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Potentials of Advanced Simulation and Modelling in Advanced Manufacturing

FAN3D

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Unit Overview

MODULE 01	MODULE 02	MODULE 03	MODULE 04
2 hrs	3 hrs	6 hrs	3 hrs
Simulation Techniques for Process Optimization	**Advanced Modelling Techniques in Manufacturing**	**Computer-Aided Design and Optimization**	**Case Study (Aerospace & Defence)**
Format: 2+0	*Format: 3+0*	*Format: 2+4*	*Format: 0+3*
(theory + practical)	*(theory + practical)*	*(theory + practical)*	*(theory + practical)*

Learning Outcomes

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By the end of this unit, learners will demonstrate the following competencies:

KNOWLEDGE

Factual and broad understanding of:

- Fundamental simulation techniques (DES & FEA) and their applications in modelling complex processes and identifying bottlenecks
- Advanced modelling techniques — VR and AR — and their role in enhancing product design and development
- Principles of CAD and topology optimization and their contribution to 'right-first-time' designs in advanced manufacturing

SKILLS

Learners will be able to:

- Apply simulation techniques to analyse manufacturing processes and identify areas for optimisation and improvement
- Analyse CAD and topology optimisation techniques to create efficient designs that minimise resource use and reduce errors in production
- Evaluate the application of simulation and modelling techniques in the aerospace and defence sectors

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Simulation Techniques for Process Optimization

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Cost of trial-and-error

- Manufacturing defects commonly account to 5-10% reject rates
- Preventing defects is cheaper than letting components reach failure

The importance of simulation

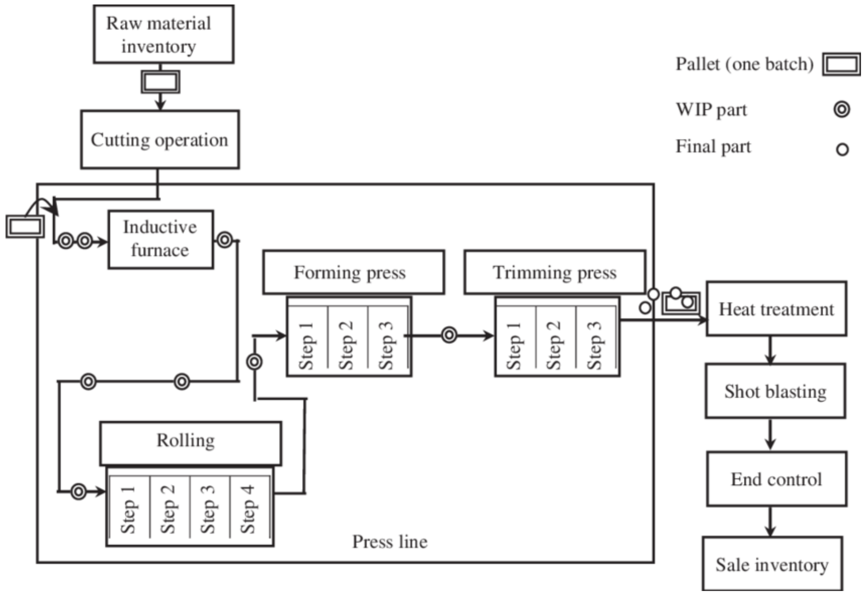
•Manufacturing systems are too complex to optimise by intuition alone

•Physical prototyping and live trials are slow, expensive, and disruptive

•Simulation creates a safe environment to ask "what if?"

•Enables decisions to be made earlier

•In regulated sectors like aerospace and defence, simulation provides auditable evidence of design decisions



Cost of trial-and-error

Approach	Time Cost	Financial Cost	Risk
Redesign after physical build	Weeks to months	£50k–£500k+ depending on scale	High — problems found late
Rework on live production line	Days to weeks of downtime	£10k–£100k/day in lost output	High — affects delivery commitments
Over-engineering "just in case"	None upfront	15–40% excess material cost	Medium — waste built into the design
Wrong staffing/resource model	Months to correct	Excess labour or missed output targets	Medium — hard to reverse quickly
Simulation-driven design	Days to weeks upfront	£5k–£50k depending on complexity	Low — problems caught before commitment

Discrete Event Simulation (DES)

What is DES?

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- Models systems as sequences of discrete events occurring over time
- Captures dynamic behaviour: queues, resources, throughput, and timing
- Allows 'what-if' analysis without stopping real production operations
- Software examples: Siemens Plant Simulation, AnyLogic, Arena

Discrete Event Simulation (DES)

Applications of DES

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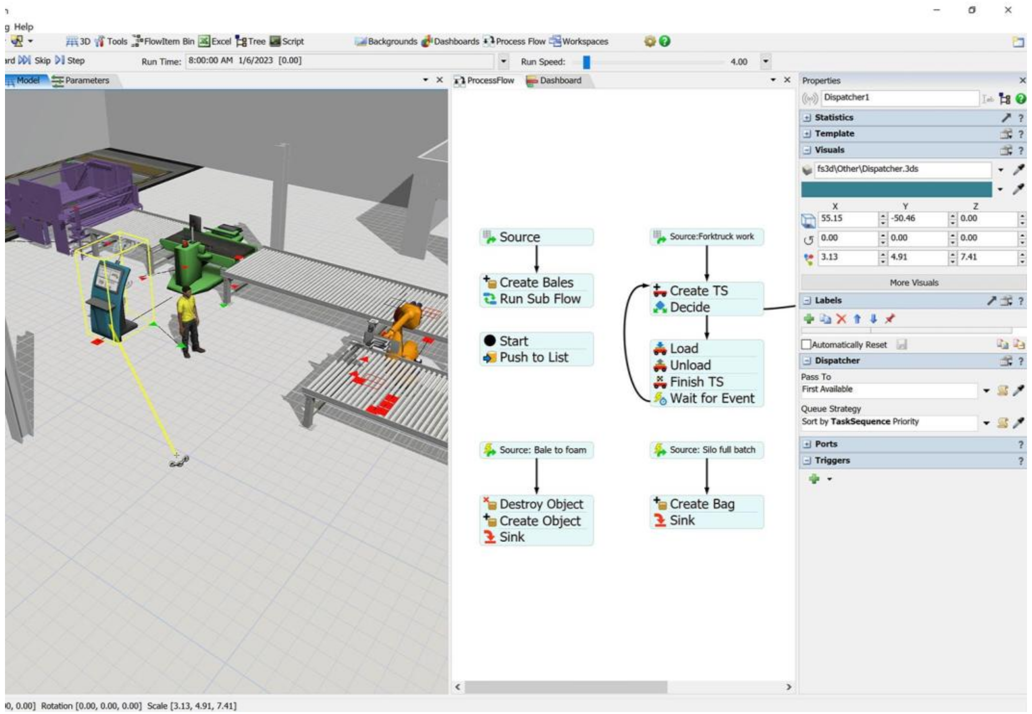
- Identify bottlenecks in assembly, machining, and logistics chains
- Optimize resource allocation: machines, workers, and materials
- Test shift patterns, batch sizes, and factory layouts virtually
- Reduce downtime and improve Overall Equipment Effectiveness (OEE)



Discrete Event Simulation (DES)

Risk in production - Activity

Should We Run the Simulation? Scenario: A defense subcontractor has been awarded a 6-month urgent contract to manufacture 400 precision parts. The program manager is deciding whether to commission a DES study before starting production.

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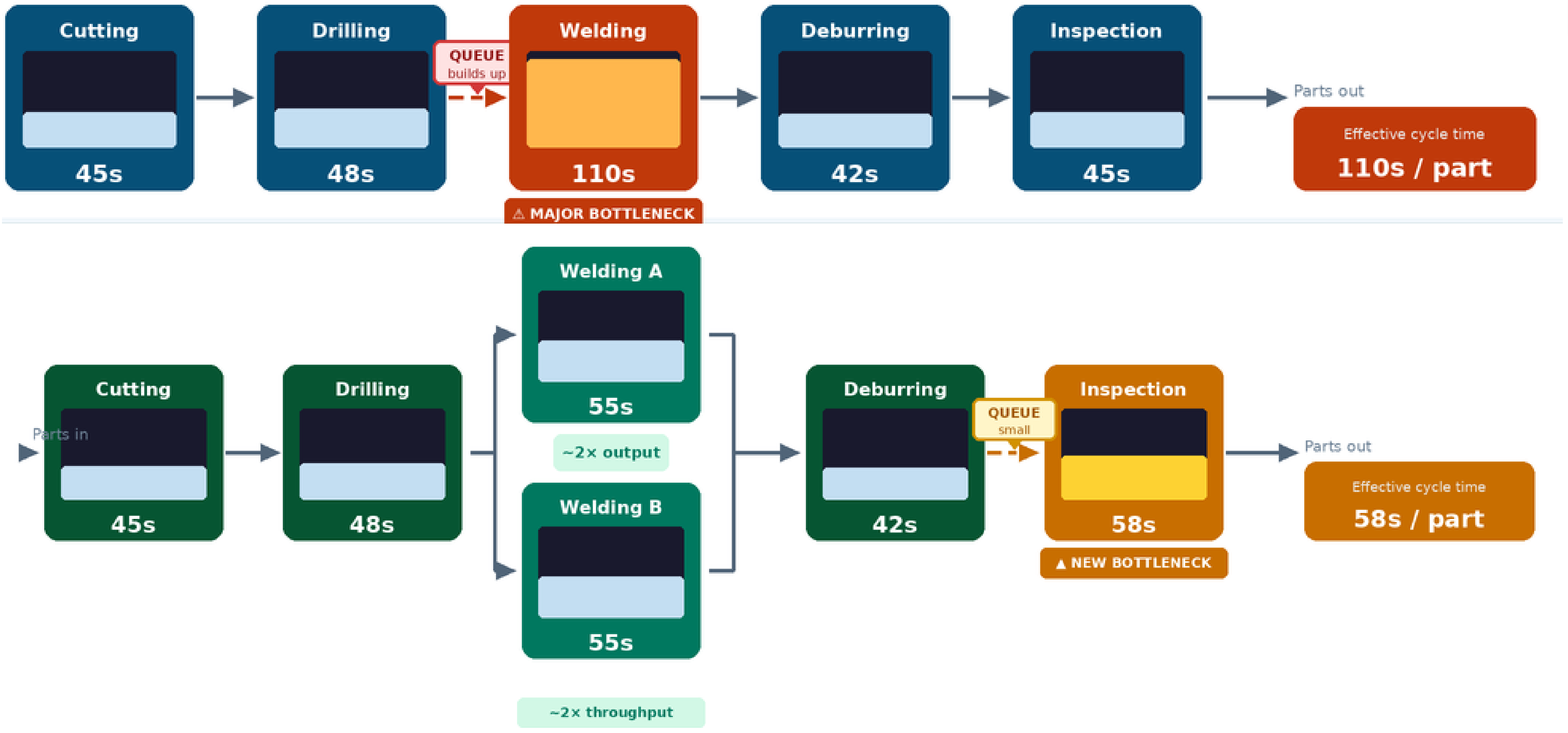
Contract value	€2.4 million
Delivery deadline	Fixed — 26 weeks. Penalty clause: €40,000/week late
DES study cost	€28,000 (external specialist)
DES study duration	5–7 weeks to complete and validate full line study
Current production data	Limited — this component type is new to the facility
Facility status	Line is already partially configured from a previous contract
Engineering team view	"We've run similar jobs before — we know this line"
Programme manager concern	Spending 6 weeks on simulation eats into an already tight schedule
Risk flagged by quality lead	Two comparable jobs in the past 3 years hit bottlenecks at the finishing stage — both ran late
Alternative option	Run a 2-week manual process review (in-house, no cost) instead

Line balancing & bottlenecks



Typical manufacturing problems

Problem Type	Description	DES Can Help?
Bottlenecks	One stage limits the output of the entire system	Yes — identifies where and why
Idle time	Machines or workers waiting between tasks	Yes — exposes gaps in scheduling
Queue build-up	Work-in-progress accumulates at certain points	Yes — models queue dynamics over time
Shift & staffing mismatches	Wrong number of people at the wrong times	Yes — tests staffing scenarios virtually
Layout inefficiency	Excessive material or operator travel distance	Yes — compares layout alternatives
Unreliable supply	Variable input delivery disrupts downstream flow	Yes — models variability and its knock-on effects
Demand spikes	Sudden increases in orders strain capacity	Yes — stress-tests the system before it happens
Structural failure risk	Component breaks under load or temperature	No — this requires FEA, not DES

DES Applications for Defense

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Maintenance & Lifecycle	Supply Chain & Logistics	Training & Readiness	Scenario Testing	Decision Support
Improve availability, plan MRO	Test resilience, manage disruptions	Optimize capacity, improve outcomes	Evaluate strategies risk-free	Support procurement & planning

Finite Element Analysis (FEA)
What is it?

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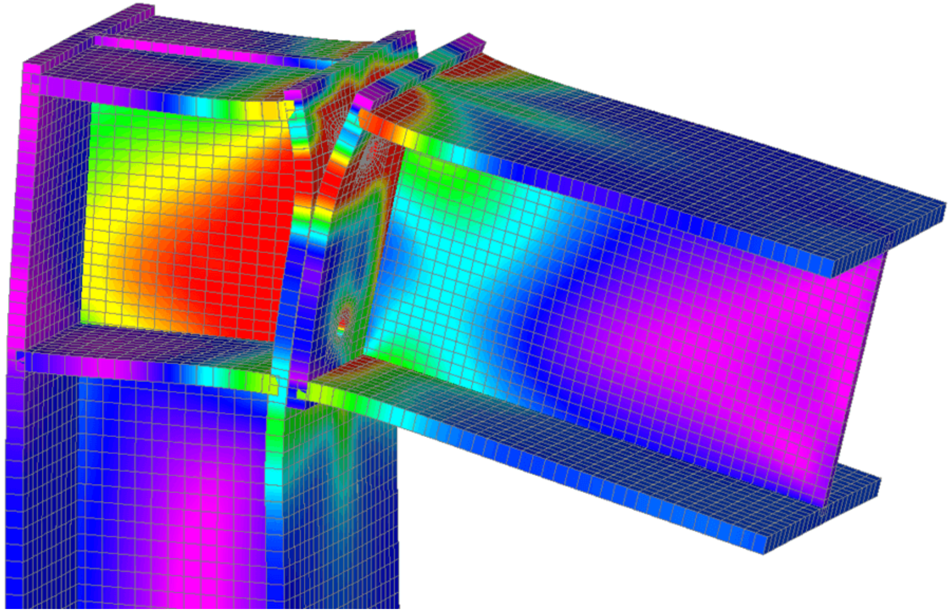
- **FEA** is a numerical method used to solve complex engineering and physics problems by discretizing
- An analysis in finite element modelling involves simulating real-world conditions
- It considers internal characteristics, while also incorporating external conditions.
- **FEA** enhances sustainability and reduces trial and error in prototyping



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Finite Element Analysis (FEA)
Key applications

- Stress and strain analysis on components before any physical prototyping
- Thermal performance modelling (cooling, heat dissipation, hot spots)
- Identifying failure points and fatigue life early in the design cycle
- Mandatory requirement for structural certification in aerospace (FAA/EASA)

Finite Element Analysis (FEA)

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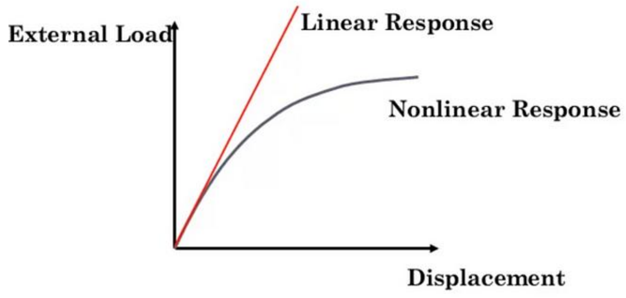
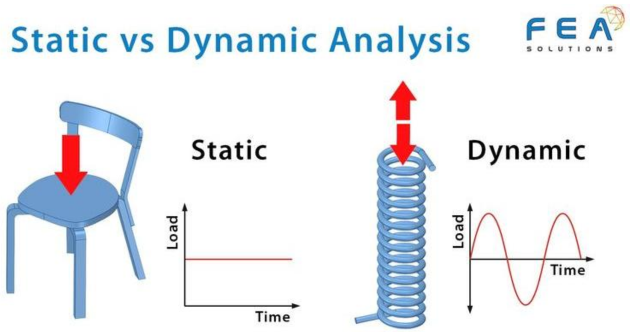
Analysis Type

Common types of analysis include linear static, nonlinear static, dynamic, buckling, heat transfer, fatigue, and optimization.

