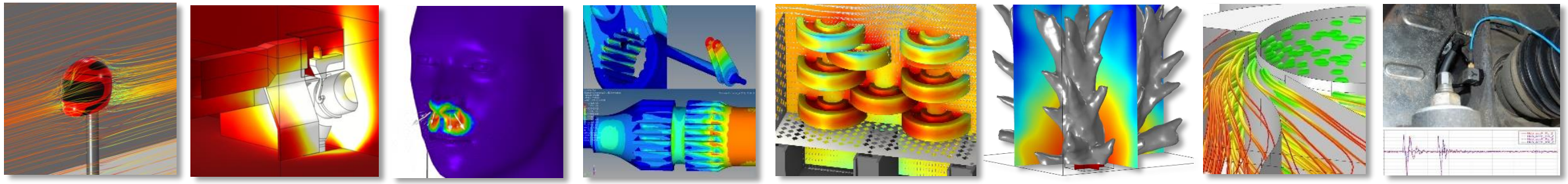
Be challenging, Be smart: Be CAE & Test!



Konference COMSOL Multiphysics 2025

From Material Characterization to Topology Optimization in Additive Manufacturing

Giuseppe Petrone

http://www.be-caetest.it/

2025, May 22-23

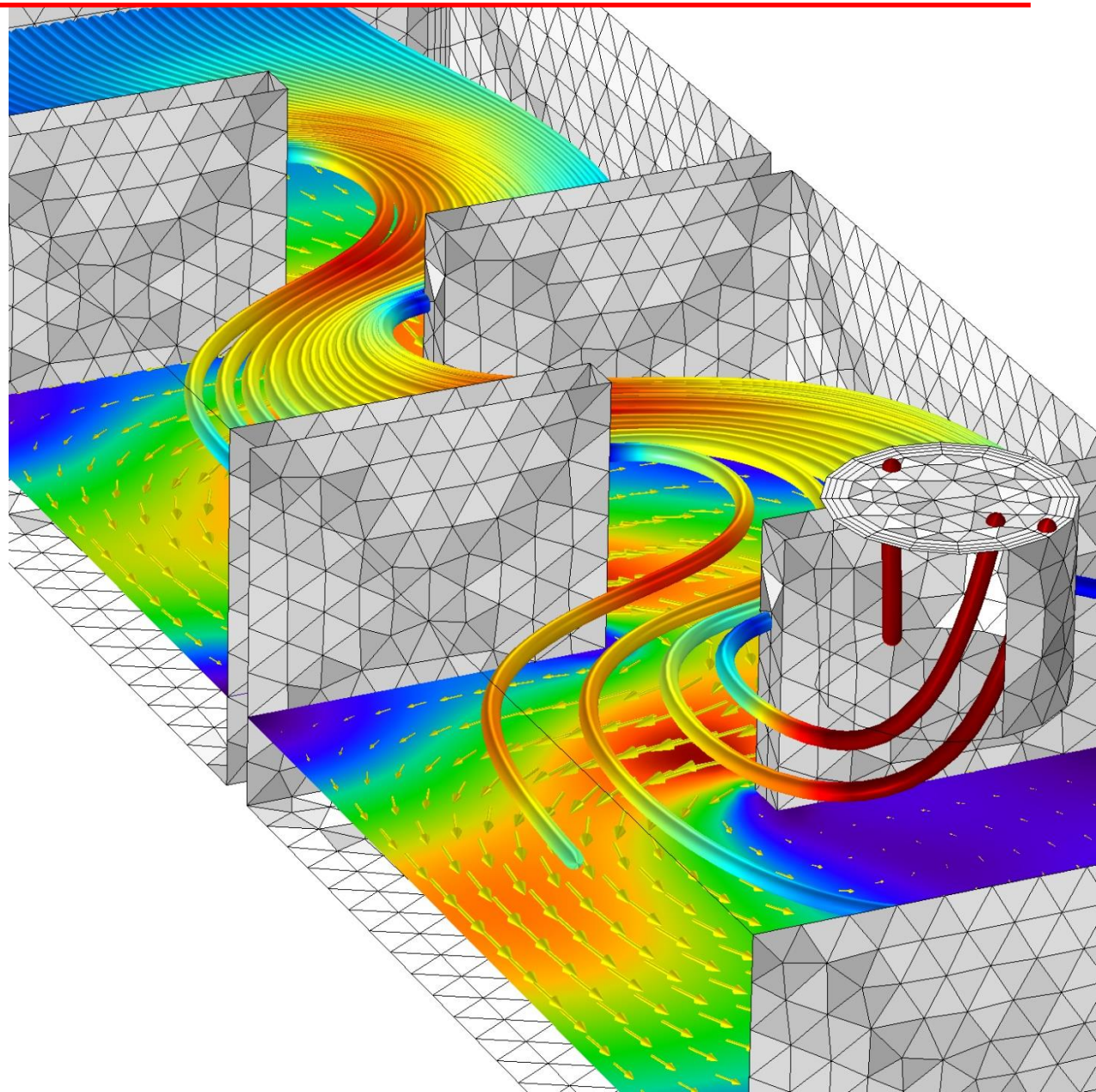
COMSOL Certified Consultant

"…annual meeting of Czech and Slovak users and enthusiasts of virtual development and computer simulations…"

https://www.humusoft.cz/en/event/comsol-2025/agenda/

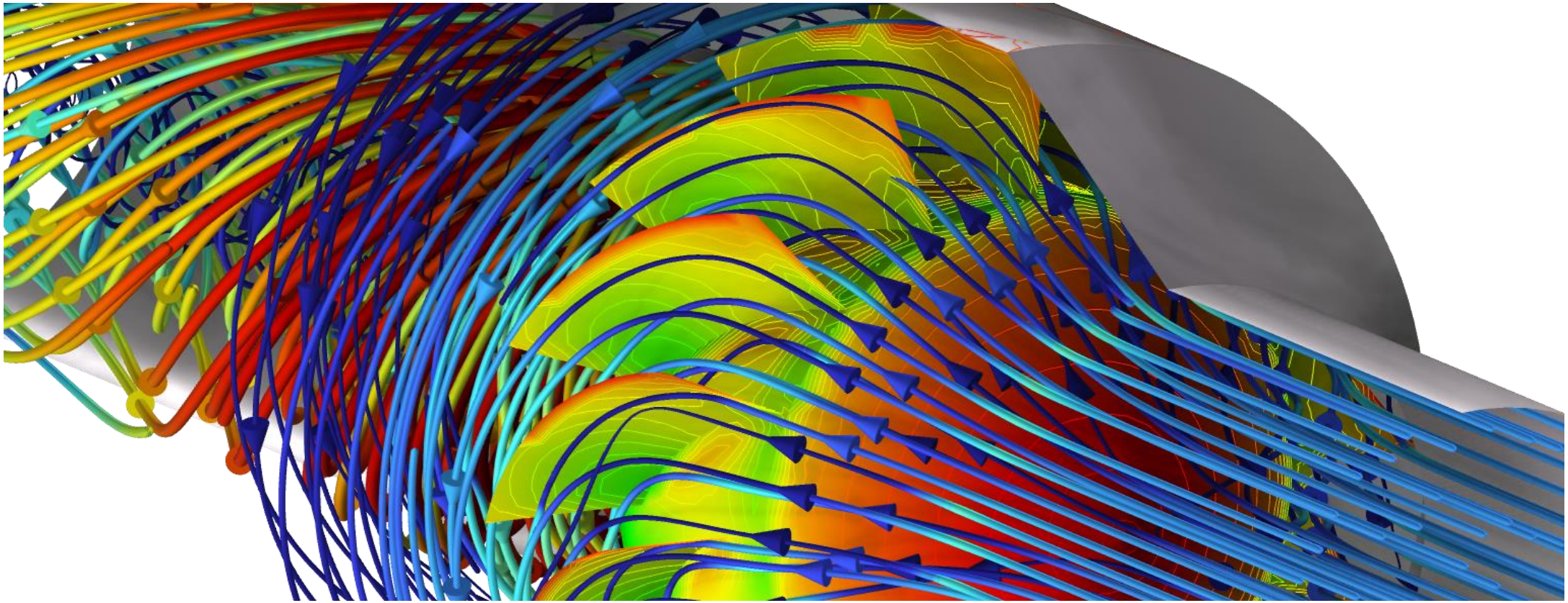
Outline

1. Company introduction
2. Applications in COMSOL Multiphysics
3. Today's topic



We offer **consulting** services using innovative **CAE** simulation tools and **test** facilities.

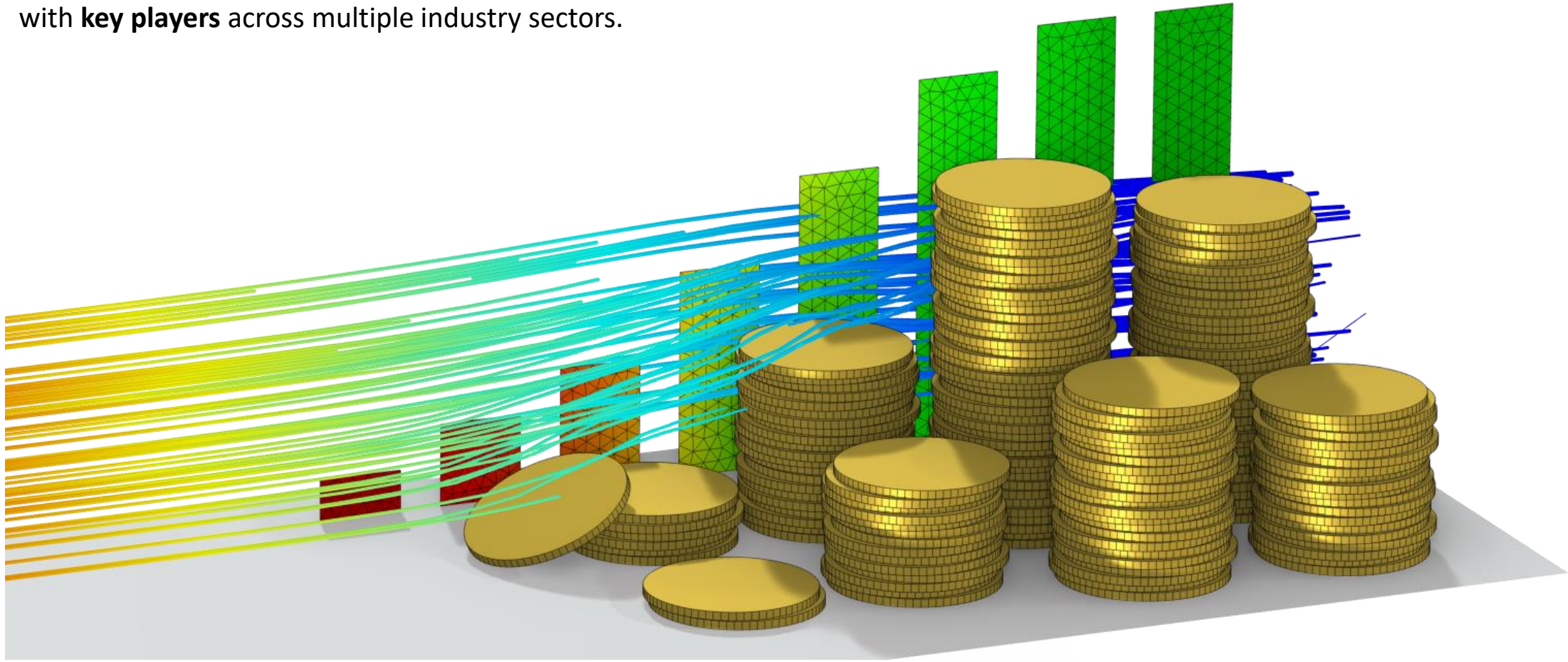
The company was **founded in 2014** by three Italian PhD mechanical engineers who have been working **as a team** in the consulting market since 2008.



About us | Mission | Services

We provide our clients with **efficient** and **cost-effective solutions** to **reduce time to market**.

Steady growth over the years has gradually **increased** the service **portfolio** and markets, resulting in reliable with **key players** across multiple industry sectors.



Company

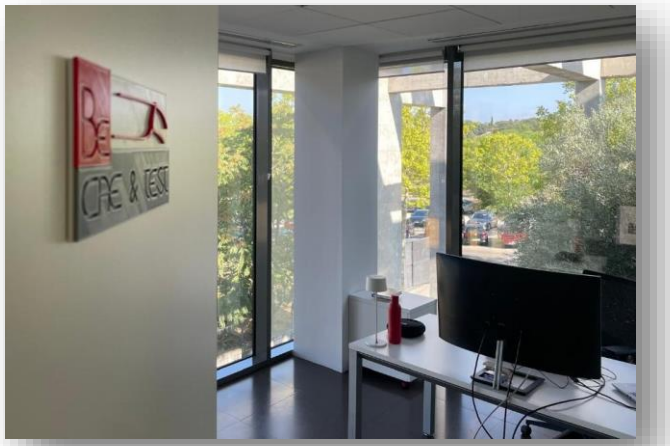
About us | Mission | Services

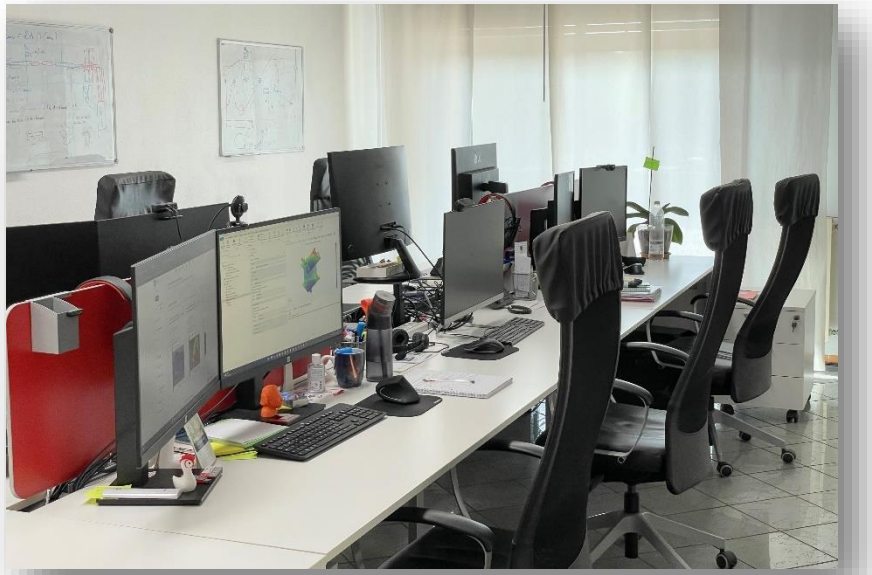
http://www.be-caetest.it/
BE CAE & Test
info@be-caetest.it
+39 095 216 6426

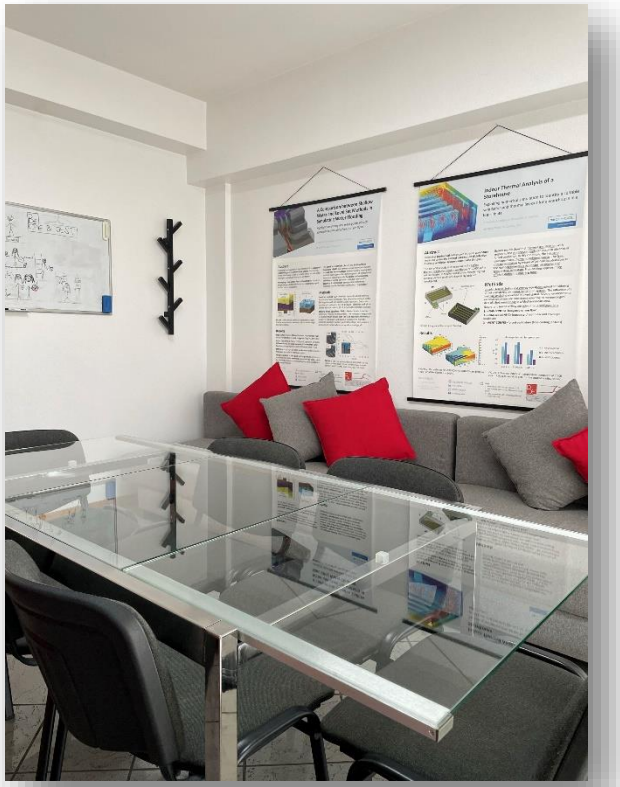
ITALY
- Viale Africa, 170 - 95129 Catania (CT)
- Via Toscana, 104 - 41053 Maranello (MO)

