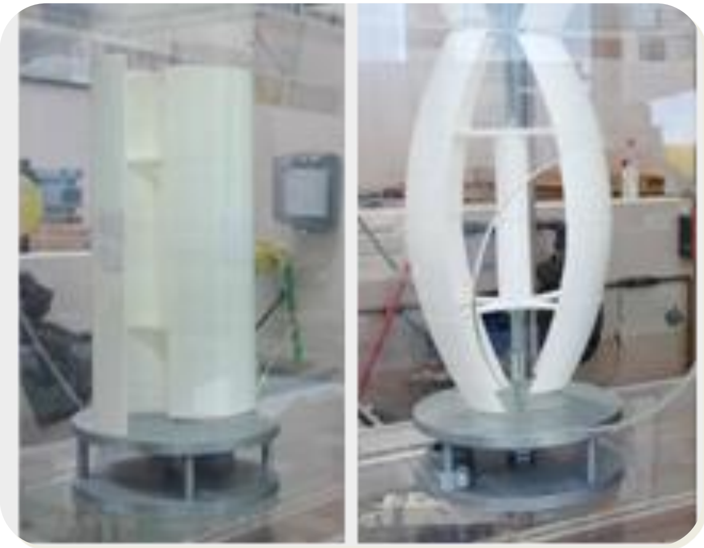


Using a scale model, the design geometry was experimentally validated for the unixial pure compression load scenario to which it is subjected.

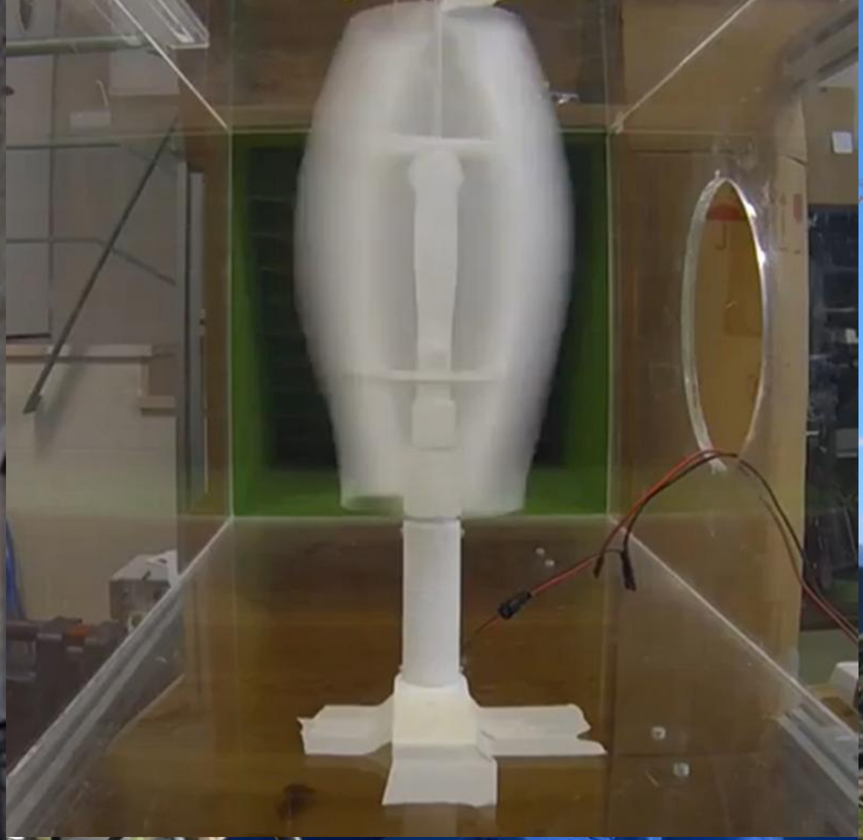


Experimental & Numerical Validation

Ecodesign



Sustainability & renewable energy



Renewable Energy

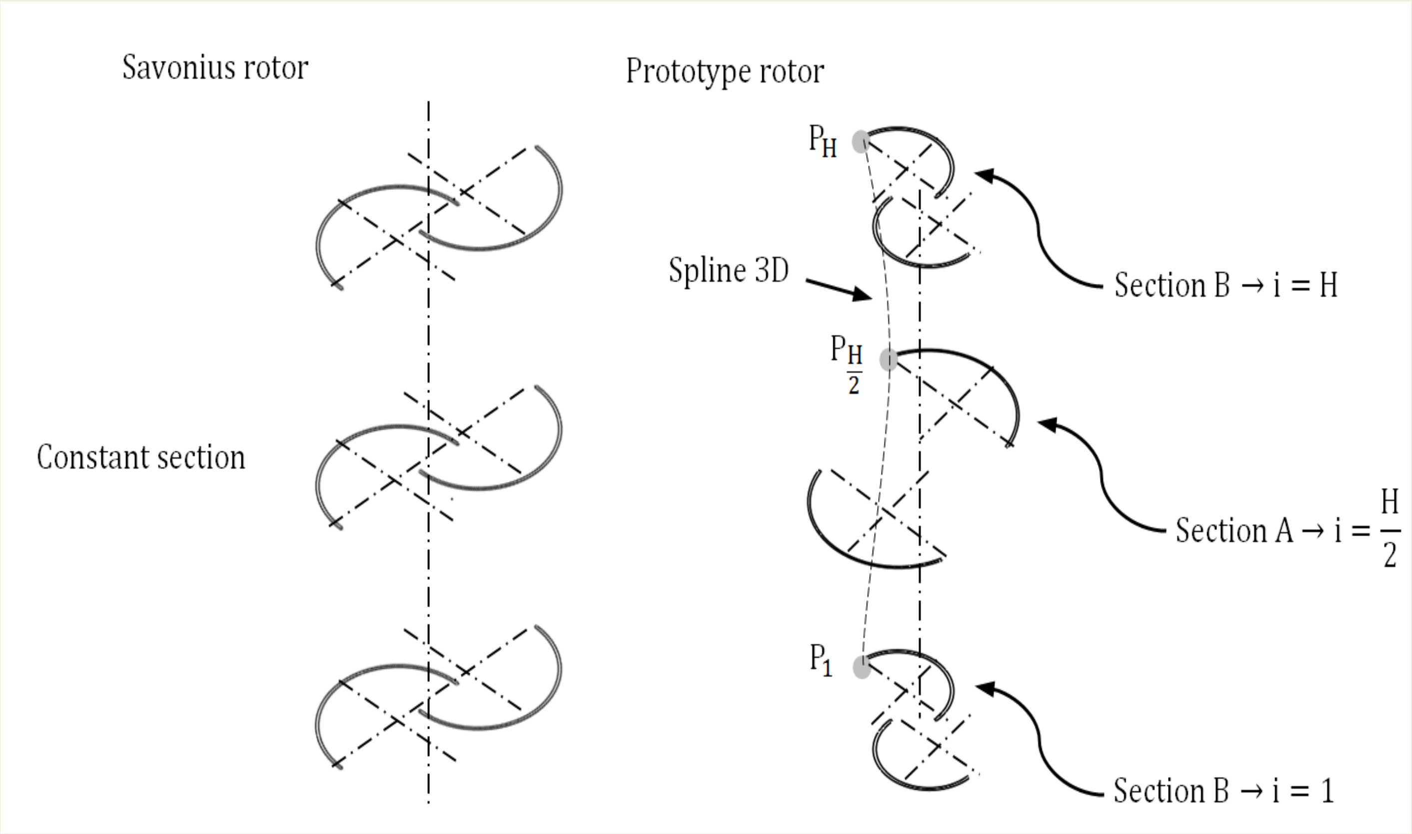
Geometric design of a new propeller

Adaptation of tools for hiking and outdoor activities

Decorative application in social settings

Sustainable (Plastic material)

Geometric design of a new propeller

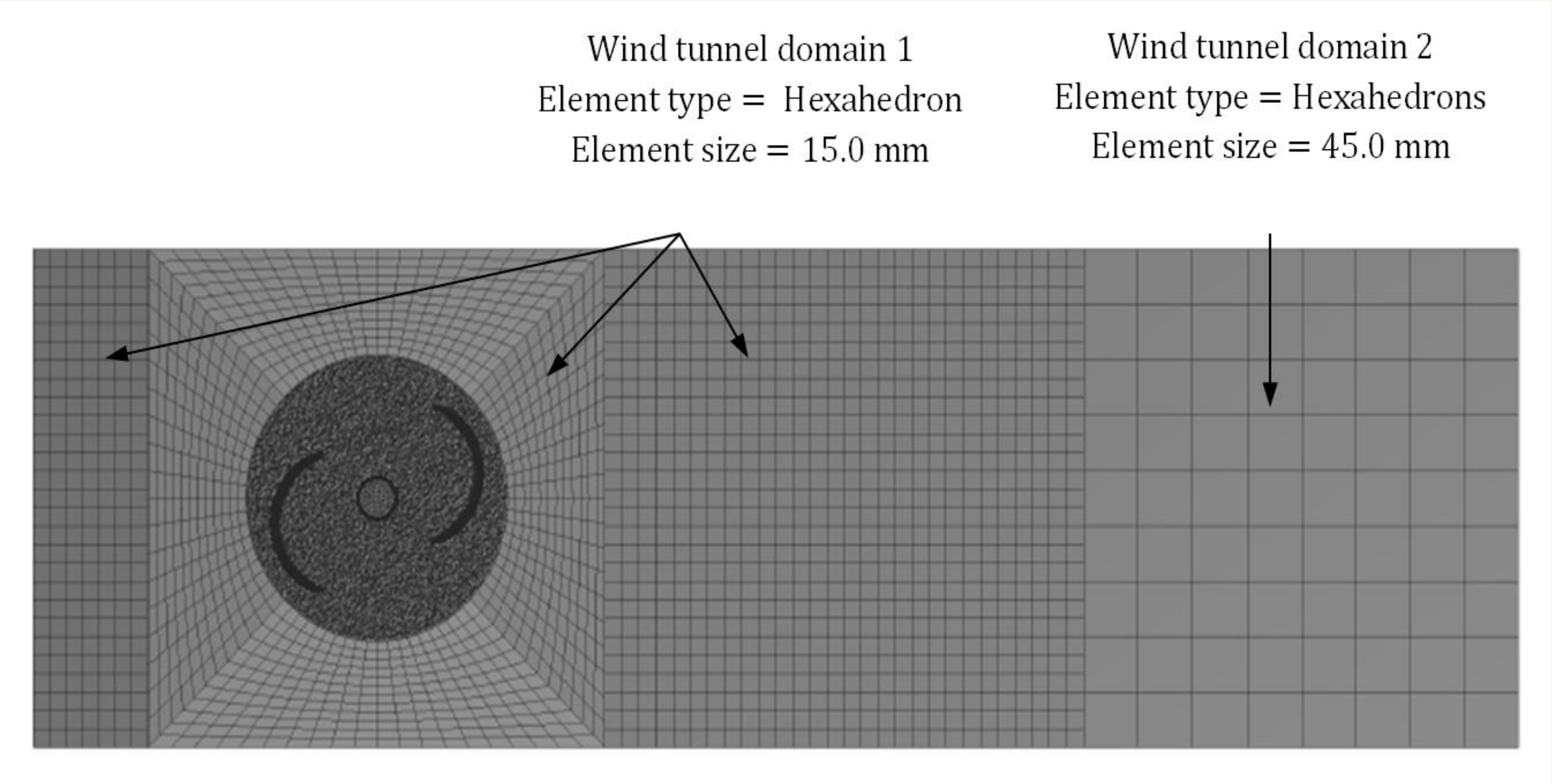


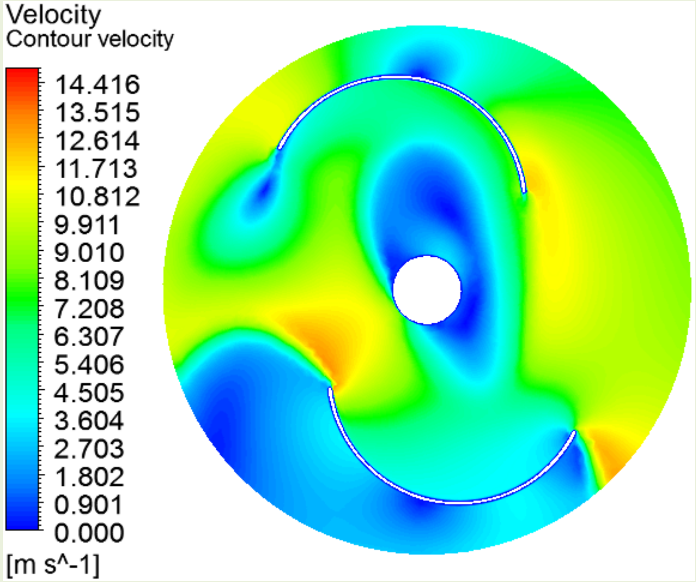
The design is based on a Savonius-type propeller. Given the need for an interior space region, the geometry is modified to facilitate accessibility.

Numerical & Experimental Validation

Wind tunnel validation

Numerical & Experimental Validation





CFD Software validation

WO 2018/015604 A1

(54) Title: ELECTRONIC HIKING POLE

(54) Título: BASTON ELECTRONICO DE SENDERISMO

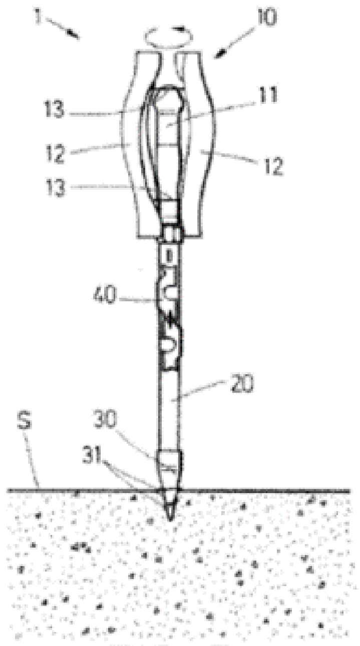
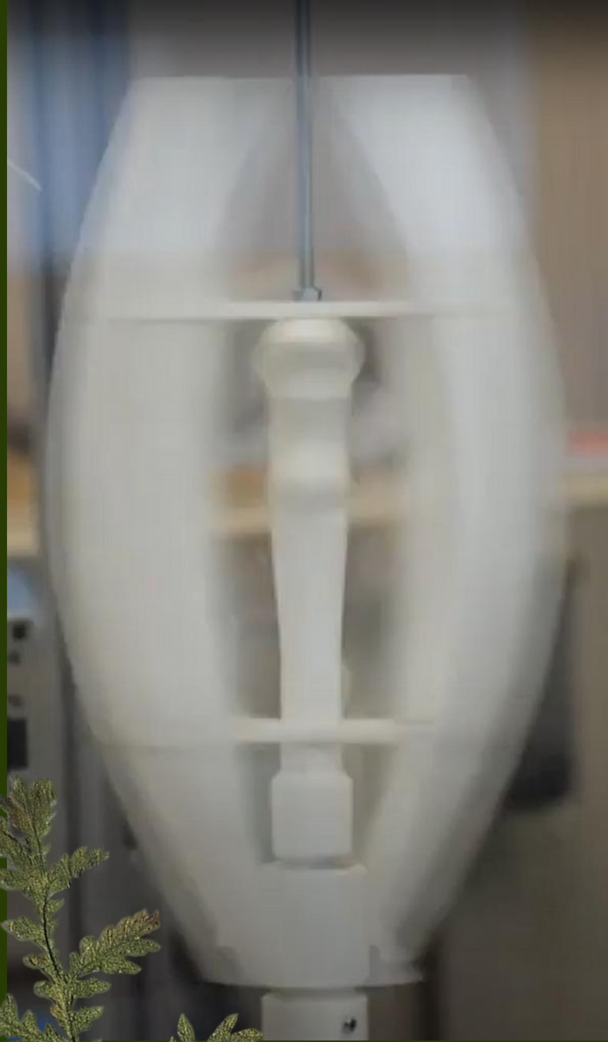


FIG.1B

(57) Abstract: The invention relates to an electronic hiking pole which can act as a conventional pole for sport practice and as an electrical generator for producing electricity from primary energy sources such as wind energy and hydraulic energy. The electronic hiking pole comprises: a gripping part (10) having at least one housing body (12) that laterally surrounds a handle (11), leaving at least one free entrance (A) sufficient for the insertion of a hand, the gripping part (10) assembly being rotatable about the imaginary axial axis of the handle (11); a central tube (20) which contains an electrical generator (23), a junction box (24) and a battery (25), the generator (23) having a rotary shaft (23A) inserted into a lower end of the handle (11), such that the rotary movement of the gripping part (10) causes the mutual rotation of the shaft (23A) of the generator (23), thereby generating electrical energy which is stored in the battery (25).

(57) Resumen: Permite actuar como bastón convencional para la práctica deportiva, y como generador de electricidad a partir de fuentes de energía primarias, tales como la energía eólica e hidráulica, comprendiendo una empuñadura (10) que tiene al menos un cuerpo envolvente (12) que rodea al mango (11) lateralmente dejando al menos un acceso libre (A) suficiente para la inserción de una mano, donde el conjunto de empuñadura (10) es giratorio sobre el propio eje axial imaginario del mango (11); un tubo central (20) que aloja en su interior un generador (23) eléctrico, una caja de conexiones (24) y una batería (25), donde el generador (23) tiene un eje (23A) giratorio insertado en un extremo inferior del mango (11); tal que el movimiento giratorio de la empuñadura (10) provoca el giro solidario del eje (23A) del generador (23),produciendo así la generación de energía eléctrica, siendo ésta almacenada en la batería (25).



Ecodesign

Success in Industrial Eco-Design

Success in Industrial Eco-Design: Herman Miller – Chair Aeron

Office & Gaming Chair

- **Design for disassembly**
- **Recycled and recyclable materials**
- **Reducing the ecological footprint**

Success in Industrial Eco-Design: Muzzicycles

Cycling

- Frame made from recycled plastic
- Reducing the carbon footprint in production
- 100% recyclable bicycles

Success in Industrial Eco-Design: Dreamliner 787

Aeronautics – Carbon Fiber

- **Use of carbon fiber reinforced plastics in fuselage and wings**
- **Reduction of fuel consumption and emissions**
- **Recyclable materials at the end of the aircraft's life cycle**

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C6 – Manufacturing Technology

M1 – 3D printing processes

CO – Technical University of Cluj-Napoca

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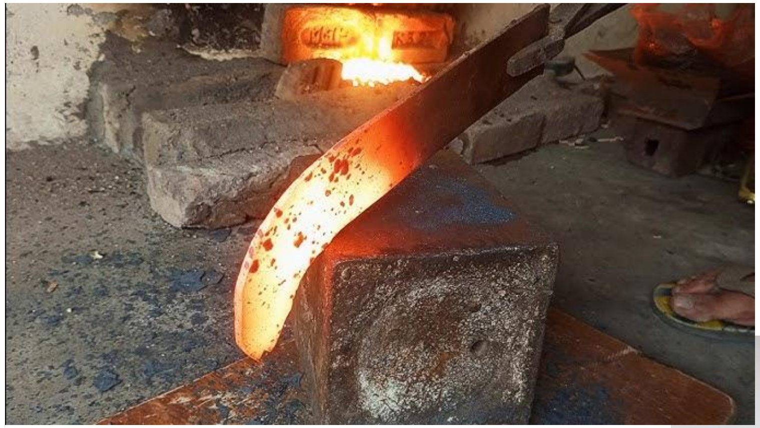

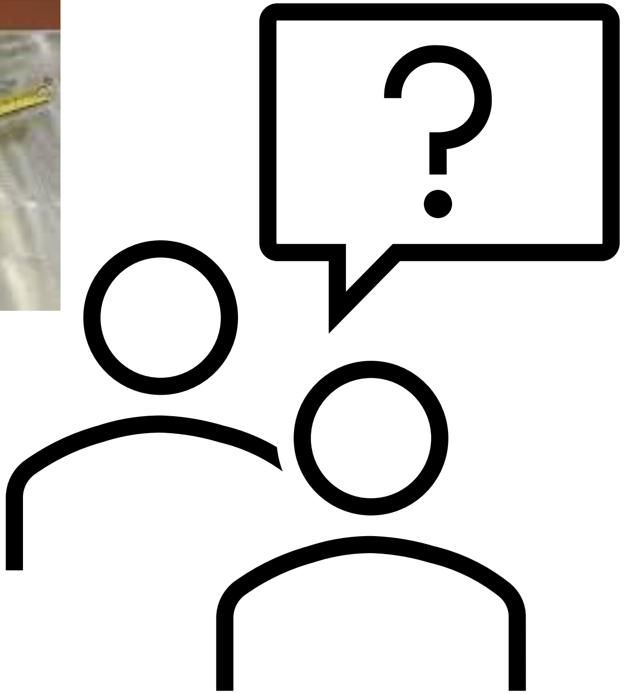
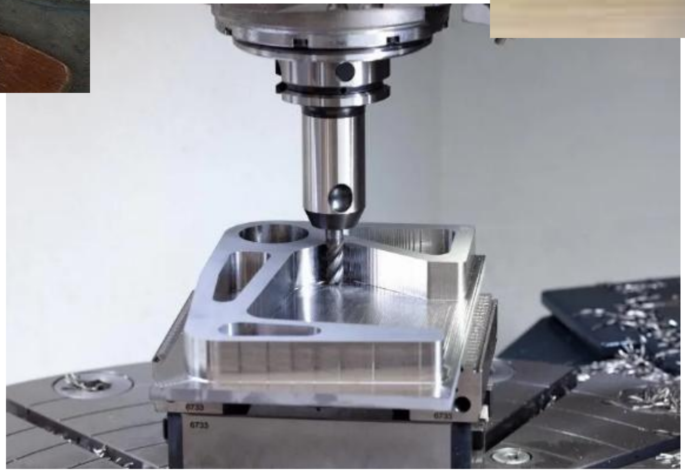


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3D printing processes

Definition after Jyan-Yuan Lee: process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies. [1]

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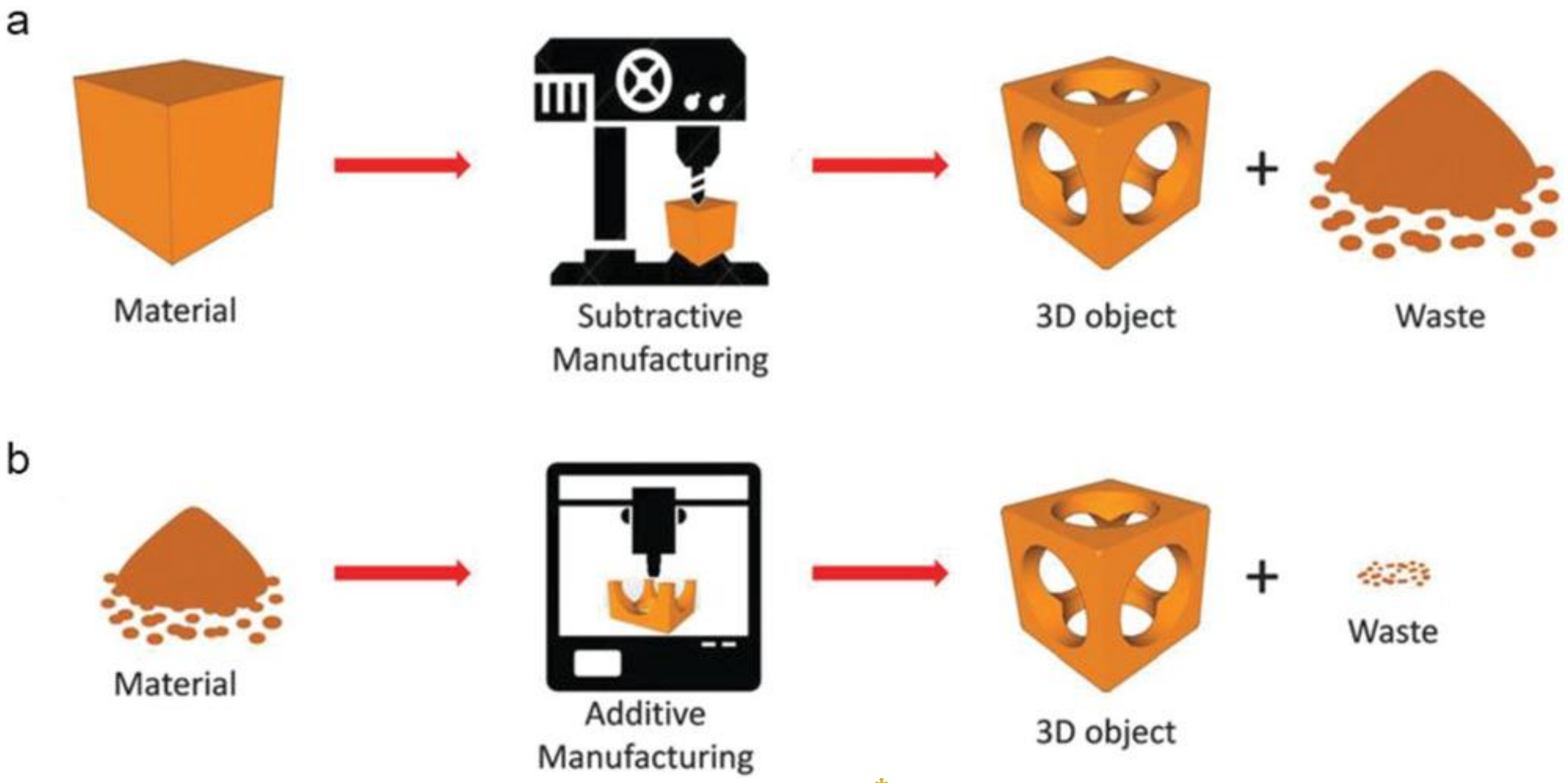
Why 3D printing?



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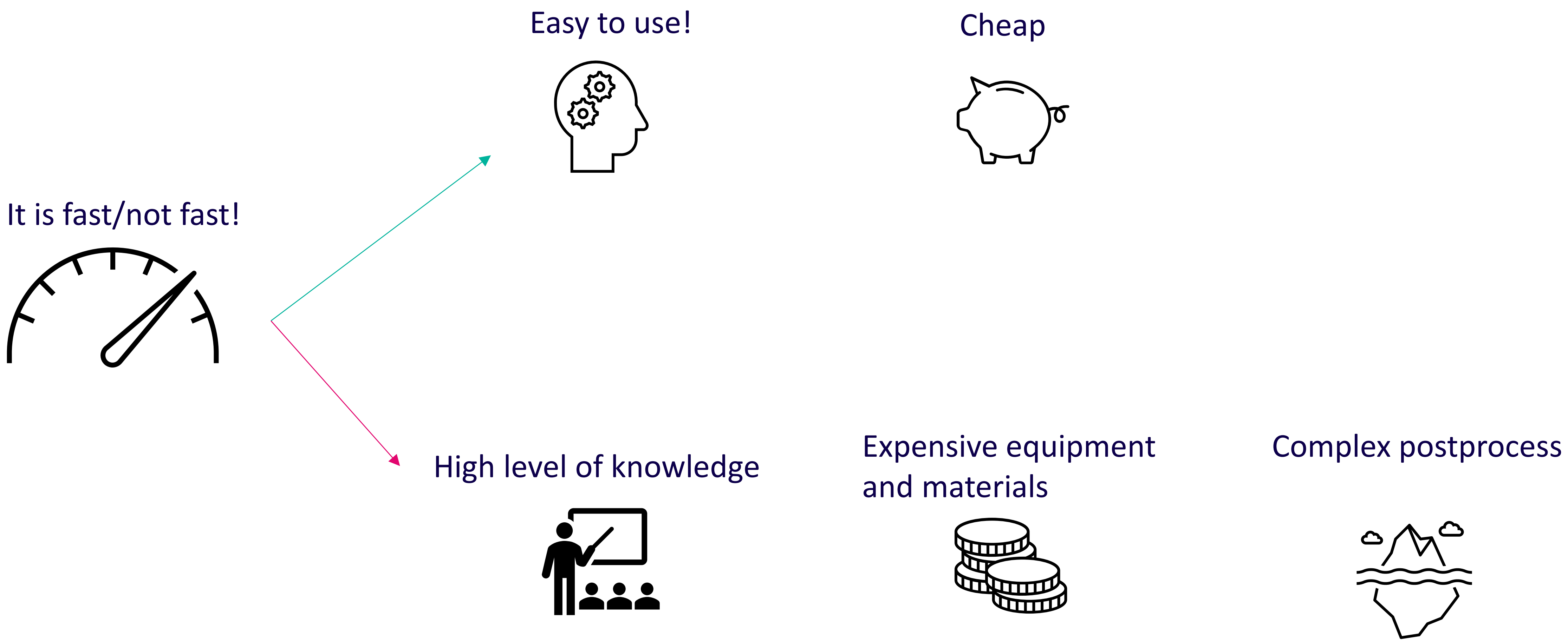

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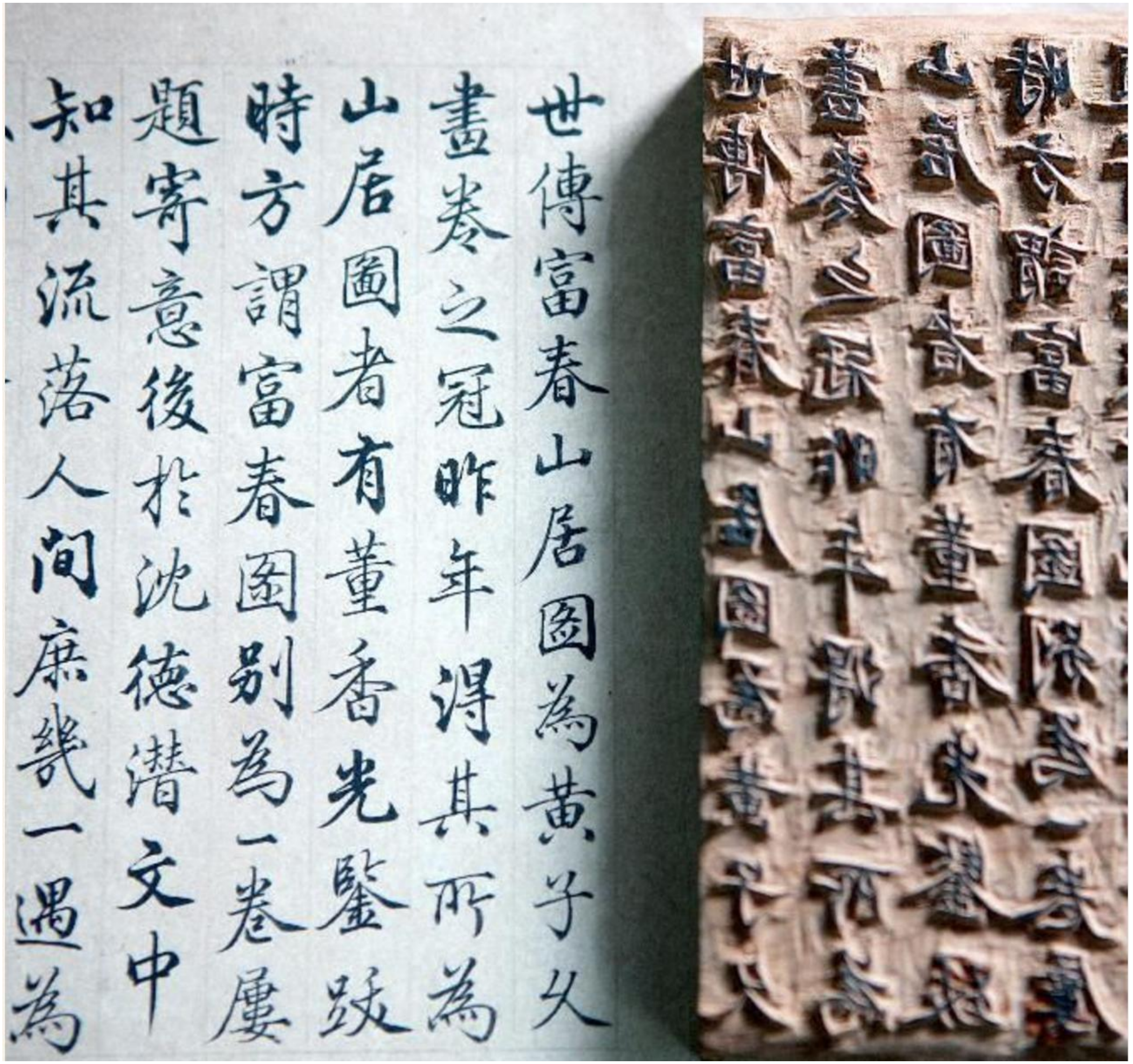
Short History

Woodblock printing or block printing – before 220 AD
- Method was perfected during Tang dynasty (618-906)



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

Movable type – 1040 AD

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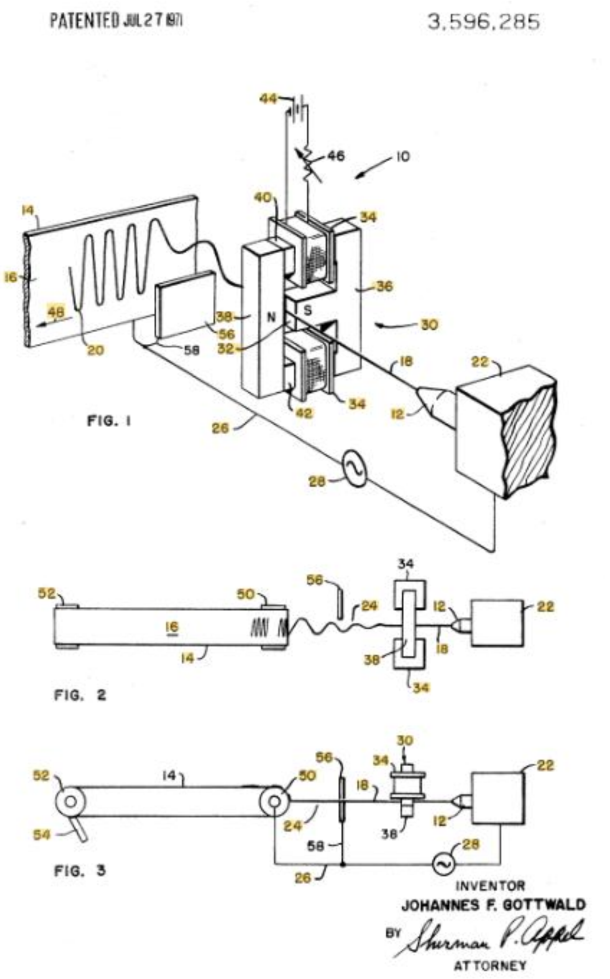
Etching – c. 1515 AD

Lithography - 1796

Liquid metal recorder - In 1971, Johannes F Gottwald patented the Liquid Metal Recorder, U.S. patent 3596285A



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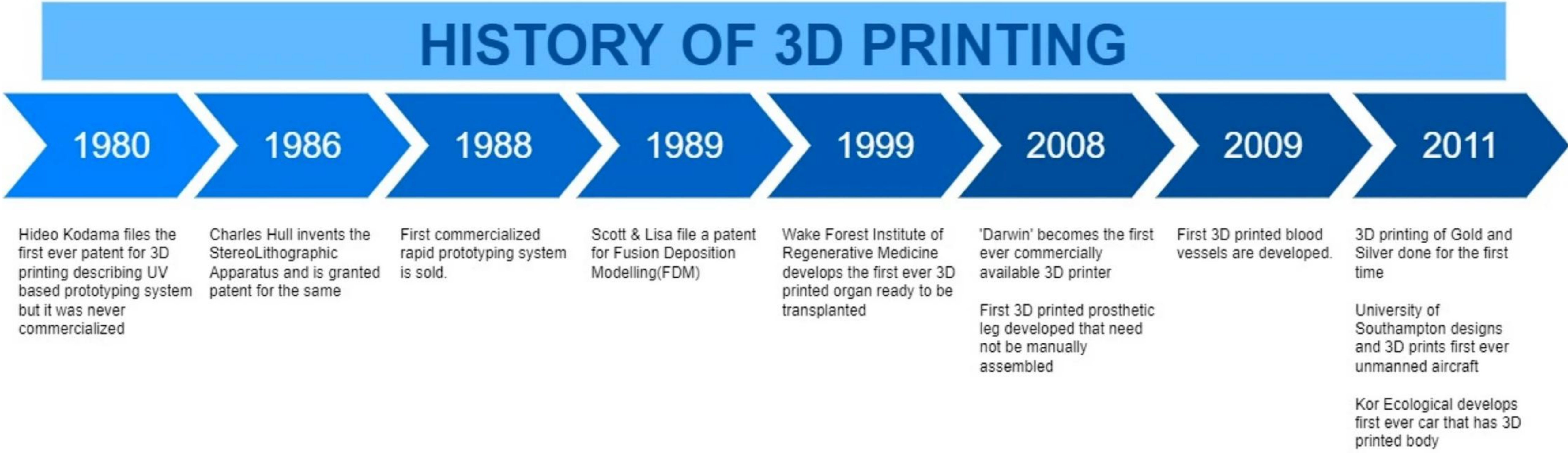

1. *Sames, W. (2016). "The metallurgy and processing science of metal additive manufacturing". International Materials Reviews.* ***61*** *(5): 315–360. Bibcode:2016IMRv...61..315S. doi:10.1080/09506608.2015.1116649. OSTI 1267051. S2CID 39704506.*

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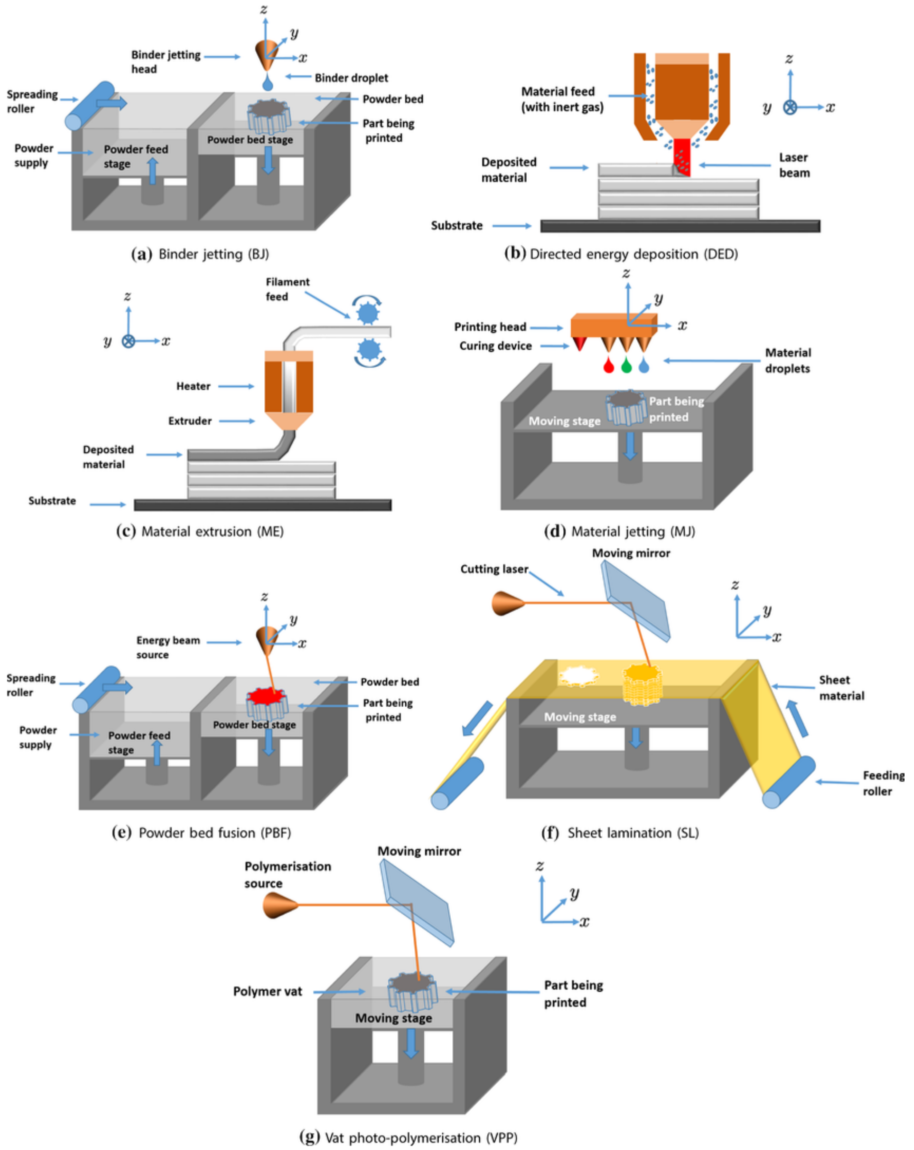


ISO/ASTM 529000:2015 additive manufacturing classification

https://www.researchgate.net/figure/Illustration-of-the-seven-ISO-ASTM-52900-21-AM-process-categories_fig1_358597103

Type	Technologies	Materials
Material jetting	Drop-on-demand or continuous (single- or multi-nozzle) particle deposition	Hot-melt materials (wax, thermoplastic, metal alloy), dispersed materials (technical ceramics, metals, polymers)
Material extrusion	Fused deposition modeling (FDM) or fused filament fabrication (FFF) and fused pellet fabrication or fused particle fabrication	Thermoplastics, eutectic metals, edible materials, rubbers, modeling clay, plasticine
	Robocasting or MIG welding 3D printing[11] or direct ink writing (DIW) or extrusion based additive manufacturing of metals (EAM) and ceramics (EAC)	Metal-binder mixtures such as metal clay, ceramic-binder mixtures (including ceramic clay and ceramic slurries), cermet, metal matrix composite, ceramic matrix composite, metal (MIG welding)[11]
	Additive friction stir deposition (AFSD)	Metal alloys
	Composite filament fabrication (CFF)	Nylon or nylon reinforced with carbon, Kevlar or glass fibers
Light polymerized	Stereolithography (SLA)	Photopolymer (including preceramic polymers)
	Digital light processing (DLP)	Photopolymer
	Continuous liquid interface production (CLIP)	Photopolymer + thermally activated chemistry
Powder Bed	Powder bed and inkjet head 3D printing (3DP)	Almost any metal alloy, powdered polymers, Plaster
	Electron-beam melting (EBM)	Almost any metal alloy including titanium alloys
	Selective laser melting (SLM)	Titanium alloys, cobalt-chrome alloys, stainless steel, aluminium
	Selective heat sintering (SHS)[12]	Thermoplastic powder
	Selective laser sintering (SLS)	Thermoplastics, metal powders, ceramic powders
	Direct metal laser sintering (DMLS)	Metal alloys
Laminated	Laminated object manufacturing (LOM)	Paper, metal foil, plastic film
Powder fed	Laser metal deposition (LMD) or Directed Energy Deposition (DED)	Metal alloys
	Extreme high-speed laser cladding (EHLA)[13]	Metal alloys
Wire	Electron beam freeform fabrication (EBF^3)	Metal alloys
	Wire-arc additive manufacturing (WAAM)	Metal alloys

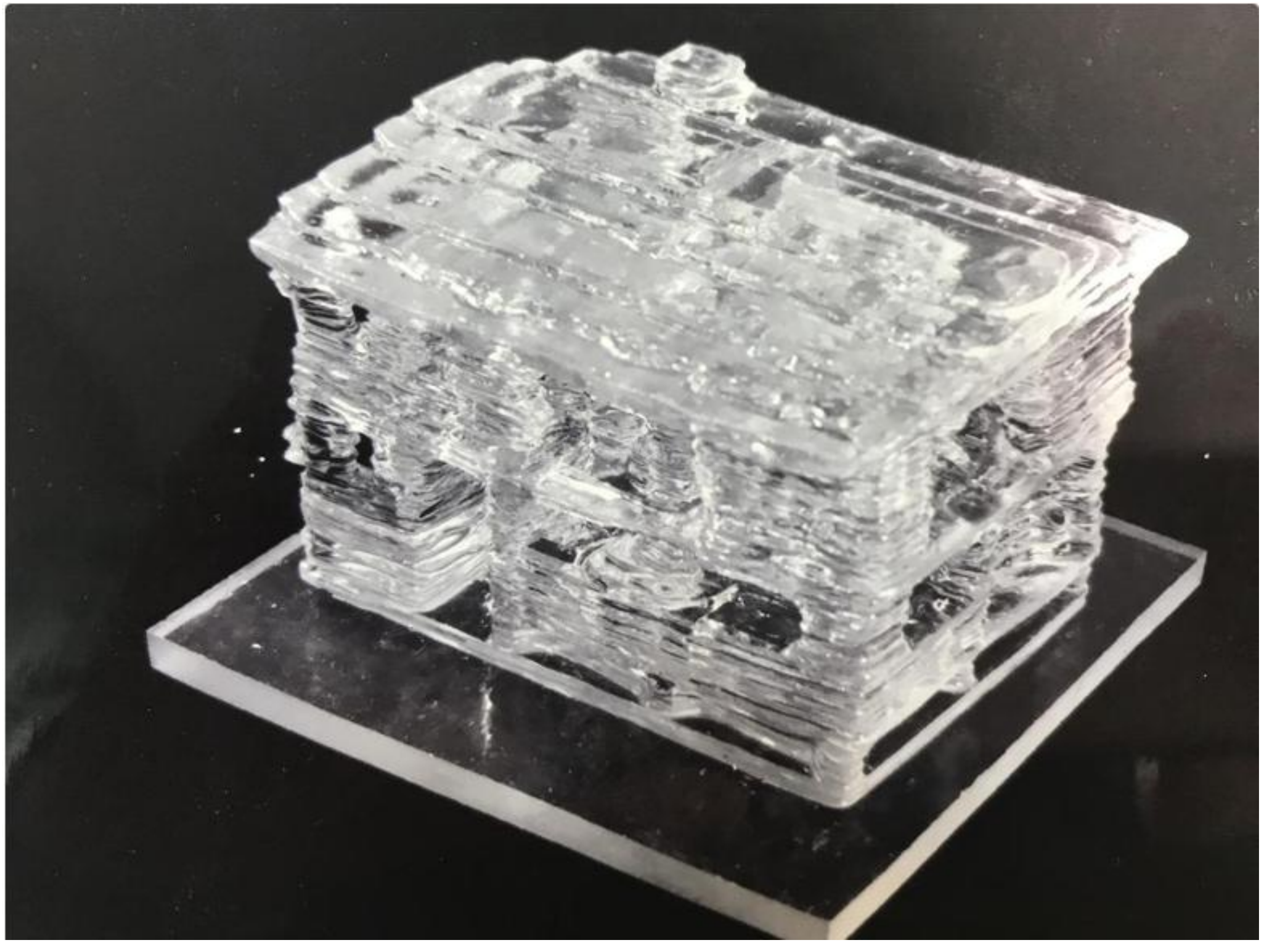
https://en.wikipedia.org/wiki/3D_printing_processes

Application	Printing technology	Materials	Customization	Cost*
Implantable medical devices	Powder bed fusion, directed energy deposition	Metal (titanium alloy or CoCr alloy), polymer	Yes	Medium to high
Bio-absorbable implants	Material extrusion	PLA, PCL, PCL/β-TCP	Yes	Medium to high
Prosthesis and orthosis	Vat photopolymerization, powder bed fusion	Polymer	Yes/no	Medium to low
Surgical guides	Powder bed fusion, vat photopolymerization	Polymer	Yes	Low
Surgical planning and simulations	Vat photopolymerization	Polymer	Yes	Low
Education	Vat photopolymerization, sheet lamination, material jetting	Polymer	Yes/no	Low

*High: Over 10,000 USD; Medium: about 5,000 USD; Low: less than 1,000 USD. This is relative value. It depends on the situation of each country. CoCr, cobalt chrome; PLA, polylactic acid; PCL, polycaprolactone; β-TCP, beta-tricalcium phosphate

https://pmc.ncbi.nlm.nih.gov/articles/PMC10409621/table/T1/

Stereolithography Apparatus (SLA) - by Hideo Kodama (1980)



Kodama's sample 3D print: ~50mm tall, 27 layers at 2mm thickness cured resin
(source [Meidai Watch: 3D Printing & Nagoya University](#))

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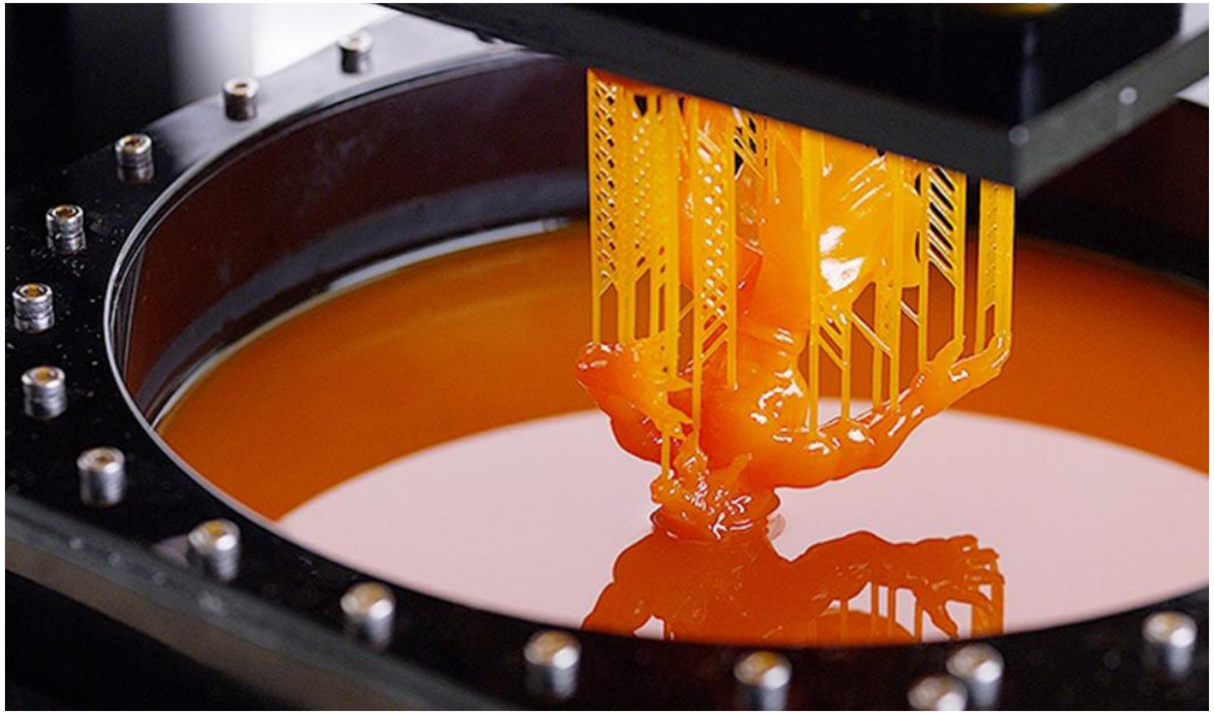
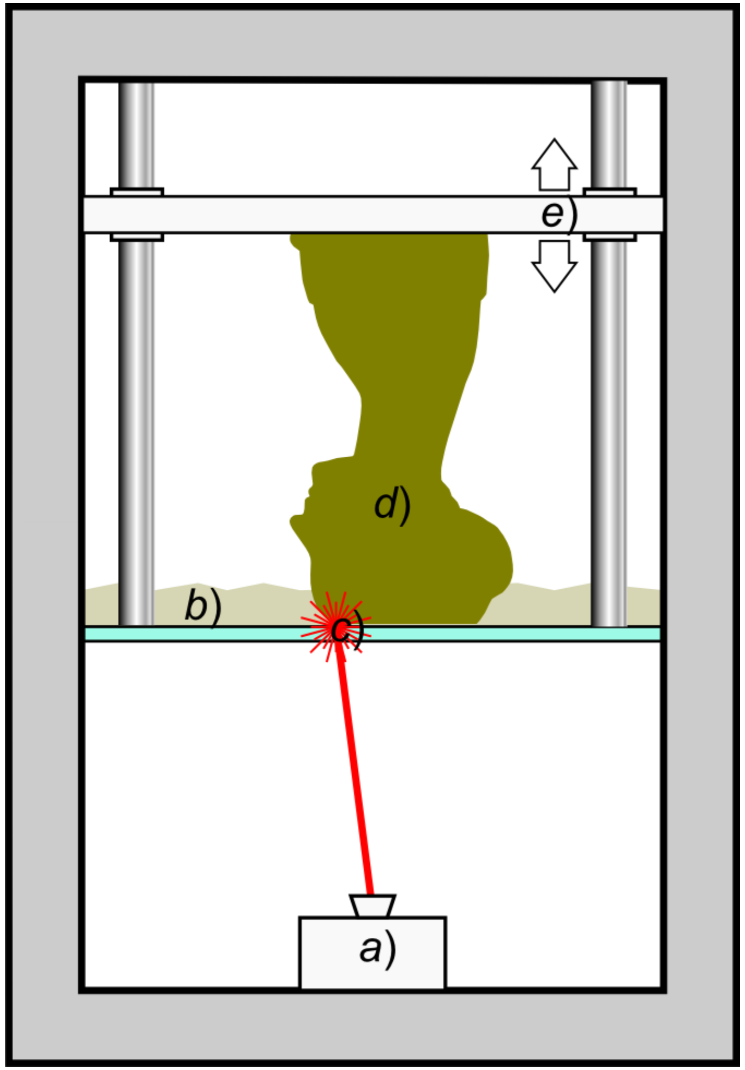
Stereolithography (**SLA** or **SL**; also known as **vat photopolymerisation**,[1] **optical fabrication**, **photo-solidification**, or **resin printing - 1980**)





https://en.wikipedia.org/wiki/Stereolithography#/media/File:Schematic_representation_of_Stereolithography.png

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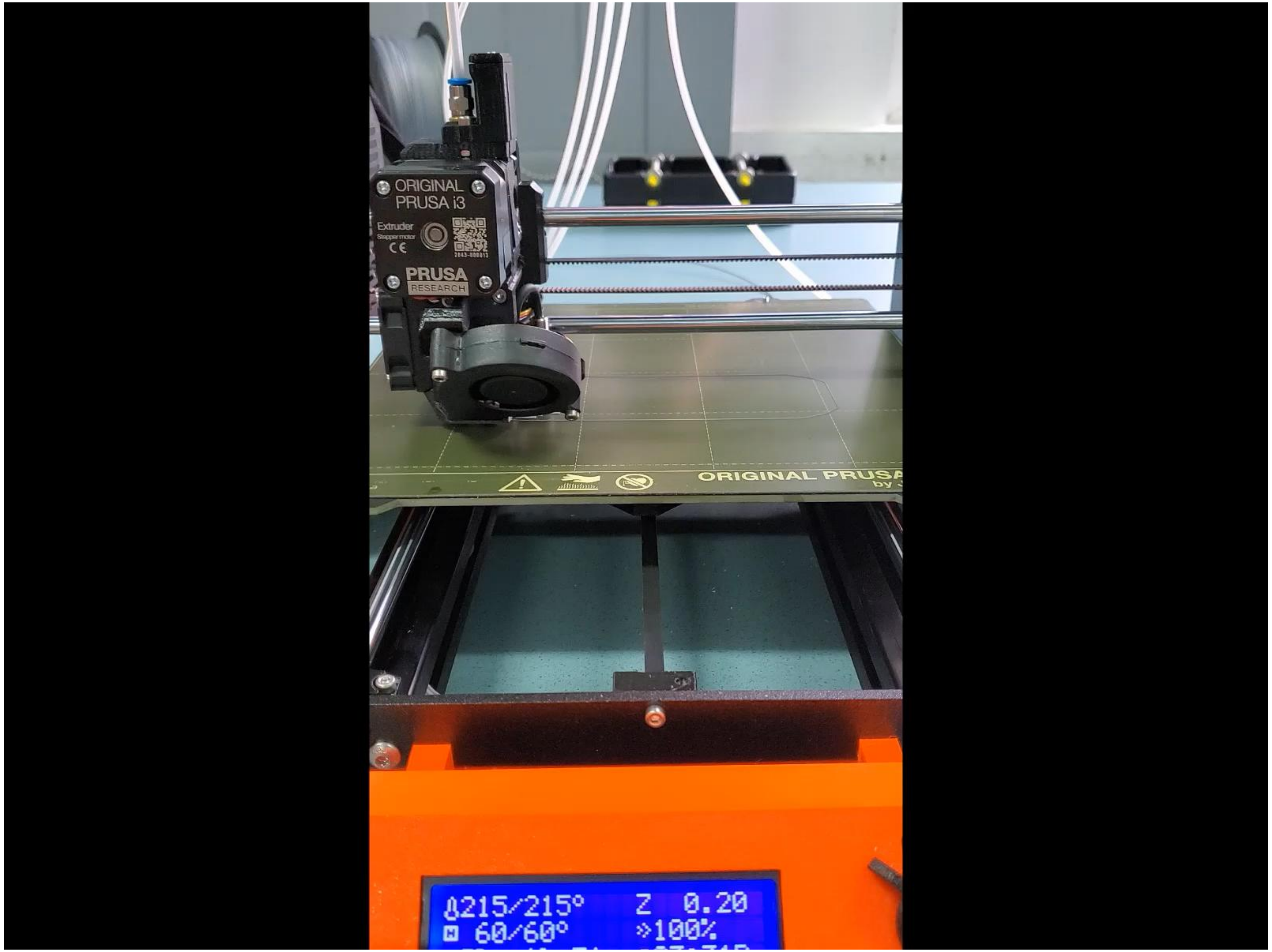
FFF – fused filament fabrication / filament freeform fabication

FDM - Fused Deposition Modelling (trademark acronym) 1986 - Scott Crump (1988), who later founded Stratasys



Additive Friction-Stir Deposition

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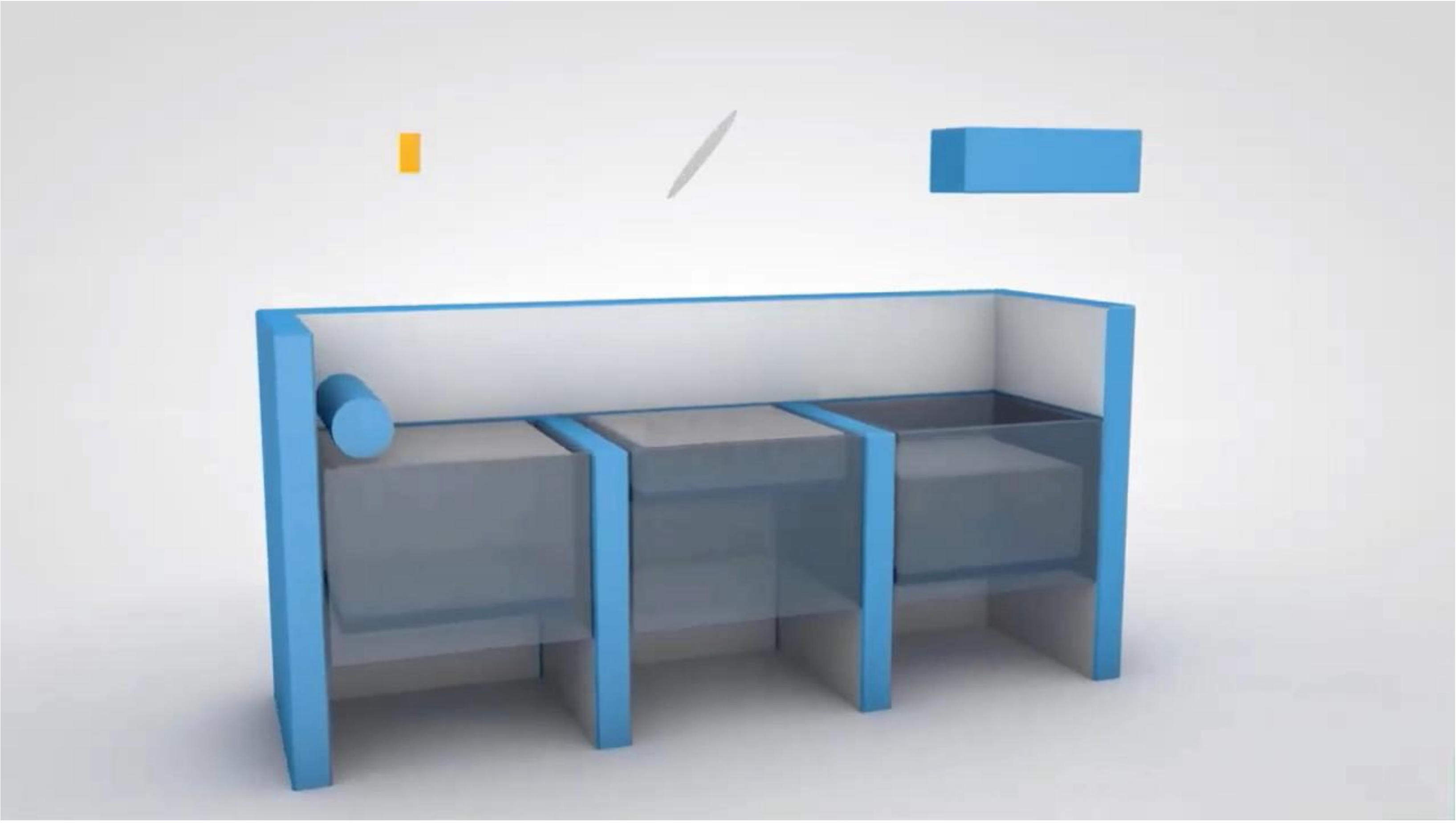
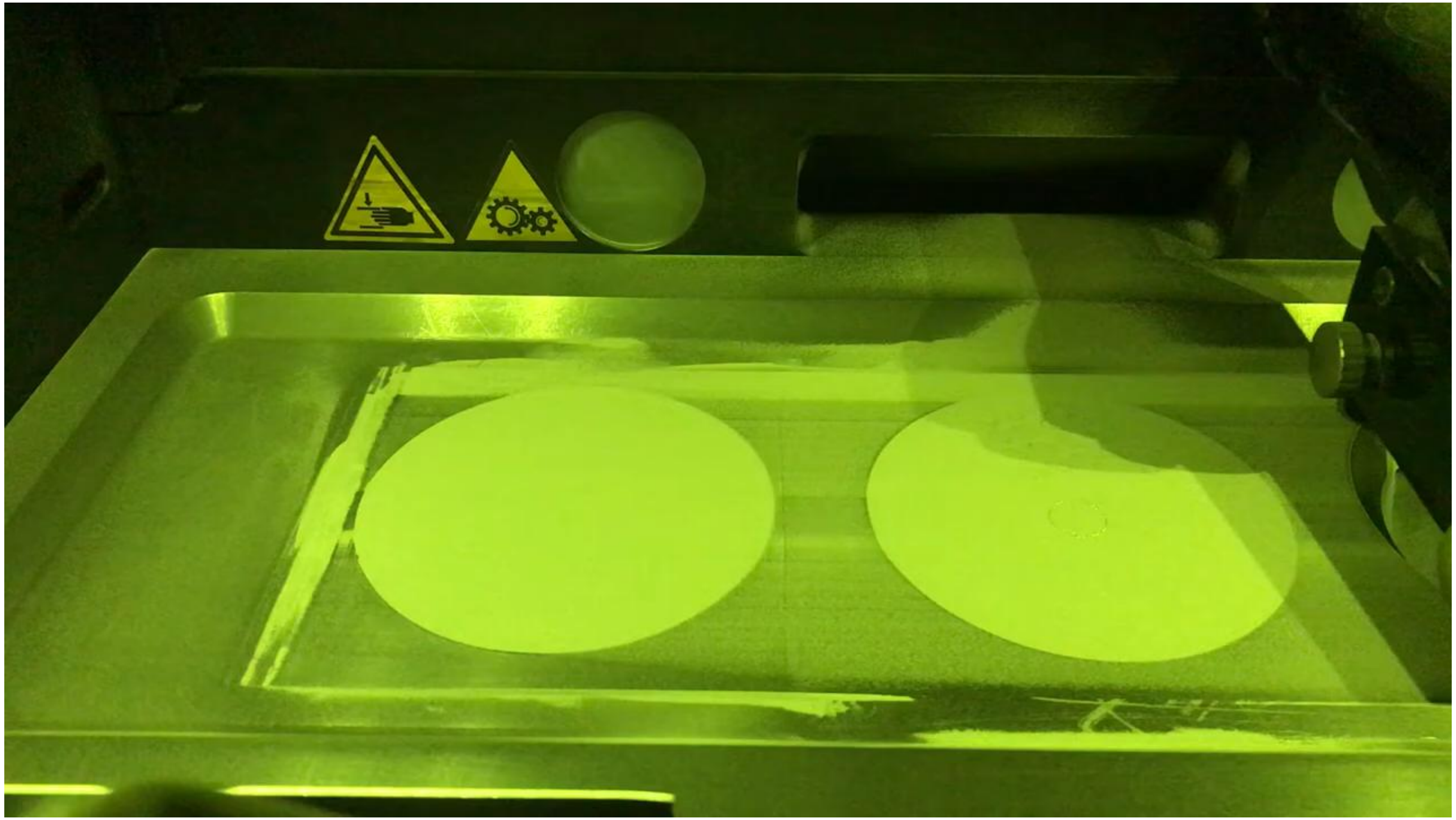
SLS Selective Laser Sintering



https://www.youtube.com/watch?v=2DU-NKKa35o

SLM Selective Laser Melting



https://www.youtube.com/watch?v=rHIuiqjPF4s

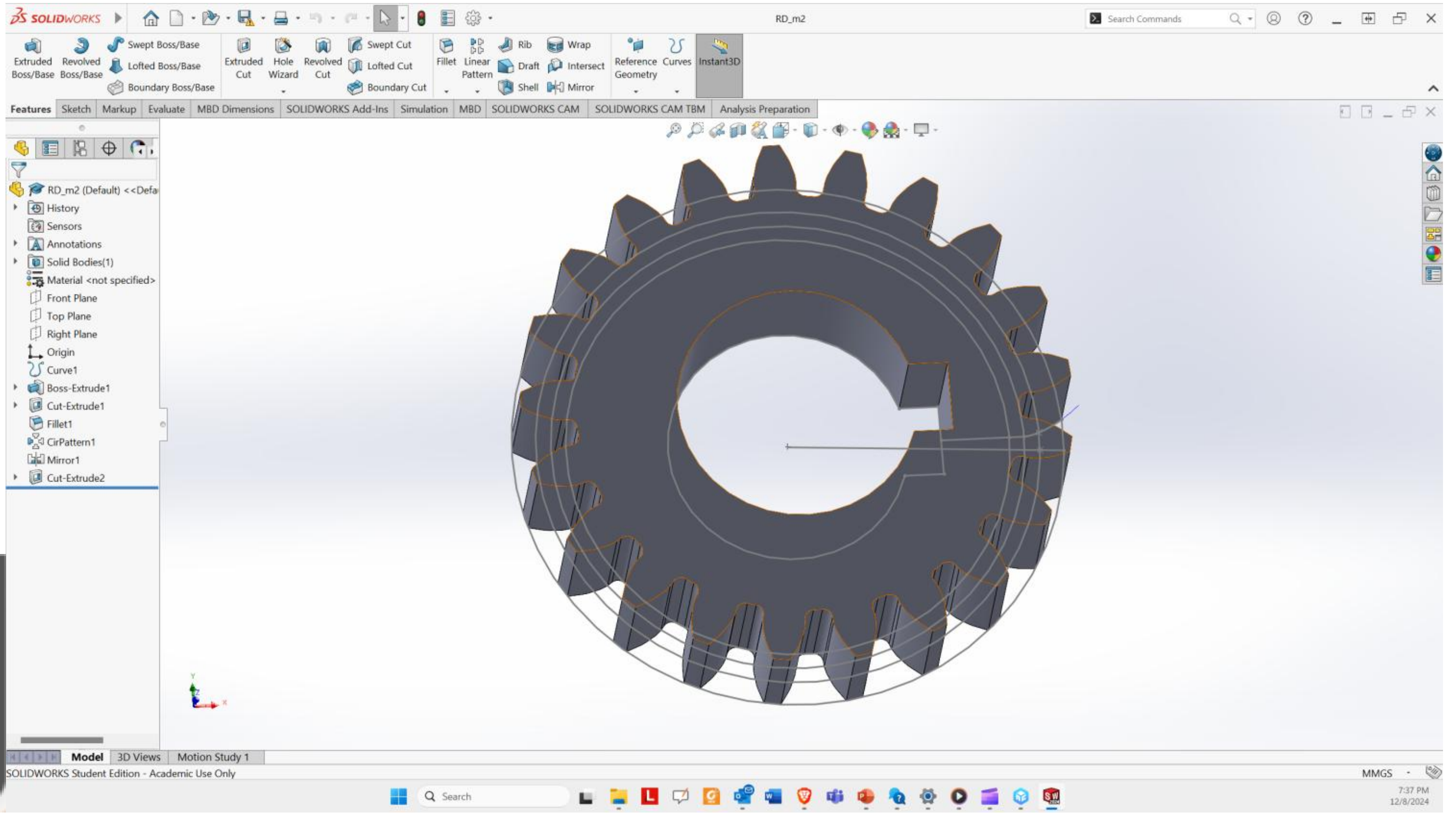
EBM Electron Beam Melting

https://www.youtube.com/watch?v=M1NhxcZQz1U

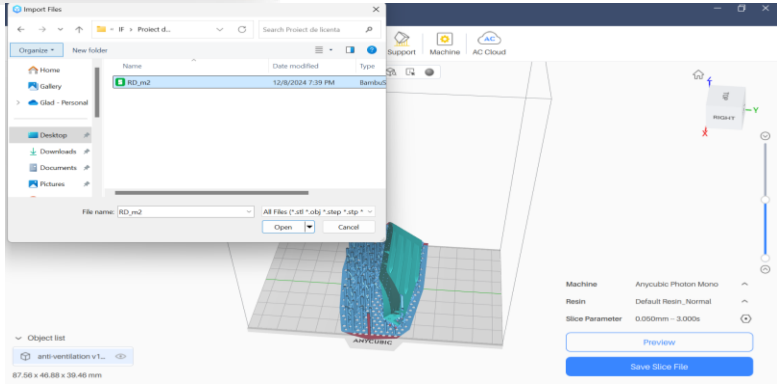
SLA – Stereolithography Aparatus

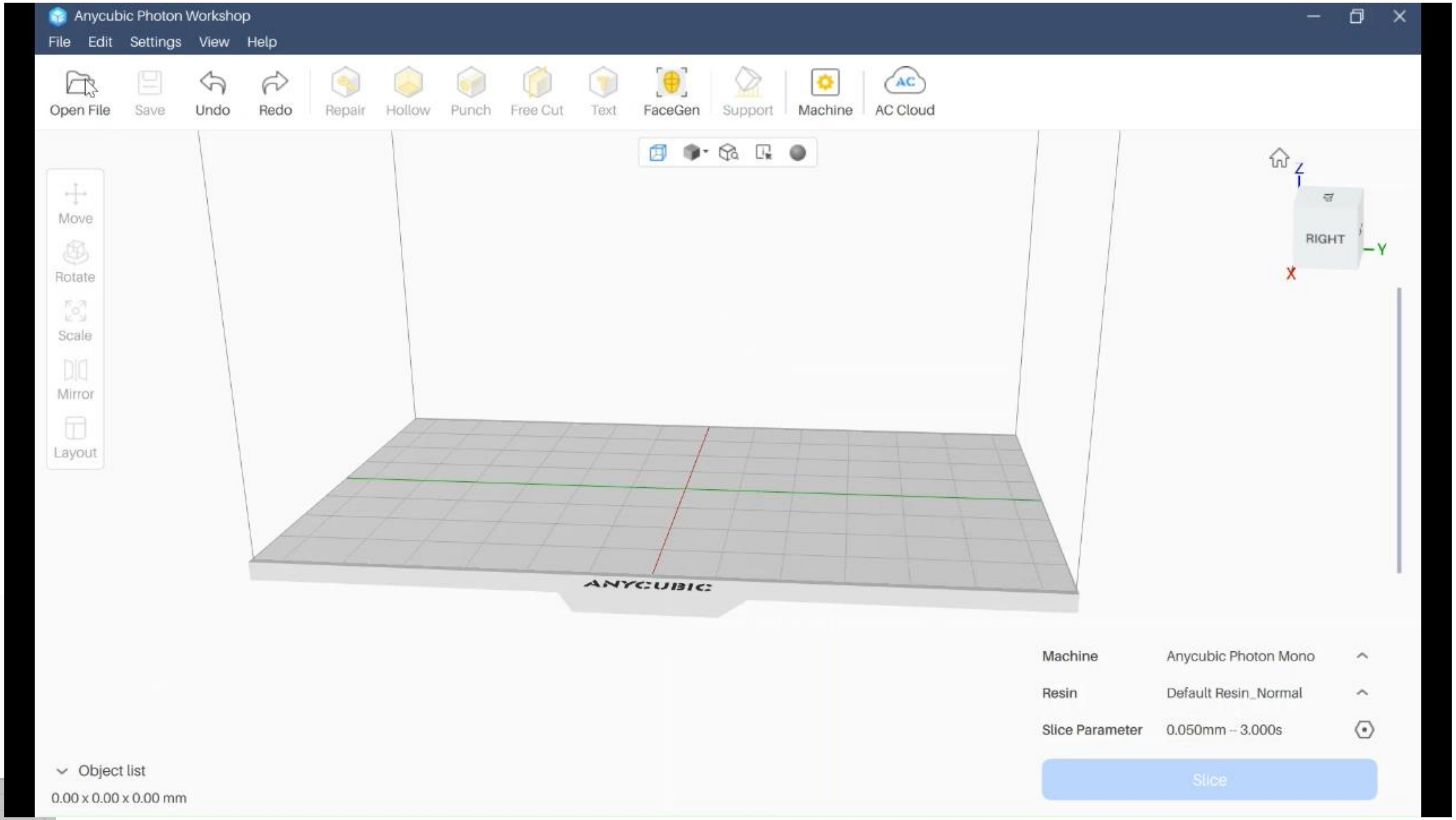
Hideo Kodama (1980); Developed by 3D systems in 1988.