- **Linear analysis** assumes small deformations and linear material behaviour, making it faster and suitable for simpler cases.
- **Nonlinear analysis** considers large deformations, material nonlinearity, and contact effects, providing more accurate results at higher computational cost.



- **Static FEA** analyses structures under loads that are applied slowly and remain constant or change gradually over time, ignoring inertia and damping effects.
- **Dynamic FEA** considers time-dependent loads and includes inertia and damping, making it suitable for analysing impacts, vibrations, or rapidly changing forces.



Finite Element Analysis (FEA)

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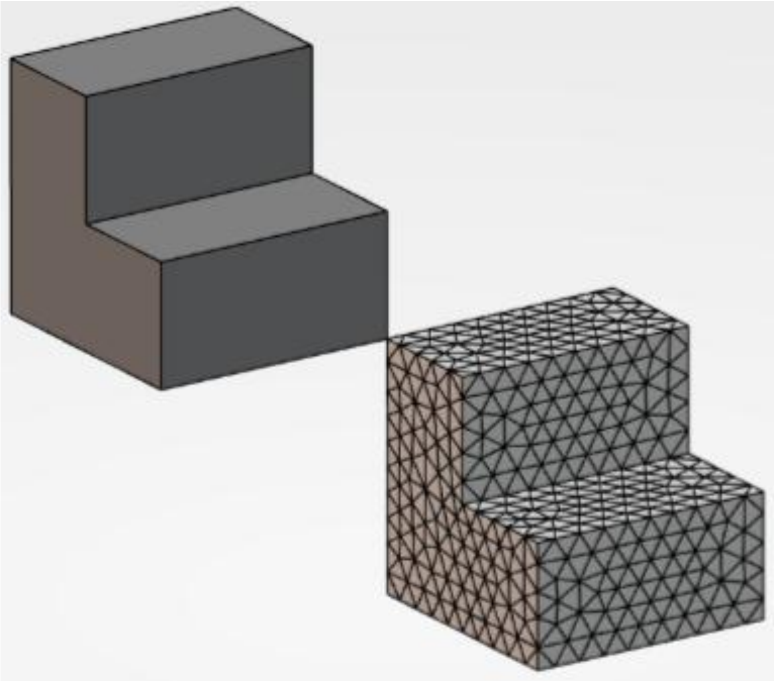
Mesh

- Before running a simulation, the geometry must be discretized into smaller geometric shapes known as elements. This process of breaking down the model into elements is called **meshing**.
- Elements are connected through shared nodes. While elements are not infinitely small, they are sufficiently small relative to the overall model size to provide accurate results.
- A mesh can range from thousands to millions of elements.
- Loads are applied at specific nodes, and their effects are distributed across neighbouring elements.
- Selecting the appropriate mesh type and mesh size is crucial, as they significantly influence the accuracy of simulation results.



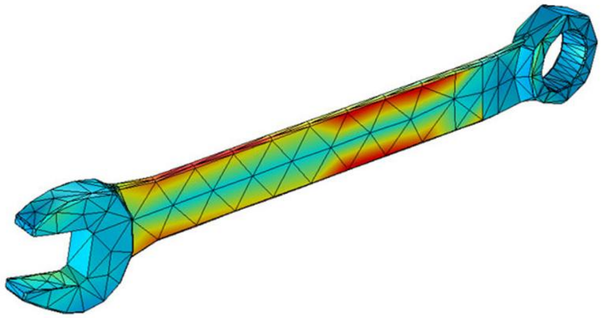
Finite Element Analysis (FEA)

Mesh Size Definition:

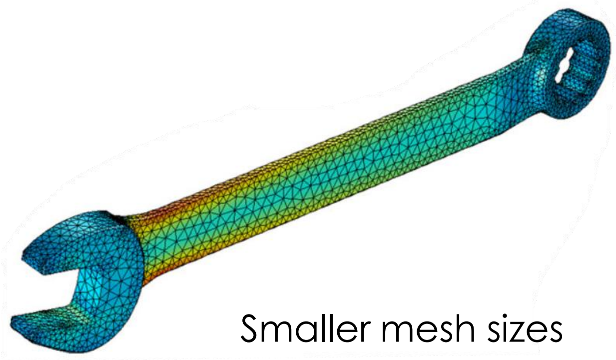
Mesh size refers to the granularity of the elements used to divide the geometry in FEA simulations. It directly impacts the precision and quality of results.

Mesh – Element size.

– The mesh size decides the quality of the simulation results



Coarse mesh



Smaller mesh sizes

Finite Element Analysis (FEA)

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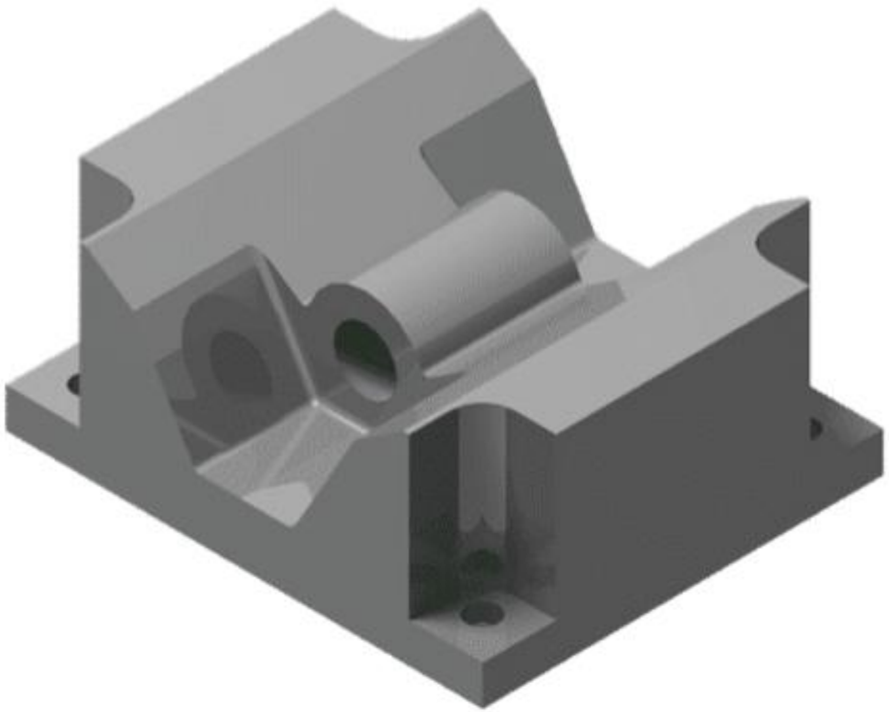
Apply material

– You can either create materials from scratch or reus must be applied to the simulated component.

– A material is defined by its domains, such as Appearc run the optimization on the part, only the simulation d

– To run a FEA, **material density** and its elastic properti the **Poisson's Ratio** are mandatory.



Finite Element Analysis (FEA)

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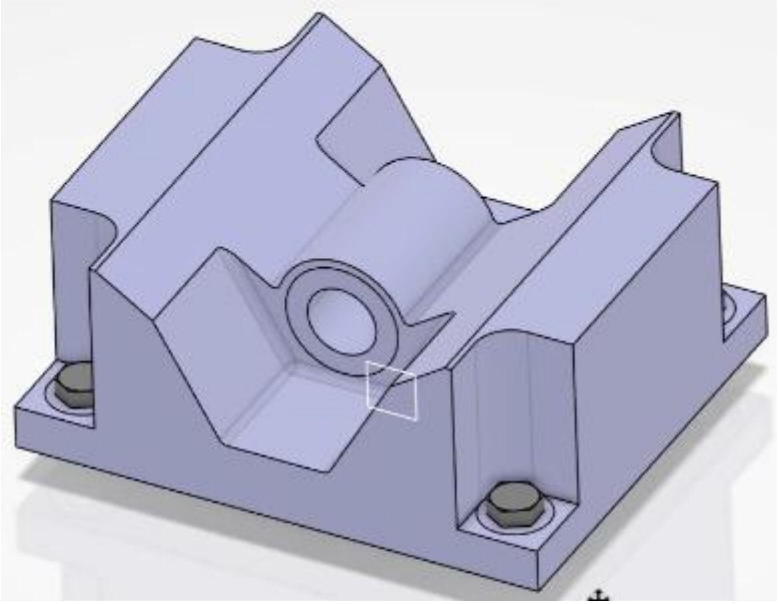
Connection

- When you are simulating only one component of an assembly, you must appropriate connections to replicate the real-world scenario.
- We can identify these connections:
  - Rigid connection
  - Spring
  - Pin
  - Bolt
  - Surface-based Contact
  - Coupling



Finite Element Analysis (FEA)

Loads

- The basic idea behind performing a structural analysis for a geometry is to check the mechanical component for its strength and serviceability against all the loads it is likely to face during its life cycle.
- You can apply various loads to the part from the available list:
  - Gravity
  - Pressure
  - Force/Remote Force
  - Bearing Load
  - Torque/Remote Torque
  - Centrifugal Force

Finite Element Analysis (FEA)

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Restraints

- You must define a restraints to limit the degrees of freedom of the model.
- You can create restraints to limit the motion of one or more parts of a simulation model.
- You can apply various restraints to the part from the available list:
  - Clamp
  - Fixed Displacement
  - Applied Translation
  - Ball Joint
  - Slider
  - Hinge

Finite Element Analysis (FEA)

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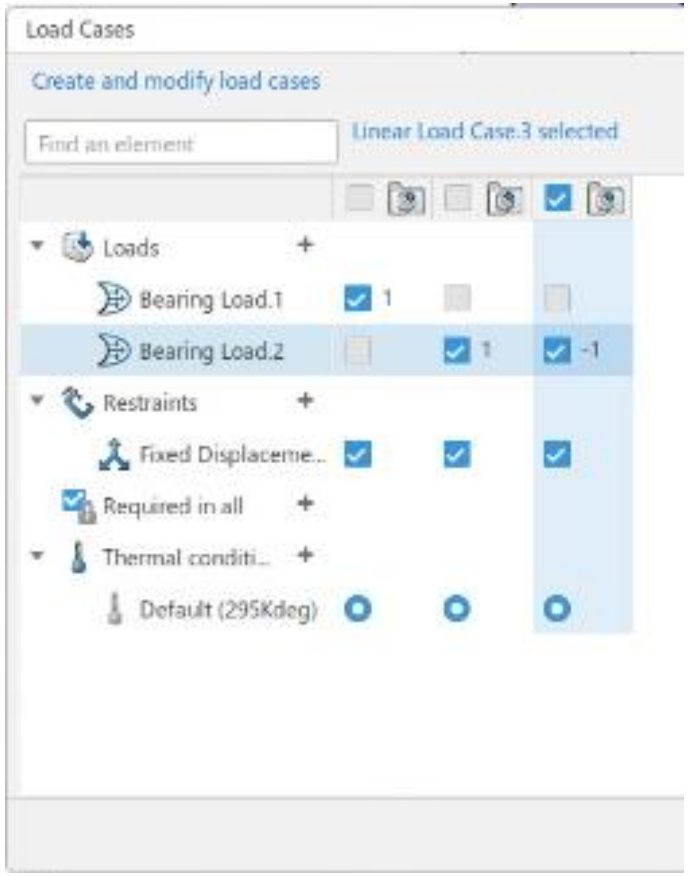
Load Cases

- A design may undergo multiple different loading conditions during its useful life.
- Grouping loads and restraints into a load case ensures that only those required for the setup are applied.
- A load case is a group of loads and restraints that define a particular loading condition.
- You can create multiple load cases and and Restraints



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Finite Element Analysis (FEA)

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The result visualization

- After configuring the mesh, the next step is to run the validation simulation to ensure the setup is accurate and aligns with the desired parameters.
- You have the flexibility to execute the simulation either on a local machine or in the cloud, depending on your resources and preferences:
  - **Running the simulation locally** provides immediate access and control over the process, making it suitable for smaller-scale simulations or when computational resources are readily available.
  - Alternatively, leveraging **cloud computing** allows you to take advantage of scalable resources, enabling faster processing for complex or large-scale simulations. This choice ensures that the simulation environment aligns with your project requirements and available infrastructure.