SPAIN
- Calle Impresores, 20 - 28660 Boadilla del Monte (Madrid)

Our offices



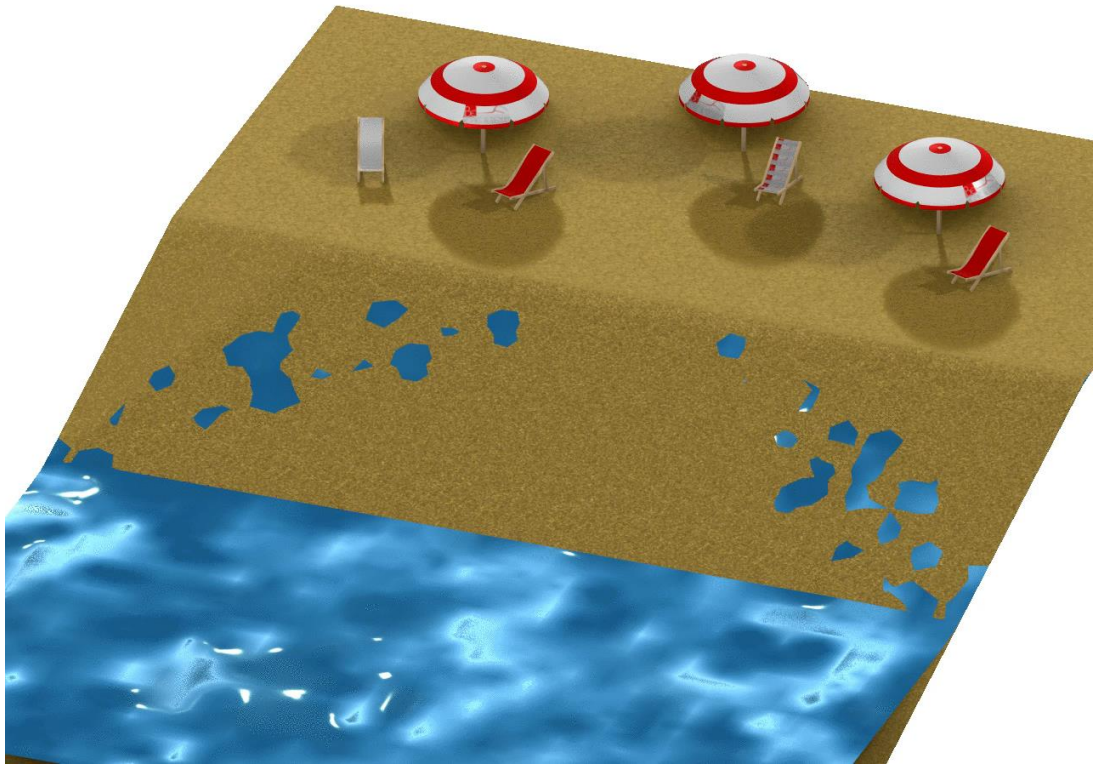




BE CAE & Test is a COMSOL Certified Consultant

- COMSOL Certified Consultants have extensive experience using the COMSOL Multiphysics® platform product as well as the many add-on and interfacing products.
- You may benefit from contacting a certified consultant if you are seeking guidance on starting a new simulation project or looking for ready-to-run models and reports with an in-depth analysis of the simulation results.

www.comsol.com/certified-consultants/bus



Our mission is our client, their goals are our goals

The support we provide to the client in each project is inspired by the following values which, over the years, have enabled us to create stable, effective and efficient collaborations.

People

We are people, we work for people... human relations in the BE team and with the client are a priority for us.

Listening	Synergy	Innovation	Experience
Understanding our **client's needs**, their **vision**, their **priorities**	Working **with** and **for** the client	Technology goes fast and we are doing our best to keep company **updated**	Providing **over 20 years** of engineering services

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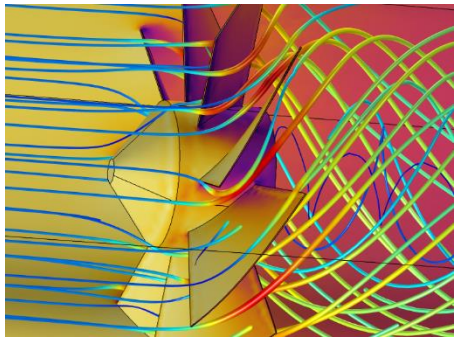
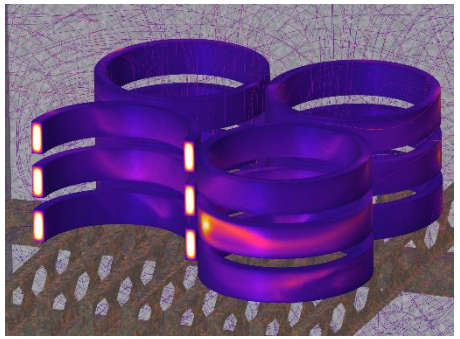
CAE/Multiphysics Simulation



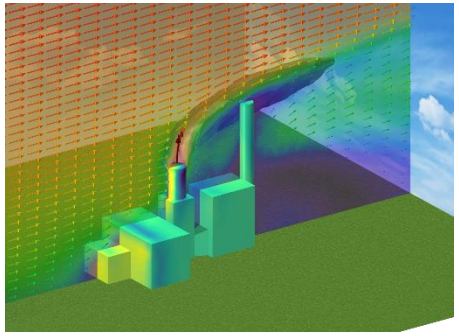
Fluid dynamics

- Laminar/turbulent single-phase flow
- Multi-phase flow
- Free-surface and saturated porous media flow
- High Mach number flow



Heat transfer

- Conduction
- Buoyancy flow and forced convection
- Radiation
- Psychrometry
- Phase change



Multiphysics

- Electro-thermo-structural interaction
- Fluid-structure interaction
- Reacting flow
- Particle tracing

User interfaces

- Fully parametric model
- Surrogated model
- Stand-alone customized COMSOL app

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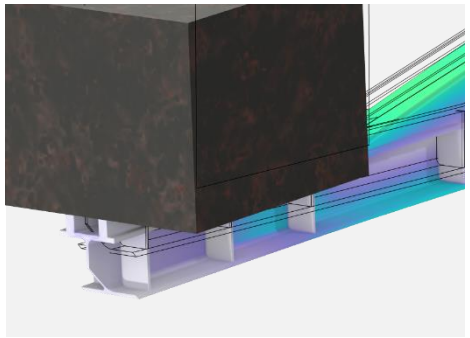
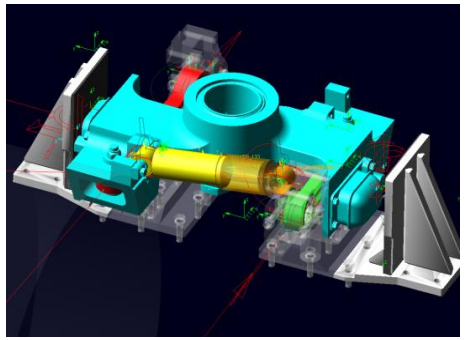
CAE/Multiphysics Simulation



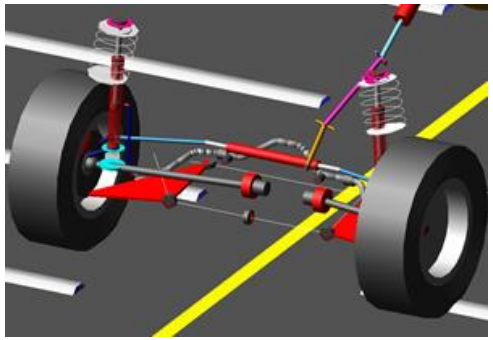
Structural mechanics

- Static linear and nonlinear
- Modal analysis
- Frequency responses
- Optimization



Multibody dynamics

- Kinematics and dynamics of mechanical systems
- Co-simulation
- Mechatronics and controls



Vehicle dynamics

- MultiBody K&C analysis of suspension units (Adams/Car)
- MBS of full vehicle models (Adams/Car)
- Real-time vehicle dynamics (VI-Grade CarRealTime)

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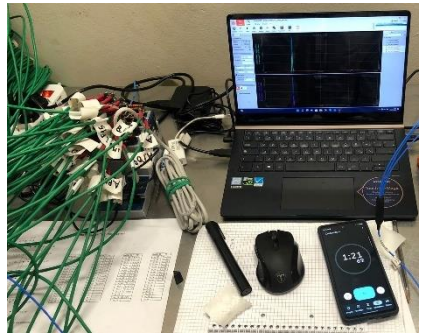
Test/On-Site Measurements


Applications

- NVH (vehicle and powertrain on road and test-bench)
- Ride comfort (vehicle)
- Experimental modal analysis
- Industrial plants vibration monitoring
- Temperature/pressure in industrial process lines
- Experimental validation of numerical models
- Customized hardware

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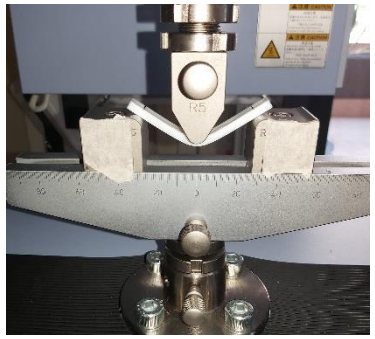
Test/Laboratory



Shaker

- Sentek Shaker M4040-PA140
- Sentek Slip-table 900x900mm (Mg)
- Max acceleration, velocity, displacement: 980m/s^2, 2m/s, 76mm (51)
- Max payload: 500kg (400)
- Additional services :
  - on-site vibration measurement → shaker reference profile
  - fixture design & prototyping
  - failure analysis (CND, SEM, RX, Microscope)



Tensile Tester

- SHIMADZU AGS-X 10 kN
- Max. Load Capacity: 10kN
- Crosshead : Max. Return Speed: 1500 mm/min
- Crosshead : Speed Range: 0.001 to 1000 mm/min (stepless)
- Thermal Chamber TCE 300: range -70°C to +280°C

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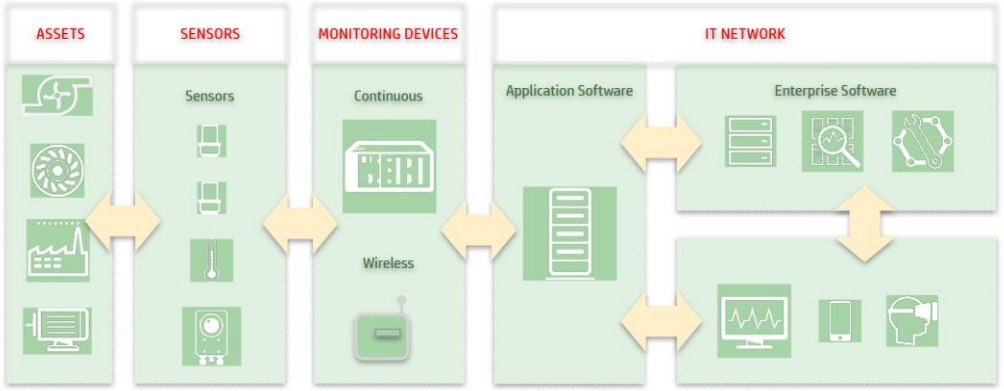
Machine Condition Monitoring/Industry 5.0



- Track, record, and analyze the performance and operation of machines in real time
- Monitor machine health
- Predict potential failures
- Plan maintenance tasks
- Custom solutions

Applications

- Manufacturing
- Automotive & Aerospace
- Energy sector
- Mechanical industry
- Smart cities

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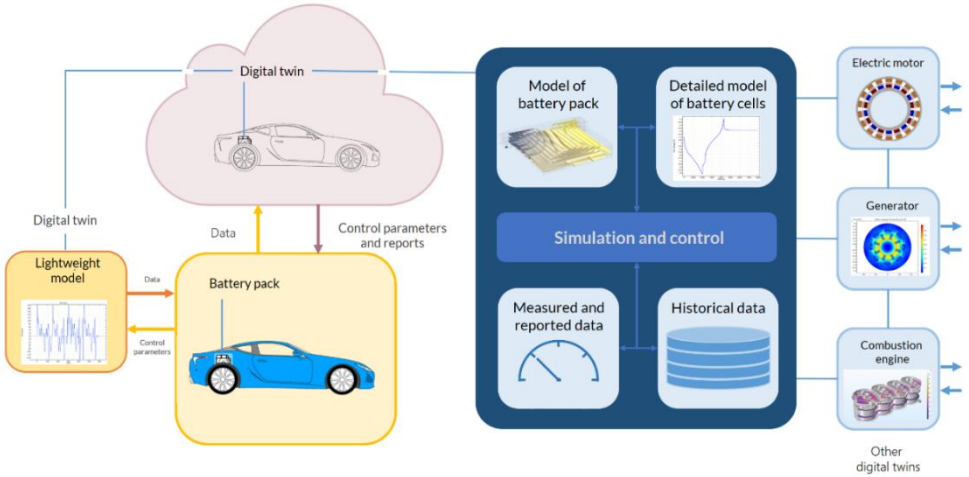
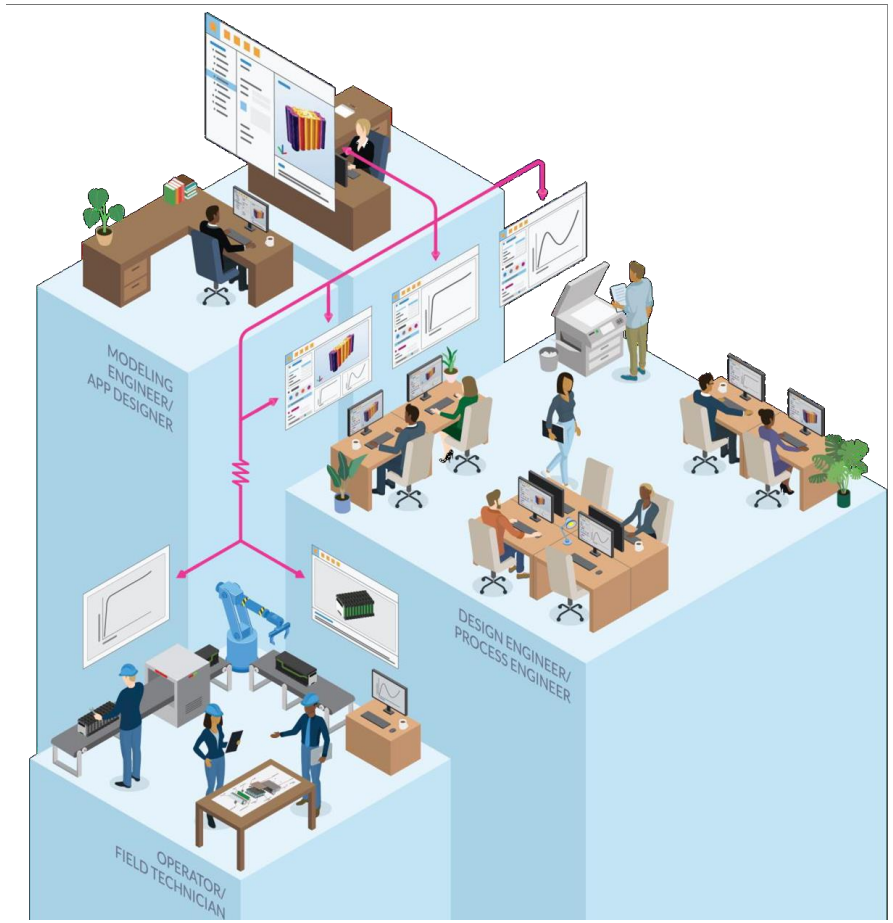
Digital Twins/Industry 5.0



- Standalone simulation app
- Real-time monitoring: data from sensors and other data sources
- Continuous training of the DNN (Deep Neural Network)
- Process Management
- Product Lifecycle Management



