Enabling circular geometry assurance

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Director Wingquist Laboratory

Research Group Leader Geometry Assurance & Robust Design

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Digital quality assurance for sustainable industry

(Vinnova, Uppskalning för en hållbar industri, 2021-2024)

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- Kristina Wärmefjord, Chalmers
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- Roham Sadeghi Tabar, Chalmers
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- Richard Lindqvist, Saab AN
- Mikael Nilsson, Saab AN
- Lars Lindkvist, RD&T Technology AB
- Markus Lindén, LK Scandinavia
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Geometrical Variation

Geometrical variation on individual parts (form and size), as well as assembly variation, affects requirements on:

Assembly

Function

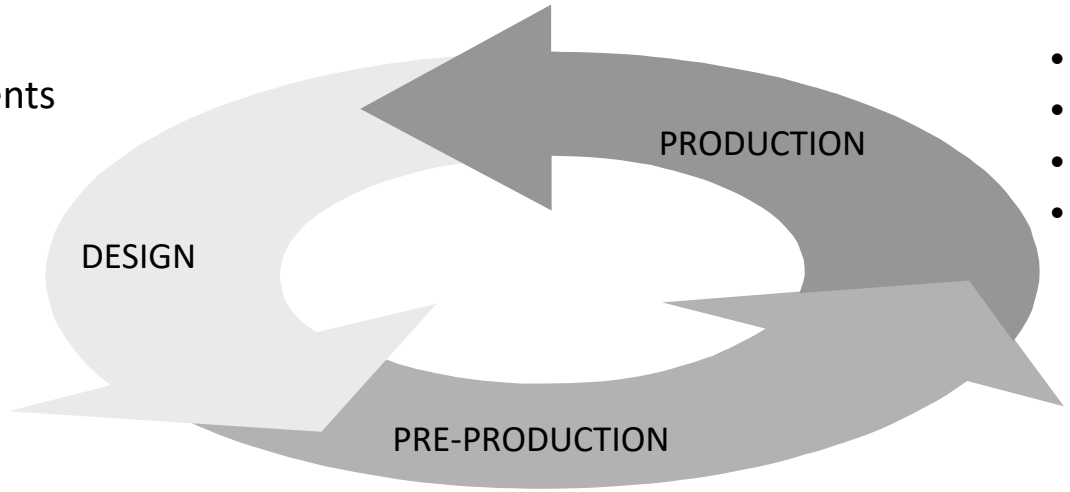
Perceived Quality

Geometry Assurance

Geometry Assurance is the set of activities that aims to **minimize the effect of geometrical variation in the final product**.

Specification of:

- product requirements
- part tolerances
- locators/datums

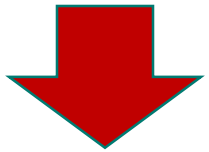


- Inspection
- Data analysis
- Process control
- Design feedback

- Inspection preparation
- OLP of inspection devices

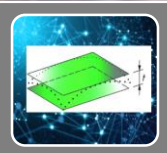
The industrial problem

- No uniform, digital, standardized way to specify and verify geometry requirements (in use)
- No efficient way to measure and evaluate details independent of fixture
- No efficient way to automatically configure an inspection task
- No efficient way to return and verify measurement data against requirements



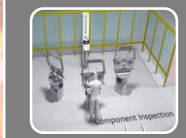
- Difficult to streamline value chains (OEM/SME)
- Difficult for large and small companies to participate in the future digital marketplace
- Difficult to realize the digital, sustainable and circular production system of the future

Digital quality assurance for sustainable industry

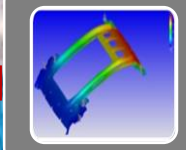


SPECIFY

FIXTURE



MEASURE



ANALYZE

How to specify geometrical requirements digitally?

How to verify geometrical requirements fixture-independent?

How to configure and optimize an inspection cell automatically?

How to evaluate a part or subassembly virtually?

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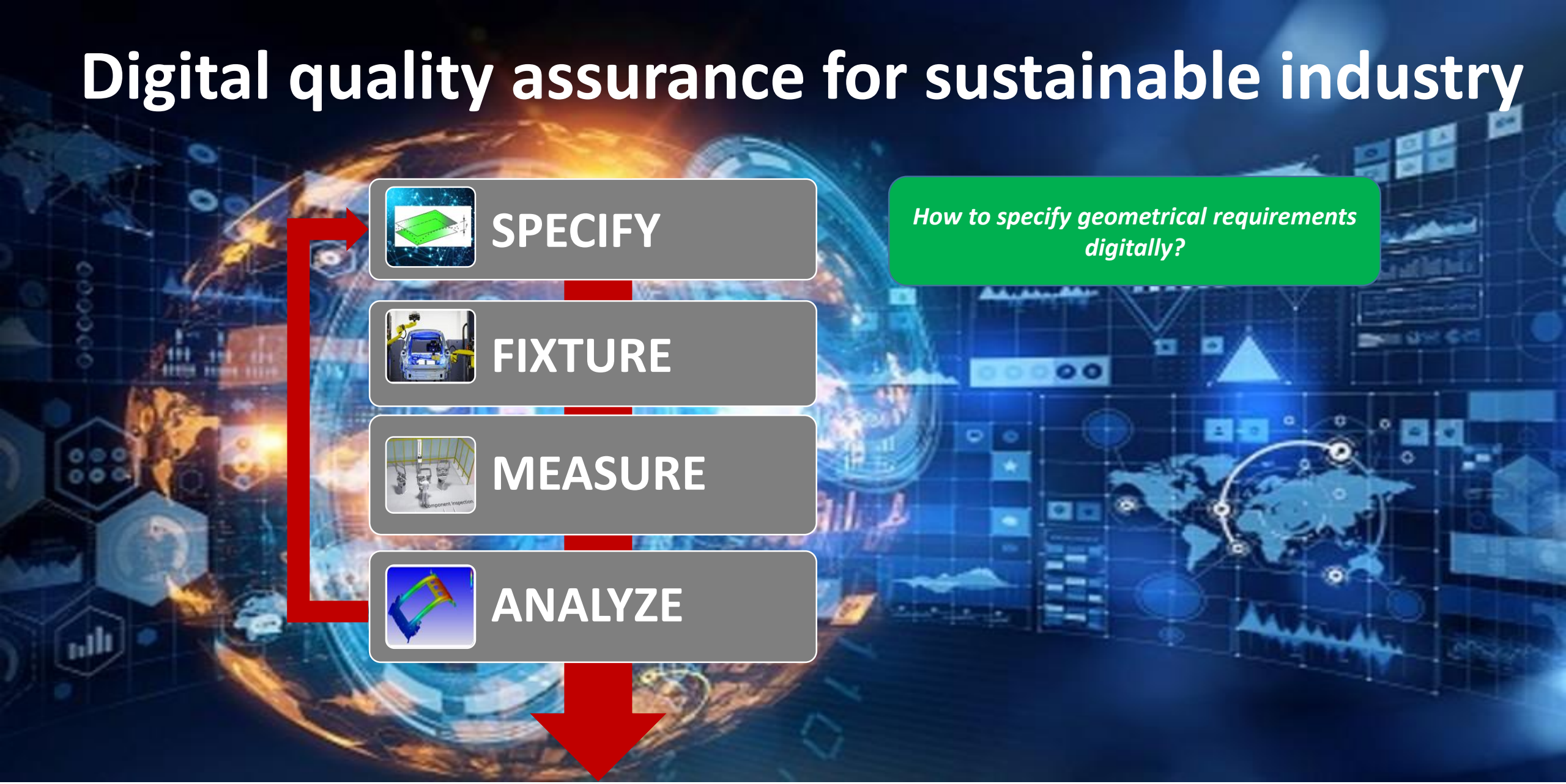