- Main steps

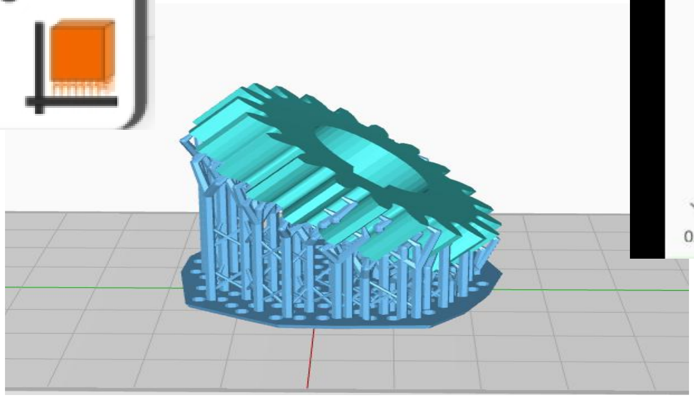


02 IMPORT THE MODEL INTO 3D PRINTING SOFTWARE





03 ORIENT & ADD SUPPORTS



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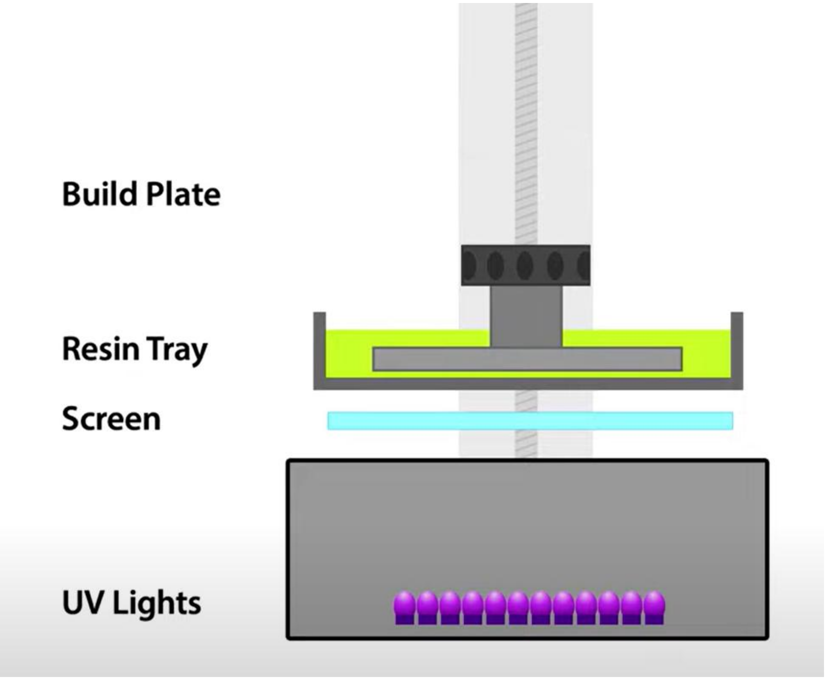

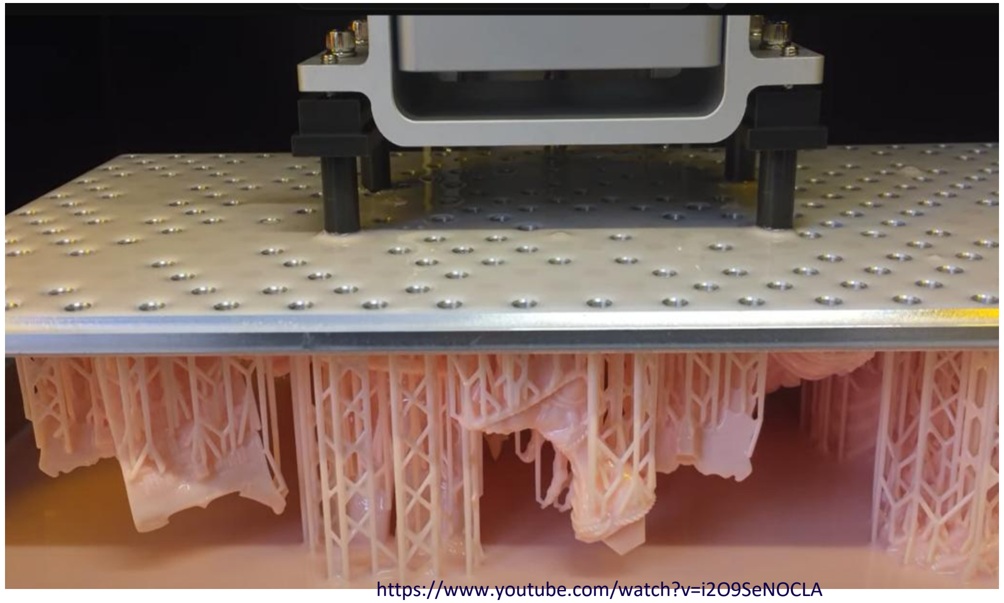

https://www.youtube.com/watch?v=i2O9SeNOCLA

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09
MONITOR THE PRINT
10
POST-PROCESSING
11
REMOVE SUPPORTS & FINE-TUNE
12
INSPECT & EVALUATE

Advantages and disadvantages

+

- High level of detail and accuracy
- Smooth and finely finished surfaces
- Wide range of material options
- Ability to create complex geometries and intricate designs
- Supports for small and intricate parts
- Intuitive technology
- Efficient use of materials
- Prototyping and iteration
- Smooth integration with post-processing techniques
- Great for visualizing concepts
- Wide range of applications

−

- Higher cost compared to other 3D printing methods
- Limited build size
- Longer printing times compared to some other 3D printing technologies
- Higher skill level required for successful printing and post-processing.
- Resin exposure to UV light can be dangerous
- Certain types of resins can be messy and may leave behind residue on surfaces or clothing.
- Resins can also emit odors or fumes during printing
- Resins have a limited shelf life
- Certain resins may be sensitive to environmental factors like temperature and humidity, which can affect print quality.
- The final printed object may not be as durable or strong as those produced with other 3D printing technologies

https://thriam.com/sla-3d-printing

Material Jetting

- Poly Jet Technology
- Nano particle Jetting
- Drop on Demand

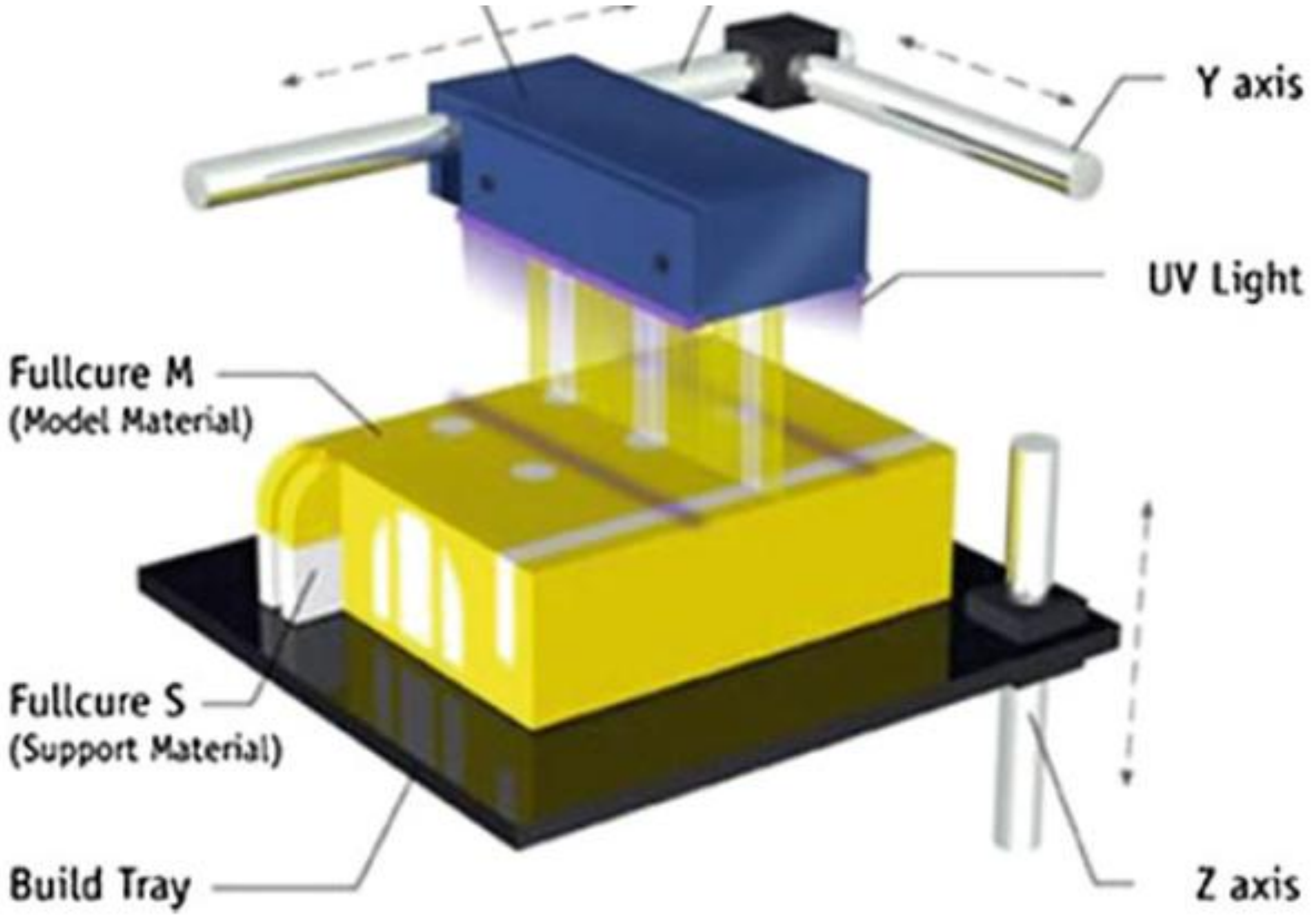
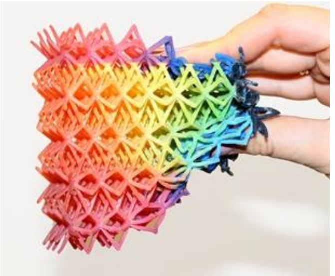
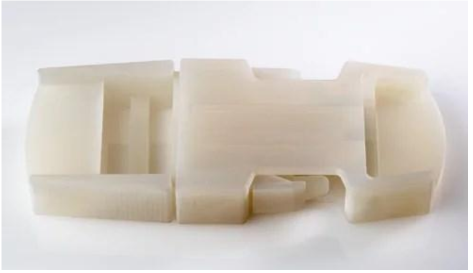


Image source www.vt.me.edu

Prototip mâner șurubelniță – multimaterial



Flexible materials



Rigid materials

Tango – soft-touch, flexible materail

DraftWhite – rigid materail, used for medical applications (orthopedic and cranial implants).

Source: https://www.stratasys.com

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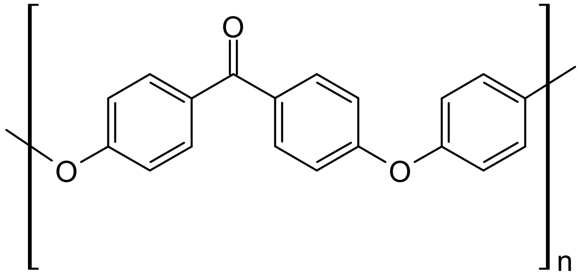
Applications

- Biomedicine
- Industry
- Education

- Peek material for implants
- Normal/strong resin
- Resin



https://www.youtube.com/watch?v=X5fBVcSj8SQ

$(C_{19}H_{12}O_3)_n$

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- Highly accurate parts with resolution down to 14 microns
- Due to high accurate layer resolution, it can produce smooth parts with surfaces comparable to injection moulding and very high dimensional accuracy
- Low wastage due to accurate jetting and material on-demand dropping technology, unlike processes like powder bed fusion where sintering takes place inside the power chamber
- Multi-material and multi-colour capability within the same print volume
- Material Jetting has homogeneous mechanical and thermal properties

- Material jetted parts are mainly suitable for non-functional prototypes, as they have poor mechanical properties. Regarding mechanical properties, NPJ and DOD produce better parts than PolyJet.
- Mechanical properties of photosensitive material used in PolyJet degrade over time quickly.
- MJ machines are still expensive compared to other AM technologies, making them unfeasible for some applications.
- Produces relatively brittle parts, making it difficult to use in a production load-bearing part
- Although it’s easier to remove, most of the parts often require support material.
- High accuracy can be achieved, but materials are limited. PolyJet can only be used with polymers and waxes.

Drop on demand

- two print heads and two cartridges for main and support materials;
- Each layer is printed similarly to how generally AM technologies work.
- Each layer Is precisely milled to keep the layer thickness and flatness
- Support material is automatically laid down / no need for suport design
- The support dissolves away leaving a high-precision wax model.

https://engineeringproductdesign.com/knowledge-base/material-jetting/#What_is_Material_Jetting

1.Precision and Accuracy: DOD provides highly precise and accurate droplet placement. It can be easily used in microelectronics and medical devices. Resolution of +/-22 µm in X & Y and 25 µm for layer thickness

2. 5000 × 5000 drops per inch dropping resolution produces high-definition parts

3. It can print both resin and wax.

4. Material Efficiency: This method can efficiently deposit material only where needed, reducing waste and making it suitable for intricate geometries and lightweight structures.

5. **Versatile Use**: DOD can handle a variety of materials, including waxes, photopolymers, and other specialised fluids.

1.Build Speed: - in case of DOD, the printing speed is lower compared to other 3d printing technology. Not usable for large scale production.

2.Material Limitations: Low range of materials that can be used. Usable in jewelry and electronics and not in the industry board.

3.Post-Processing: It is necesarly to post process the workpieces, whisch means more effort and time in order to obtain the finished part.

https://engineeringproductdesign.com/knowledge-base/material-jetting/#What_is_Material_Jetting

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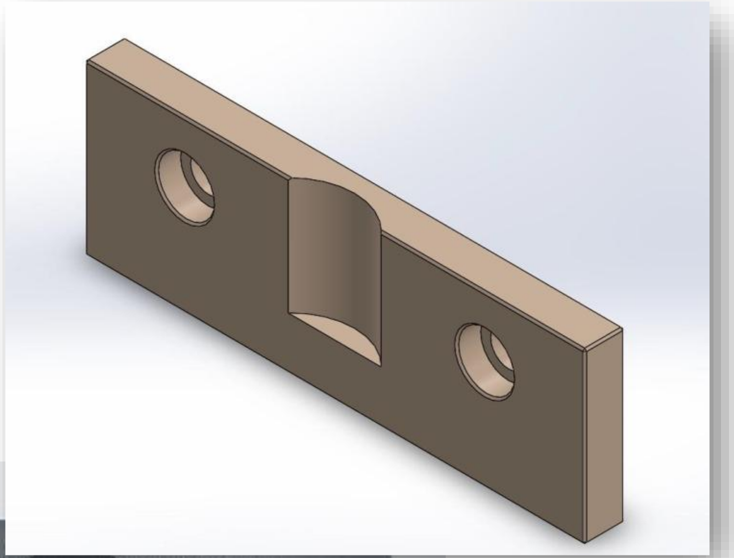

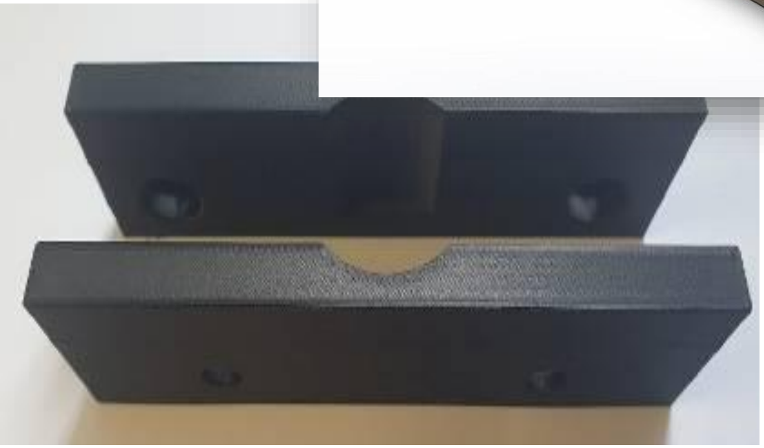

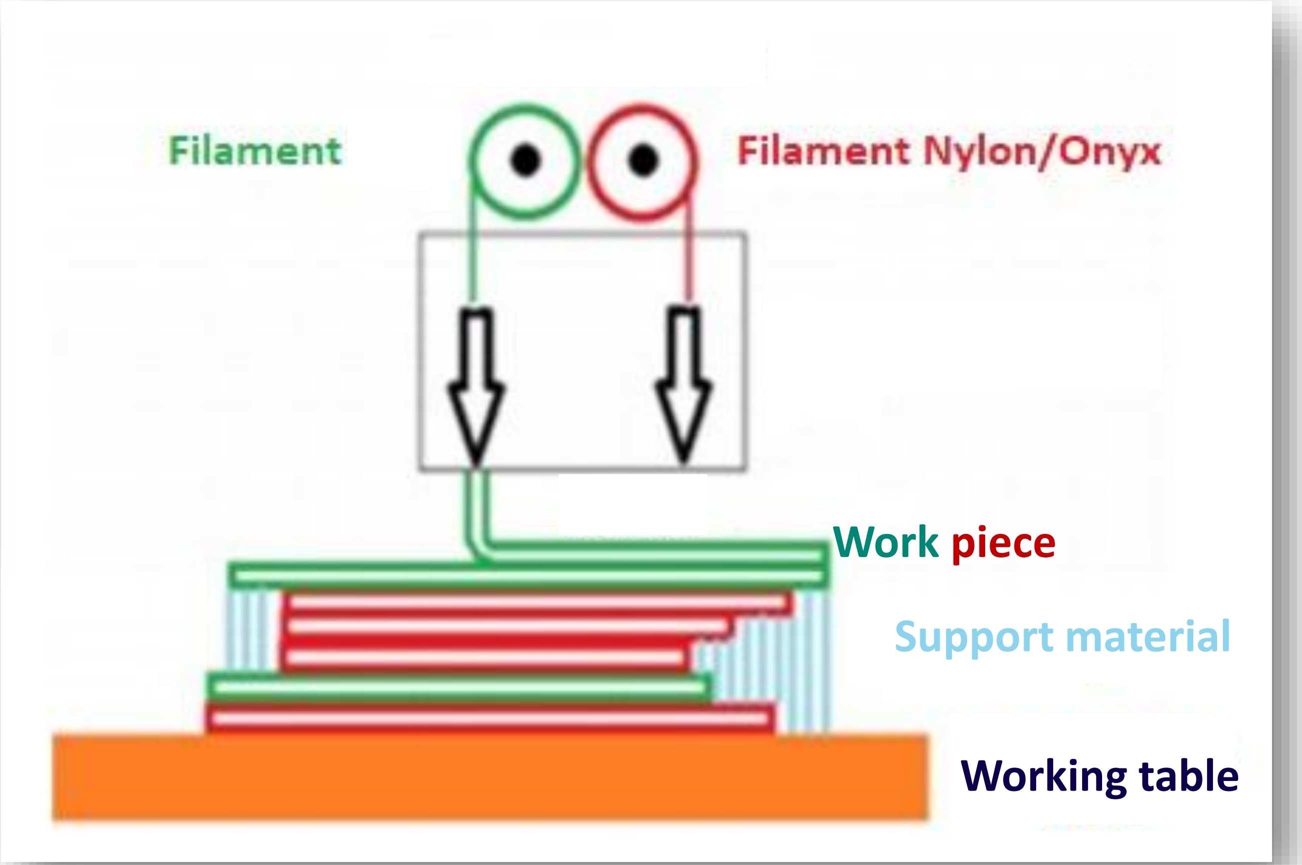

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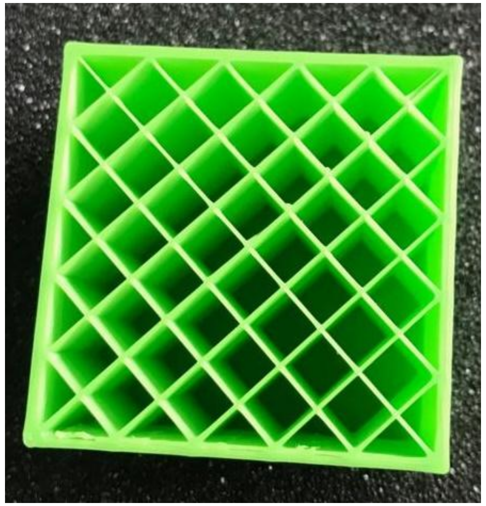
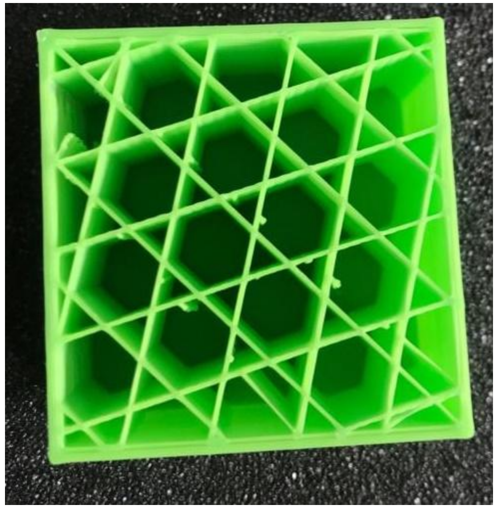
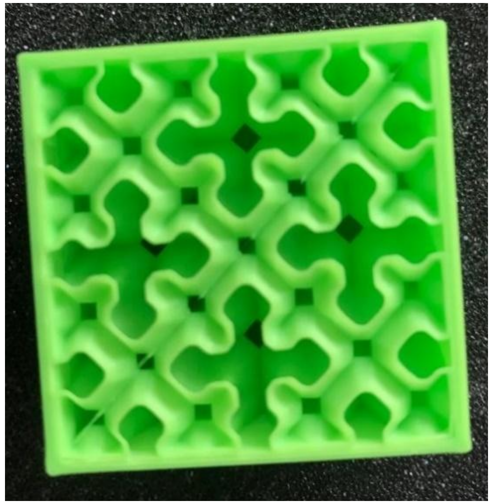
Internal structures for FDM technologz



"Rectangle"

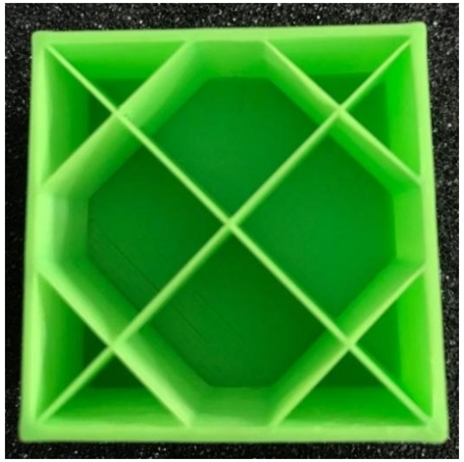


"Tri-hexagon"



"3D Cross"

"Cross"



"Cubic" infill 10 %

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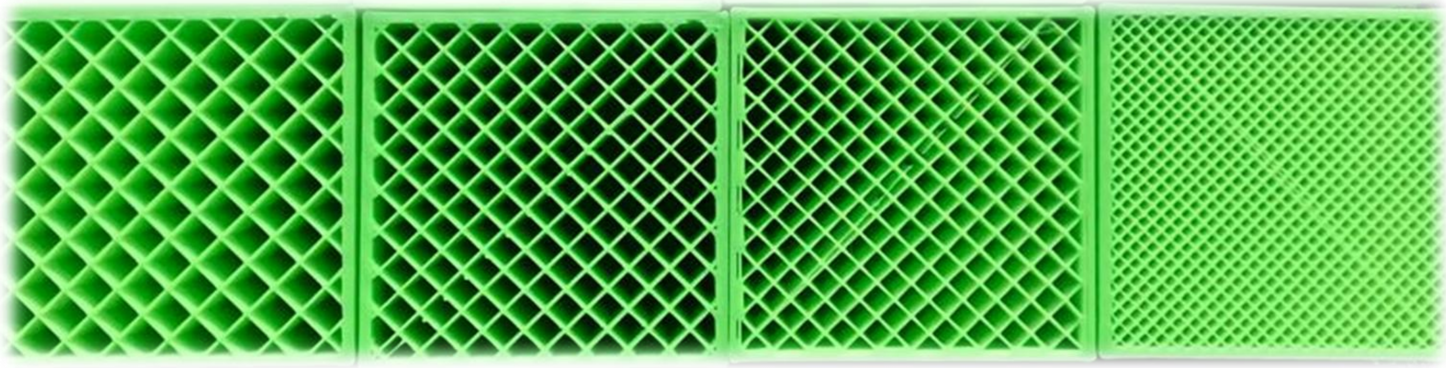
0% 10% 20% 30%



40% 50% 60% 80%

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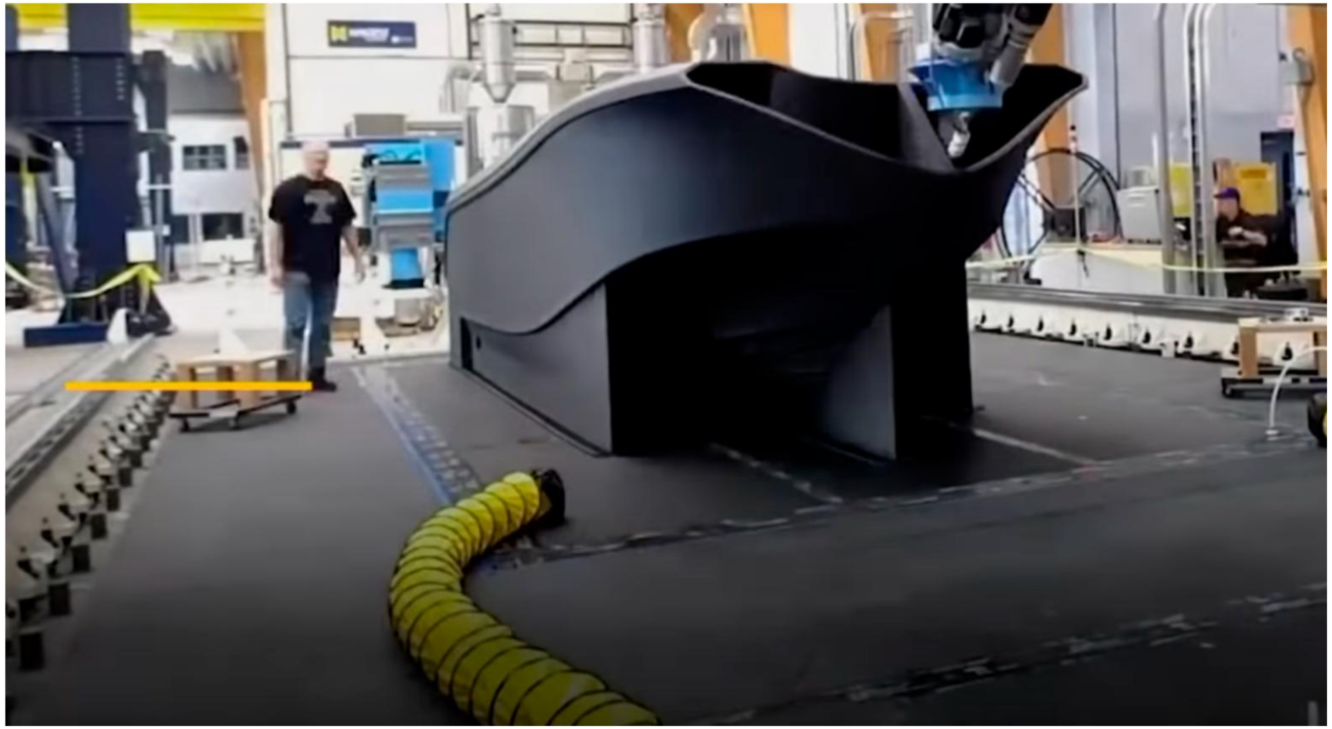
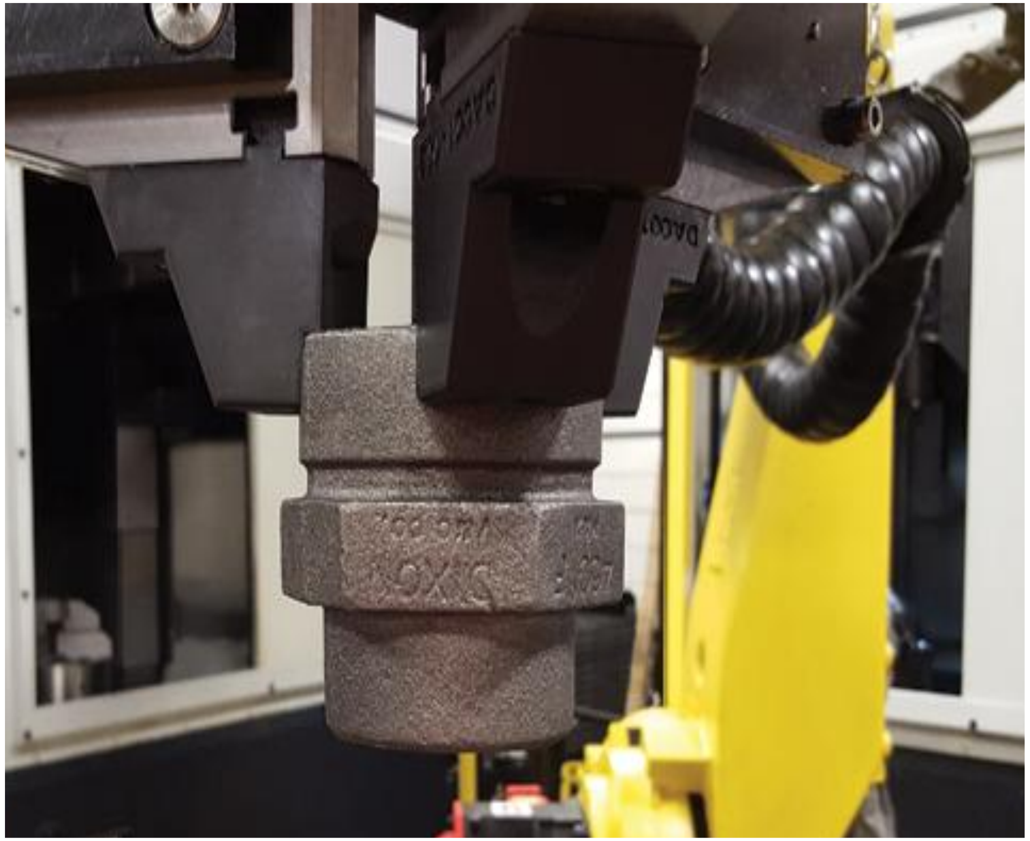


https://reprap.org/wiki/Boat

Aaron Porter | Professional BoatBuilder Magazine

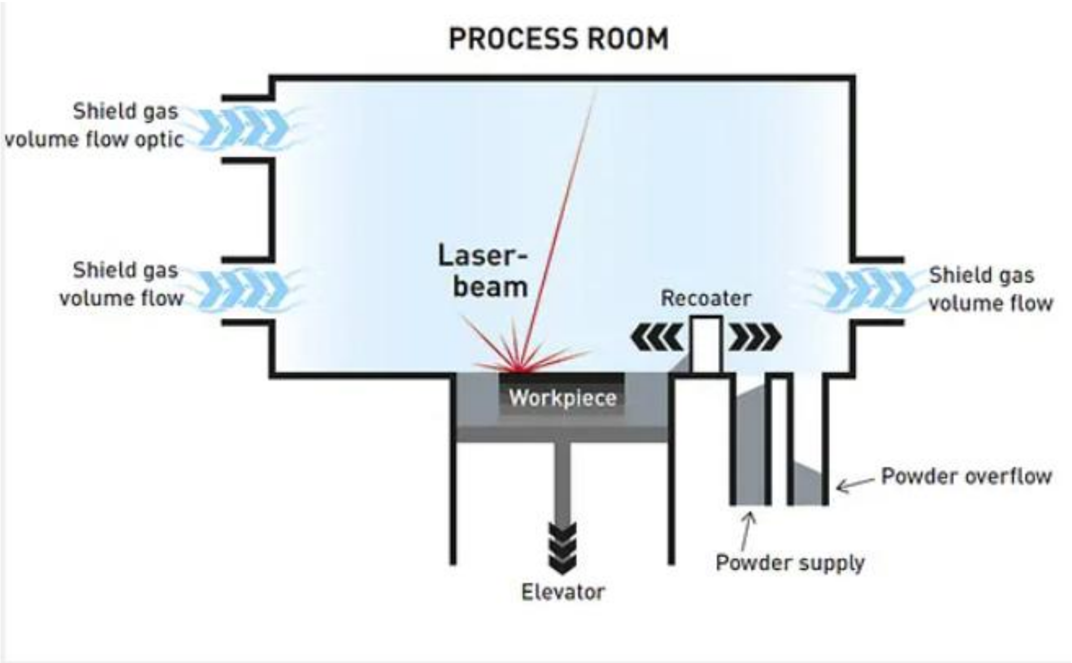
Nylon wrench reinforced with kevlar and carbon fiber



Griper made from onyx

SLM

Selective laser melting



https://en.dmgmori.com/products/machines/additive-manufacturing/powder-bed/lasertec-12-slm

https://www.youtube.com/watch?v=WzZP4vuptQE

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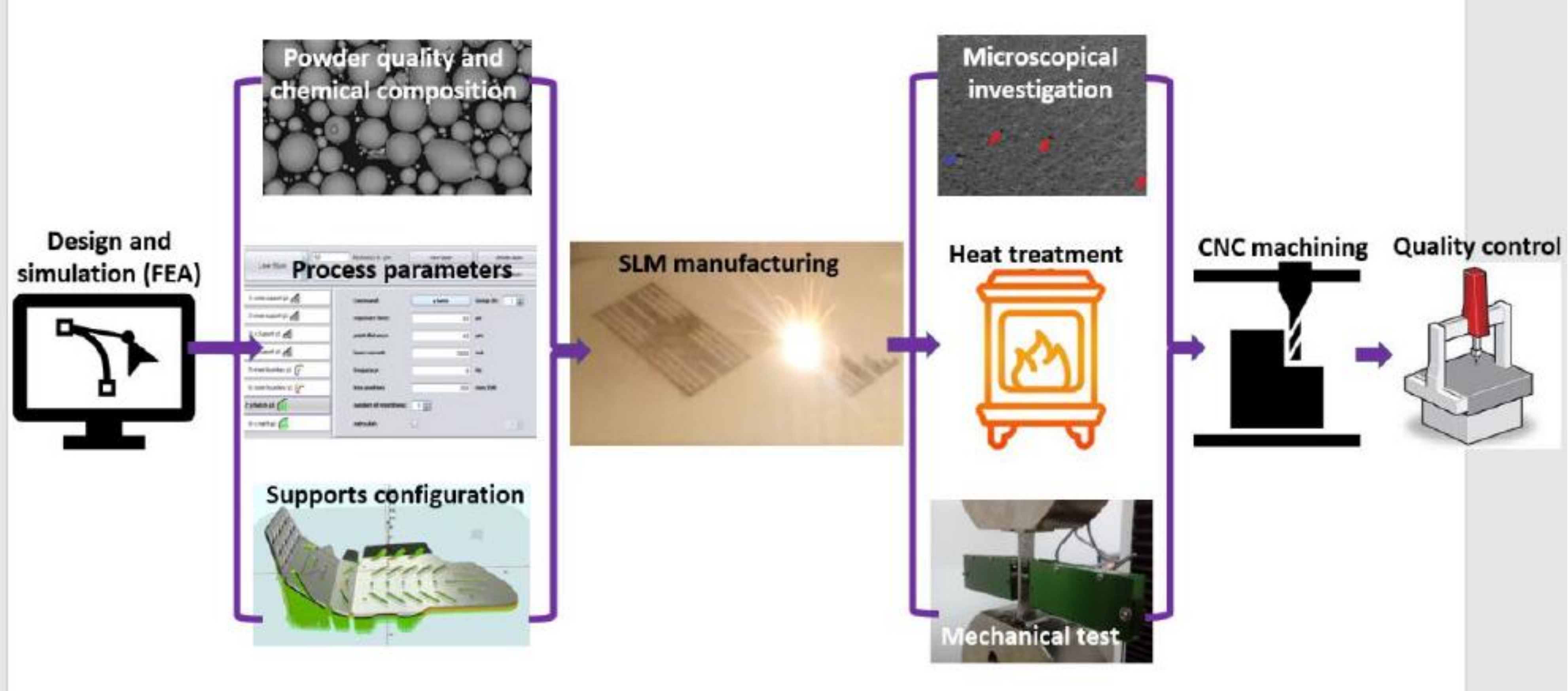
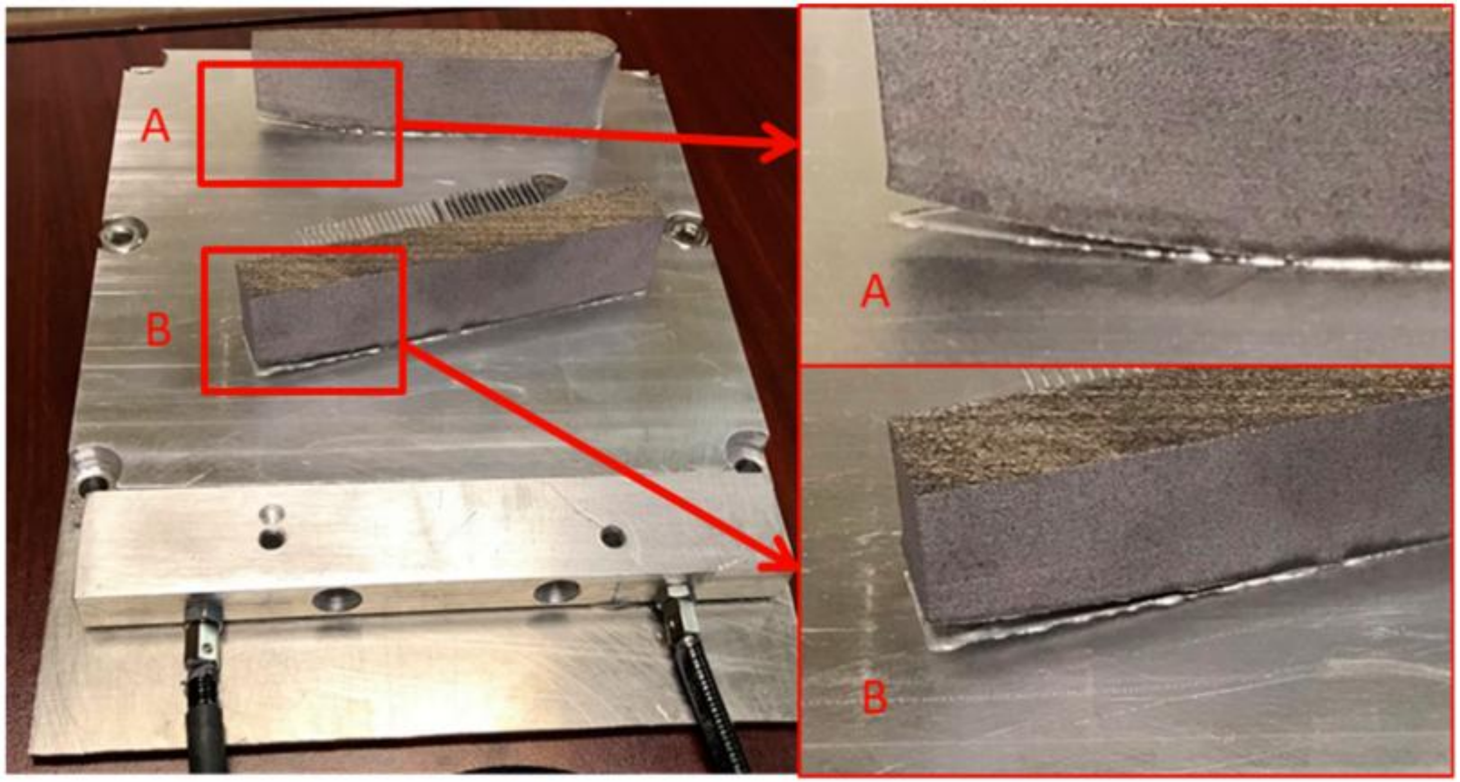
Technology



Design and simulation (FEA)
Powder quality and chemical composition
Process parameters
Supports configuration
SLM manufacturing
Microscopical investigation
Heat treatment
Mechanical test
CNC machining
Quality control

https://www.youtube.com/watch?v=dpHT6YPBFgI



Adam Hehr et al., **Smart Build-Plate for Metal Additive Manufacturing Processes**
https://doi.org/10.3390/s20020360, *Sensors* **2020**, *20*(2), 360

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Typical machine

System Parameters	
Bauraum in mm (x/y/z) Build Chamber in mm (x/y/z)	248 x248 x 250 (350)
Laserleistung Laser Power	200/400 W, YLR-Faser-Laser
Baugeschwindigkeitsrate* Build Speed Rate*	20 ccm/h
Prakt. Schichtdicke Pract. Layer thickness	20 µm - 75 µm (100 µm)
Min. Spurbreite / Wandstärke Min. Scan Line / Wall Thickness	150 µm
Operativer Strahlfocus frei wählbar Operational Beam Fokus variable	60 µm -100 µm (85 µm -130 µm)
Belichtungsgeschwindigkeit Scan Speed	20 m/s
Schutzgasverbrauch im Prozess Inert Gas Consumption in Operation	Ar/N_2, 1,5 l/min

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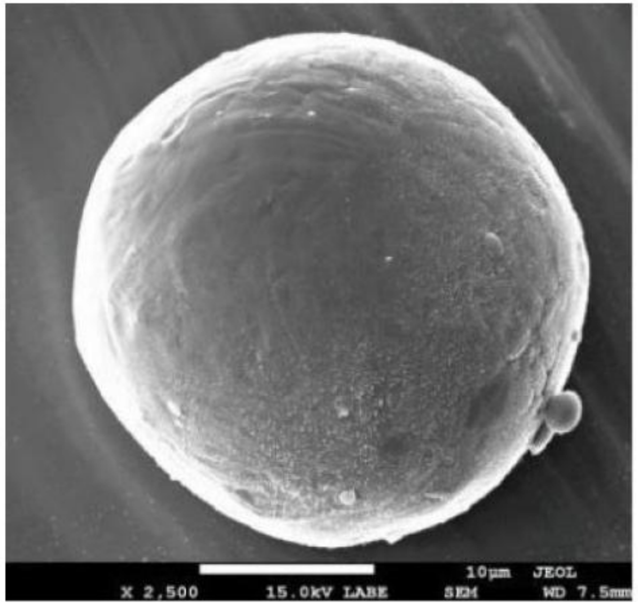
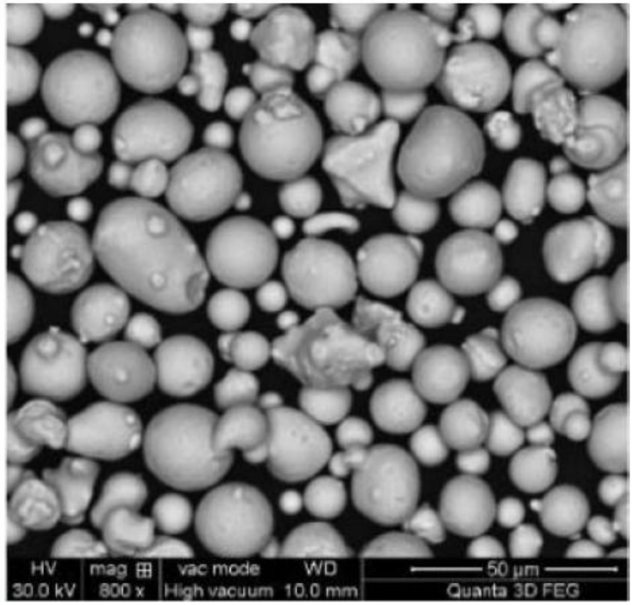


b)



- pure titanium (Ti)
- titanium alloy (Ti6Al4V)
- Co-Cr
- Aluminum
- nickel (Inconel 625, 718)

diameter between 10 µm to 90 µm

Titanium Alloy TiAl6V4:	420 – 540 €/kg
Pure Titanium Grade 1 or 2:	360 – 480 €/kg
Stainless Steel 316L (1.4404):	70 – 110 €/kg
Cobalt Chromium Alloy (CoCrWMo):	240 – 370 €/kg

Quality indicators for the metal powder:
 - d90 value (90% of the particles are smaller than 90 microns;
- Flowability - time necessary for 50 grams to flow gravitationaly trough an orifice of 2,5 mm diameter (s/50 – ASTM B213). Tipicaly the flow rate is between 15 and 40 sec.

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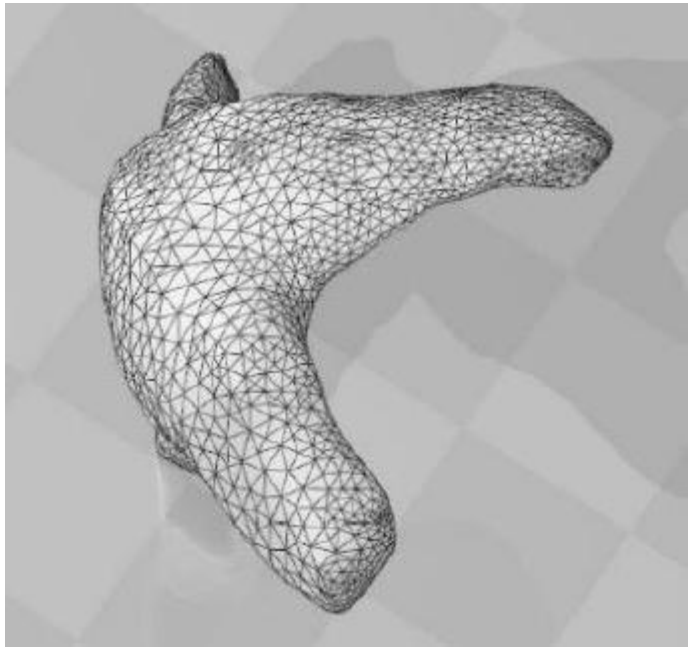
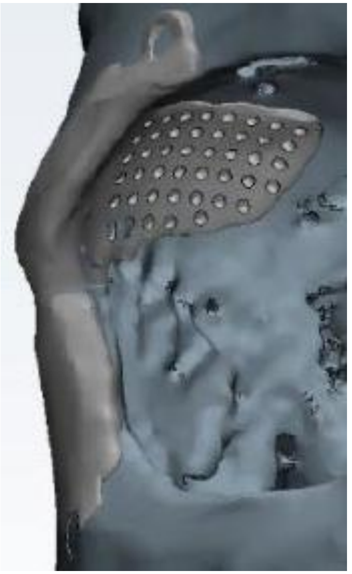
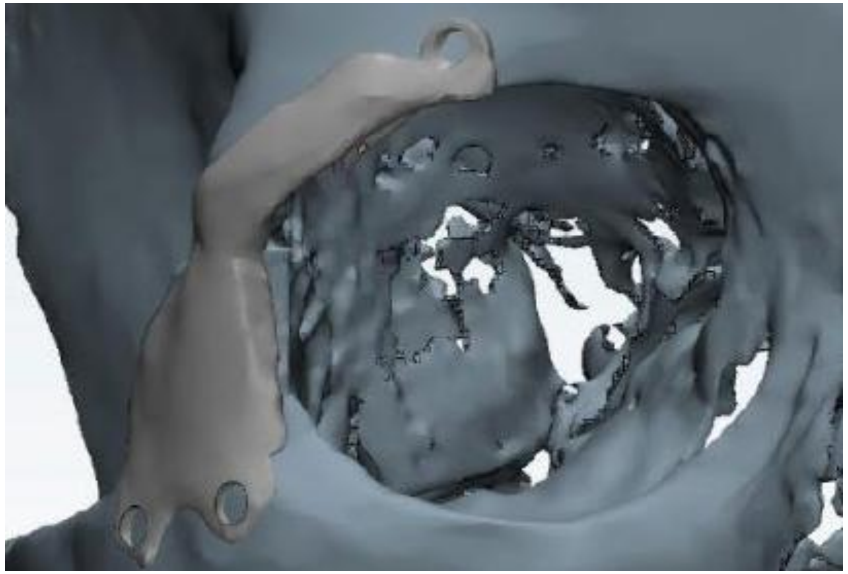
Applications

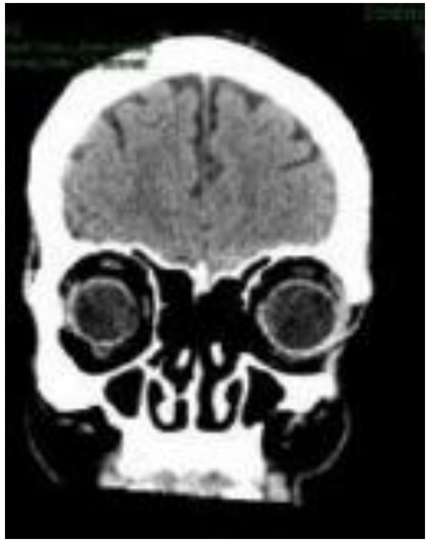
Mostly implants







Example



CT scan

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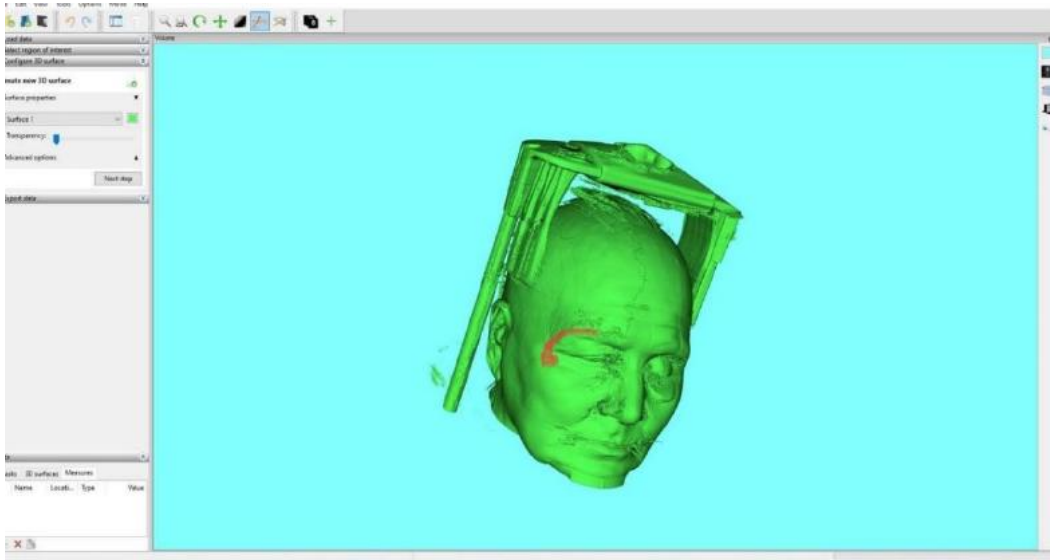
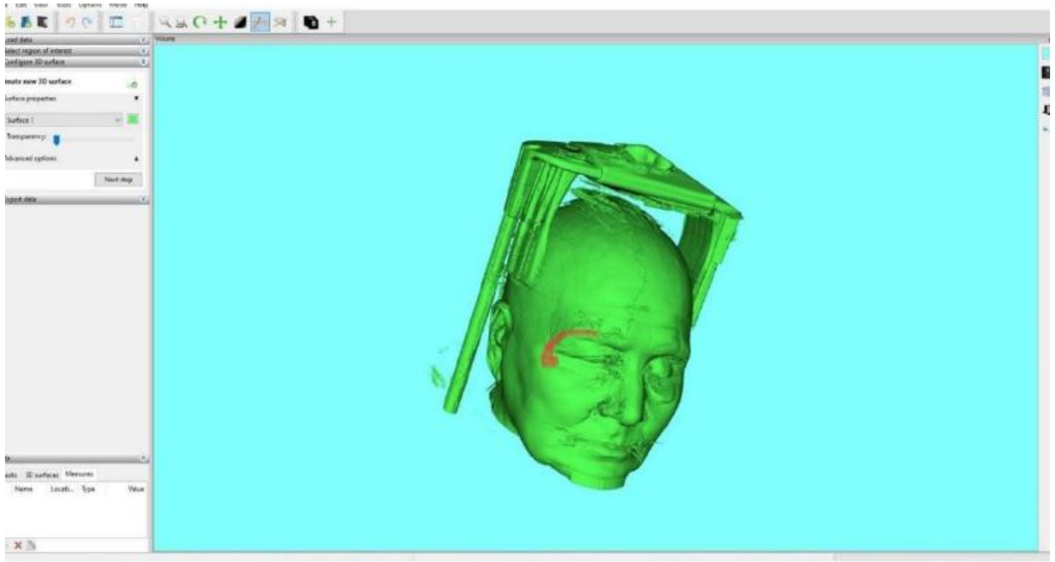
Example



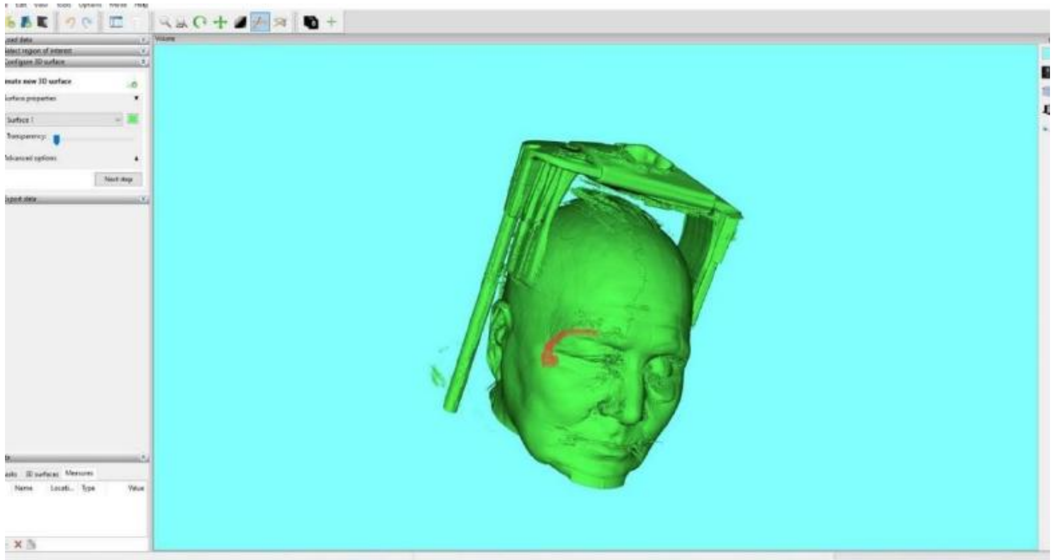
Virtual reconstruction of facial bones and soft tissues

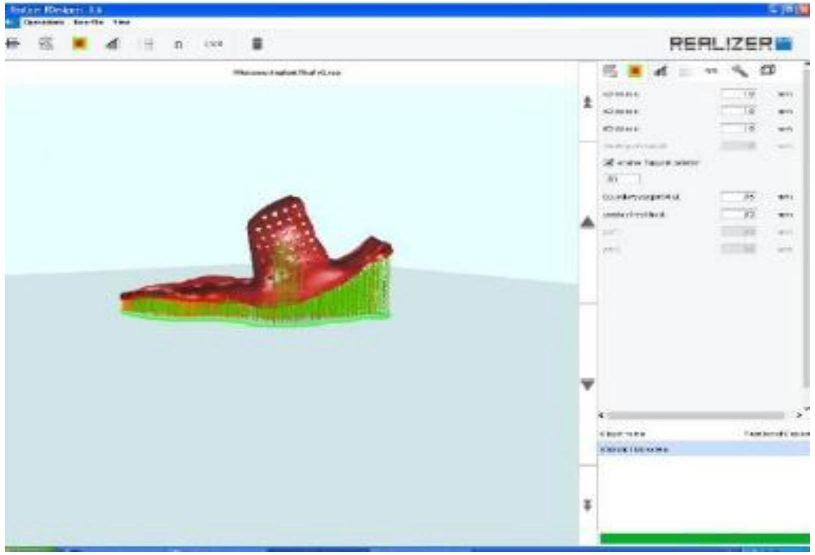
Example



Recostruction of the damaged bone in CAD Software

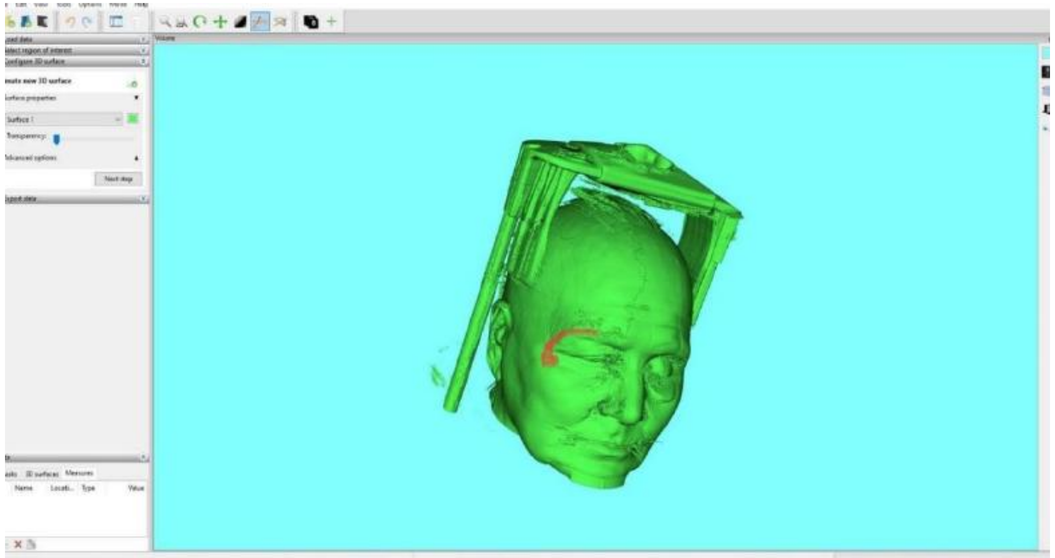
Example



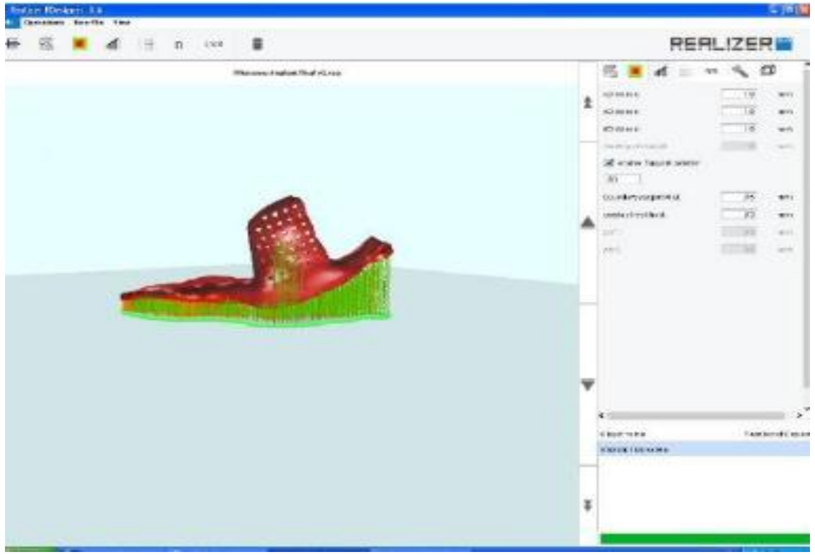


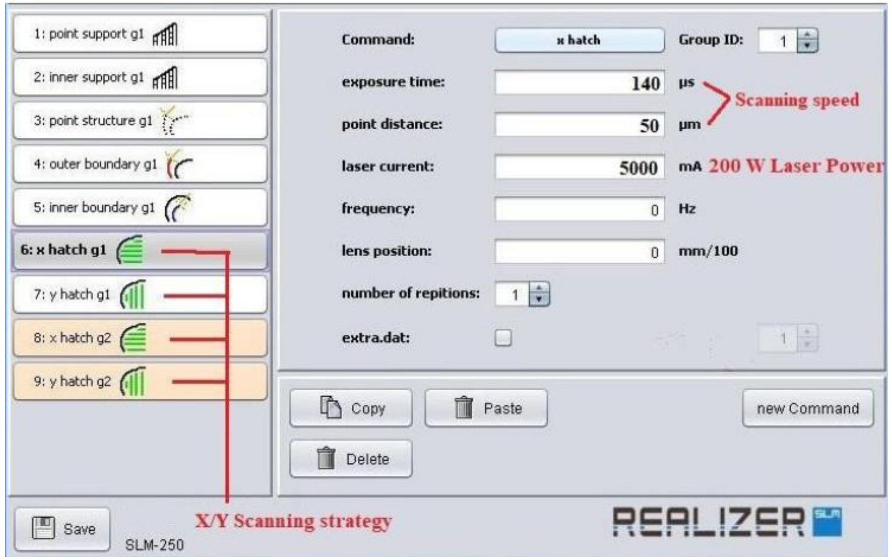
Workpiece orientation in RDesigner Software

Example



Establish the parameters for the manufacturing process





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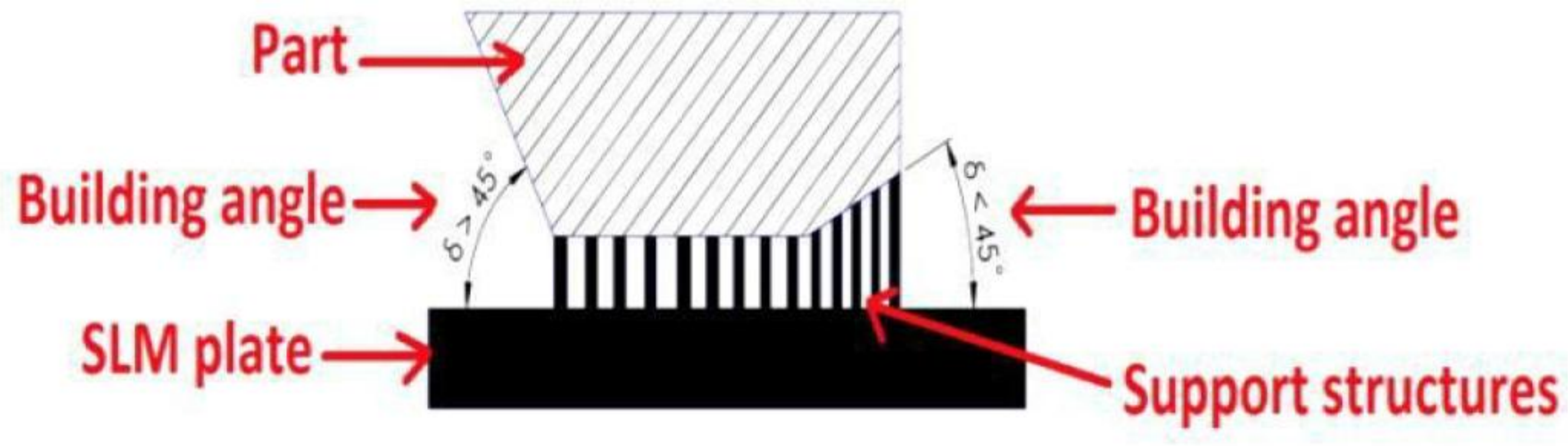
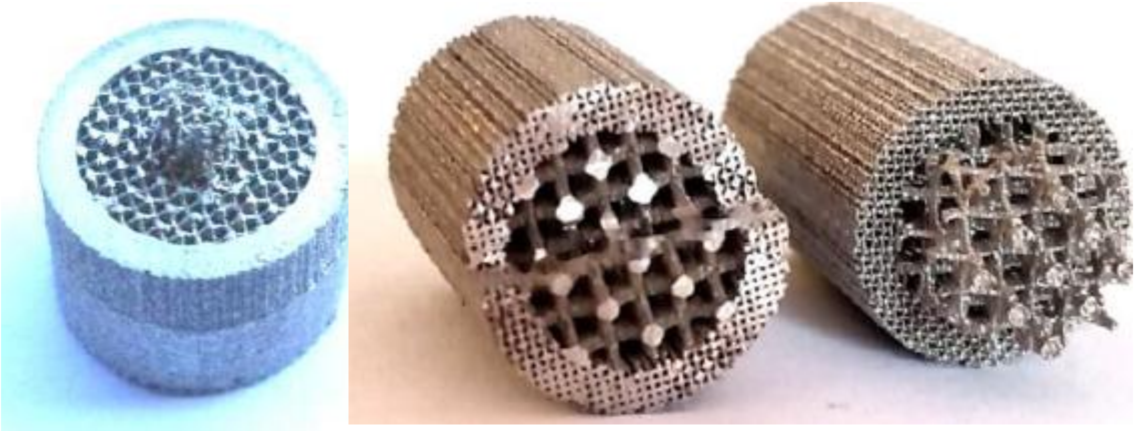


Support structures needed to anchor surfaces. Surfaces with angles higher than 45° are possible to fabricate without supports

Applications

Regenerative medicine using lattice structures



Applications

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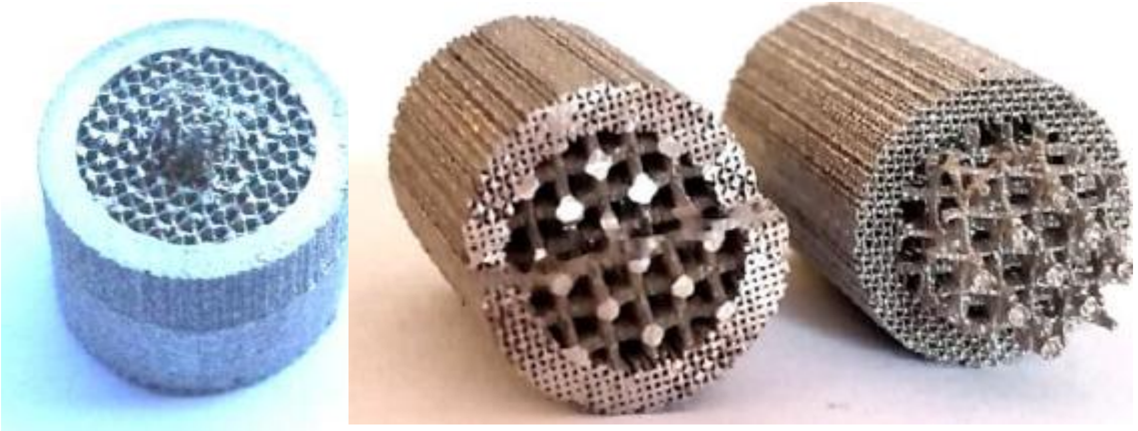
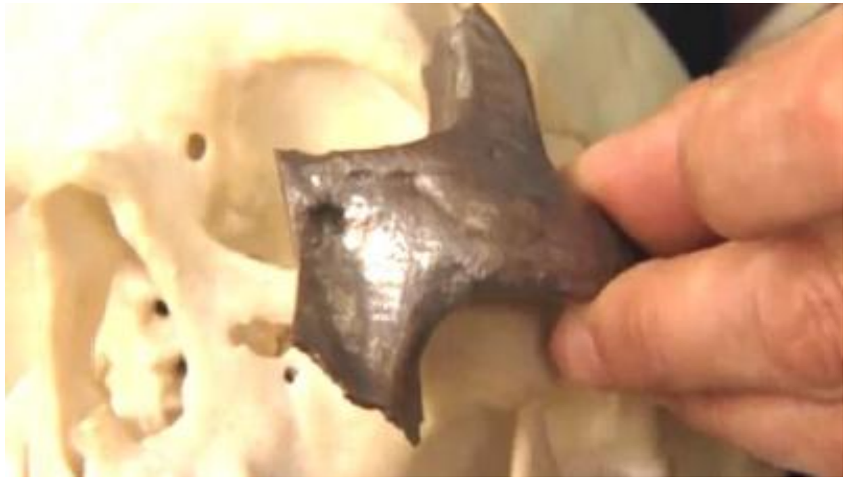


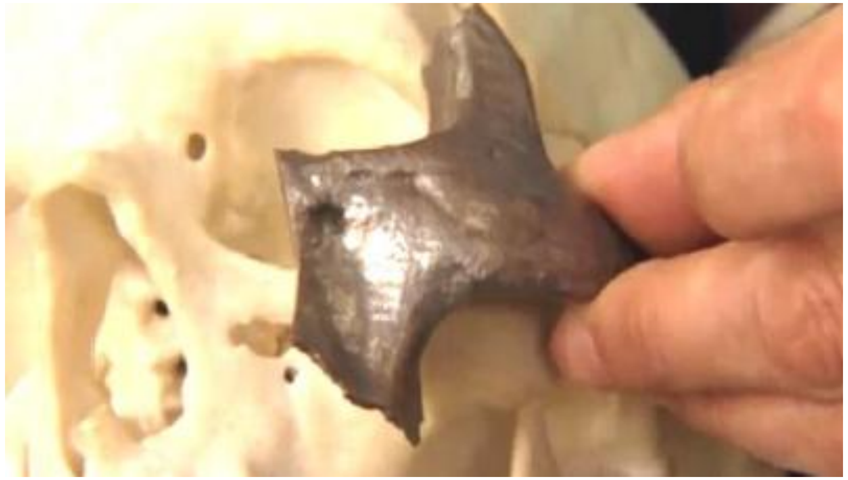
Cranio-Maxilo-Facial Surgery



Applications

Regenerative medicine using lattice structures

Cranio-Maxilo-Facial Surgery



Dentistry

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Work tool manufacturing

https://en.dmgmori.com/products/machines/additive-manufacturing/powder-bed/lasertec-12-slm

Work tool manufacturing

https://en.dmgmori.com/products/machines/additive-manufacturing/powder-bed/lasertec-12-slm

Inconel 718 turbine Blade

https://it.china-3dprinting.com/metal-3d-printing/inconel-718-slm-3d-printing-turbine-blade.html