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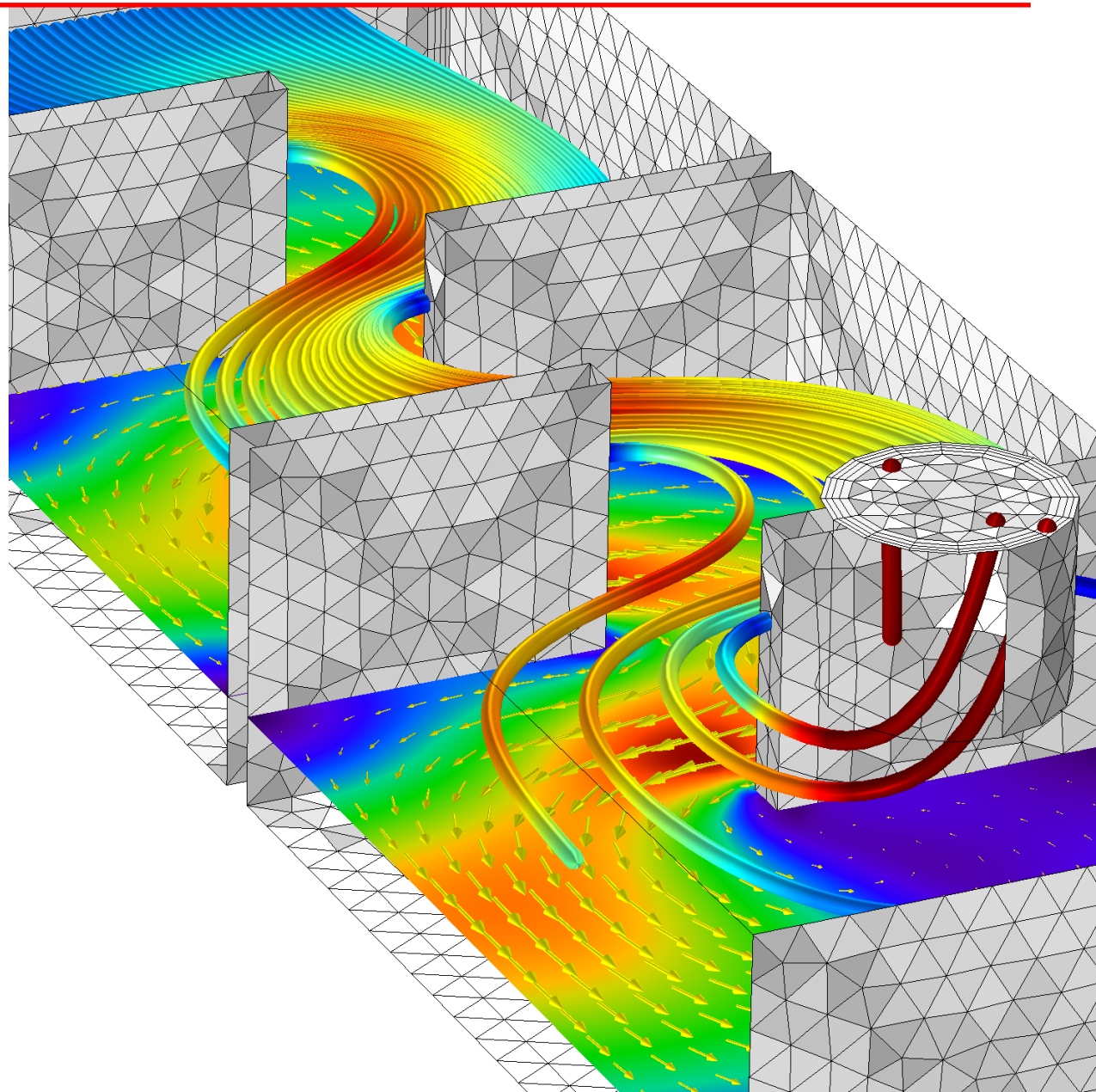
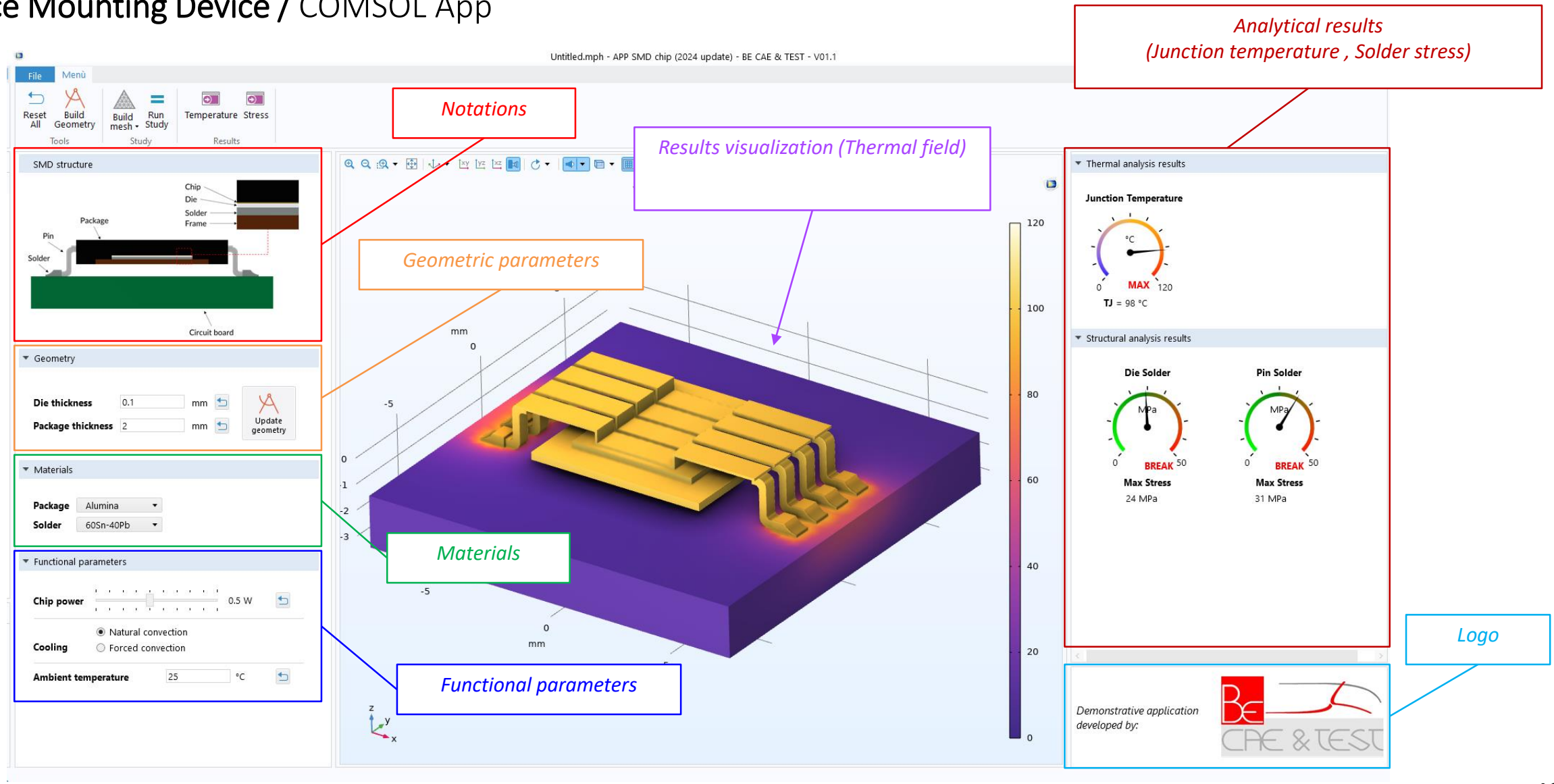


Surface Mounting Device / COMSOL App



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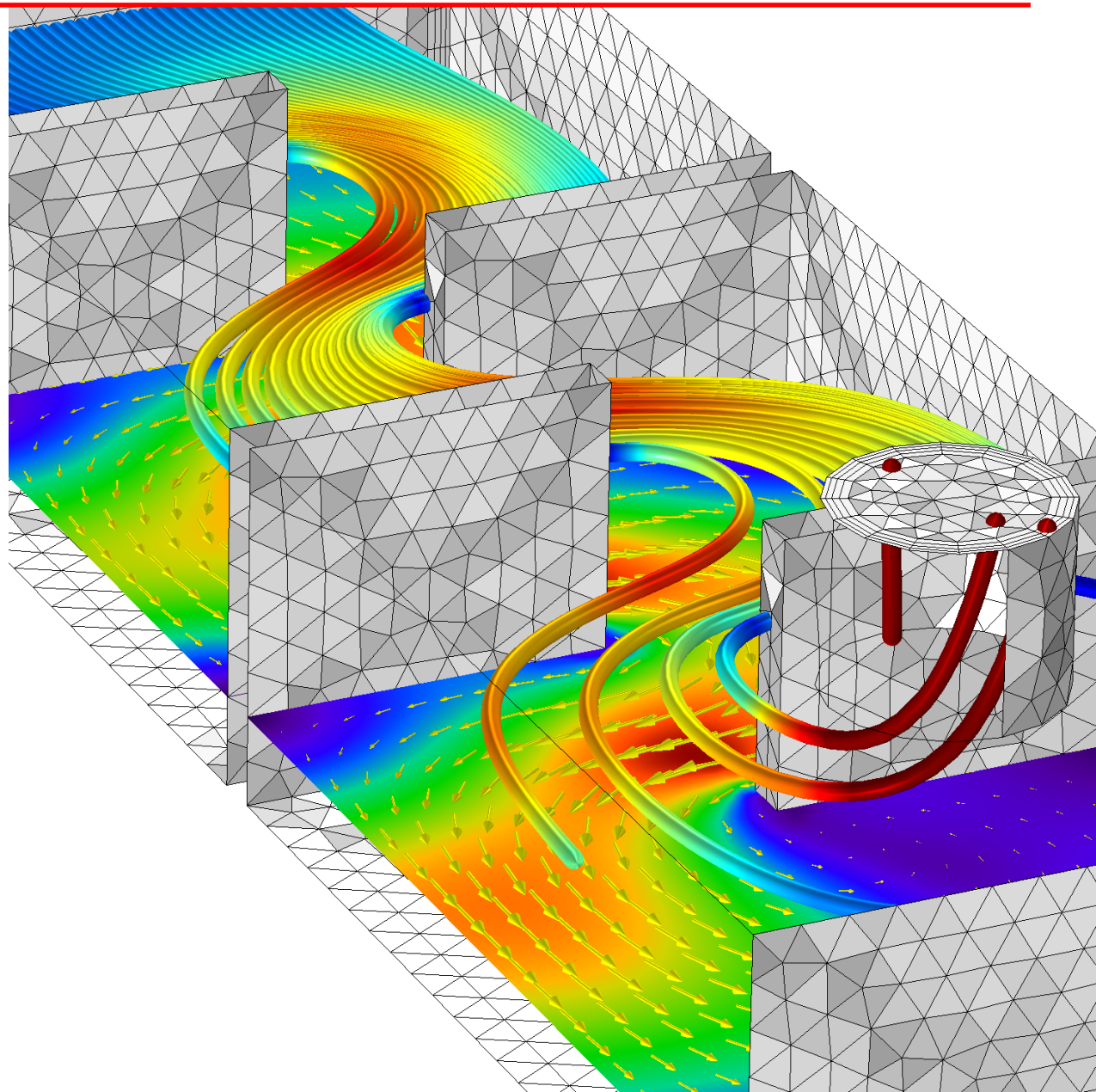
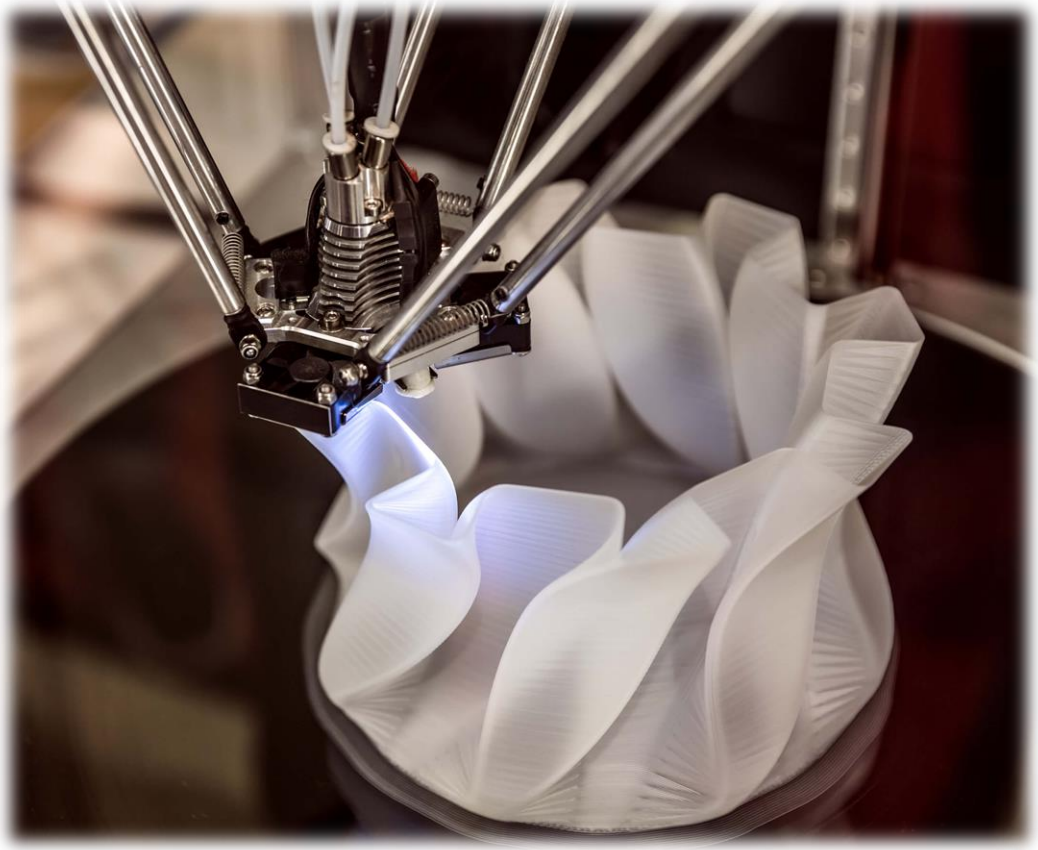
From Material Characterization to Topology Optimization in Additive Manufacturing



Additive Manufacturing

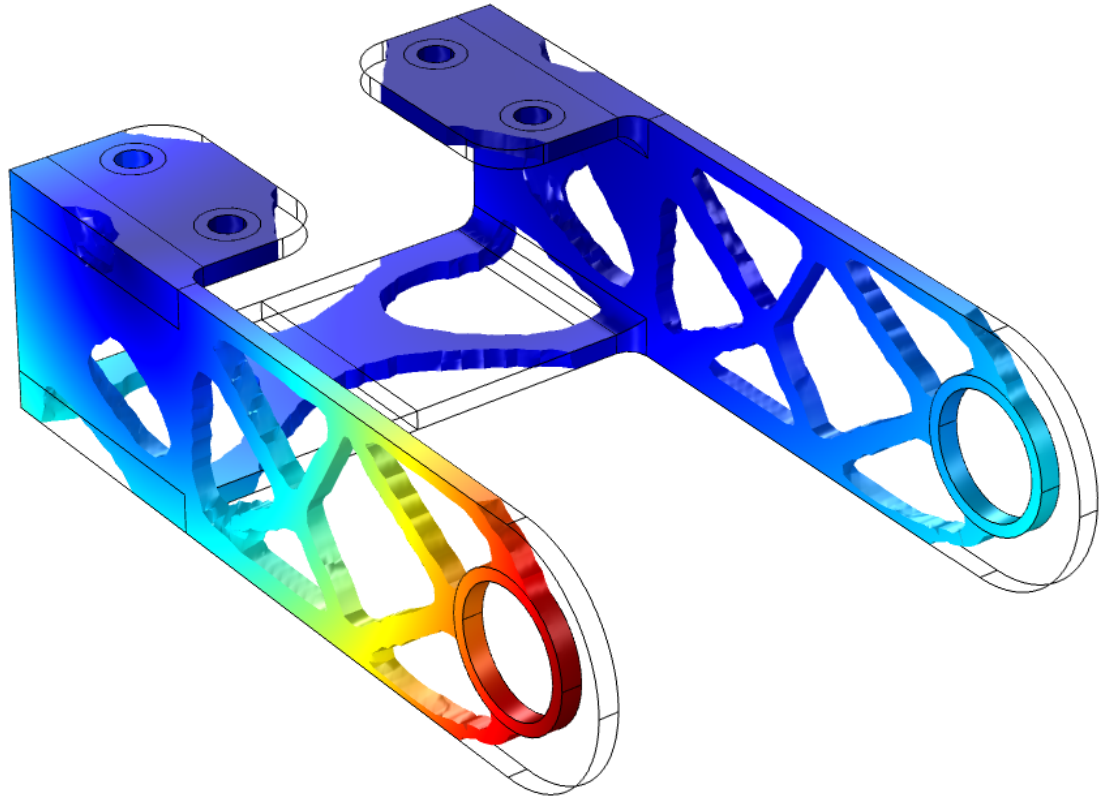
- **Additive Manufacturing** is undergoing **rapid** technological **evolution**, **unlocking design freedom** and performance thresholds **previously considered unachievable** across a wide range of **industrial applications**