Finite Element Analysis (FEA)

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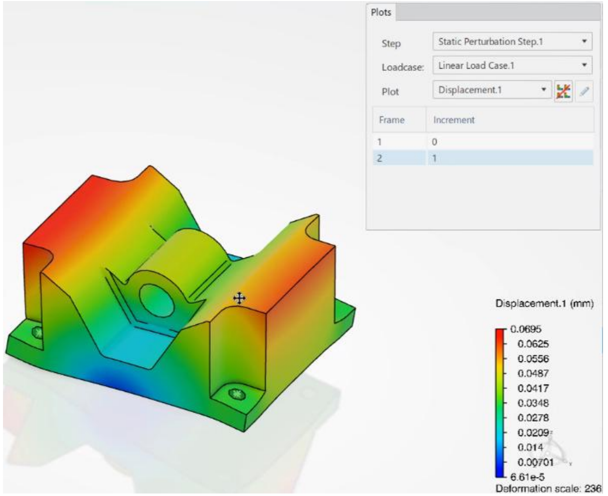
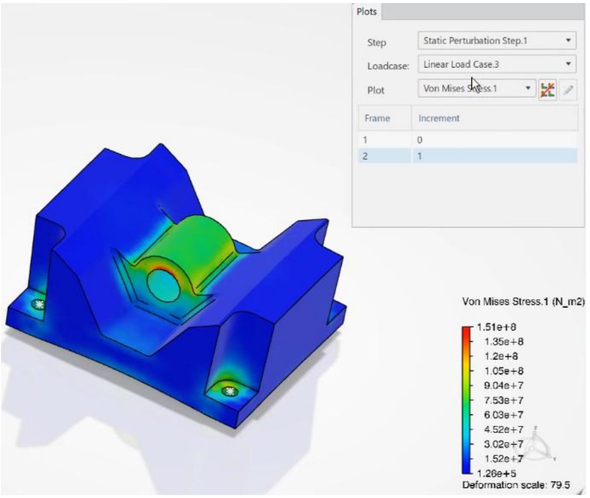
The result visualization

- After running the validation simulation, you can review **displacement** and **Von Mises stress** plots across all defined load cases to assess whether the model responds realistically.
- The geometry is considered structurally fine if the Von Mises stress remains below the material's elastic limit, meaning no yielding occurs.





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FEA in Manufacturing Contexts

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•FEA is used whenever a component or structure must withstand predictable physical forces — before it is built and tested physically

•In manufacturing, this means validating that parts will survive the conditions they are designed for: load, pressure, heat, vibration, fatigue

•It is standard practice in aerospace, defence, automotive, and energy — sectors where failure is unacceptable and physical testing is prohibitively expensive

•FEA does not replace physical testing entirely

•Results inform design choices

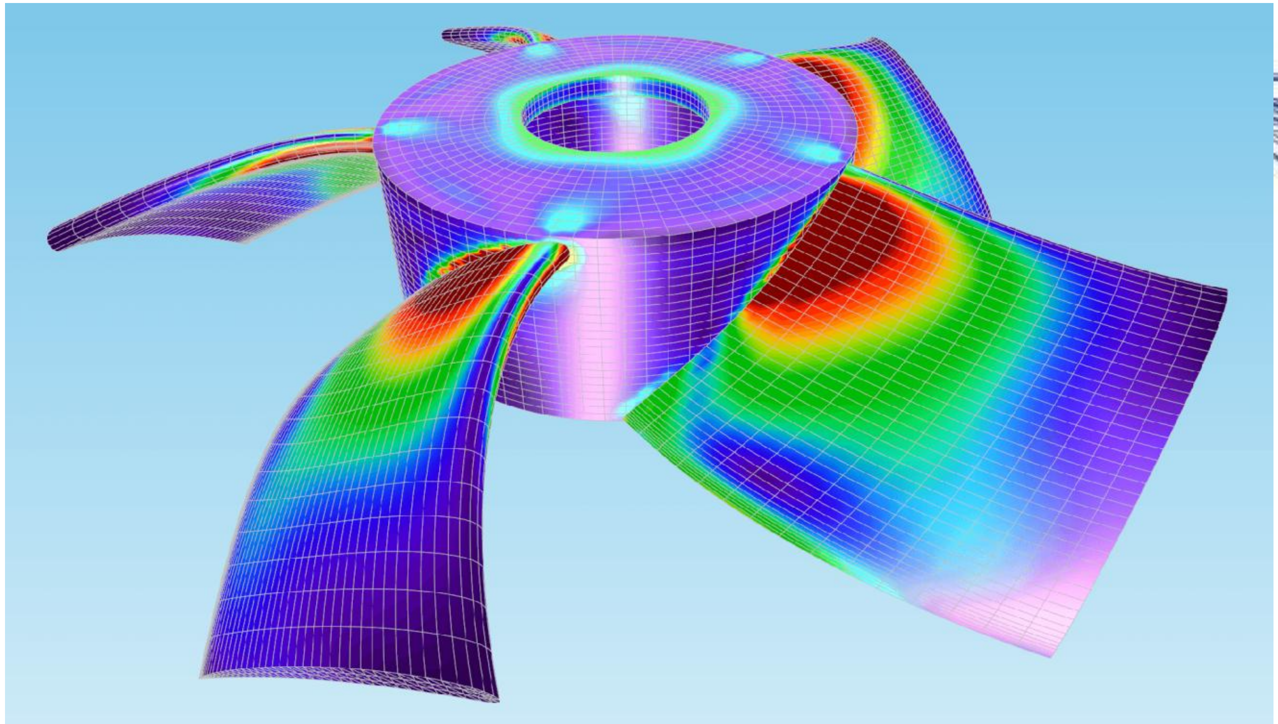
Types of FEA analysis

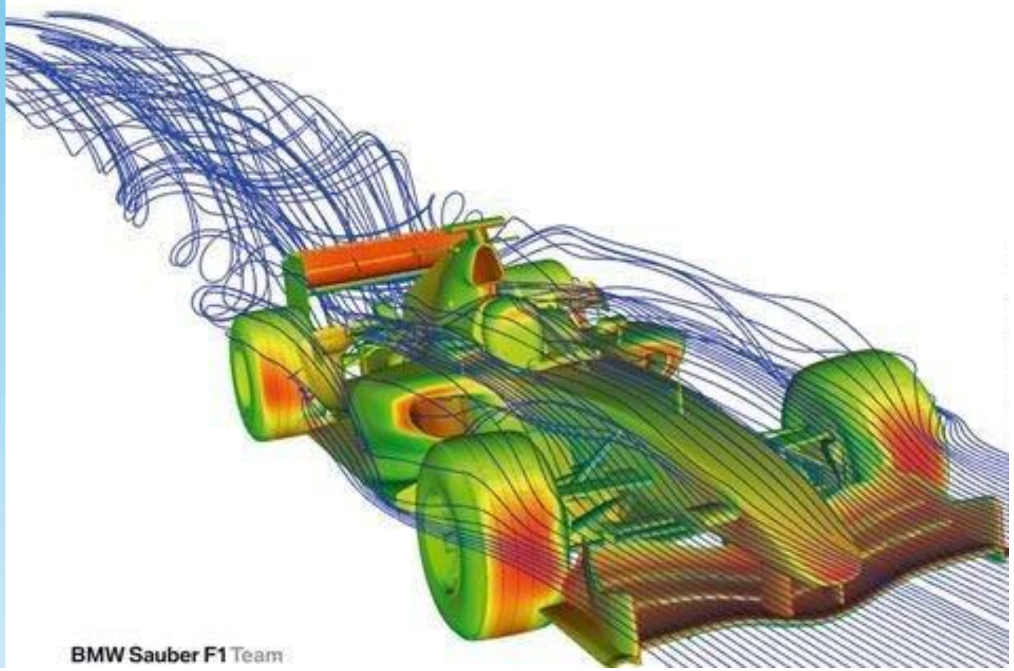
Analysis Type	What It Models	Typical Manufacturing Use
Static structural	Response to constant, non-changing loads	Brackets, frames, housings under sustained force
Modal / frequency	Natural vibration frequencies of a component	Avoiding resonance in rotating machinery or vehicle components
Thermal	Heat distribution and temperature gradients	Tooling, castings, components near heat sources
Fatigue	Cumulative damage under repeated loading cycles	Any component subject to repeated stress — critical in defence applications
Buckling	Instability and collapse under compressive load	Thin-walled structures, panels, columns
Dynamic / transient	Response to time-varying or impact loads	Blast resistance, drop testing, shock loading

Limitations of FEA

- Results are only as good as the inputs
- Mesh dependency
- Linear behaviour
- Does not model manufacturing defects
- Does not replace physical validation
- Requires specialist interpretation

Examples of FEA





When simulation is “good enough”

Situation	Simulation is likely sufficient	Physical testing still needed
Early design exploration	Iterate quickly, discard weak options	—
Comparing design alternatives	Relative performance is reliable	—
Well-understood geometry and loads	Validated models produce reliable results	—
Novel materials or processes	—	Simulation cannot substitute for real material data
Safety-critical certification	—	Regulatory bodies require physical evidence
Complex dynamic or impact events	Useful for understanding behaviour	Physical validation essential
First-of-kind design	—	Insufficient validation data for model confidence
Iterative refinement of a tested baseline	Changes relative to a known baseline are lower risk	—

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Advanced Modelling Techniques in Manufacturing

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Virtual Reality (VR) Modelling
What is VR?

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- Fully immersive, computer-generated environment — replaces the real world
- Engineers 'walk through' a factory or product before it is physically built
- Supports collaborative design reviews across distributed global teams
- Delivered via headsets with six-degrees-of-freedom tracking

Virtual Reality (VR) Modelling
Benefits of VR

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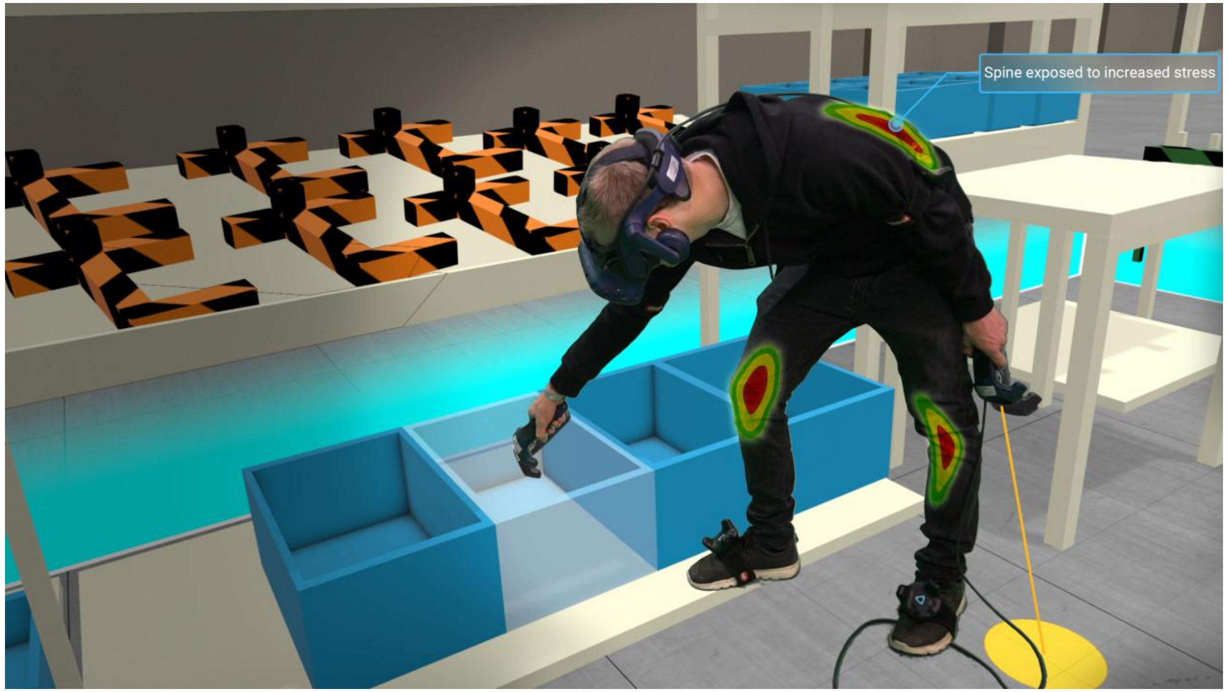
- Reduces need for physical prototypes
- Enables ergonomic assessments of workstations and layouts
- Detects design clashes and issues at the earliest possible stage
- Shortens development cycles and accelerates stakeholder sign-off



Virtual layouts

What VR enables	Why
Walk a full-scale aircraft assembly bay or weapon system integration cell before build Validate ground support equipment positioning, tooling access, and maintenance clearances Test multiple hangar or production line configurations without halting live operations Catch FOD (Foreign Object Debris) risk areas and restricted access points at design stage	Defence facilities often cannot be reconfigured during an active program — errors are locked in BAE Systems and Airbus use VR layout review to validate final assembly lines before civil construction begins Regulatory bodies increasingly accept VR-evidenced layout reviews as part of facility certification packages Moving a virtual jig costs nothing; modifying a physical one on an active aircraft program does

Ergonomics & accessibility

- Validate technician reach into confined airframe structures before the aircraft is built
- Identify postural injury risks in repetitive assembly tasks — a known cost driver in aerospace manufacturing
- Simulate line-replaceable unit (LRU) removal in the virtual environment
- Poor access design is a leading cause of extended MTTR on military platforms
- DEF STAN and MIL-STD human factors requirements can be evidenced through VR assessment
- Accepted as supporting documentation in safety cases for complex defence systems

Virtual commissioning

- Real PLC and control code tested against a virtual model of the production system
- Robotic assembly cells, automated NDT lines, and CNC machining centres all validated before installation
- Safety interlocks and emergency stop sequences tested without risk to personnel or equipment
- Standard in Airbus A320 family production; increasingly adopted across defence prime contractors

Augmented Reality (AR) Modelling
What is AR?