How to specify geometrical requirements digitally?

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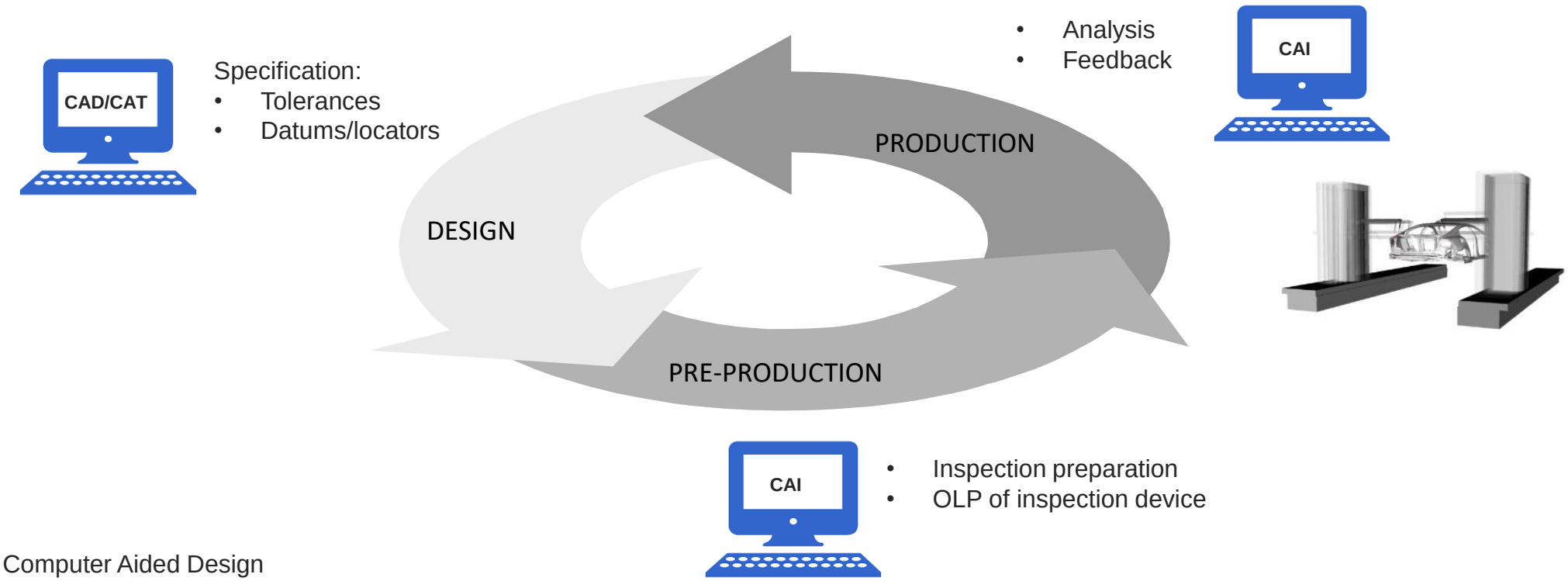
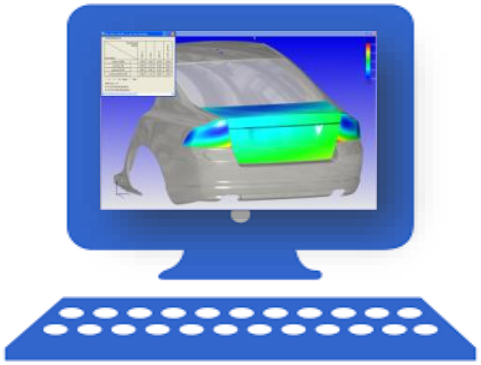
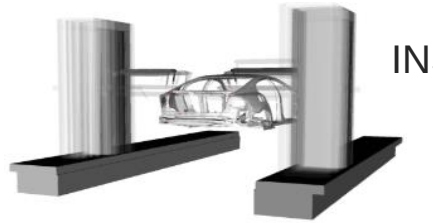
The information loop



CAD – Computer Aided Design
CAT – Computer Aided Tolerancing
CAI – Computer Aided Inspection

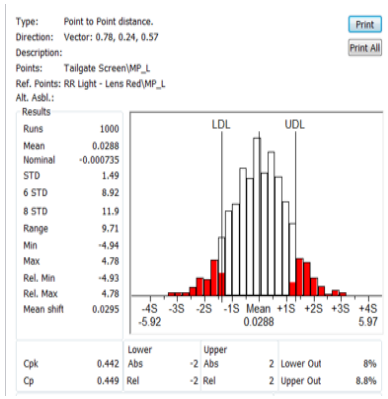
From CAD to CAT: STEP AP242 and/or QIF





INSPECTION

SYMBOL	CHARACTERISTICS
	Straightness
	Flatness
	Circularity
	Cylindricity
	Profile of a Line
	Profile of Surface
	Angularity
	Perpendicularity
	Parallelism
	Position
	Concentricity
	Symmetry
	Circular Runout
	Total Runout