Additive Manufacturing and Numerical Modelling

- **Additive Manufacturing** is undergoing **rapid** technological **evolution**, **unlocking design freedom** and performance thresholds **previously considered unachievable** across a wide range of **industrial applications**

- The **impact** of this emerging technology is **exponentially amplified by** the integration with **numerical simulation** tools - such as **COMSOL Multiphysics** - enabling predictive design and **optimization**



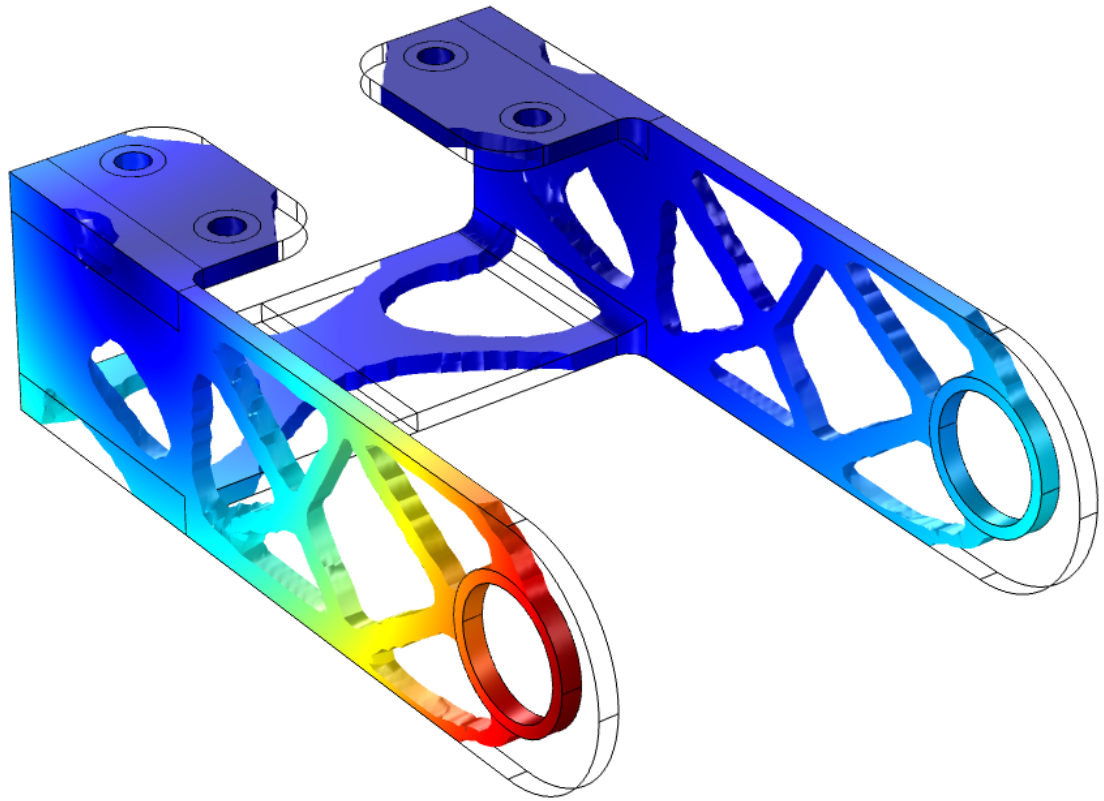
https://www.comsol.com/model/bracket-topology-optimization-69891

Additive Manufacturing and Numerical Modelling

- **Additive Manufacturing** is undergoing **rapid** technological **evolution**, **unlocking design freedom** and performance thresholds **previously considered unachievable** across a wide range of **industrial applications**

- The **impact** of this emerging technology is **exponentially amplified by** the integration with **numerical simulation** tools - such as **COMSOL Multiphysics** - enabling predictive design and **optimization**

- This **synergy** enables the **conception and production of non-conventional components** and structures—solutions once considered impossible using **traditional design methods** and **manufacturing tools**



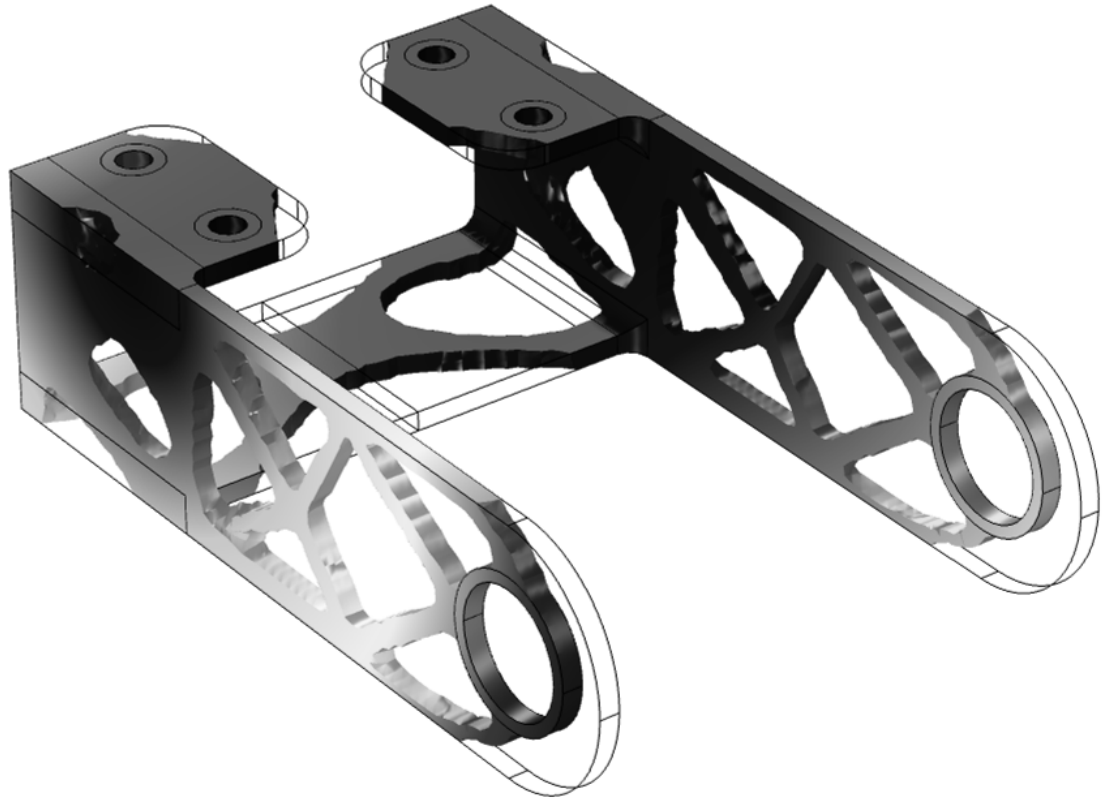
BEYOND THE LIMITS!

https://www.comsol.com/model/bracket-topology-optimization-69891

Additive Manufacturing -> Some grey areas..

- In several cases, the printed material is **not homogeneous**, and its **key structural characteristics may not be known** a priori or may **depend heavily on the 3D printing process/settings**

- Therefore, compared to 'traditional' manufacturing materials, **a more complex procedure** is required **to properly handle** it **in the modelling and simulation** phases



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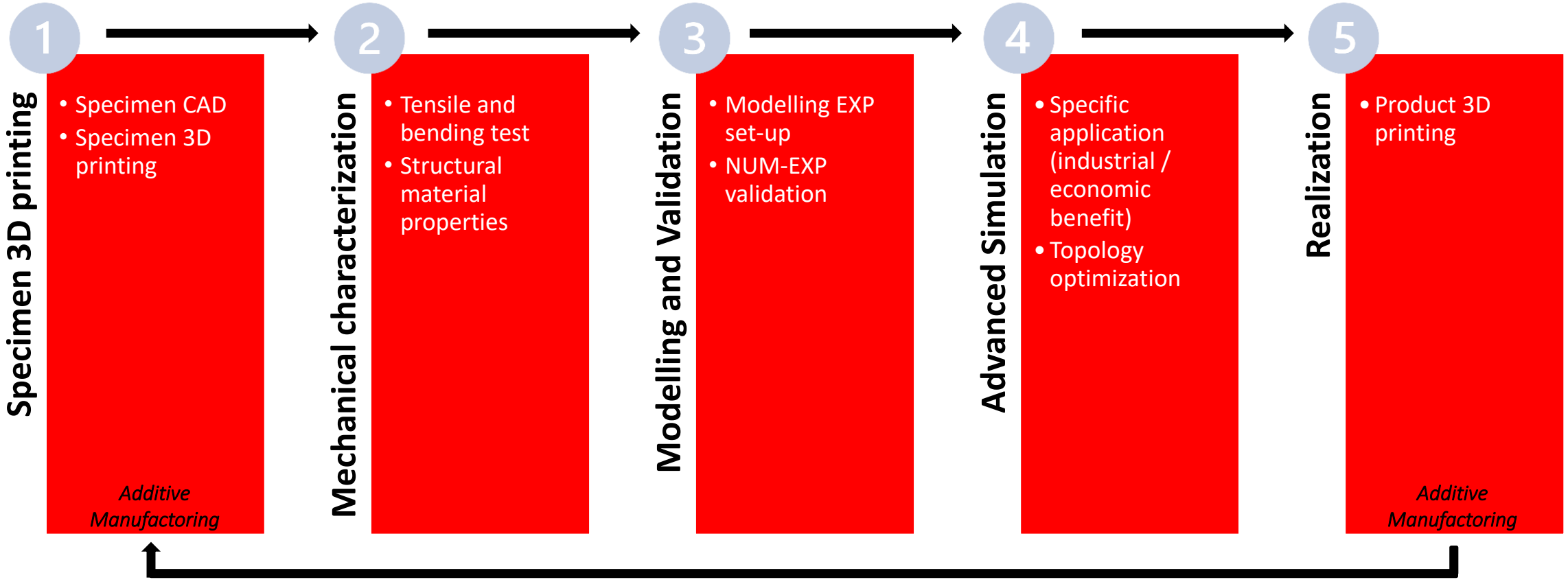
The path forward: *From Material Characterization to Topology Optimization in Additive Manufacturing*



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can manage the entire workflow!

The path forward: *From Material Characterization to Topology Optimization in Additive Manufacturing*

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3D drawing standard specimens

Tensile test

(1) Reference ISO 527-1-2

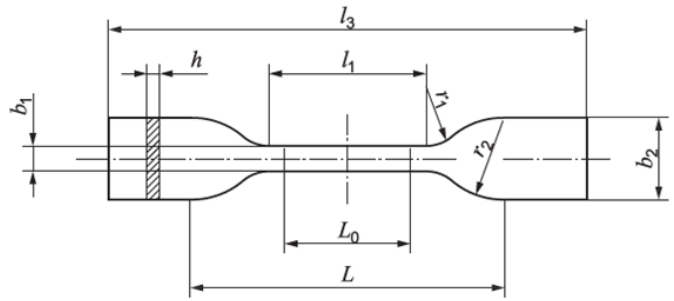
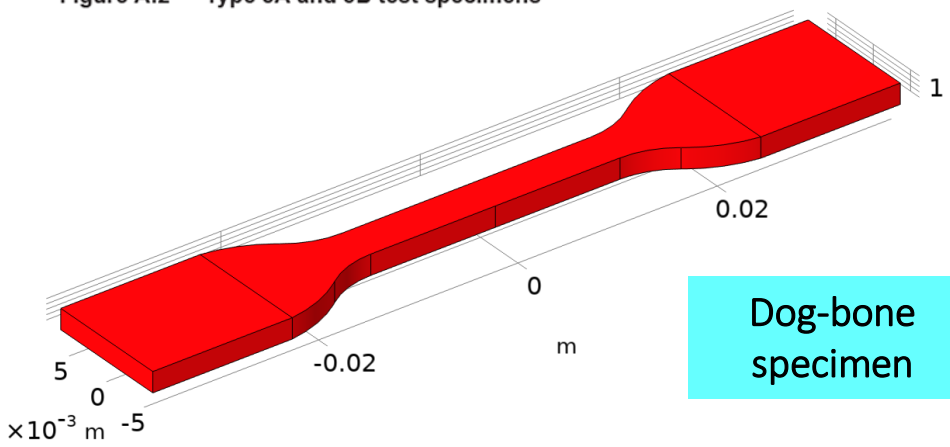


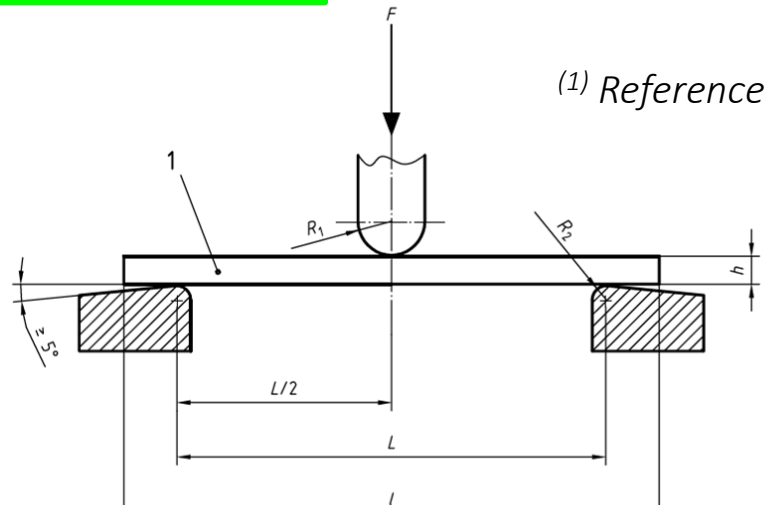
Figure A.2 — Type 5A and 5B test specimens

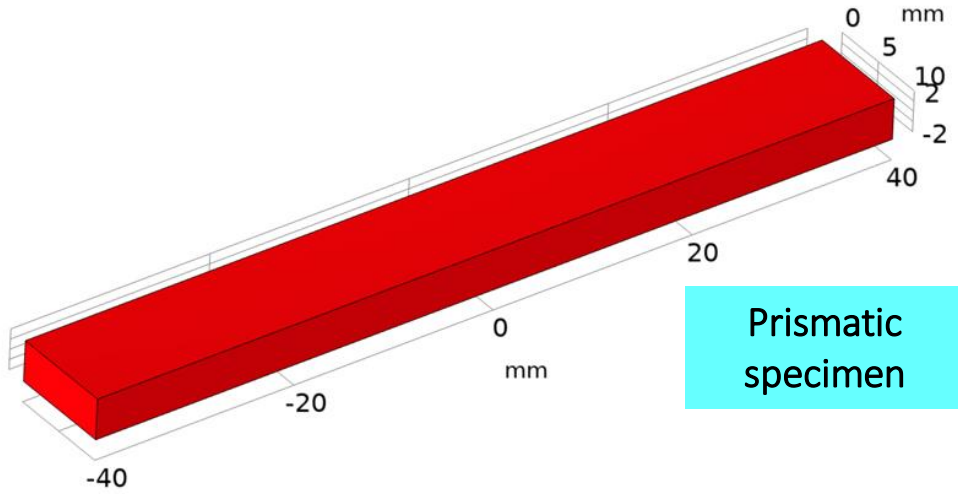


Dog-bone specimen

Bending test

(1) Reference EN ISO 178



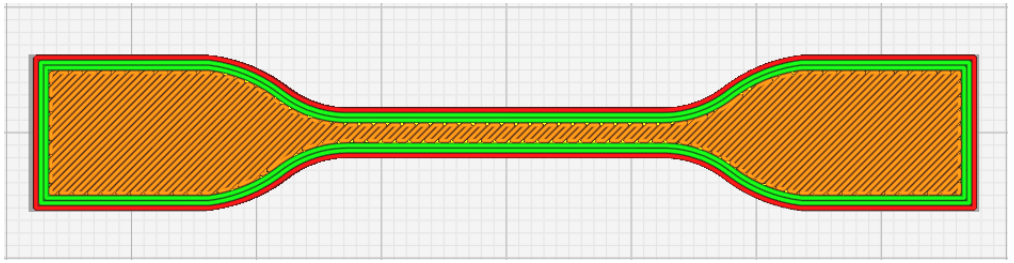


Prismatic specimen

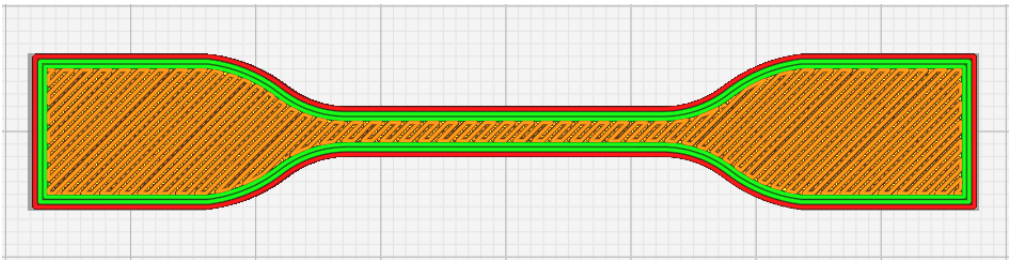
Print standard specimens with different settings