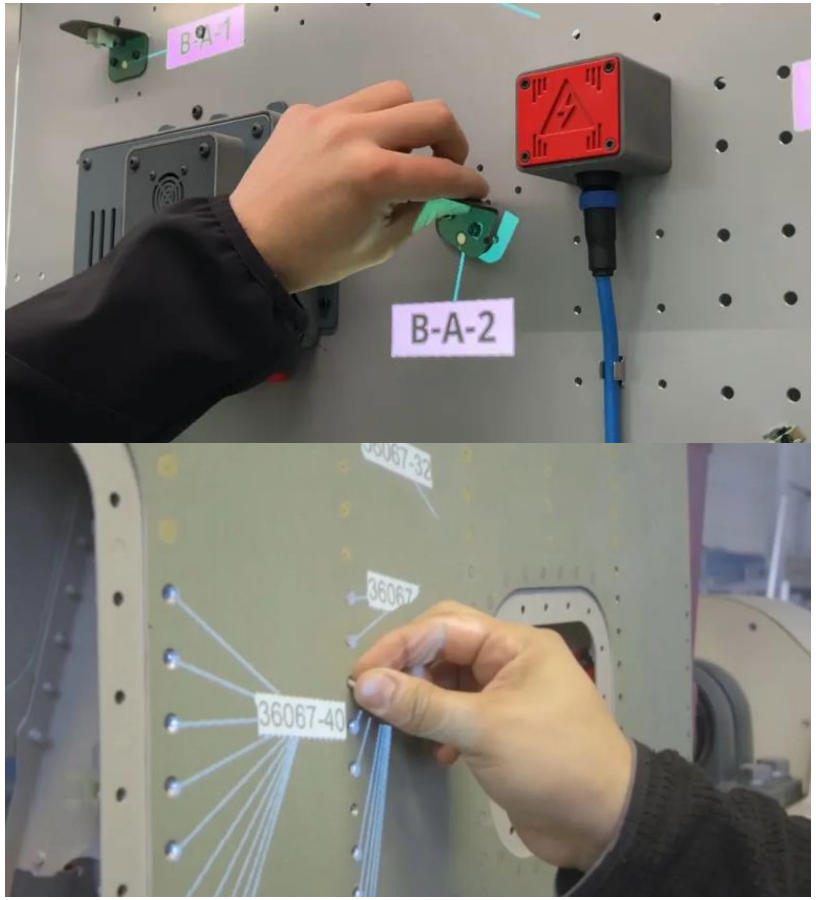
- Overlays digital information onto the real world — instructions, models, data
- Delivered via smart glasses, tablets/smart-phones, or heads-up displays (HUD)
- Operator remains in the real environment — digital layer enhances it
- Can be linked to other systems for live, contextual data

Augmented Reality (AR) Modelling
Benefits of AR

- Assembly guidance: step-by-step digital overlays reduce errors and training time
- Maintenance & repair: technicians guided by live schematics and annotations
- Quality inspection: compare finished parts against digital reference models

Assembly guidance

- Step-by-step instructions projected directly in the technician's field of view
- Correct fastener, correct torque value, and correct sequence displayed
- Wrong steps trigger an immediate alert
- Every step is logged automatically



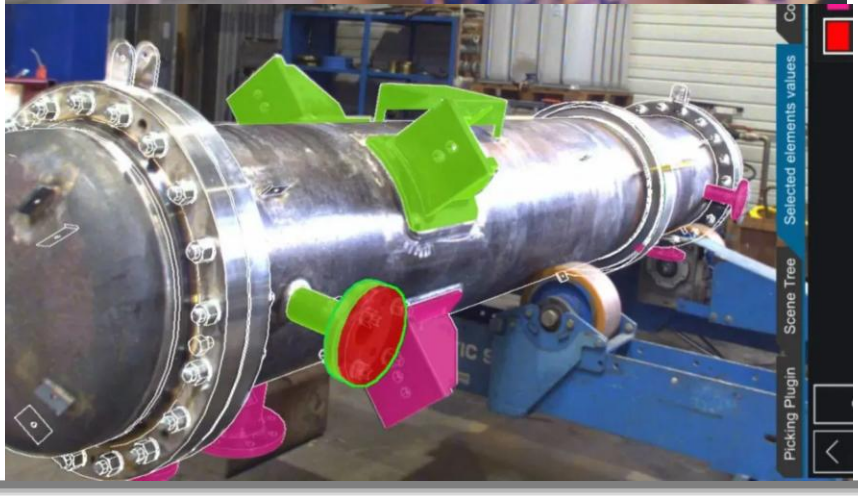
Inspection & maintenance

- Finished component scanned against digital reference

- Technician sees live fault codes, schematics, and repair procedure overlaid on the actual equipment

- Remote expert annotates the technician's field of view in real time

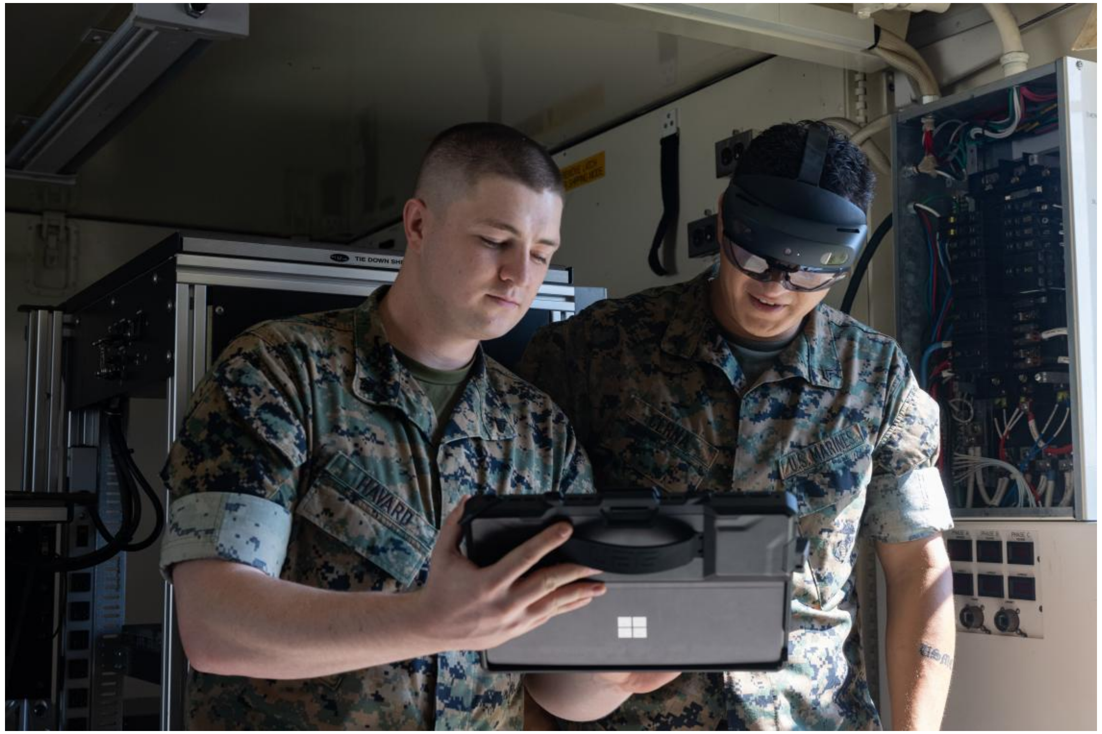
- Reduces mean time to repair



Use case:
AR-Enabled maintenance in US Marine Corps

Limitations of the traditional approach:

- Reliance on paper manuals
- Limited access to expert knowledge on-site
- Slow diagnostics and troubleshooting
- High equipment downtime



Use case:
AR-Enabled maintenance in US Marine Corps

The solution: **AR-Enabled Tele-Maintenance**

- Technicians use AR devices (e.g., headsets/tablets)
- Digital instructions are overlaid onto real equipment
- Remote experts can guide maintenance in real time

Use case:
AR-Enabled maintenance in US Marine Corps

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Remote Expert Support

- Experts can assist technicians **from any location**
- Reduces need for on-site specialists
- Improves response time

Enhanced Diagnostics

- Real-time visualization of components
- Faster identification of faults
- Improved decision-making

Hands-Free Support

Digital Guidance on-site

Use case:
AR-Enabled maintenance in US Marine Corps

Impacts:

Operational:

- Reduced downtime
- Faster repair cycles
- Improved efficiency

Financial:

- Lower support costs
- Reduced travel for experts

Strategic:

- Increased operational readiness
- Scalable maintenance capability

Use case:
AR-Enabled maintenance in US Marine Corps

Limitations:

- Need for reliable communication systems
- Hardware limitations in harsh environments
- Integration with existing workflows
- Training and user adoption

Activity – VR vs AR Decision Matrix

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– For each scenario below, decide whether VR, AR, or a combination of both is most appropriate.

1. A new aircraft wing is being designed — engineers across three sites need to review assembly clearances and detect clashes.
2. Technicians on the production floor are fitting complex cable harnesses and need live, step-by-step visual guidance.
3. Quality inspectors need to compare finished structural components against digital tolerances in real time.
4. A new assembly station is being designed — ergonomic risks and operator reach envelopes need to be assessed before build

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Computer-Aided Design and Optimization

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Conventional vs Advanced Manufacturing

- Traditional design:
  - Geometry-first
  - Experience-driven

- Advanced manufacturing design:
  - Constraint-driven
  - Simulation-supported

Constraint-driven design

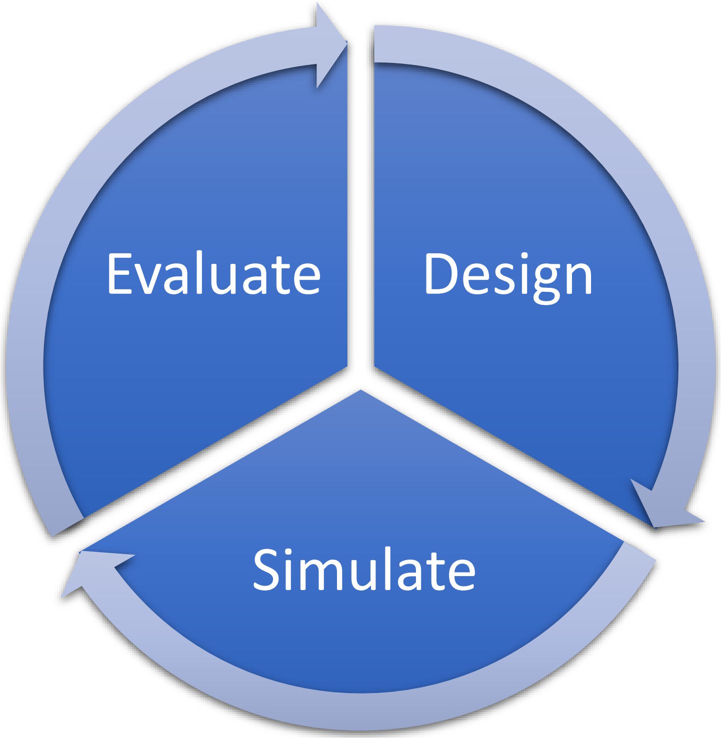
- When designing parts for AM, constraints should be addressed in the beginning of the workflow, rather than at the production phase.
- Potential constraints include:
  - Mechanical resistance
  - Vibration
  - Manufacturing Capabilities
  - Cost
  - Weight targets

Simulation-supported design

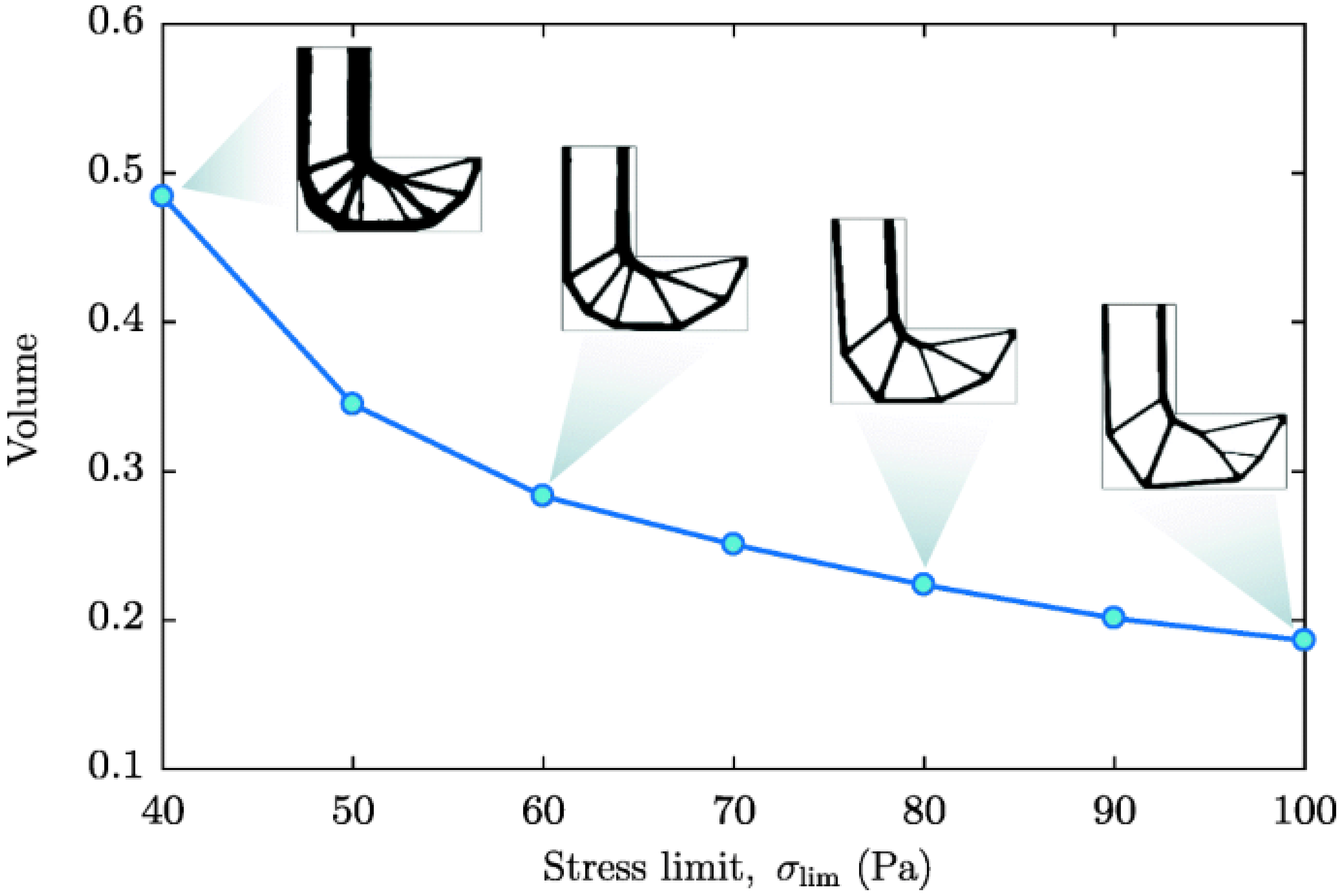
- Simulation enables early validation of design decisions
- Allows testing of:
  - Structural performance
  - Thermal behavior
  - Process feasibility
- Reduces reliance on physical prototypes
- Enables faster and more informed iterations