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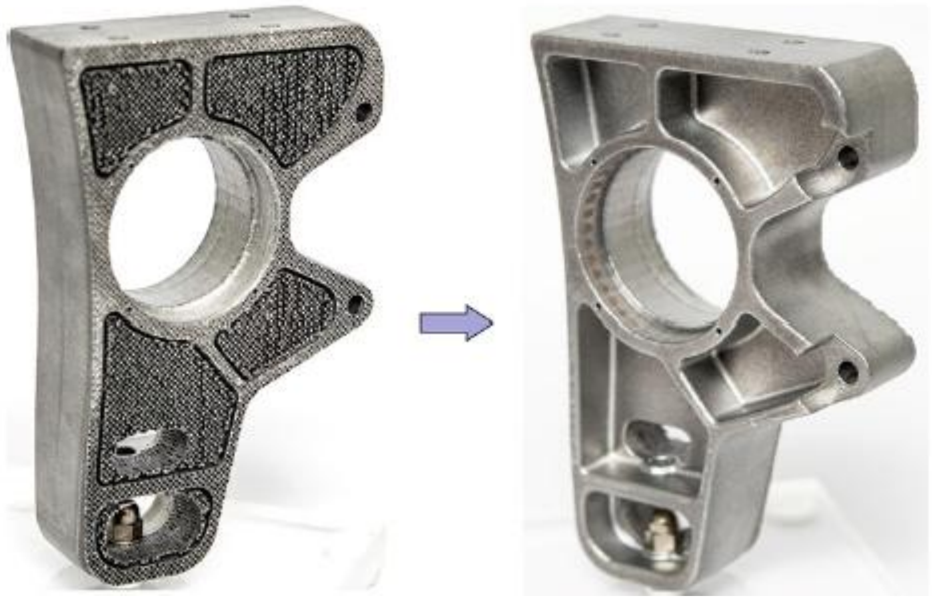
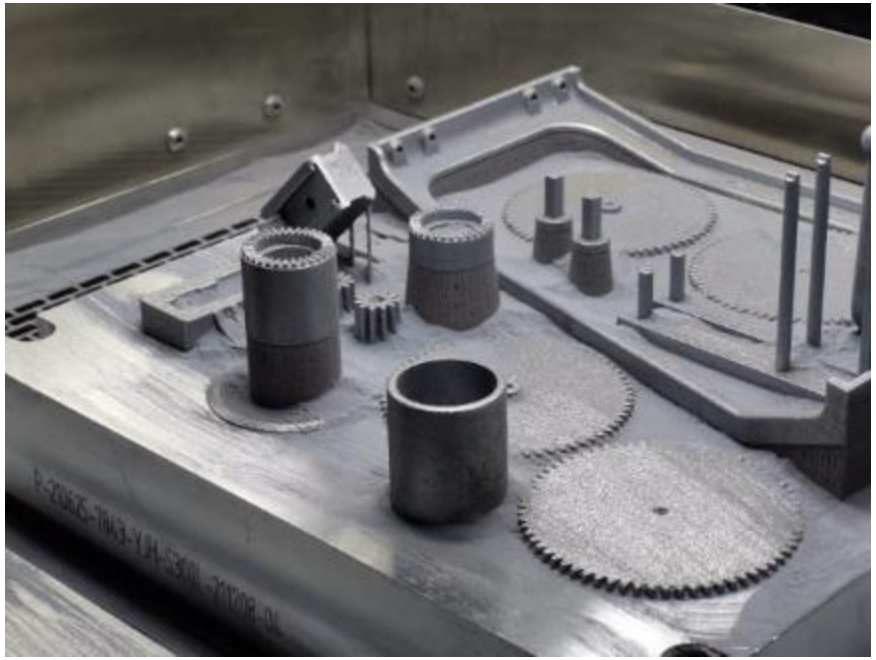
Postprozess



Necessity of postprocessing the workpieces [3]



https://www.wenext.com/3d-printing/slm

Taking the parts out from the plate:
1) Chiseling
2) Bandsaw
3) Wire EDM

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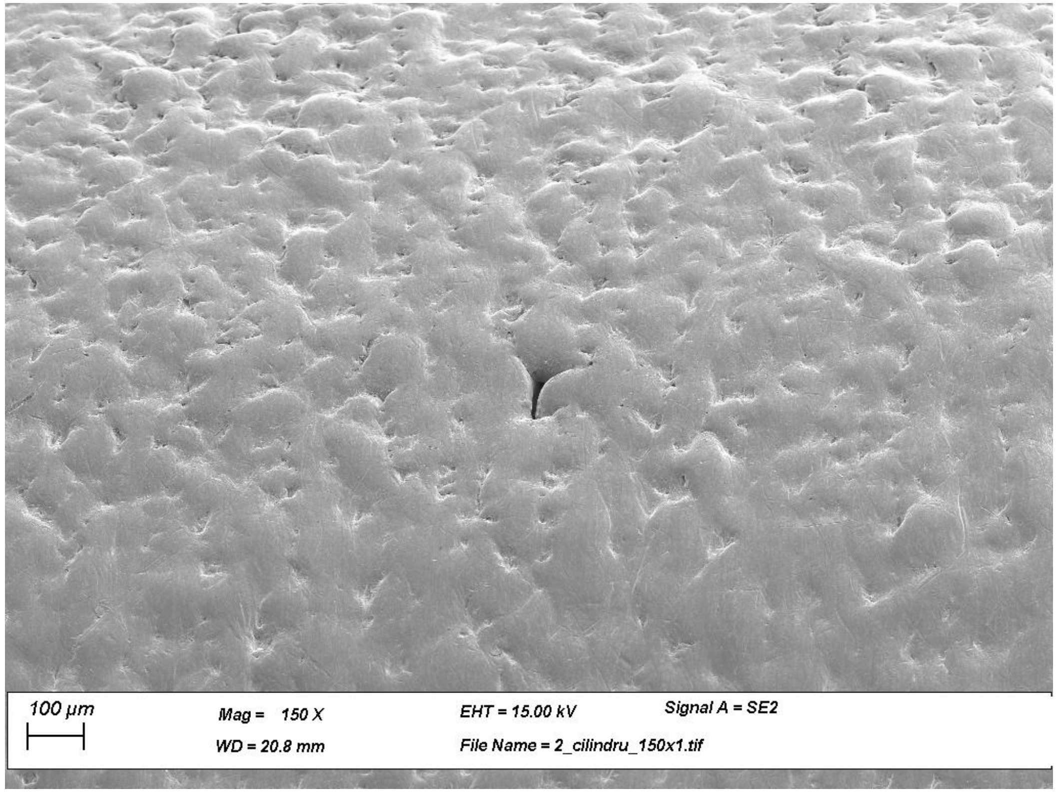
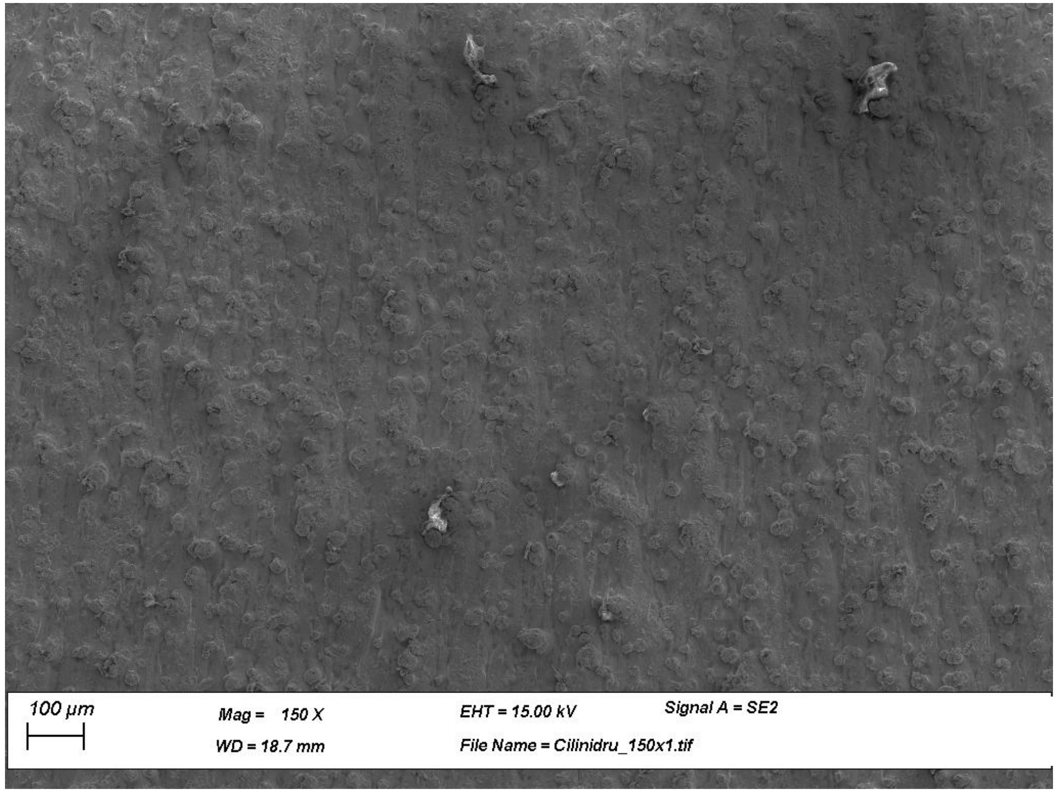
Postprocessed surface





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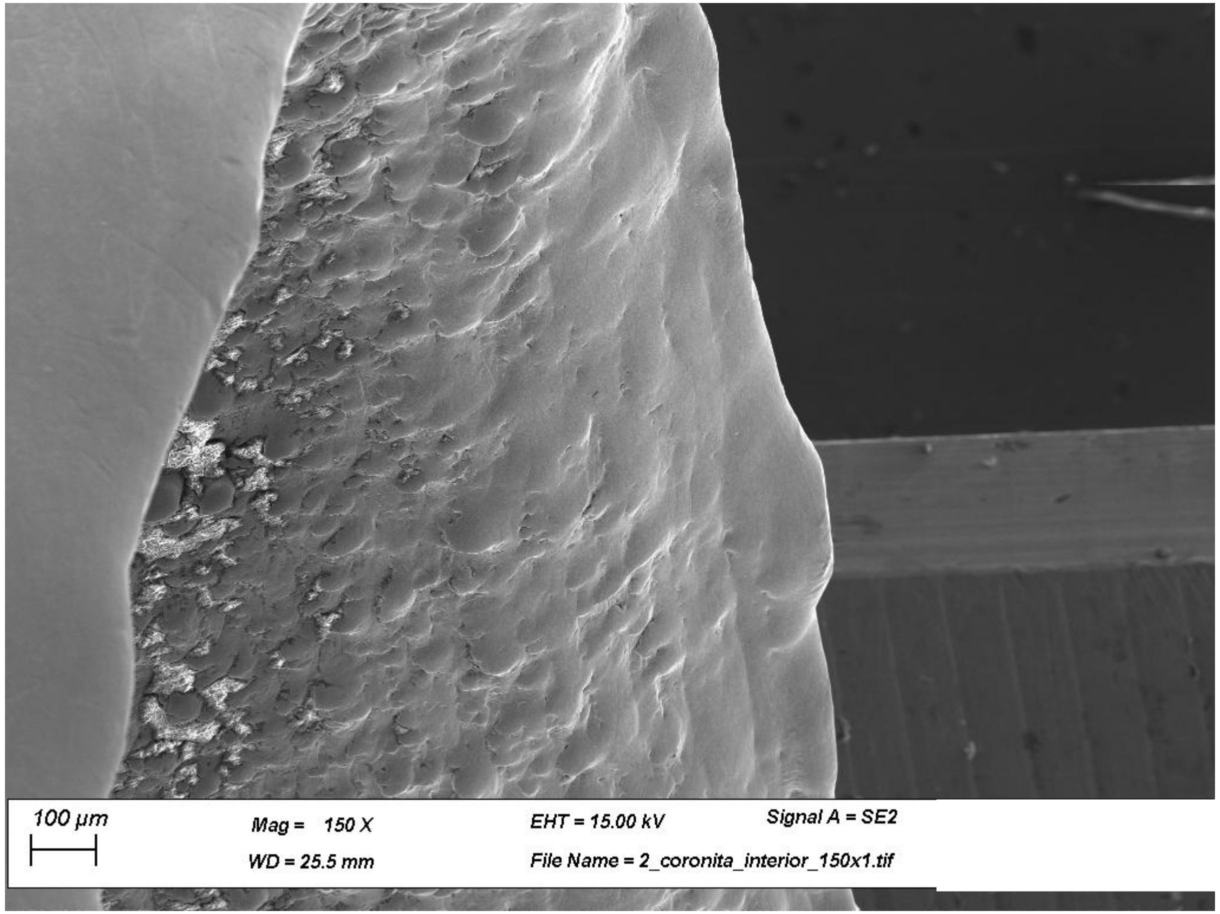
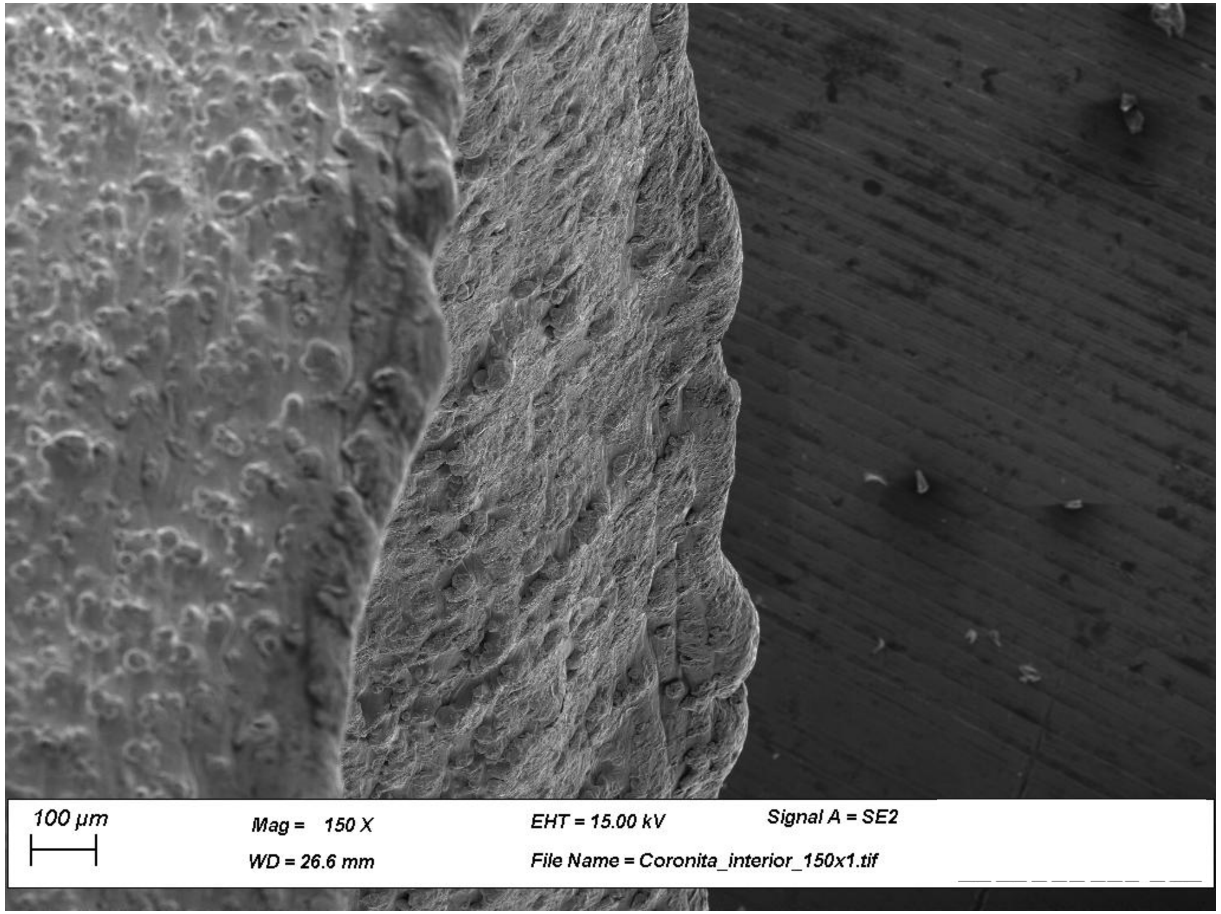

100 µm
Mag = 150 X
WD = 25.5 mm
EHT = 15.00 kV
File Name = 2_coronita_interior_150x1.tif
Signal A = SE2


100 µm
Mag = 150 X
WD = 26.6 mm
EHT = 15.00 kV
File Name = Coronita_interior_150x1.tif
Signal A = SE2

When to use SLM?

- functional, end-use parts
- Prototyping in production
- Low volume production (Qty < 250)
- Highly complex geometry which is impossible to generate through other technologies
- Where is needed low weight part (using Lattice structures)
- Specific requirement for workpieces that are used under in high temperature or in corrosive solutions.

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https://www.youtube.com/watch?v=x_r5oXQ4B8U

References

[1] Jian-Yuan Lee, Jia An, Chee Kai Chua, Fundamentals and applications of 3D printing for novel materials, Volume 7, June 2017, Pages 120-133, https://doi.org/10.1016/j.apmt.2017.02.004 , Applied Materials;

[2] Tarek I. Zohdi, Modeling and Simulation of Functionalized Materials for Additive Manufacturing and 3D Printing: Continuous and Discrete Media, ISSN 1613-7736, Springer International Publishing AG 2018;

[3] Roland Lachmayer, Rene Bastian Lipper, tThomas Fahlbusch Hrsg., 3D-Druck beleuchtet, Additive Manufacturing auf dem Weg in die Anwendung, DOI 10.1007/978-3-662-49056-3, Springer-Verlag Berlin Heidelberg 2016;

[4] Jiayun Shao, Arash Samaei, Tianju Xue, Xiaoyu Xie, Shengmin Guo, Jian Cao, Additive friction stir deposition of metallic materials: Process, structure and properties, Materials & Design, 234 (2023) 112356, https://doi.org/10.1016/j.matdes.2023.112356

[5] Li Yang, Keng Hsu, Brian Baughman, Donald Godfrey, Francisco Medina, Mamballykalathil Menon,Soeren Wiener, Additive Manufacturing of Metals: The Technology, Materials, Design and Production, ISSN 1860-5168 ISSN 2196-1735 (electronic) Springer Series in Advanced Manufacturing ISBN 978-3-319-55127-2, ISBN 978-3-319-55128-9 (eBook), DOI 10.1007/978-3-319-55128-9, Springer International Publishing AG 2017;

[6] Hans Albert Richard, Britta Schramm, Thomas Zipsner, Additive Fertigung von Bauteilen und Strukturen, ISBN 978-3-658-17779-9 ISBN 978-3-658-17780-5 (eBook), DOI 10.1007/978-3-658-17780-5, Springer Fachmedien Wiesbaden GmbH 2017.

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C6 – Manufacturing Technology

M2 – Manufacturing technology of MEMS

CO – Technical University of Cluj-Napoca

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About NextGEng Project

- Three-year Erasmus+ Cooperation Partnership project that started in October 2022
- International consortium consisting of 3 universities and 3 companies from European countries
- Project co-funded by the European Union and coordinated by Technical University of Cluj-Napoca, Romania

Technical University of Cluj-Napoca

Jamk University of Applied Sciences

University of Jaén

Integracion Sensorial y Robotica

Valmet Technologies Oyj

Robert Bosch SRL

Co-funded by the European Union

About NextGEng Project

- **NextGEng Project** aims to create new pedagogical models that promotes international team-teaching with the support of new learning materials for existing courses in the curricula

NextGEng comprises three types of activities

Training

Tailored training program for teachers that sustain the skill improvement of HEI partners staff in new/innovative teaching methods.

International Team-Teaching

international pilot program.
Upgrade a set of engineering courses, belonging to the HEI partners curricula, in close collaboration with companies' partners.

CEL Projects

Cases of Experiential Learning projects.
Type of projects where students learn by doing in an international and multidisciplinary environment.

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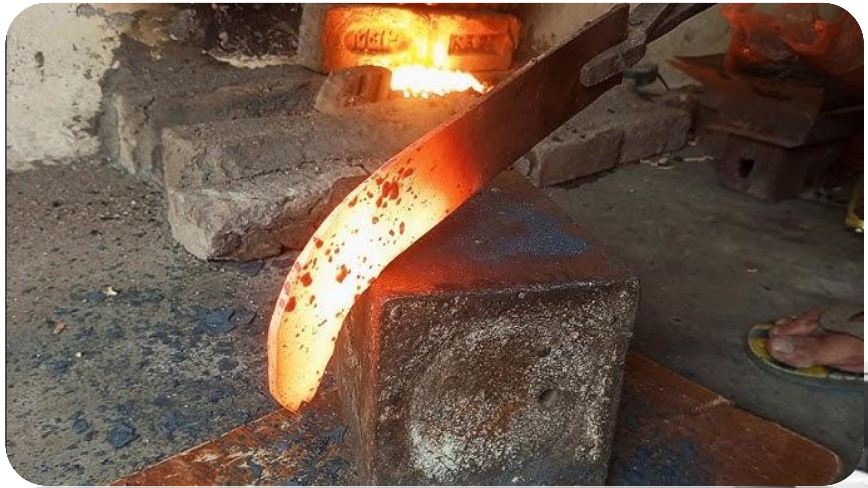

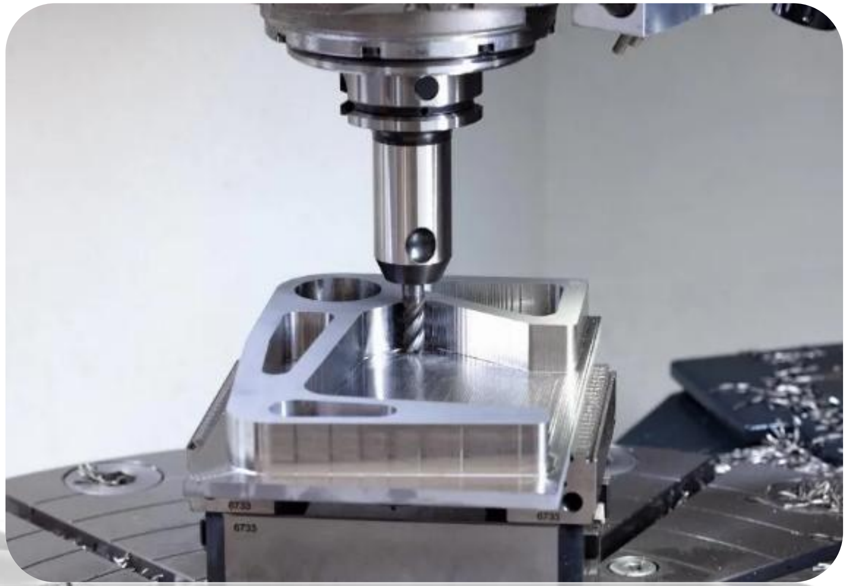

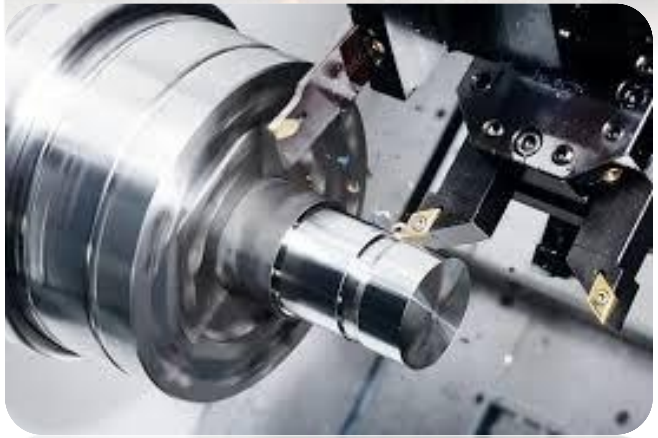

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Electronic technology – microelectronics

- Deals with the processes of making electronic components and circuits and the methods of assembling them.
- **The development of manufacturing technologies** has led to increased product reliability, reduced product dimensions, modification of shape, interconnection method etc.

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What are the microtechnologies?

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What are the microtechnologies?

- According to Krar Stephen, microtechnologies deal with technologies whose technological characteristics are on the order of micrometers;

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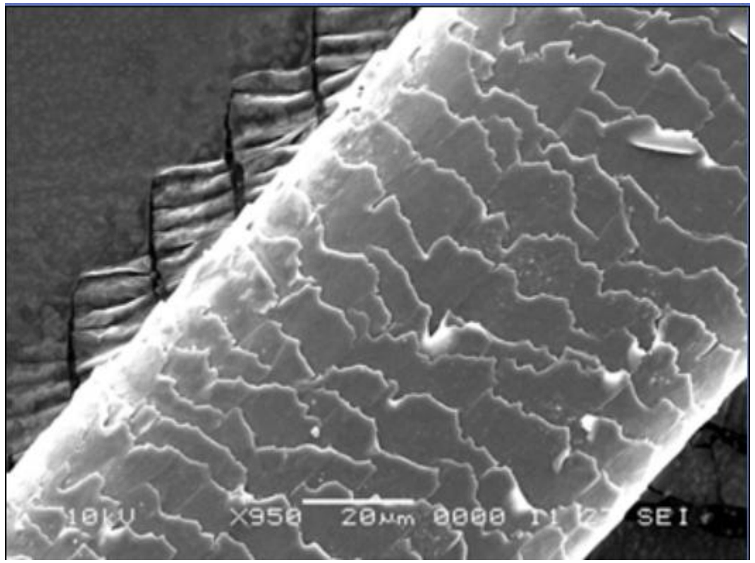

Human hair – 950x SEM

http://www.bio.miami.edu/em/sempics.html

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Micro components (examples)

Micro components (examples)

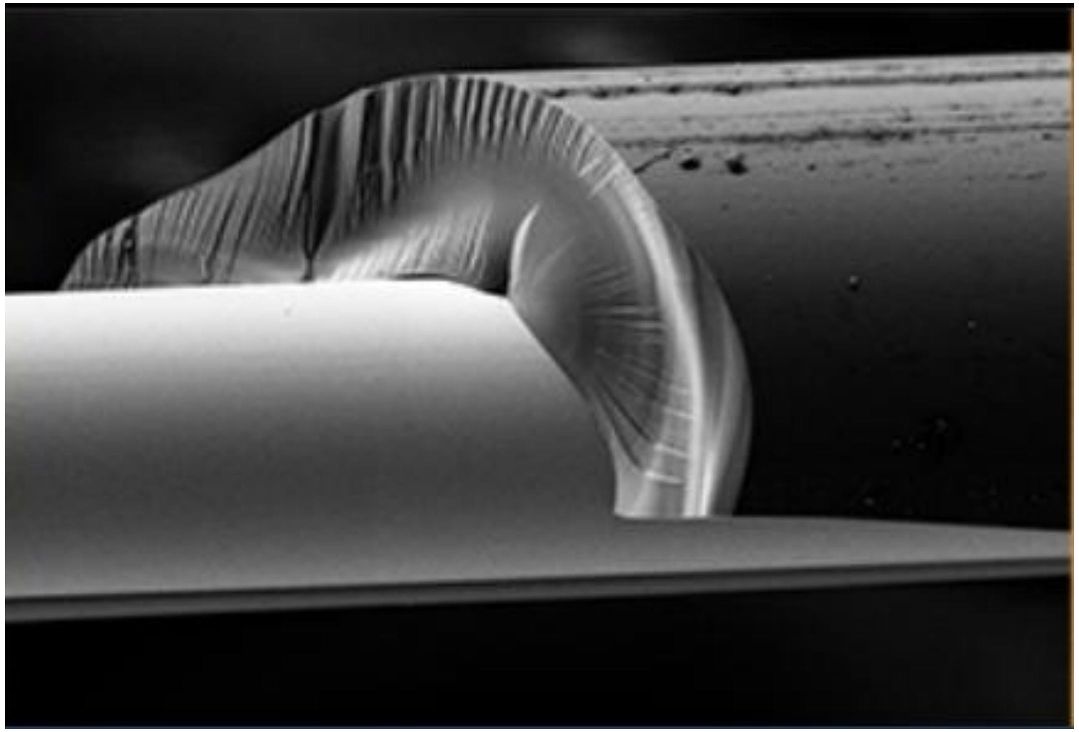
- MEMS (Microelectromechanical Systems – micro-electro-mechanical systems) – microscopic devices, particularly those that exhibit reciprocal movements.

https://circuitdigest.com/tutorial/what-is-mems-various-mems-devices-and-applications

Micro components (examples)

- MEMS (Microelectromechanical Systems – micro-electro-mechanical systems) – microscopic devices, particularly those that exhibit reciprocal movements.
- Items to be constructed at the microlevel:

- wires
- Reisistors
- Transistors
- Diodes
- Sensors
- Capacitors



https://www.phys-iasi.ro/en/research-directions/microwires

Micro components (examples)

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- Reisistors
- Transistors
- Diodes
- Sensors
- Capacitos
- Microrobotics

https://news.cnrs.fr/articles/when-microrobots-manipulate-cells

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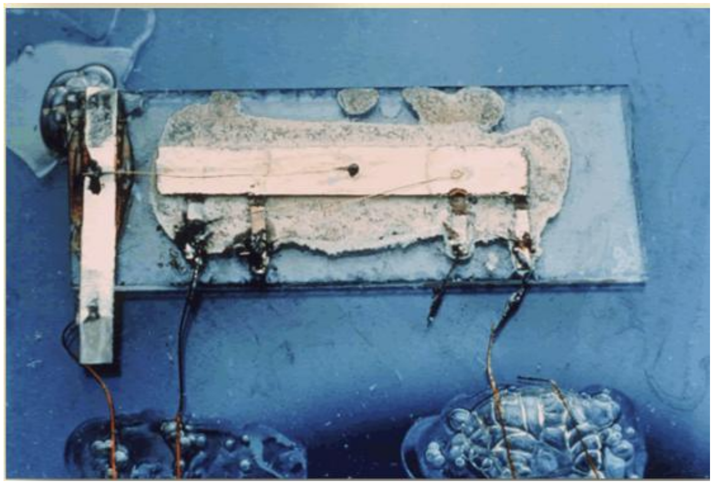
Microcomponents particularities

- Dimensions: 1 ÷ 100 µm (Usually 20 µm);
- Microprocessors – electricity(electro);
- They have moving components (mechanical)

Evolution



Texas Instrument's First Integrated Circuit [Photos Courtesy of Texas Instruments]

- Inventin – 1965;
- Production / starting with 1980;
- Currently there are over 100 billion types of MEMS used in: phones, GPS, cars, etc.

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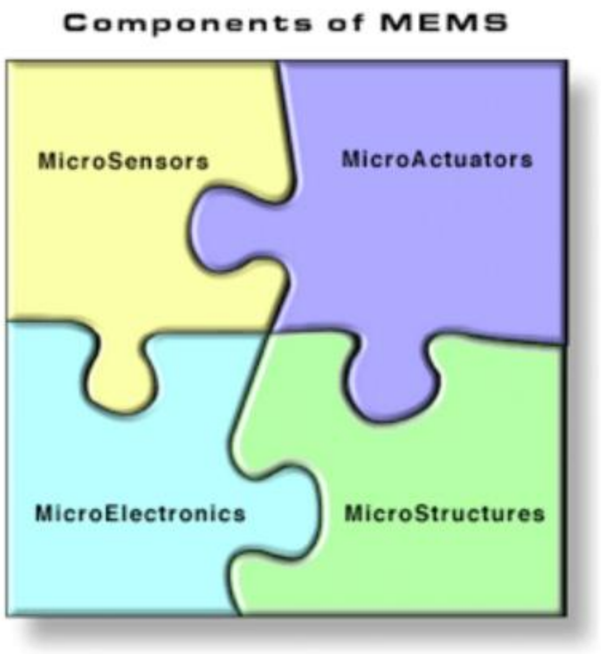
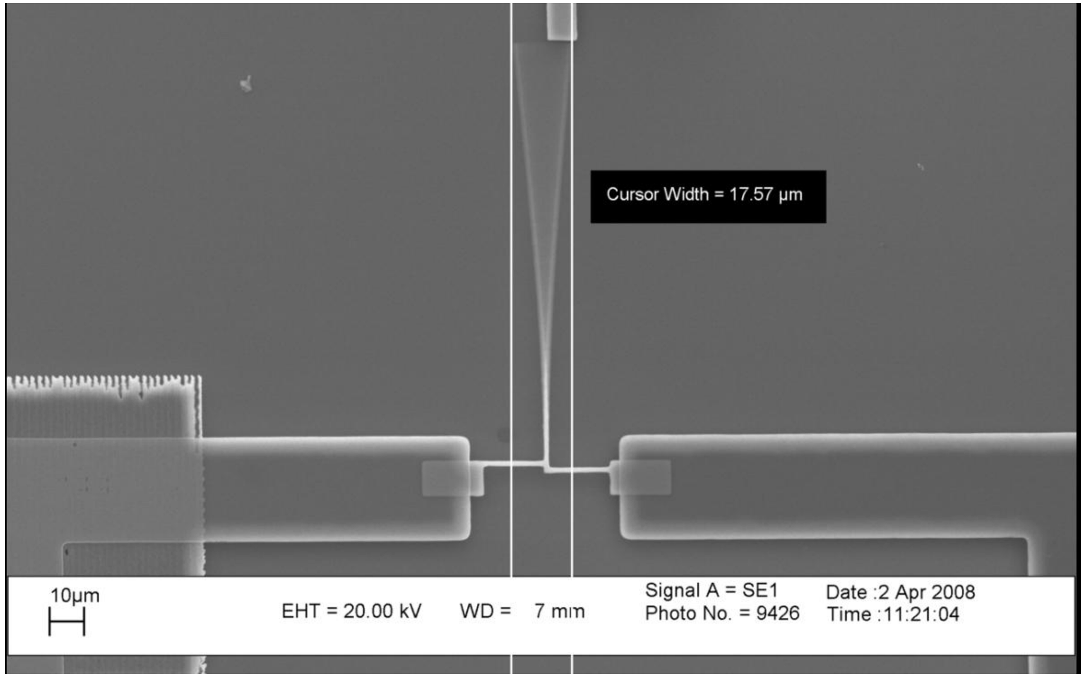
Main structure of MEMS

- They consist usually of 4 components.
- Miniaturised structures that can transform one kind of energy to other (mechanicat signal to electrical signal)

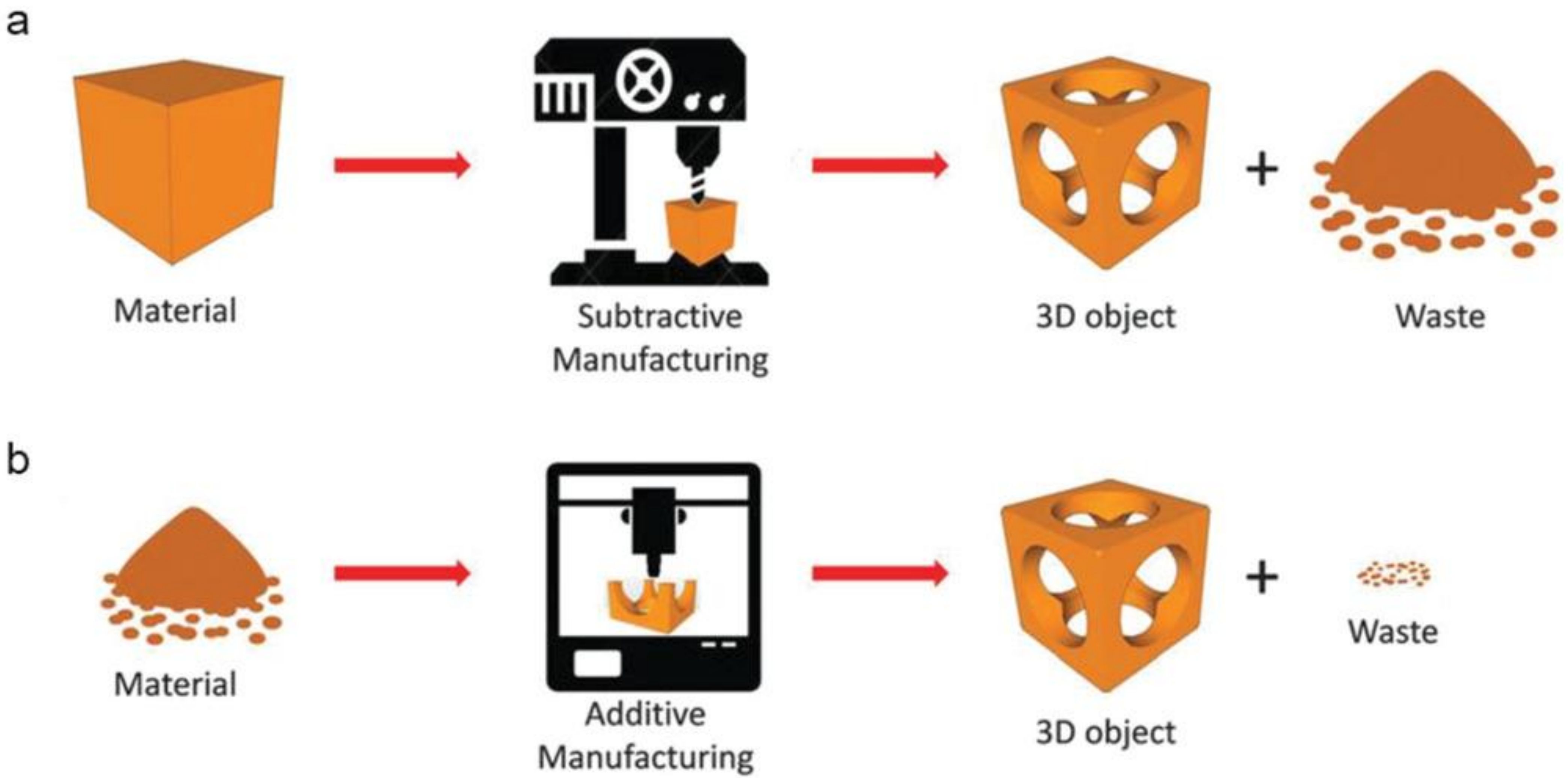


“How it’s made?”

- Usual dimensions of the MEMS components 0.001 ÷ 0.1 mm;
- MEMS dimensins 0.02 ÷ 1 mm;
- Components arranged in arrays can be mode than 1000 mm^2.



Why not classical methods?



https://www.youtube.com/watch?v=G55kLhv2d_4

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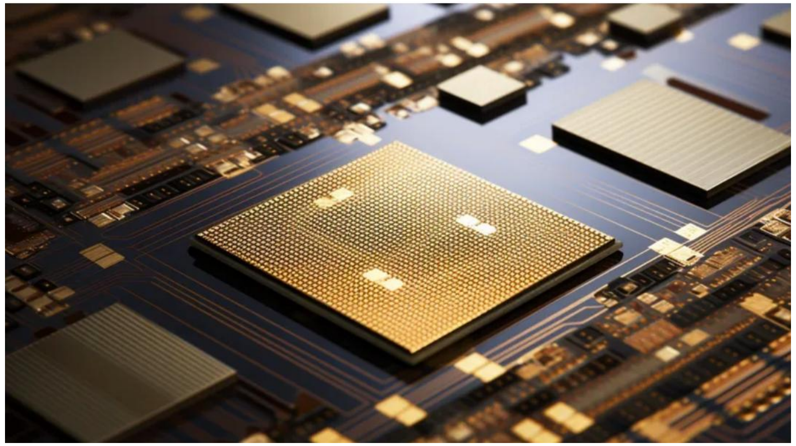
Main Processes

- Deposition proceses

Main Processes

- PVD – Physical Vapour deposition



https://www.wevolver.com/article/pvd-coating-in-semiconductors-a-comprehensive-guide

- Deposition proceses

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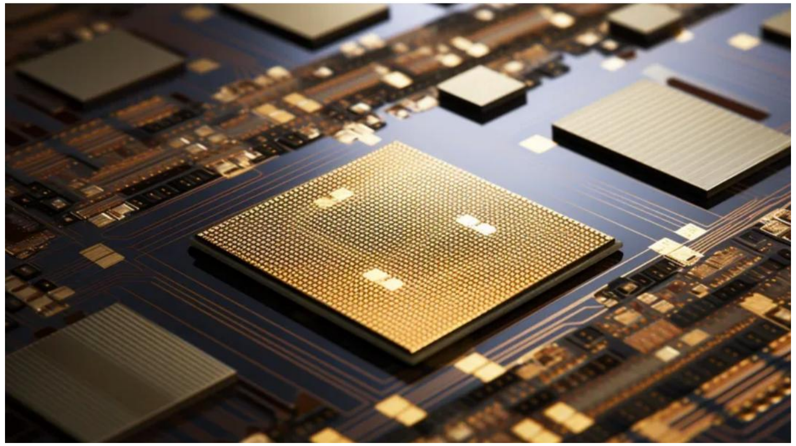
Main Processes

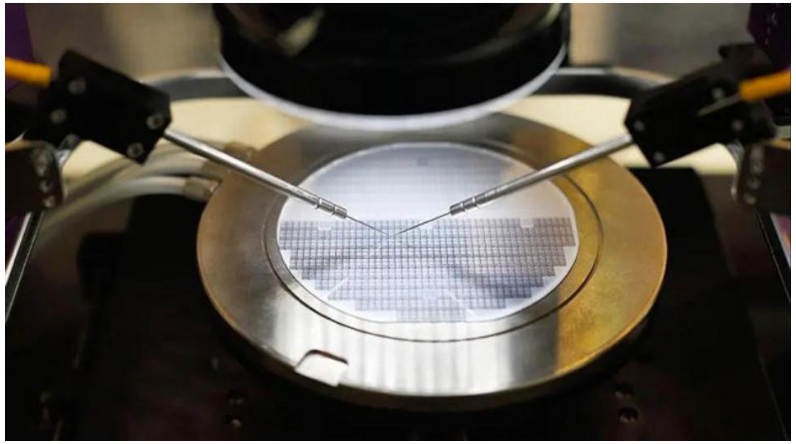
- Deposition proceses

- PVD – Physical Vapour deposition



https://www.wevolver.com/article/pvd-coating-in-semiconductors-a-comprehensive-guide

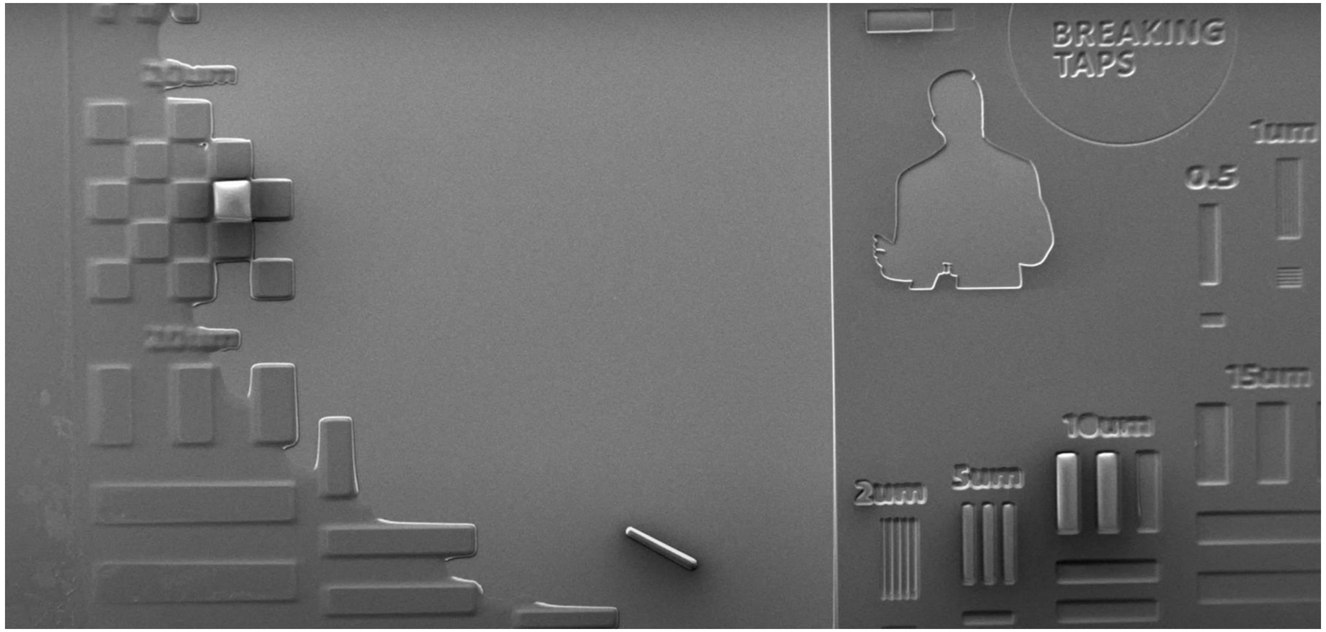
- CVD – Chemical deposition



https://www.aemdeposition.com/blog/principle-of-chemical-vapor-deposition.html

Main Processes

- Lithography

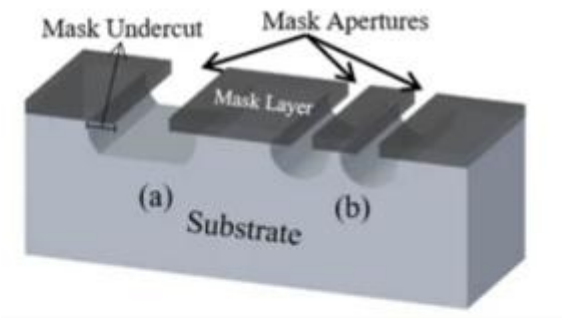


https://www.youtube.com/watch?v=RuVS7MsQk4Y

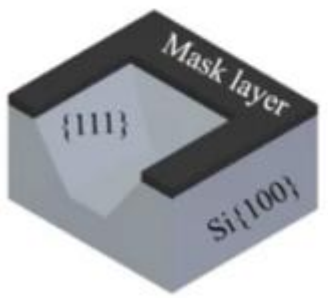
Main Processes

- Etching

Isotropic etching



Anisotropic etching



Source: https://mnsl-journal.springeropen.com/articles/10.1186/s40486-021-00129-0

MEMS design criteria:

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- In the case of micro-nano structures, frictional forces, capillary, electrostatic, atomic, etc. are significant;

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- The heat developed or transmitted in these systems;

MEMS design criteria:

- In the case of micro-nano structures, frictional forces, capillary, electrostatic, atomic, etc. are significant;
- The heat developed or transmitted in these systems is significant and its dissipation can be problematic;
- Micro-hydraulic systems are prone to blockages;

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MEMS design criteria:

- In the case of micro-nano structures, frictional forces, capillary, electrostatic, atomic, etc. are significant;
- The heat developed or transmitted in these systems is significant and its dissipation can be problematic;
- Micro-hydraulic systems are prone to blockages;
- Material properties;

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MEMS design criteria:

- In the case of micro-nano structures, frictional forces, capillary, electrostatic, atomic, etc. are significant;
- The heat developed or transmitted in these systems is significant and its dissipation can be problematic;
- Micro-hydraulic systems are prone to blockages due to the very small diameter through which fluids (liquids) must pass;
- The properties of materials must be analyzed at the micro scale.
- MEMS functioning conditions.

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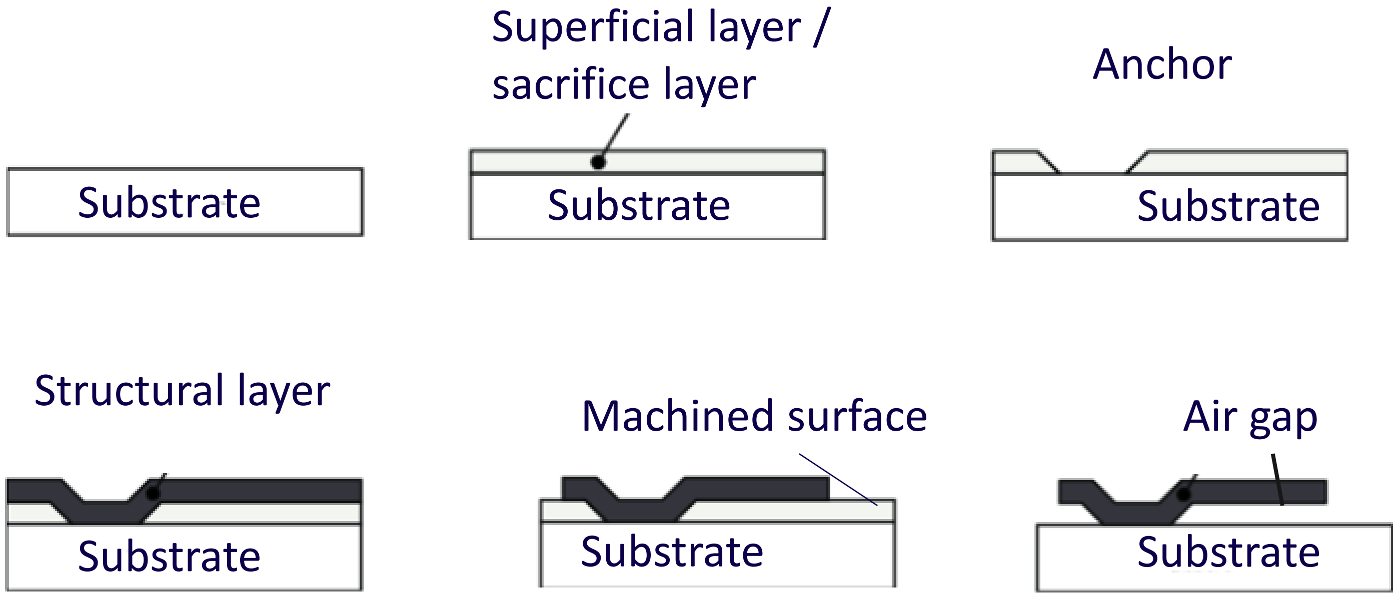
Surface micromachining

Operations/phases:

- a) obtaining a base layer/substrate
- b) deposition of a superficial/sacrificial layer;
- c) creation of a path/pattern;
- d) deposition of the structural;
- e) formation/processing of the layer pattern;
- f) removal of the superficial/sacrificial layer.



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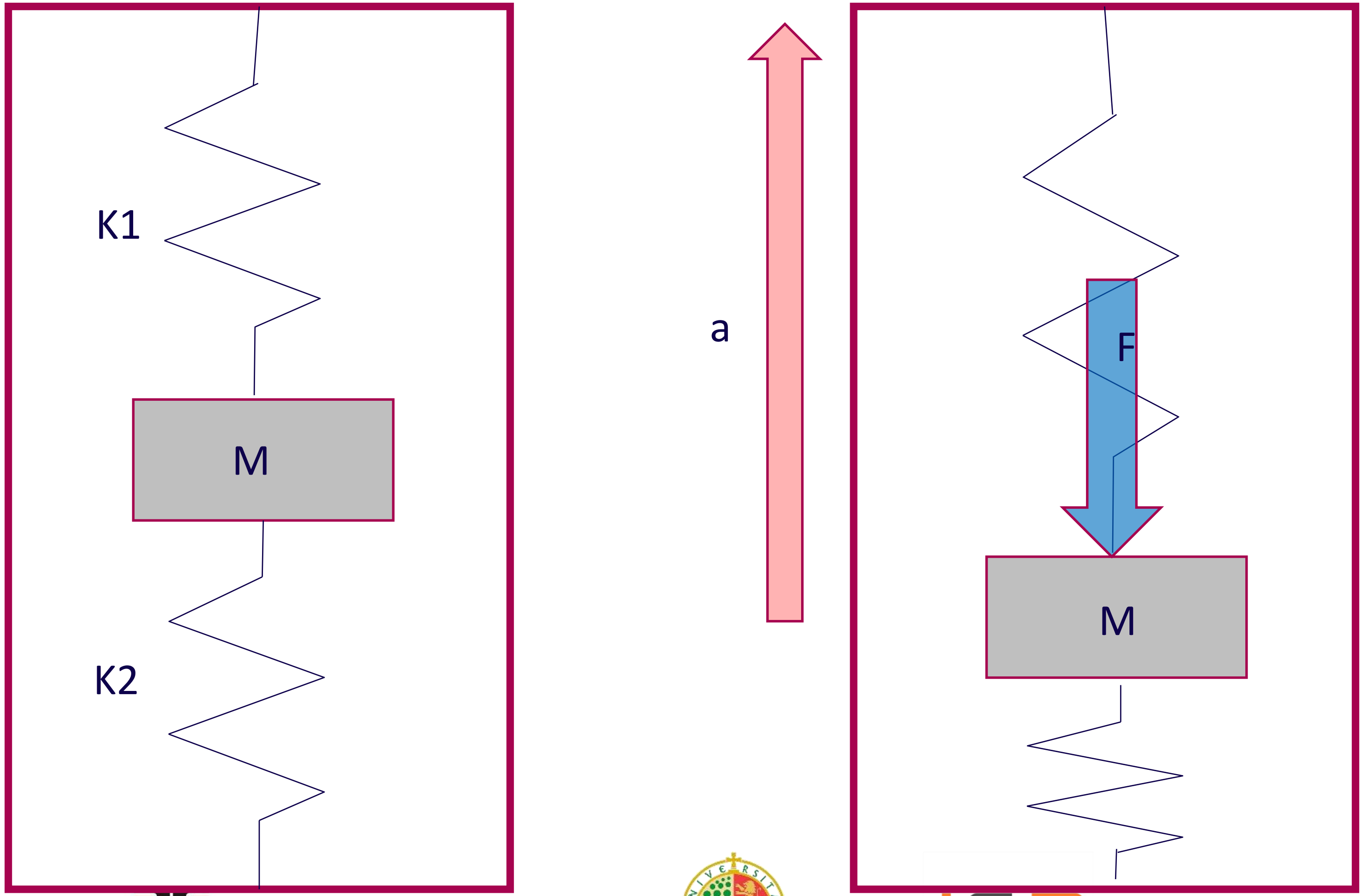
Surface micromachining

Accelerometer principle



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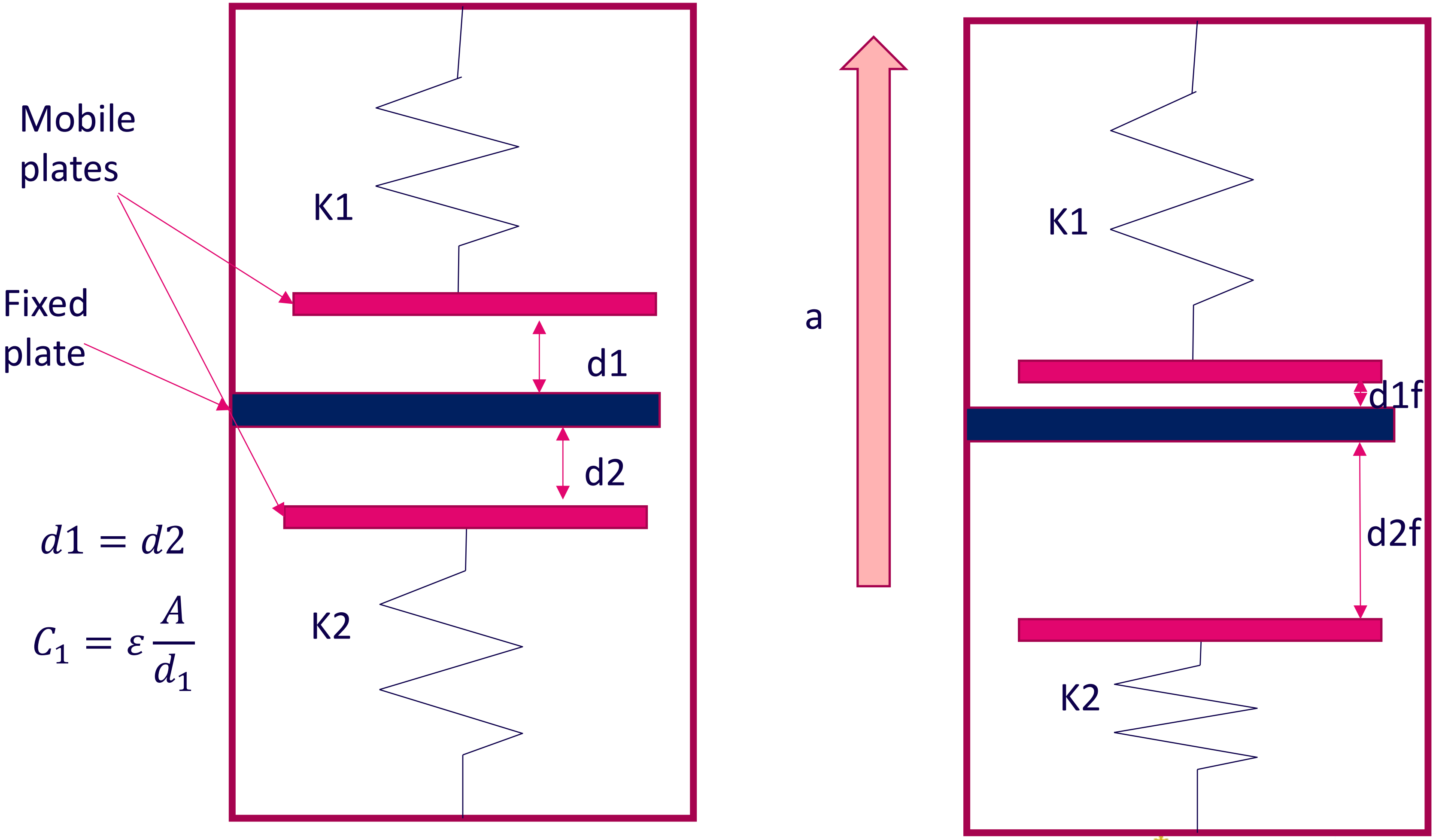
Surface micromachining

Accelerometer principle



$$d1 = d2$$

$$C_1 = \varepsilon \frac{A}{d_1}$$

$$d1 > d2$$

$$C_2 = \varepsilon \frac{A}{d_2}$$

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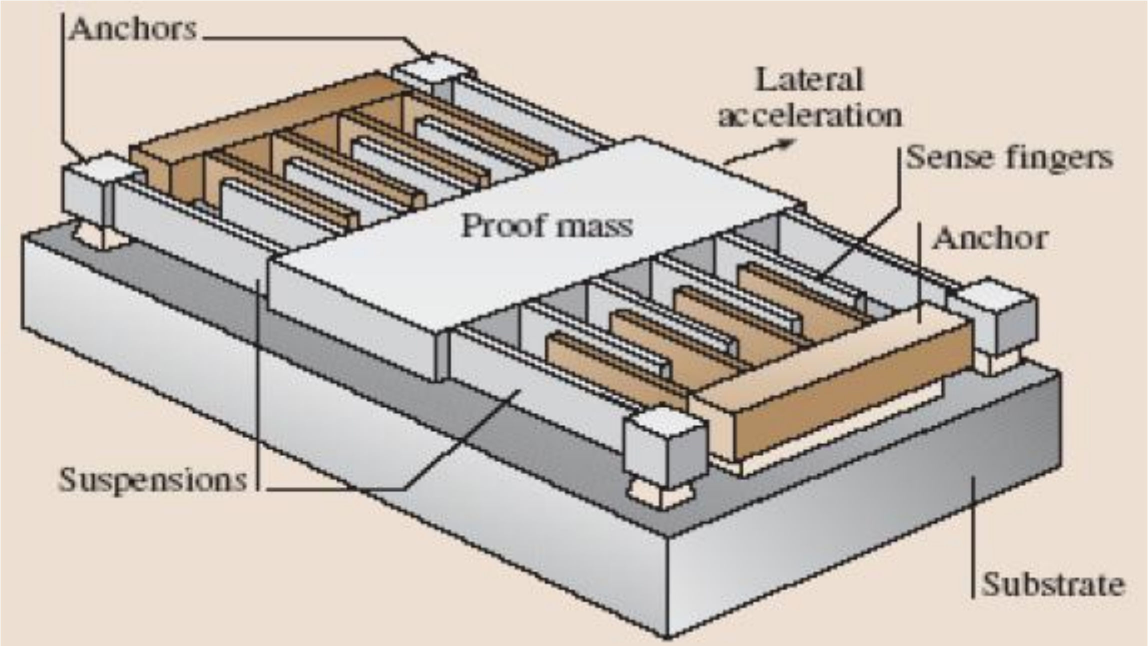
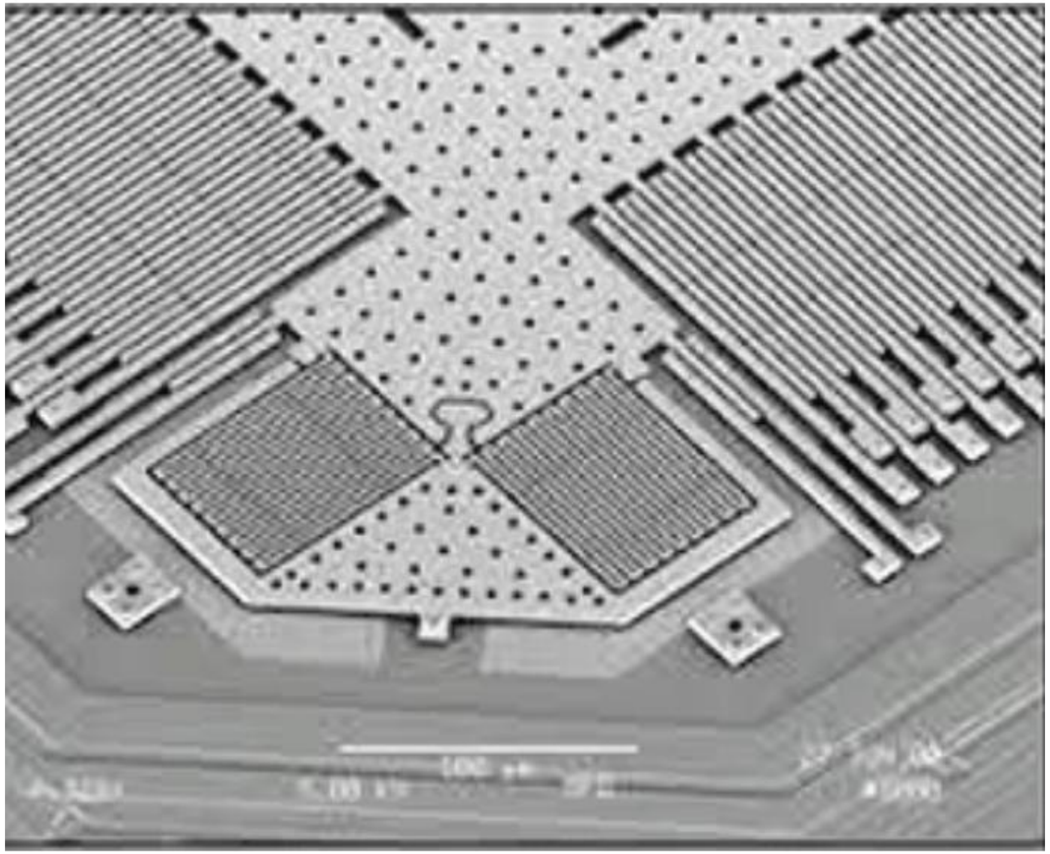
Surface micromachining

MEMS accelerometer

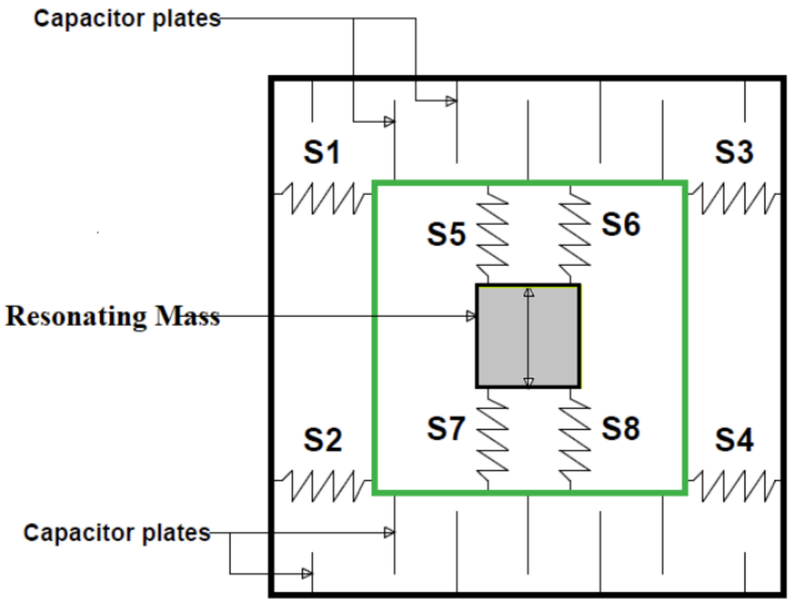




https://circuitdigest.com/tutorial/what-is-mems-various-mems-devices-and-applications

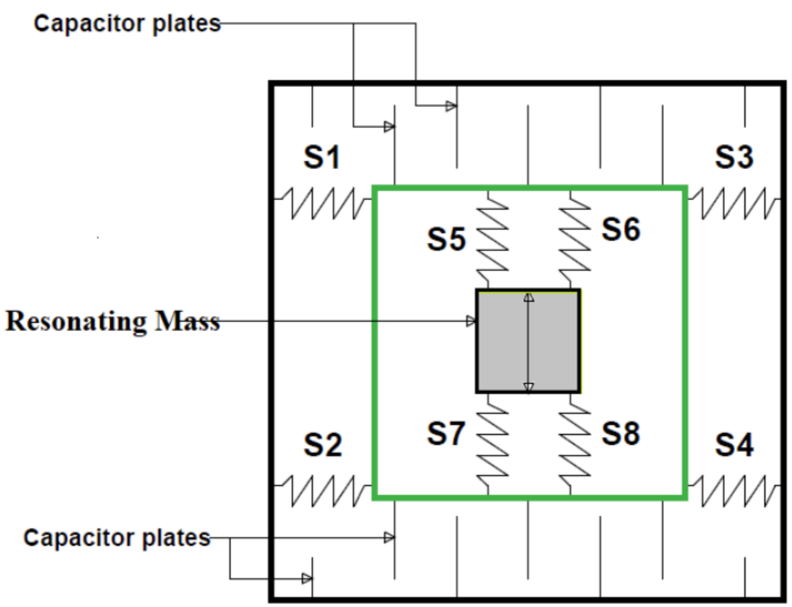
Surface micromachining

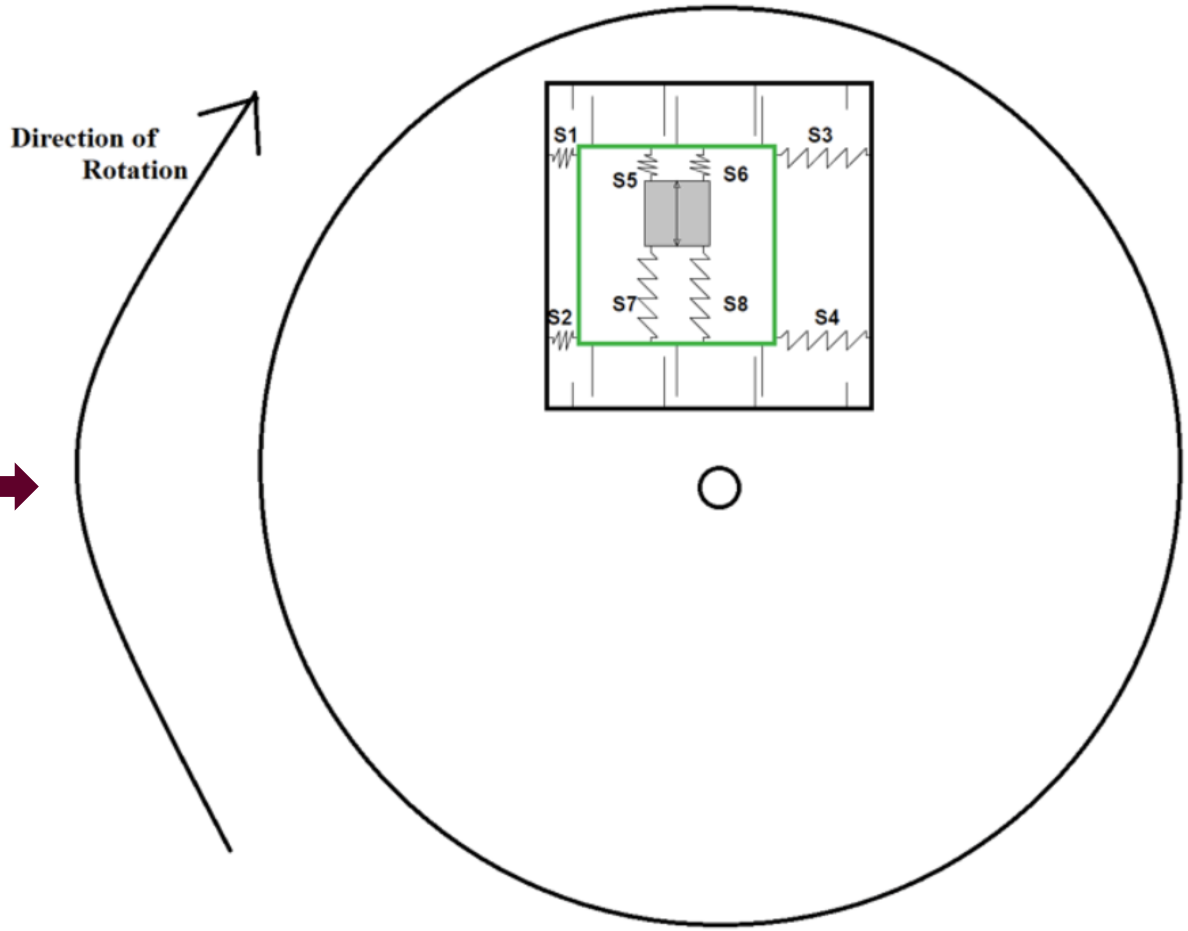
MEMS gyroscope



Surface micromachining

MEMS gyroscope





https://circuitdigest.com/tutorial/what-is-mems-various-mems-devices-and-applications

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Bulk Micromachining

- It involves the processing by corrosion of the basic structure of following operations:

a) - obtaining the base layer / substrate;

b) deposition of silicon dioxide;

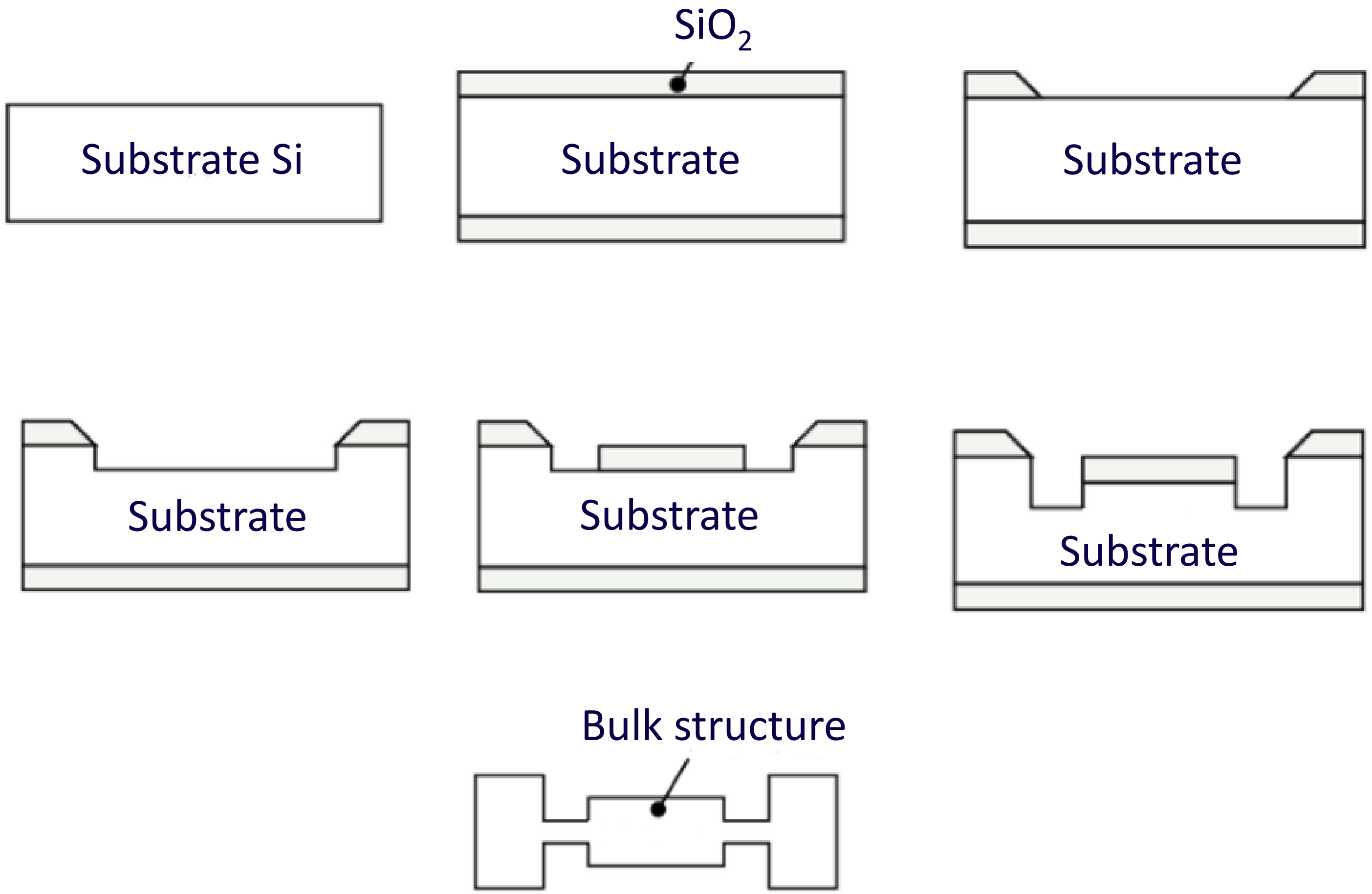
c) patterning (Photoresist + Lythography);

d) etching the base layer;

e) etching the base layer to create structures;

f) repeating steps a) – e);

g) removal of the silicon dioxide layer.