Tensile test

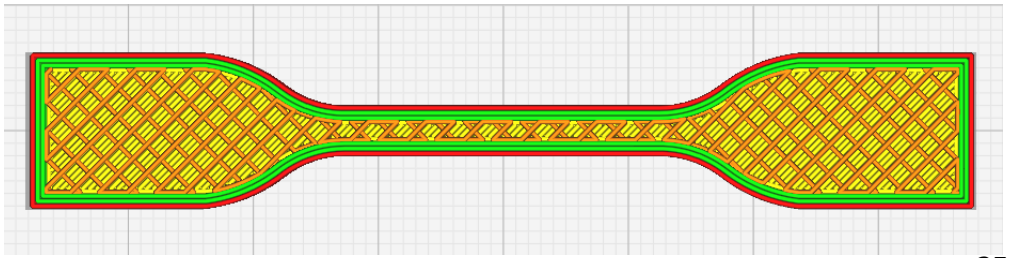
PLA INFILL 100%



PLA INFILL 75%

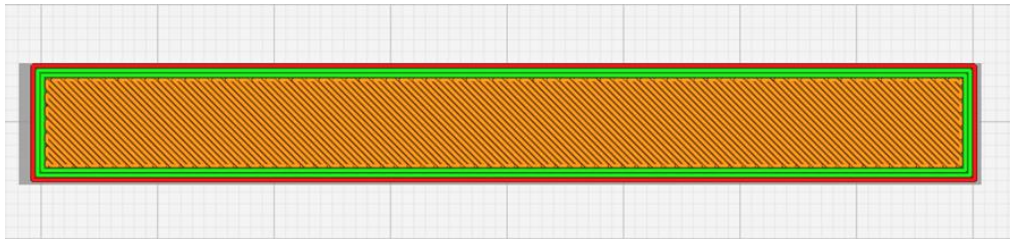


PLA INFILL 25%

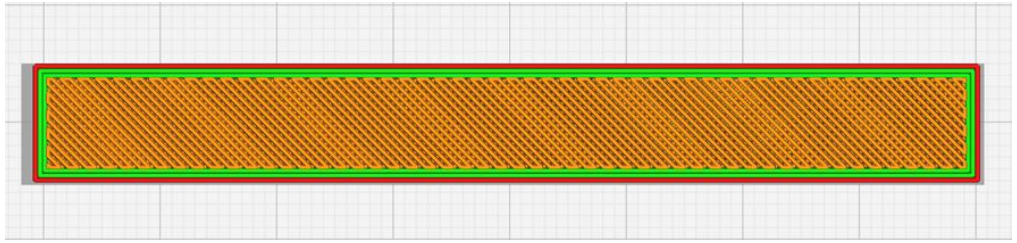


Print standard specimens with different settings

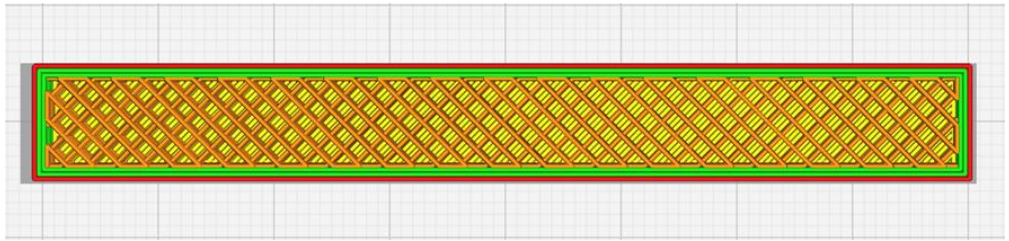
PLA INFILL 100%



PLA INFILL 75%



PLA INFILL 25%



Bending test

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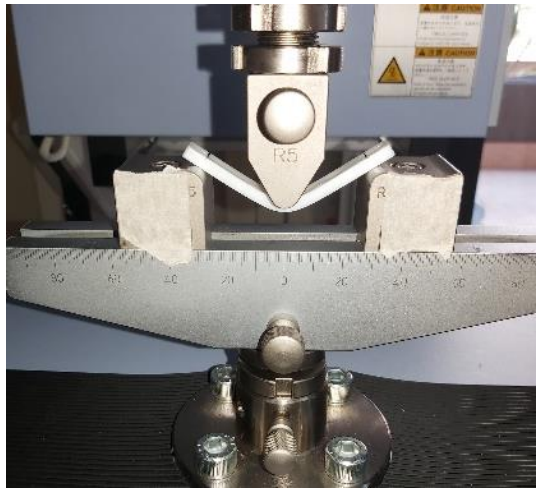
Machine description





Universal machine with Thermal chamber

- Shimadzu AGS-X 10 kN
- Max. Load Capacity: 10kN
- Crosshead : Max. Return Speed: 1500mm/min
- Crosshead : Speed Range: 0.001 to 1000 mm/min (stepless)
- Thermal Chamber TCE 300: range -70°C / +280°C

Test operating method

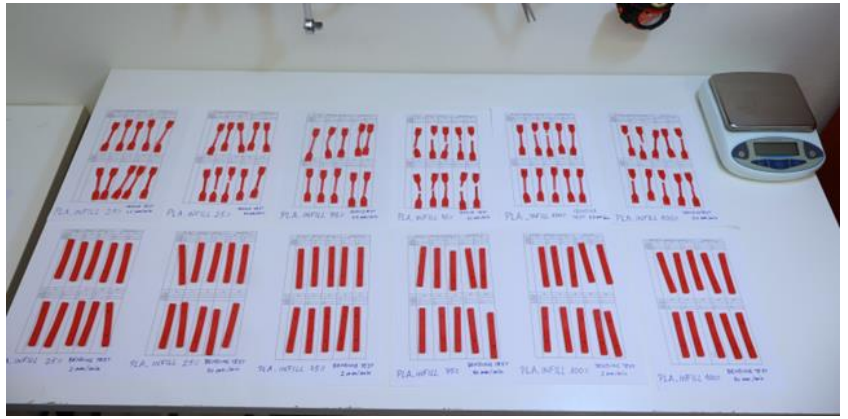
Test performed for **No.3** specimen **type** (PLA **INFILL 100% - 75% -25%):**

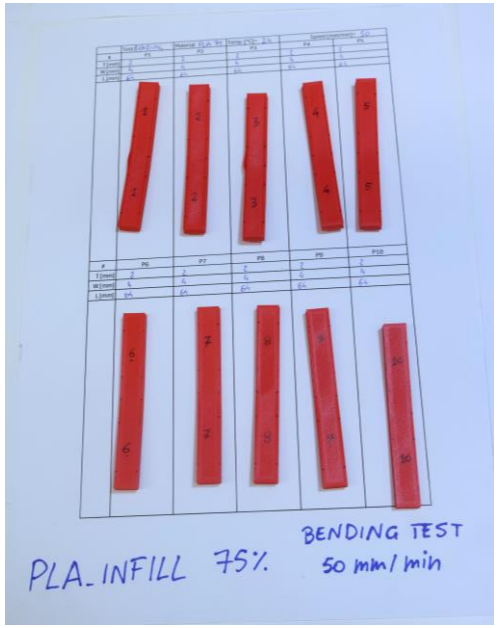
- **Tensile test** at 1-5 [mm/min] and 50 [mm/min].

- **Bending test** at 2 [mm/min] and 50 [mm/min].

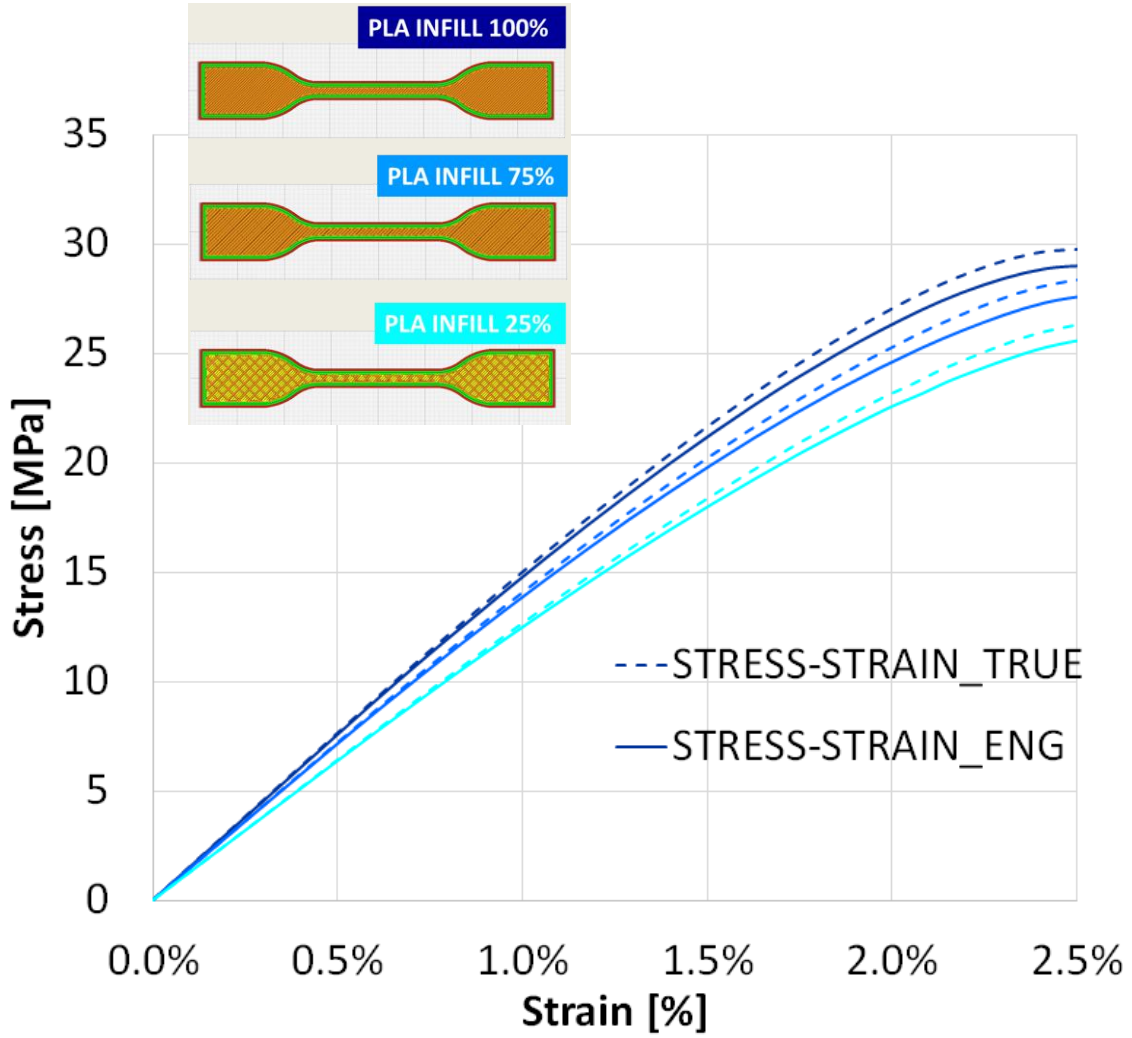
- Number of specimens: 10 per test;
- All tests performed at **(23 ± 2) °C**
- All samples are weighed

➢ The tensile test identified the E_t , **Yield Point** and the **Stress function** used to characterize materials in the model.





Test results



PLA INFILL 100%	
E_linear	1470 [MPa]
Yield Stress Point	26 [MPa]

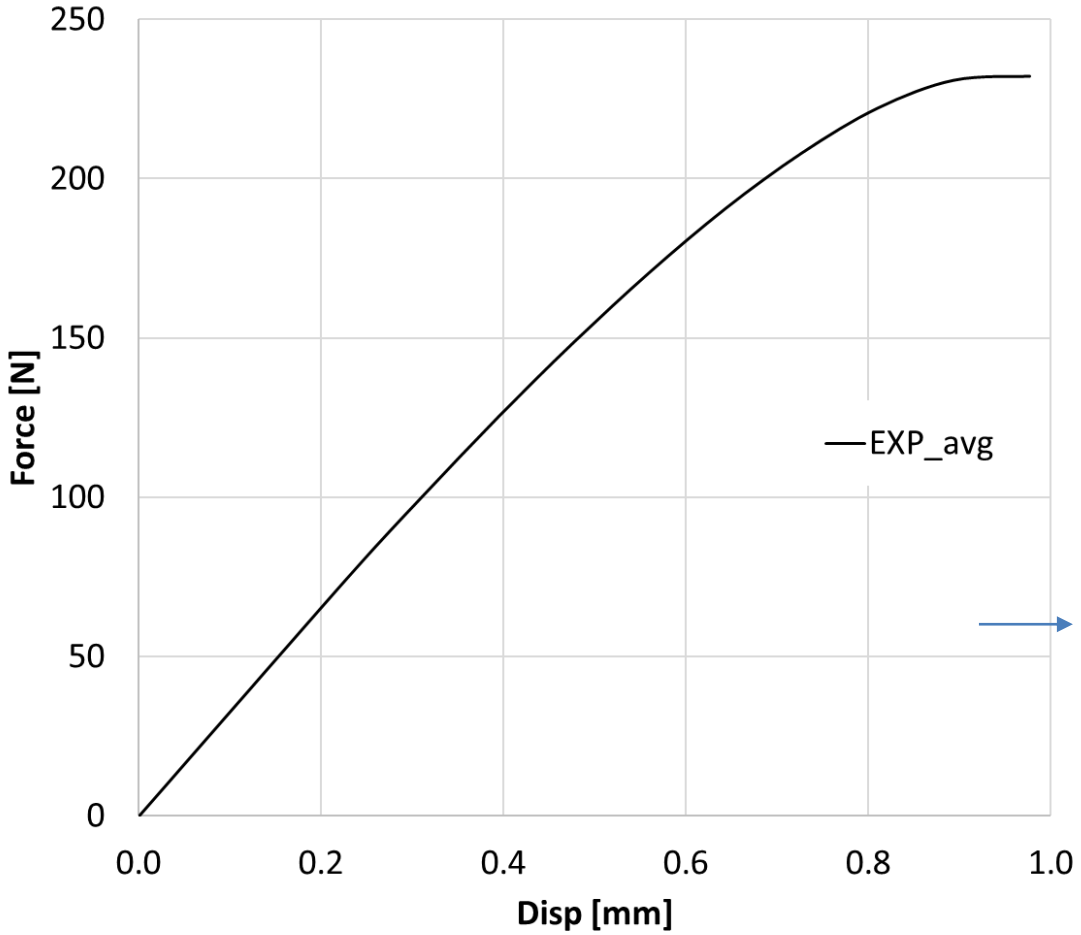
PLA INFILL 75%	
E_linear	1380 [MPa]
Yield Stress Point	24.3 [MPa]

PLA INFILL 25%	
E_linear	1240 [MPa]
Yield Stress Point	23 [MPa]