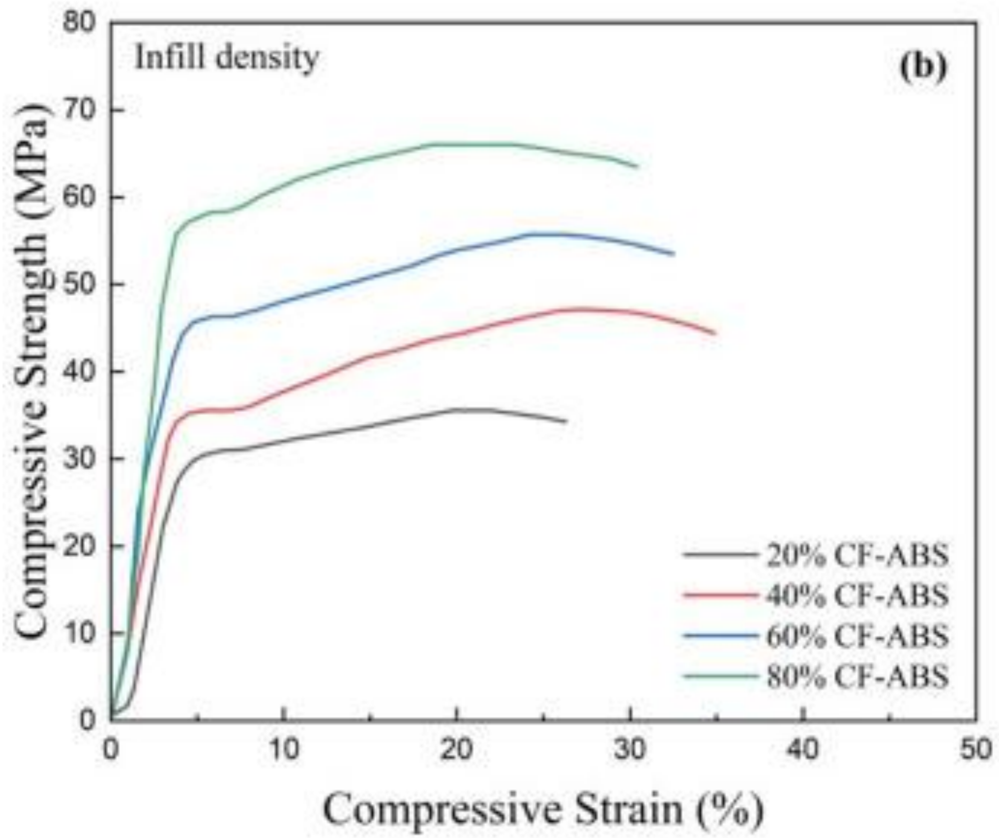
Design Optimization Logic

– Optimization is a structured decision process, not trial-and-error
– Based on:
  - Objectives (e.g., minimize weight)
  - Constraints (e.g., stress limits)



Weight vs stiffness

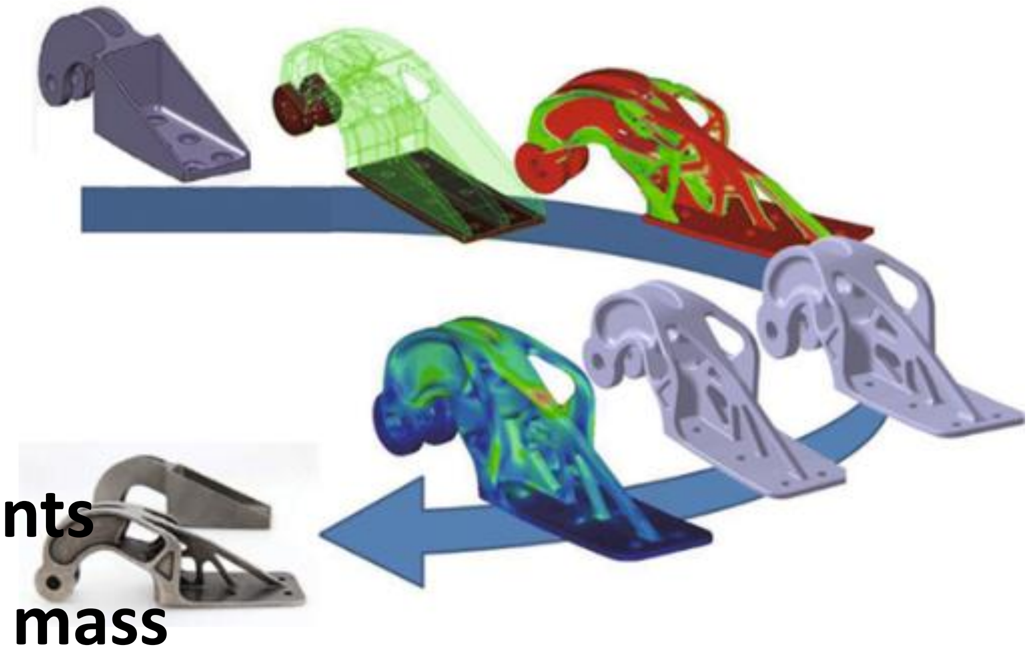




Topology optimization

TO is a mathematical method that operates on the principle of removing and redistributing material within a defined space of the original part's shape.

It is carried out based on a FEA analysis



Typical TO analysis:

1. **Maximize stiffness for a given mass**
2. **Minimize mass while respecting constraints**
3. **Maximize lowest frequencies for a given mass**

Topology Optimization

Advantages of TO

Advantages of topology optimizations are:

- Design optimization
- Saving money
- Saving time
- Reducing environmental impact
- Eliminating errors

Topology Optimization

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TO Workflow consists of 8 steps in the following sequence:

1. Design space creation
2. Model configuration
3. Analysis model setup
4. Setup validation
5. TO setup and process execution
6. Concept shape generation and validation

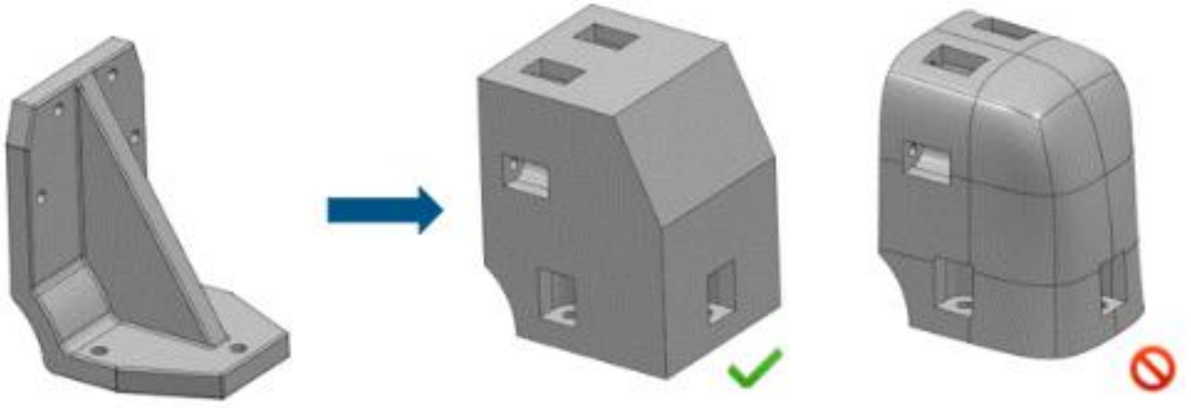
Topology Optimization

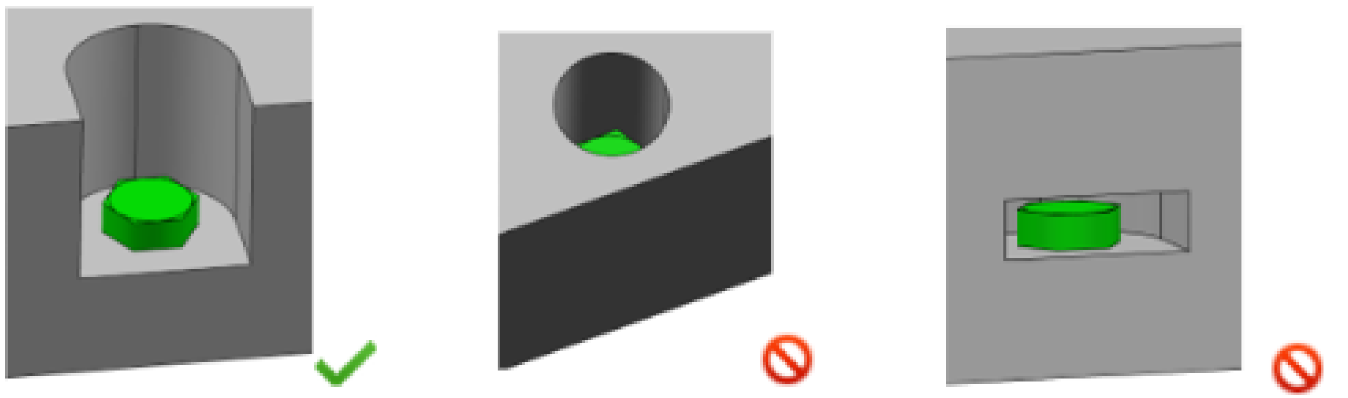
Design space

Conceptual volume where design freedom is defined

Geometry should be simple and functional

The part should be "feasible" in its unoptimized state





Topology Optimization

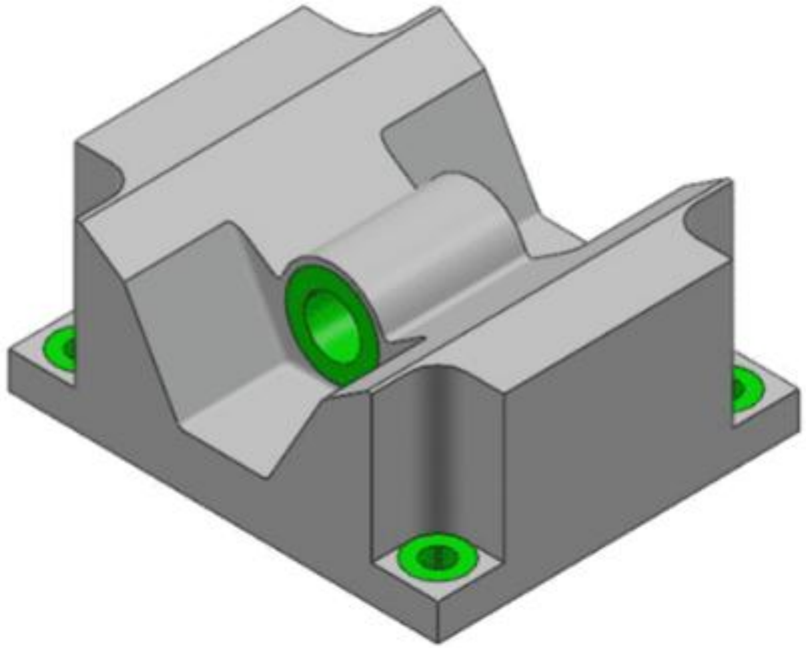
Model Configuration:

In this phase, two key volumes are defined:

- The volume subject to optimization
- The functional regions that need to be maintained

It is also in this phase that the the assembly in the study is defined, including:

- Material
- Connectors



Topology Optimization

Analysis model setup

Applying loads is essential for evaluating how a structure performs under real-life conditions.

To accurately simulate the physical behaviour of a model, it's necessary to define restraints that limit its degrees of freedom.

Topology Optimization

There are several types of loads that can be applied to a part, including:

- Gravity
- Pressure
- Force or Remote Force
- Bearing Load
- Torque or Remote Torque
- Centrifugal Force

Topology Optimization

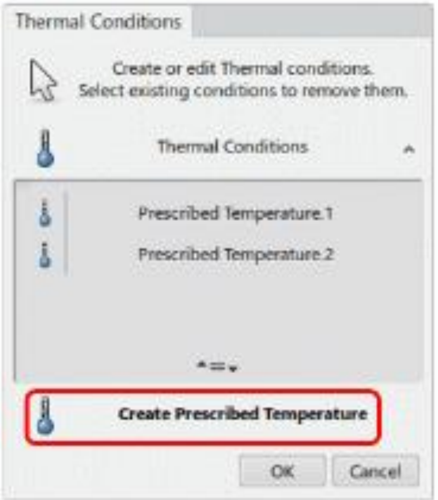
Some common types of restraints include:

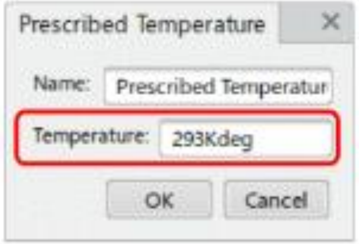
- Clamp
- Fixed Displacement
- Applied Translation
- Ball Joint
- Slider
- Hinge

Topology Optimization

Thermal conditions are optional in topology optimization, but including them enables the design to adapt to real-world thermal loads and improve overall robustness.

To apply a prescribed temperature, you must define thermal expansion properties for the material used in the simulation domain.





Topology Optimization

In topology optimization, a design might need to perform reliably under multiple loading scenarios throughout its intended use.

To handle this, loads and boundary conditions (restraints) can be grouped into load cases, allowing you to evaluate different performance situations within a single optimization setup.

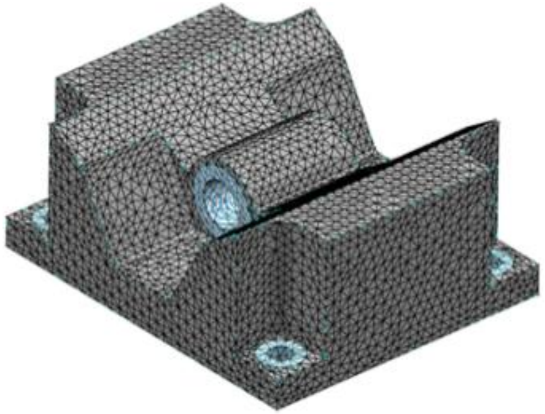
Topology Optimization

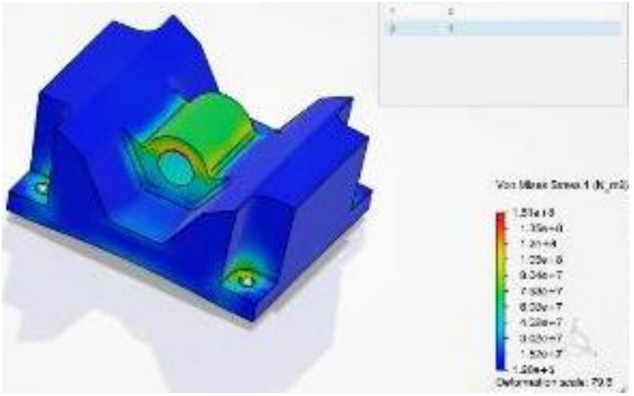
Setup Validation

In this step the mesh is defined and the results of the simulation are validated

After running the validation simulation, you can review **displacement** and **Von Mises stress** plots to assess whether the model responds realistically.

The geometry is considered structurally fine if the Von Mises stress remains below the material's elastic limit, meaning no yielding occurs.