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“Short history of bulk machining”

- Etched armor - Renaissance period - Daniel Hopfer, about 1515-1525, steel, Augsburg - Germany.http://www.vam.ac.uk/content/articles/a/acid-etched-metal-in-renaissance-and-early-modern-europe/

Thin layer deposition

Deposits of thin layers based on physical processes – PVD

Deposits of thin layers based on chemical reactions – CVD;

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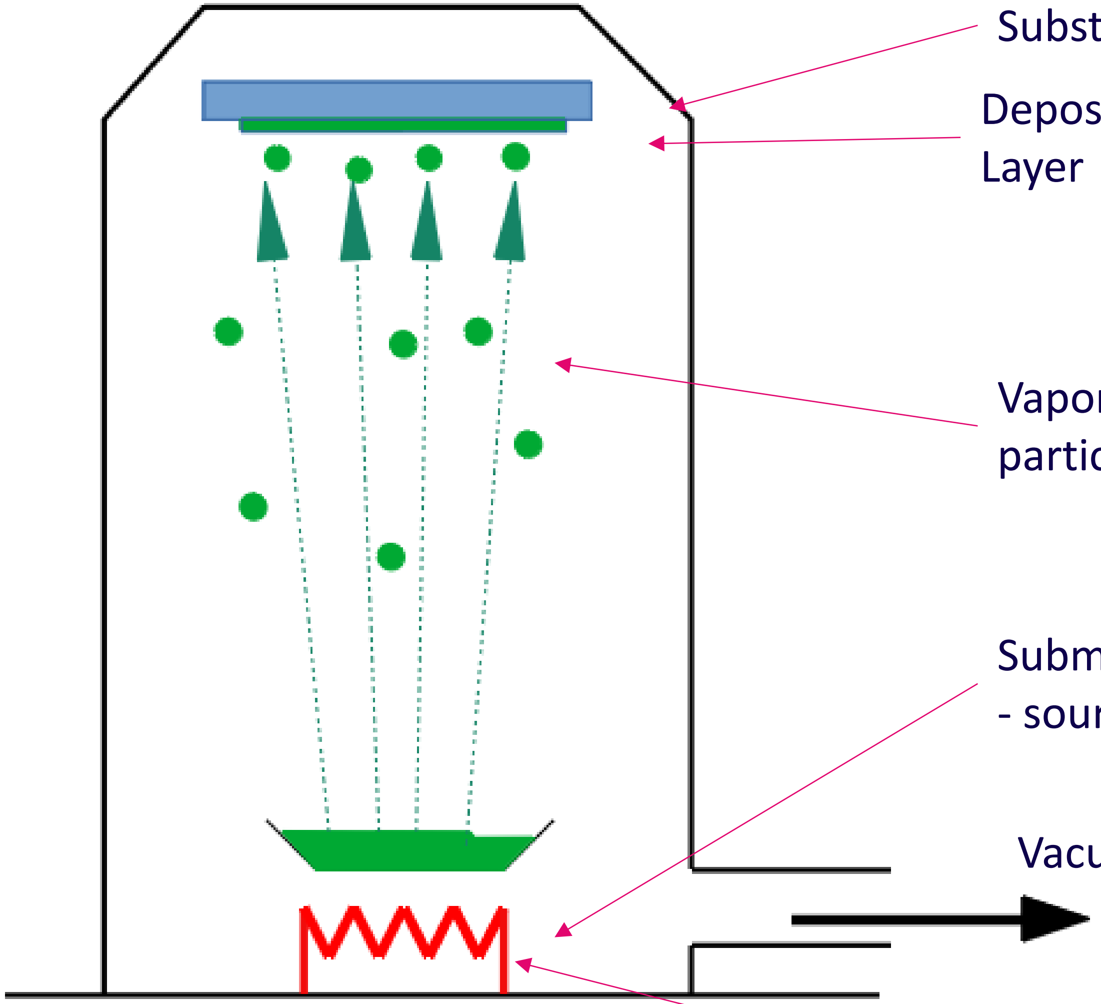
PVD – Phisical Vapor Deposition

- It involves the deposition of materials on a substrate in order to change the surface properties of a part (the number of defects in the surface layer increases.

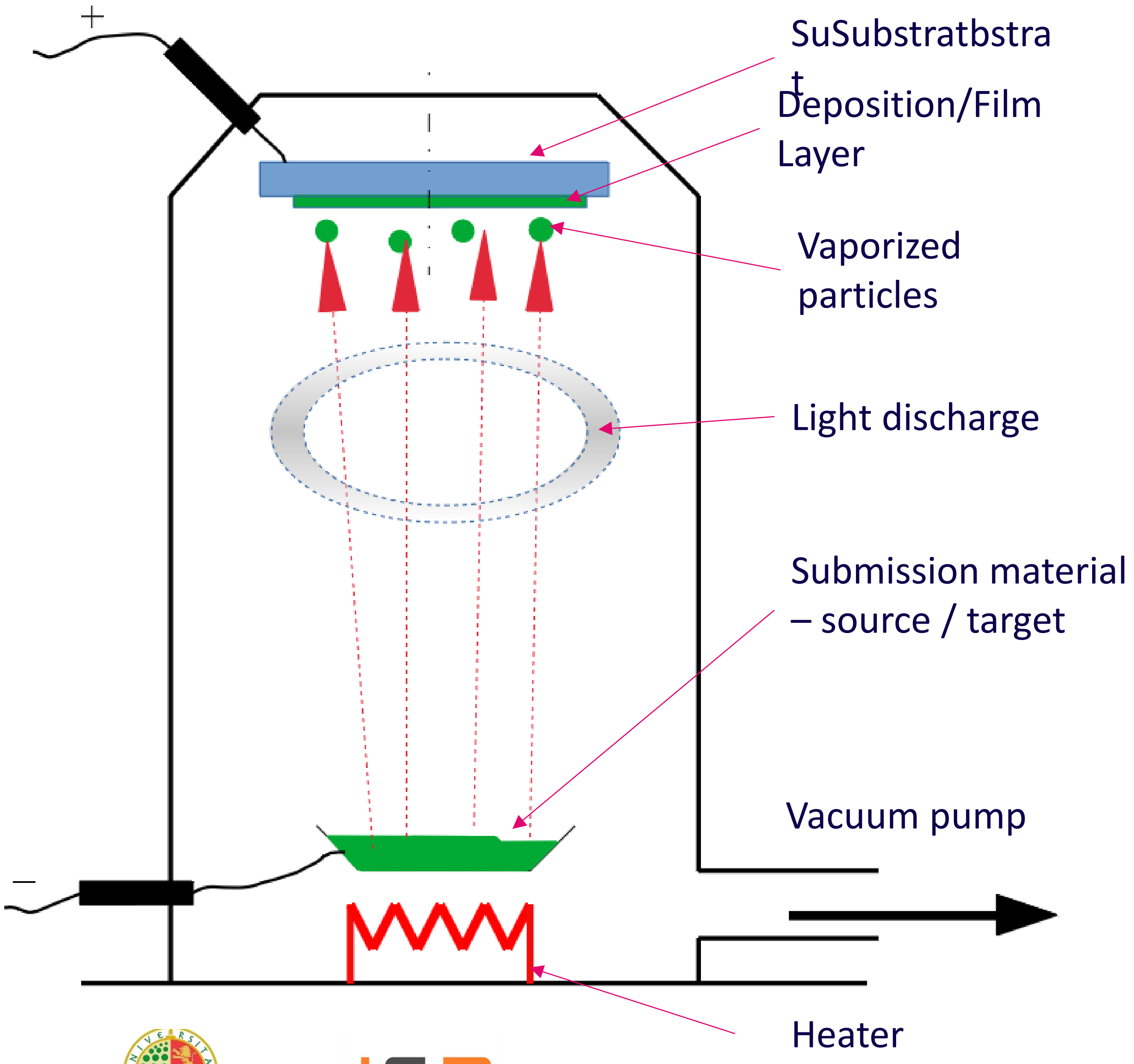
Vacuum Vaporization

- Physical process: transformation of the deposition material into vapor with the help of plasma and then transporting it to the substrate and solidifying it in the form of thin films/deposition layers.

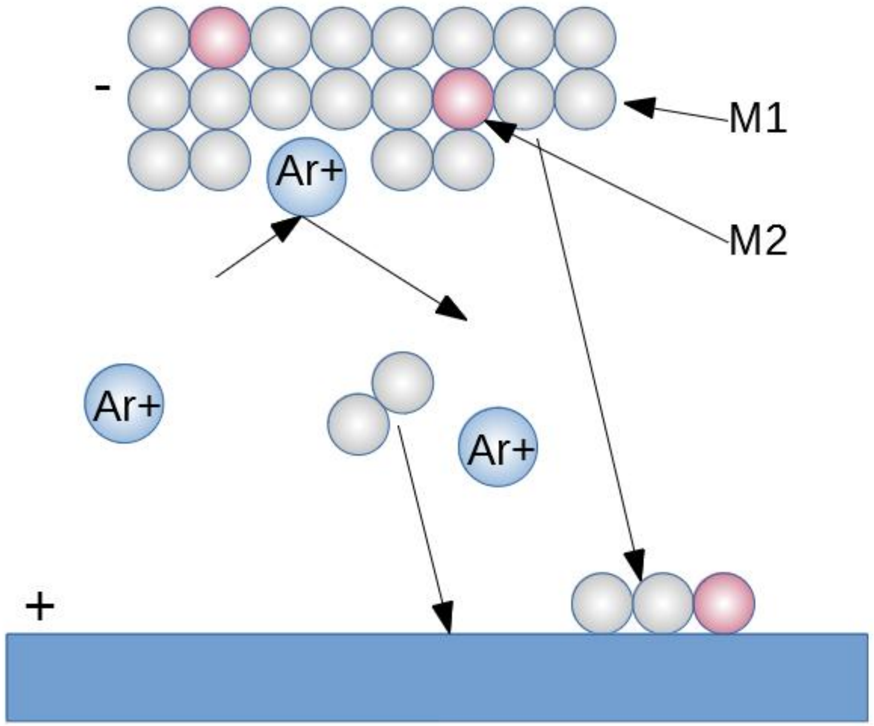


Ion plating PVD

RIP reactive ion plating;
CIP Chemical ions plating;
VIP Vacuum ion plating.

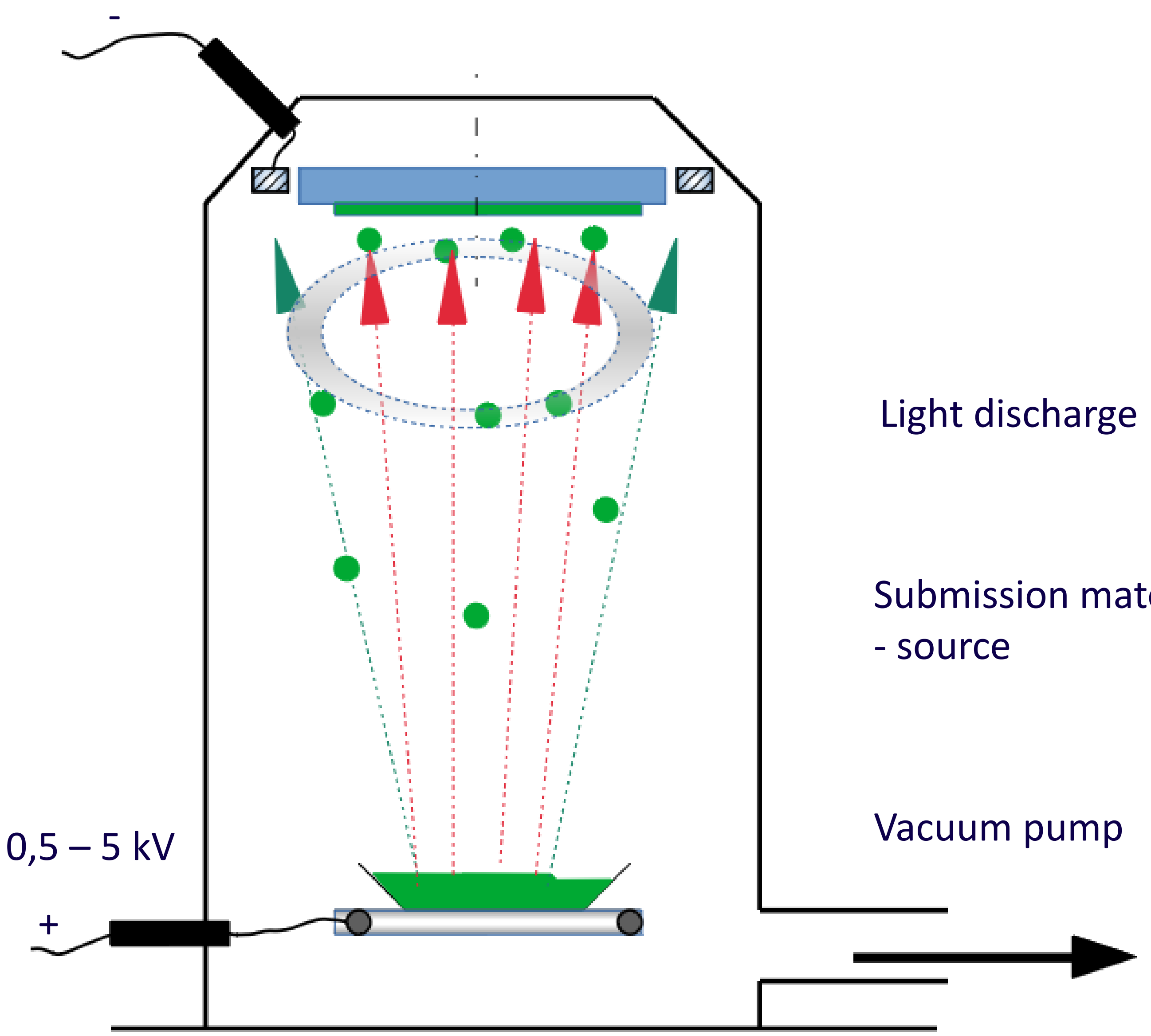


https://www.youtube.com/watch?v=TFCATQ3VbFY



Sputtering

Reactive Sputtering;
Sputtering with diodes;
Sputtering with high energy densities;
Sputtering with magnetron.



Light discharge

Submission material - source

Vacuum pump

- PVD Manufacturing process / technology
- PVD (evaporation and ion plating) – the material is heated by induction, radiation, electron beam or LASER. In the spraying stage, the material with which the coating is made is not melted. Ion bombardment of the materials/cover plates is performed.

https://www.youtube.com/watch?v=9OEz_e9C4KM

- The techniques can be used for direct deposition of material for "reactive" use, in which reaction occurs in the vapor phase (in the form of plasma) between the atoms of the coating material and the reactive gases.
- Usually, the coating temperature does not exceed 200-400^{o}C. Considerably lower than in the case of CVD. In special cases, higher temperatures can also be reached, but only if necessary.
- For uniform coverage, rotation of parts in the installation is practiced. (https://www.youtube.com/watch?v=CK1eic4r73I&ab_channel=GuehringTV)
- The vacuum level is 0.1 – 1 Pa.

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- The maintenance time of the parts in the plasma environment depends on their shape, their number, the type of material to be deposited and the thickness of the layers.
- The deposition rate is generally between 50 and 500 μm/h, depending on the technology.
- The costs are higher than in the case of CVD (usual). However, in some cases they do not exceed 1% of the total production costs of some components.
- It can be applied to a very wide variety of components, including decorative ones (on glass, plastic or even organic materials, corrosion-resistant tubes, coatings resistant to abrasive, corrosive wear, cutting tools.
- From an industrial point of view, it is most often found when covering cutting tools.

https://www.guehring.ro/?page_id=164

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CVD Process

- Basic principle:
- condensation of products obtained from chemical reactions produced between the gases of a reactor;
- Technologies used: - Low Pressure CVD (LPCVD – uniform layers are deposited in terms of thickness and properties but temperatures above 600 ^{0} C and catalyst substances are required;
- Plasma enhancel CVD (PECVD) - the plasma introduced promotes chemical reactions and lower temperatures are required (< 300 ^{0} C);
- Athmospheric pressure CVD APCVD).

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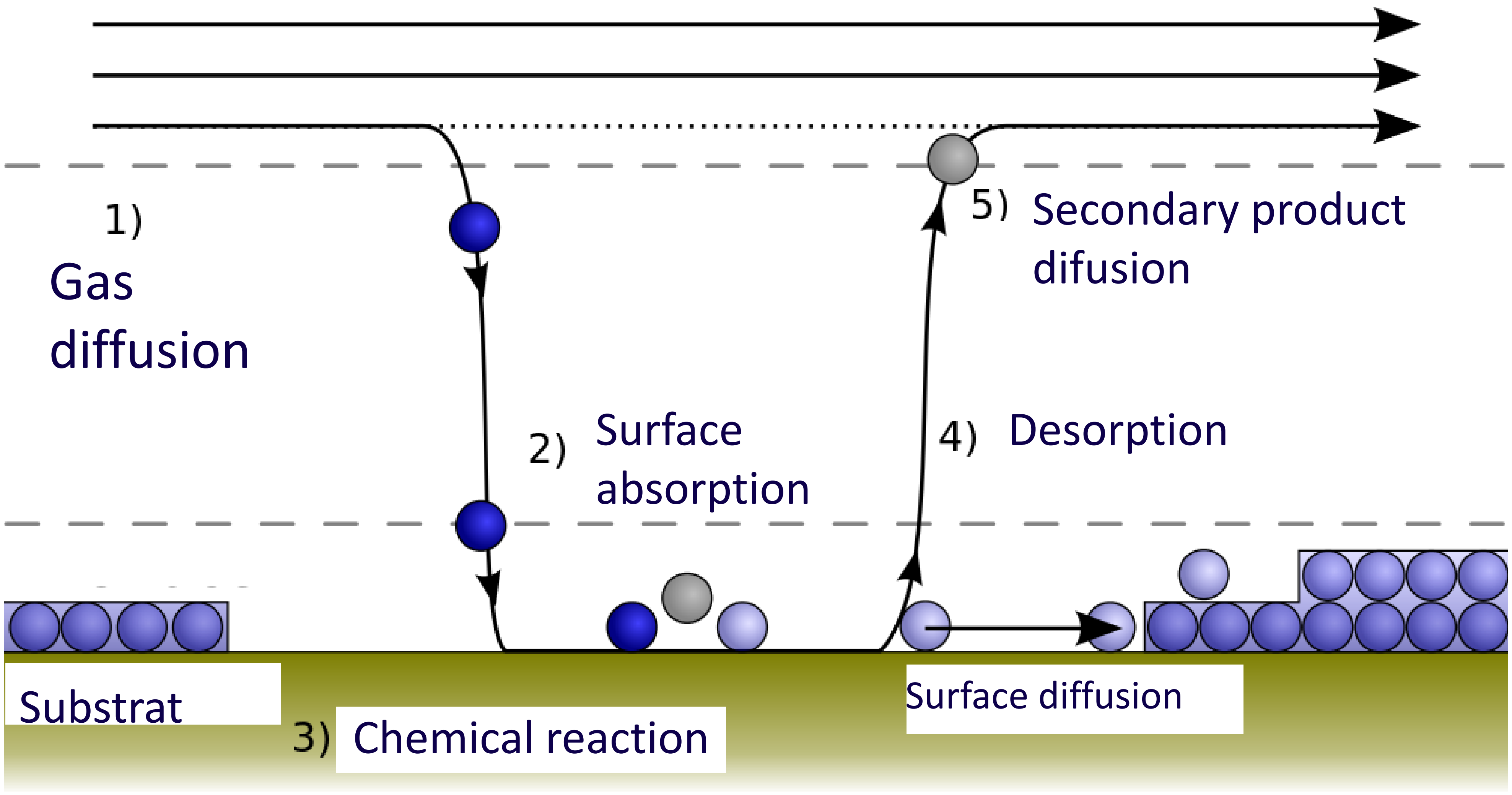
Gas flow through the reactor



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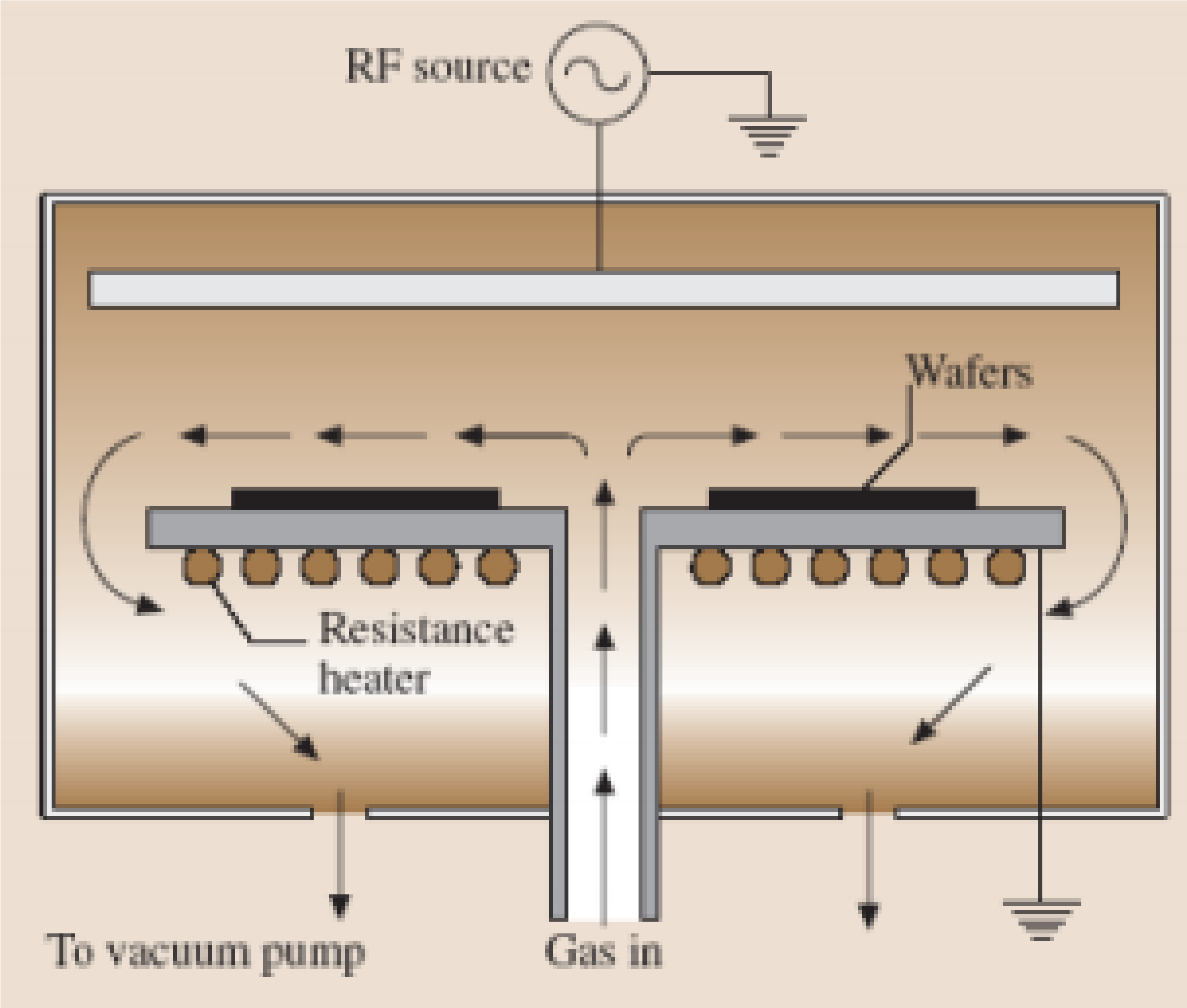
PECVD



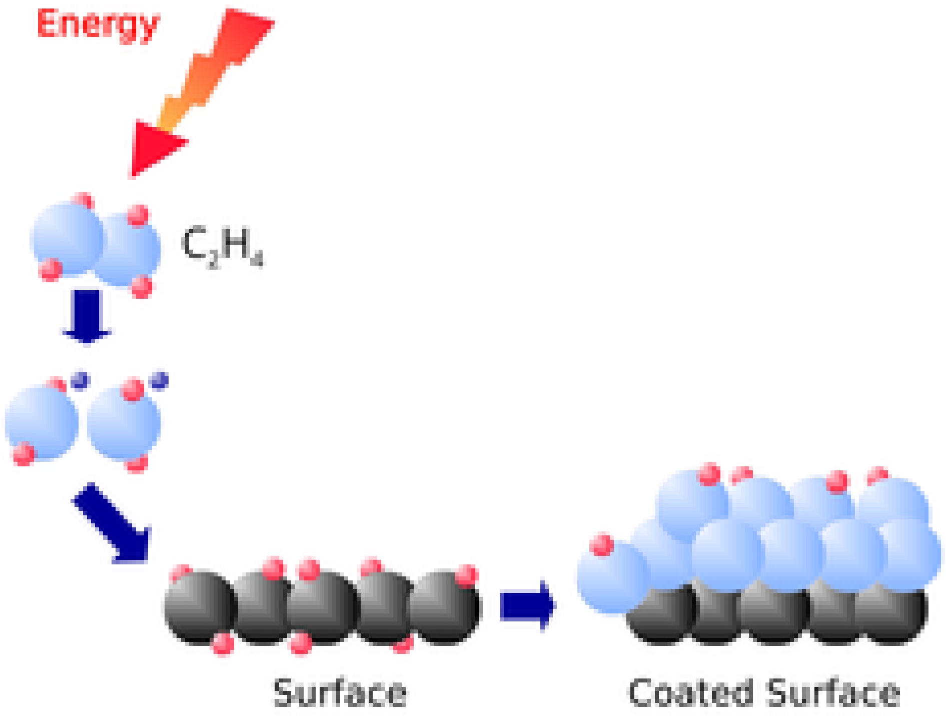
Principle scheme for PECVD [2]

https://mec.tuiasi.ro/diverse/MICROSISTEME%20MECATRONICE.pdf

Use:

- deposition of amorphous silicon and polycrystalline silicon layers;
- the deposition of protective layers;

Dimond like carbon(DLC)



Scheme of the CVD of DLC

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Epitaxy = „Orderly Rise Above”

https://www.asm.com/our-technology-products/epitaxy

- Homoepitaxy - The film and the substrate are made of the same material (e.g. Si pe Si). It is used to improve surface quality or add a pure, flawless coating.
- Heteroepitaxy - The deposited material is different from that of the substrate (e.g. GaN on Si). Used in special MEMS or optical/IR sensors.
- Pseudohomoepitaxy – the deposition and the substrate are the same material but with different dopings.

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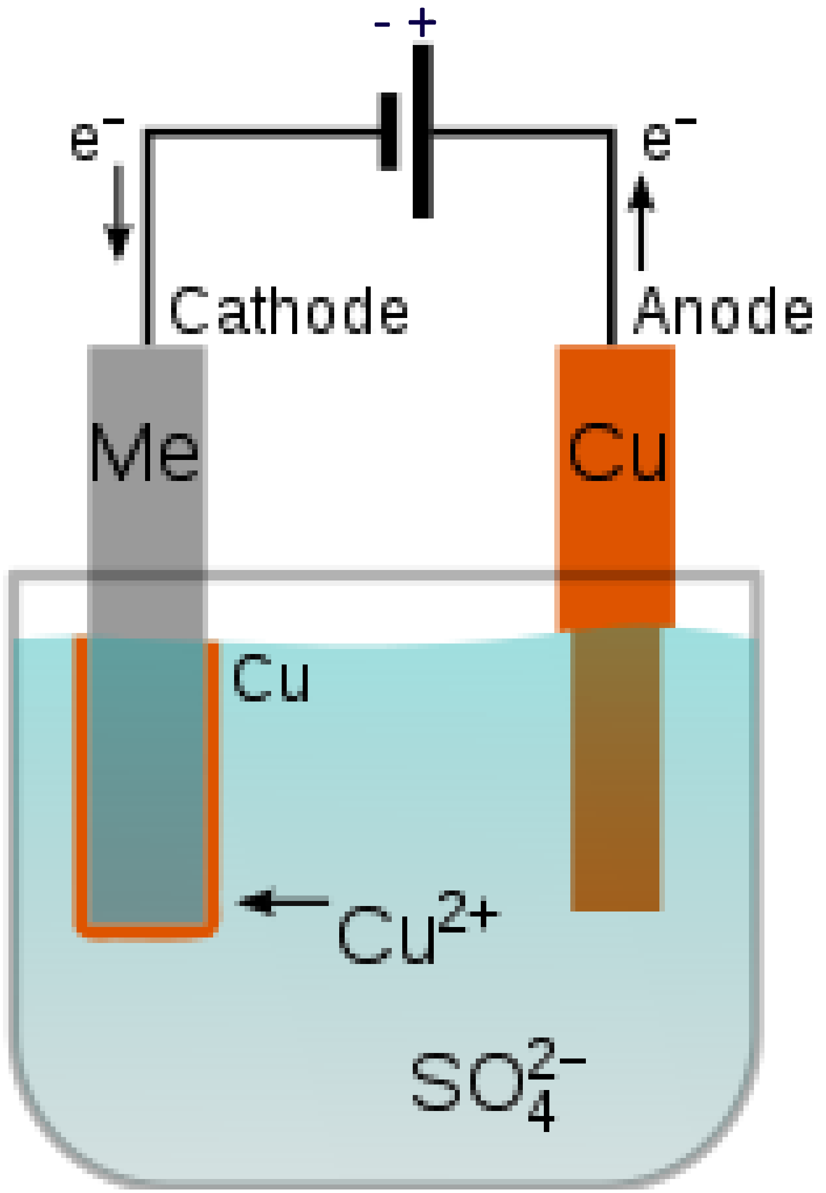
Electroplating

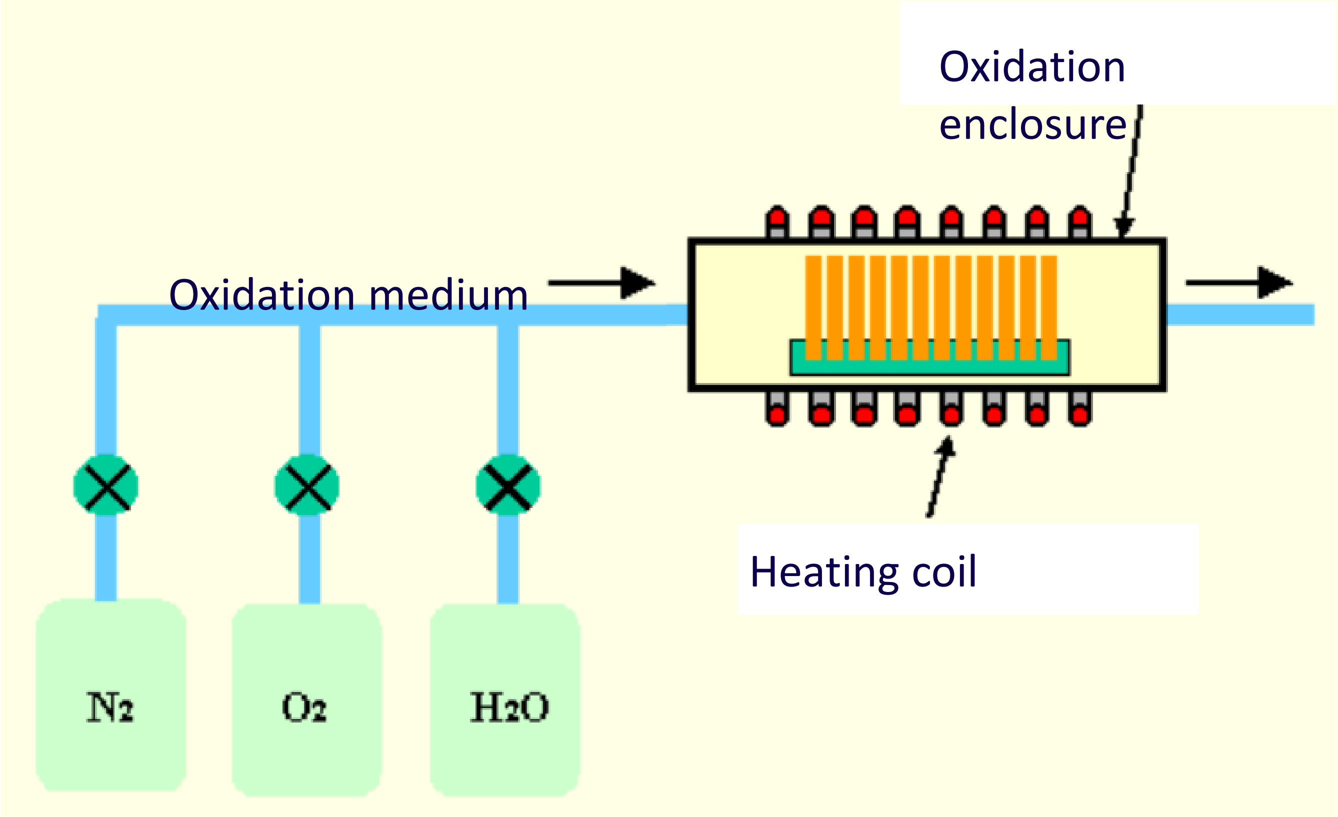
- It applies to electrically conductive materials;
- Chemical processes based on the deposition of thin layers following chemical processes carried out under the influence of the electrical potential between the deposition surface and the electrode (the deposition material).
- Deposition of Au, Cu, Ni, Zn, etc. with thicknesses between 1 and 100 microns



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

Thermal oxidation

- It consists of oxidation of the layer in an oxygen-rich environment at high temperatures (800º -1100ºC)
- Types of oxidation:
- Thermal oxidation with oxygen supply – dry oxidation;
- Thermal oxidation in the presence of oxygen and water vapor – wet oxidation;
- Oxidation in the presence of water vapor (without oxygen supply) – vapor oxidation;
- Electrochemical oxidation – anodic oxidation;
- Oxidation with the help of oxygen in the plasma state – oxidation in plasma;



- Oxidarea termică presupune oxidarea stratului de siliciu superficial dinspre exterior înspre interior:

$$Si_{solid} + O_2 \rightarrow SiO_{2\ solid}$$

$$Si_{solid} + 2H_2O \rightarrow SiO_{2\ solid} + 2H_2$$

- ➢ pentru calități satisfăcătoare ale stratului de oxid de Si, se optează pentru oxidarea termică în mediu O2 sau in vapori de apă.
- ➢ În mediu de oxigen pur, creșterea stratului se face lent dar cu calități bune (din punct de vedere electronic, cu impurități puține);
- ➢ Oxidarea în vapori de apă conține mai multe defecte dar se produce mai rapid (mascare, izolare cu grosimi de strat de ordinul Angström-ilor);
- ➢ Si- se oxidează și în mediul ambiant dar grosimea oxidulu ieste de ordinul 2-3 straturi atomice. Acest strat protejează structura de bază de o continuă oxidare.
- ➢ Pt 1micron de SiO2 este necesar de 0,46 microni de Si.
- ➢ Există posibilitatea apariției diferențelor de nivel pe suprafață în cazul oxidărilor izolate.

https://microelectronique.univ-rennes1.fr/ro/ch7b.htm

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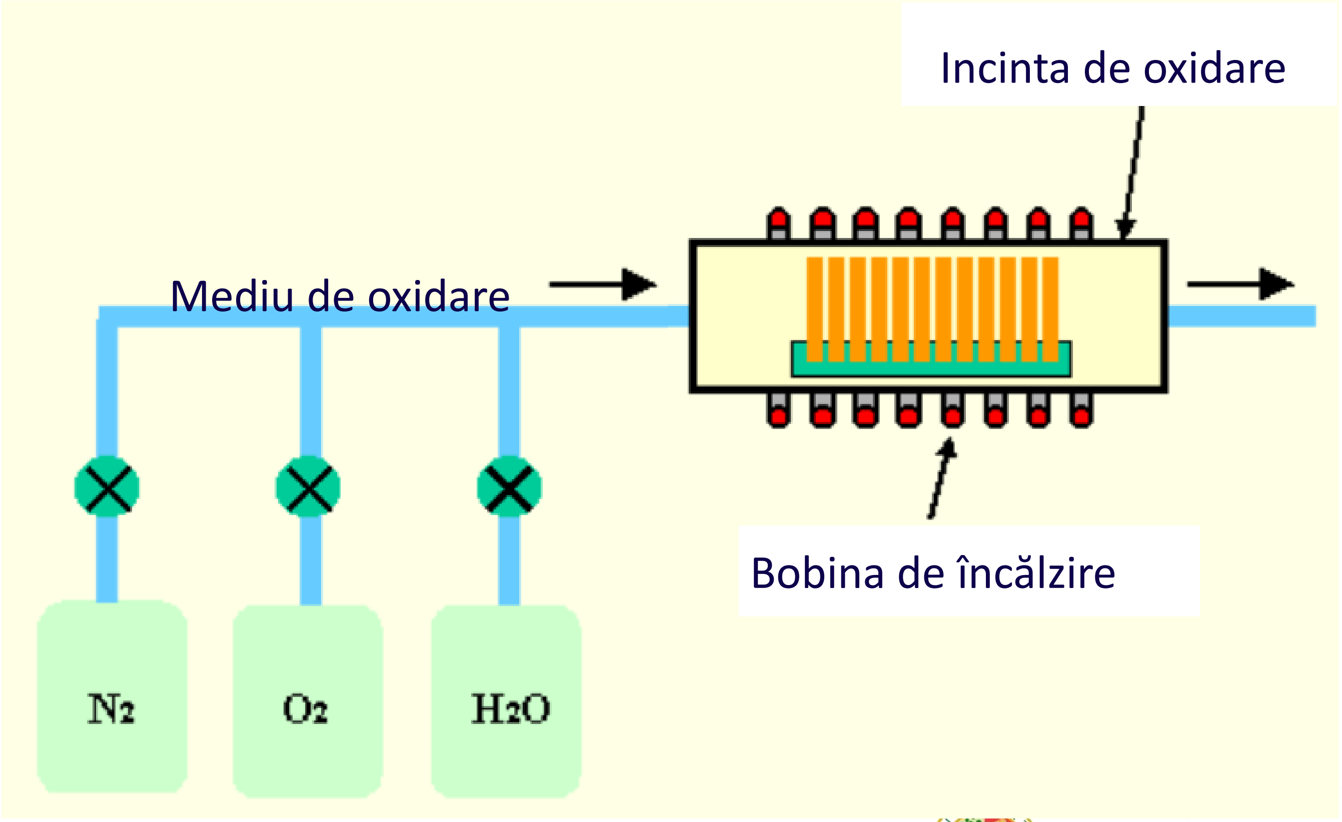
Schema de principiu a instalației de oxidare termică



https://microelectronique.univ-rennes1.fr/ro/ch7b.htm

ETCHING

- Corrosion is the microfabrication process by which, with the help of a chemical reaction, the deposited material is separated from the surface of the plates to obtain the necessary shapes/circuits.
- Substances used:

➢ hydrofluoric acid for corrosion of silicon dioxide; -

➢ phosphoric acid for corrosion of silicon nitride; -

➢ nitric acid + hydrofluoric acid/acetic acid for monooctistalin silicon.

Circuit masking

- *Lithography – the process of transferring the image/drawing/motifs from a template (physical mask) to the plate/plate. (lithos=stone)*
- *The technique allows the localization on the silicon wafer of oxidation, doping, metallization, etc. operations, which are very well defined. Microcircuits can finally be obtained.*
- *The main possible processes: - photolithography / Laser;*
- *- röntgenlithography;*
- *- electrolithography;*
- *- ionolithography;*
- *- UV laser lithography.*

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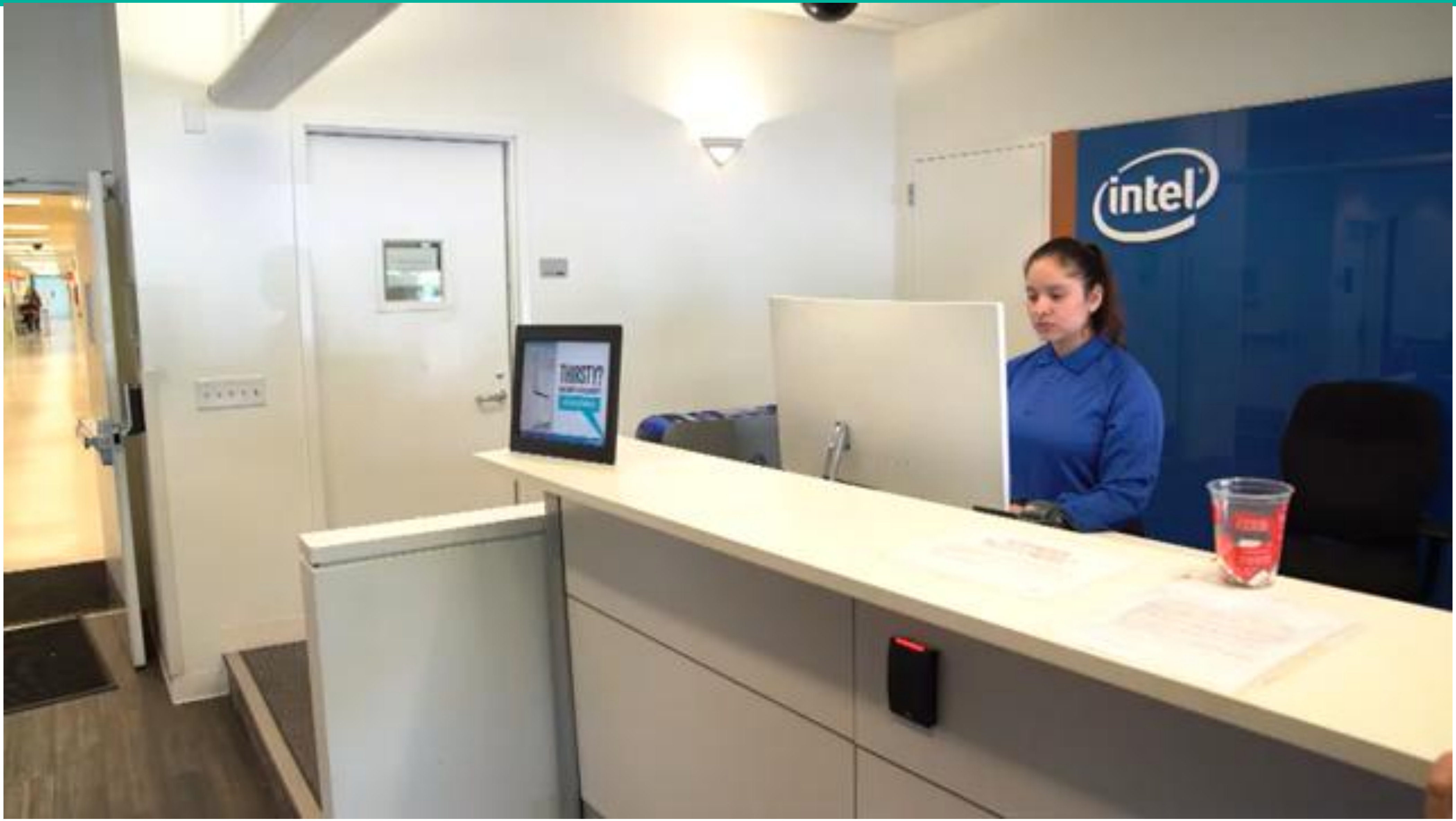
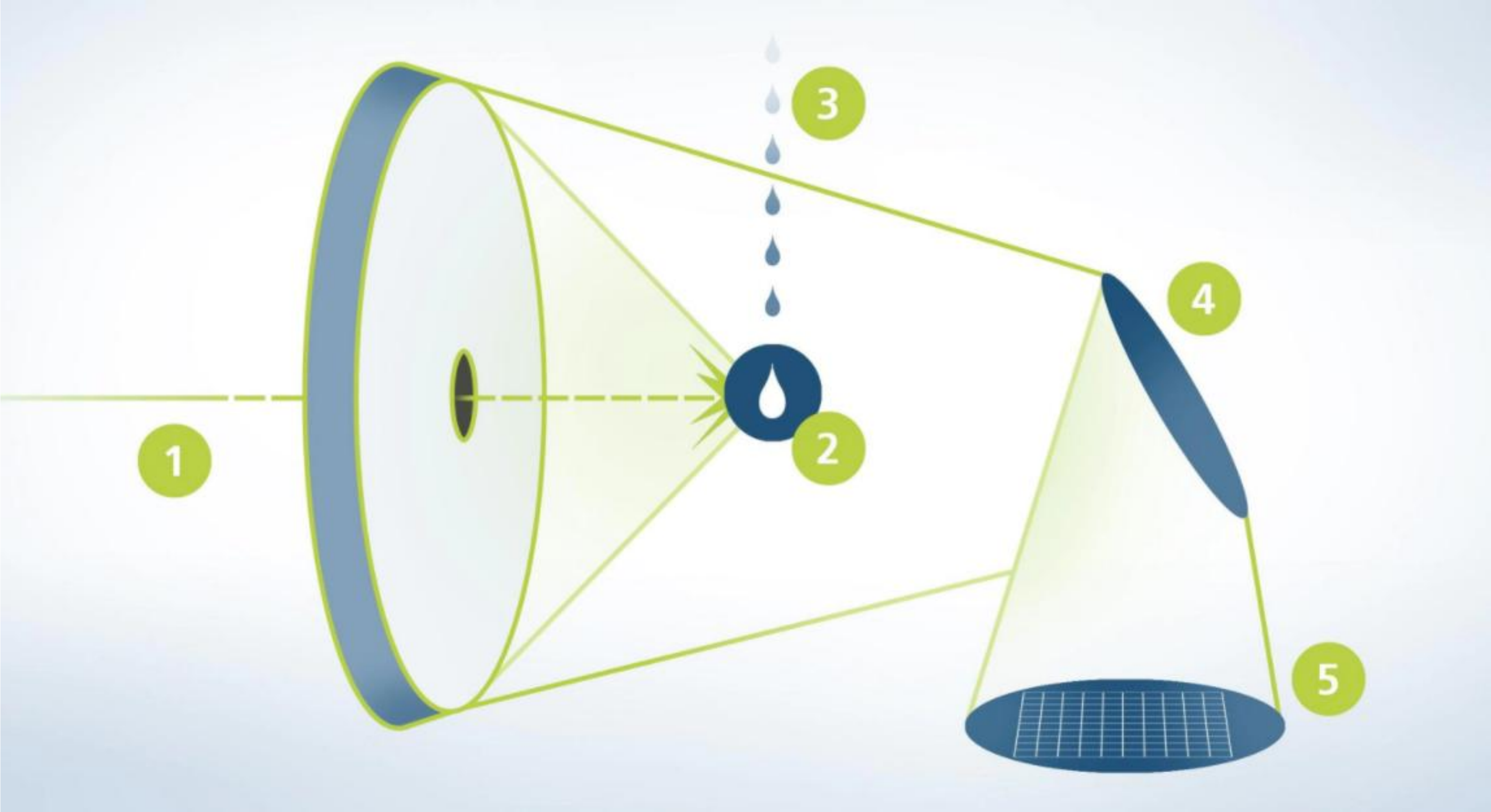
- Photolithography: - is based on chemical reactions between different organic compounds that are activated under the action of radiation. Radiation has a selective character. Light quanta sensitizes only certain molecules in the photoresist varnish, leaving the rest of the molecules intact. – templates are used.
- - mercury vapor lamps (λ=436 nm) are used,
- - new KrF laser systems (λ=248 nm)
- - ArF (λ=248 nm)
- - EUVL – Extreme ultravile lithography (λ=13.5 nm)https://www.youtube.com/watch?v=u3ws0UebnSE&ab_channel=IntelNewsroom



https://www.youtube.com/watch?v=u3ws0UebnSE&ab_channel=IntelNewsroom

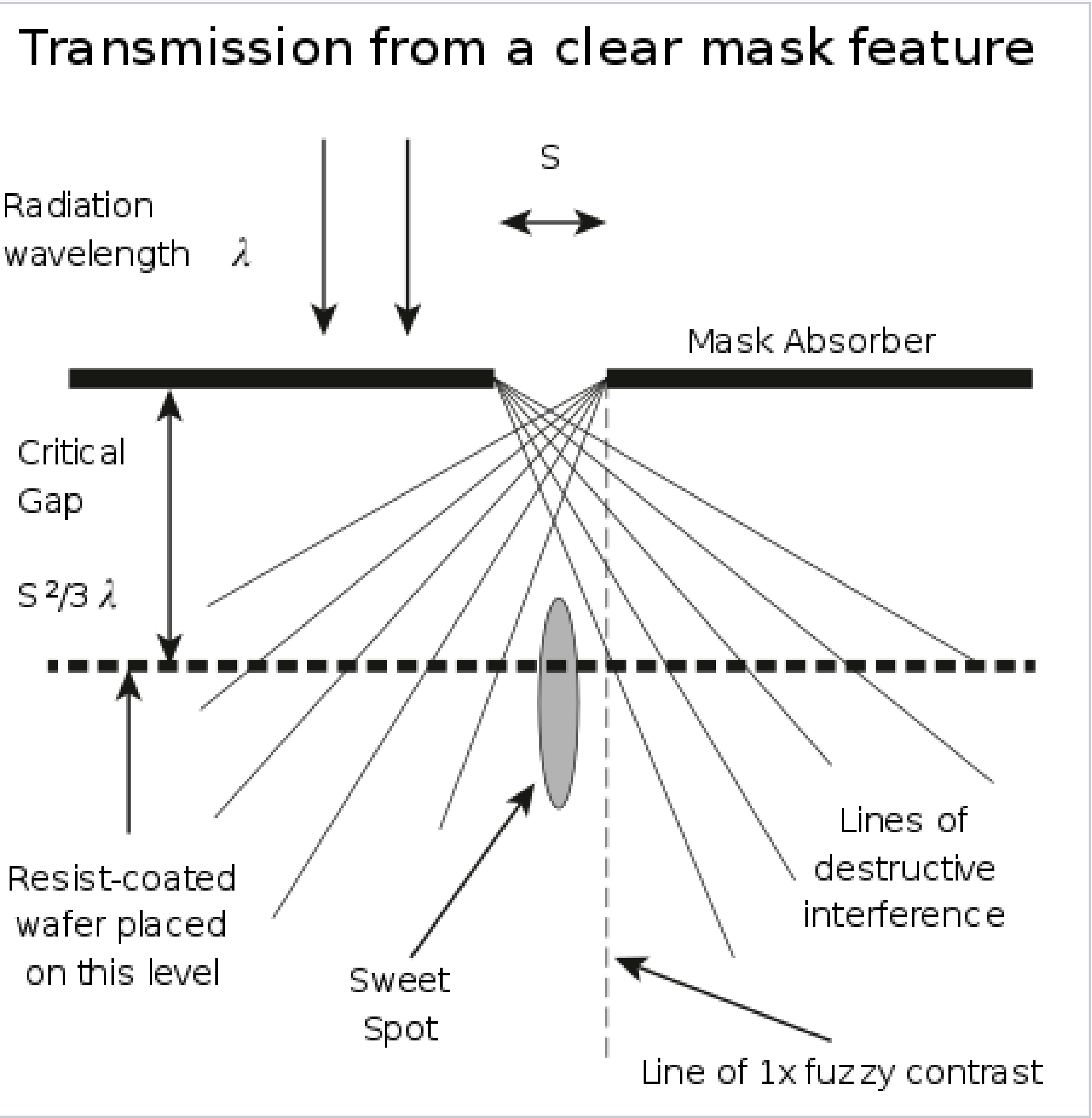
EUVL



EUVL Tumpf

https://www.trumpf.com/ro_RO/solutii/aplicatii/litografia-euv/

X-ray lithography



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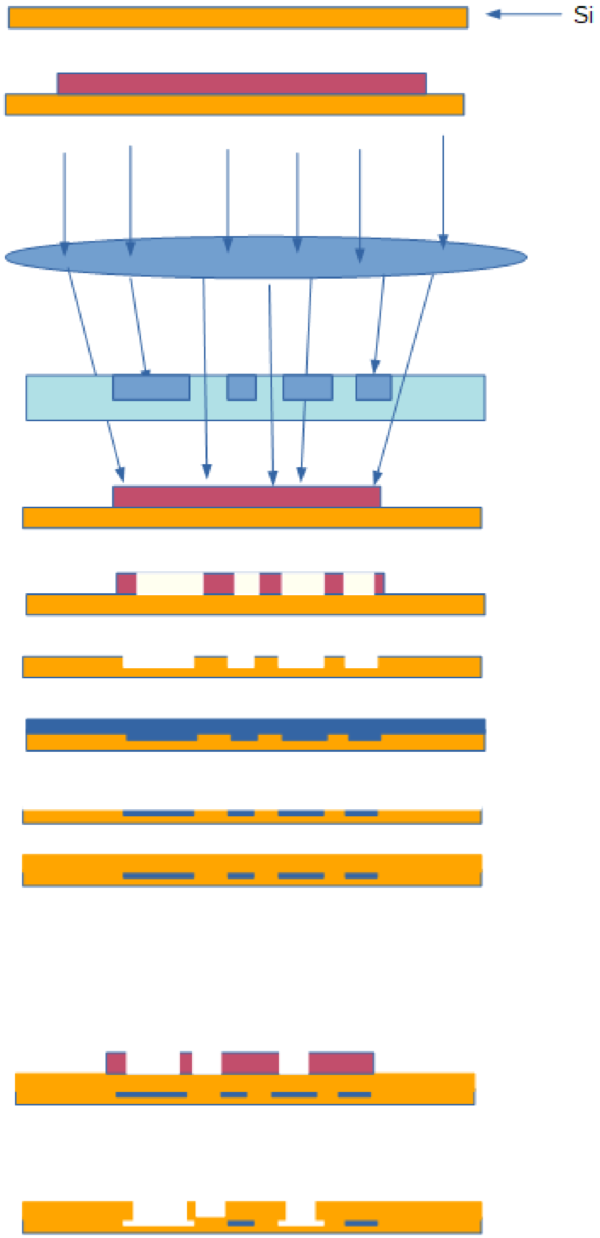


1 – Si plate

2 – deposition of photoresistant material

3 – Selective polymerization

4 – photoresist dissolving

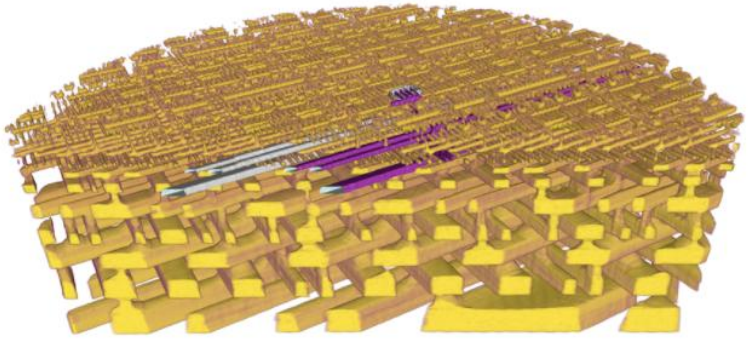
5 – Silicon Corrosion

6 – silicon dioxide deposition

7 – silicon dioxide removal

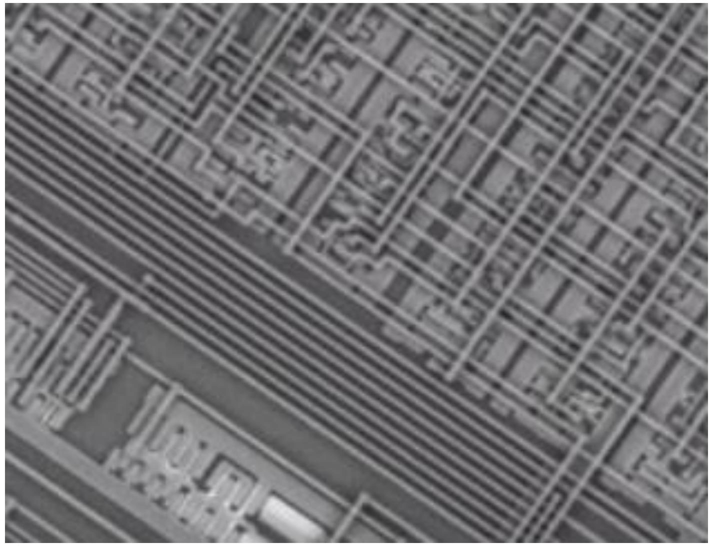
1 – Silicon deposition

2 – 3 - 4



3-D representation of the internal structure of a microchip. Copper circuit connections shown in yellow. The lines shown individually are around 45 nanometres wide. (Photo: Paul Scherrer Institute/Mirko Holler)

https://synchrotron-analysis.ch/application-examples/featured-projects/108-non-destructive-3d-x-ray-imaging-microchips



https://www.extremetech.com/extreme/191996-zoom-into-a-computer-chip-watch-this-video-to-fully-appreciate-just-how-magical-modern-microchips-are

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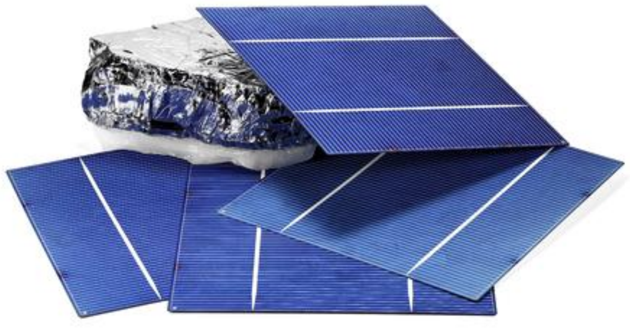
- *Mono-ctistaline silicon – high-quality material used in selective anisotropy electronics (Used in the construction of piezoelectric sensors) – melting temperature 1410 °C;*
- *- density 2.33 g/cm3*
- *yield strength 7·109N/mm2*
- *modulus of elasticity E=1.6·1011N/mm2*
- *Polycrystalline silicon – used for the deposition of sacrificial films for MEMS (surfaces of micro-machines, actuators);*

Sursa: https://www.greenmatch.co.uk/blog/2014/12/how-are-solar-panels-made



Sursa: https://www.123rf.com/photo_65607985_solar-cells-with-polycrystalline-silicon-isolated-on-white-background.html

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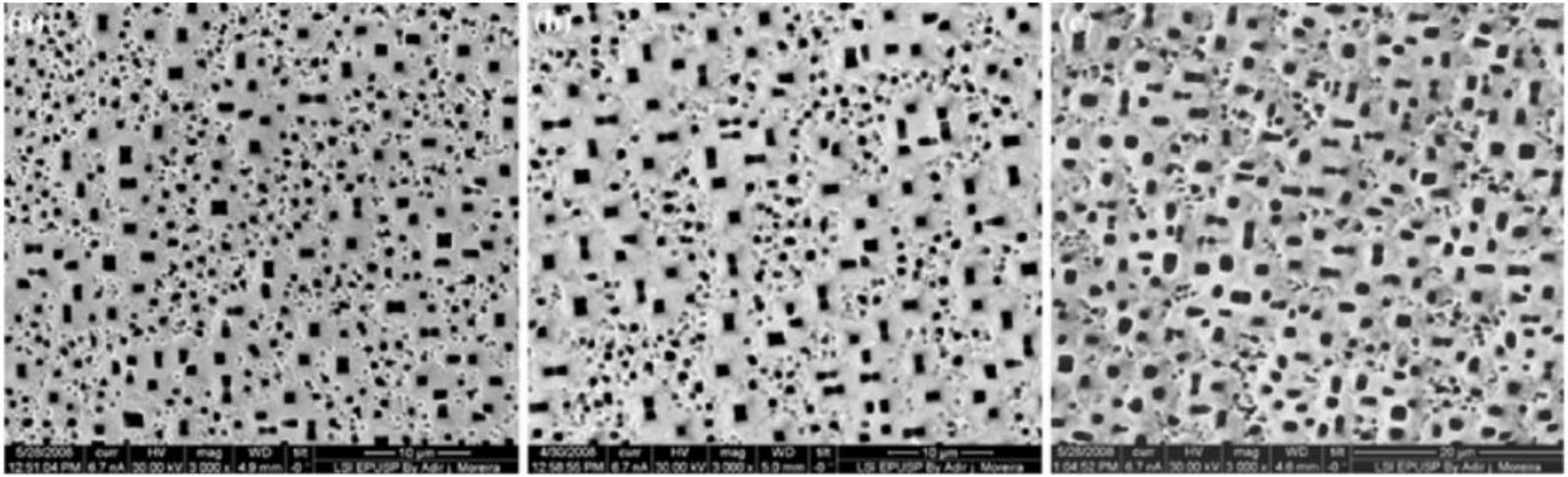
- **Silicon dioxide (SiO_2)** – used to create insular surfaces compatible with polycrystalline silicon (sacrificial layers for making micro-machines, passivation layers);
- **Si nitrates (Si_3N_4, Si_xN_y)** – island surfaces with high chemical resistance;
- **Polycrystalline germanium** - used in MEMS integrated surfaces;
- **Other materials**: Au (electroconductive thin films) – microscopy;
- Nickel-iron – magnetic material (magnetic actuators);
- Titanium-nickel – shape memory (thermal actuators);
- Silicon carbide – electrical and mechanical stability;

Plolicrystalline silicon

- LPCVD Submission Process
- Deposition conditions 580-650 °C
- 100 – 400 mtorr
- $SiH4$ silan atmosphere

https://www.tokuyama.co.jp/eng/products/specialtyproducts/polysilicon.html

Porous Silicone



https://www.researchgate.net/figure/The-SEM-images-of-porous-silicon-structures-obtained-from-the-silicon-wafer-that-was_fig4_257594257

SiO_2

Silicon dioxide (SiO_2) is used as an electrical insulating layer and sacrificial layer in the manufacture of MEMS. It has good chemical resistance, making it ideal for protecting and passivating components. It is compatible with silicon and allows for fine shaping by corrosion. It is also used for thermal insulation or lithography.