Data processing procedure

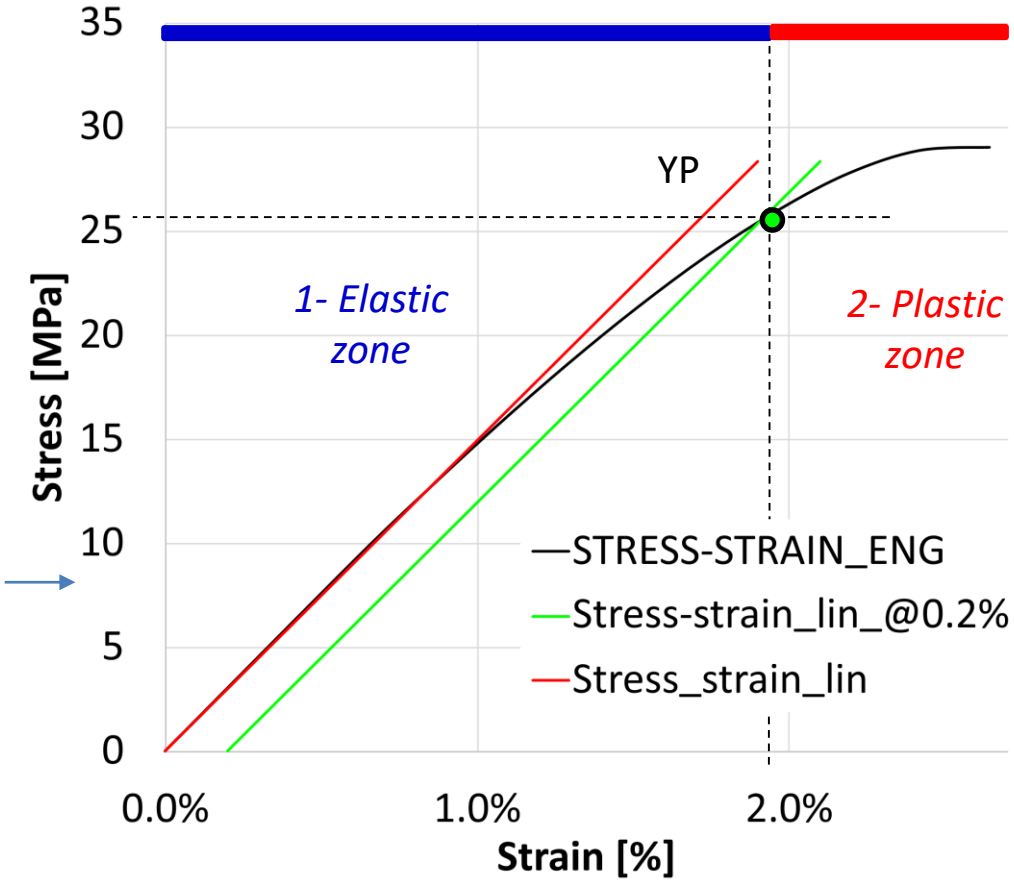
$$\varepsilon_{true} = \ln(1 + \varepsilon_{eng})$$

$$\sigma_{true} = \sigma_{eng}(1 + \varepsilon_{eng})$$

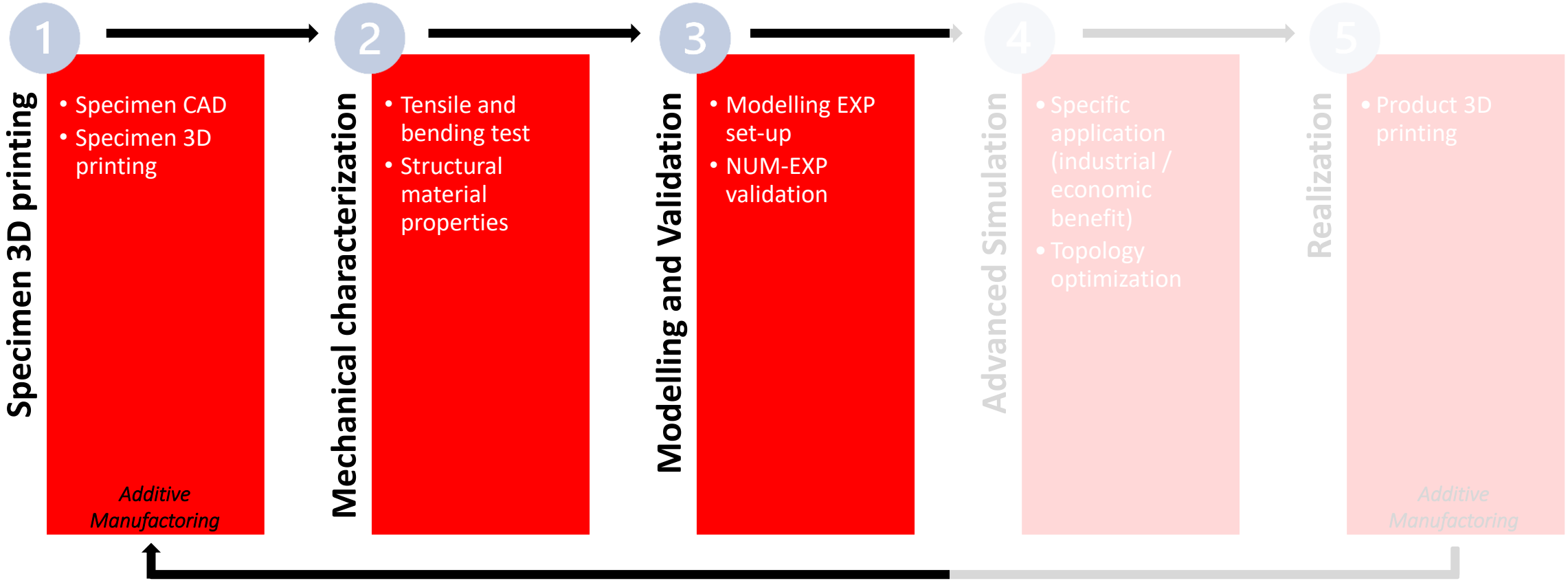


$$\varepsilon_{eng} = \frac{\Delta l}{L_1}$$

$$\sigma_{eng} = \frac{F}{A}$$



The path forward: *From Material Characterization to Topology Optimization in Additive Manufacturing*



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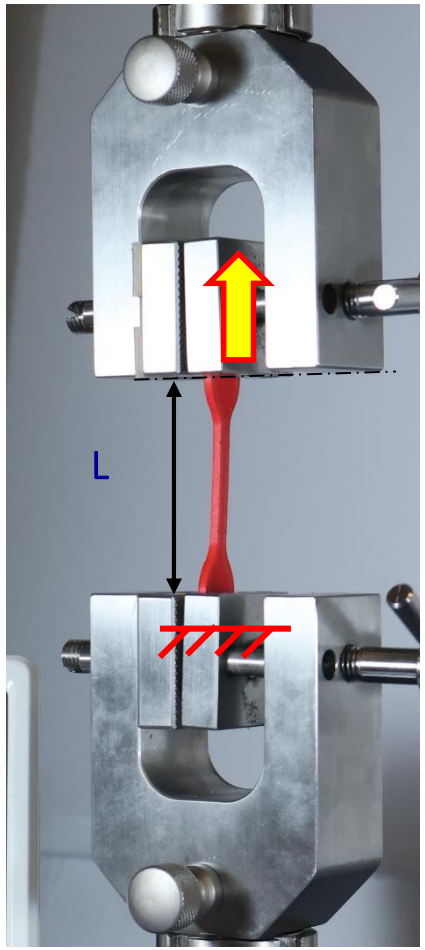
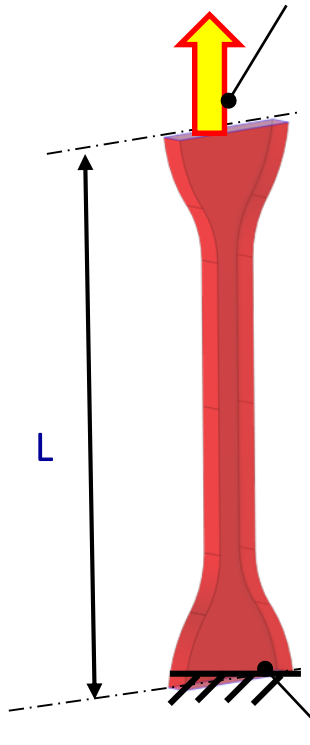
Model settings / Boundary conditions

Tensile test



Prescribed displacement
< disp>



Constraint
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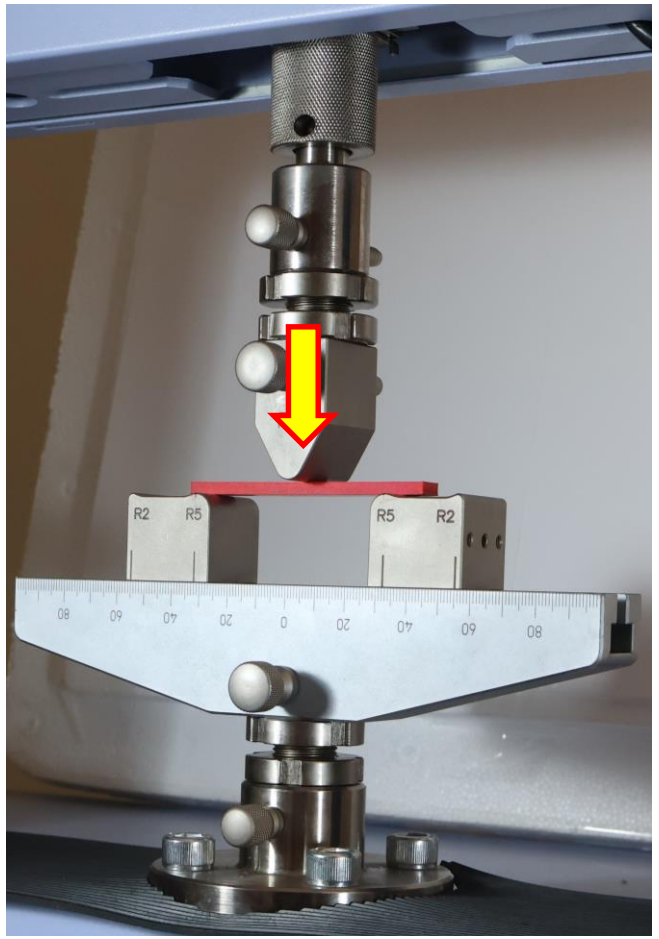
Bending test



Prescribed displacement
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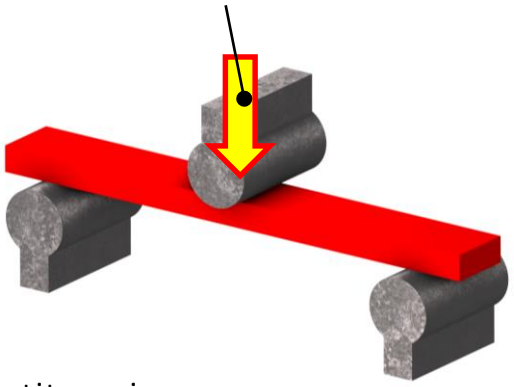
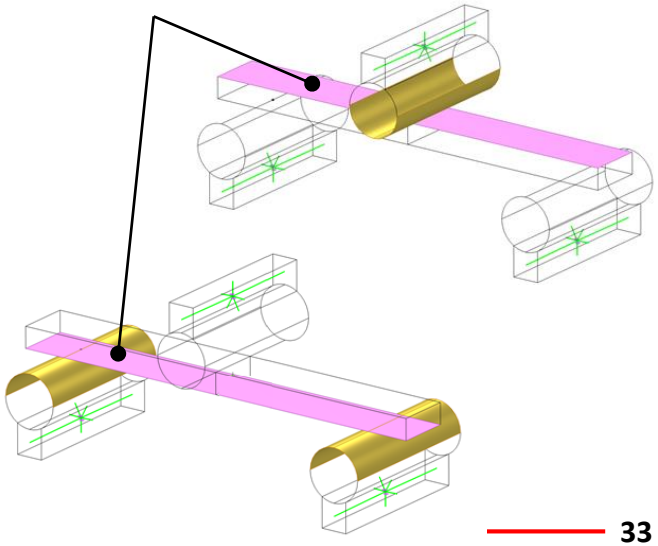
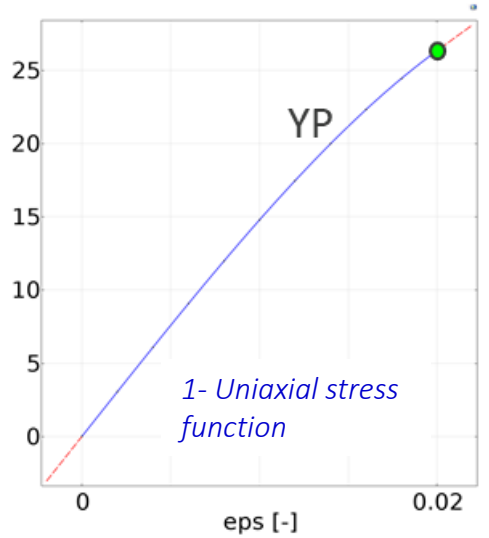


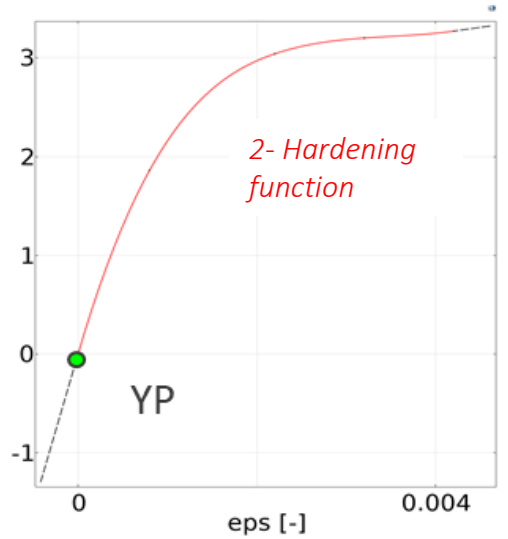
Identity pairs
< contact >



Model settings / Nonlinear Elastic Material - Plasticity

- Solid Mechanics *(solid) {solid}*
  - Linear Elastic Material 1 *{lemm1}*
  - Free 1 *{free1}*
  - Initial Values 1 *{init1}*
  - Prescribed Displacement 2 *{disp2}*
  - Fixed Constraint 3 *{fix3}*
  - Nonlinear Elastic Material 1 *{nlemm1}*
    - Plasticity 1 *{plsty1}*
    - Equation View *{info}*
  - Equation View *{info}*





Nonlinear Elastic Material

Material model:

Uniaxial data

$\sigma_{ax}(\epsilon_{ax} = 0) = 0$

Uniaxial stress function:

σ_{ax} User defined

stress_strain_curve_eng_elastic(solid.eax) N/m²

Specify:

Poisson's ratio

Use nonsymmetric stress-strain data

Poisson's ratio:

ν From material

Density:

ρ From material

Plasticity Model

Equivalent stress:

σ_e von Mises

Initial yield stress:

σ_{ys0} From material

Plastic potential:

Q_p Associated

Equivalent plastic strain:

ϵ_{pe} von Mises

Isotropic hardening model

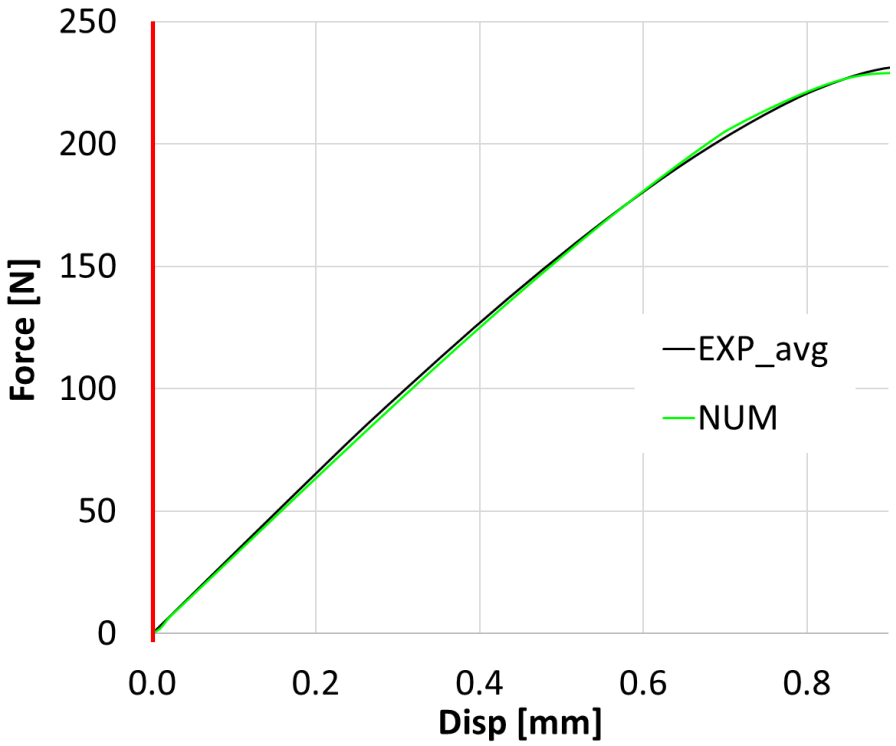
Hardening function

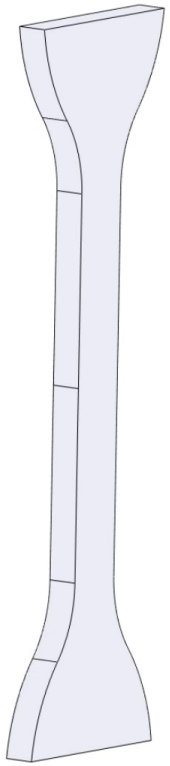
$\sigma_{ys} = \sigma_{ys0} + \sigma_h(\epsilon_{pe})$