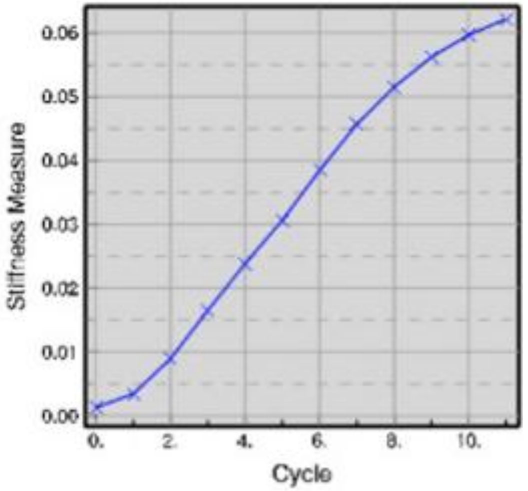
Topology Optimization

Setup and and process execution

Before executing the TO, it is essential to define the objectives and constraints for the study:

1. **Defining Optimization strategy**
2. **Setting Optimization constraints**
3. **Applying Shape controls**

Cycle 10



Topology Optimization

Topology Optimization can follow different strategies:

1. **Maximize stiffness for a given mass**
2. **Minimize mass while respecting constraints**
3. **Maximize natural frequencies for a given mass**

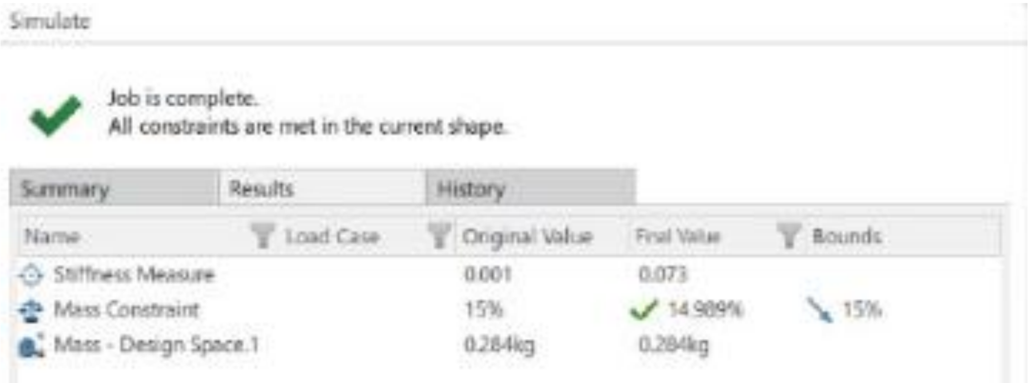
Topology Optimization

Optimization constraints define the boundaries within which the optimization must operate

.

You can apply a range of constraint types, including:

- **Frequency Constraint**
- **Displacement Constraint**
- **Stress Constraint**
- **Fastener Force Constraint**
- **Centre of Gravity Constraint**



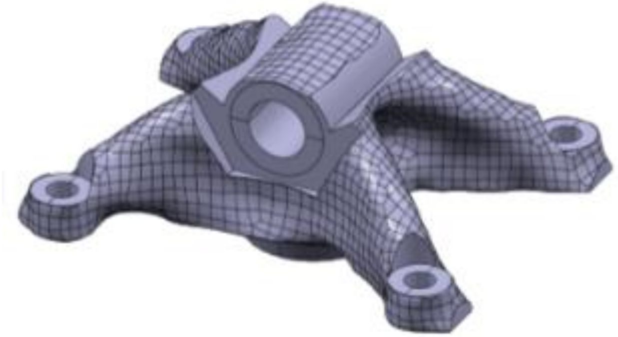
Topology Optimization

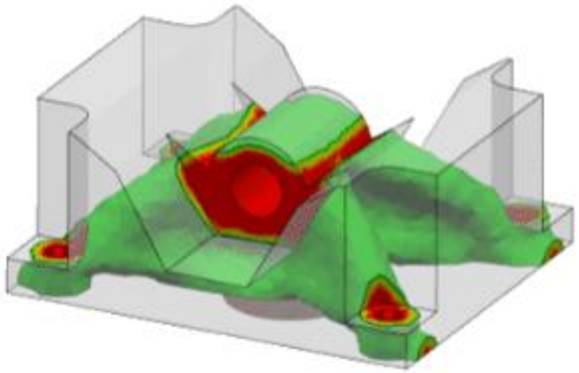
Concept shape generation and validation

After completing the topology optimization process, the result is a finite element representation of the optimized shape.

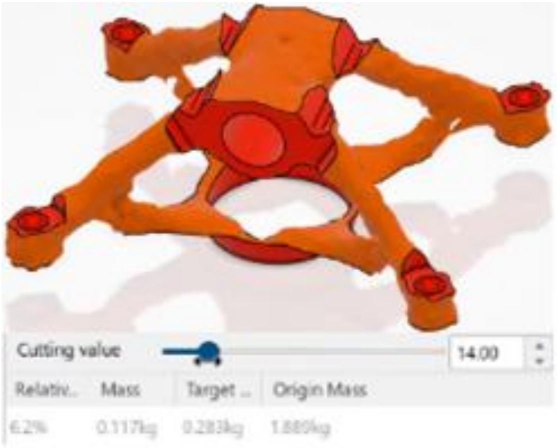
To proceed, this representation must be converted into a 3D solid model

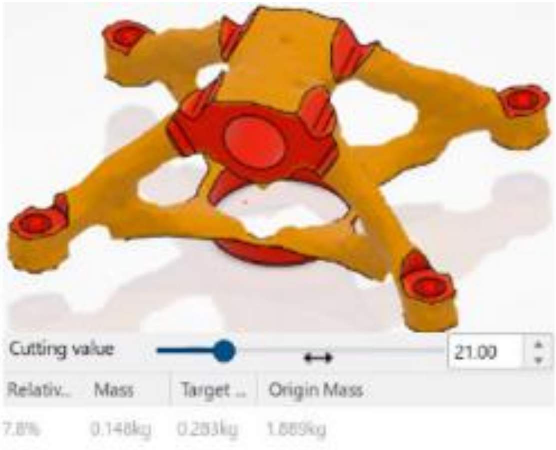
You can adjust the relative element density and apply a cutting value to determine which regions are removed

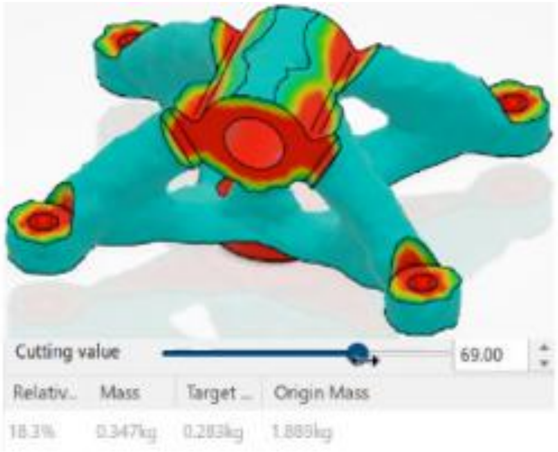


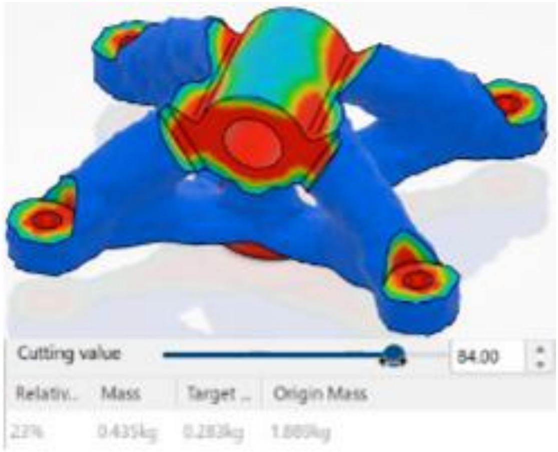


Topology Optimization









Interpreting results

Generative Design

– Generative design is an iterative design process that uses software to generate outputs that fulfill a set of constraints, iteratively adjusted by engineers and designers

Digital Twin for First-Time-Right Manufacturing

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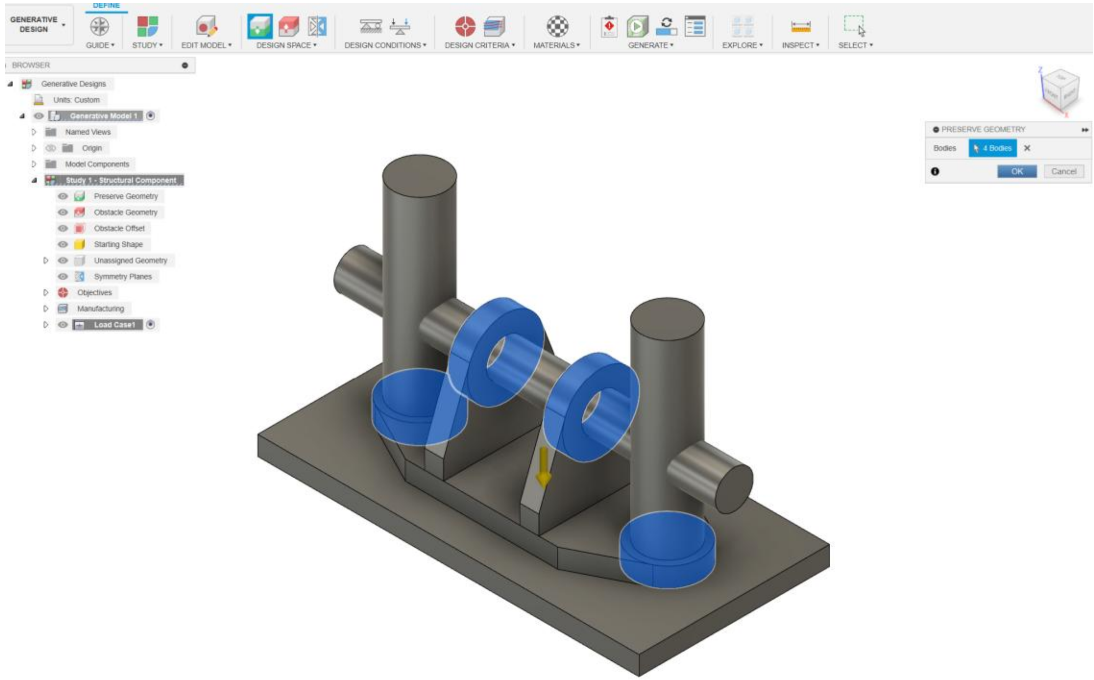
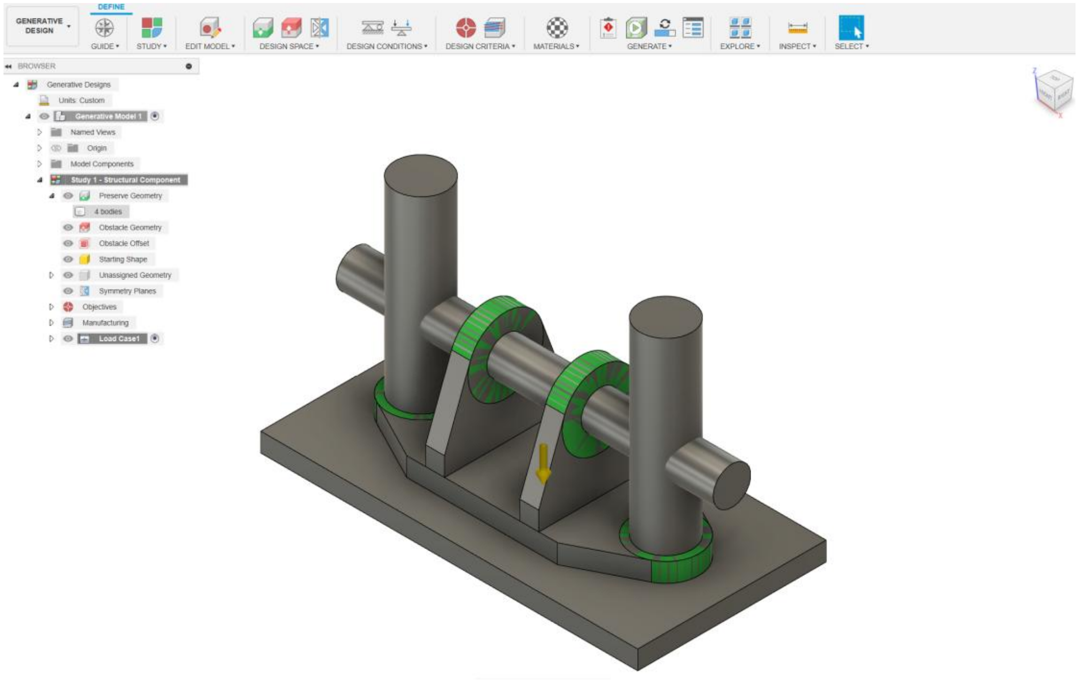
- **Define load cases –** These represent the operating surroundings that your model must survive.
- **Specify design pretensions –** This could be a target safety factor or a limit of displacement.
- **Add constraints –** - Specify how the design interacts with objects not included in the model.
- **Select materials –** Selecting materials is a crucial aspect of the design requirements in a generative study. You should choose materials by considering the manufacturing method and the requirements for your generative part.
- **Run the optimization** and monitor the generation process. Review the outcomes to ensure they meet the design requirements specified in the generative study.
- **View the results.**

Generative Design

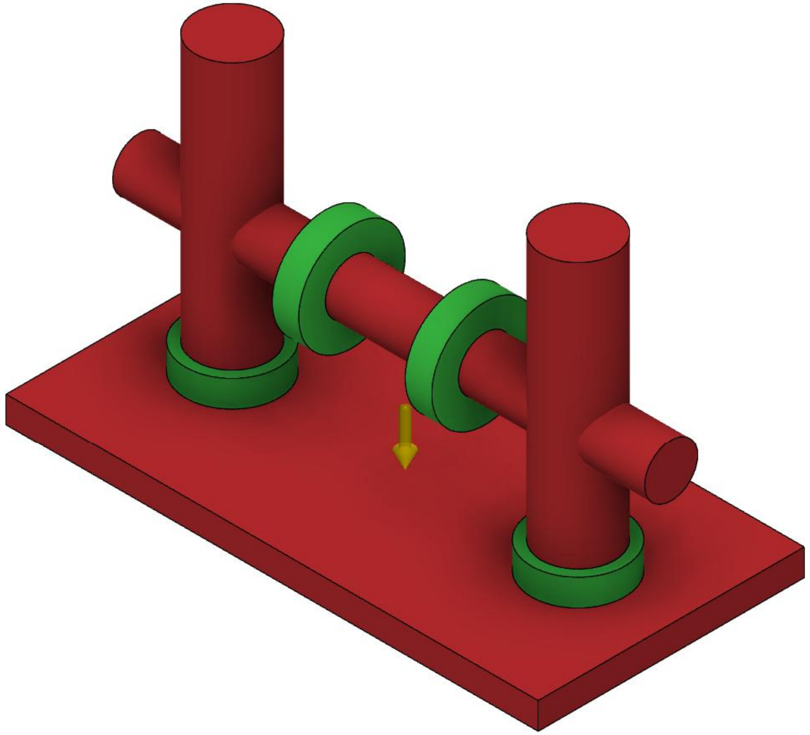
– Creating zones to be preserved





Generative Design

- Obstacle geometry prevents the software from adding material where the part will interact with the world
- It is imperative that the obstacle geometry does not interfere with the preserve regions



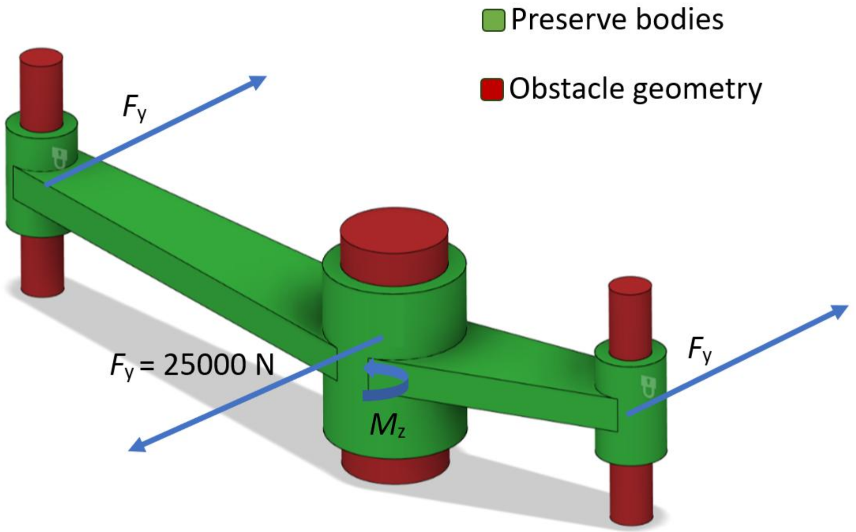
Generative Design

– GD Trade off study

Define load cases.