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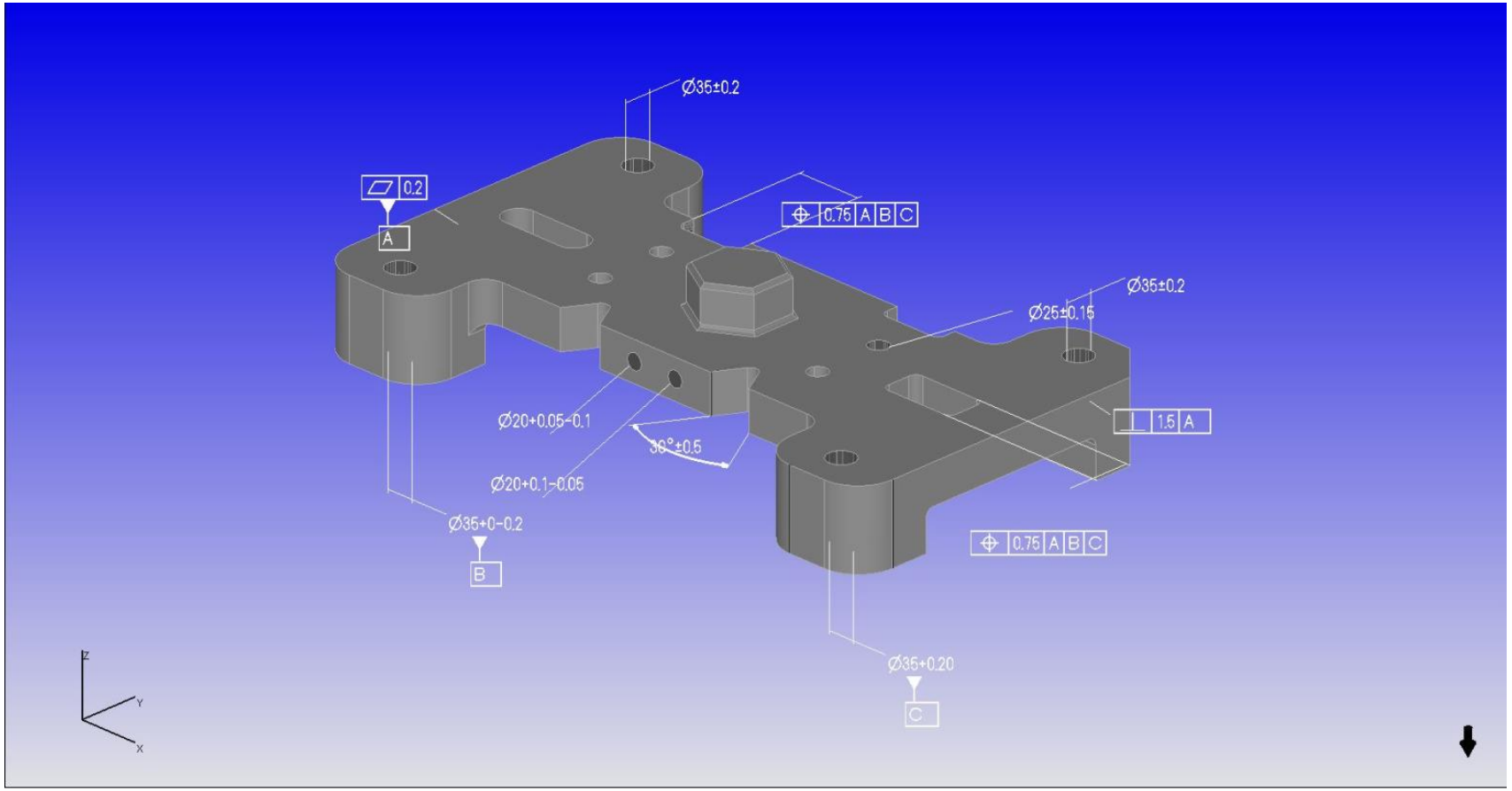
QIF


7
QIF Statistics
Statistical process control using QIF
QIF MBD
CAD and PMI data
1
6
QIF Results
Measurement result data
QIF Library
QIF Plans
Bill of Characteristics ("what") and Measurement Plan ("how") data
2
5
DMIS
ISO/DMIS 5.3 is fully linked to QIF
QIF Resources
Measurement Resource information
QIF Rules
Measurement templates, macros, and best practices
4
3

From CAD to CAT via QIF: Part



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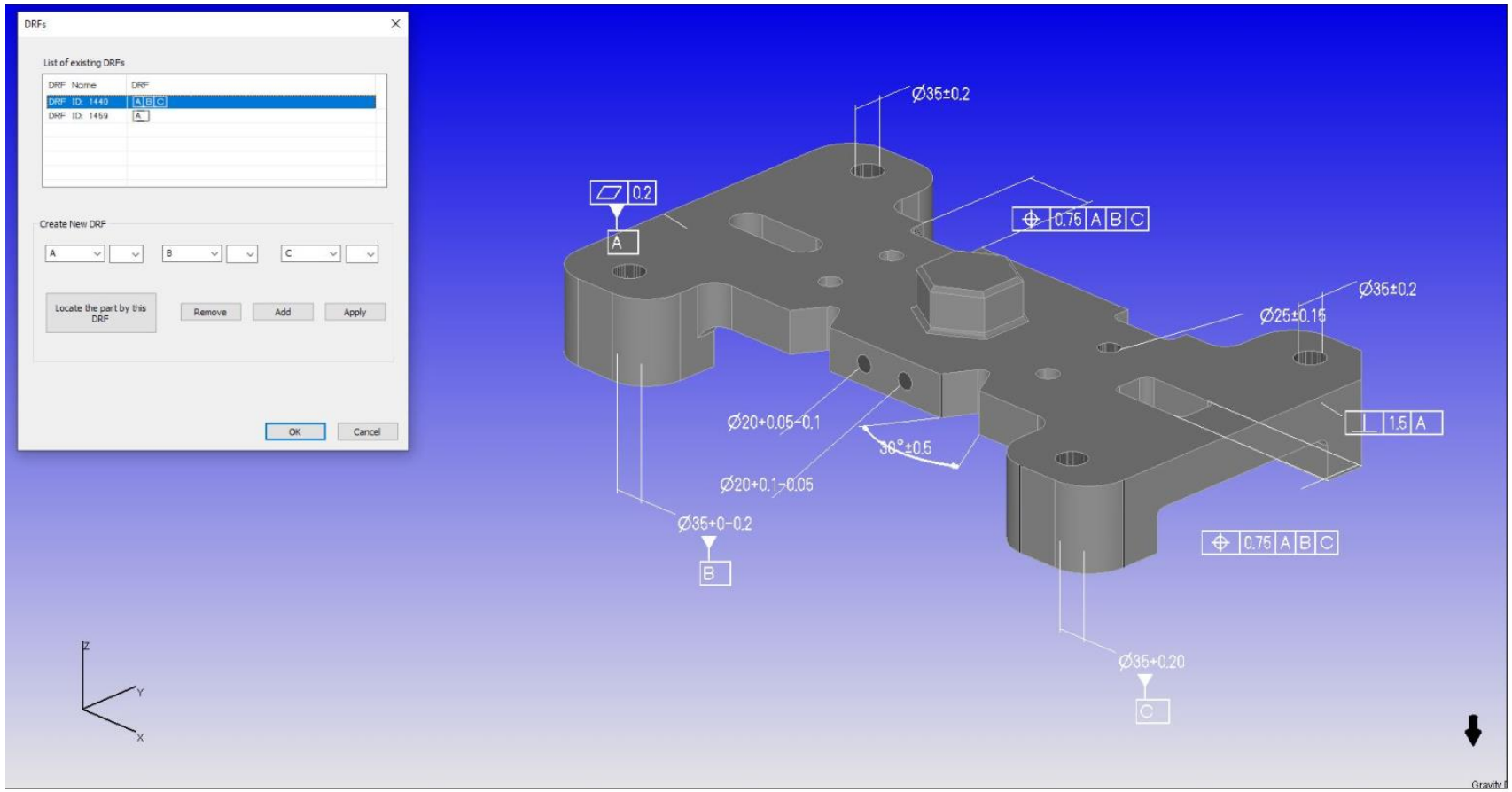