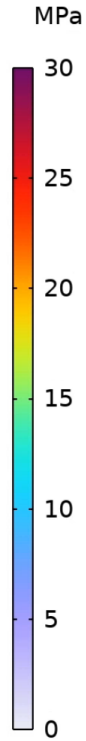
σ_h From material

Results

- Plots on the right: Force [N] - Disp [mm]comparison between Numerical (**green curve**) and Experimental data (**black curve**)

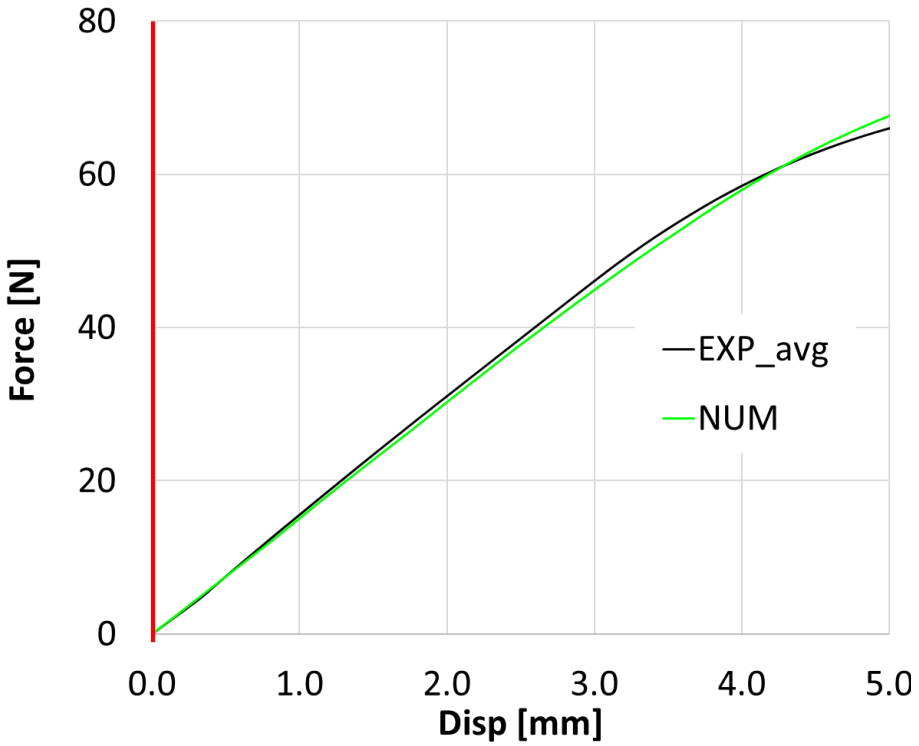


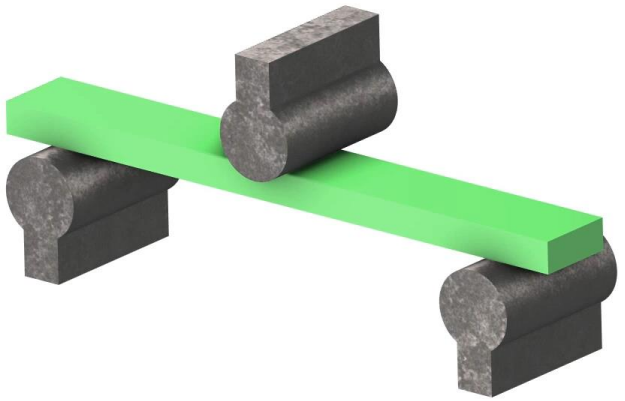


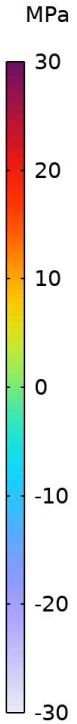


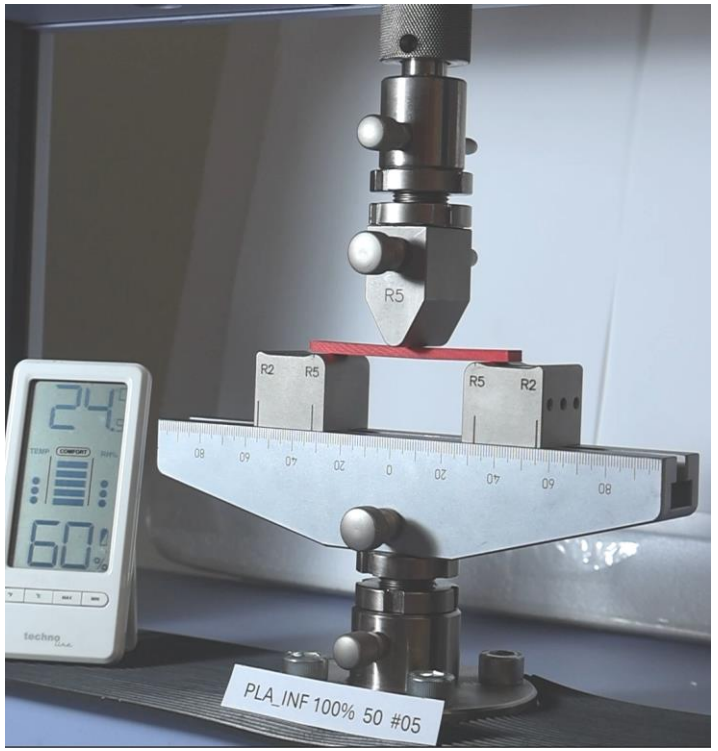
Results

- Plots on the right: Force [N] - Disp [mm]comparison between Numerical (**green curve**) and Experimental data (**black curve**)

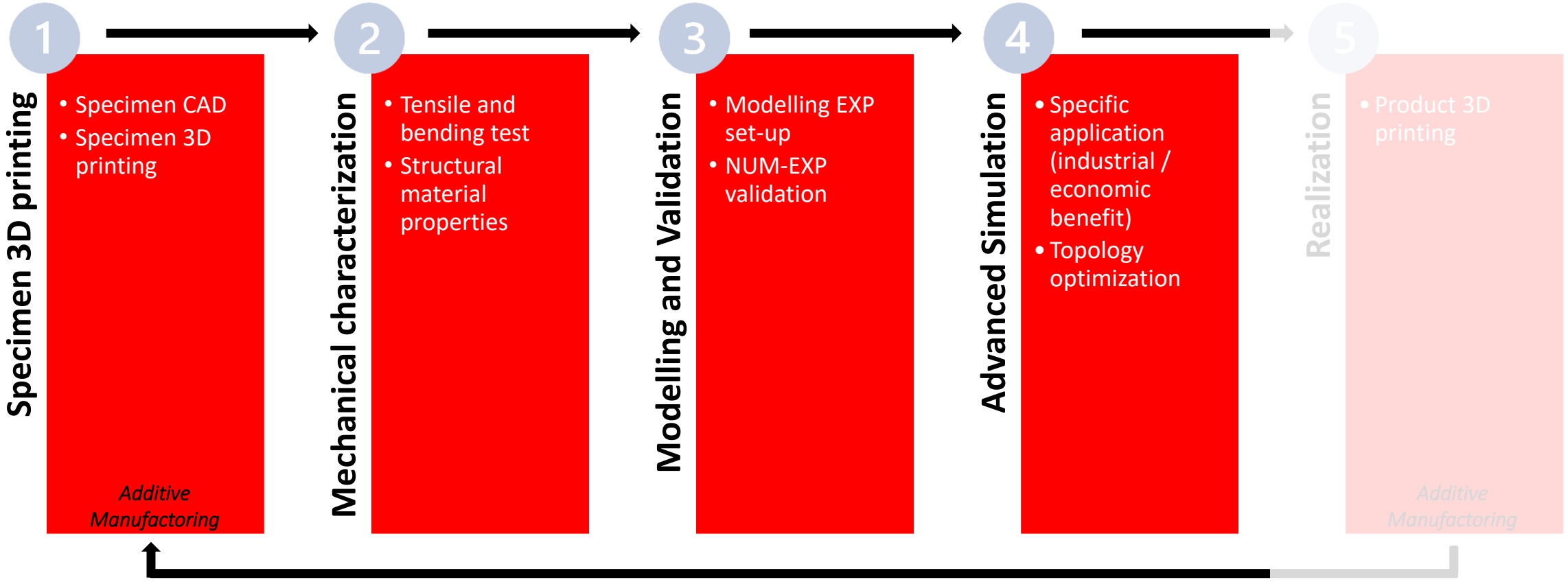








The path forward: *From Material Characterization to Topology Optimization in Additive Manufacturing*



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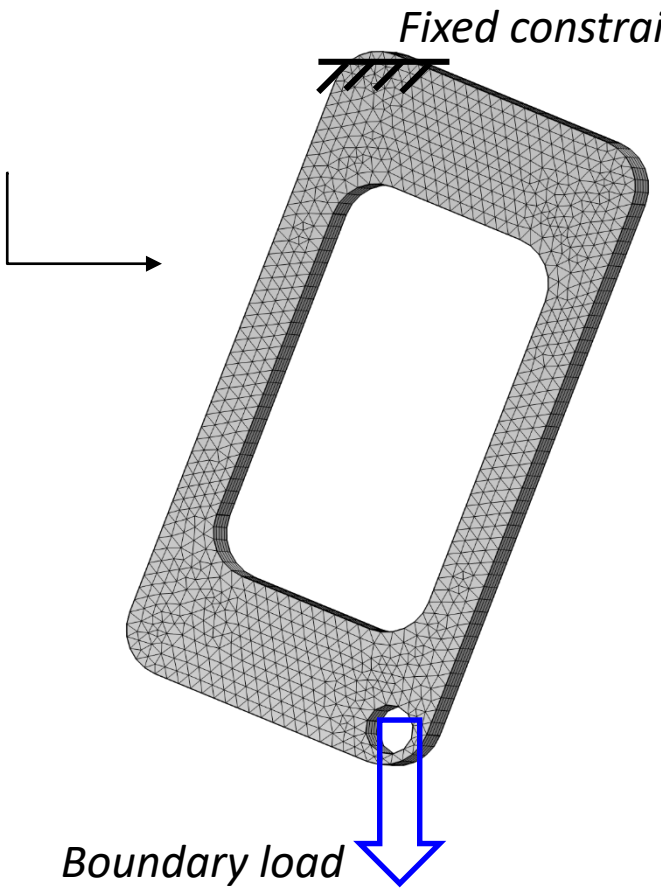
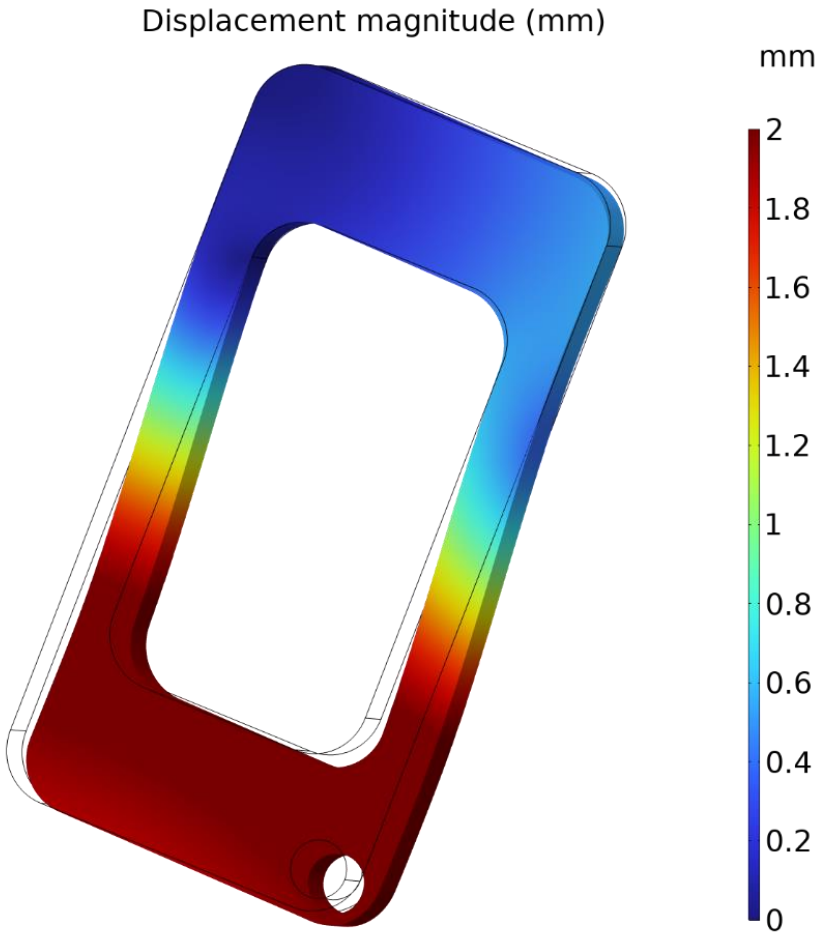
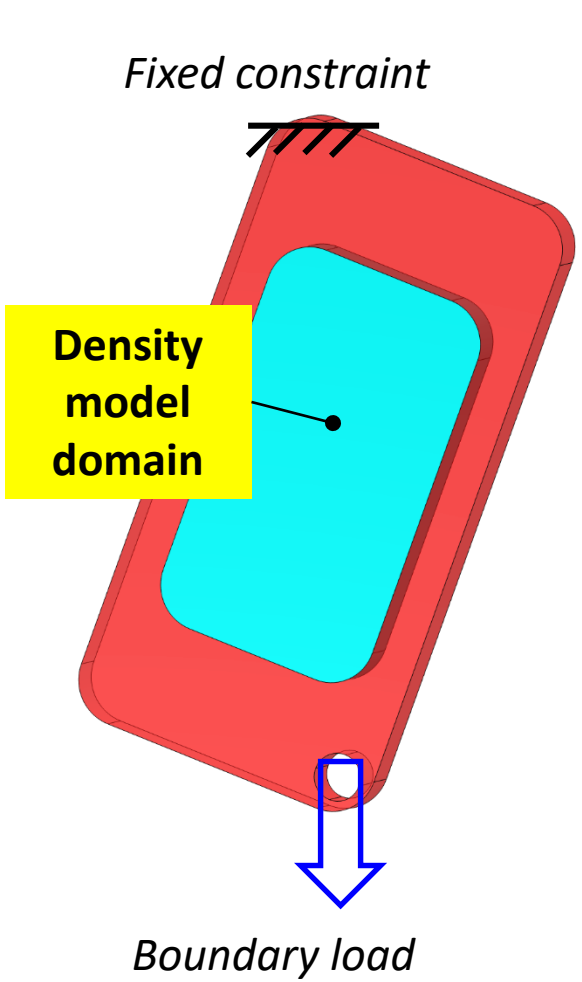
Structural Mechanics & Topology Optimization in COMSOL Multiphysics