Specify design constraints.

Define manufacturing methods.



Generative Design

Generative design outcomes

Outcome	Mass (g)	Mass score Weight = 1	Displacement (mm)	Displacement score Weight = 0.5	Cost (€)	Cost score Weight = 0.5	Total weighted score
#1	72	6,00	0,86	6,00	114,54	1,61	9,80
#2	76	4,00	0,95	5,04	90,47	6,00	9,52
#3	72	6,00	1,02	4,30	113,71	1,76	9,03
#4	72	6,00	1,07	3,77	114,54	1,61	8,69




Generative Design

Criterion	Value
Mass (g)	140
Cost (€)	185,3
Max Displacement (mm)	1,17
Technology	Additive Manufacturing

original part

Criterion	Value
Mass (g)	67
Cost (€)	177
Max Displacement (mm)	0.14
Technology	Additive Manufacturing

optimized part

Generative Design

Generative Design

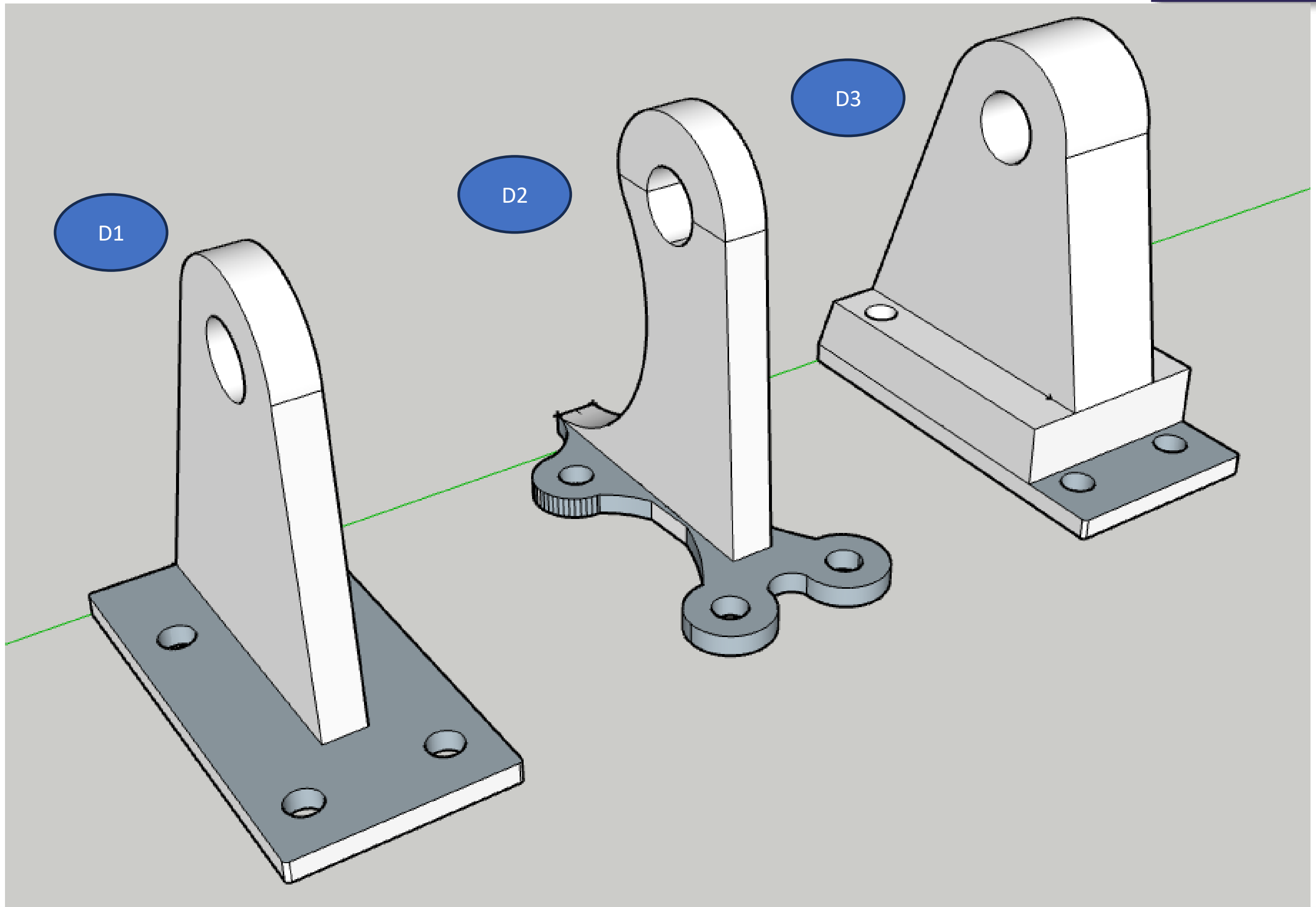
- Generative design is an iterative design process that uses software to generate outputs that fulfill a set of constraints, iteratively adjusted by engineers and designers

Case Study - Bracket

a) **Product definition:**

- D1 →316 Steel bracket, Traditional machining. V = 570.116 cm^3. M=4.561 kg
- D2 → 316 Steel bracket, PBF AM. V= 359.225 cm^3. M= 2.874 kg
- D3 → Carbon-Fiber Reinforced bracket. FDM. V =1432.512 cm^3. M= 1.432 kg

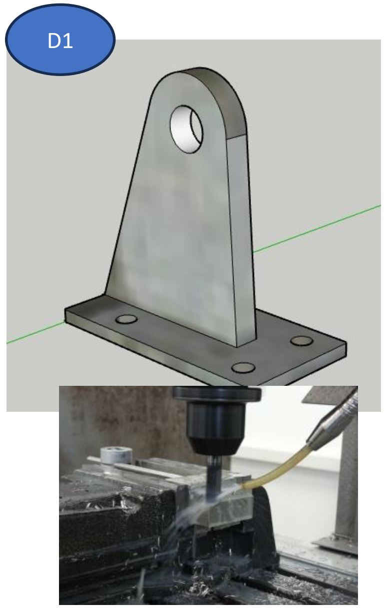
(We assume that these solutions "work")



Case Study - Bracket

d) Questioning about differences between alternative paths

What about product performance and end of life?



- Ok… this is the “standard”, isotropic part.
- We can assume it does not only cover the basic requirements, but that it´s a “for life” component… Really… It´s never going to broke.
- “Prices to pay”: it´s heavy, it´s going to be responsible of consuming quite an amount of fuel during it 20-30 years lifespan.
- And as long as it consist in one material, end of life and recyclability will be as good (or as bad) as any other pure and identified metal.
- Thus, it is going “to fly”, won´t cause any problems, and won´t require maintenance.

Case Study - Bracket

d) Questioning about differences between alternative paths

What about product performance and end of life?

D2

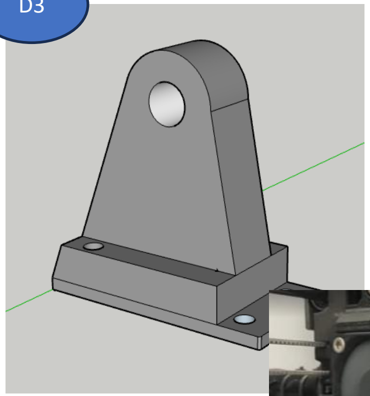
- This an optimized, <u>isotropic metal part</u>. We can assume it does not only cover the basic requirements, but again, that it´s a “for life” component.
- Advantages/cons: it´s 40% lighter than the machined part, so important fuel saves are expected during its 20-30 years lifespan.
- And as long as it consist in one material, end of life and recyclability will be as good (or as bad) as any other pure and identified metal.
- Thus, it is going to fly, won´t cause any problems, will save important amounts of fuel and won´t require maintenance.

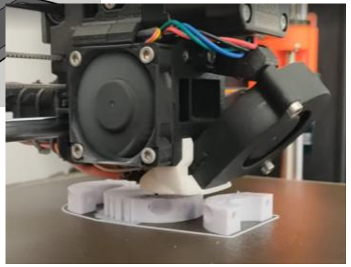
Case Study - Bracket

d) Questioning about differences between alternative paths

What about product performance and end of life?

D3





- Carbon fibre reinforced, but anisotropic (weaker in Z axis). This is what you need when it comes to change metal for polymer, if you want to make it comply with requirements, at least for a given time.
- We assume that it will have to be replaced from time to time.

- Advantages/cons: it´s 70% lighter than the machined part, so very important fuel saves are expected.

  - No big chances on recycling the part materials (there is not a standard CF reinforced filament)

    - Thus, it is going to fly, save great amounts of fuel, but it will have to be replaced from time to time.

Case Study - Bracket

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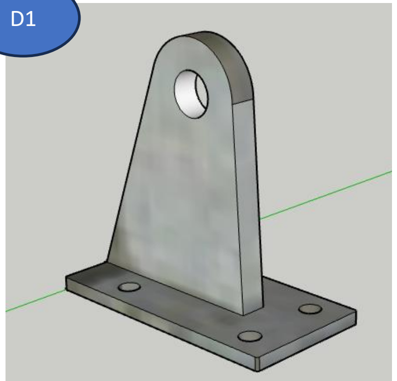
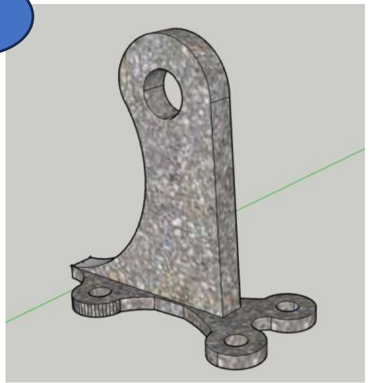
e) Trying to "put numbers" to our process. **Energy consumption during raw material generation**

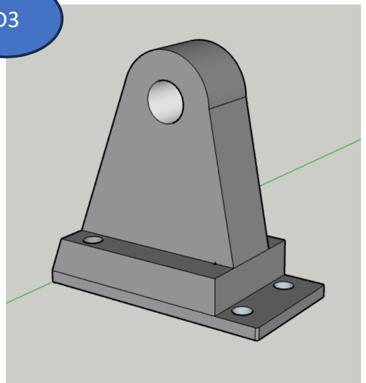
D1



D2



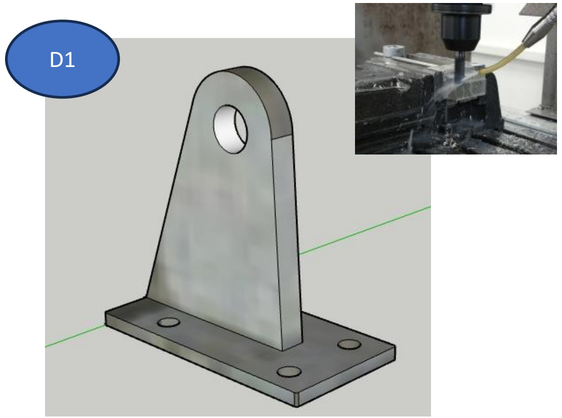
D3

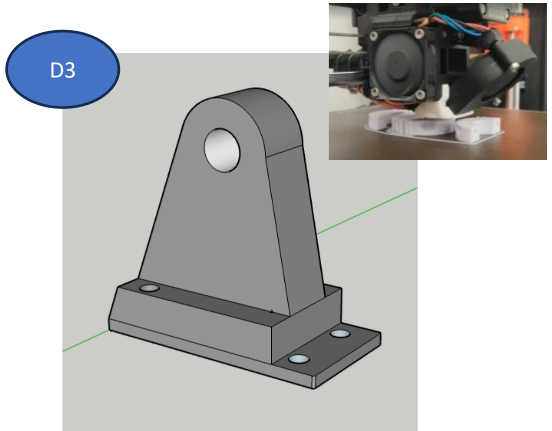


	D1	D2	D3	
Energy comsuption/Kg of net raw material required	1 kWh/Kg	2 kWh/Kg	3 kWh/Kg	
Net material required	16 Kg	3.7 Kg	1.4 Kg	
	16 kWh	**7.4 kWh**	**4.2 kWh**	**Energy for Raw material generation**