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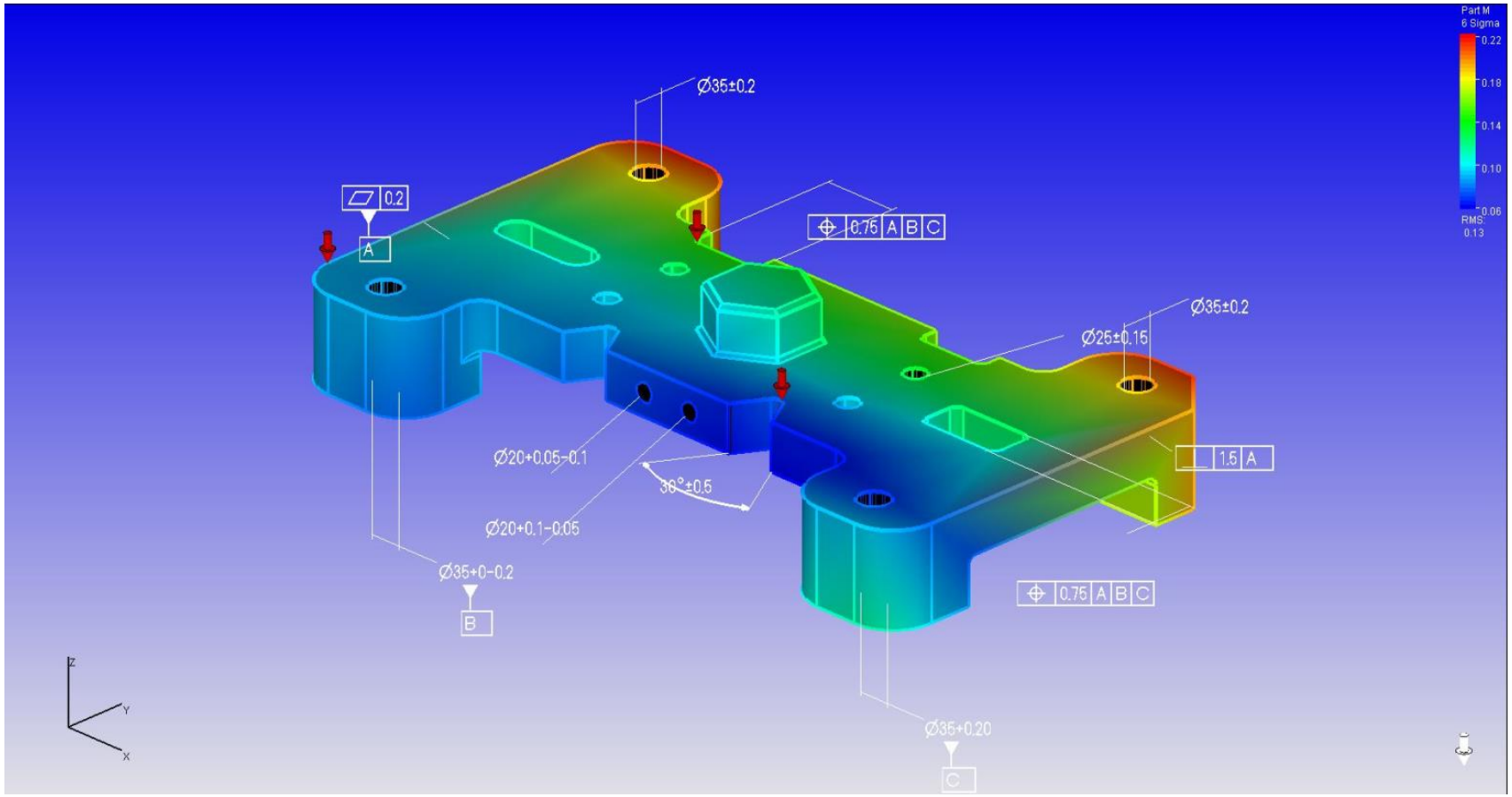