- Sursa: http://ro.swewe.net/word_show.htm/?52810_1&Dioxid_de_siliciu

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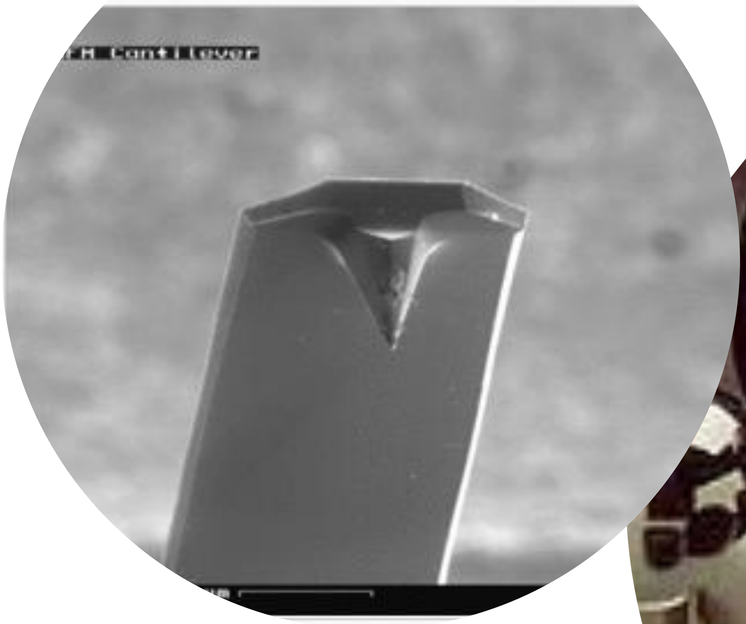
Si nitride(Si_3N_4)



- Temodynamic stable material
- Used in the automotive industry (engine construction)
- Chemical barrier for integrated circuits

- https://en.wikipedia.org/wiki/Silicon_nitride

Polycrystalline Germanium

- Used as a sacrificial layer
- Opice components in the manufacture of infrared lasers.

https://ro.honoroptics.com/high-quality-chinese-infrared-germanium-lenses/

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https://mec.tuiasi.ro/diverse/MICROSISTEME%20MECATRONICE.pdf;

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https://terpconnect.umd.edu/~sandborn/research/JPL_MEMS/microeng_bulk.html;

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[3] Tarek I. Zohdi, Modeling and Simulation of Functionalized Materials for Additive Manufacturing and 3D Printing: Continuous and Discrete Media, ISSN 1613-7736, Springer International Publishing AG 2018;

[4] Roland Lachmayer, Rene Bastian Lipper, tThomas Fahlbusch Hrsg., 3D-Druck beleuchtet, Additive Manufacturing auf dem Weg in die Anwendung, DOI 10.1007/978-3-662-49056-3, Springer-Verlag Berlin Heidelberg 2016;

[5] Jiayun Shao, Arash Samaei, Tianju Xue, Xiaoyu Xie, Shengmin Guo, Jian Cao, Additive friction stir deposition of metallic materials: Process, structure and properties, Materials & Design, 234 (2023) 112356, https://doi.org/10.1016/j.matdes.2023.112356

[6] Li Yang, Keng Hsu, Brian Baughman, Donald Godfrey, Francisco Medina, Mamballykalathil Menon,Soeren Wiener, Additive Manufacturing of Metals: The Technology, Materials, Design and Production, ISSN 1860-5168 ISSN 2196-1735 (electronic) Springer Series in Advanced Manufacturing ISBN 978-3-319-55127-2, ISBN 978-3-319-55128-9 (eBook), DOI 10.1007/978-3-319-55128-9, Springer International Publishing AG 2017;

[7] Hans Albert Richard, Britta Schramm, Thomas Zipsner, Additive Fertigung von Bauteilen und Strukturen, ISBN 978-3-658-17779-9 ISBN 978-3-658-17780-5 (eBook), DOI 10.1007/978-3-658-17780-5, Springer Fachmedien Wiesbaden GmbH 2017.

https://mec.tuiasi.ro/diverse/MICROSISTEME%20MECATRONICE.pdf;

https://terpconnect.umd.edu/~sandborn/research/JPL_MEMS/microeng_surface.html;

https://terpconnect.umd.edu/~sandborn/research/JPL_MEMS/microeng_bulk.html;

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M3 – Design for Additive Manufacturing (DfAM)

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Additive Manufacturing

”3D-Printing”

- Informally known as 3D-Printing
- In industrial and professional context, Additive Manufacturing

[Reprap]

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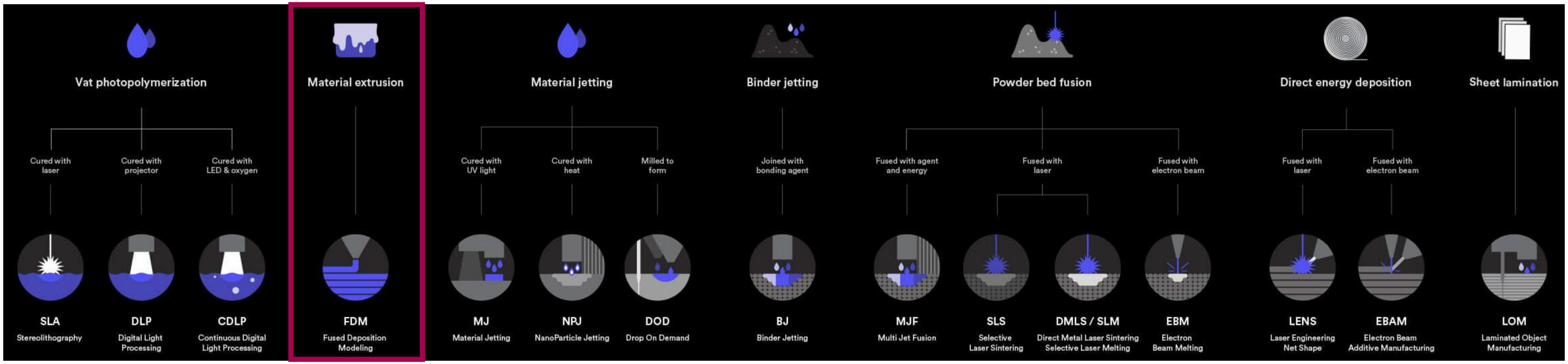
Additive Manufacturing

AM-methods and technologies



[hubs]

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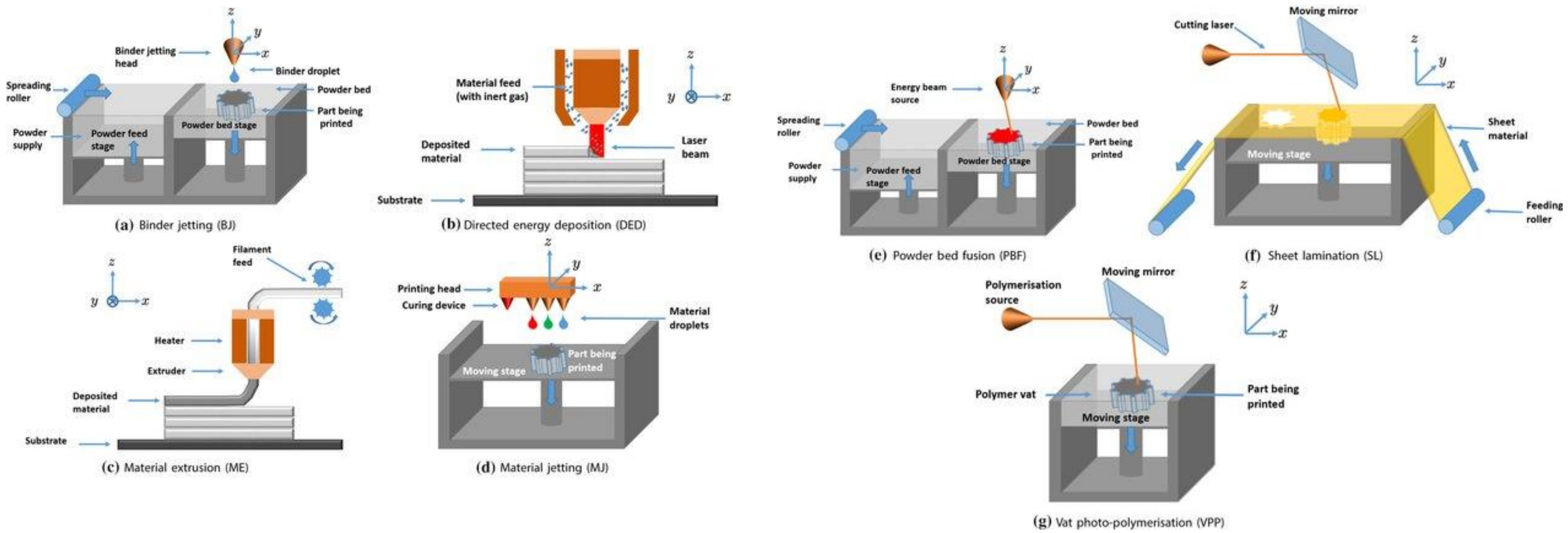
Additive Manufacturing

AM-methods according to ISO/ASTM 52900:2021

- Binder Jetting
- Direct Energy Deposition
- Material Extrusion
- Material Jetting
- Powder bed fusion
- Sheet Lamination
- Vat photopolymerization

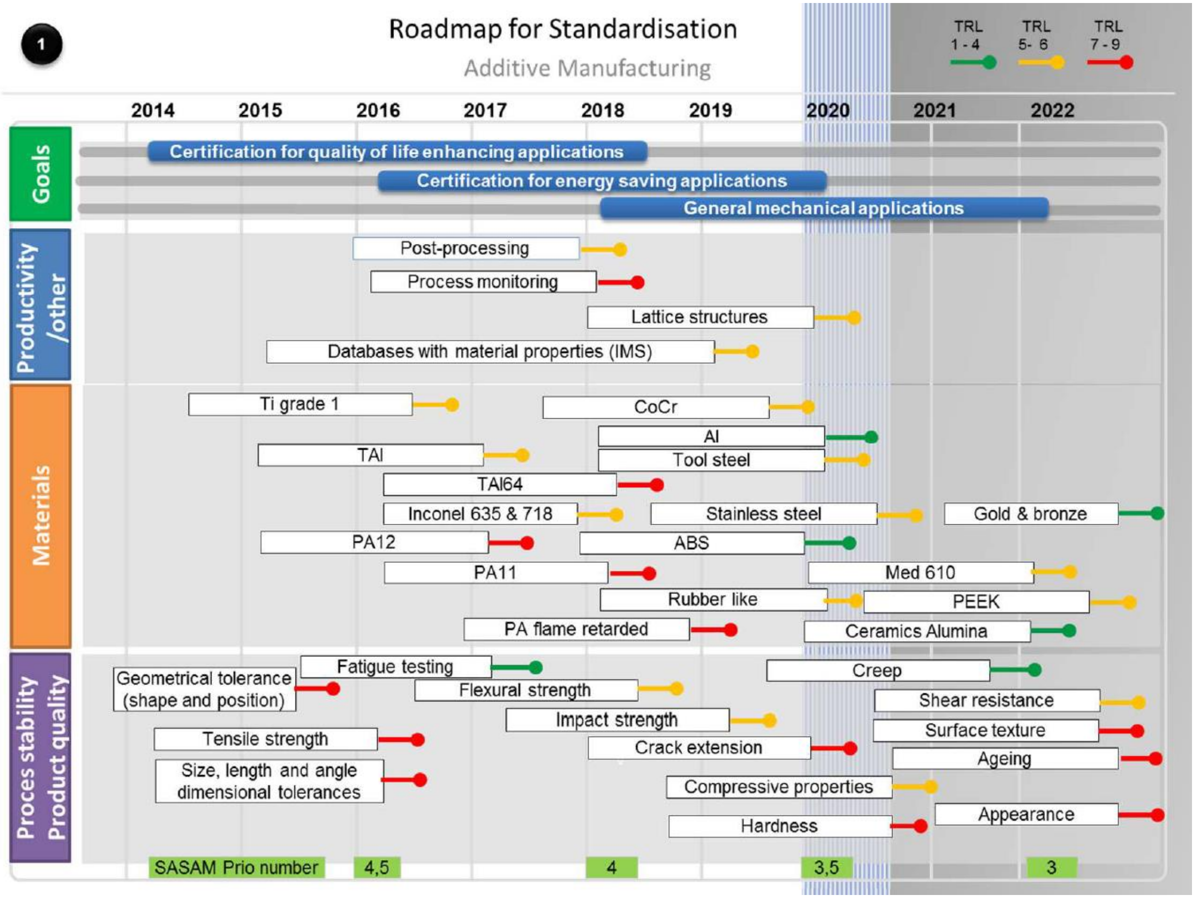


[ResearchGate]

Standardization

ISO/ASTM 52900:2021

- Standardization for the methods is basically ready and has been mostly done in the last 10 years
- Focus today is on applications and materials
- Indicates a maturity of the technologies



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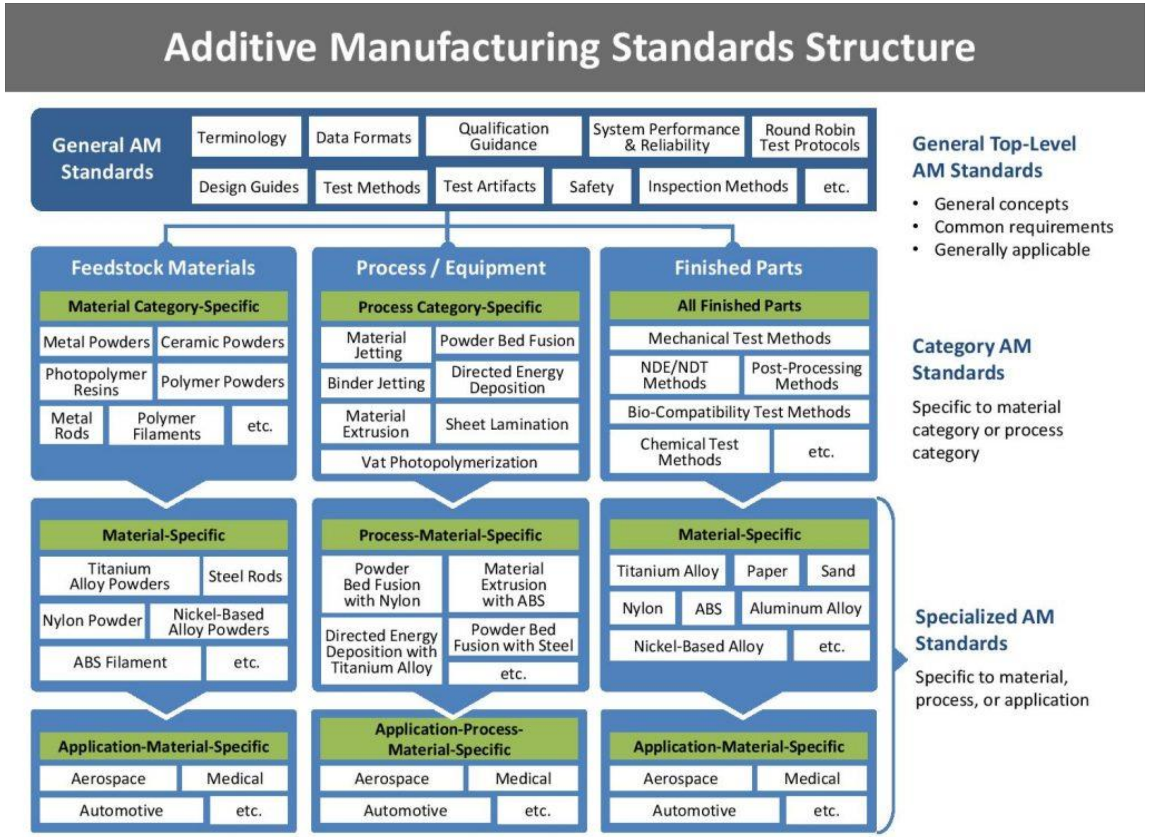

[3D Printing Industry]

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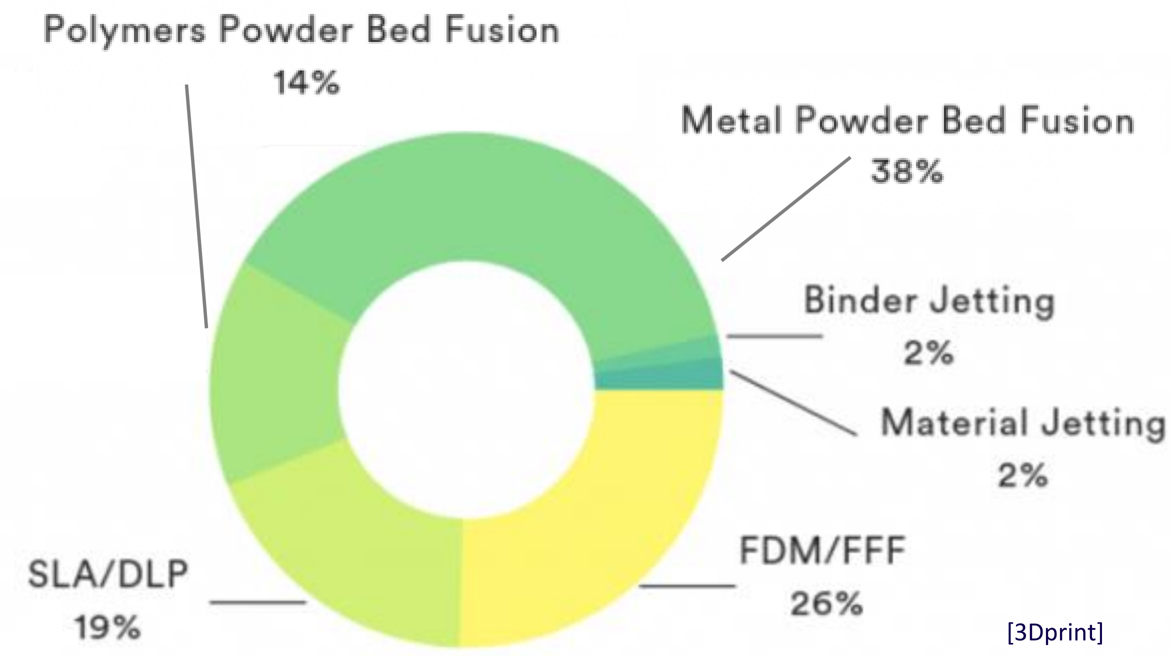
Additive Manufacturing

Materials – Industrial and Professional use

- Plastics, resins and rubber-like materials are widely used
- Metal printing is on the rise and incresing quickly
  - Steels, inconel, aluminium, titanium
- Plenty of other material can be 3d-printed
  - Composites, ceramics, concrete, paper, human tissue…



[3Dprint]

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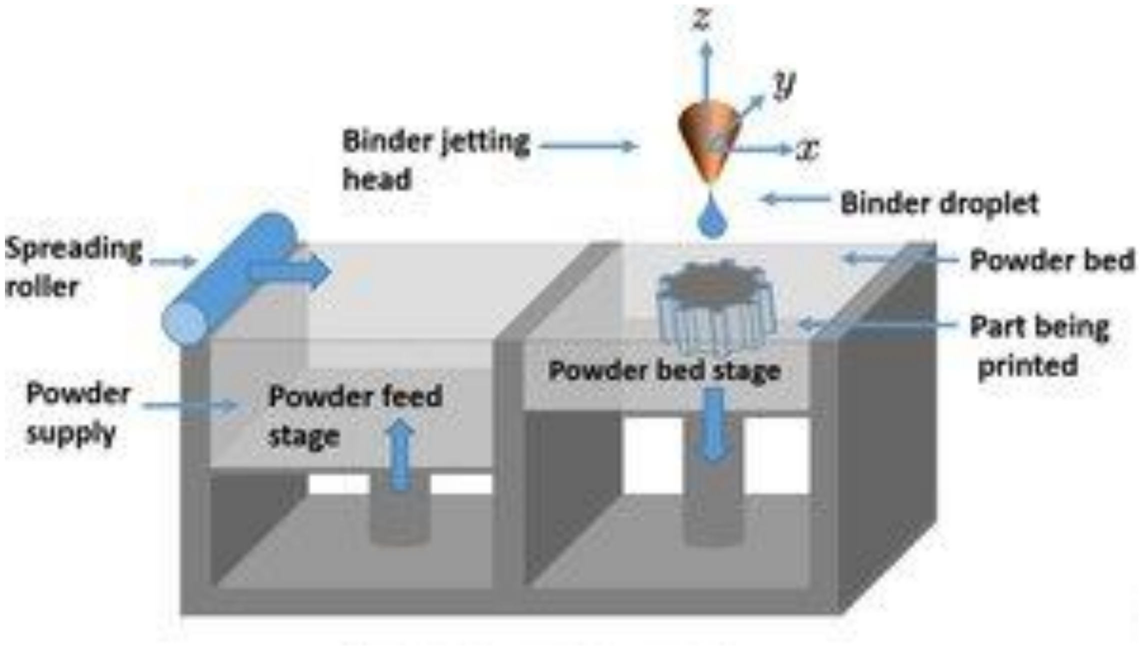
Additive Manufacturing

AM-methods

Binder Jetting

- https://www.youtube.com/watch?v=hjIoGPZPNjU



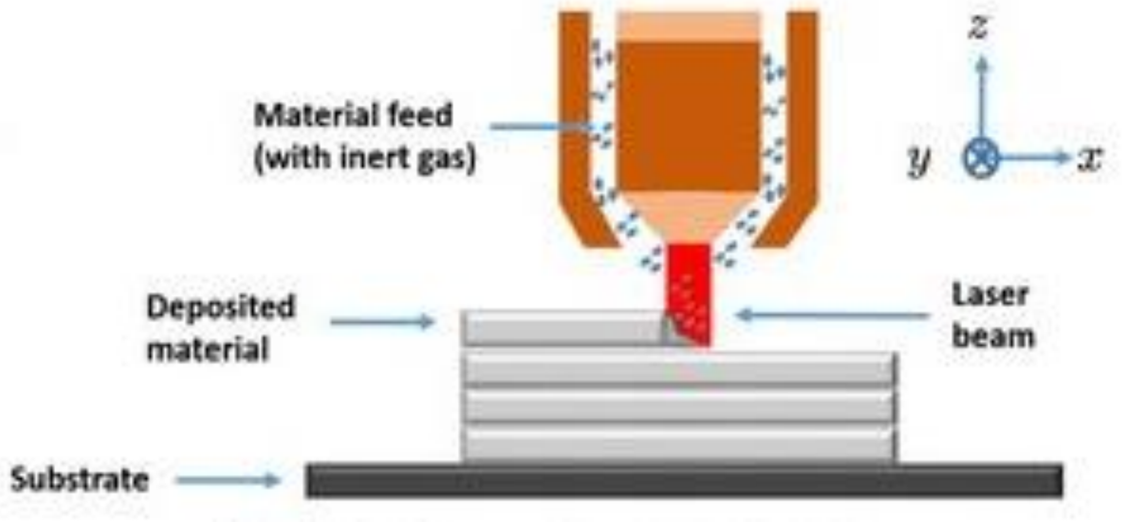
[ResearchGate]

Additive Manufacturing

AM-methods

Direct Energy Deposition (WAAM)

- https://www.youtube.com/watch?v=oL7bMhPTtDI&t=2s
- https://www.youtube.com/watch?v=_SB34fwj4GQ



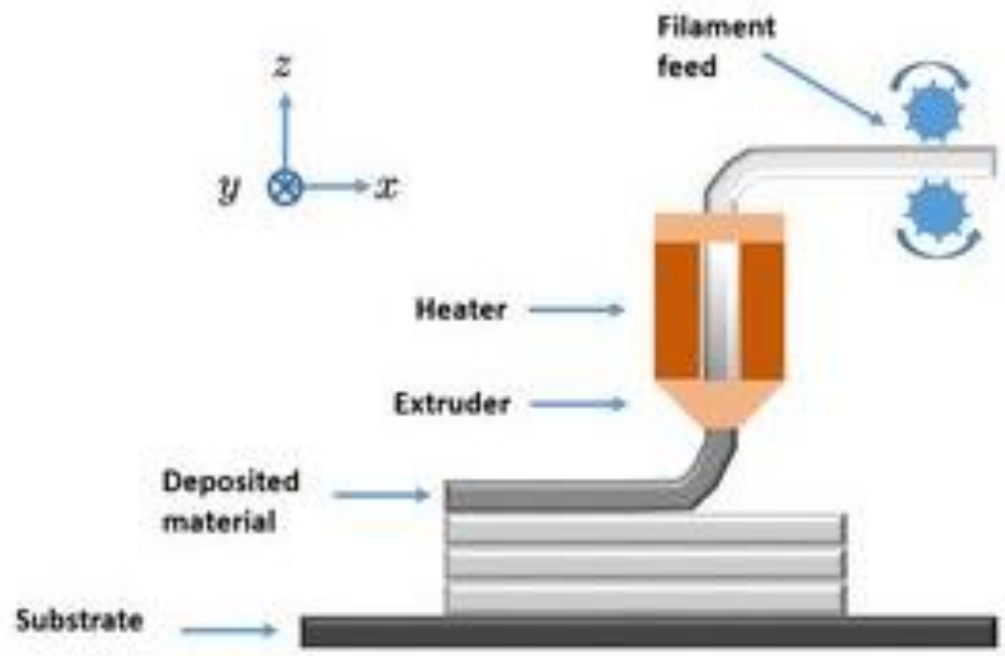
[ResearchGate]

Additive Manufacturing

AM-methods

Material Extrusion

- https://www.youtube.com/watch?v=m_QhY1aABsE
- https://panopto.jamk.fi/Panopto/Pages/Viewer.aspx?id=521f551b-7aa7-49a1-8702-af58006c2cdf



[ResearchGate]

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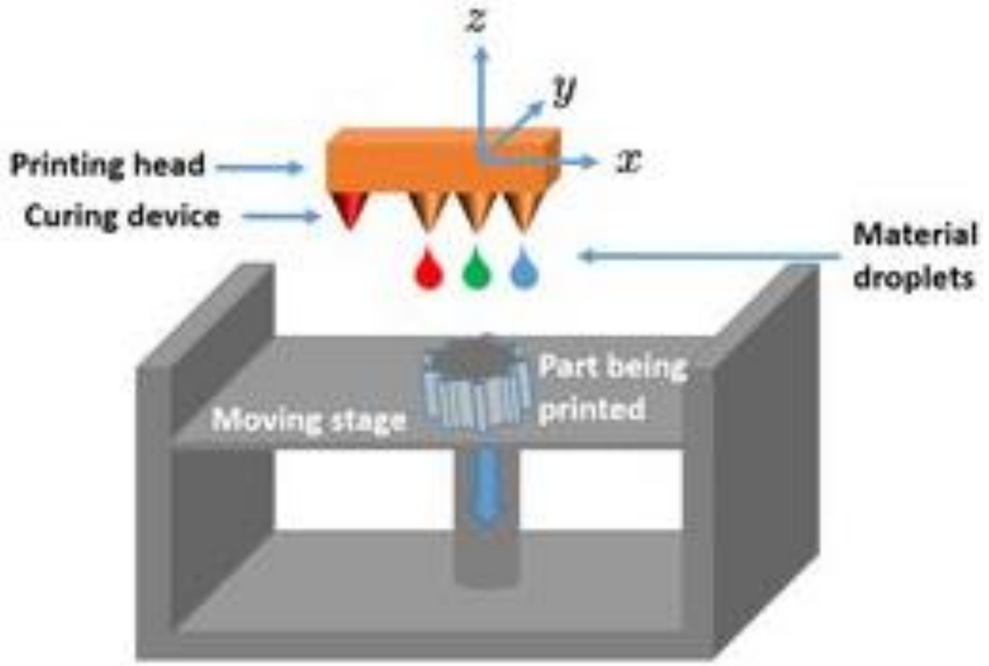
Additive Manufacturing

AM-methods

Material Jetting

- https://www.youtube.com/watch?v=m8n6FBKgY2g



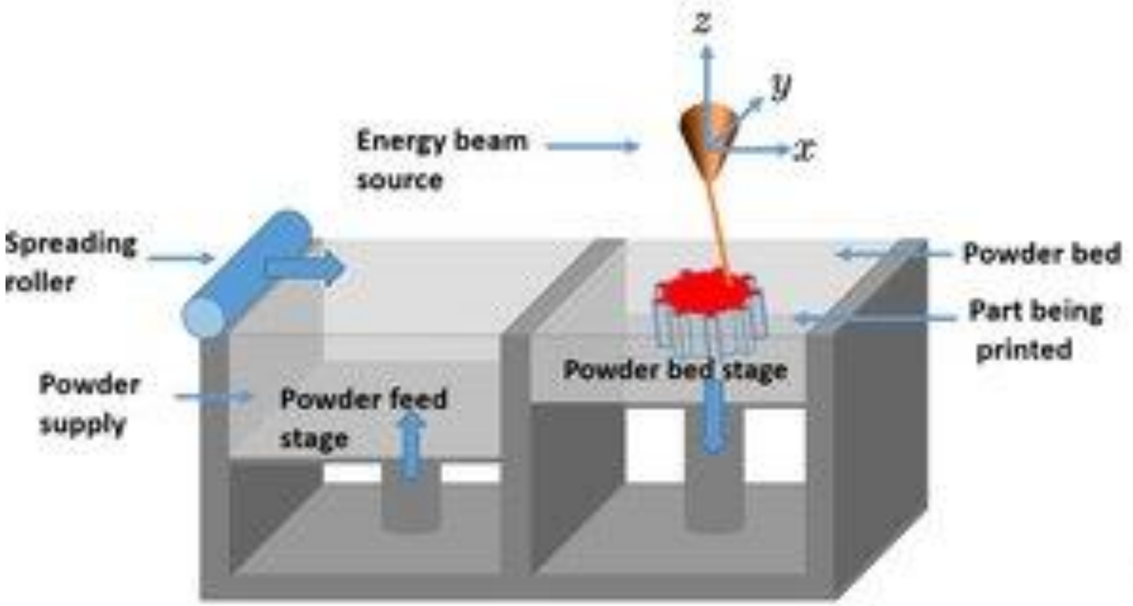
[ResearchGate]

Additive Manufacturing

AM-methods

Powder Bed Fusion

- https://panopto.jamk.fi/Panopto/Pages/Viewer.aspx?id=df4cea77-32cc-483e-a4e7-af5800635abc



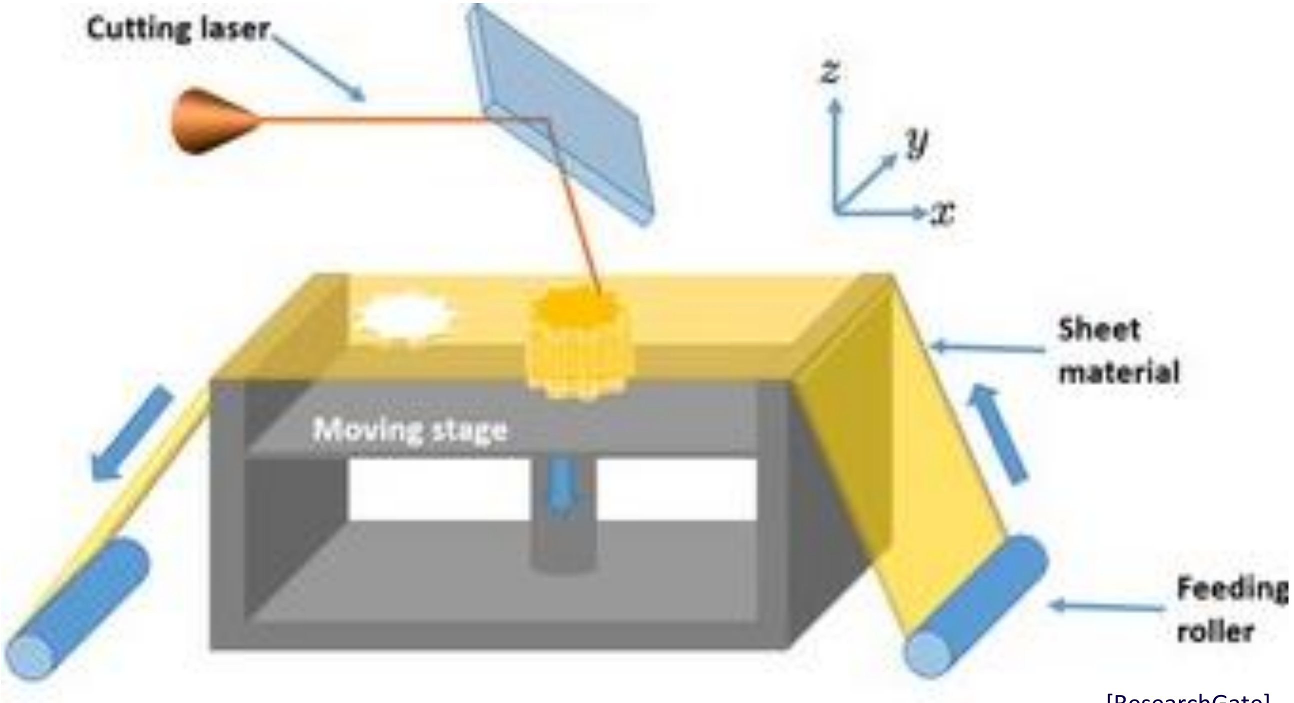
[ResearchGate]

Additive Manufacturing

AM-methods

Sheet lamination

- https://www.youtube.com/watch?v=ciCxNgROtm4



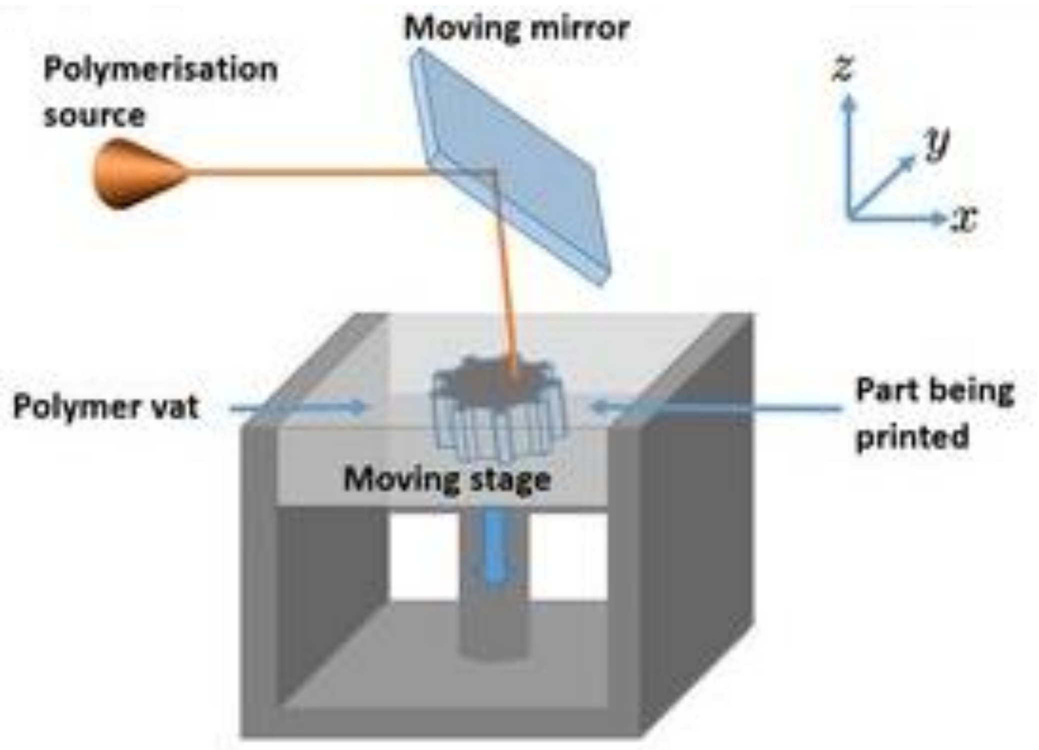
[ResearchGate]

Additive Manufacturing

AM-methods

Vat polymerisation (SLA)

- https://www.youtube.com/watch?v=CmU1ImG8n3M
- https://www.youtube.com/watch?v=n_muoXfXlEg



[ResearchGate]

Traditional Manufacturing

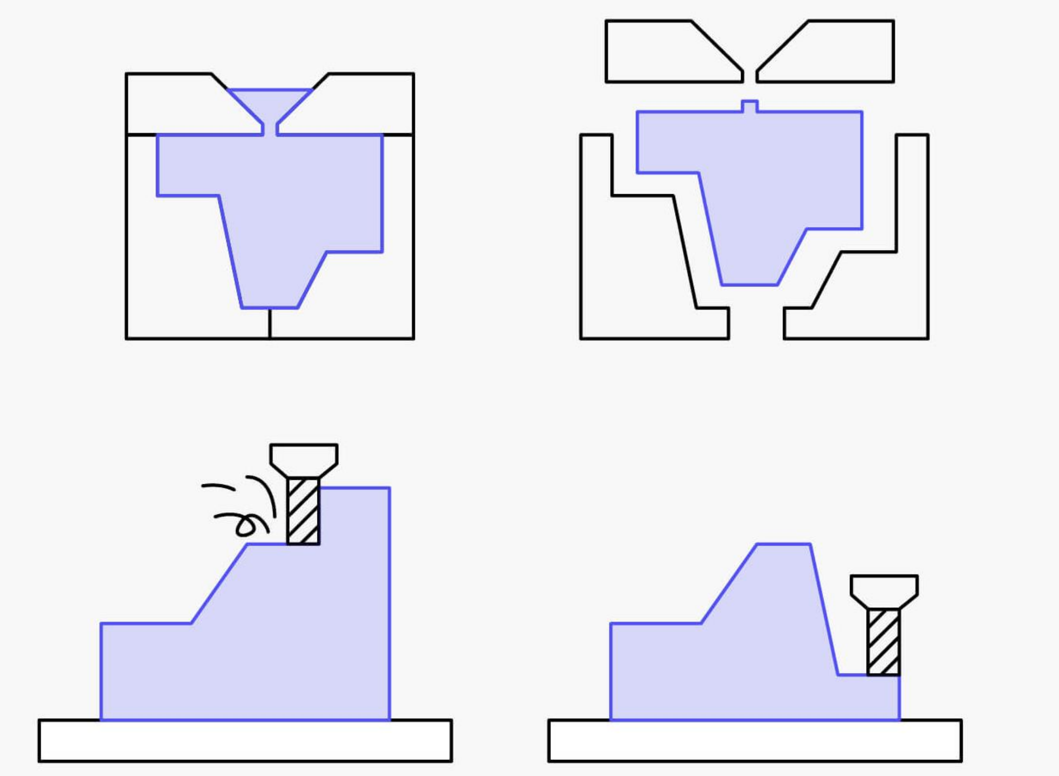
Principle

Formative manufacturing

- Casting, bending

Subtractive manufacturing

- Machining



[hubs]

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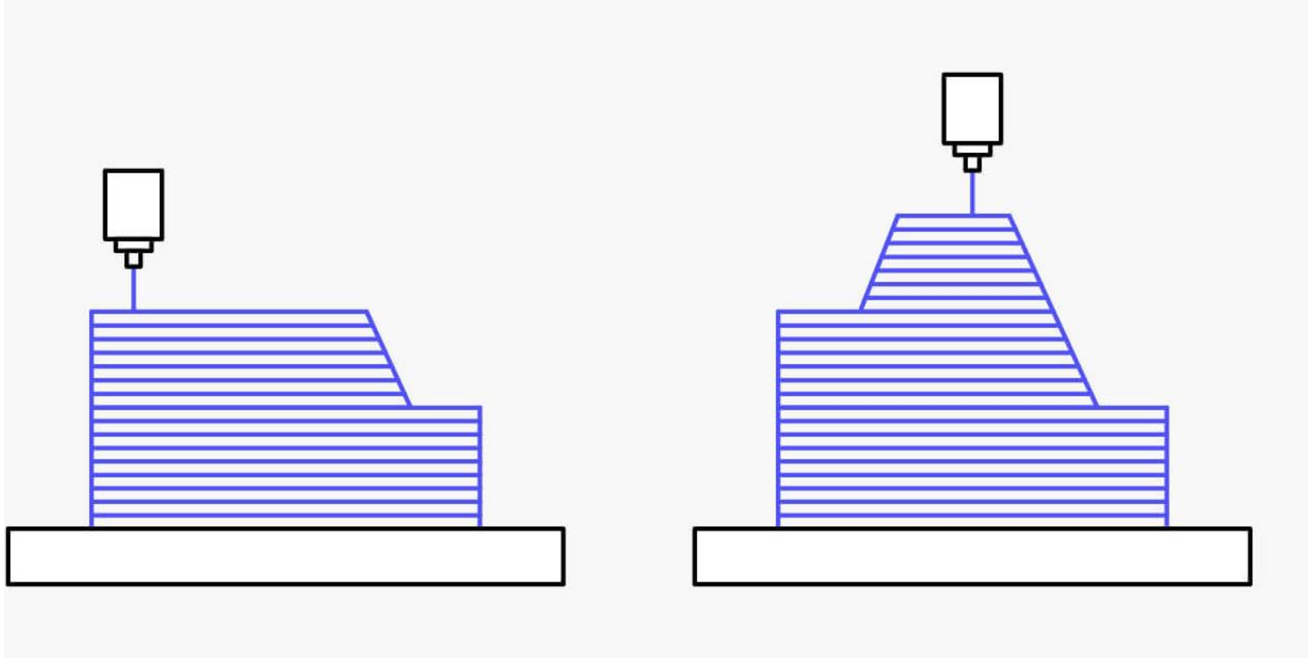
Additive Manufacturing

Principle

Additive manufacturing

- Part is manufactured layer by layer
- Material is added only where it is needed
- Minimal need for post-processing is pursued



[hubs]

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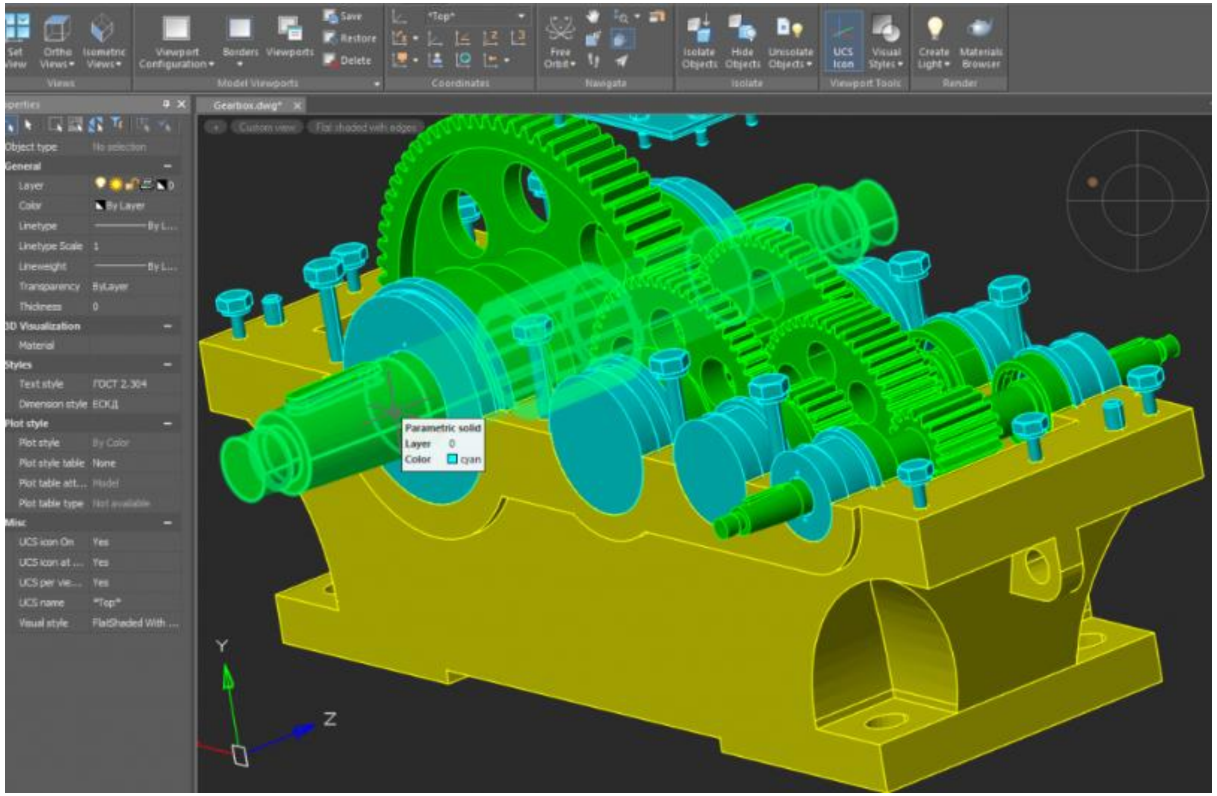
3D-modeling

Feature-based modeling

- Solid- and Surface-models
- 3D-CAD
- Engineering applications
- Mathematically defined models
- ”Mechanical” shapes



[SelfCAD]

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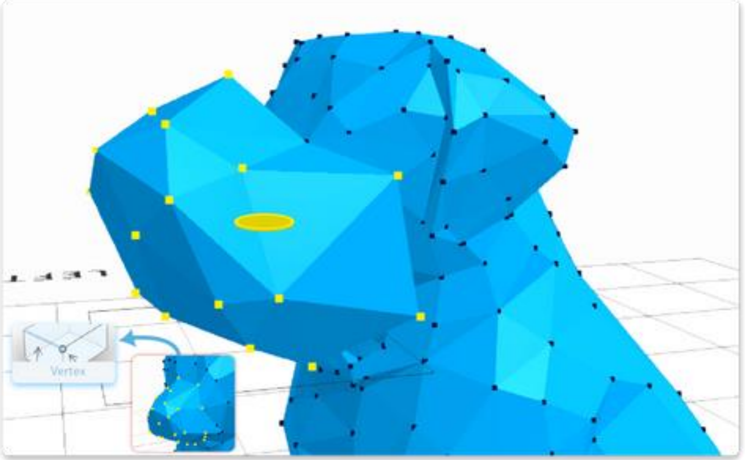
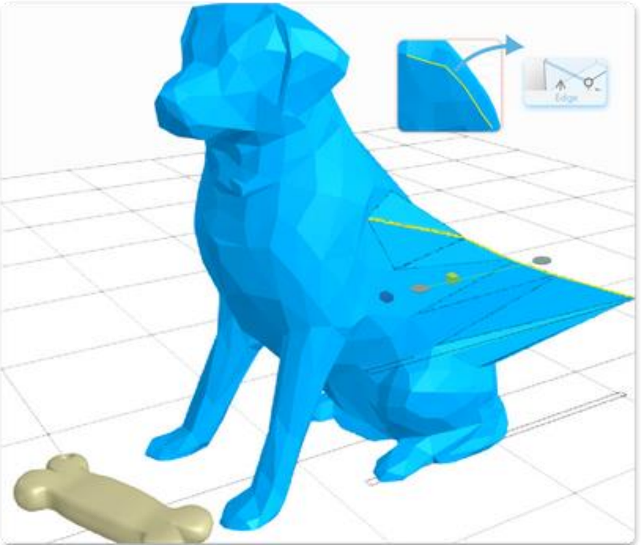
3D-modeling

Polygonal modeling

- Triangle-based Meshes
- 3D-printing and 3D-scanning
- Game-, Entertainement-, Art- and Effects-use
- Organic shapes
- ”Carved” and ”molded” models



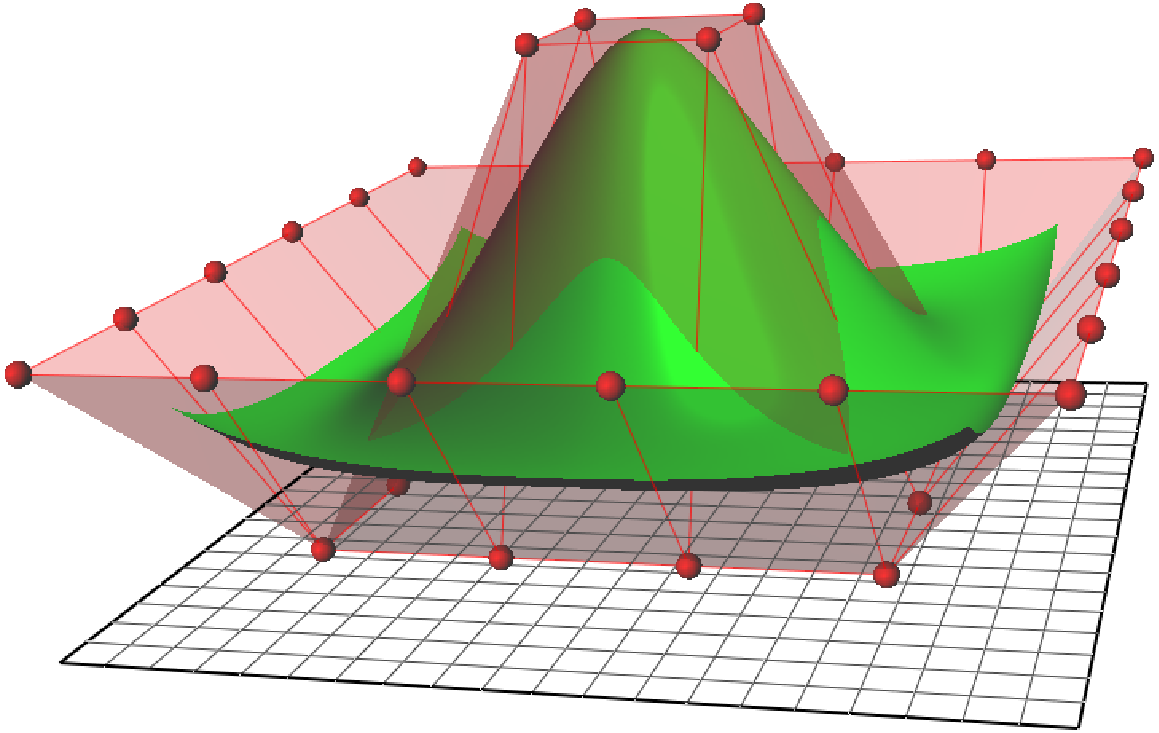


[SelfCAD]

3D-modeling

Spline- and surface models

- Splines
- NURBS-surfaces
- Mathematically defined models
- Something in between traditional CAD-models and polygonal models



[SelfCAD]

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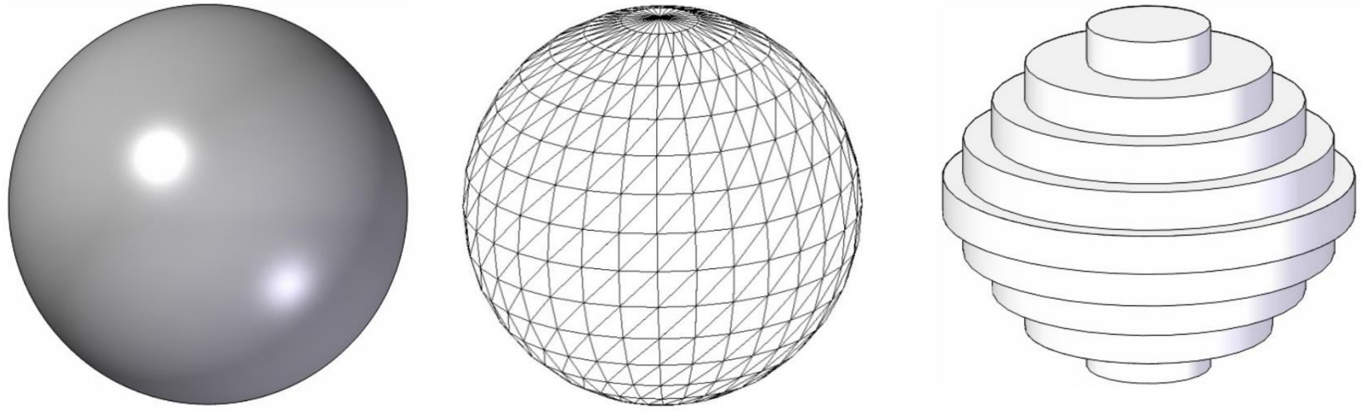
Additive Manufacturing

Principle

- Part is modeled in 3D CAD-program
- 3D-model is converted to triangular mesh
- Mesh is sliced to layers (cross-sections of the model)
- 3D-printer manufactures the part layer by layer



Jesse Kontio AIP WORKS

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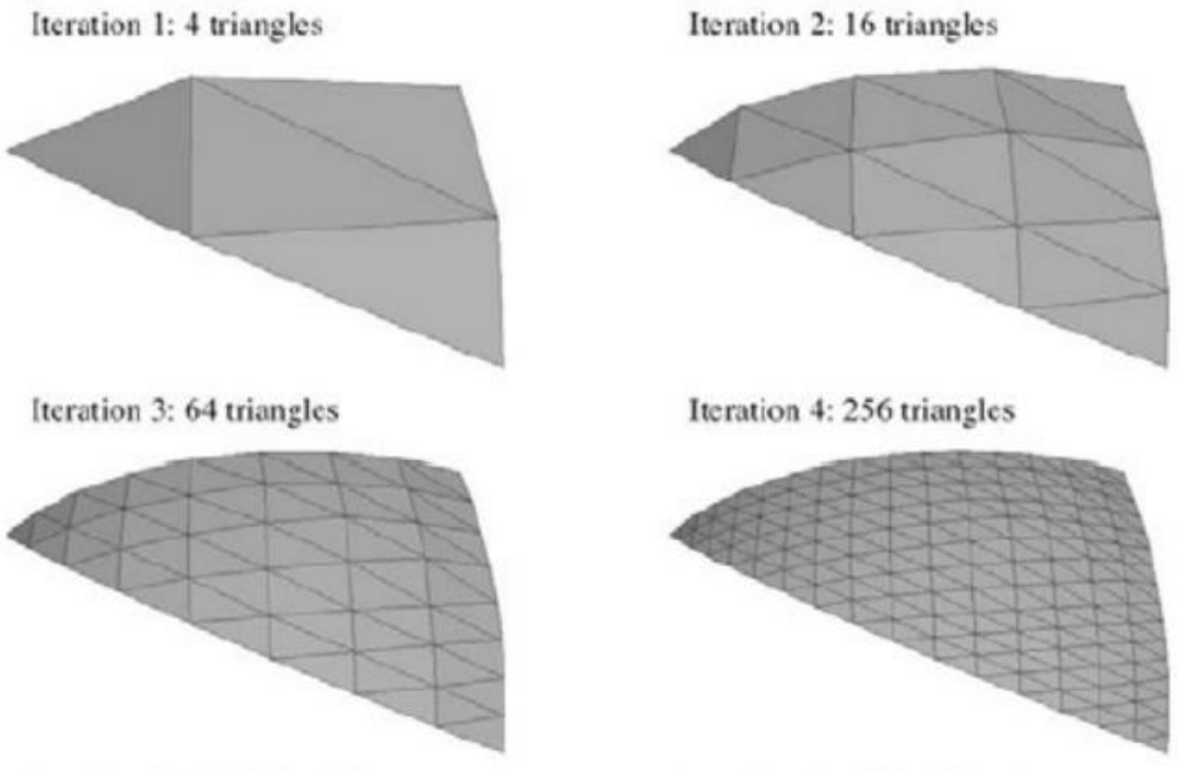
Additive Manufacturing

Principle

- The number of triangles in the mesh affects the final surface quality and dimensional accuracy
- Most common Mesh-file formats: STL, AMF, OBJ

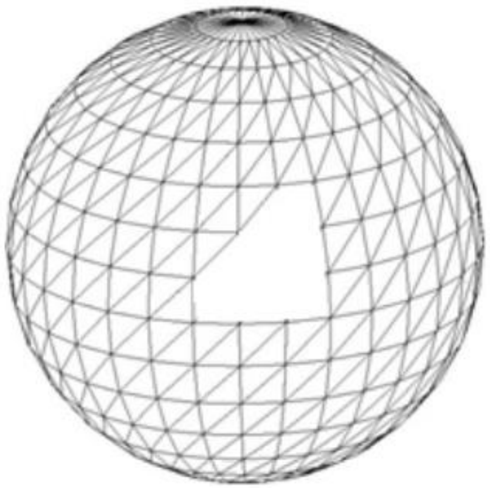


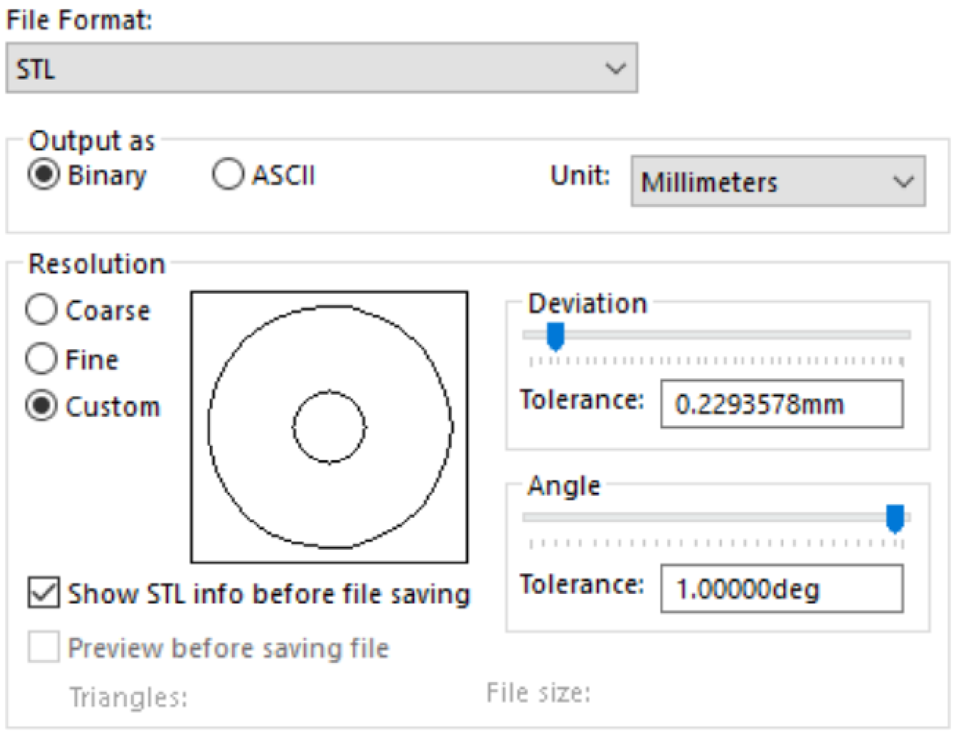
[bourke]

Additive Manufacturing

Principle

- Almost all 3D-CAD programs support printable file formats
- Exporting example from SolidWorks
- In order to be printable, the mesh must be water-tight





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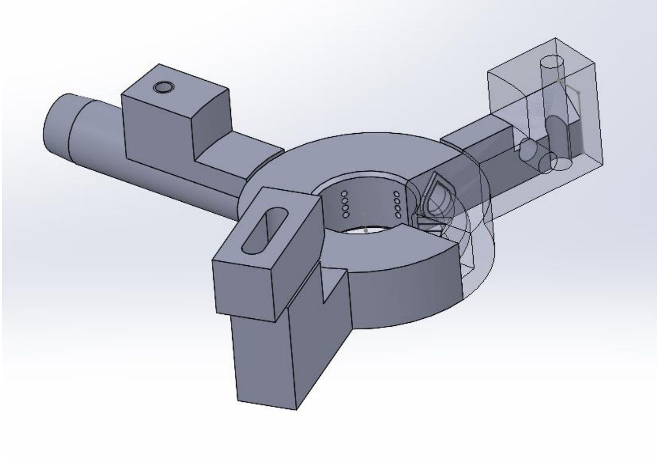
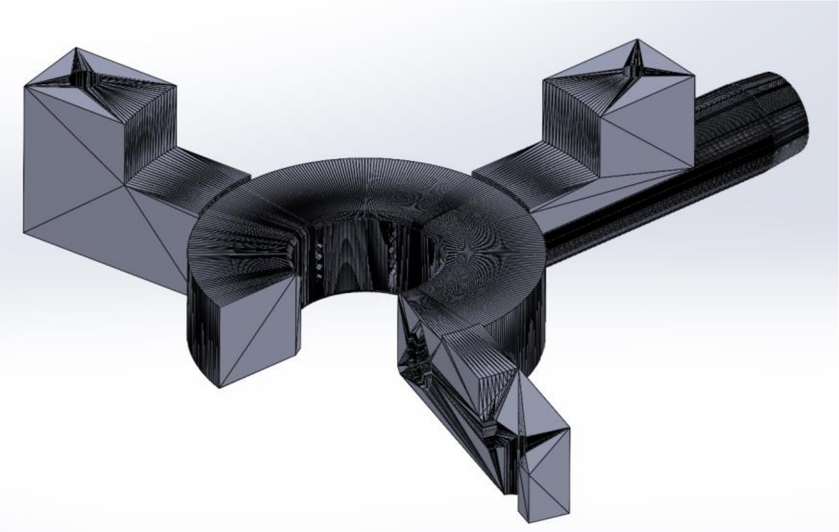
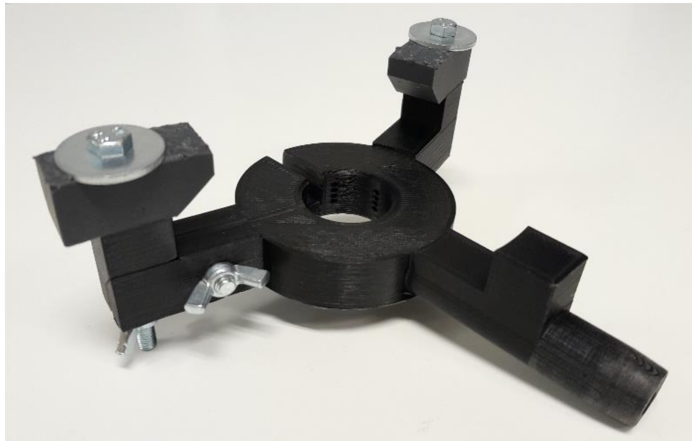
Additive Manufacturing

Principle

- Example part from 3D-model to the final product







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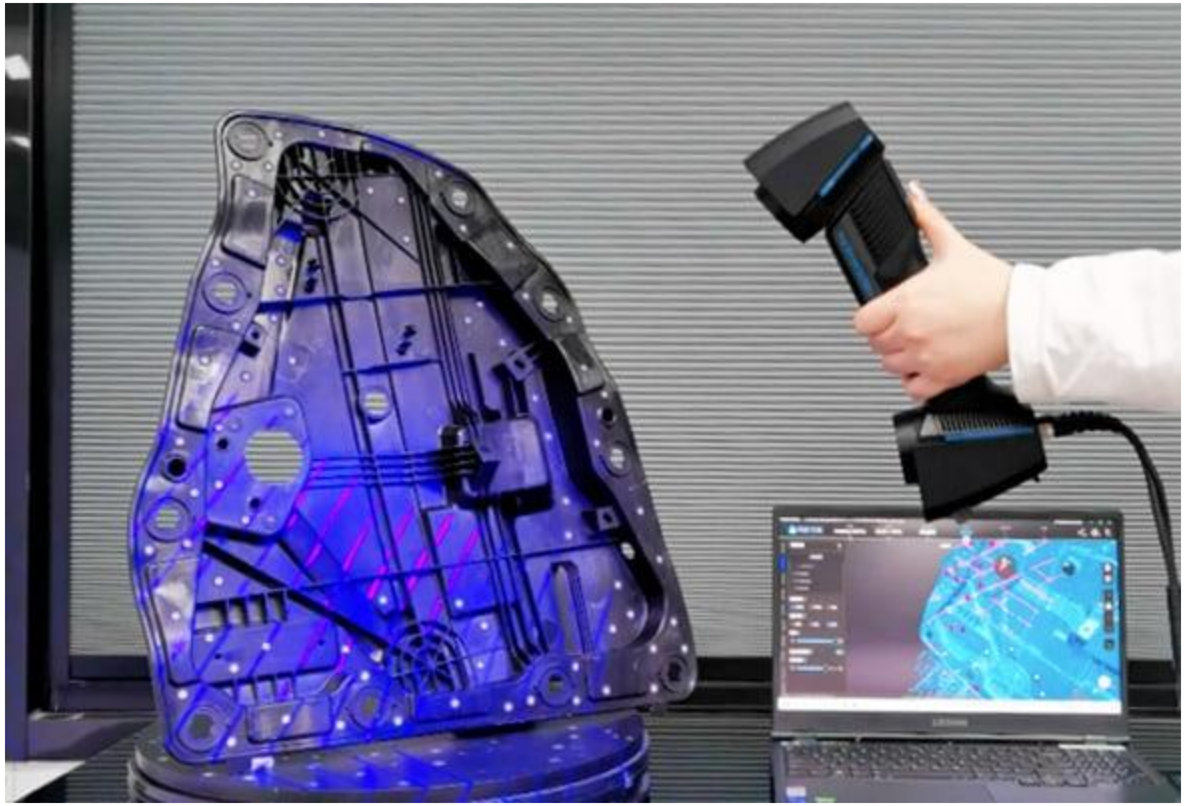
3D-scanning

Reverse Engineering

- Laser- and/or light-based 3D-measuring
- Based on processing Point Clouds and Triangular meshes
- Combined with AM can expedite 3D-modeling in cases where spare parts are needed
- 3D-Scans always require post-processing in order to be printable



[3DNatives]

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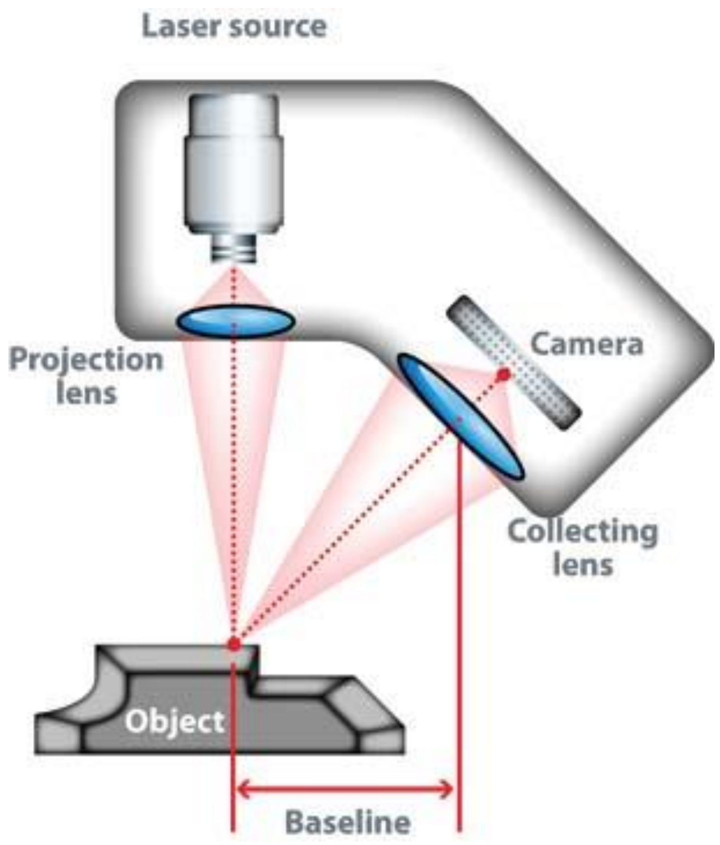
3D-scanning

Principle

- Essentially automized laser-based distance measuring
- Object is scanned with the laser (or another type of light source)
- The camera in the scanner measures the reflections based on triangulation and/or travel time of the beam
- Millions of points are measured in order to determine the geometry of the part



[DigitalEngineering]

3D-scanning

Principle

- Scanners of different types and sizes
  - Handheld
  - 360 deg
  - Fixed installations
  - Mobile (eg. Drones)

[EngineersGarage, Artec]

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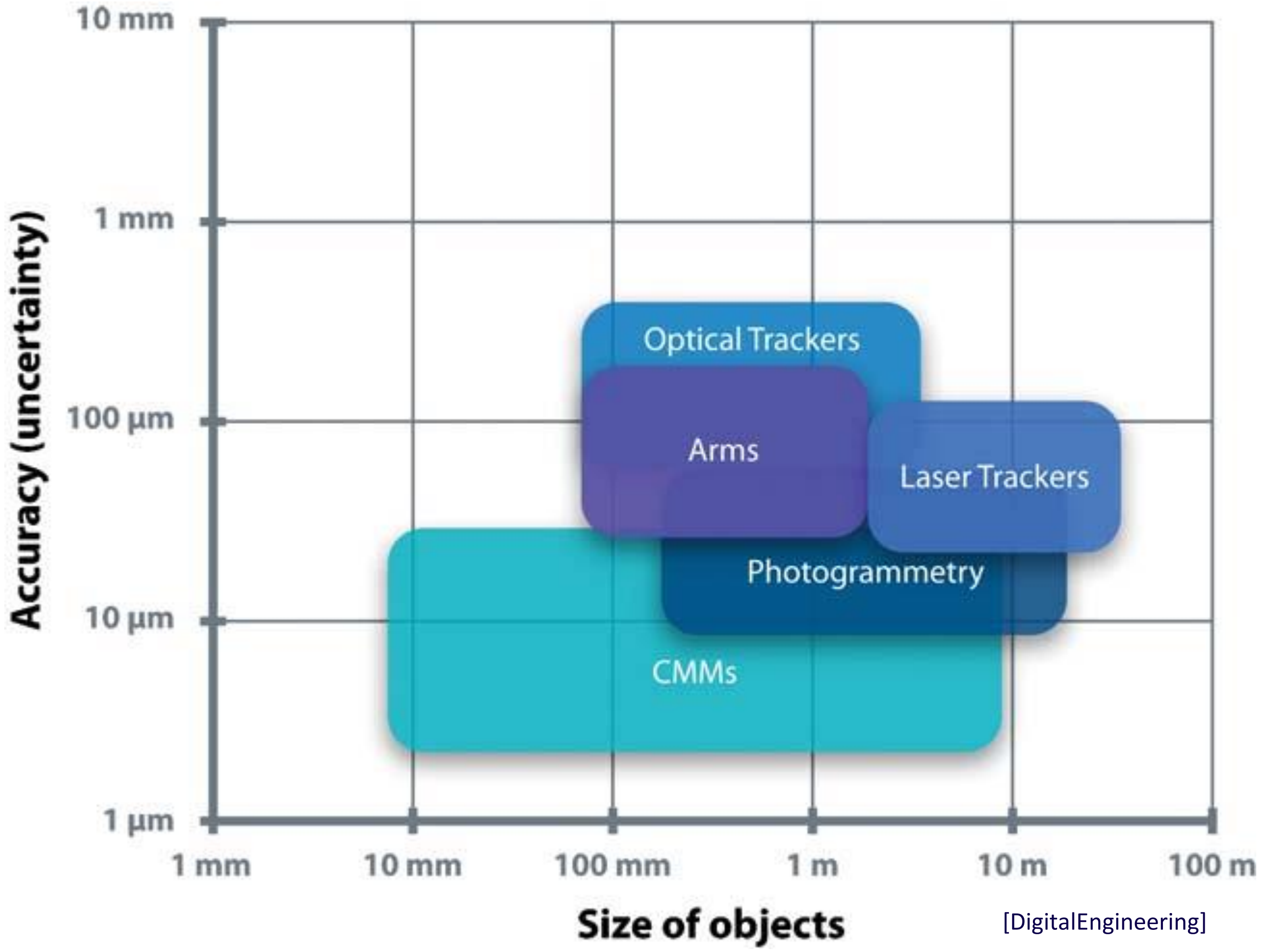
3D-scanning

Principle

- Other related technologies:
  - Photogrammetry,
  - Combination of scanning and touch-based coordinate measuring (CMM)
- The bigger the targer, the lower the accuracy



[DigitalEngineering]

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AI

Producing 3D-models with AI

While AI is not quite there yet for engineering purposes, it is making waves also in the field of 3D-printing and 3D-modeling

- https://3d-models.hunyuan.tencent.com/
- https://3dprintingindustry.com/news/spare-parts-3d-launches-new-ai-powered-2d-to-3d-model-digitization-tool-229349/
- https://makezine.com/article/technology/artificial-intelligence/can-i-use-ai-to-make-models-for-3d-printing/
- https://3dprintingindustry.com/news/new-ai-driven-3d-printed-prosthetic-eyes-developed-by-fraunhofer-228728/

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Additive Manufacturing

Pros

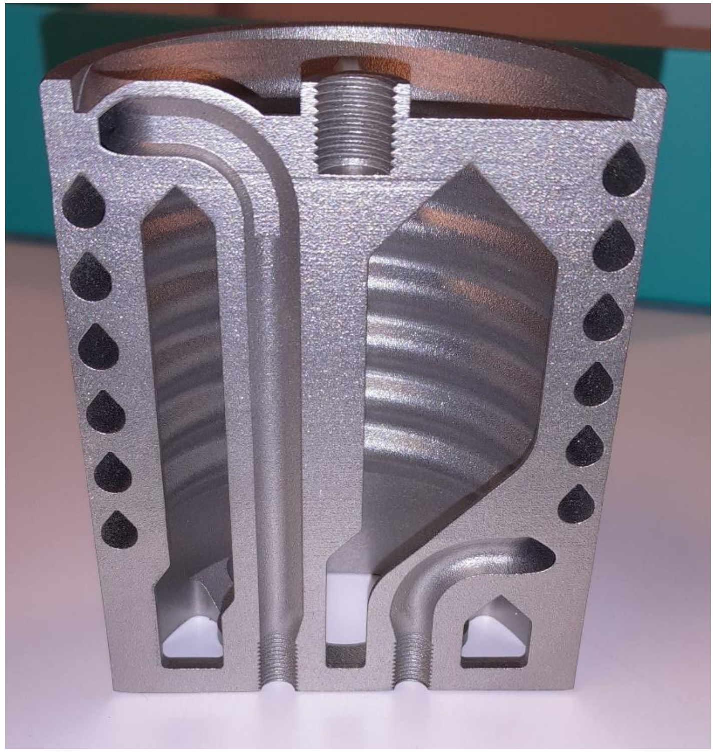
- Material and Energy usage and waste is minimized
- Manufactured parts can be lightweight
- Removing materials **decreases** costs (cf. Traditional manufacturing)
- Rapid response time, also in the middle of production
- Other, e.g. logistical advantages

[ge]

Additive Manufacturing

Pros

- AM enables structures and features that are exceedingly hard or completely impossible to make using any traditional manufacturing methods
- Especially internal shapes



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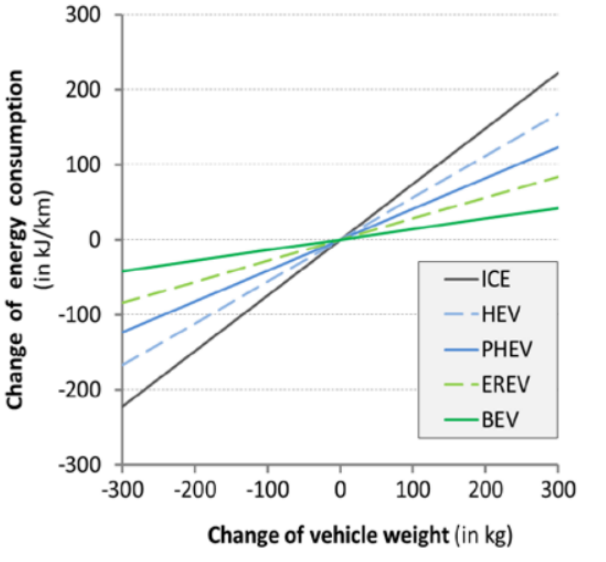
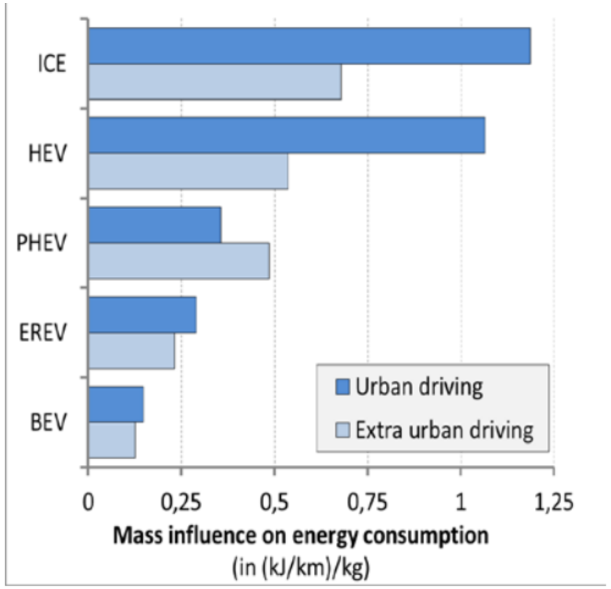
Additive Manufacturing

Pros

- Reducing the weight of a vehicle improves the energy efficiency
  -10% weight -> +5-15% range
- -1kg in the weight of a plane (~40t) saves 5000l in fuel over the lifetime of the plane
- Launching 1kg to the low-earth orbit costs 2500-20000$ depending on the rocket used
- Similar logic applies to the freight costs and emissions caused by transporting products





[EEVC]

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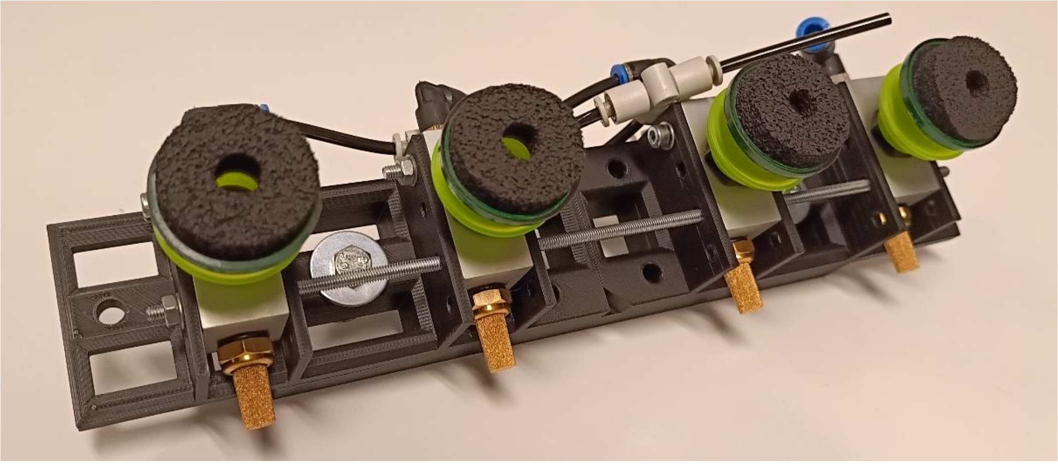
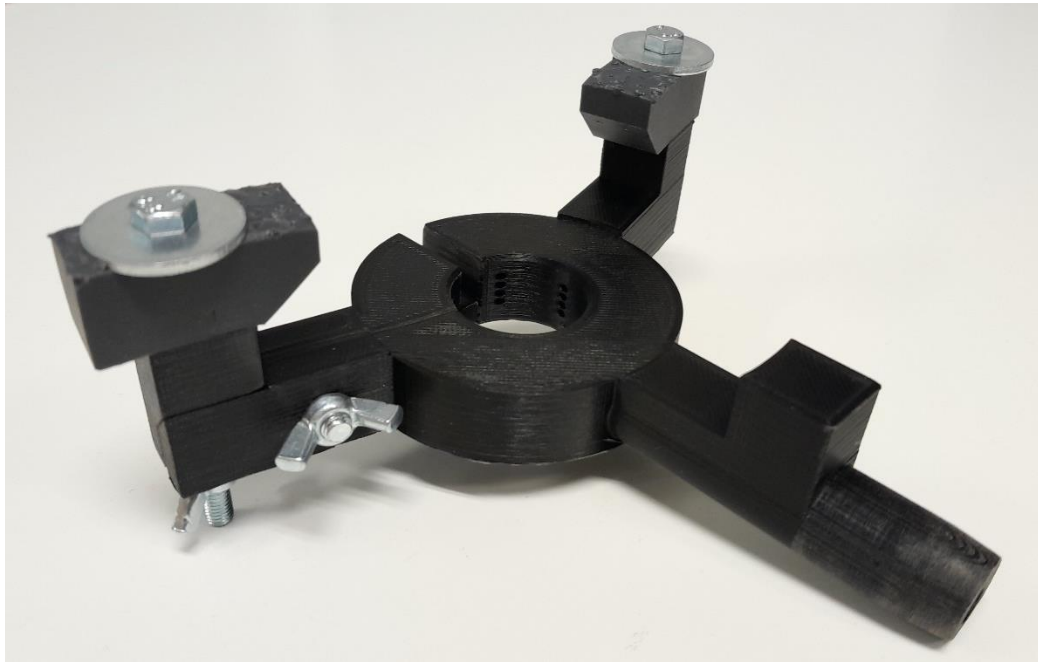
Additive Manufacturing