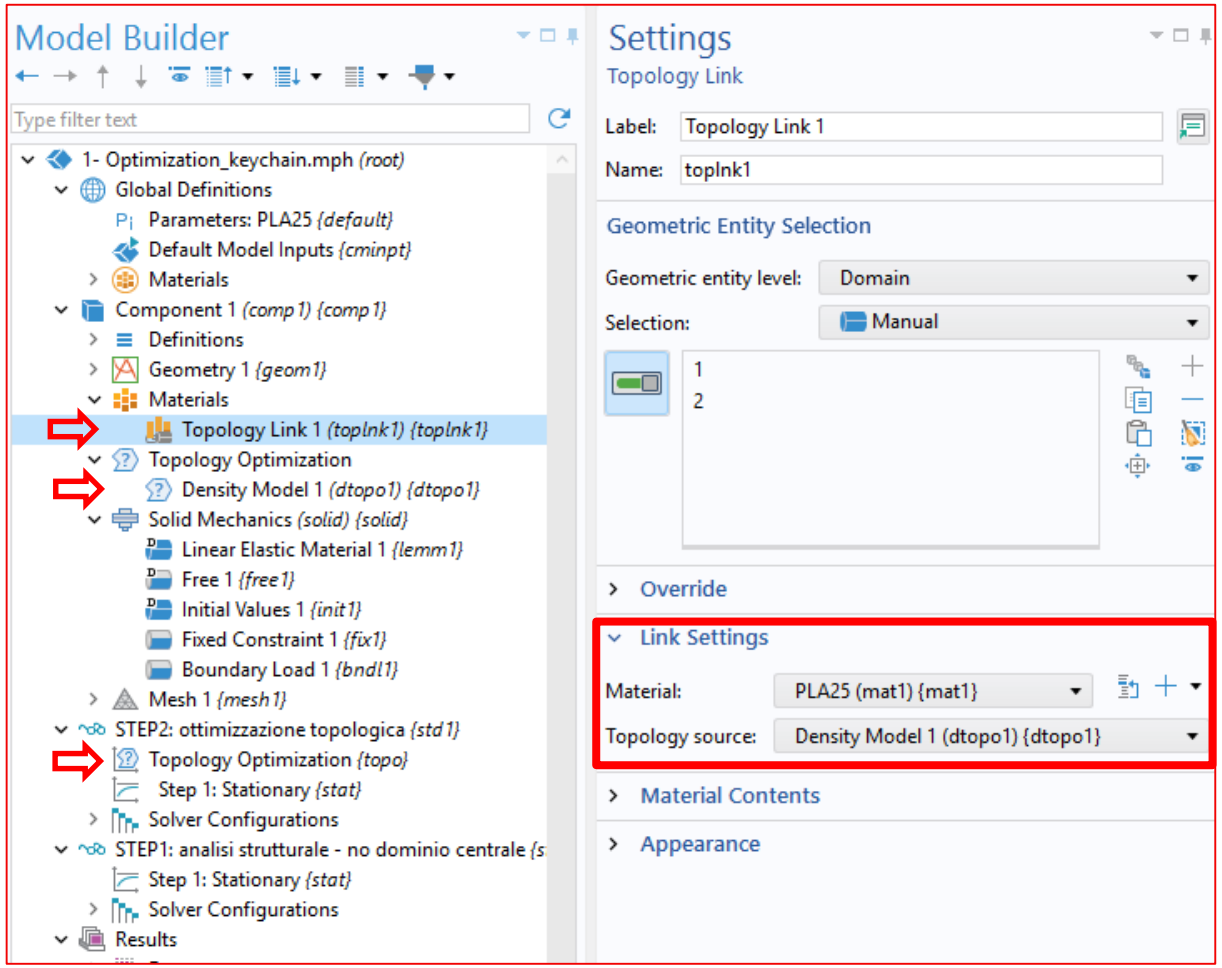


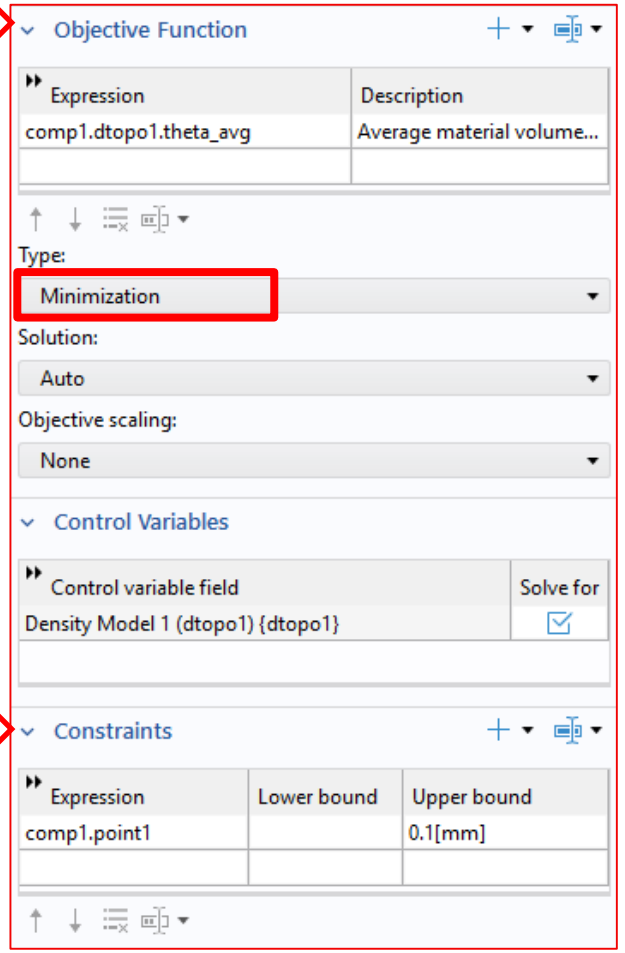
Resuts



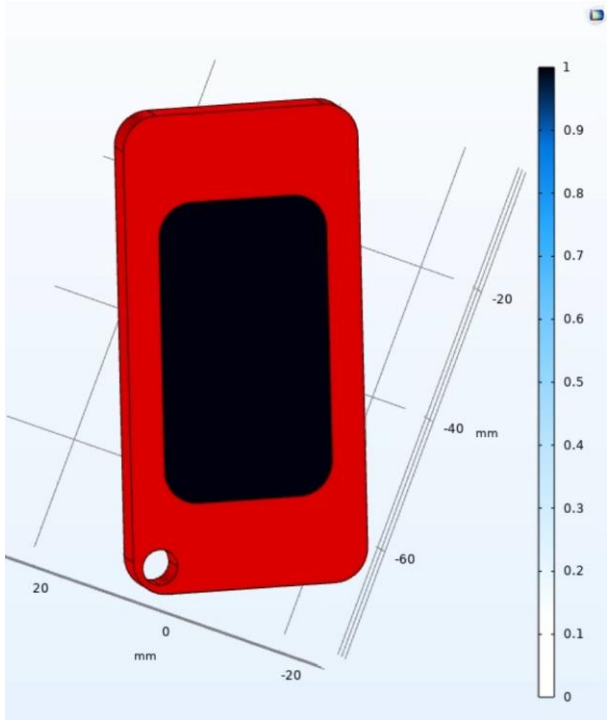
Structural Mechanics & Topology Optimization in COMSOL Multiphysics

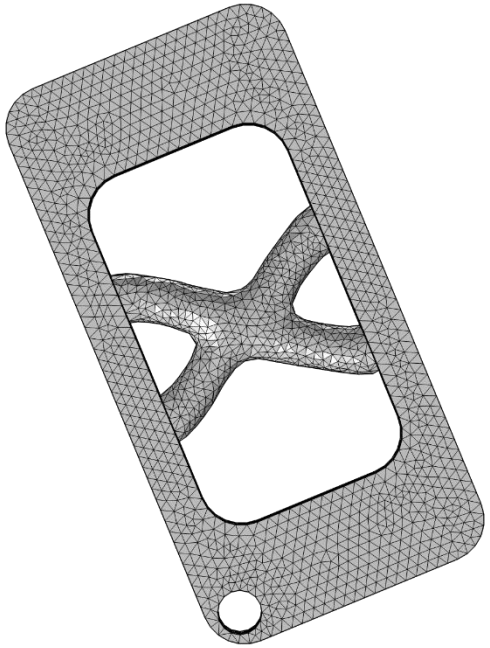


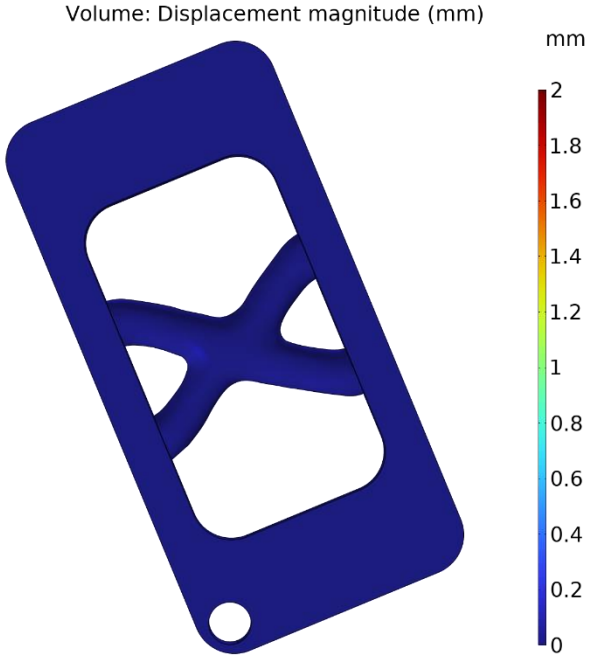




Structural Mechanics & Topology Optimization in COMSOL Multiphysics







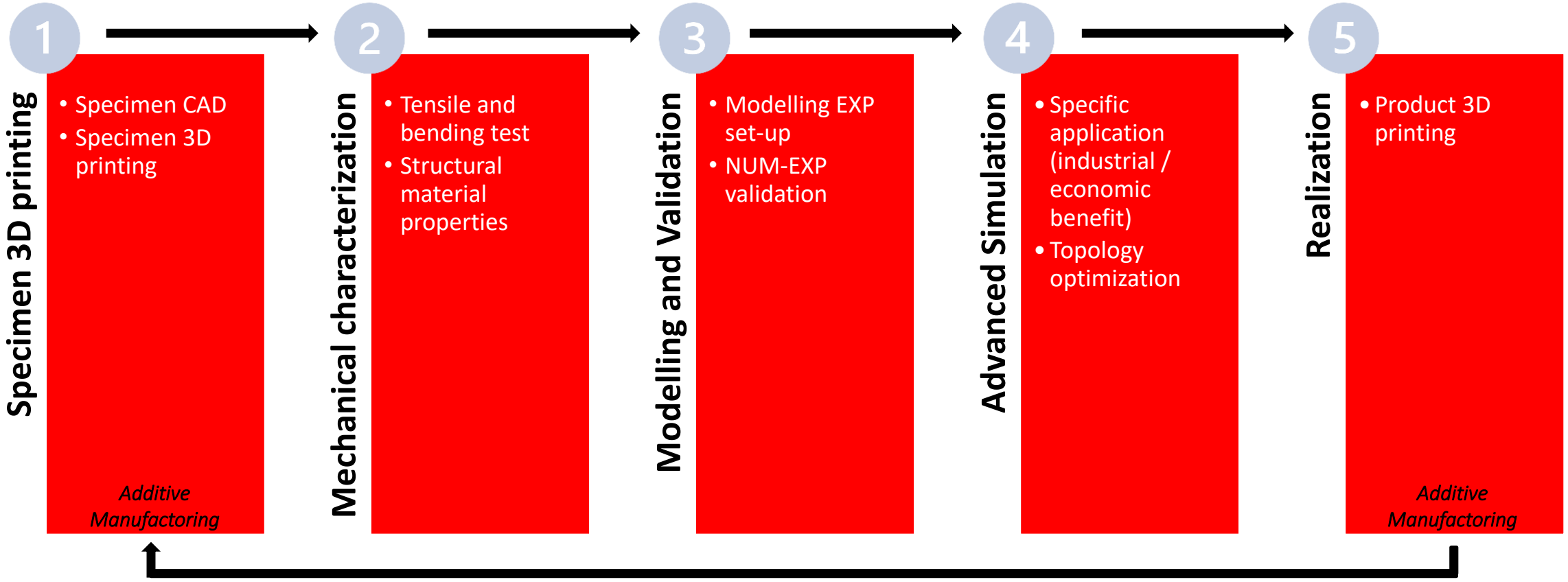
Original geometry

Optimized geometry

Reimported and meshed

Numerically verified

The path forward: *From Material Characterization to Topology Optimization in Additive Manufacturing*



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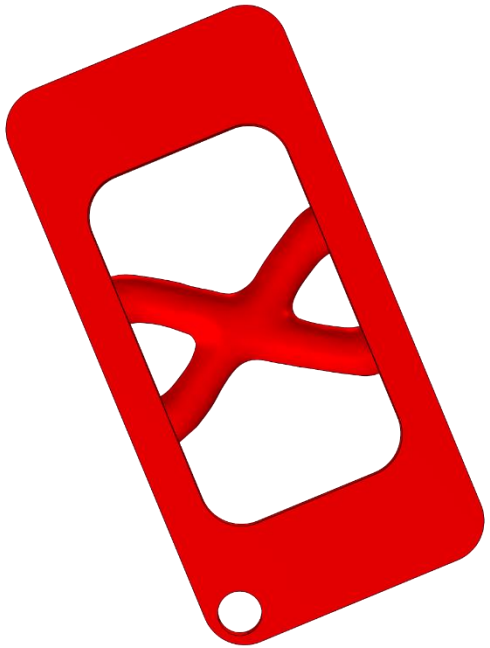
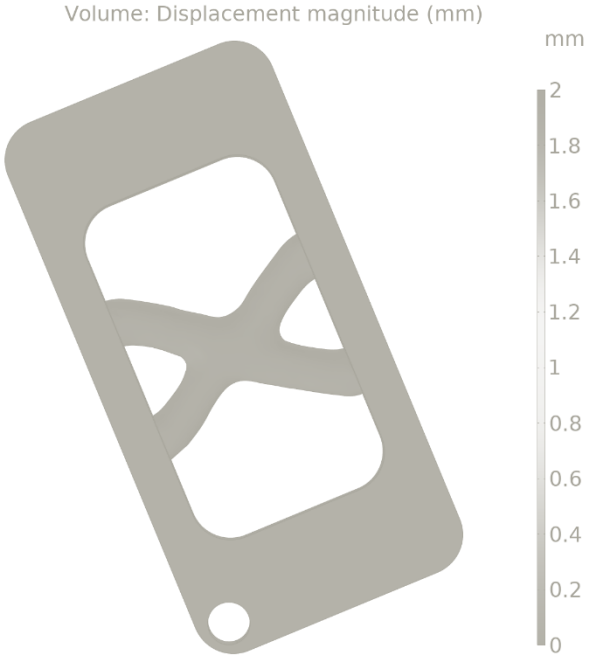
Structural Mechanics & Topology Optimization in COMSOL Multiphysics



Optimized geometry

Reimported and meshed



Numerically verified

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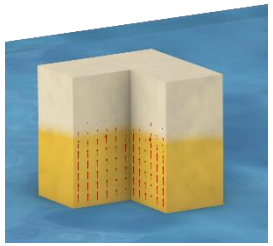
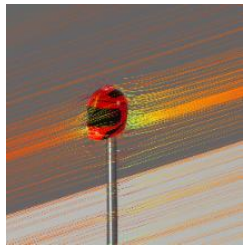
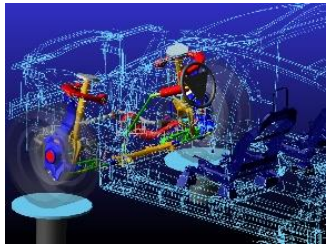
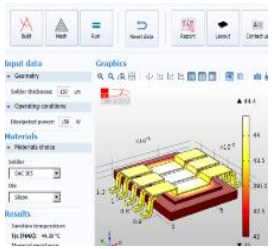
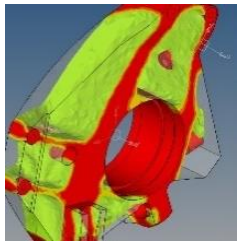
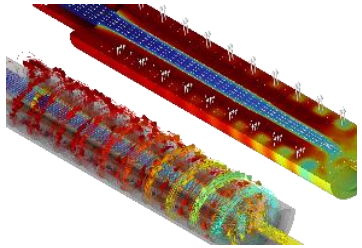
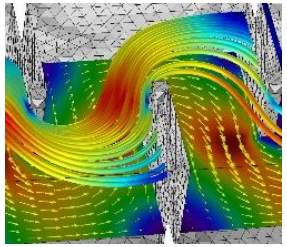
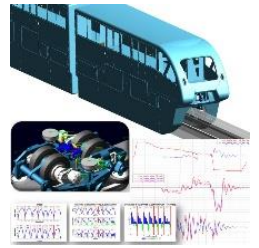

BE CAE & Test s.r.l.

- Viale Africa, 170 A - 95129 Catania (CT)
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- www.be-caetest.it
- info@be-caetest.it
- +39 095 216 64 26

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