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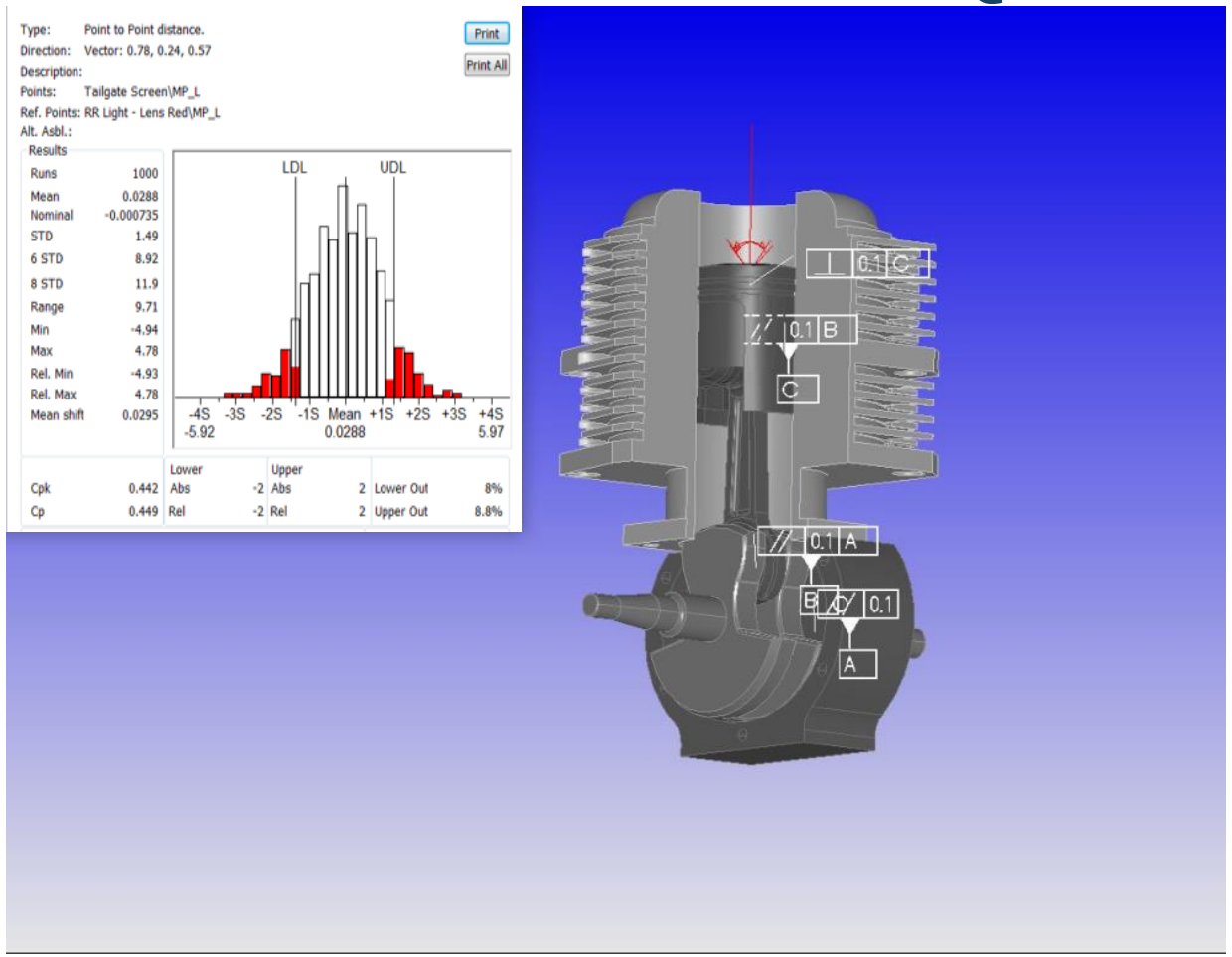
From CAD to CAT via QIF: Assembly



AR Aderiani, K Wärmefjord, R Söderberg (2022). Model-based definition in computer aided tolerance analyses. Procedia CIRP 114, 112-116

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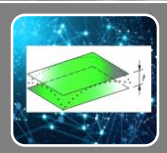
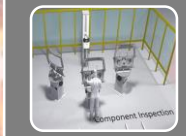
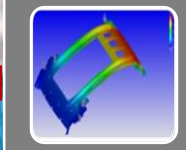

SPECIFY


FIXTURE


MEASURE


ANALYZE

How to verify geometrical requirements fixture-independent?

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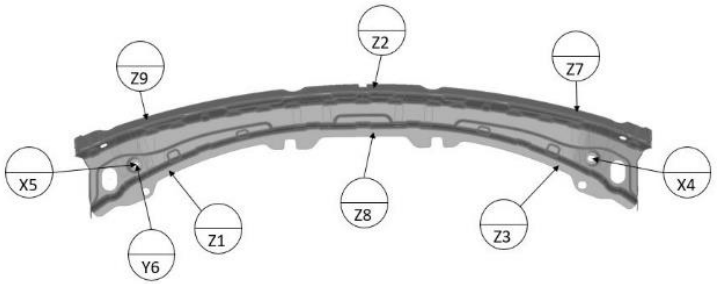
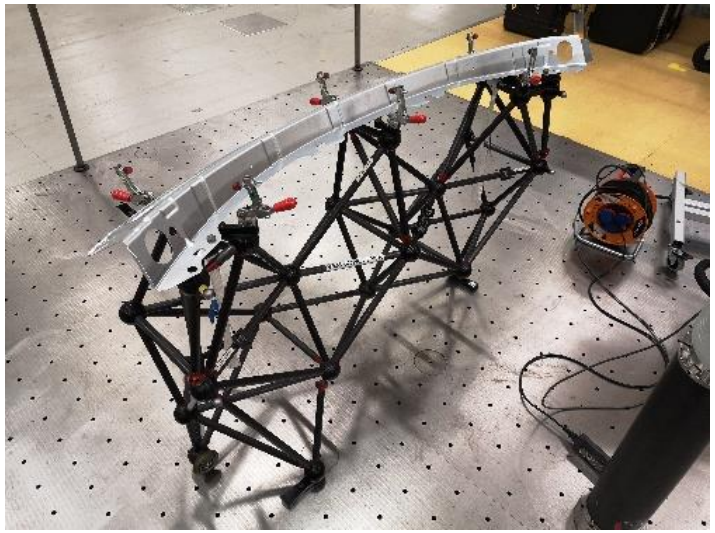
Today parts are measured in part-specific physical fixtures (over-constrained)

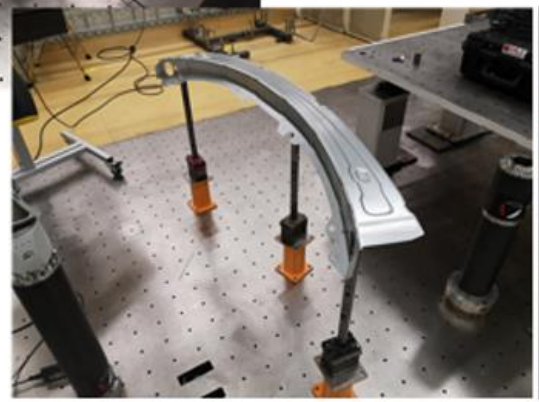




- *Design*
- *Manufacture*
- *Transport*
- *Prepare measurement program*
- *Rig the part*
- *Measure*
- *Store the fixture*
- *Scrap/recycle*

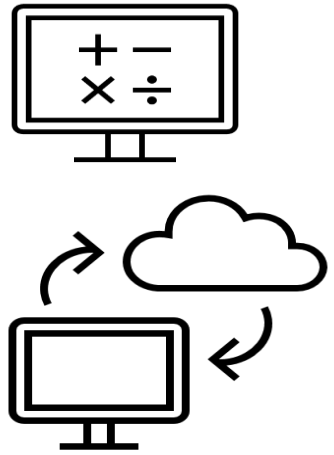
Parts are measured over-constrained
(does not reflect the real shape in free state)

We propose a method that allow parts to be inspected in ”free state” (real shape)