Applications – Rapid manufacturing and prototypes

- Manufacturing tools, jigs and prototypes ”overnight”





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Additive Manufacturing

Applications – Spares & Small series

- Small series manufacturing especially with powder bed printers
  - Serial production of parts where the number of parts needed is relatively low
- Spare parts
  - Production of spares for own products on demand
  - Producing spares for machines and products no longer supported by the manufacturer

[AMFG, 3DBavaria]

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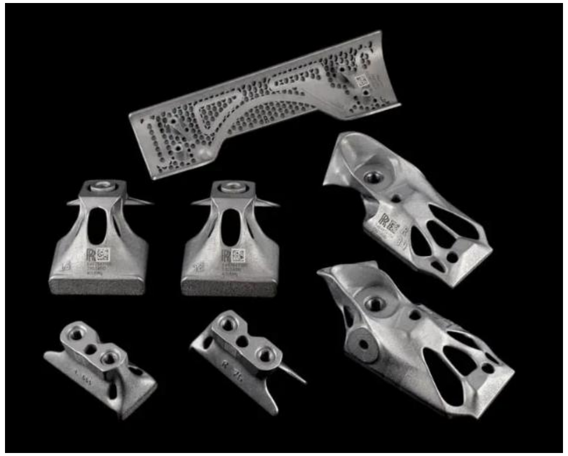
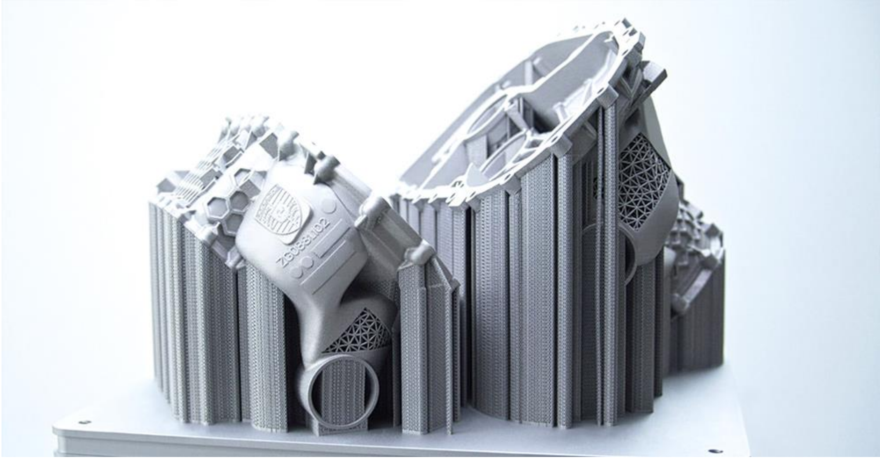
Additive Manufacturing

Applications – Mass production

- Actual mass production for parts with high complexity



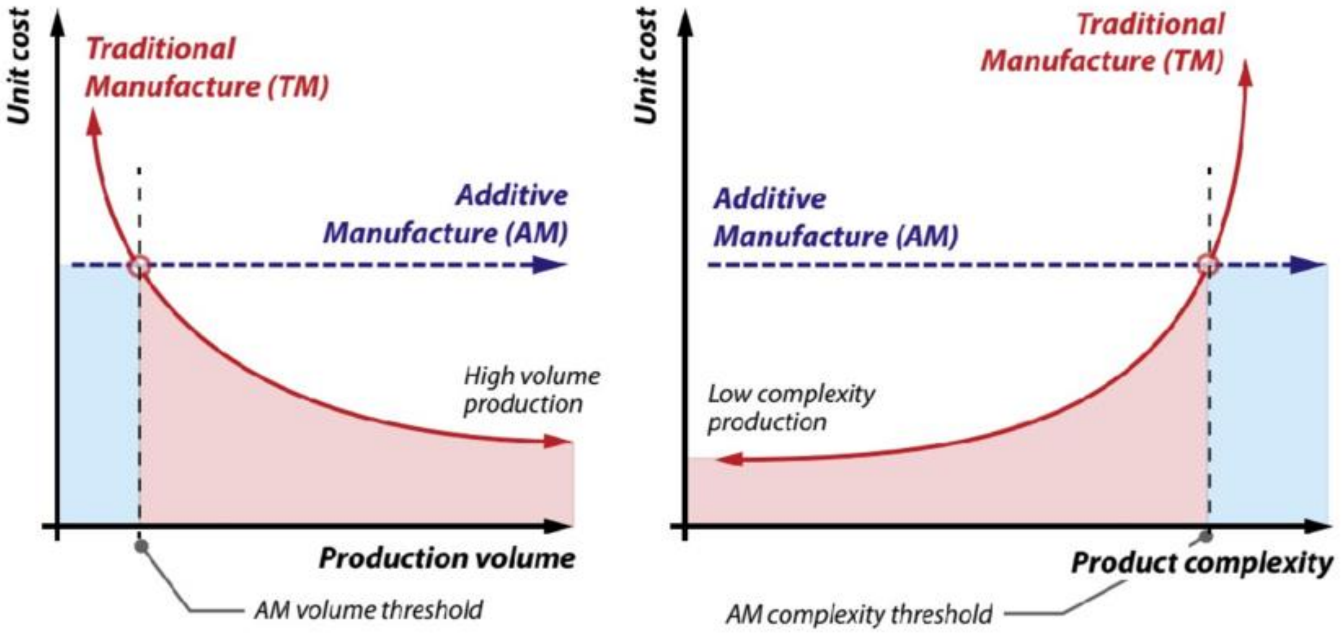


[AMFG, BMW, All3DP, Control]

AM application in manufacturing

Price & Complexity

- Unit price in AM remains approximately constant regardless of the production volume and part complexity
- -> AM can be competitive even in mass production when complexity is high

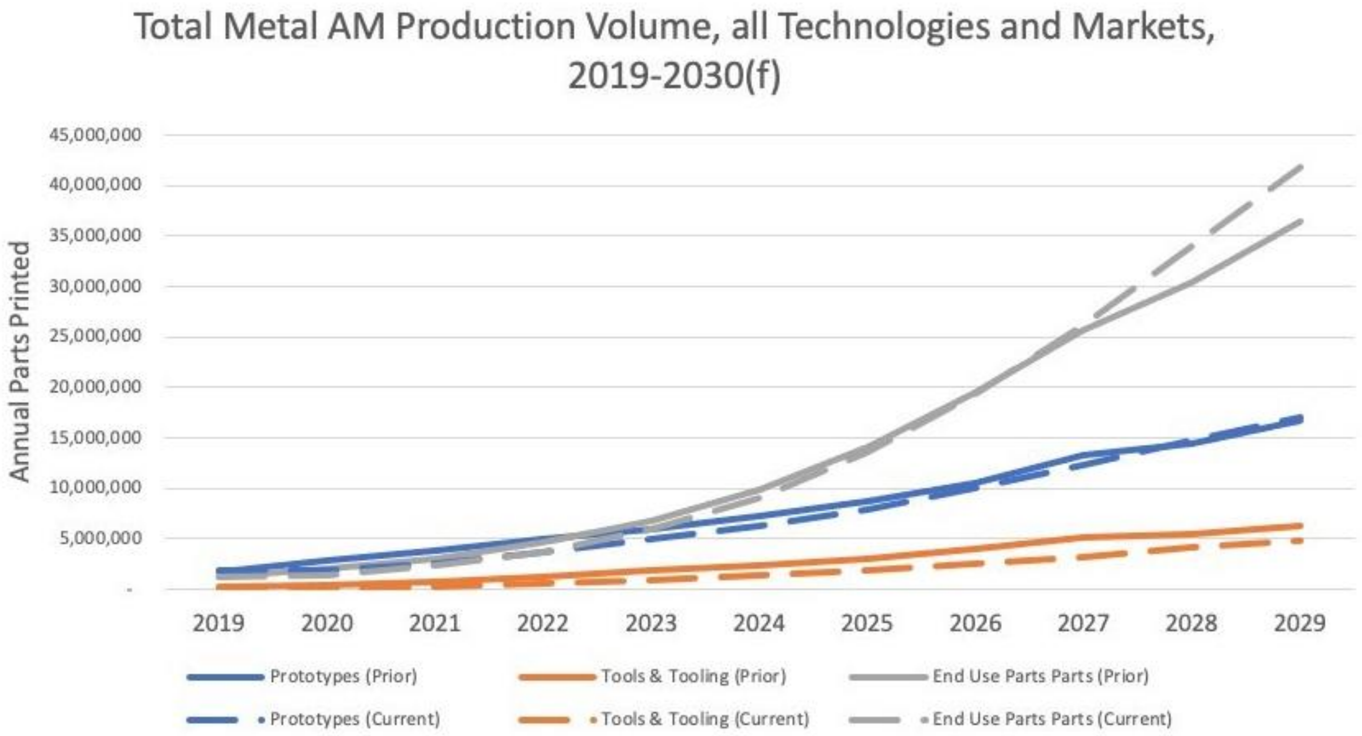


[Malbasic]

Trends

Applications

- Metal printing growing rapidly
  - 13.8 bn$ globally in 2021
  - Focus shifting from testing and prototypes to end use production
- Plastic printing is already in everyday use also in end use and mass production



[Tonerbuzz, SmarTech]

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Trends

AM Materials

- In metal printing, the material selection is expanding:
  - High-end Tool Steels, High durability Aluminium
  - Copper
  - Specialized Alloys
- Ceramic printers are maturing to Industrial use
- Recycled and sustainable materials

[All3DP, EOS]

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Trends

Applications

- The size and complexity of the prints is getting higher and higher, also in very demanding applications
  - E.g. pictured pressure vessel: https://www.dimecc.com/the-pressure-vessel-3d-printed-by-andritz-savonlinna-works-oy-and-fame-ecosystem-is-a-european-giant/
- Enabling mass production and enhancing solutions for automatization of the printing process and production monitoring

[Dimecc]

Design for AM

In general

- Best results are achived, when AM is taken into consideration already in the design phase
- Replacing traditional manufacturing methods directly is rarely worthwhile
- Different AM-methods have their own requirements for design, e.g. regarding the support structures
- Orientation of the part during the manufacturing matters

[ge]

Design for AM

Levels of DfAM

- Printability
  - Suitability of the Geometry for AM
  - Considering the differences of AM technologies
  - Minimizing the post-processing
- Redesigning & Maximizing the benefits of AM
  - Elimination of geometric restrictions
  - Possibilities for light-weighting
  - Topology optimization and Generative Design
- Designing for mass production and Sustainable Design

[ge]

Design for AM

AM method -dependent

- Size of the parts
- Durability and strength of the parts
- Accuracy and minimum feature size
- Printing orientation and the need for support structures
- Sufficient contact surface to build plate
- Infill and other automated light-weighting
- Possible need for draining holes or channels

[ge]

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Design for AM

Rules-of-thumb

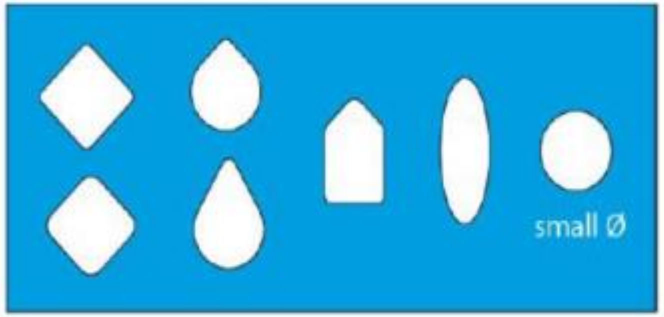
	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

[hubs]

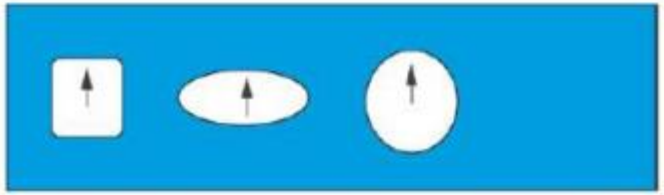
Design for AM

Printability

- Geometry directly influences the printability of the part
- Requirements vary depending on the printing methods
- Need for support structures can be minimized by taking into account the limitations imposed by the chosen printing method
- As a rule of thumb, part can be expanded at 45° outside of the previous layer



a) Self supporting cross sections for holes and channels



b) Holes requiring support during printing

[VTT]

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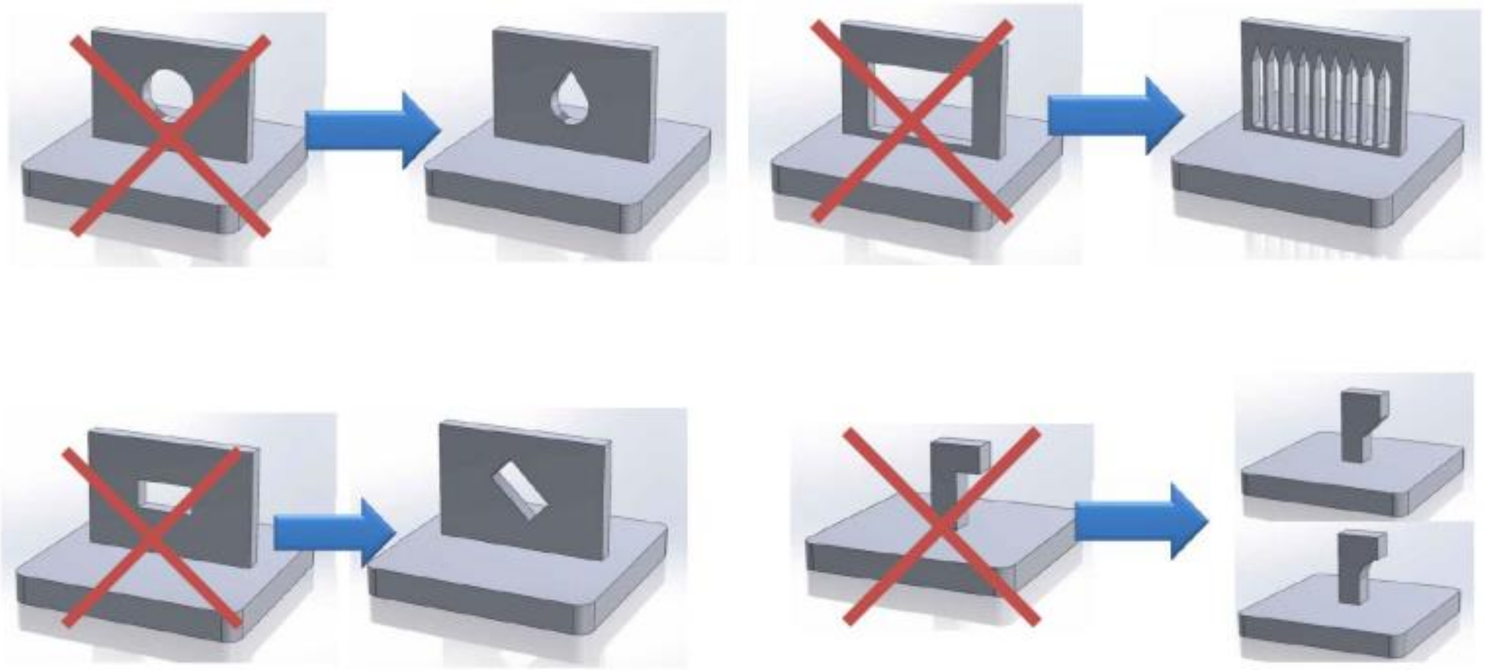
Design for AM

Printability

- Examples of replacing problematic features with ones that are easily printable

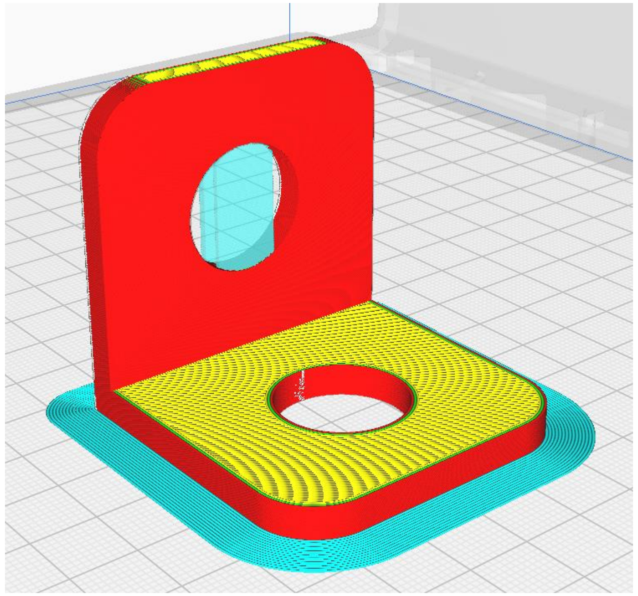


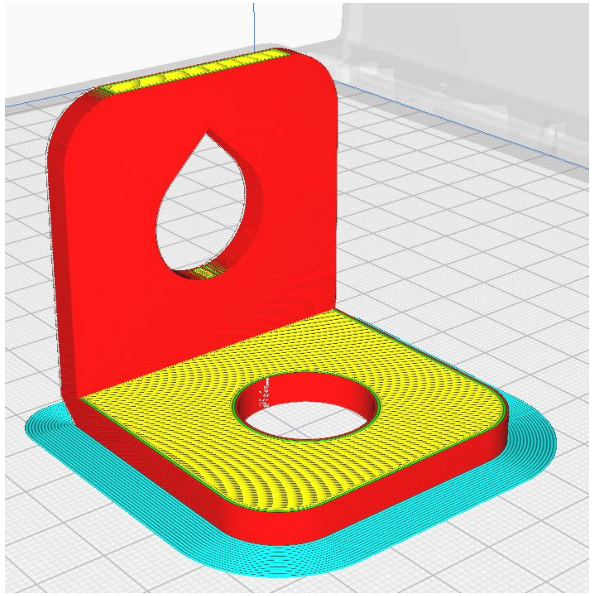
3D-printing basics LUT 2016

Design for AM

Printability

- Examples of compromizes between printability and required changes in geometry

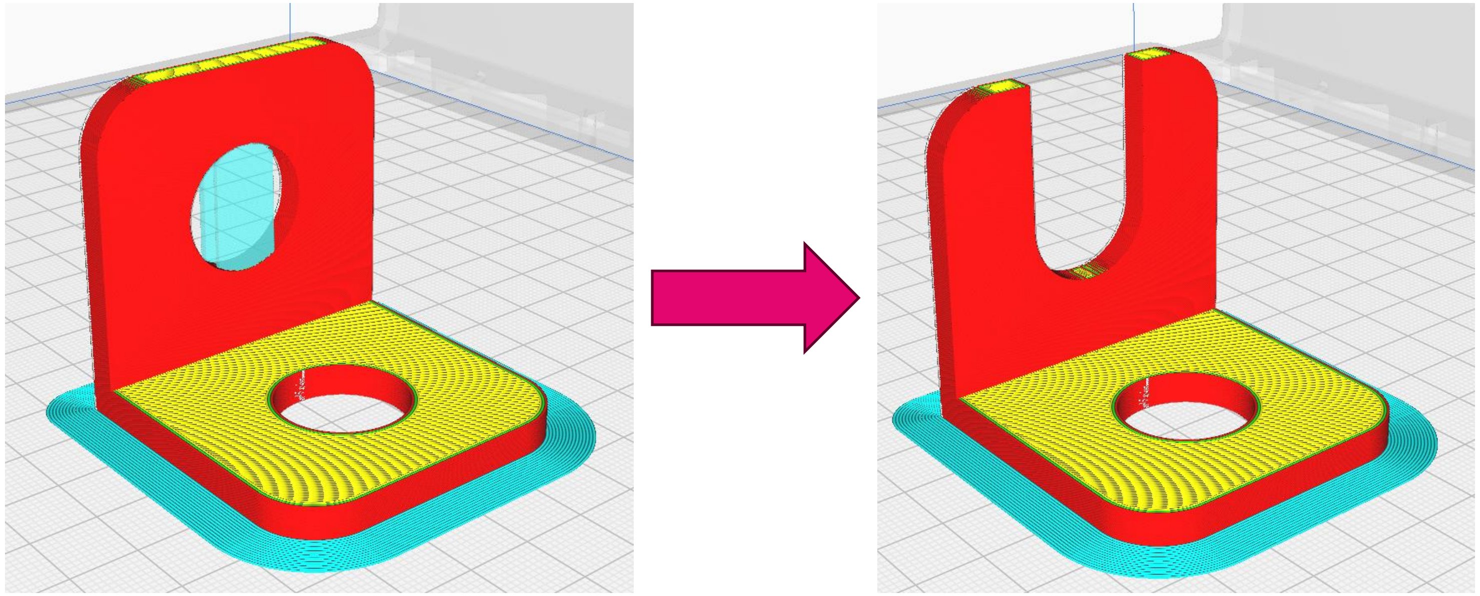




Design for AM

Printability

- Examples of compromizes between printability and required changes in geometry



Design for AM

Printability

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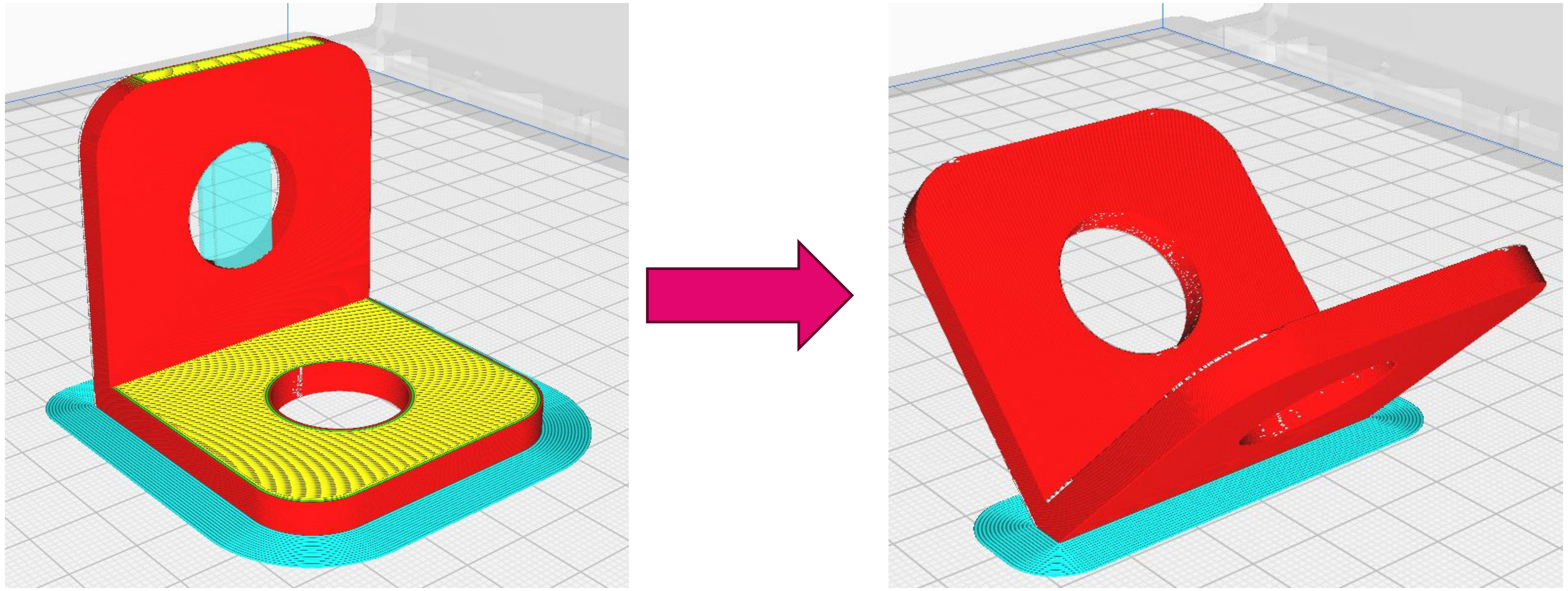

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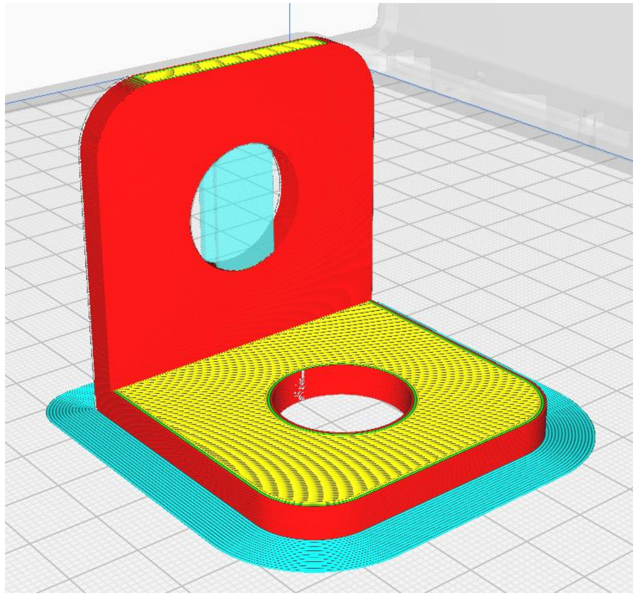
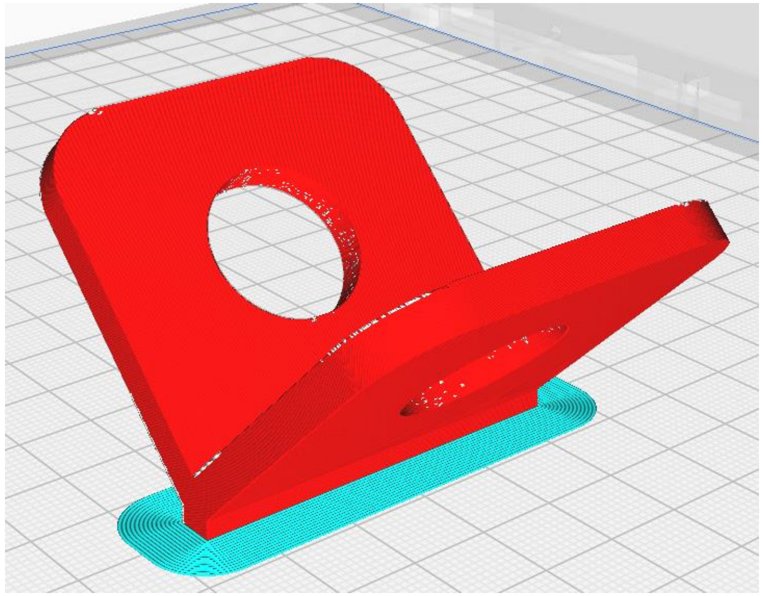
Printability

- Examples of compromizes between printability and required changes in geometry





Design for AM

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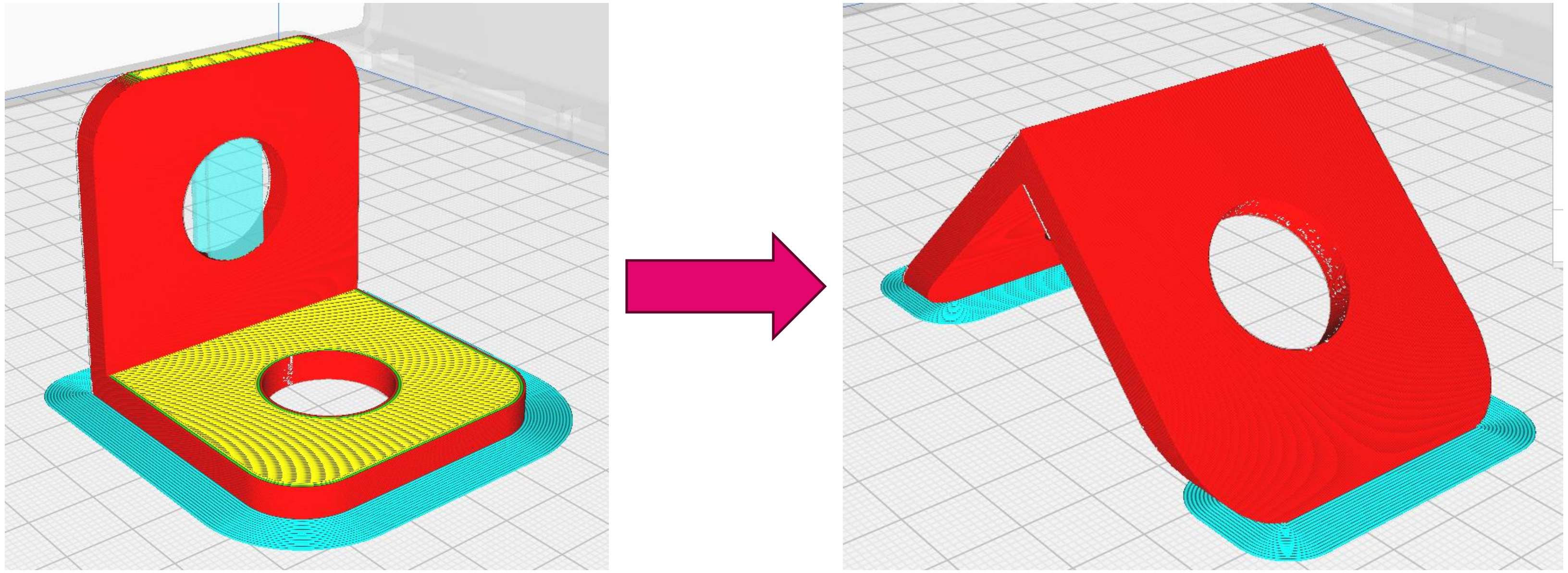
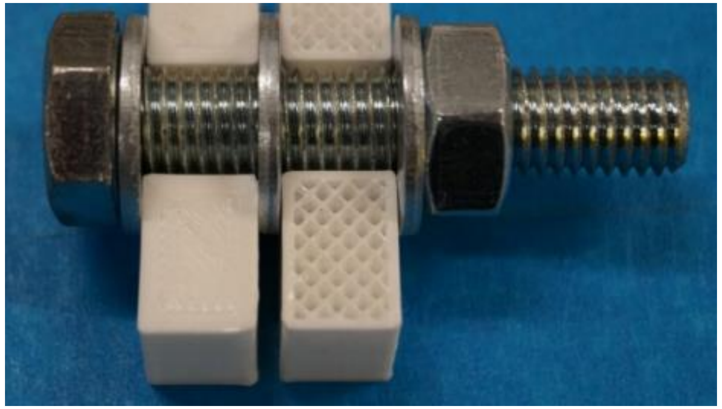
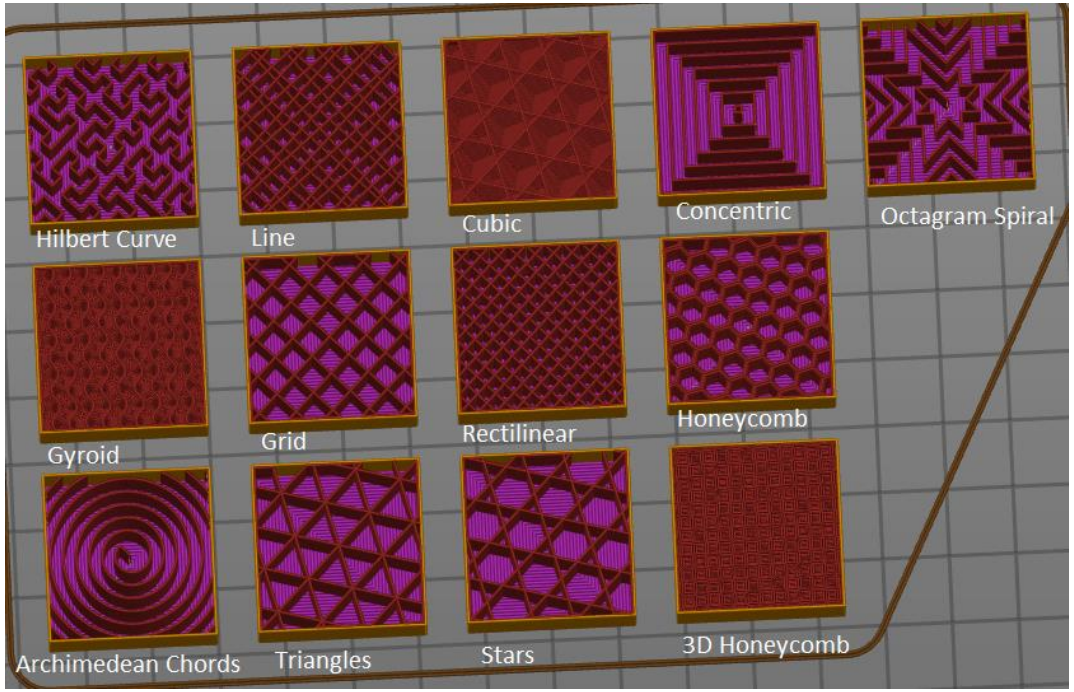


Design for AM

Infill

- Internal solid features can be only partially printed in order to save material and shorten the printing time
- Density and pattern can be adjusted





[MoJee 3D]

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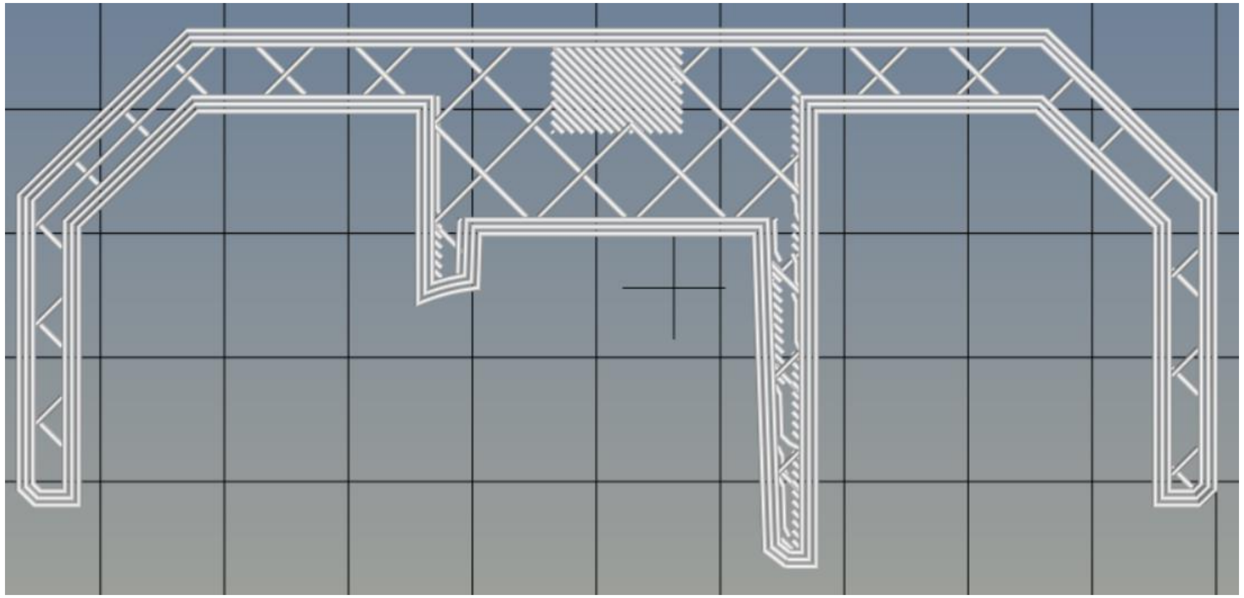
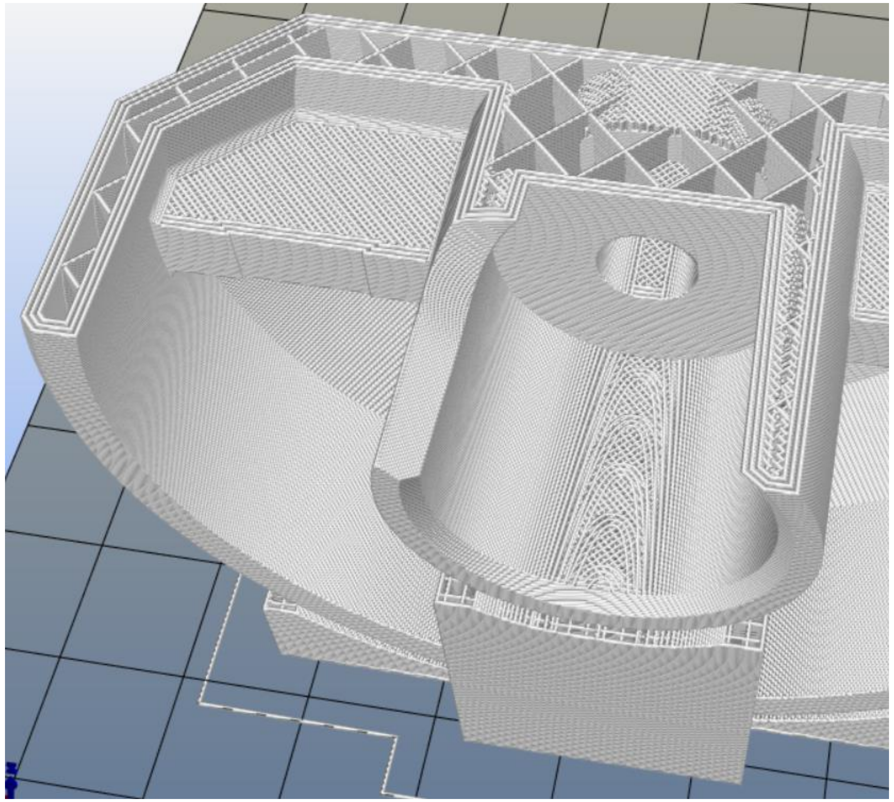
Infill and layer cross sections

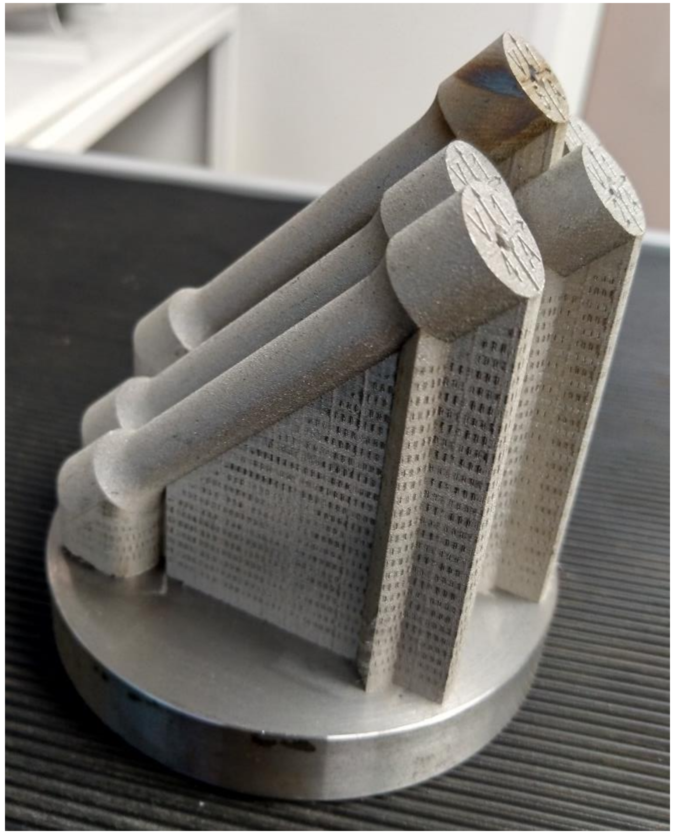




Design for AM

Support Structures

- Printing ”on top of nothing” is rarely possible
- Separate support structures are used when needed
- Supports are usually made from the same material as the part itself, but in some cases a special support material can be used
- In metal printing, the supports also conduct the heat away
- Need for supports depends on the geometry of the part, the printing method used and the quality and dimensional accuract requirements for the manufactured part



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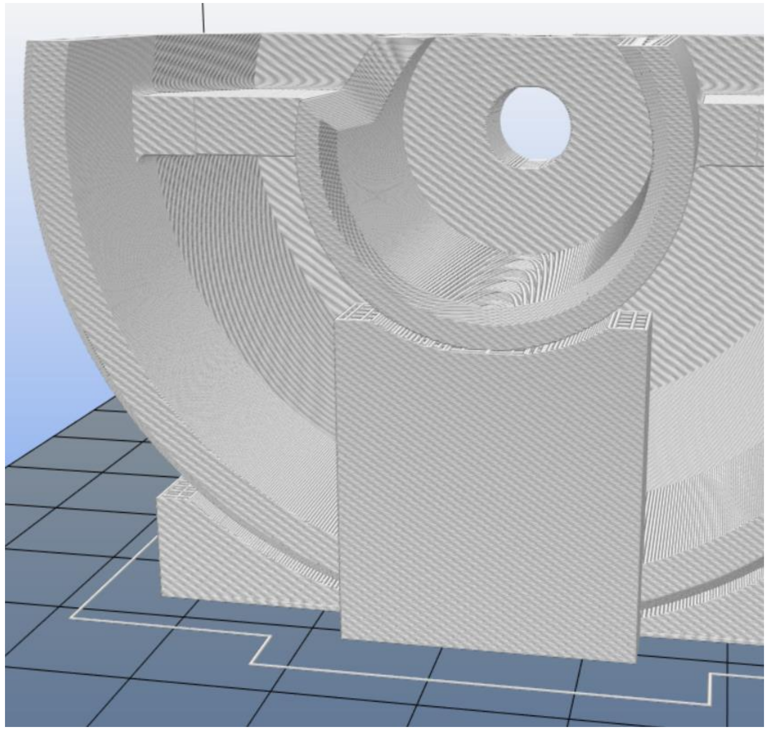
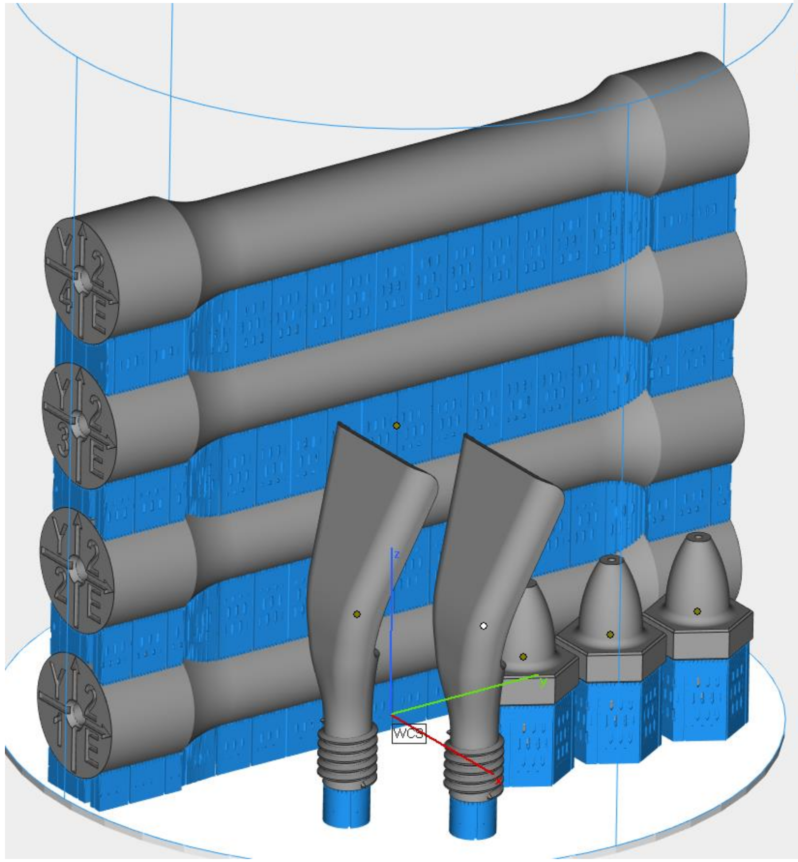
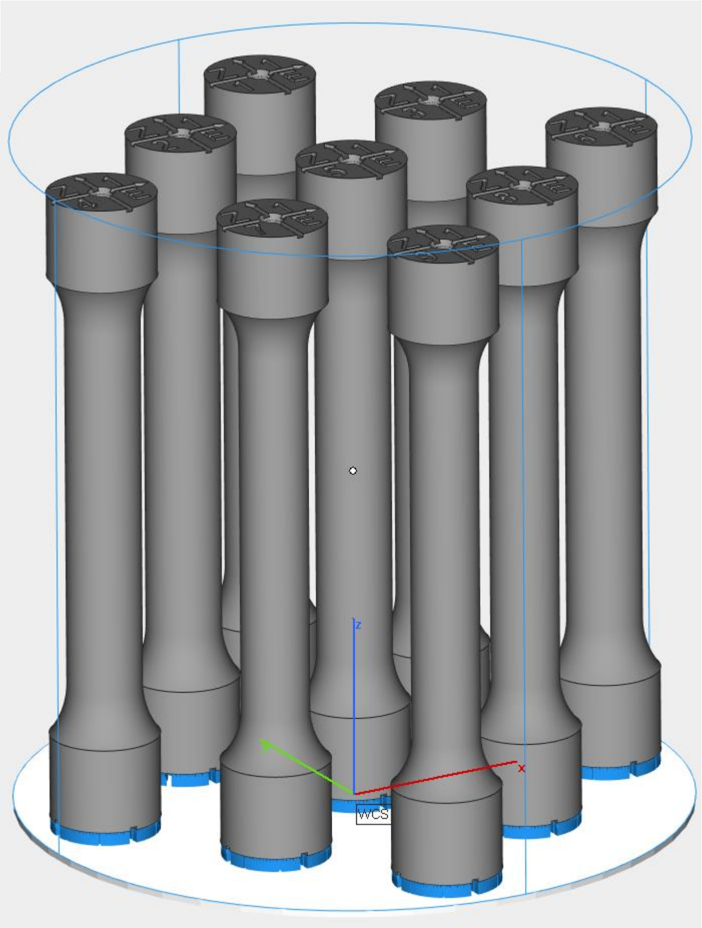
Support Structures







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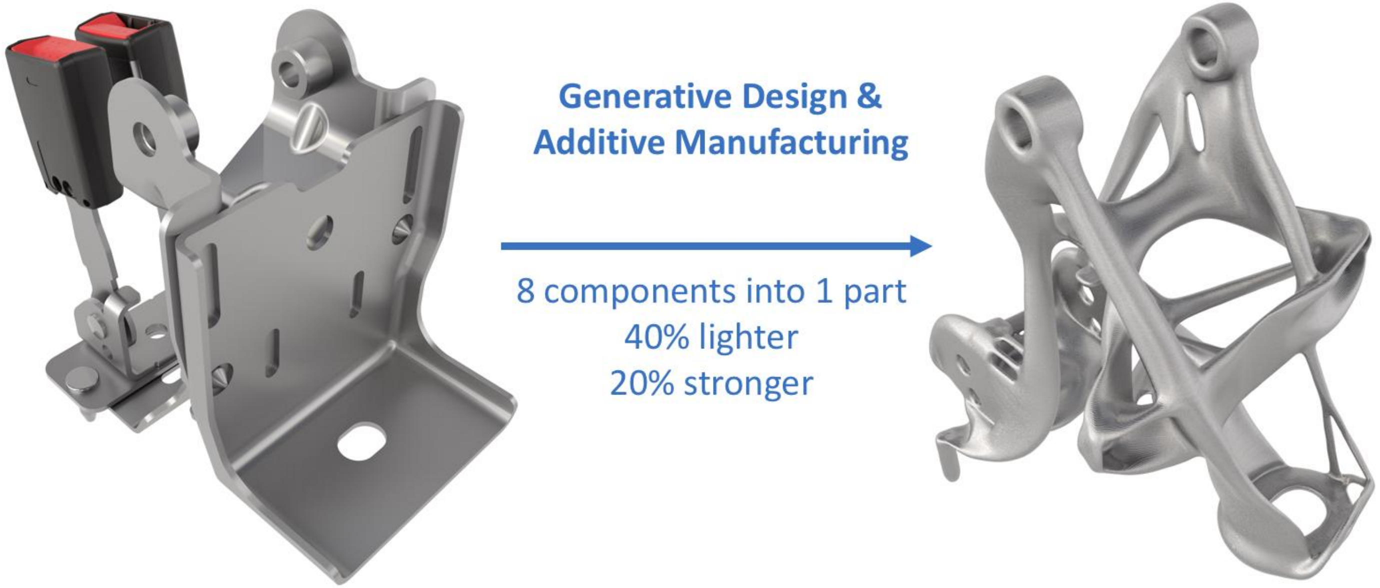
Design for AM

Rethinking structures and assemblies

Assemblies can be replaced by a single part:

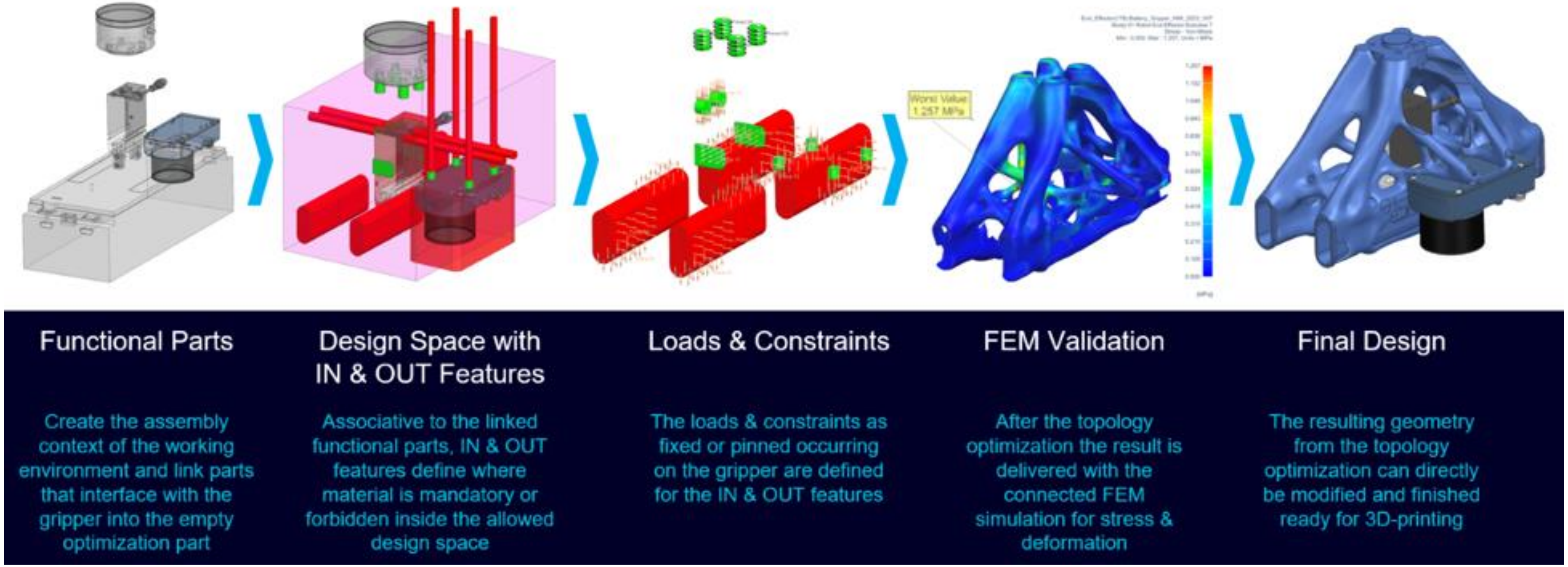
- Reduced weight
- Assembly phase speed-up
- Fewer parts that can have failures or defects
- Logistical benefits
- Topology optimization and generative design



[Autodesk]

Design for AM

Generative design



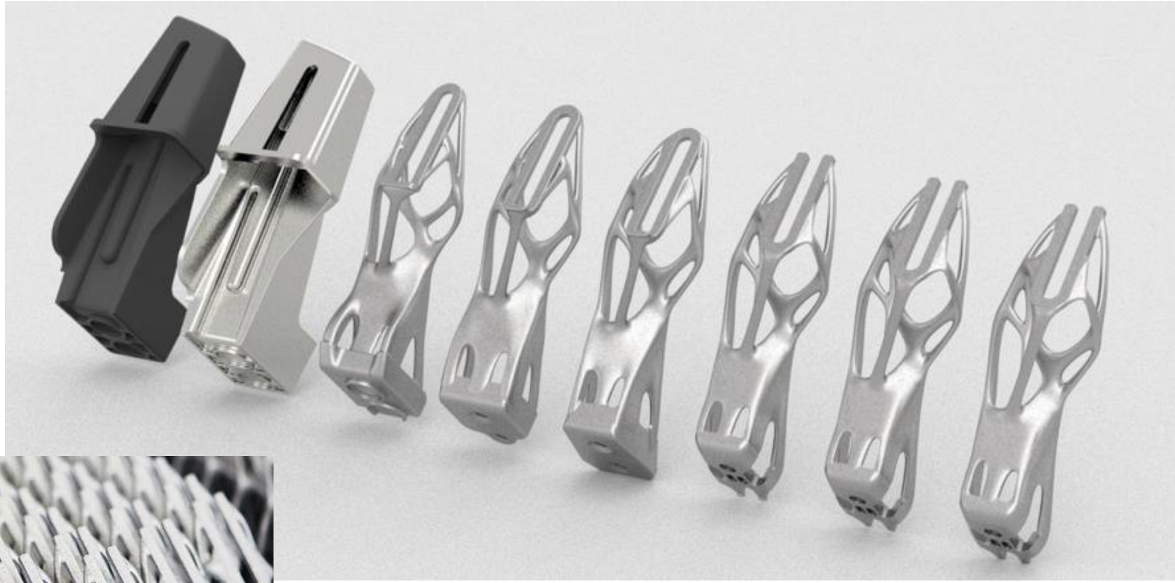
[Siemens]

Design for AM

Mass production

Process optimization for mass production

- Optimal orientation for minimization of the need for supports and post-processing
- Manufacturing as many parts as possible in one printing run (Nesting)



[BMW]

Design for AM

Nesting

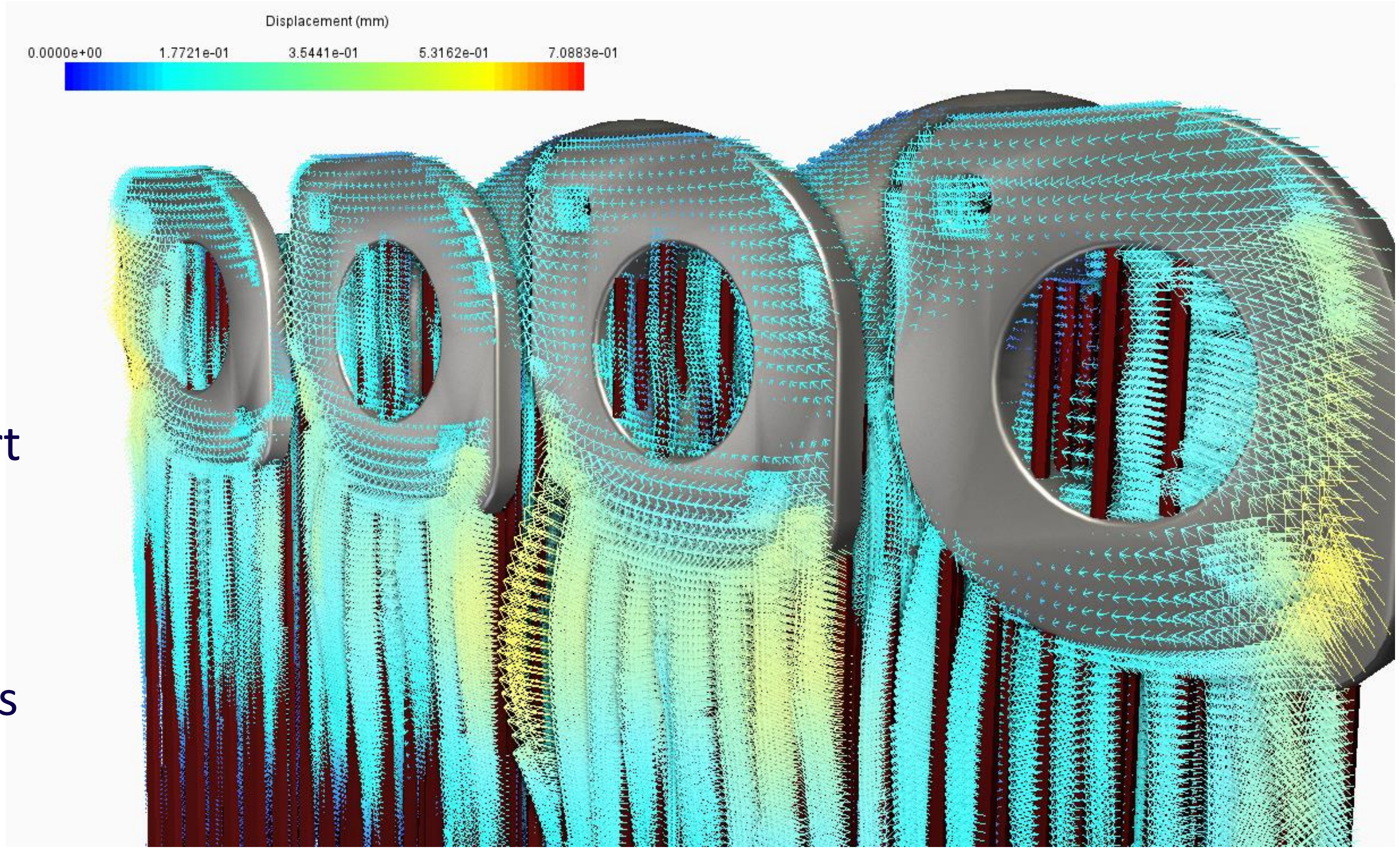
- The whole printing chamber is used during a printing run
- Possible to manufacture multiple different parts simultaneously
- Specialized programs available for Nesting

[3D Printing Industry]

Design for AM

Simulation

- Printing can be simulated
  - Testing the printing settings and avoiding possible issues
  - Minimizing the amount of support structures
  - Minimizing the printing time
  - Simulating the microstructure, shape variations, internal tensions



[Hubs]

Design for AM

Material Selection

- Balancing between technical requirements, costs, sustainability etc

	FDM	SLA	SLS
Pros	Low-cost consumer machines and materials available	Great value High accuracy Smooth surface finish Range of functional materials	Strong functional parts Design freedom No need for support structures
Cons	Low accuracy Low details Limited design compatibility High cost industrial machines if accuracy and high performance materials are needed	Sensitive to long exposure to UV light	More expensive hardware Limited material options
Applications	Low-cost rapid prototyping Basic proof-of-concept models Select end-use parts with high-end industrial machines and materials	Functional prototyping Patterns, molds, and tooling Dental applications Jewelry prototyping and casting Models and props	Functional prototyping Short-run, bridge, or custom manufacturing
Materials	Standard thermoplastics, such as ABS, PLA, and their various blends on consumer level machines. High performance composites on high cost industrial machines	Varieties of resin (thermosetting plastics). Standard, engineering (ABS-like, PP-like, flexible, heat-resistant), castable, dental, and medical (biocompatible). Pure silicone and ceramic.	Engineering thermoplastics. Nylon 11, nylon 12, glass or carbon-filled nylon composites, polypropylene, TPU (elastomer).

[FormLabs]

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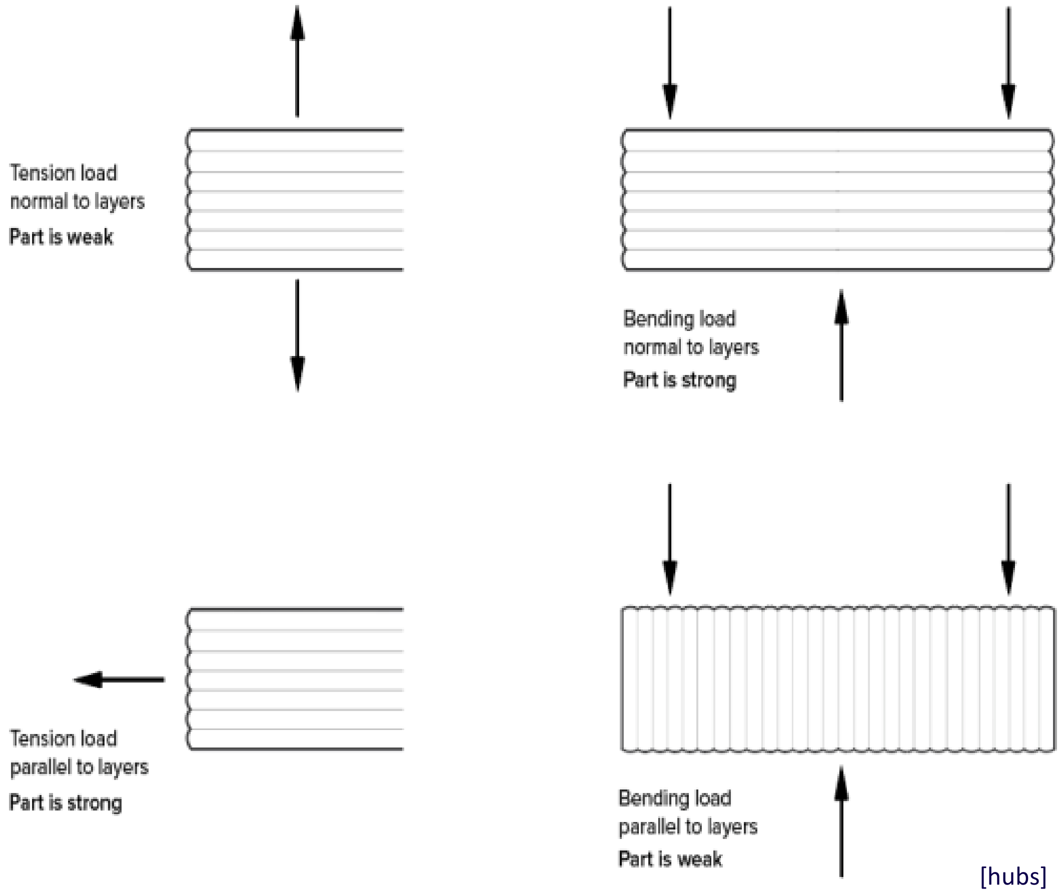
Design for AM

Material Selection

- AM parts are anisotropic
- Strength of the part can vary significantly depending on the printing orientation
- The layers can separate from each other (delamination)
- Must be taken into consideration especially in material extrusion –based AM



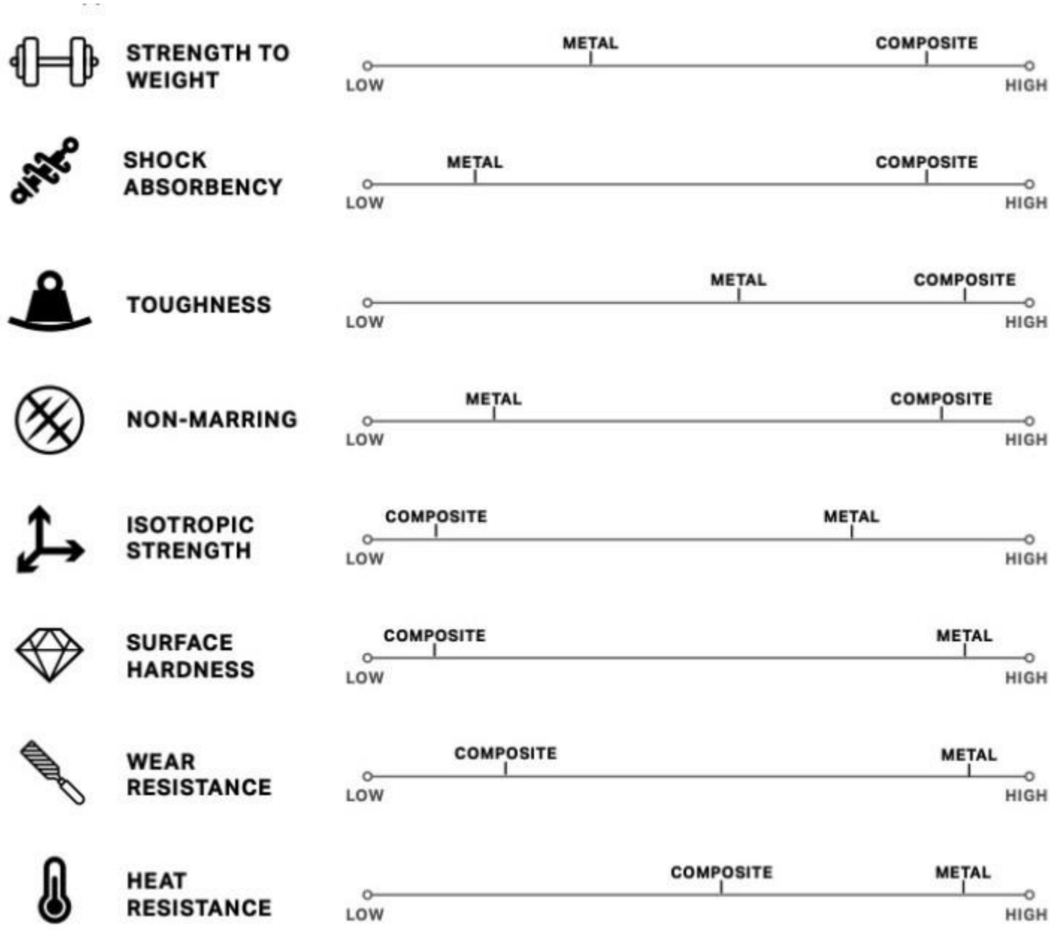
[hubs]

Design for AM

Material Selection

Technical requirements

- Comparison chart for metal and composite prints ->
- Materials selected depending on what is needed: Surface durability, strength etc.
- Combination of materials can be used

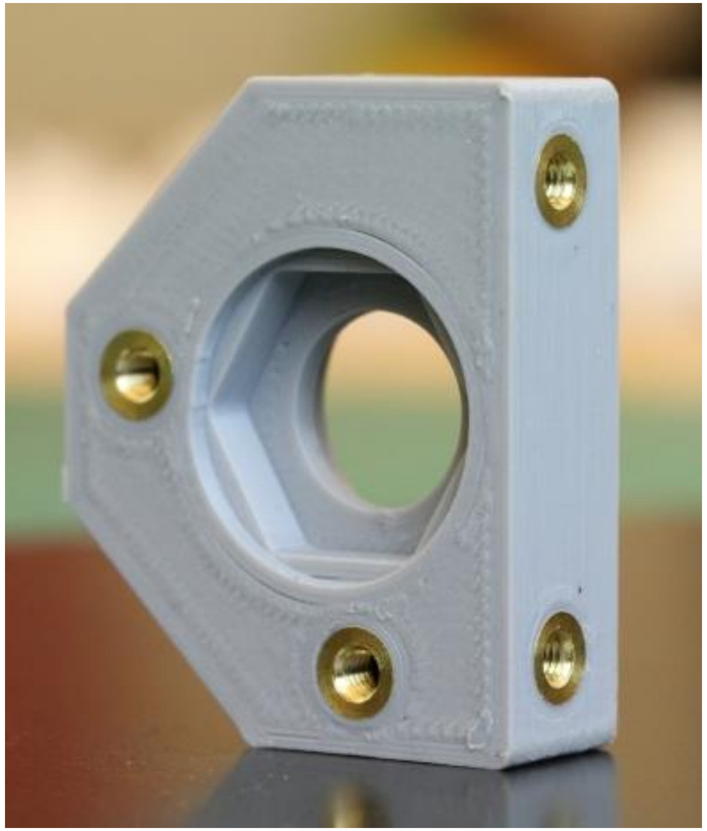


[Markforged]

Design for AM

Hybrid models

- Different kinds of 3D-prints can be combined both together and with various shelf components
- Metal insert in plastic parts for threads



[Hackaday]

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Hybrid models

- Combinations of materials used depending on what is needed: Surface durability, strength etc.