Case Study - Bracket

e) Trying to “put numbers” to our process. Consumptions during manufacturing

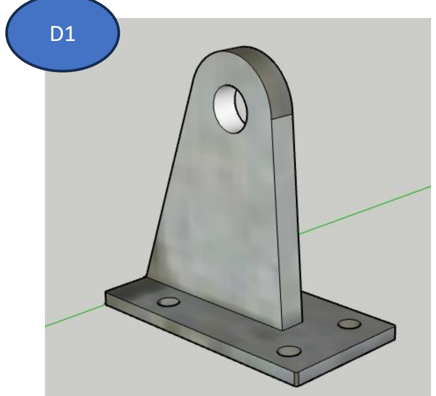


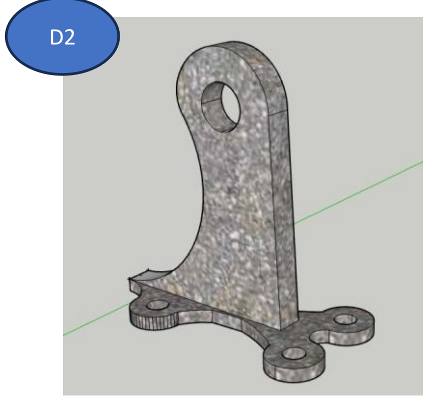


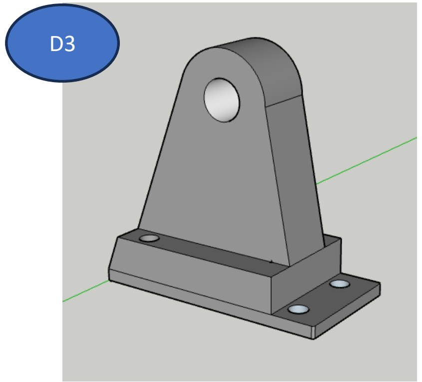
	D1	D2	D3
Power comsuption	14 kW	3 kW	2 kW
Manufacturing hours	2 h	8 h	12 h
Fungibles	2l/h cutting fluid (0.5 kWh/l)	20 l/h Inert gas (0.5 kWh/l)	----
Energy required for manufacturing	**30 kWh**	**104 kWh**	**24 kWh**

Case Study - Bracket

e) Trying to “put numbers” to our process. Fuel consumption during lifespan







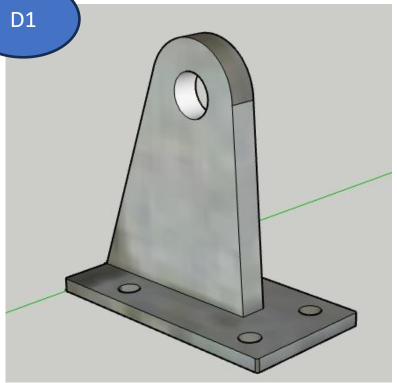
	D1	D2	D3
Part Mass	4.5 Kg	2.9 Kg	1.4 Kg
Fuel consumption/Kg*h	0.02 l/Kg*h	0.02 l/Kg*h	0.02 l/Kg*h
Energy required/l	0.5 kWh/l	0.5 kWh/l	0.5 kWh/l
Part lifespan	60000 h	60000 h	20000 h
Energy consumtion during lifespan	**2250 kWh**	**1450 kWh**	**280 kWh**

Case Study - Bracket

e) Trying to "put numbers" to our process. **Summary of energy consumption:**

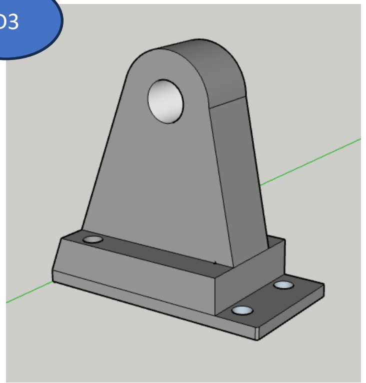
One important thing!

D1



D2

D3



Part lifespan	60000 h	60000 h	20000 h

We need 3!

Case Study

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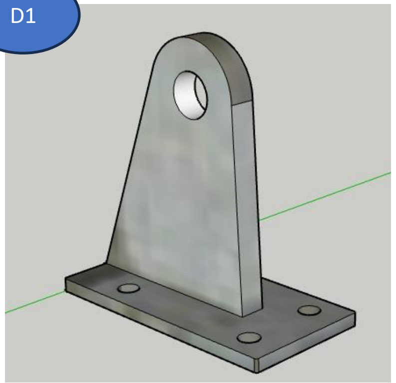
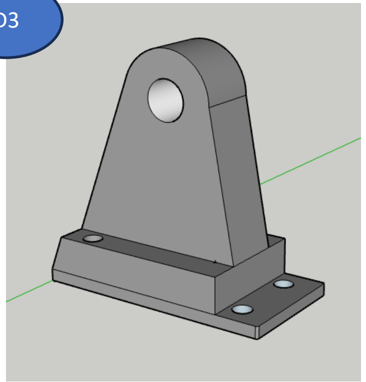
e) Trying to "put numbers" to our process. **Summary of energy consumption:**

D1



D2

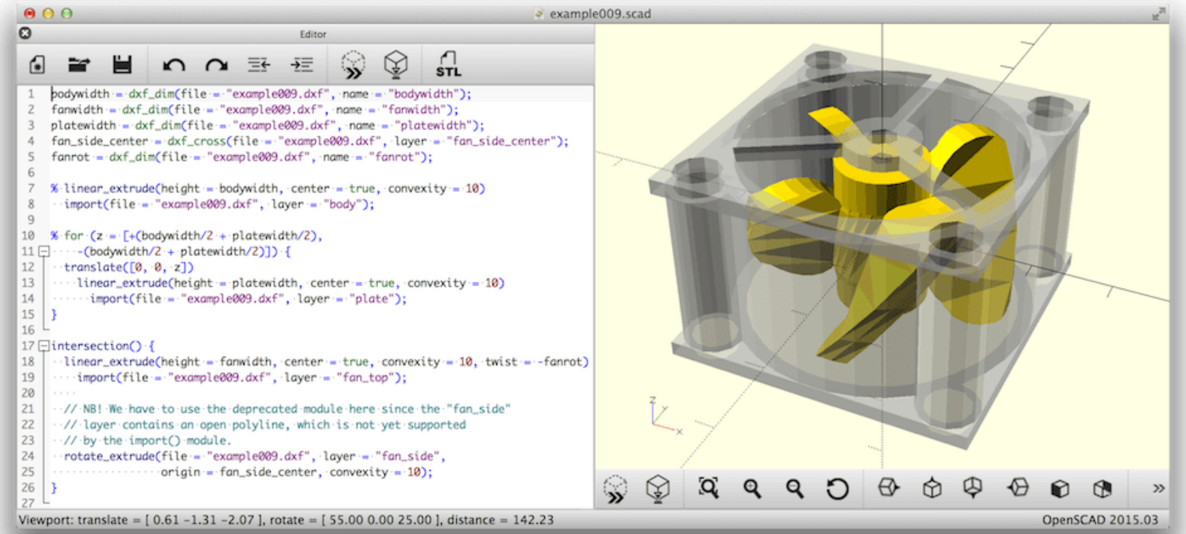
D3

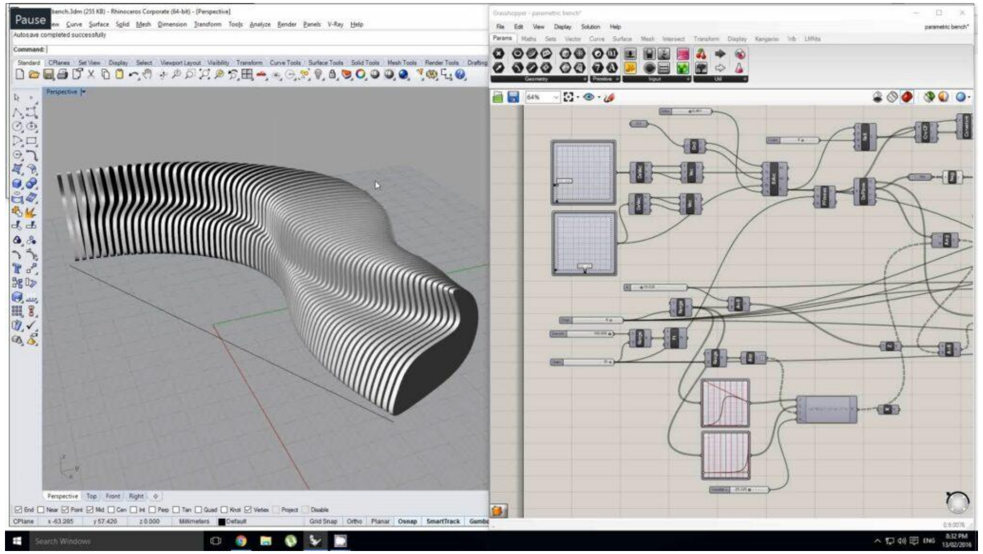


	D1	D2	D3
Raw material generation	16 kWh	7,4 kWh	4,2 kWh * 3
Manufacturing	30 kWh	104 kWh	24 kWh * 3
Reciclyng/waste treatment	11.4 kWh	32.4 kWh	0 kWh
Part lifespan	2250 kWh	1450 kWh	280 *3 kWh
Total Energy Consumption	**2307 kWh**	**1594 kWh**	**925 kWh**

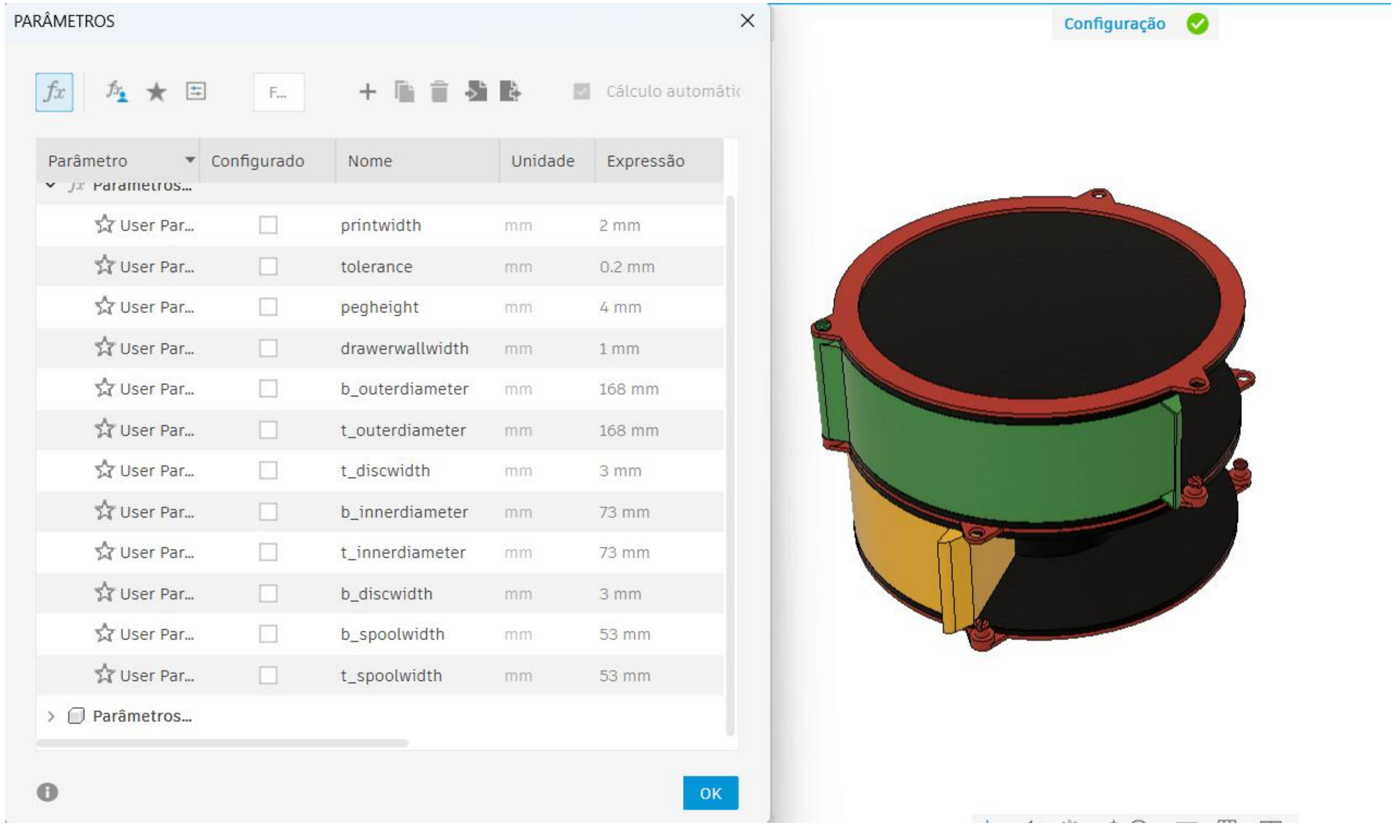
Parametric design

Parametric design is a design approach that uses adjustable parameters and relationships to define and control geometry, making it possible to quickly generate, modify, and optimize complex designs while maintaining consistency and efficiency across iterations.





Parametric design

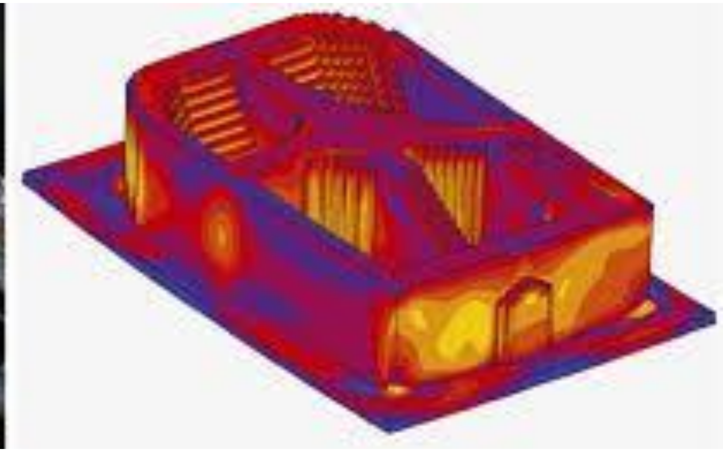


Parametric design

Right first time approaches

A “right first time” approach is a production approach that consists in designing and validating components digitally, so they are correct before any physical work begins

Process simulation is a computational method that models and analyzes manufacturing or operational processes in a virtual environment, allowing engineers to predict performance, optimize parameters, and reduce errors, cost, and development time.



Digital twin for right first time approaches

- Digital representation of a **physical system or process**
- Continuously updated with real-world data
- Combines:
  - Design models
  - Simulation
  - Operational data
- Enables:
  - Virtual validation before production
  - Continuous performance monitoring
  - Predictive adjustments
- Supports:
  - Process optimization
  - Quality assurance
  - Lifecycle management

Any questions?

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Case Studies

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Co-funded by the European Union

Instructions: Case study selection

- Choose a mechanical component:
- Examples:
  - Bracket
  - Support
  - Housing
- Requirements:
  - Clear function
  - Subject to loads/constraint

Instructions: Case study presentation

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Describe the Part
- Include: Function, Loads and constraints, Material, Current Manufacturing method (if known)
- What are the challenges? (ex: Excess weight, High stress areas, Inefficiencies)
- Why improve this design?

Justify Selection
- Why did you choose this part?
- Why is it suitable for redesign?
- Expected improvements

(Optional) Run FEA
- Identify Stress distribution, Critical regions, Current Factor of safety

Run GD or TO

Present the results
- Weight, Stress distribution, Performance
- Manufacturability, Cost
- Other