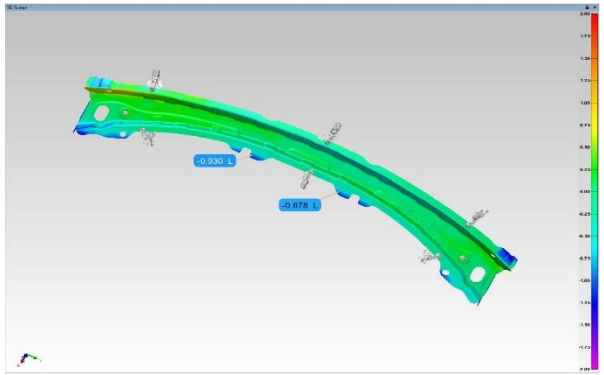


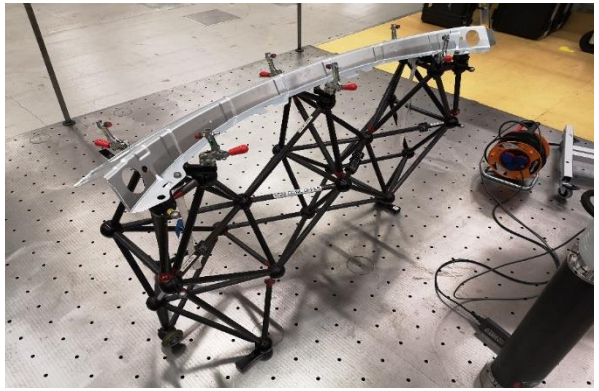
Rigging on three spheres

Scanning



Calculation of real shape (gravity compensation)

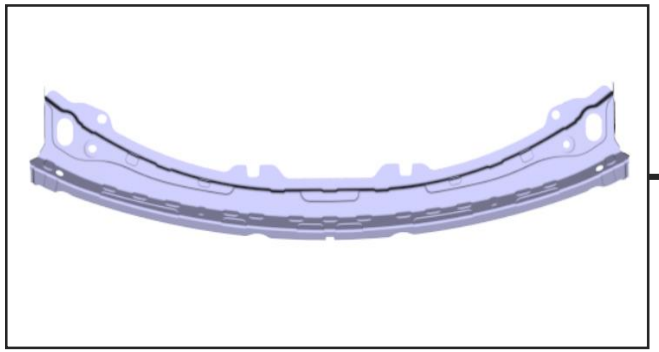




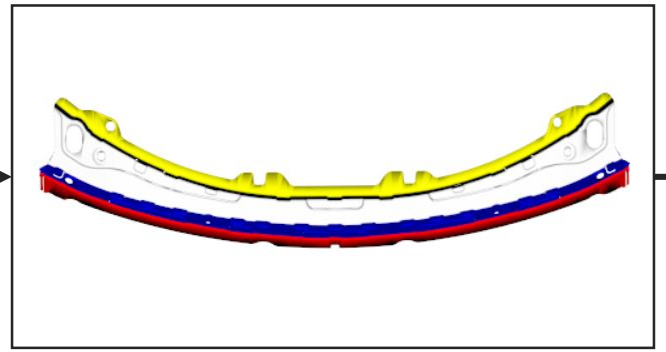
Evaluation in free state or over-constrained in virtual fixture

Inspection paths for a robot or a manikin can then be calculated automatically

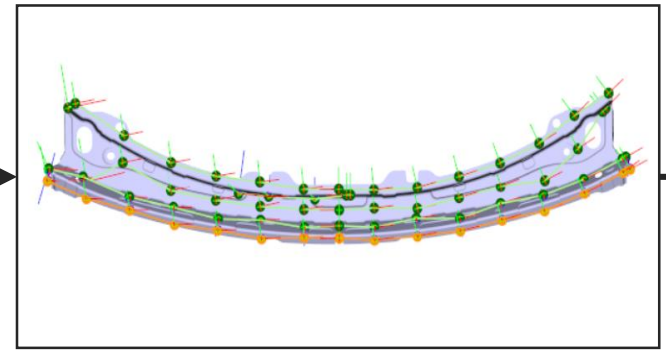
Input geometry



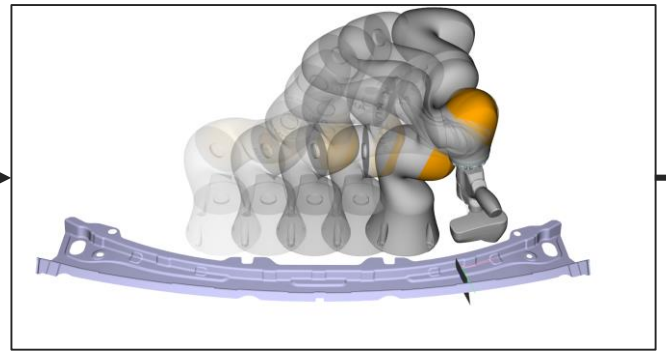
Geometry segmentation



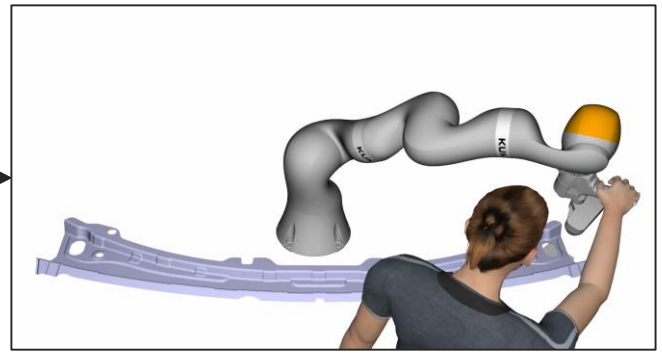
Automatic curve generation



Robot placement optimization



Robot/Manikin motion planning



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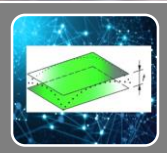
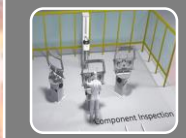

SPECIFY


FIXTURE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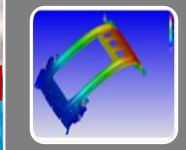
ANALYZE

How to configure and optimize an inspection cell automatically?