[Markforged]

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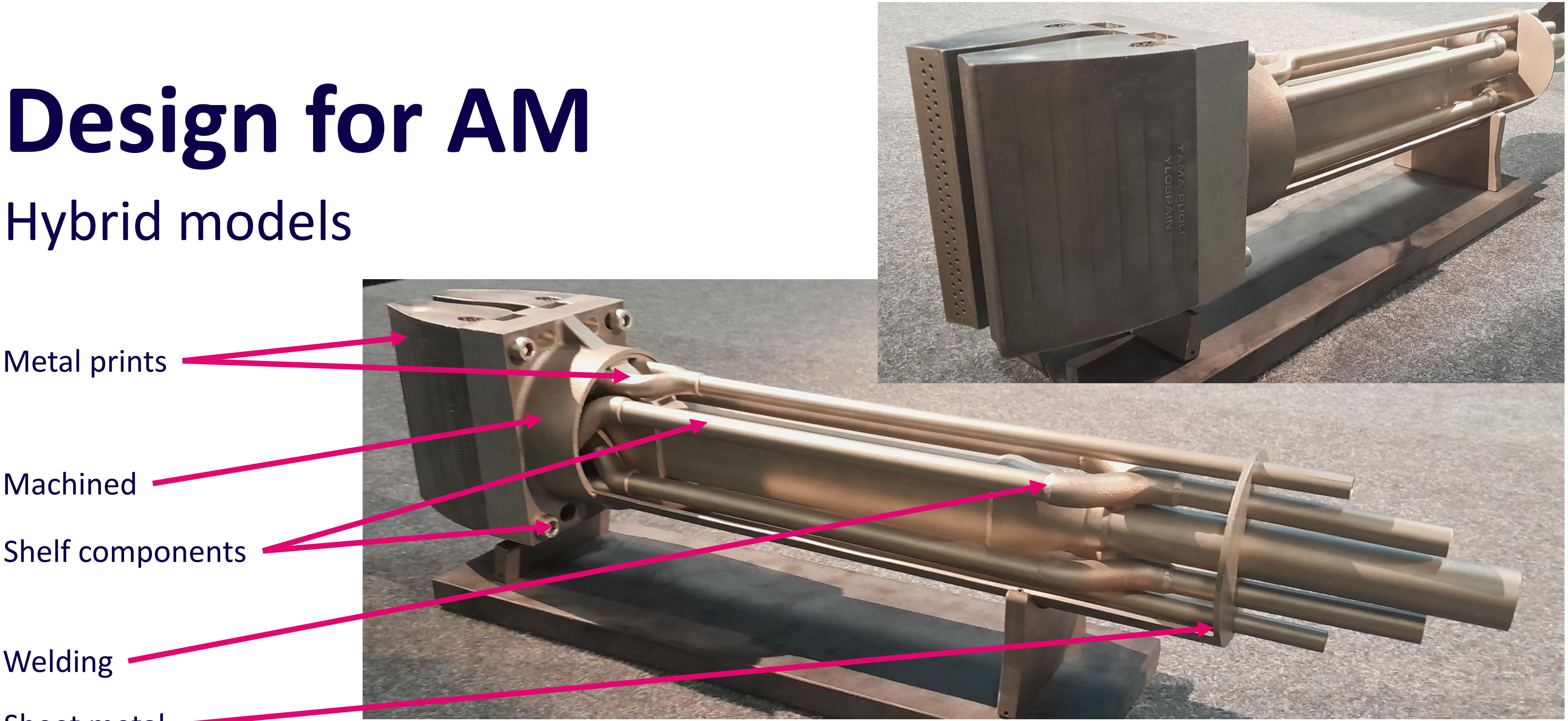
Hybrid models

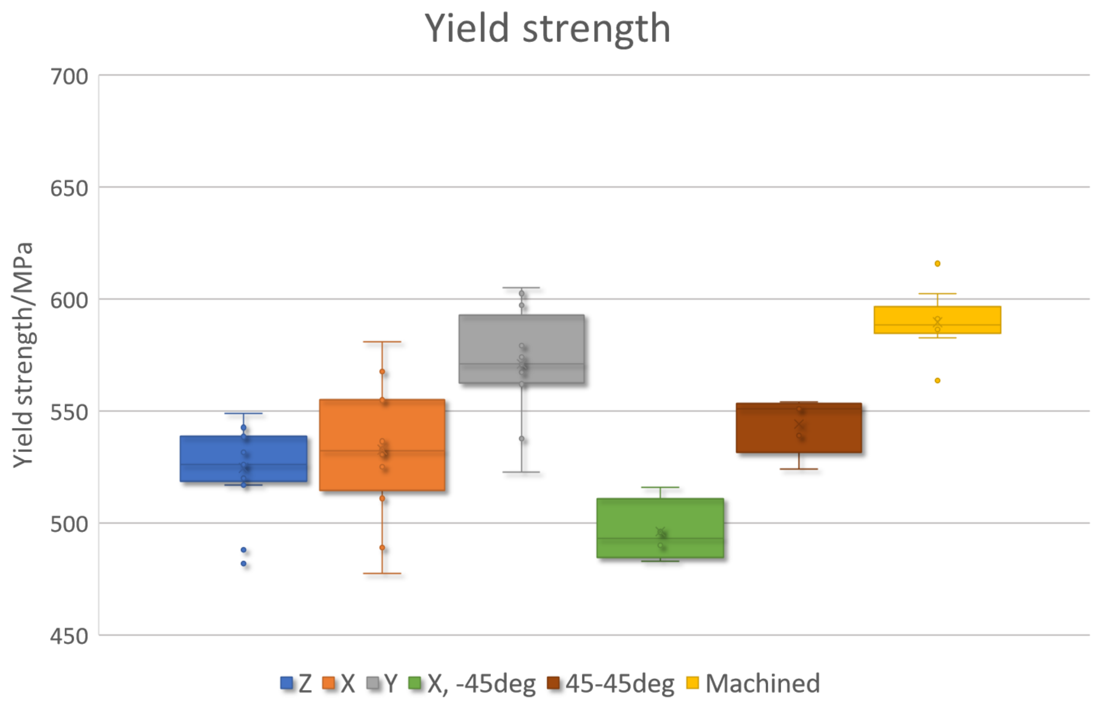


[Valco]

Design for AM

Strength of Metal prints & the effect of the orientation

- Metal prints under static loads are comparable to machined parts
- The printing orientation has a significant effect on the strength



Design for AM

Sustainable materials

Sustainable alternatives for printing materials are available, e.g.Y:

- Wood-based and other biodegradable bioplastics and -composites
- Filaments, pellets and powders can be made using recycled materials
- Cement-free concrete

[UPM]

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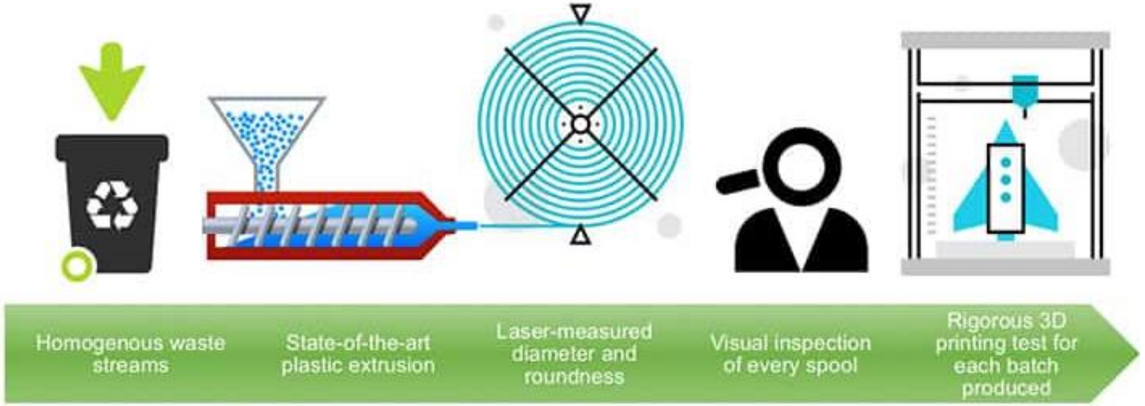
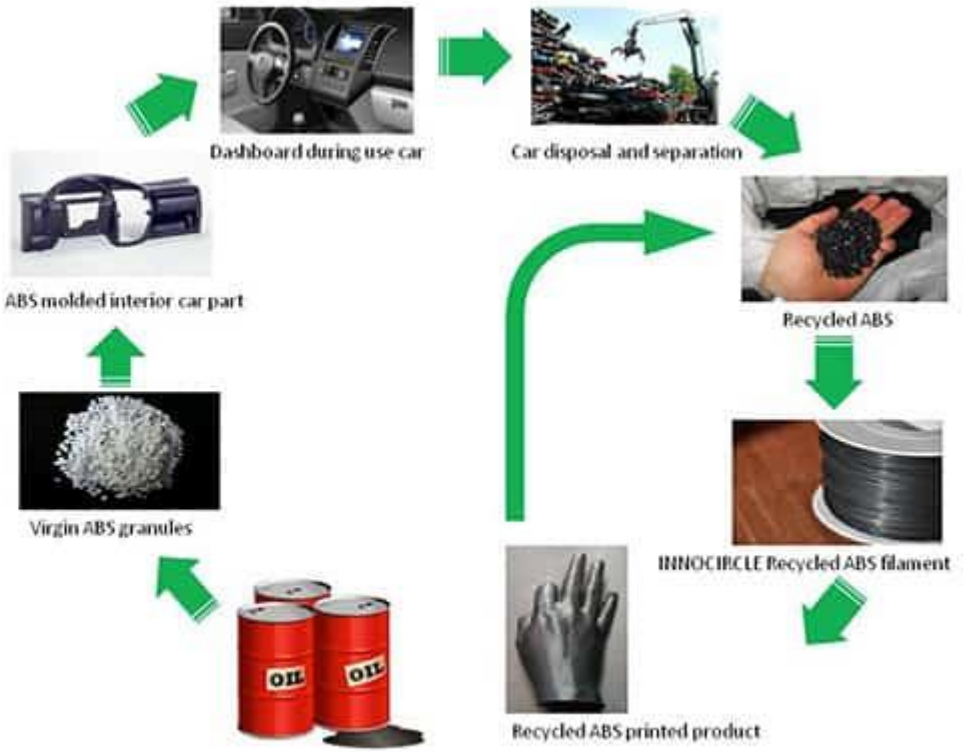
Design for AM

Usage of recycled materials

- Usage of recycled plastic
- Both normal plastic waste and waste from 3D-printing can be utilized





[3D Beginners]

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AM Materials

Recycling printing materials

Thermoplastics (Thermosoftening Plastics)

- No permanent chemical bonds, can be remelted – Easy to recycle
- Includes most filaments and powder bed materials

Thermosets (Thermosetting Plastics)

- Permanent chemical bonds are formed during printing and cannot be reversed – Not recyclable
- Includes most Photopolymerization materials

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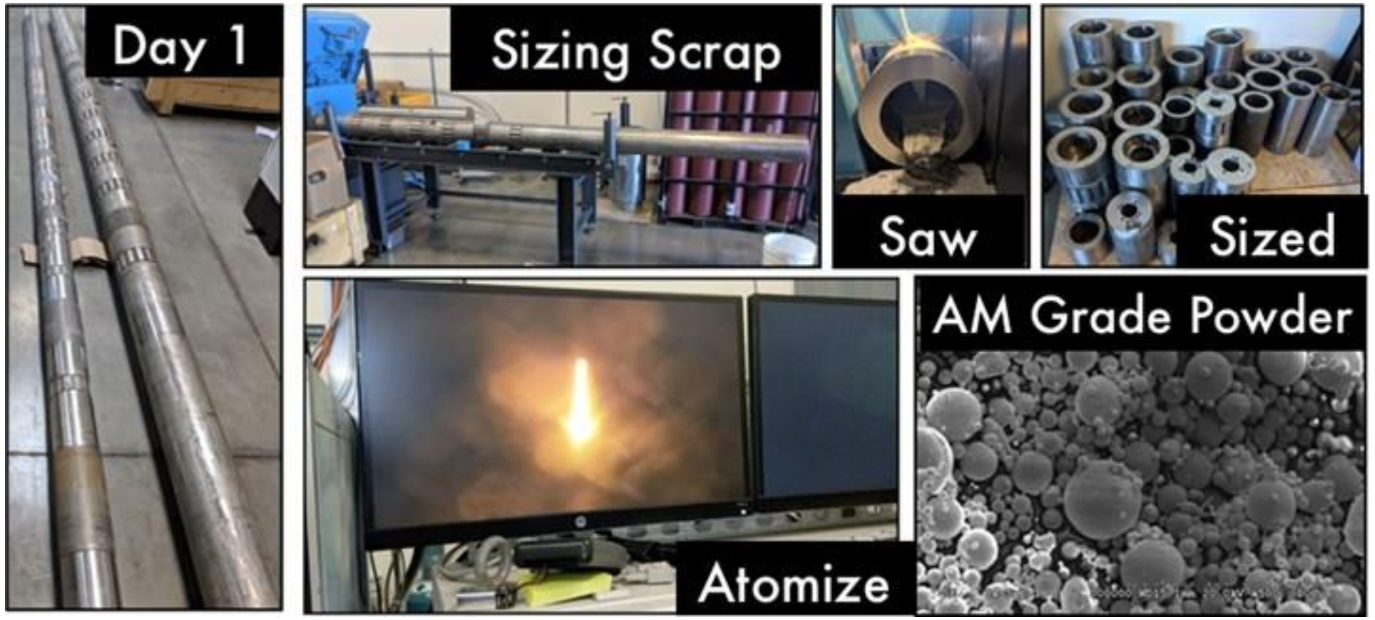
AM Materials

Recycling printing materials

- Metal powder for powder bed printers can be made from recycled materials and is already available
- Metal prints can be further recycled



[Additive Manufacturing]

Sustainable Design

Agenda2030

- A UN-lead global program for promoting Sustainable Development Goals (SDGs)
- National programs for reaching the goals
- Inclusion of whole society to Sustainability work

[UM]

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Sustainable Design

Agenda2030

- Is it possible to further the goals of Agenda 2030 through Additive Manufacturing?

[UM]

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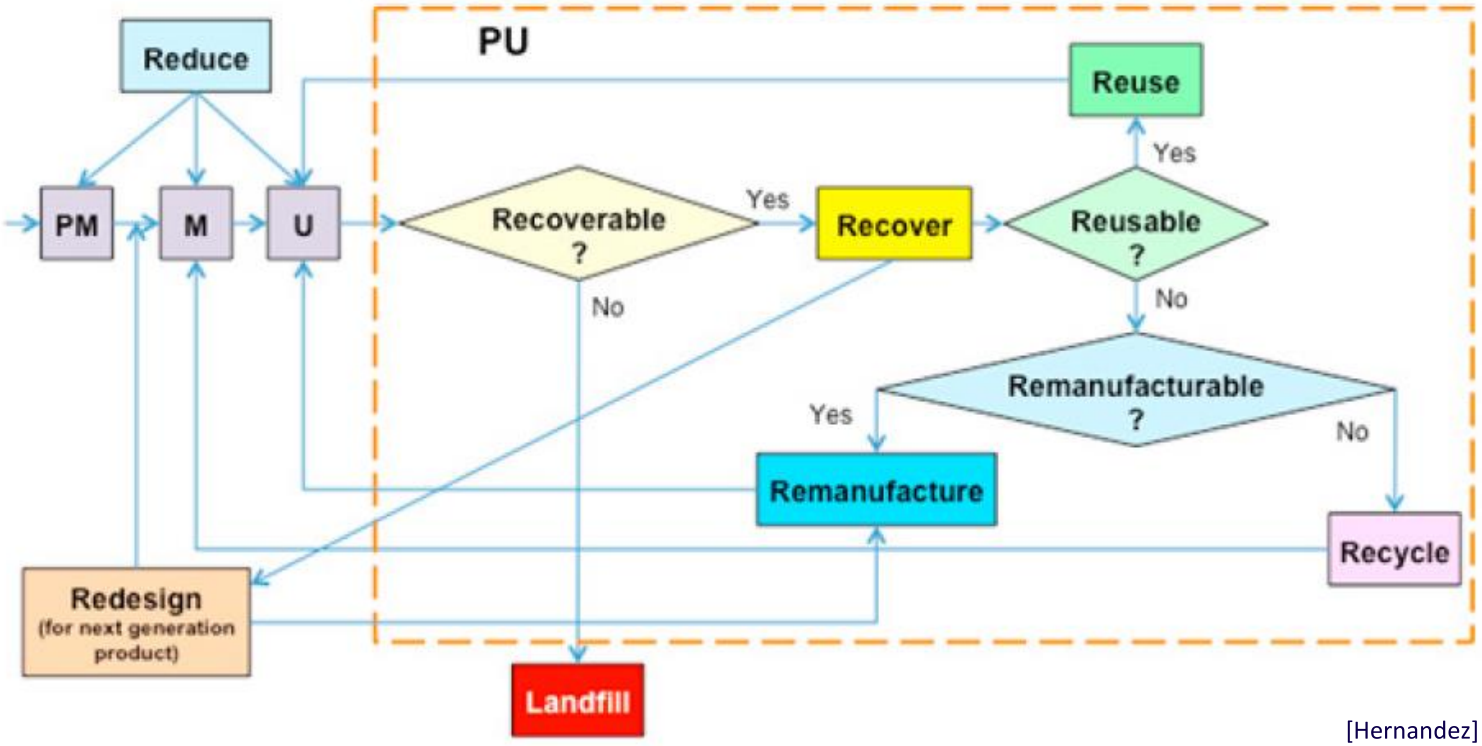
Sustainable Design

6R –model of Sustainable Design



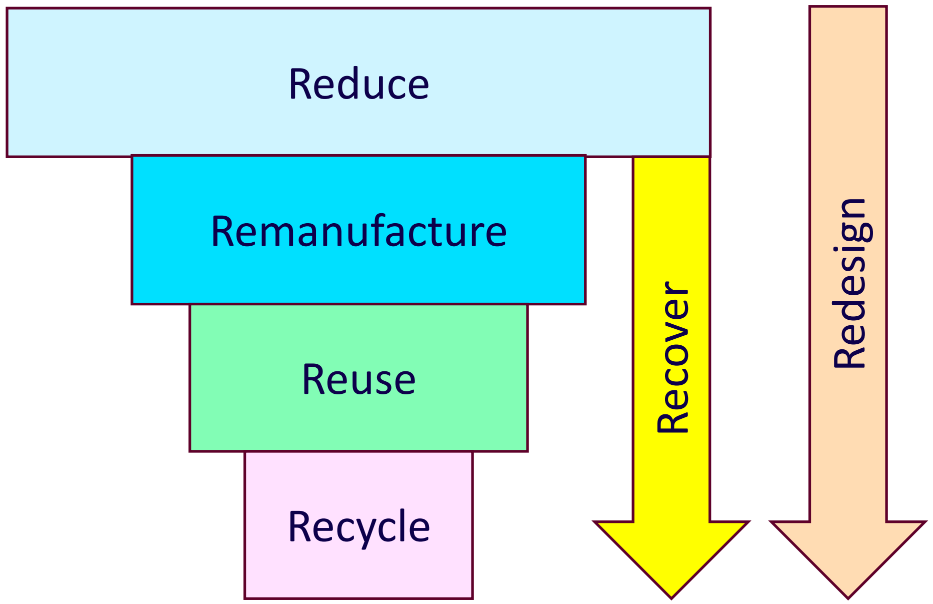
PM = Pre-Manufacturing stage
M = Manufacturing stage
U = Use stage
PU = Post-Use stage

[Hernandez]

Sustainable Design

6R –model of Sustainable Design

- Reduce
- Recover
- Remanufacture
- Reuse
- Recycle
- Redesign



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Sustainable Design

6R –model of Sustainable Design

- Reduce – Use of resources is reduced in every stage of the product lifecycle
- Recover – Disassembly of the product and sorting of recoverable components and materials
- Remanufacture – Product is refurbished, repaired or rebuilt using existing parts when possible
- Reuse – Components of the product are reused elsewhere
- Recycle – Materials from the product or it's components are recycled
- Redesign – The product is redesign, so that it is possible to reduce resource usage, repair and refurbish the product, reuse the components, and recycle the materuals

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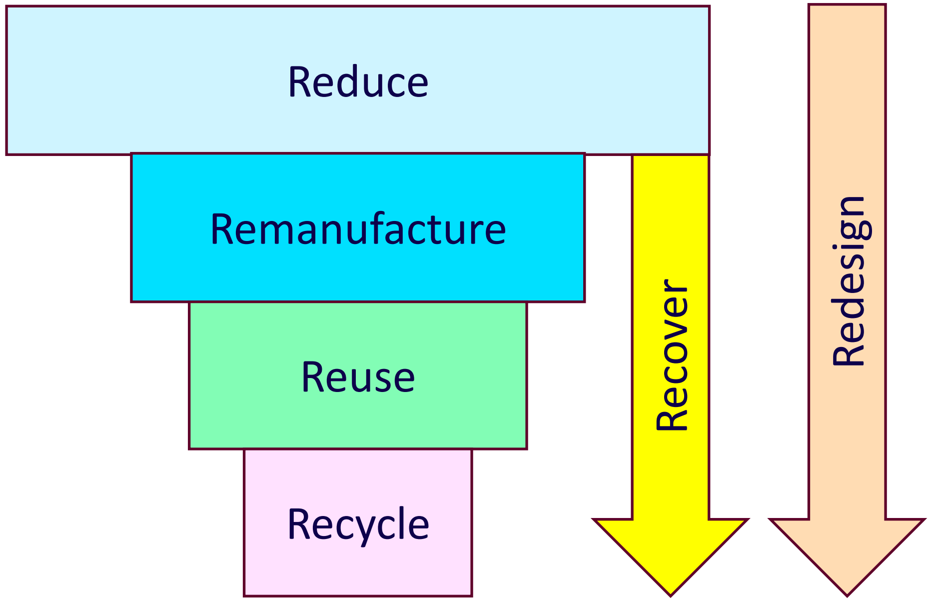
Sustainable Design

6R –model of Sustainable Design

- **Reduce**
- Recover
- **Remanufacture**
- Reuse
- **Recycle**
- **Redesign**



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Additive Manufacturing

Summary

- AM as a term is an umbrella for various printing methods
- AM is one method of manufacturing among the others
- Has it’s own pros and cons & requirements
- Does not replace any of the traditional methods of manufacturing directly, but supplements them
- Requires understanding and knowledge already in design phase
- Not only prototyping and playing around, but a serious manufacturing method, that is already widely used and growing rapidly

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Design for AM

Things to consider

- DfAM – is the part designed for printing?
- Deformations (bending, shrinkage) and especially in metal printing the effect of the temperature
- Detachment from the printing plate (sufficient surface area, additional support structures when needed)
- Material selection (temperature, chemicals, other requirements posed by the environment e.g. UV light)
- Utilizing the advantages of AM including Sustainable Design

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Feedback form

R3.9g - Tailored Lectures Activities
(spring semester 2025)

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Thank you!

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C6 – Manufacturing Technology

M4 – Additive Manufacturing Materials

P2 – University of Jaén

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About NextGEng Project

- Three-year Erasmus+ Cooperation Partnership project that started in October 2022
- International consortium consisting of 3 universities and 3 companies from European countries
- Project co-funded by the European Union and coordinated by Technical University of Cluj-Napoca, Romania

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NextGEng

About NextGEng Project

- **NextGEng Project** aims to create new pedagogical models that promotes international team-teaching with the support of new learning materials for existing courses in the curricula

NextGEng comprises three types of activities

Training

Tailored training program for teachers that sustain the skill improvement of HEI partners staff in new/innovative teaching methods.

International Team-Teaching

international pilot program.
Upgrade a set of engineering courses, belonging to the HEI partners curricula, in close collaboration with companies' partners.

CEL Projects

Cases of Experiential Learning projects.
Type of projects where students learn by doing in an international and multidisciplinary environment.

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Content

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NextGEng

Introduction

Introduction

General aspects of 3D printing processes

- **Additive Manufacturing:**

Revolutionary technology with a lot of possibilities. It creates 3D objects layer by layer from a digital design.

- **Key factors:**

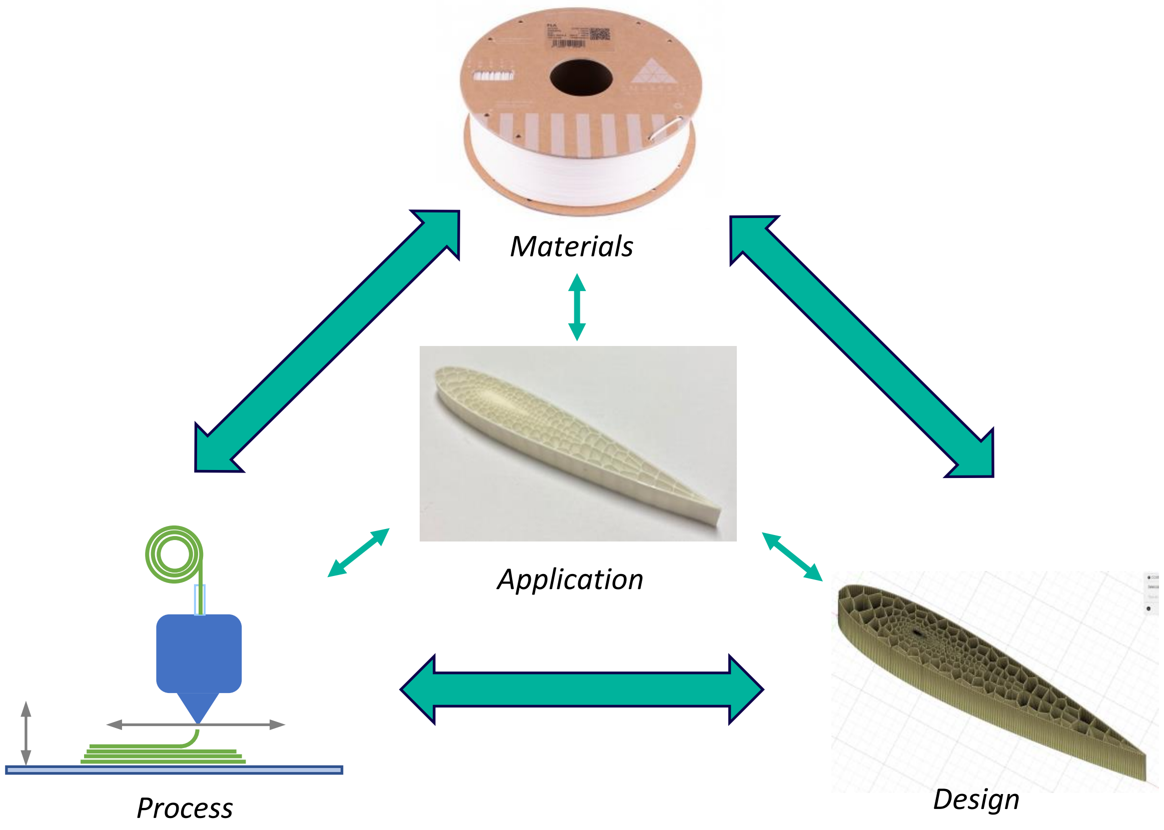
Wide range of materials that can be used to produce objects with different properties and characteristics. These include plastics, metals, ceramics, composites, and even biological materials

It enables the production of **complex and intricate designs** that were previously very difficult to create.

- **Construction diagram:**

There is a relationship between the additive manufacturing process, the material and the design.

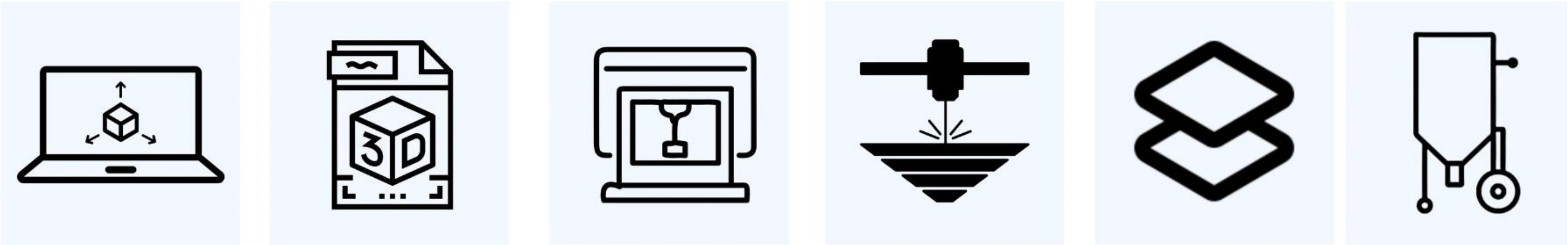
The development of new materials leads to more complex designs that allow the manufacture of parts with increasingly novel applications.



Construction diagram

Introduction

- **How does AM work? Steps of an Additive Manufacturing process**



1. Design of digital 3D model with a CAD software
2. Design discretization. Generation and manipulation of the STL file
3. Process machine setup
4. Building part layer-by-layer
5. Part and support structures removal
6. Post-processing techniques

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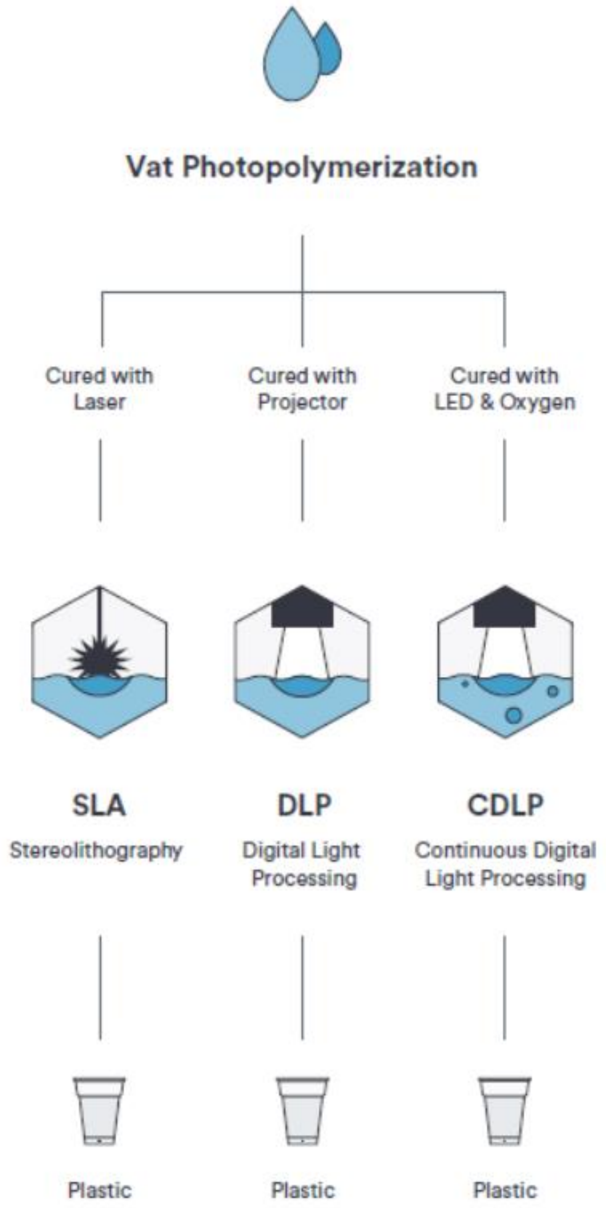
Introduction

- **Additive Manufacturing technologies**

The International Organization for Standardization created the ISO/ASTM standard 52900 to standardize the exploding terminology around 3D printing. 3D printers can be categorized into one of **seven types of processes**:

1. **Vat Photopolymerization:** liquid photopolymer resin is being exposed to certain wavelengths of light and becoming solid



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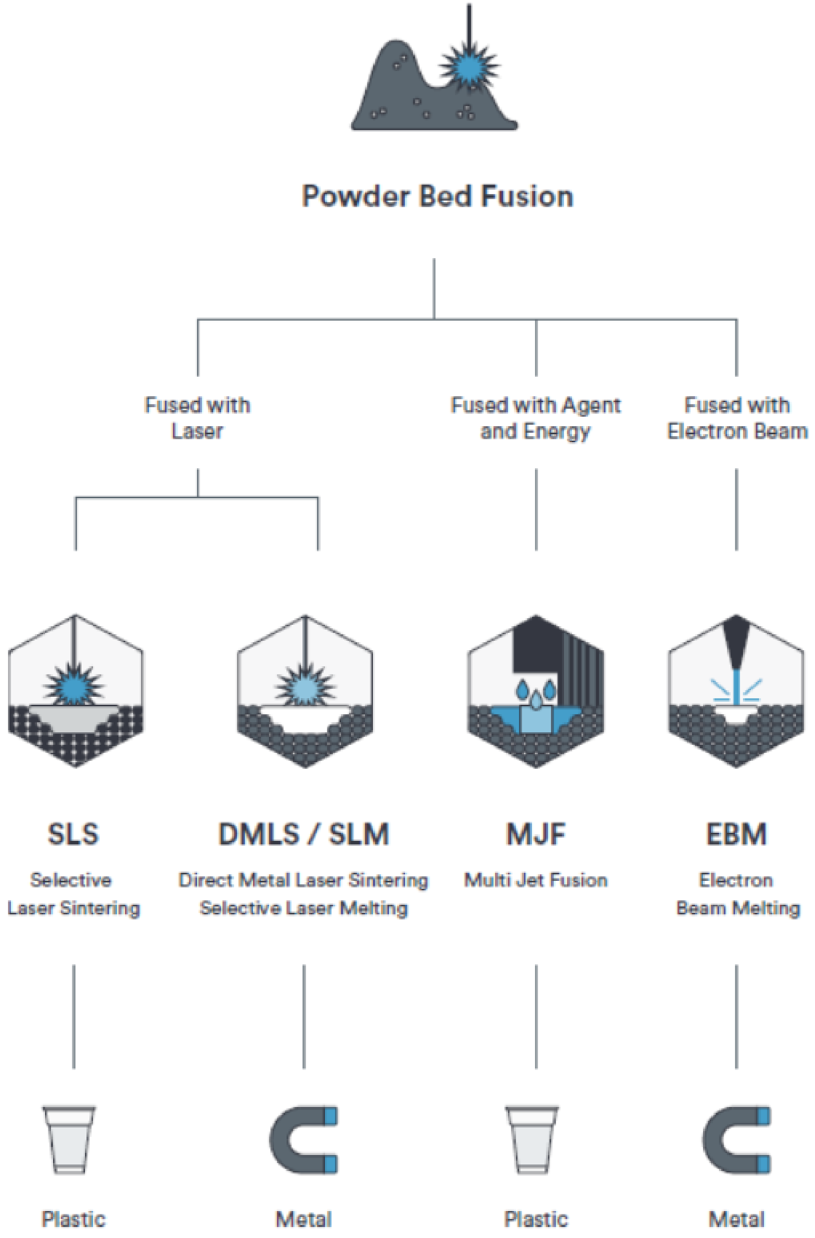

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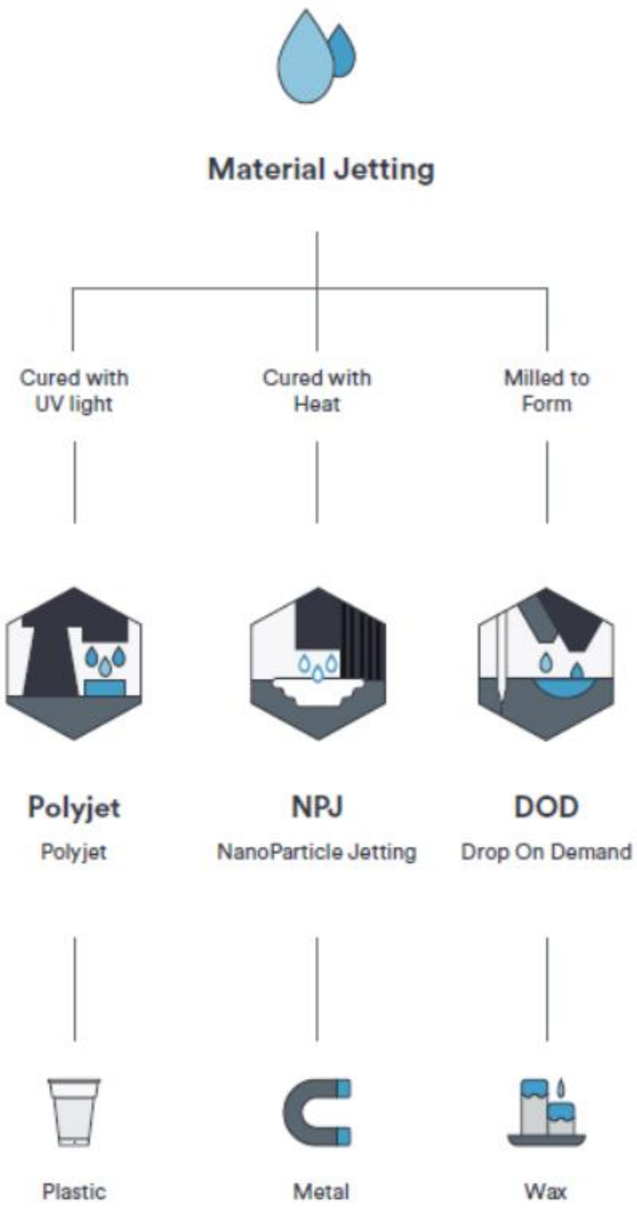

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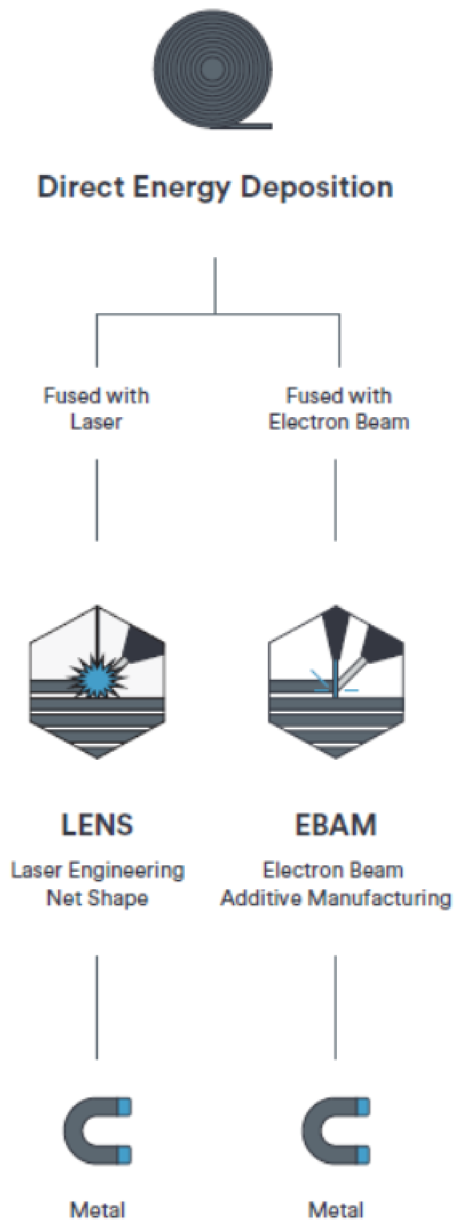

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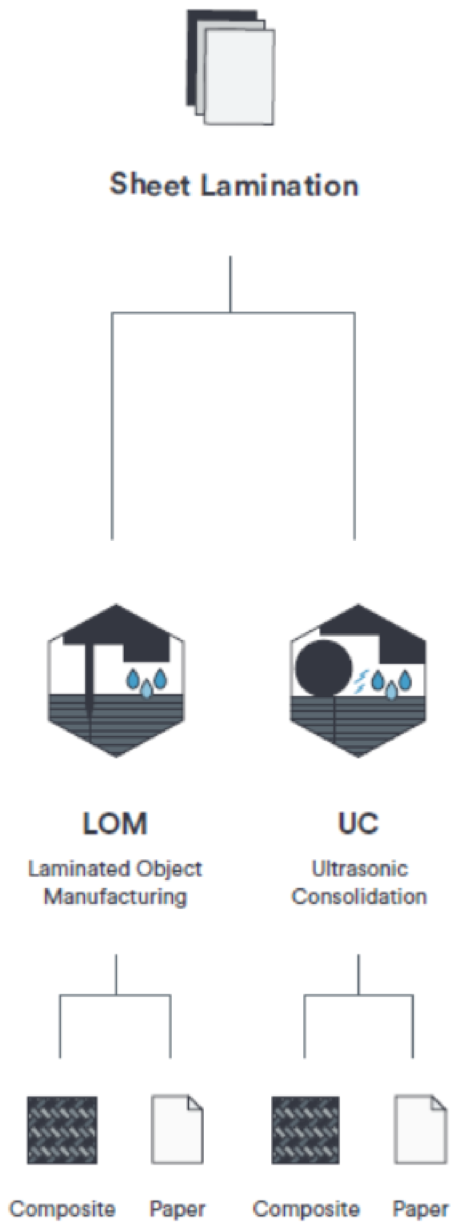
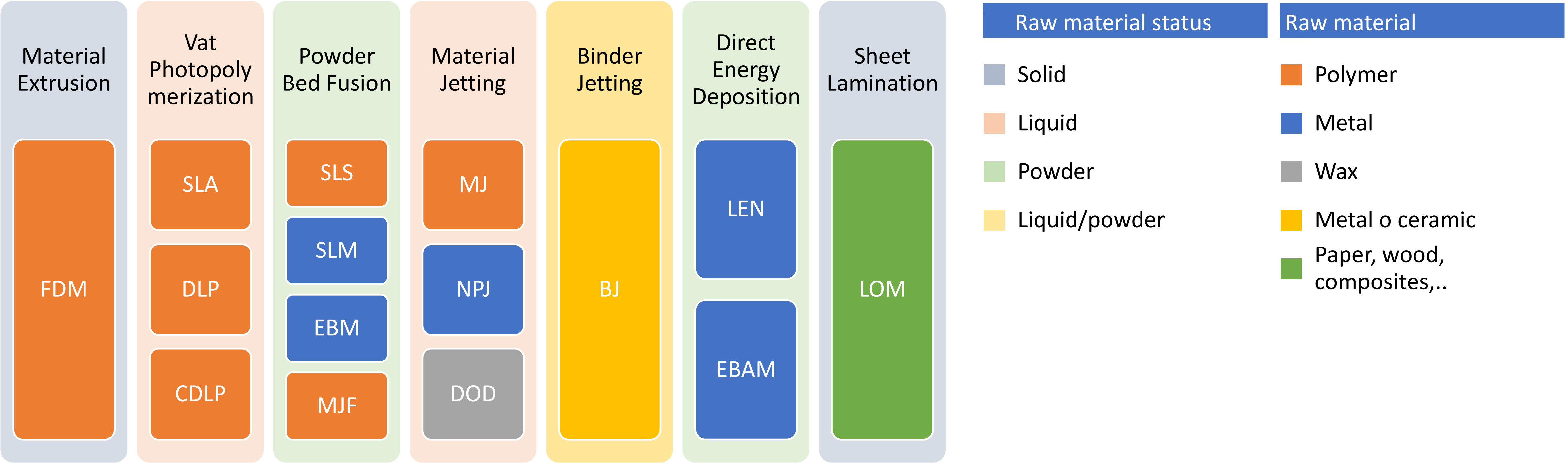
6. **Direct Energy Deposition**: molten metal simultaneously deposited and fused
7. **Sheet Lamination:** individual sheets of material are cut to shape and laminated together



Introduction

- **Additive Manufacturing materials according to technologies**

  Diagram showing the main materials arranged according to technology



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Topic 1: Most used 3d printing materials

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1.1 Polymers

3D printing polymer materials in liquid state or with low melting point are widely used in 3D printing industry due to their **low cost, low weight and processing flexibility**

FDM Classics Thermoplastic Polymers:

- Polylactic acid (PLA)
- Acrylonitrile butadiene styrene (ABS)
- Polyethylene terephthalate glycol-modified (PETG)
- Acrylonitrile Styrene Acrylate (ASA)
- Thermoplastic Polyurethane (TPU)
- Polypropylene (PP)
- Polyvinyl Alcohol (PVA)

Applications:

- Prototyping
- Aerospace and aerodynamic applications
- Automotive industry
- Artistic objects
- Household items
- Maintenance

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1.1 Polymers

PLA (Polylactic acid)

- One of the most popular polymer materials
- Obtained through the starch extracted from corn, beet, or sugar cane

- Simple printing
- Wide variety of colors and patterns
- Biodegradable
- Low melting point
- Lack of toxicity or irritation
- Good biocompatibility

- Brittle
- Weak mechanical properties.

Applications:
Prototyping, models, DIY projects, artistic objects, household items, low-wear toys, packaging, and biomedical applications

1.1 Polymers

ABS (Acrylonitrile butadiene styrene)

- Another popular material
- It comes from petroleum

- Good mechanical qualities
- Good impact, chemical, and abrasion resistance
- Withstands higher temperatures
- Easily machined

- Not biodegradable
- Dangerous fumes
- Requires heated bed
- Prone to warping

Applications:
Phone covers, high-wear toys, tool handles, automotive trim components, and electrical enclosures

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1.1 Polymers

PETG (Polyethylene terephthalate glycol-modified)

- An increasing popular material

- Flexible and strong
- Simple to print
- Very good chemical resistance
- Good resistance against water and UV light
- Biocompatible

- Prone to dampness
- Easily scratched

Applications:
Mechanical parts, printer parts, and protective components.

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1.1 Polymers

ASA (Acrylonitrile Styrene Acrylate)

- An alternative to ABS
- Can withstand environmental conditions

- Good dimensional stability
- Superior UV resistance
- Thermal stability
- Durability
- Allow machined processing

- Difficult to print
- Close chamber recommended

Applications:
Parts exposed to sunshine and for outdoor applications.
Automobile sector.

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1.1 Polymers

TPU (Thermoplastic Polyurethane)

- Flexible polymers with rubber-like qualities
- They can be stretched to moderate elongations and return to their original shape.

- Extremely flexible and durable
- Flexible properties support low temperatures
- Good abrasion resistance.
- Good resistance to oils and greases.

- Very challenging to print
- High temperature sensitivity

Applications:
Automotive components, home appliances, and medical supplies that require parts that can bend or compress. Manufacturing of shock absorbers.

1.1 Polymers

PP (Polypropylene)

- Very light polymer with a certain flexibility
- Its density is lower than water, can float

- Strong mechanical qualities
- Good resistance to impact and fatigue
- High chemical resistance
- Low friction

- Very difficult to print.
- High deformation in the base
- Difficult to adhere to the base
- Machining leaves surface imperfections

Applications:
Functional parts that need to be durable, resistant to chemicals, and wear resistant. Food packaging.

1.1 Polymers

PVA (Polyvinyl Alcohol)

- Water-soluble polymer used as a support material in intricate 3D printing designs

- 100% biodegradable
- Dissolution residues are non-toxic
- It dissolves very quickly in water

- Just for support

Applications:
Support material for the construction of complex geometries with multi-extrusion printers.

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1.1 Polymers

Stereolithography (SLA)

- Liquid monomers, called **photopolymer resin**, are tied together to form polymers
- Resins consist of additives namely stabilizers, flexibilities, monomers/oligomers, solvent, photo-initiators, and reactive diluents etc.

Materials	Properties	Applications/ Industries
DC 100	**Lesser shrinkage** with higher accuracy.	Used for the casting of patterns for pieces of jewelry.
DC 500	**Like wax** in nature and can easily burn out.	For the making of precise and thinner wire patterns of jewelry.
DL 350	**Highly flexible and resistant** to fatigue and chemicals etc	Used to produce parts for industrial as well as general purposes.
DL 360	**Strong and transparent** in nature.	Produces parts for general purposes which require transparent properties.
AB 001	Provides **good strength and stiffness** and electrical characteristics	Used for producing parts that are strong and smooth in nature.
GM 08	Highly **flexible, strong and elastic**.	Produces parts that don't require further finishing operations
DM 210	Great **surface qualities** and including ceramic-type properties.	Used for jewellery patterns that require liquid silicone that can be extracted quite easily from rubber

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1.2 Metals

3D metal printing has gained popularity in recent years

Most frequently used materials in 3D metal printing

- Cobalt–chromium alloy
- Stainless steel 316L
- Aluminum6061
- Titanium Ti6Al4V

Applications

- Automation
- Healthcare
- Aerospace industries
- Military industry

Main technologies

- Selective Laser Melting (SLM) / Electron Beam Melting (EBM)
- Binder Jet (BJ)
- Direct Energy Deposition (DED) / Laser Metal Deposition (LMD)

1.2 Metals

Selective Laser Melting (SLM) / Electron Beam Melting (EBM)

Materials	Properties	Applications/ Industries
Titanium	Resistance to corrosion and thermal expansion with great **biological compatibility,** along with the **high strength and lower density**.	Its applications are included in but not limited to design, medical, automotive, aerospace, marine industry, and jewelry industries, etc.
Stainless Steel	Increased **resistance** to wear and tear, corrosion, along with compatible **ductility, hardness, and hardenability**.	Application in automotive industry, maritime and medical technology, toolmaking and in varied areas of mechanical engineering
Aluminium	Light metal with **low density** and **good electrical conductivity**. Easy to process abilities.	Used in aerospace engineering, automotive industry, in the area of prototype construction with complicated geometries.
Cobalt-Chrome	**Biologically compatible**, with increased **hardness**, corrosion resistance with comparable strength.	In the medical and dental field, and industries requiring greater thermal resistant properties for example in jet engines
Nickel based alloys	Great **weldability** and **hardenability** along with the resistance to corrosion and mechanical strength.	Used in aerospace engineering and fields requiring thermal resistant properties also have applications in tool making.

Titanium

Stainless steel

1.2 Metals

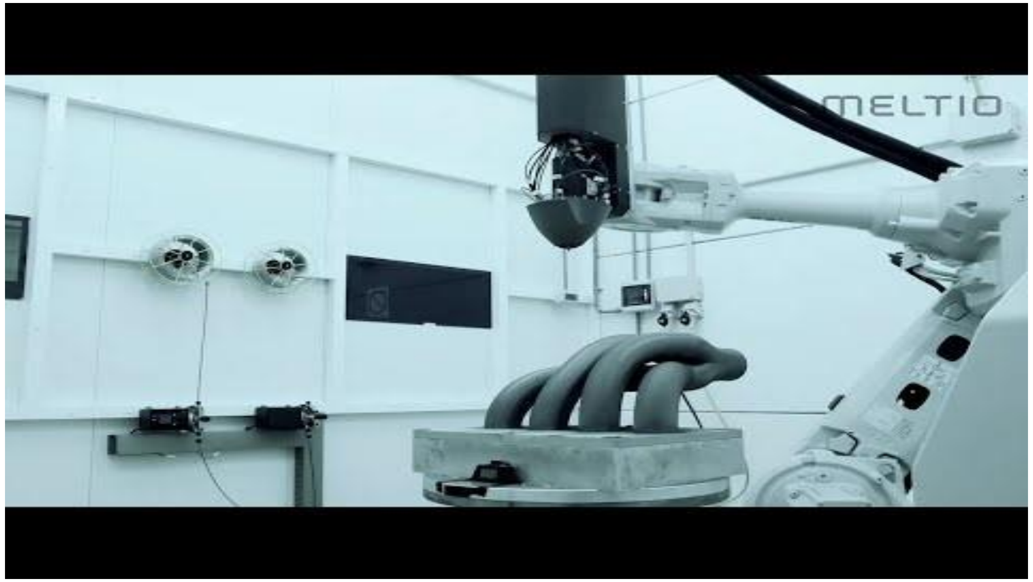
Binder Jet (BJ)

Materials	Properties	Applications/ Industries
Stainless steel	Resistant to heat and corrosion with greater tensile strength.	Used for parts of pump, drilling and mining machinery
Inconel alloy	Supplementing the product with good mechanical properties and even greater density.	Used for the manufacturing of gas turbine blades, for producing steam generators used in pressurized nuclear water reactors, seals and also in pressure vessels, these are widely applicable in the aerospace industry.
Iron	Provides better mechanical properties and is also excellent wear resistant.	Applications are in the production and repairing of automotive components, tooling, and also in machine tools, along with this they are also popular in decorative hardware.

1.2 Metals

Direct Energy Deposition (DED) / Laser Metal Deposition (LMD)

Rocket Nozzle
SS316L
Size:117 x 117 x 180 mm
Weight:3 kg



Materials	Properties	Applications/ Industries
Titanium	Resistance to corrosion and thermal expansion with great biological compatibility, along with high strength and lower density	Used for repairing works in the automation and aerospace industry
Aluminium	Light metal with lower density and better electrical conductivity with alloying properties and easy to process abilities.	Filling of cracks and refitting of manufactured parts
Stainless steel	Resistant to heat and corrosion with greater tensile strength.	Repairing of turbine engines, and other such complex applications
Copper	Malleable, ductile, and better surface finish.	Industrial applications
Inconel	Good mechanical properties and greater density	Aerospace, biomedical applications

1.3 Others Materials

Composites

Composite materials are composed of two or more substances with combined properties that are different from the original components. They typically consist of a matrix and a reinforcement. Composite materials with the **exceptional versatility, low weight, and tailorable properties** have been revolutionizing high-performance industries.

Carbon fibers reinforced polymer composites

- Widely used in aerospace industry.
- High specific stiffness and strength
- Good corrosion resistance and good fatigue performance

Glass fibers reinforced polymer composite:

- Used for various applications
- Cost effectiveness and high-performance
- High thermal conductivity and relatively low coefficient of thermal expansion
- Cannot burn, and it not affected by curing temperatures used in manufacturing processes

1.3 Others Materials

Other FDM materials

Composites materials with a polymeric matrix and fibers of another material, such as wood, ceramic, metal, etc.
Other materials with a low melting point that can be extruded.

Materials	Properties	Applications/ Industries	
Ceramic Slurries and Clay	Alumina, Zirconia, Kaolin	Chemical and physical stability, heat resistance, and compatible thermal conductivity, strength and hardness.	General purpose uses along with the applications in dental field as well
Green Ceramic/Binder Mixture	Zirconia, Calcium phosphate	Resistance to chemicals and corrosion, hardness, wear-resistance, thermal, lower electrical and thermal conductivity and non-magnetic in nature, etc.	Structures suitable for bone substitute scaffolds, and for making piezoelectric components.
Green Metal/ Binder Mixture	Stainless steel, Titanium, Inconel, Copper	Providing binder viscosity, flowability, greater sintered density, leads to the homogeneous microstructure of parts. Results in strong, light and corrosion resistant properties	For the manufacturing of mechanical parts used in tooling and fixtures etc.
Food pastes	Sugars and Chocolates	Flowability	Cooking
Biological Materials	Bioink	Easy to print, with desired mechanical properties, can be easily biodegraded, and we can easily install modifiable functional groups on the surface. Post-printing maturation.	Bioprinted organs and scaffolds

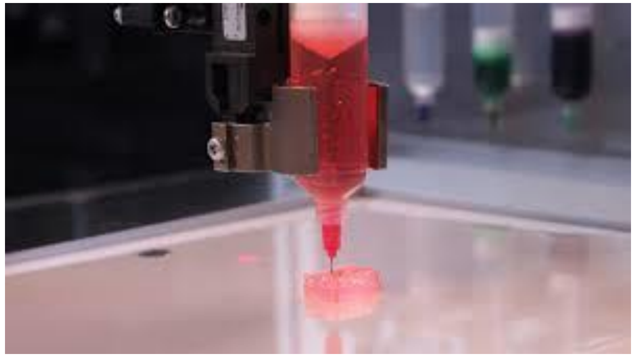
1.3 Others Materials

Other FDM materials

FDM ceramic parts

FDM Ultrafuse® 316L (comparable to stainless steel 1.4404) part

FDM Chocolate



FDM Bioink

1.3 Others Materials

Ceramic materials

3D printing technology can produce 3D printed object by using ceramics and concrete without large pores or any cracks.

- Ceramic **is strong, durable and thermal resistan**t.
- Ceramics materials is useful in the dental and aerospace application or construction
- Most used ceramics materials are **alumina, bioactive glasses and zirconia**.
- Difficult to print and curing complexity. They need **debinding and sintering**
- Used technologies:
    - **FDM**: Composite filament
    - **SLA**: Ceramic resins
    - **BJ**: Ceramic powder

Topic 2: New trends in 3D printing materials

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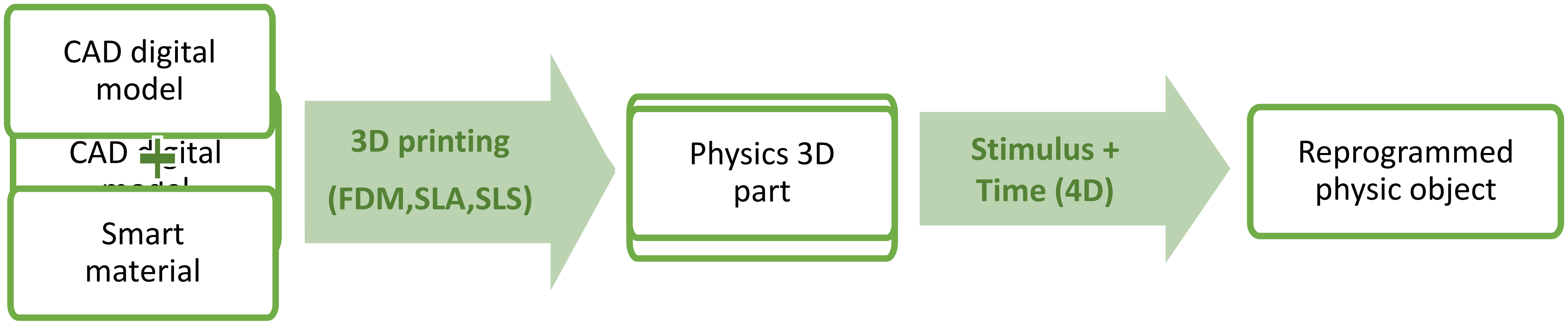
2.1 4D Printing

4D printing concept

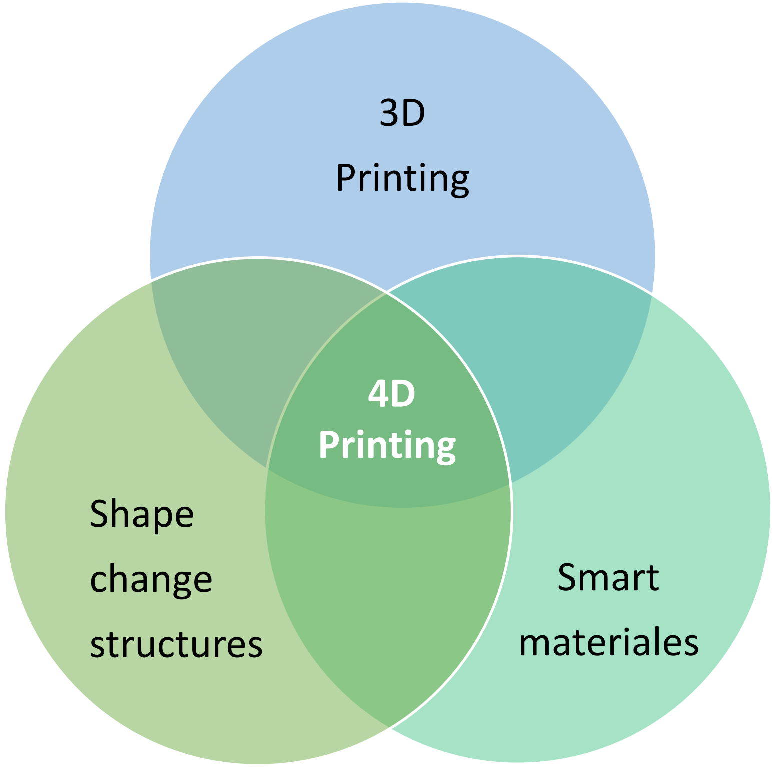
- 4D printing is a evolution process from 3D printing, that offers shape or functionality changes of the printed objects after manufacturing.
- 4D printing gets one plus dimension: **The time**

4D printing process



2.1 4D Printing

4D printing materials



Smart materials

- Development of 4D printing is linked to development of smart materials.
- Smart materials can change their shape, colors, mechanicals properties, transparence, etc.
- Changes occur when subjected to a non-mechanical field (thermic, electric, magnetic, optic, etc.)

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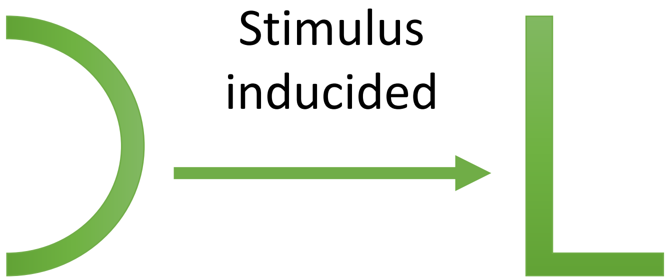
2.1 4D Printing

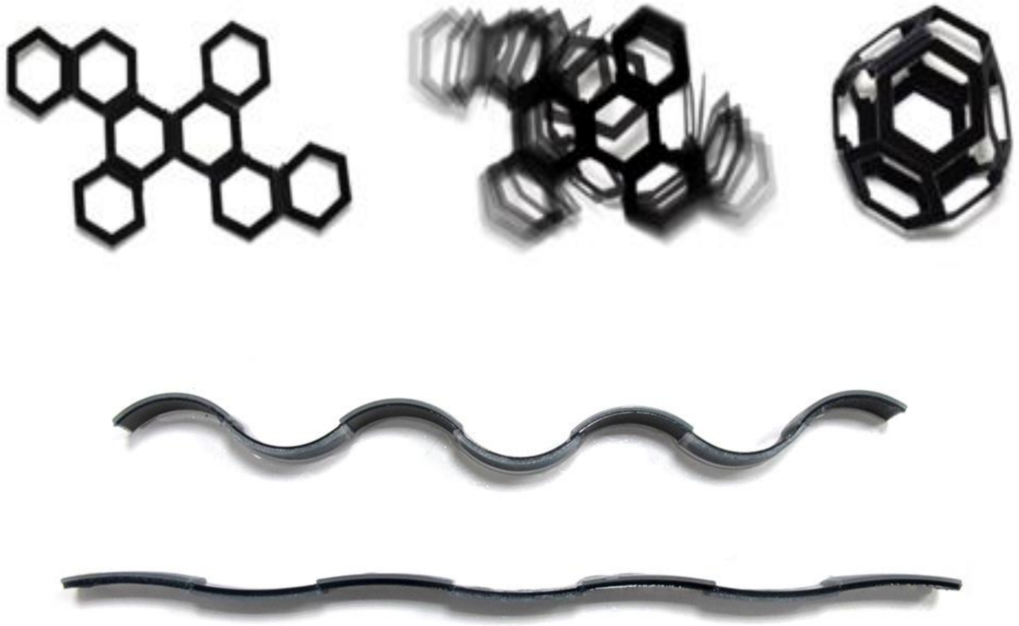
4D printing materials

Shape Change Materials (SCM)



Permanent shape 1

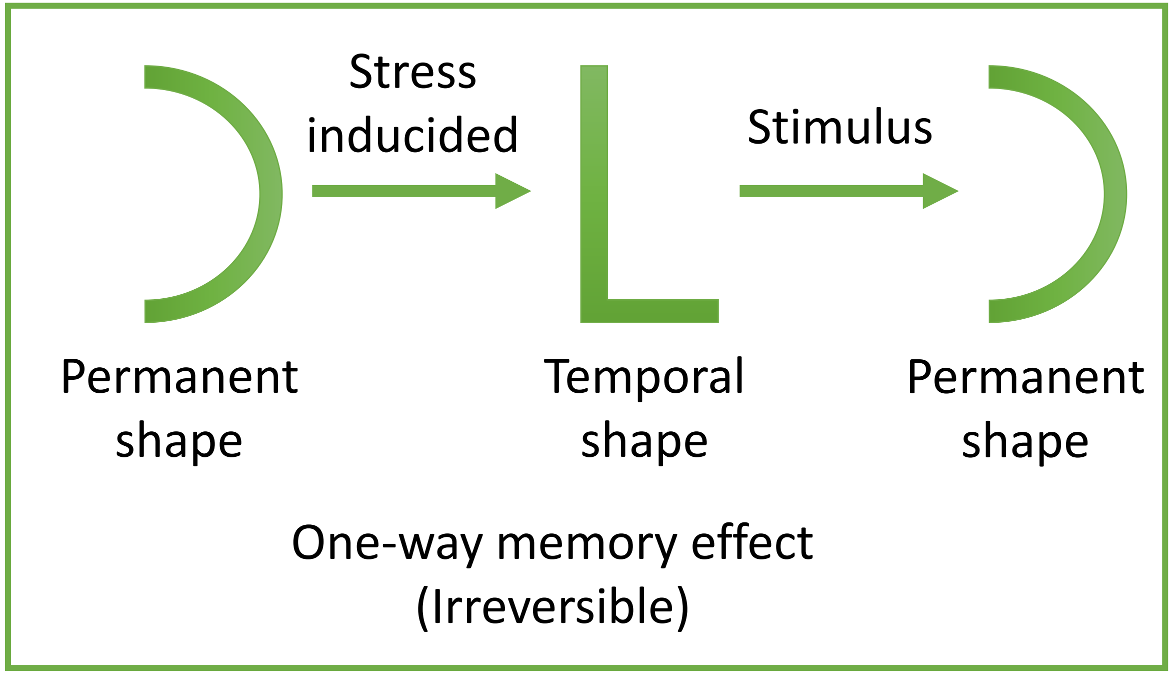
Permanent shape 2

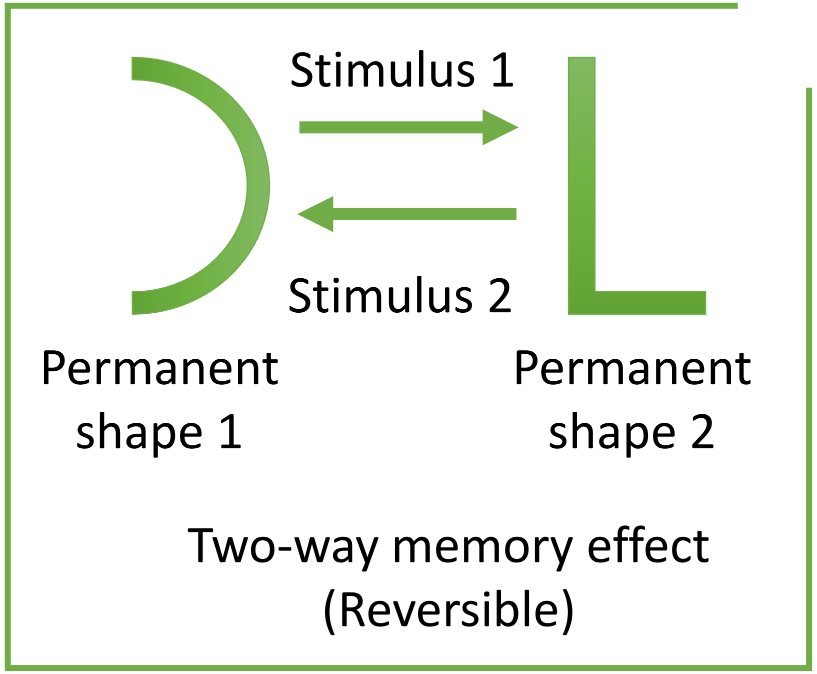


4D printing materials

Shape Memory Materials (SMM)

- SMP (Shape Memory Polymers)
- SMA (Shape Memory Alloys)
- SMC (Shape Memory Ceramics)
- SMH (Shape Memory Hydrogels)
- SMH (Shape Memory Hybrid)

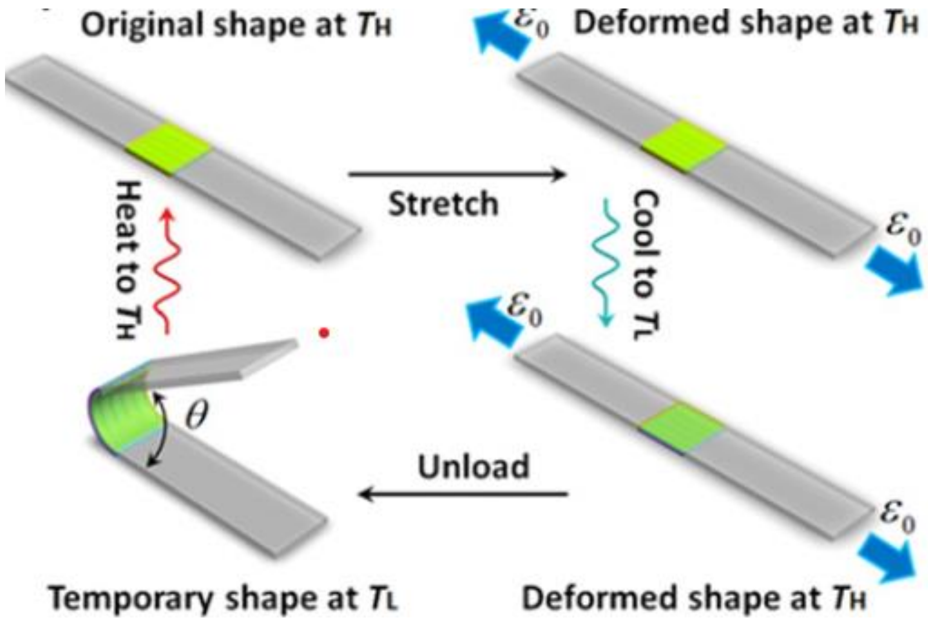


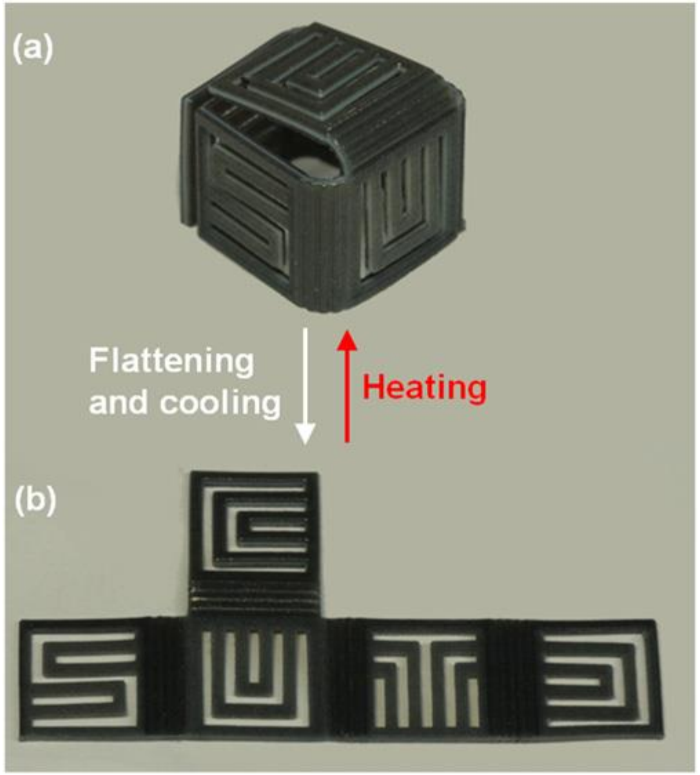


2.1 4D Printing

4D printing materials

Shape Memory Materials (SMM)





2.1 4D Printing

4D printing materials

Active materials:

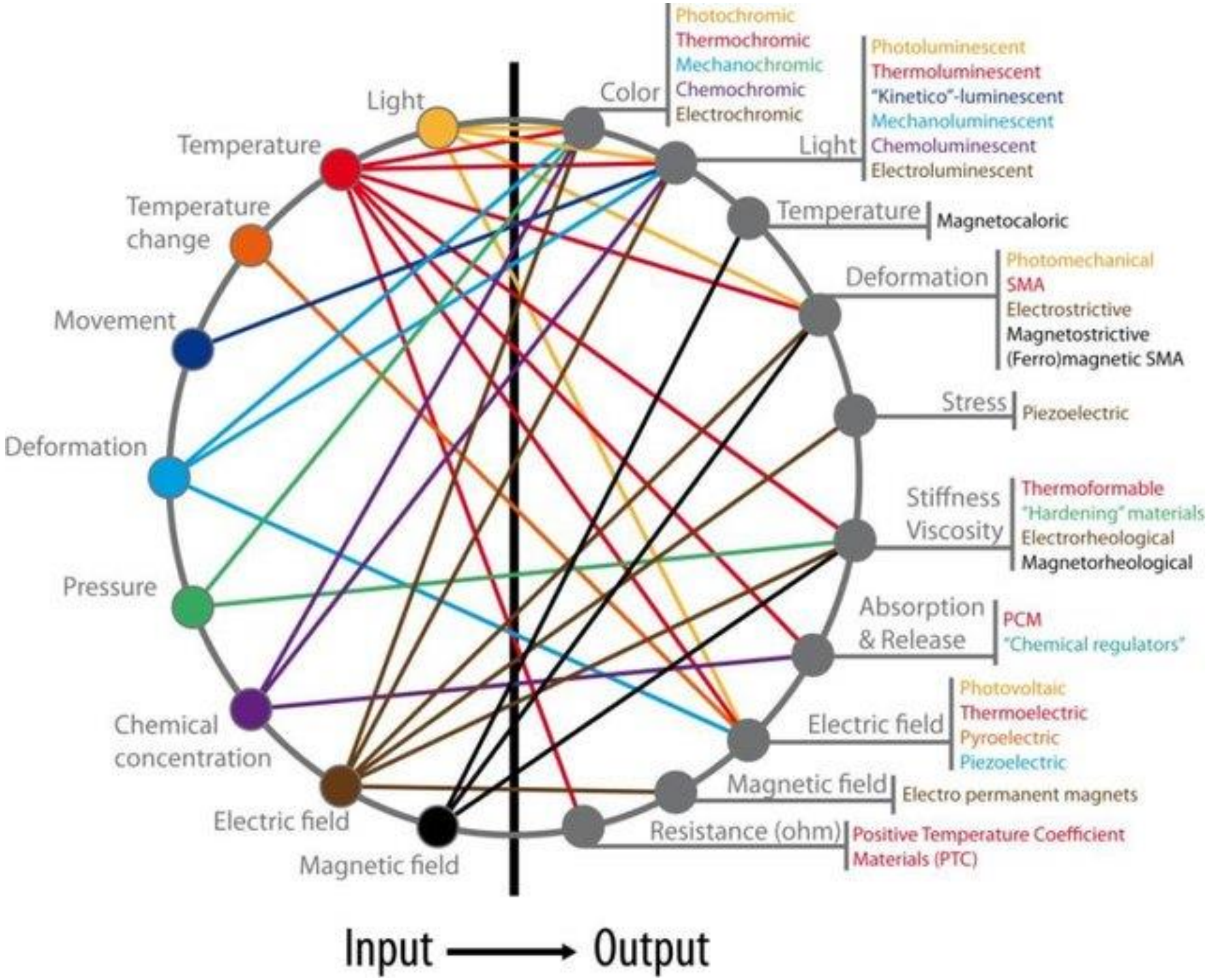
- Stimulus → Change propierties
- Very different stimulus and answers

Stimulus

- Liquid
- Chemical
- Thermal
- Luminic
- Magnetic
- Electric

Answer

- Light
- Color
- Temperature
- Deformation
- Mechanical propierties
- Movement
- Viscosity
- Electric field
- Magnetic
- Resistance



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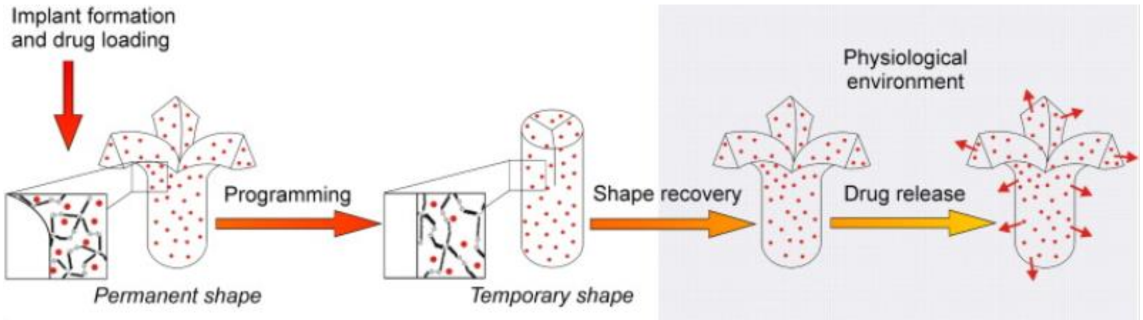
2.1 4D Printing

4D printing materials

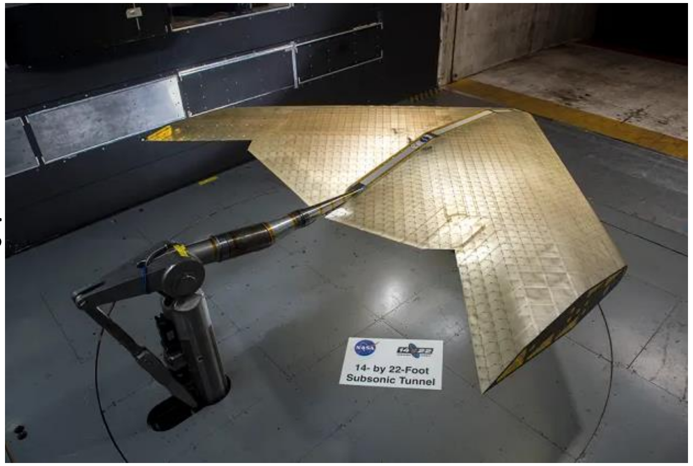
Applications

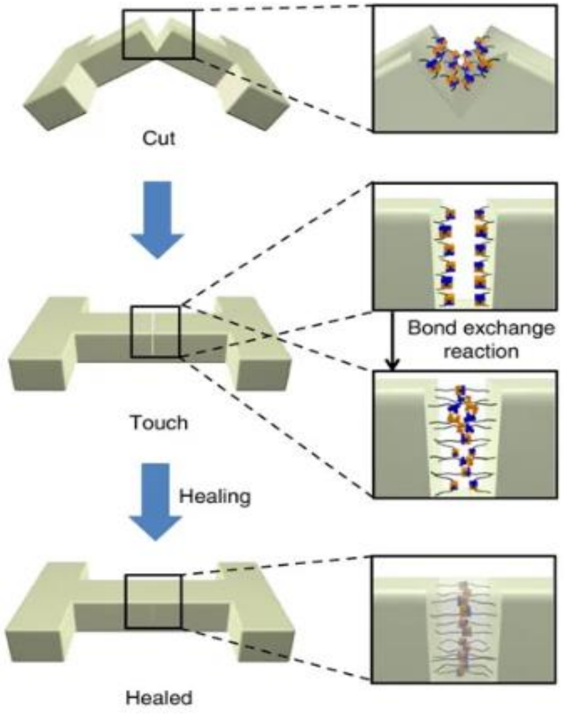
- Aeronautical and aerospace industry
- Self maintenance
- Self assembly
- Medicine and surgery
- Food industry
- ….
- Permanent evolution

Material for drug release



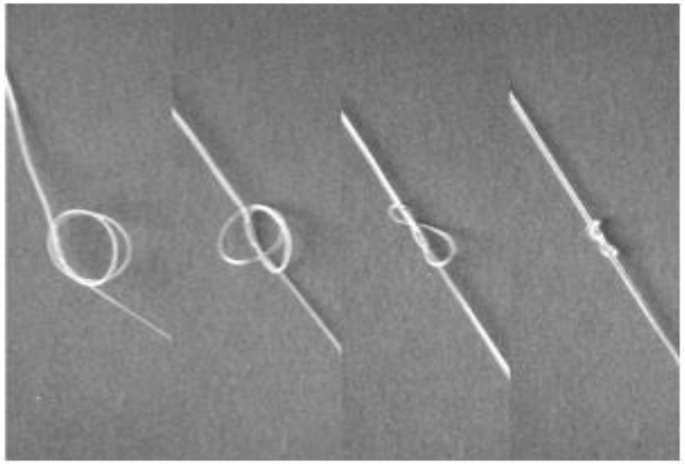
shape-changing wing prototype





Self-repair

Suture with shape memory material



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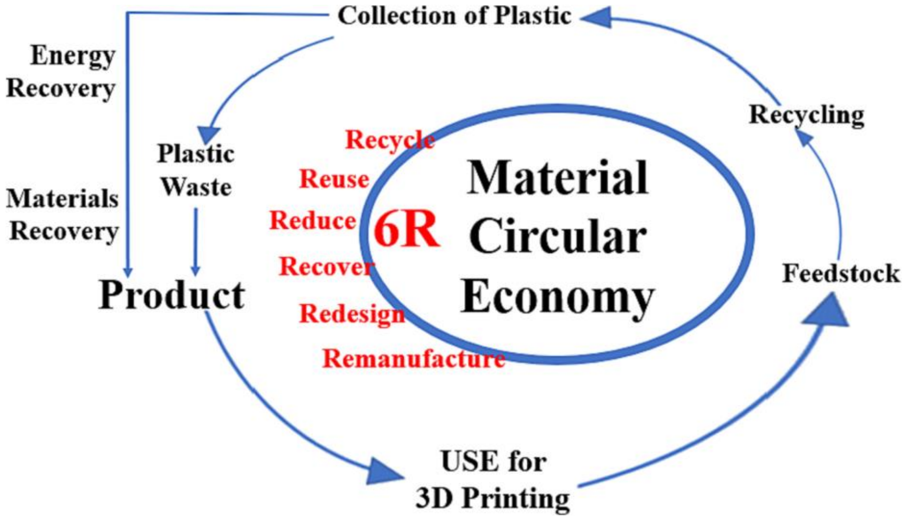
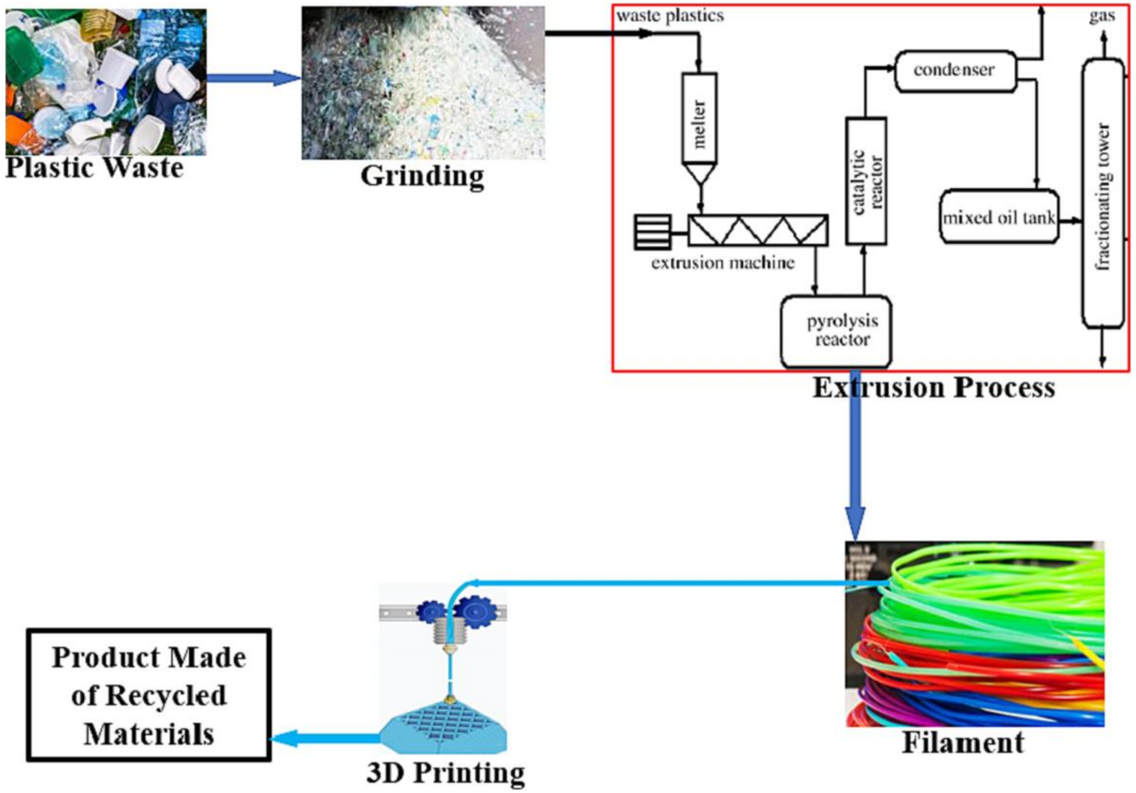
2.2 Sustainability of Additive Manufacturing

Is Additive Manufacturing Sustainable?