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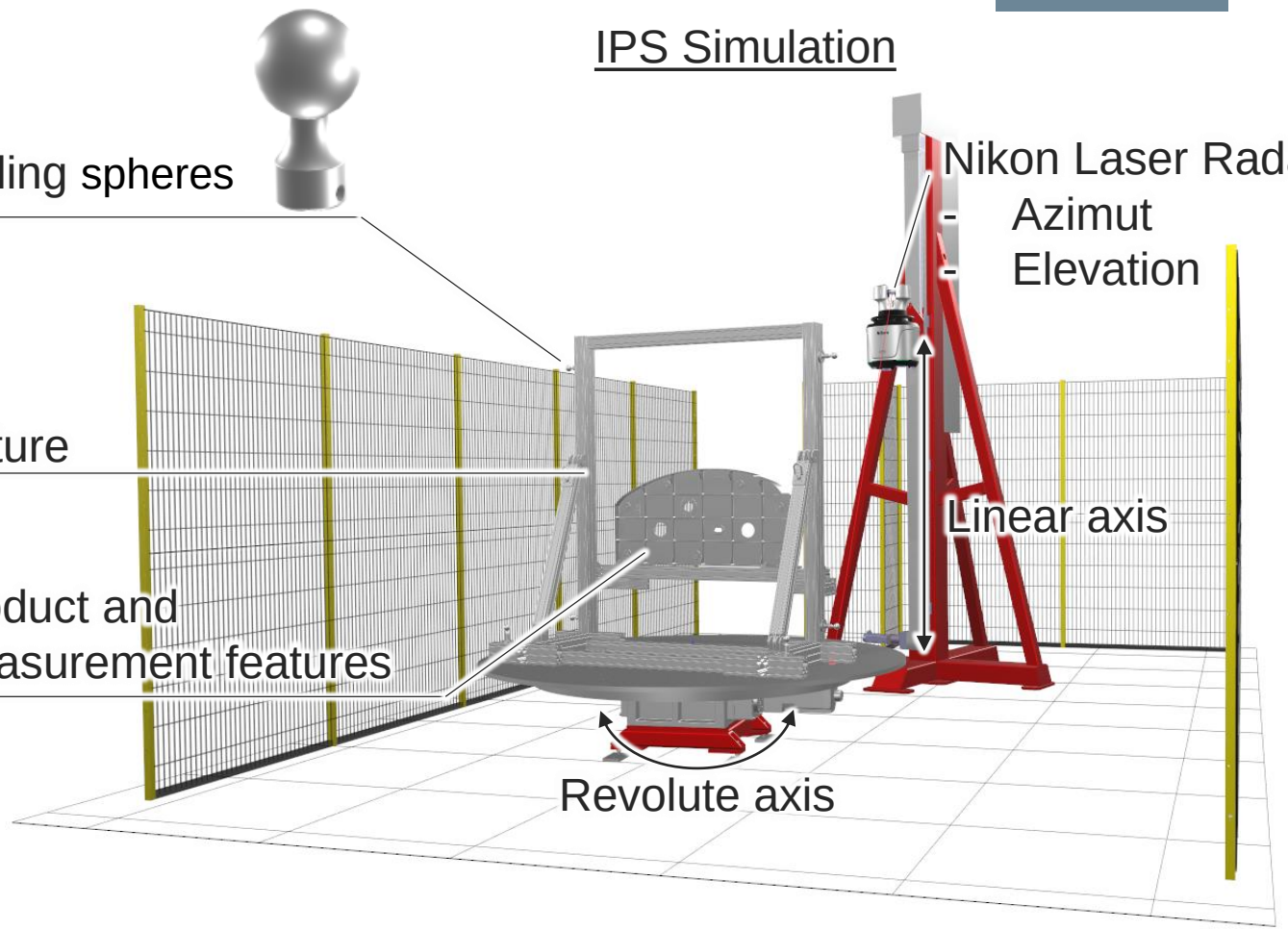
Optimization and Automatic Programming of Laser Radar

Use case from Saab Aeronautics

Real station

IPS Simulation



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Optimization and Automatic Programming of Laser Radar

- Product geometry
- Fixture
- Measurement features
- Tooling spheres

Step 1
Import measurement data to IPS

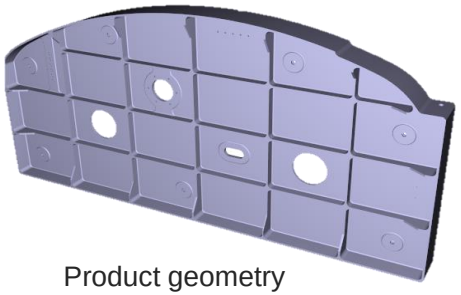
Step 2
Plan measurement tasks to find feasible measurement configurations