First thought: **Sustainable materials**

- Recycled materials or those made with biodegradable components
- Thermoplastic polymers are easy to recycle





2.2 Sustainability of Additive Manufacturing

Is Additive Manufacturing Sustainable?

Some advantages of AM:

- ✓ Less material consumption
- ✓ Absence of additional tools or fixtures
- ✓ Geometry optimization
- ✓ On-demand manufacturing → reduced storage
- ✓ Localized production → shorter value chains

→ Good environmental balance

AM technologies fit perfectly into **circular economy** models

→

- Reduction in material consumption.
- Possibility of using recycled material.
- Its application in maintenance extending the life of products.
- Possibility of optimizing designs.

2.2 Sustainability of Additive Manufacturing

Is Additive Manufacturing Sustainable?

AM technologies have the potential to achieve more sustainable production processes

- ✓ Less waste → **High material efficiency** compared to traditional machining and casting.
- ✓ **No specialized tools** or fixtures required.
- ✓ Ability to build **functionally lightweight parts** while maintaining strength.
- ✓ **Better geometry designs** → optimized geometries with very favorable strength-to-weight ratios.
- ✓ **Reduces the need** for large amounts **of raw material** within the supply chain and transportation.
- ✓ Less impact of the part during its life cycle, resulting in a **lower carbon footprint**, **less embodied energy**, and a **better economic model**.
- ✓ Ability to **create spare parts on demand** → optimizing or eliminating inventory

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2.2 Sustainability of Additive Manufacturing

Sustainable AM: aspects for improvement

Aspects for improving the environmental performance of AM systems:

1. Materials: optimization of the amount of material, recycling possibilities, use of biomaterials or composite materials.
2. Optimization of process parameters: manufacturing strategy, layer height, manufacturing speed…
3. Control of generated emissions: gases and particles.
4. Manufacturing strategy: Use technologies that minimize energy consumption.
5. Use: Promote their use in the reuse and recycling of parts.

Topic 3: Real-life success stories

Smart Materials 3D

Smart Materials 3D
Jaén, Spain
https://www.smartmaterials3d.com/en/

- Manufacturing of filaments for FDM
- Manufacture of pellets for injection or extrusion
- Development of new composite materials
- Assistance for the development of projects based on 3D printing

Pine Wood Filament

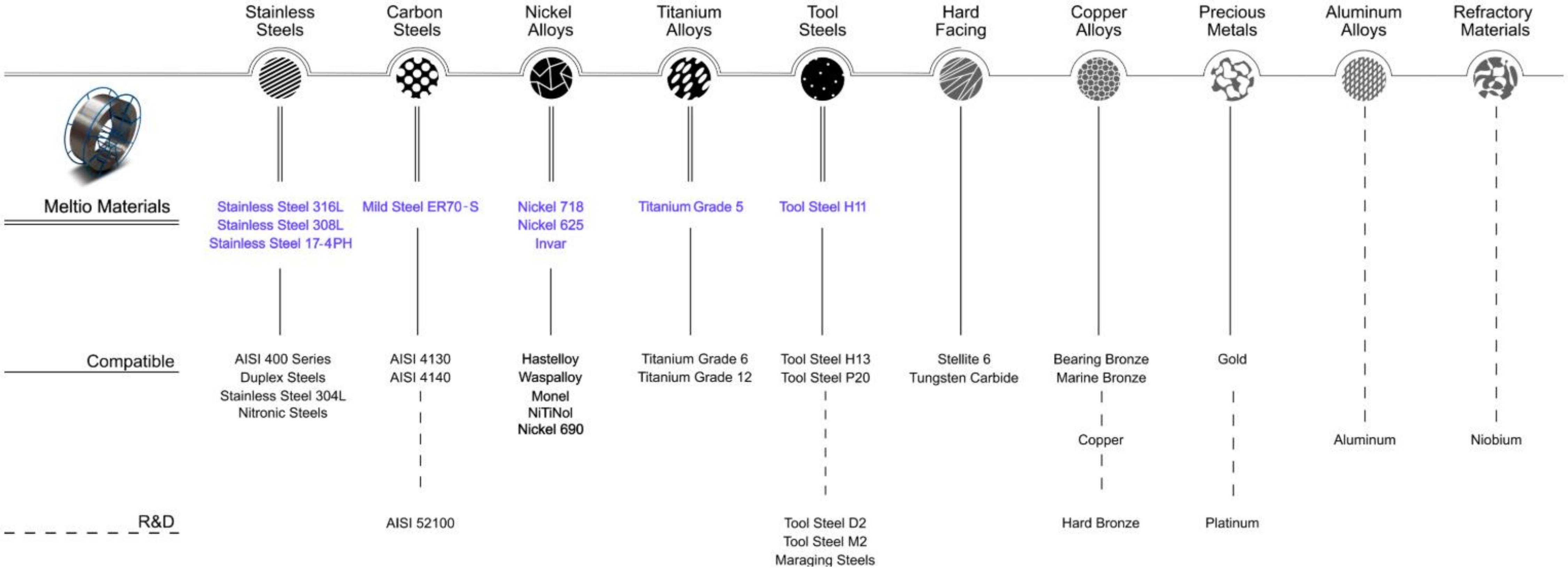
Algae Filament

Meltio

Meltio
Jaén, Spain
https://meltio3d.com/

- Design and manufacture of machines with Laser Metal Design technology
- Manufacture of 3D printed metal parts
- Development of metallic materials for LMD

Meltio



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Novus Decor

Novus Decor
Limerick, Ireland
https://www.etsy.com/market/novus_decor

Design and manufacture of decorative objects

Technology: FDM
Materials: ECO PLA

ENGA

ENGA
Switzerland
www.enga.swiss

ECO-sustainable lighting systems
Decorative objects

Technology: FDM
Materials: Recycled & Bio-based Materials

Prinsoles

Prinsoles
France
www.prinsoles3d.com

The largest distributor of custom-made 3D printed insoles in France.

Technology: FDM
Materials: TPU

ICOS

ICOS
Angola
https://icos.co.ao/

Pipes and drilling rigs for the oil sector.

Technology: FDM
Materials: TPU, TPE, ASA, ABS

Nagami

Nagami
Spain
https://nagami.design/

Exclusive designs of structures, furniture, showcases, etc.

Technology: FDM
Materials: PETG, PLA, ABS

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C6 – Manufacturing Technology

M5 – Sustainable Additive Manufacturing

P2 – University of Jaén

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About NextGEng Project

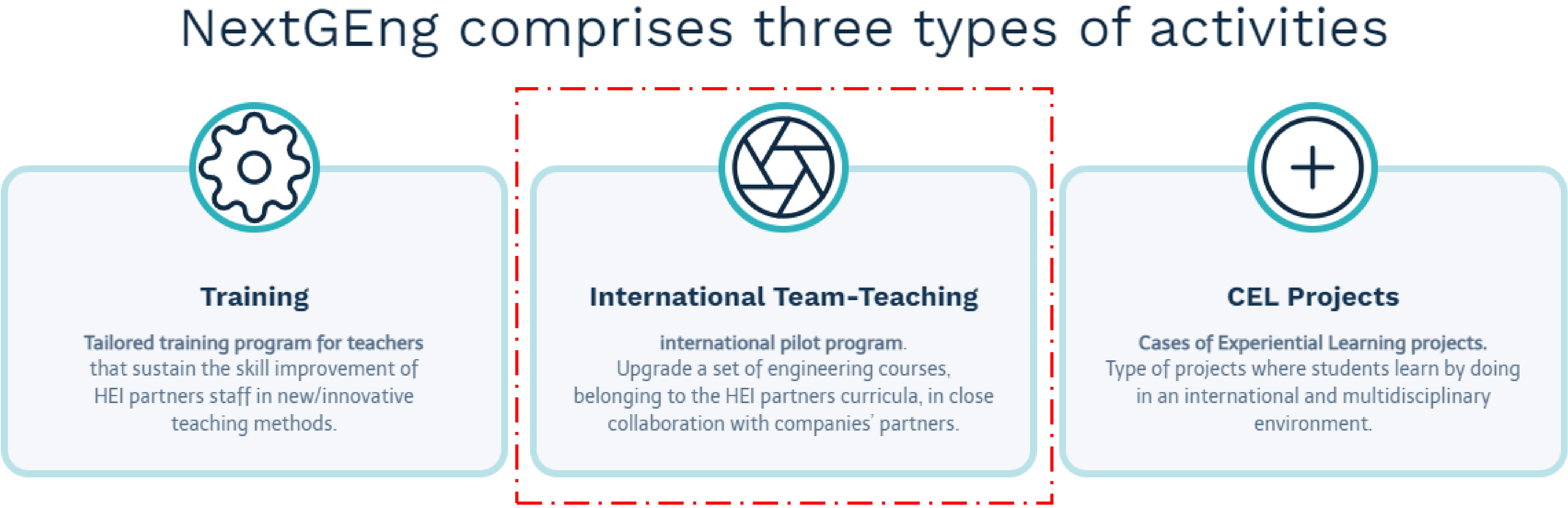
- Three-year Erasmus+ Cooperation Partnership project that started in October 2022
- International consortium consisting of 3 universities and 3 companies from European countries
- Project co-funded by the European Union and coordinated by Technical University of Cluj-Napoca, Romania

Technical University of Cluj-Napoca	Integracion Sensorial y Robotica
Jamk University of Applied Sciences	Valmet Technologies Oyj
University of Jaén	Rober Bosch SRL

Co-funded by the European Union

About NextGEng Project

- **NextGEng Project** aims to create new pedagogical models that promotes international team-teaching with the support of new learning materials for existing courses in the curricula



Content

- Introduction to sustainable manufacturing
- Topic 1: Sustainable design
- Topic 2: Circular economy
- Topic 3: Sustainability in Additive Manufacturing

Introduction to sustainable manufacturing

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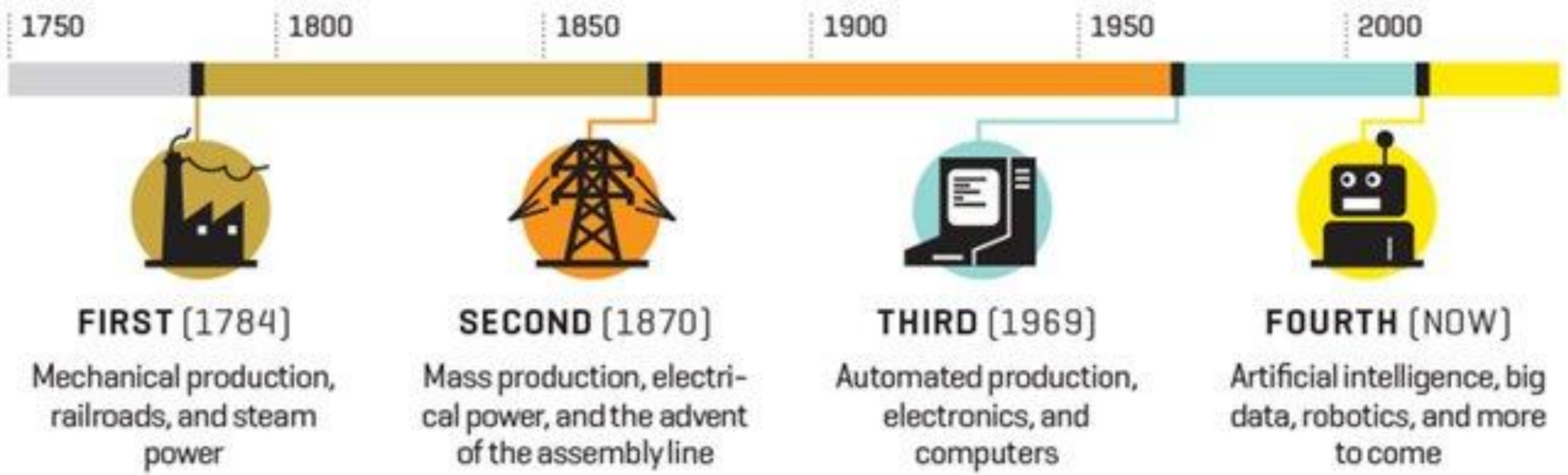
Introduction to sustainable manufacturing

From the First to the Fourth Industrial Revolution

With the First Industrial Revolution, thanks to technological development, the industrial sector emerged at the expense of the primary sector.

Subsequently, three new industrial revolutions are identified



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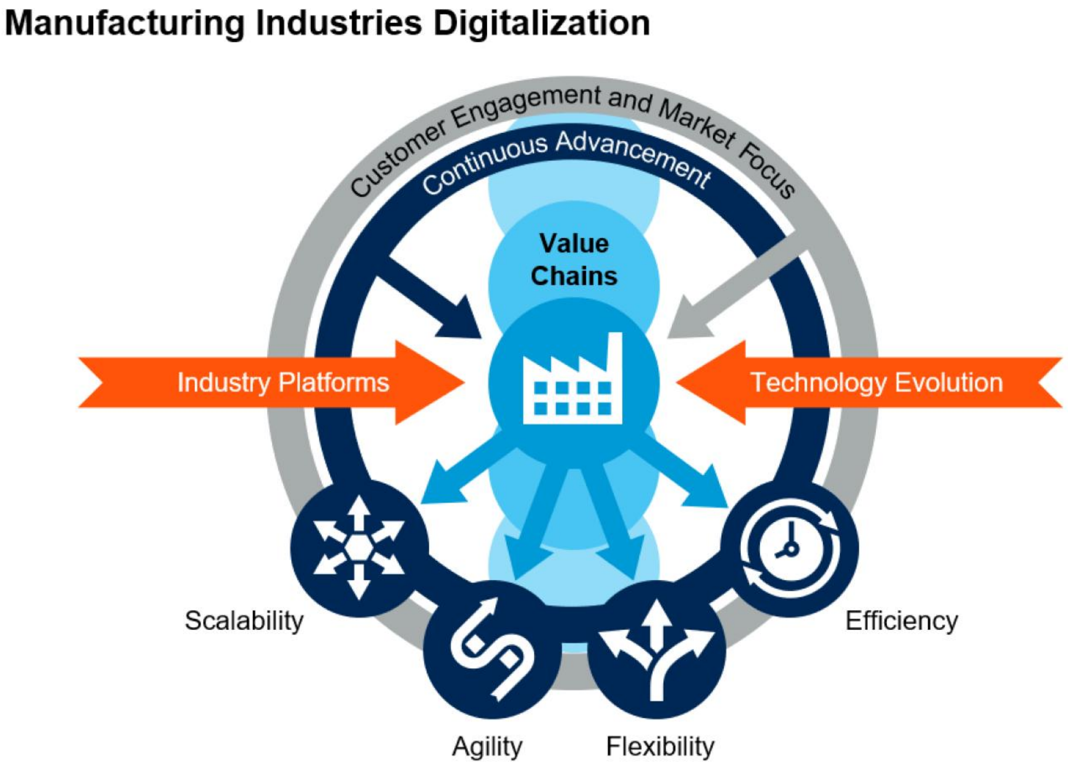
Introduction to sustainable manufacturing

From the First to the Fourth Industrial Revolution

The Fourth Industrial Revolution, also known as Industry 4.0 (Schwab, 2016), is the one that has been developing in recent decades. In this new phase, the industry is moving toward complete digitalization.



Introduction to sustainable manufacturing

From the First to the Fourth Industrial Revolution

Industry 4.0 encompasses a large number of technologies that have developed very rapidly and that complement each other to give rise to a new concept of industry: digital industry. With a **growing importance of data to the detriment of "atoms“.**

Government-led initiatives:

- Factories of the Future (FoF) of the European Commission.
- Catapult of the United Kingdom.
- Industrie du Futur of France.
- Industrie 4.0 in Germany.
- Smart Industry in the Netherlands.
- Impresa 4.0 in Italy.
- Portugal i4.0 in Portugal.

Introduction to sustainable manufacturing

The concept of sustainability

Since the First Industrial Revolution, the world has experienced enormous development without questioning the impact that industrial activities had on the environment.

After World War II, some pioneers began to emerge who warned about environmental problems (Blustein, 2003).

1960s **Club of Rome** more firmly questions the impact of industry on the environment. It publishes the "Limits to Growth" report (1972).

1970s **Oil crisis** The first important sign of a change in the growth model. The crisis produced a wave of deindustrialization in advanced countries, which, with the arrival of globalization, subsequently promoted strong industrialization in eastern countries (Balsa-Barreiro et al., 2019).

1980s The concept of sustainable growth emerged. It appears in the 1987 **Brundtland report**:

“development that meets the needs of the present without compromising the ability of future generations to meet their own needs” *(WCED, 1987)*

Introduction to sustainable manufacturing

The concept of sustainability

1990s **Earth Summit** The Brundtland Report strategies are developed, including those aimed at:

- More efficient production processes in terms of energy and resource use.
- Preventive strategies.
- Minimizing or eliminating waste.
- Clean production technologies and procedures throughout the product life cycle.

Introduction to sustainable manufacturing

The concept of sustainability

Since the emergence of environmental concerns, there has been a growing social awareness and a transformation of the problems and the way we respond to them.

An interesting example is provided by Zaccai (2012) in his comparison between the 1970s and 1980s and the 2010s.

Table 3
Environmental evolution and representations (70s–80s compared to 2010).

	Environmental evolution and representations	70s–80s	2010
1	*Most difficult environmental problems*	Pollution	Pollution, fluxes
2	*Iconic problems*	Wastes, water pollution	Climate change, biodiversity loss
3	*Pollution sources addressed by policy*	Important point sources (ex. industries)	Important and small point and mobile sources (ex. cars)
4	*Actors/activities regarded as main drivers of pollution*	Industries, production	Consumers, consumption
5	*Region regarded as the main threat for the future of the environment*	OECD (USA)	Emerging countries (China)
6	*Scale of environmental problems addressed by policy*	National, local	Global, national, local actions ("Cinderella")

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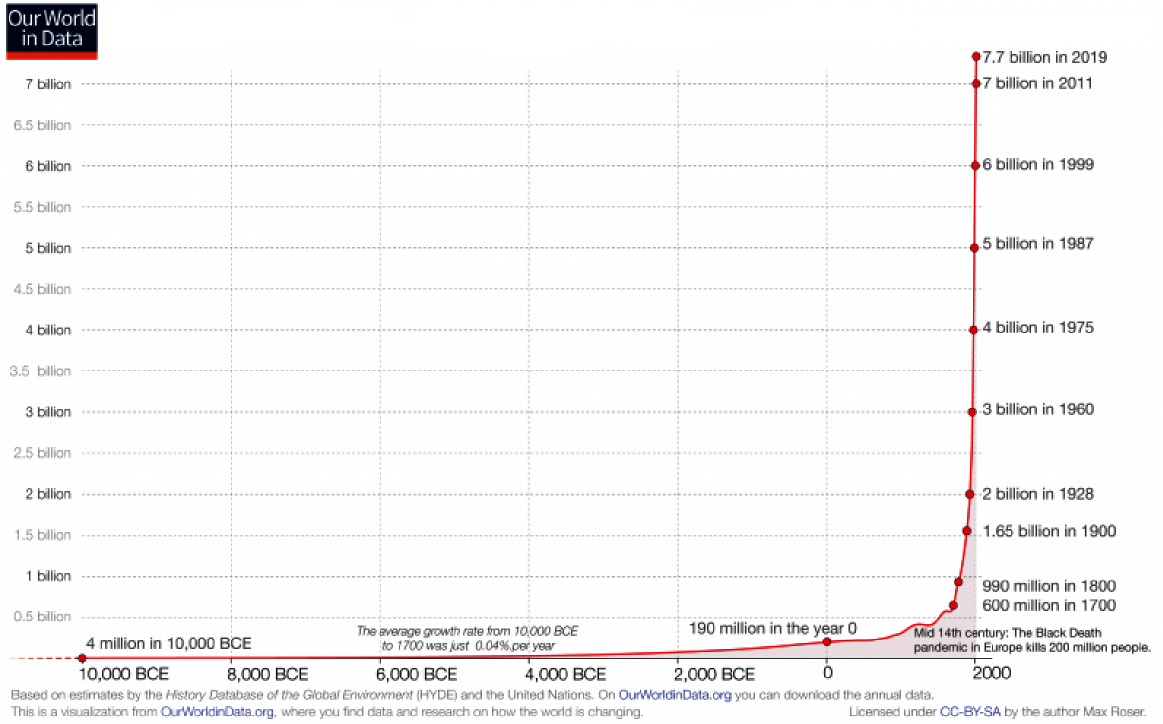
Introduction to sustainable manufacturing

The concept of sustainability

The industry emerges → ↑ World population grows exponentially → ↑ Global needs are growing → ↑ Pressure on the environment is growing

Wealth (GDP), population, and CO_2 emissions are strongly correlated.

Globalization is generating a significant transformation of the global structure in terms of wealth and resource needs, with a clear shift toward the east (Balsa-Barreiro et al., 2019).



https://ourworldindata.org

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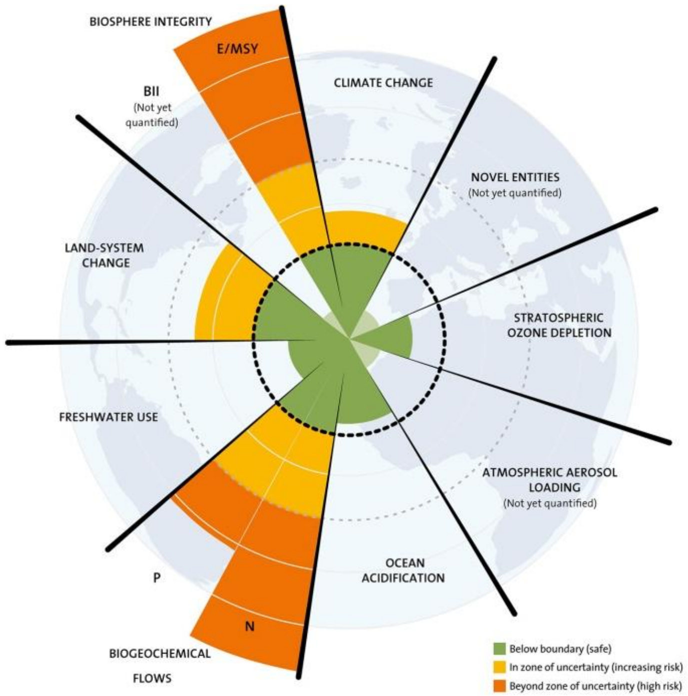
Introduction to sustainable manufacturing

The concept of sustainability

The current growth model and pace are pushing the planet to its limits, as Johan Rockström points out.



https://youtu.be/ua8PEG0AlsI

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Introduction to sustainable manufacturing

Sustainable Development Goals (SDG)

September 15, 2015 □ The UN General Assembly adopts the **2030 Agenda** for Sustainable Development, an action plan for people, planet, and prosperity, which also aims to strengthen universal peace and access to justice.

"We are determined to end poverty and hunger everywhere by 2030, to combat inequalities within and between countries, to build peaceful, just, and inclusive societies, to protect human rights and promote gender equality and the empowerment of women and girls, and to ensure lasting protection of the planet and its natural resources."

Introduction to sustainable manufacturing

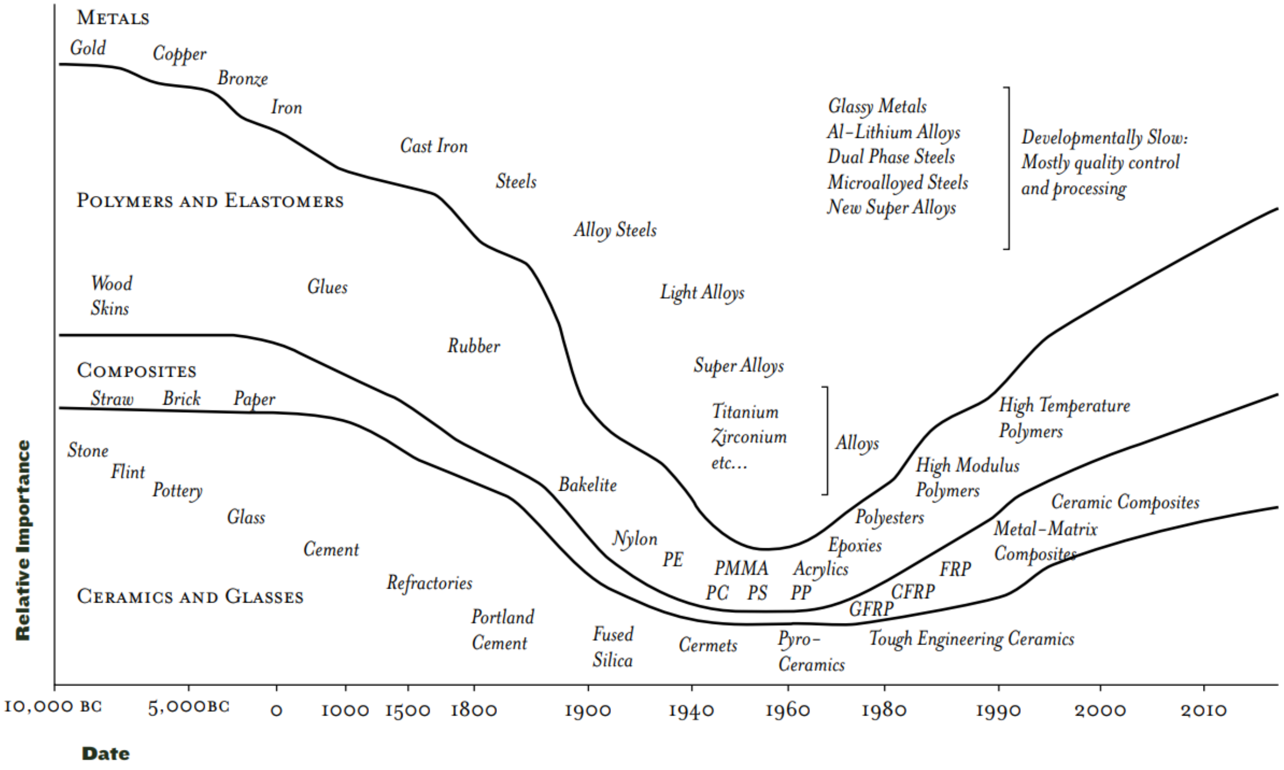
Sustainable Development Goals (SDG)

Introduction to sustainable manufacturing

Engineering to sustainability: New materials

One of the first design strategies, even prior to the new environmental awareness, was weight reduction, especially in applications oriented toward air, sea, and land transportation.

In particular, the development of new materials accelerated in the second half of the 20th century to respond to these needs (Ashby and Johnson, 2010).



Introduction to sustainable manufacturing

Engineering to sustainability: New materials

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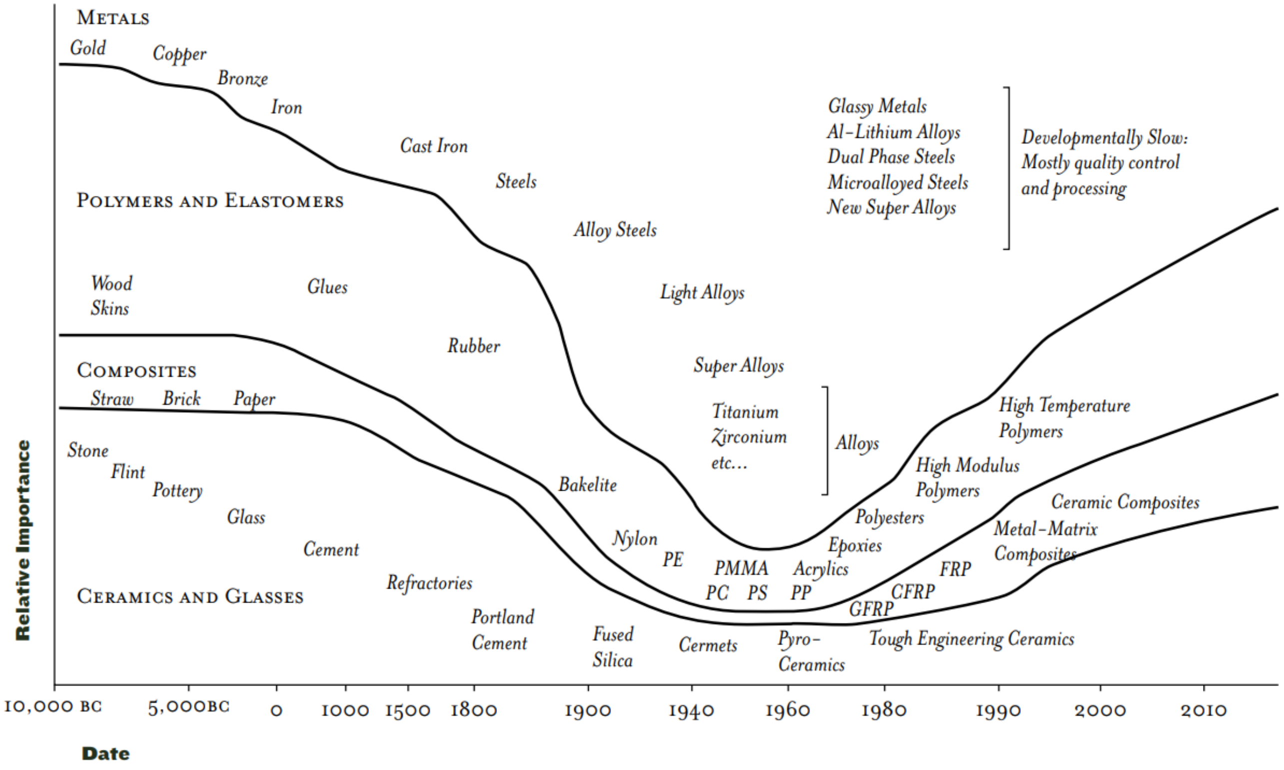

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Introduction to sustainable manufacturing

Engineering to sustainability: New materials

Additionally, R&D&I activities aim to develop sustainable materials.

For example:

- ✓ Biodegradable cutting fluids (Tazehkandi et al., 2015).
- ✓ Wood-based printing materials (Markstedt et al., 2019).
- ✓ Use of agricultural, industrial, municipal, and other waste to generate alternative bricks to traditional clay bricks (Zhang et al., 2018).
- ✓ Use of eco-materials for construction.

Introduction to sustainable manufacturing

Engineering to sustainability: repair/reconstruction

Particularly for high-cost parts, engineering has been developing component repair strategies that extend their useful life.

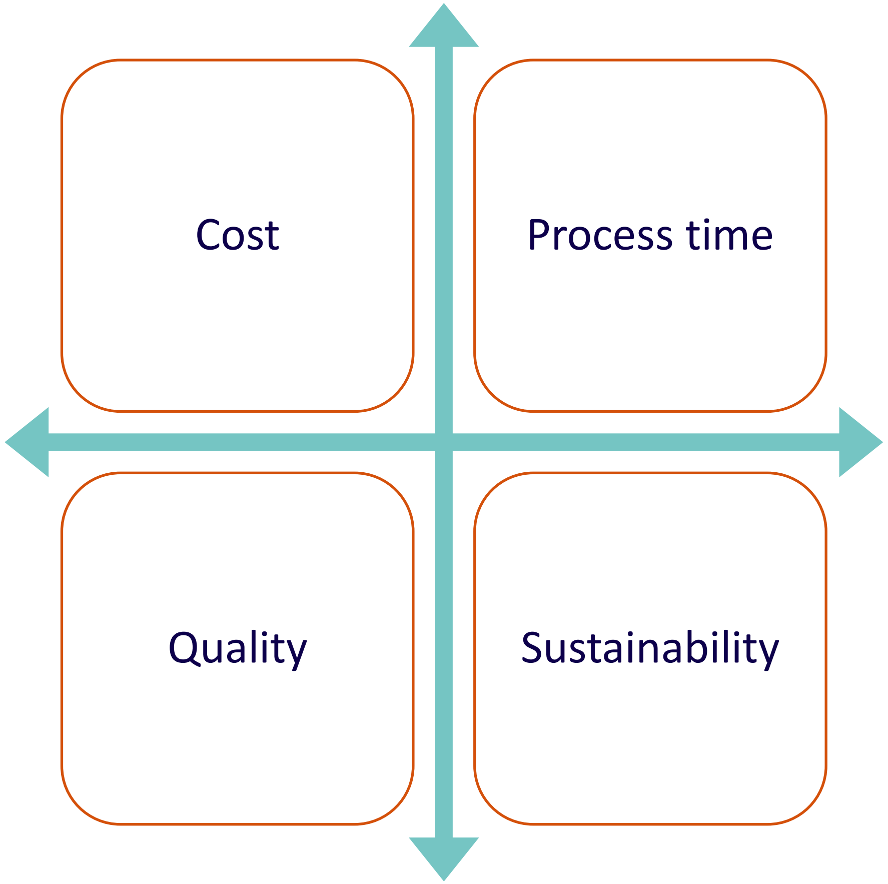
Maintenance for Sustainability Industry 4.0

A relevant example is the repair of aircraft engines by leading companies such as Rolls & Royce.

Sustainable design

Integrated Development and Sustainability

Integrated product/process development faces current challenges:



Topic 1: Sustainable design

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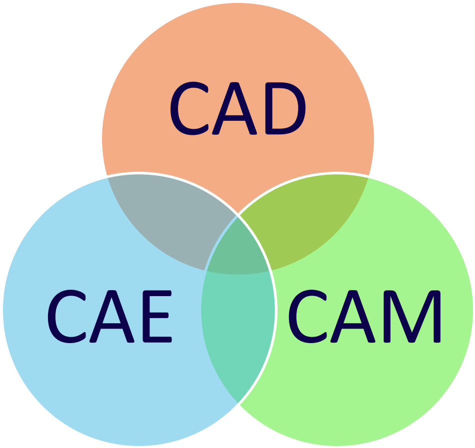
Sustainable design

Integrated Development and Sustainability



Development-Product Integration Software + Automation

New CAE engineering support applications integrate various functions: CAD, CAM, numerical simulation, etc.

This allows for evaluating and comparing the influence of design decisions on sustainability (and cost, process time or quality).

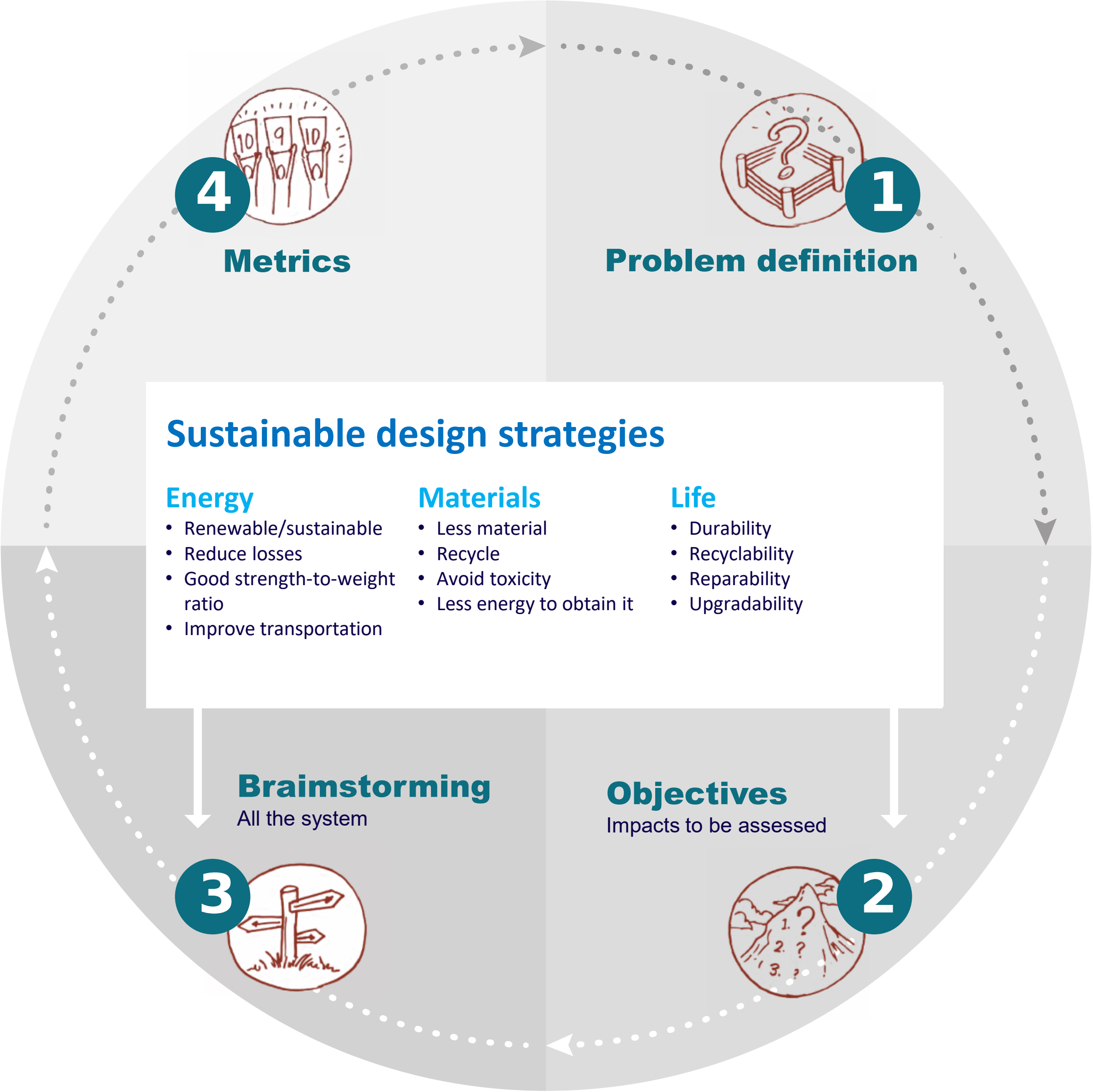
Implementing Product Development-Sustainability Integration:

- ✓ Consider design recommendations
- ✓ Use software to compare environmental impact metrics

Sustainable design

Integrated Development and Sustainability

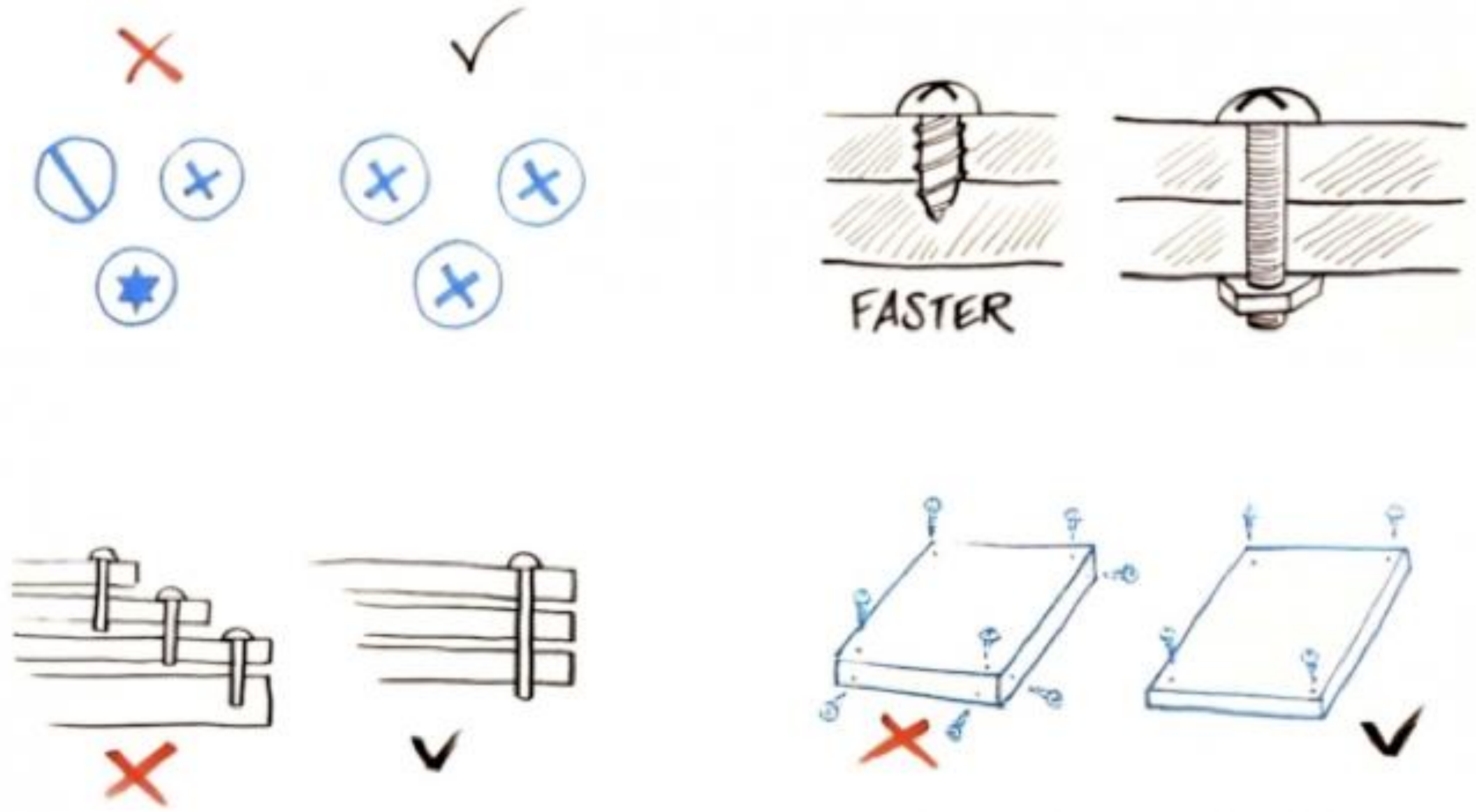
Main elements to consider in sustainable design



Sustainable design

Sustainable product development guides

Product lifespan recommendations: Ease of assembly

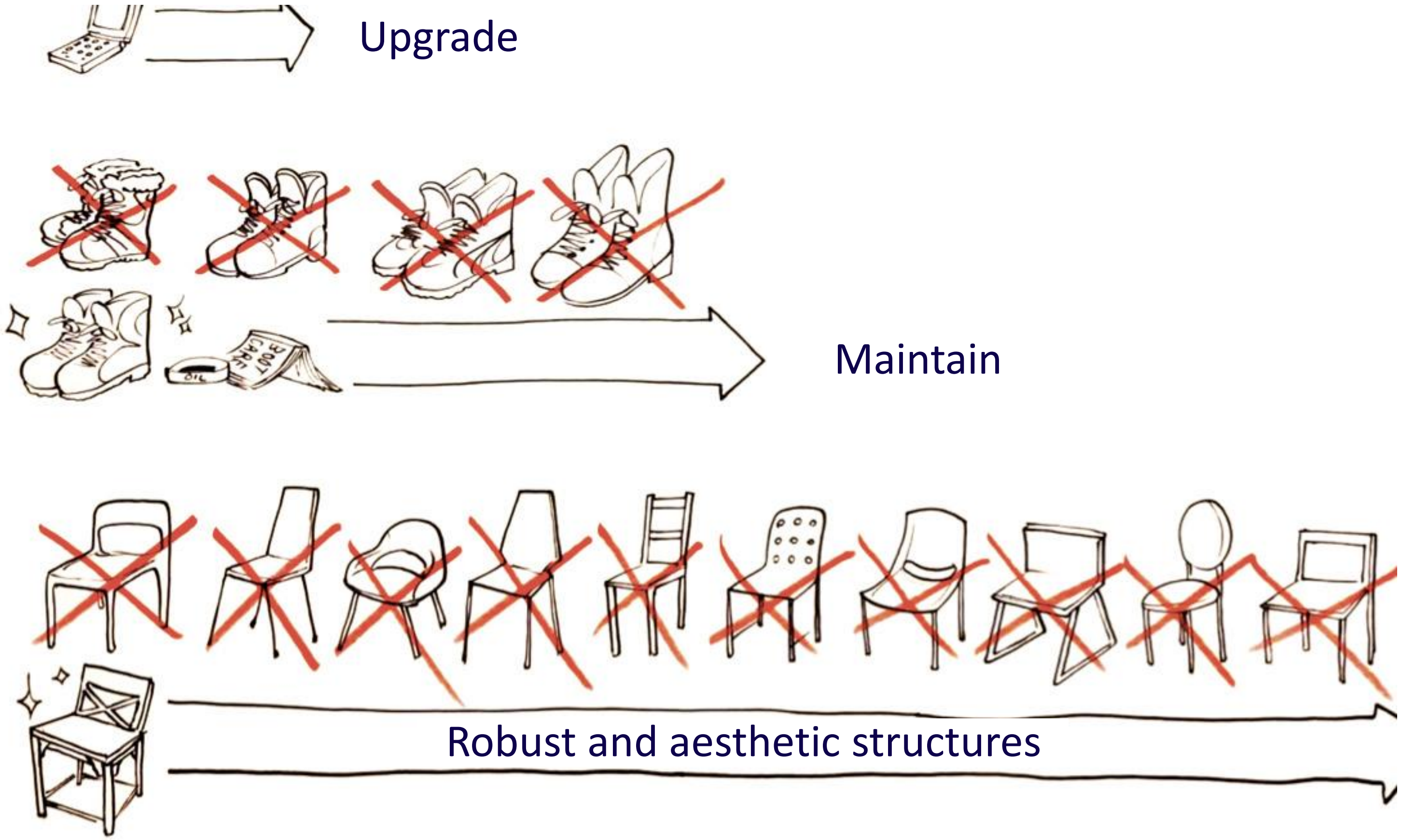


From: https://academy.autodesk.com/curriculum/principles-sustainable-design

Sustainable design

Sustainable product development guides

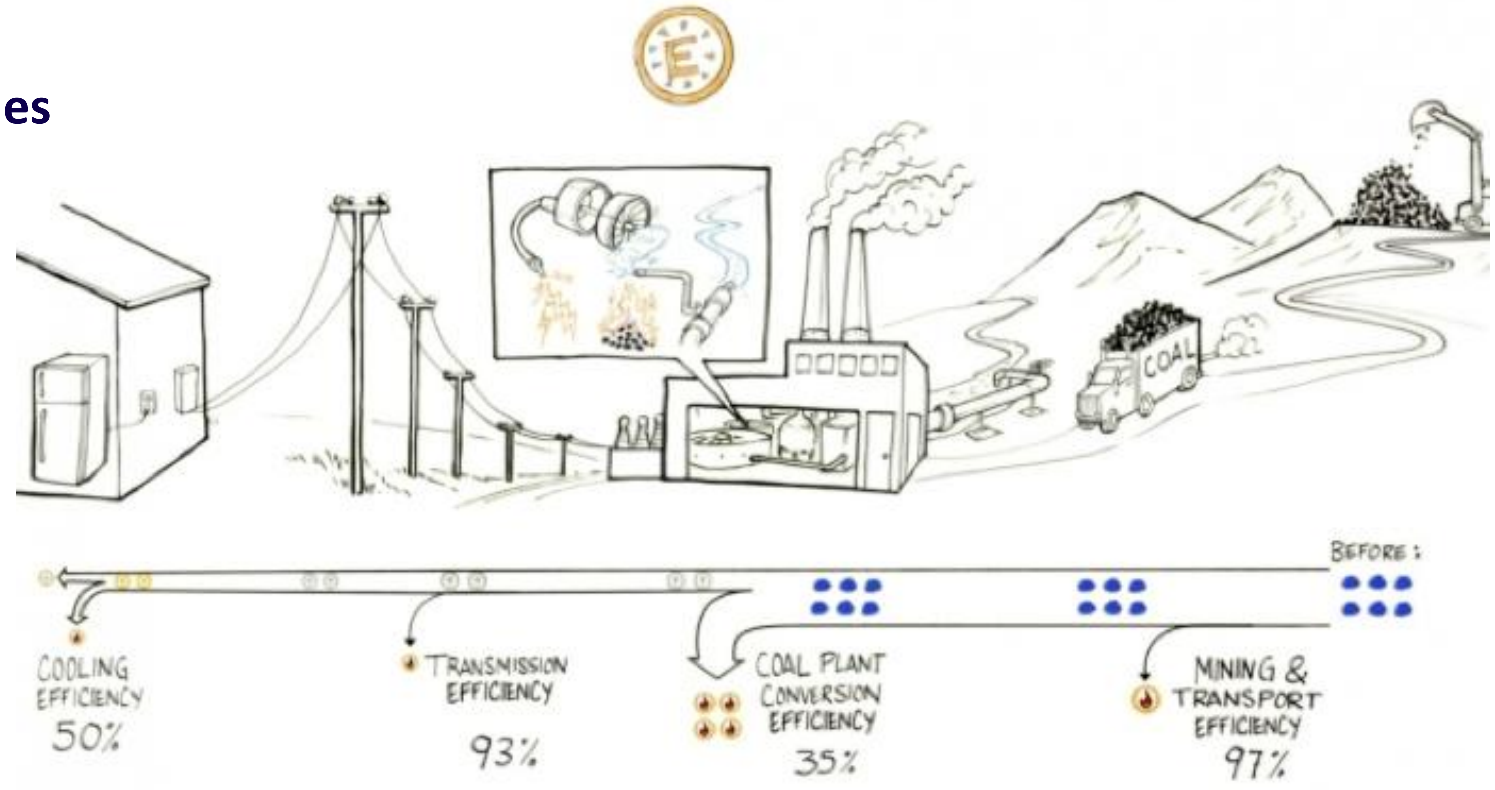
Product lifespan recommendations: Durability of non-disposable products



Sustainable design

Sustainable product development guides

Energy recommendations: Reduce Losses



- Energy: The capacity to produce work.
- Conversion between energy types is not perfect.
- Sustainable design Reducing work capacity losses.
- Reducing friction, drag, improving thermal insulation, etc.

Sustainable design

Sustainable product development guides

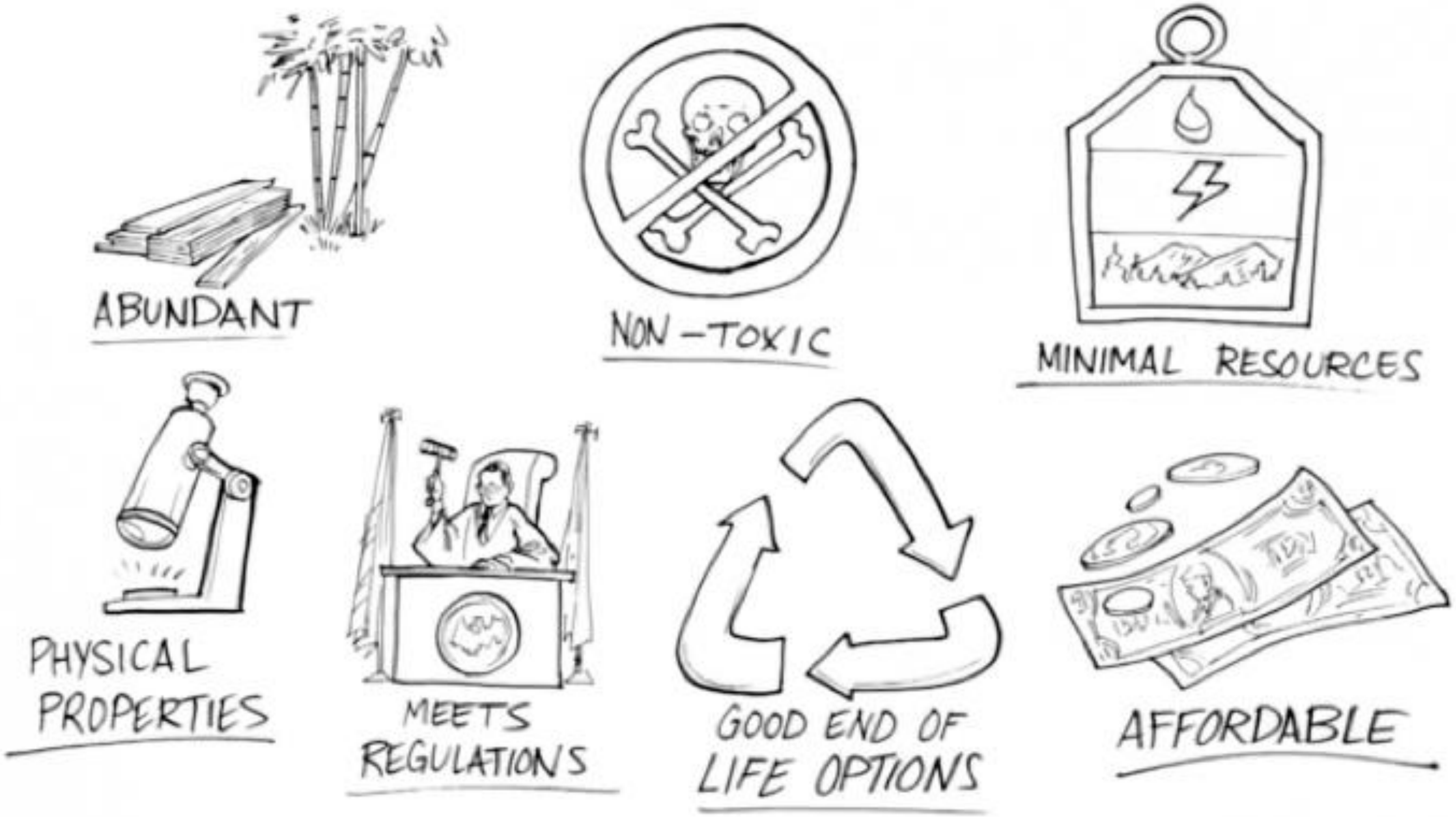
Energy recommendations: Use renewable energy

Energy with low resource consumption and low environmental impact: wind, solar, hydroelectric, tidal, geothermal and biomass energy

Sustainable design

Sustainable product development guides

Material selection recommendations:



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Sustainable design

Principles of sustainable design

Shape:

Shape represents the visual appearance of the product and is typically the main design element. Before launching a product, the designer must answer several questions: How does shape affect energy consumption, packaging, shipping costs, and emissions?

An example is IKEA's flat-pack strategy.

Function and use:

Shape contributes to sustainability indirectly, as it helps consumers use the product more easily and with less energy consumption.

Cost-effective solutions:

Many of today's sustainable products are more expensive than non-sustainable alternatives. Designers are responsible for reducing the cost of these products.

Sustainable design

Principles of sustainable design

Renewable Energy:

Designers should stop relying on carbon energy and think in terms of building products that rely on renewable energy, such as solar panels and wind farms.

Materials and Recycling:

Every designer should look for materials that can be easily recycled or that the planet can recreate in a short period of time.

For example, IKEA relies on mixed woods and innovative materials to replace traditional wood varieties that can take a long time to grow in forests. Mixed and recycled materials can also help reduce product costs.

Durable Design Solutions:

To achieve zero waste, products must be durable enough to last a long time or be fully recycled and transformed into new products. Relying on both methods can help recycle products more than once and reduce dependence on the Earth's resources.

Continuous Improvement and Knowledge Sharing Evaluation and improvement are important parts of any design process, but they become even more important for evaluating sustainable initiatives and improving them enough to achieve the same or better quality than existing products.

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Topic 3: Circular economy

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iSR www.isr.es

Valmet

NextGEng

BOSCH Invented for life

Circular economy

Circular economy concept

Today's economy leads us to a consumerist mindset, which has significant impacts through the generation of harmful substances.

Do we know how they are produced, in what quantities, and how to reduce them? Can we do anything to reduce this impact?

The concept of the circular economy began to be used in the 1980s to describe the interaction between the economy and the environment.

Early interpretations were based on waste management based on the three Rs: Reduce, Recycle, and Reuse.

(Although there are more "Rs": rethink, redesign, repair, redistribute, etc.)

Circular economy

Circular economy concept

"Strategy that aims to reduce both the input of virgin materials and the production of waste."

Moving from linear

Resource → Product → Waste

to cyclical processes

Resource → Product → Recycled resource

Circular economy

Circular economy concept

“A business model in which the conceptual logic for value creation is based on the utilization of the economic value retained in products after use in the production of new offerings” (Linder & Willander, 2015)

Circular economy

Circular economy concept

https://youtu.be/zCRKvDyyHmI

Circular economy

Examples of circular economy

Recycling:

Car floor mats and trunk liners are mostly made from recycled PET.

This is the case with the Spanish company Eko-rec, which produces these products, fashion and home accessories, from PET (polyethylene terephthalate) waste, the plastic used to make most water and soft drink bottles.

Each year, it converts 25,000 tons of PET into fibers to make new objects.

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Circular economy

Examples of circular economy

Repair and remanufacturing:

The useful life of car batteries can be extended.

Through a technology developed by Rebattery, an SME from Spain, the useful life of batteries can be extended.

Ecodesign:

The environmental impact of waste can be significantly reduced through the application of ecodesign criteria.

A Spanish supermarket group has carried out an ecodesign project with its fabric softener packaging, resulting in a more easily recyclable and lighter package. The weight of the packaging per wash has been reduced by 41.3%. For every 1,000 liters of fabric softener, 15 tons of CO_2 are saved.

Topic 4: Sustainability in Additive Manufacturing

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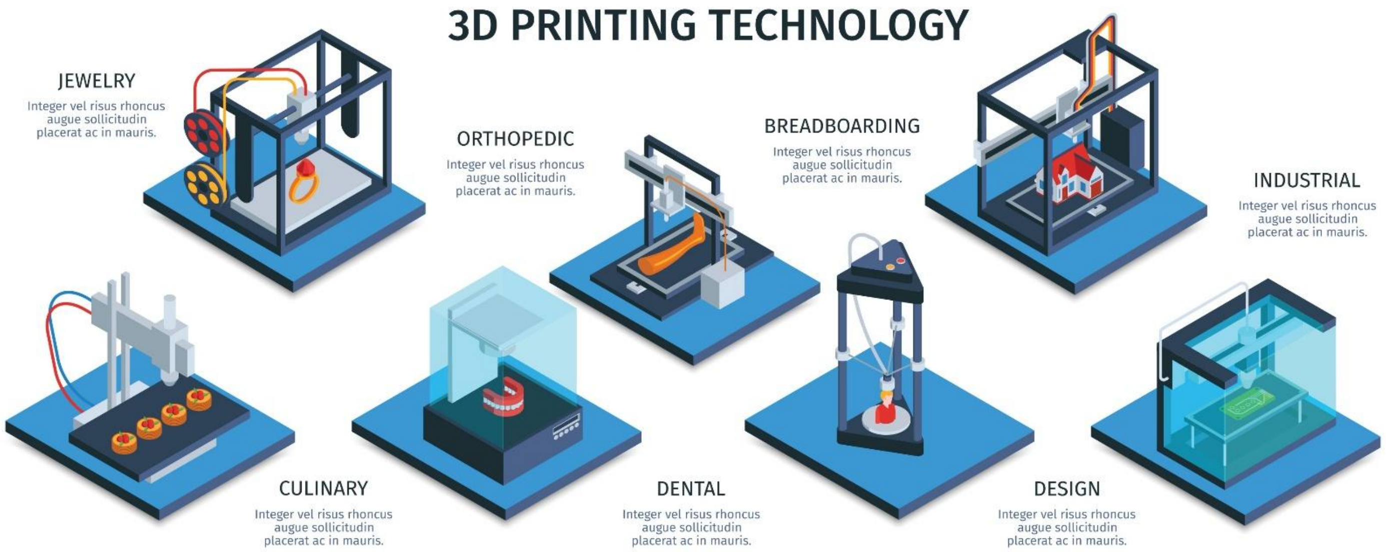
Sustainability in Additive Manufacturing

Additive Manufacturing: The Path to Industrial Sustainability

Additive Manufacturing (AM): The process of creating 3D objects from a digital model by depositing material layer by layer (unlike subtractive manufacturing).

AM has transformative potential for sustainability, although its total impact depends on the specific technology, materials, and process management.

No methodology for calculating environmental impact is suitable for AM involves a large number of factors to consider, the complexity and diversity of processes, and multiple uses.



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Sustainability in Additive Manufacturing

Additive Manufacturing: The Path to Industrial Sustainability

Some advantages of AM:

- ✓ Less material consumption
- ✓ No additional tools or fixtures
- ✓ Geometry optimization
- ✓ On-demand manufacturing ⍰ Reduced storage
- ✓ Localized production ⍰ Shorter value chains

→ Good environmental balance

AM technologies fit perfectly into circular economy models →

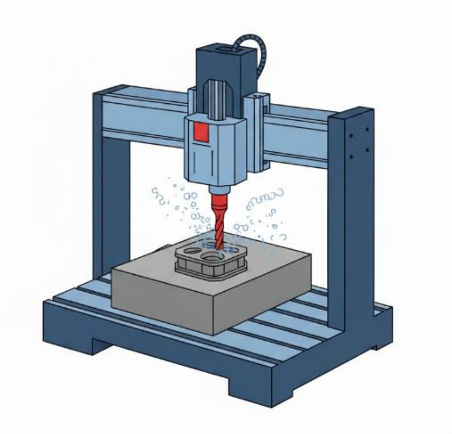
- Reduction in material consumption.
- Possibility of using recycled materials.
- Its application in maintenance extends product life.
- Possibility of optimizing designs.

Sustainability in Additive Manufacturing

Key Advantages: Material Usage

Less Waste, Greater Material Efficiency

- Additive Manufacturing (AM): An additive ("to add") process.
  - ✓ Builds the part layer by layer.
  - ✓ Advantage: Minimal material waste (material is used only where needed).
  - ✓ Contrast: Subtractive manufacturing (machining) often produces up to 90% material waste in some cases.
- Sustainable Materials:
  - ✓ Growing use of un-melted metal powders and polymers that can be recycled or reused in subsequent prints (especially in technologies like SLS).
  - ✓ Development of filaments and resins made from recycled plastics and biodegradable materials (e.g., corn-derived PLA).



MACHINING
Subtractive manufacturing

Sustainability in Additive Manufacturing

Key Advantages: Design and Product

Design Optimization and In-Use Savings

- Optimized Geometries: AM allows for the creation of complex internal structures (e.g., lattices) resulting in:
    - Weight Reduction: Without sacrificing strength.
    - In-Use Energy Efficiency: Lighter components in the aerospace and automotive sectors translate to lower fuel or energy consumption over the product's lifespan.
- Improved Functionality: Ability to consolidate multiple parts into a single component, simplifying assembly and often improving performance.
- Rapid Prototyping: Allows for quick design error correction, significantly reducing material and energy waste during initial development phases

Key Advantages: Supply Chain

Decentralization and Logistics Reduction

- Local, On-Demand Production:
    - Parts can be printed close to the point of use, reducing the need for long global supply chains.
    - This drastically decreases the carbon footprint associated with transportation and logistics.
- Inventory Reduction:
    - Manufacturing can be done "on-demand" or by order, instead of producing large batches.
    - This eliminates the waste associated with overproduction and the obsolescence of stored parts.
- Reverse Engineering: Ability to scan and reproduce obsolete or spare parts exactly when needed, promoting the circular economy and repair.

Sustainability in Additive Manufacturing

Sustainability Challenges

Outstanding Challenges for a Net Positive Impact

- **Energy Consumption:** Although material waste is low, some AM technologies (e.g., Powder Bed Fusion with lasers) have high energy consumption during the printing process.

  Solution: Use of renewable energy sources and machine optimization.

- **Material Recycling:** The recycling of powders and by-products is not universal; the purity of the recycled material and the presence of additives can limit its reuse.

  Challenge: Lack of standards and difficulty in post-processing some materials.

- **By-products and Post-Processing:** Post-printing processes (cleaning, curing, sintering) may require additional energy and materials, generating chemical or thermal waste.
- **Toxicity and Exposure:** Some materials and additives, especially chemicals or fine powders, require rigorous safety management and waste disposal.

Sustainability in Additive Manufacturing

Conclusion and Future

Conclusion: AM as a Catalyst for Sustainable Industry

- ✓ **Balance:** Additive Manufacturing offers superior environmental benefits over traditional methods in crucial areas (materials, logistics, and lightweight design).
- ✓ **The Way Forward:** To maximize its sustainability, the industry must focus on:
    1. Material Innovation: Developing 100% recyclable and bio-sourced materials.
    2. Energy Efficiency: Optimizing machines and processes to reduce consumption per part.
    3. Standards and Circularity: Establishing regulations for recycling and actively promoting full integration into Circular Economy models.
- ✓ **Final Message:** AM is not inherently sustainable on its own, but it is a technological tool with enormous potential that must be actively managed and developed toward a more responsible industrial future.

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