Step 3
Optimize measurement sequence to minimize cycle time

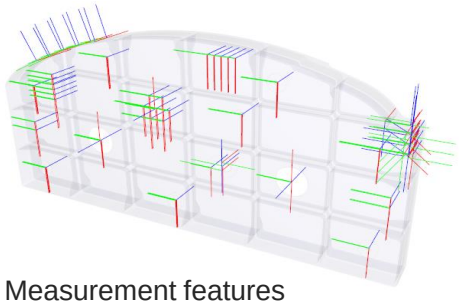
Step 4
Export program

- Inspection program

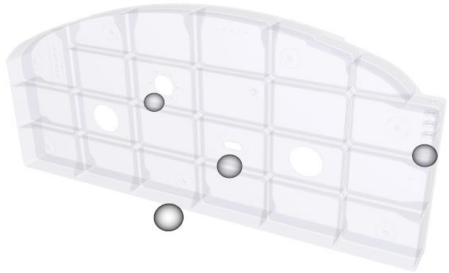
Fixture



Product geometry



Measurement features



Tooling spheres

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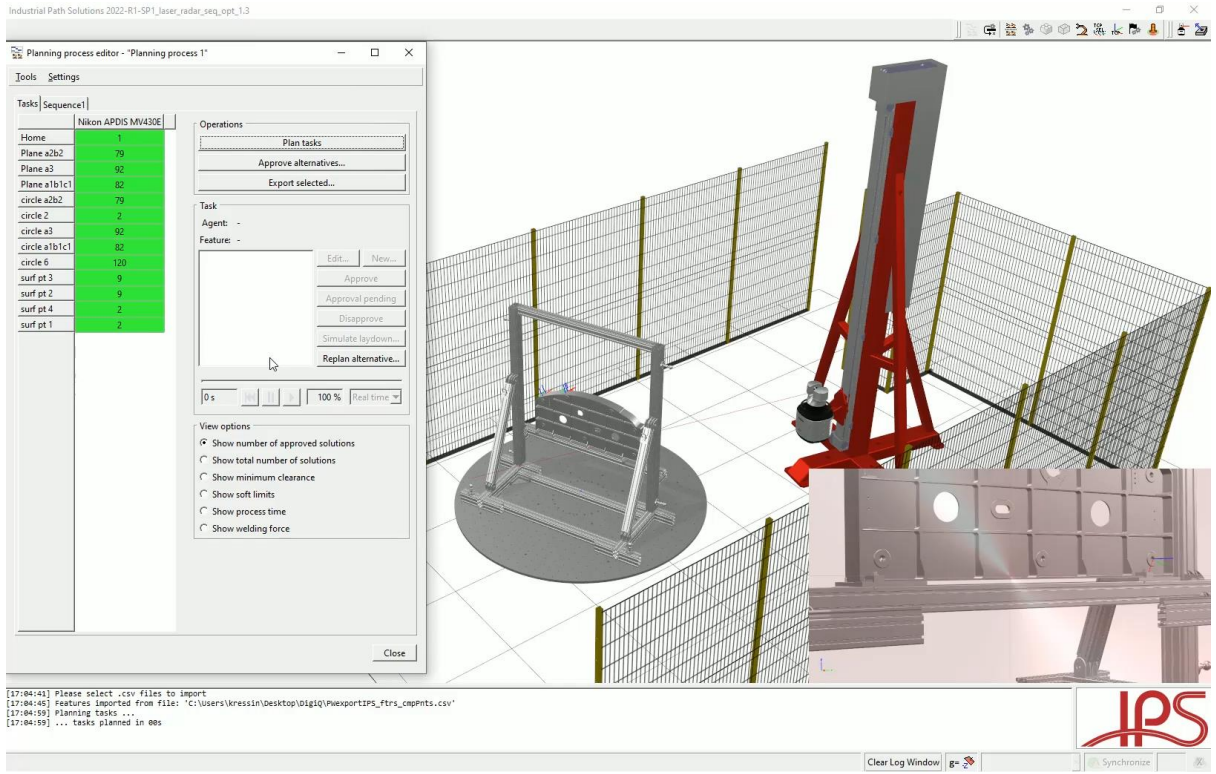
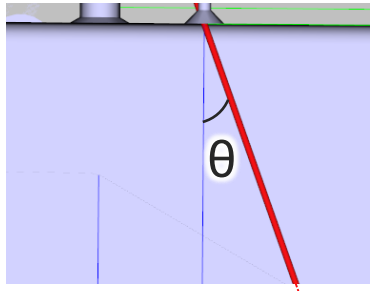
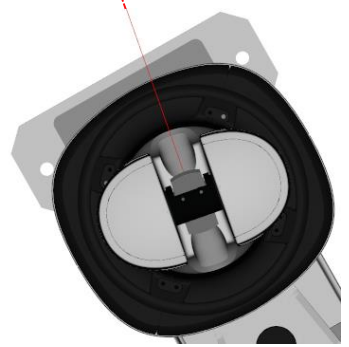




Automatically checks:

- Kinematically reachable
- Collision-free
- A ray can be cast from the laser to the feature without any obstacles in the way
- The measurement angle towards the nominal axis of the feature (θ) must be within allowed range.
- A certain number of tooling spheres must be visible



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- Tooling spheres

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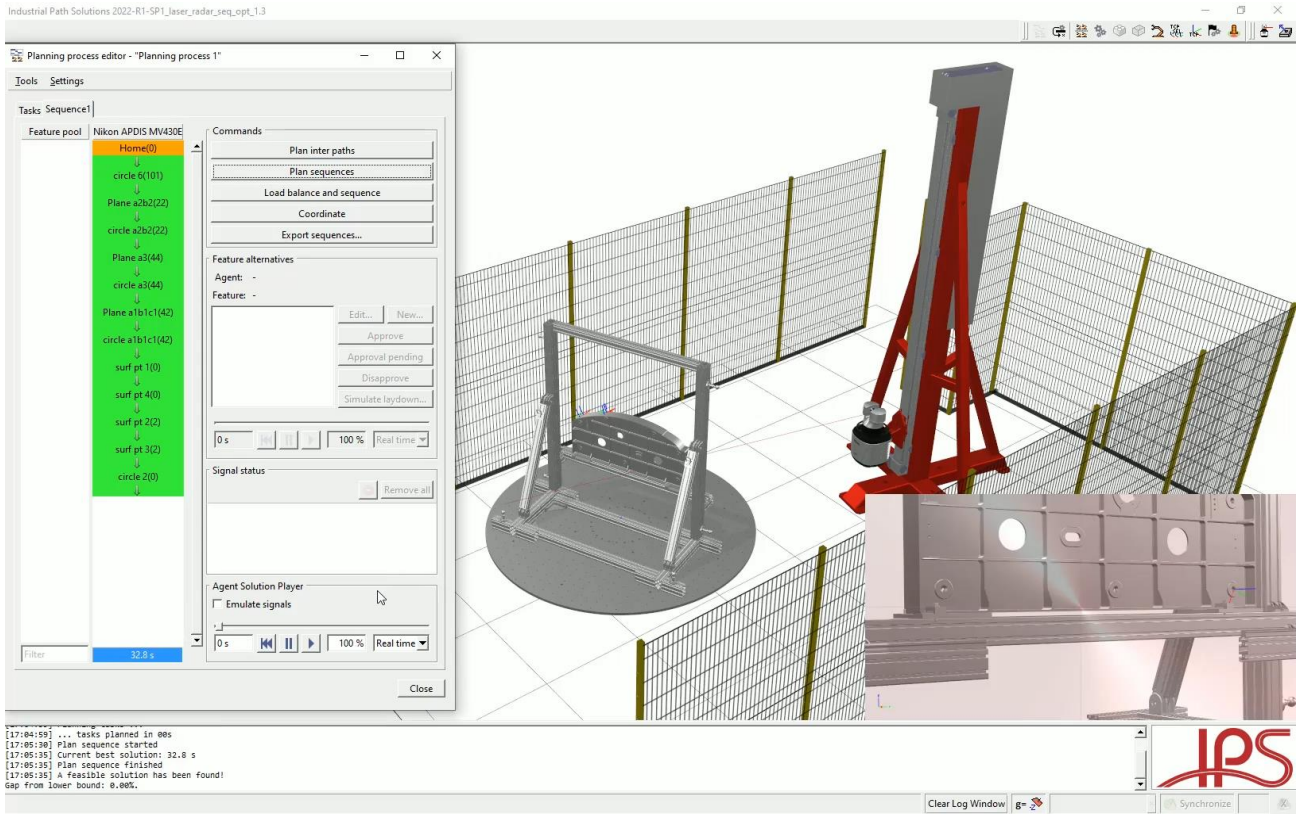

Automatic sequence optimization:

- Optimize visiting order for all measurements
- Optimize configuration alternative
- Automatic path planning
- Automatically add measurement of tooling spheres each time the linear axis or turn table moves

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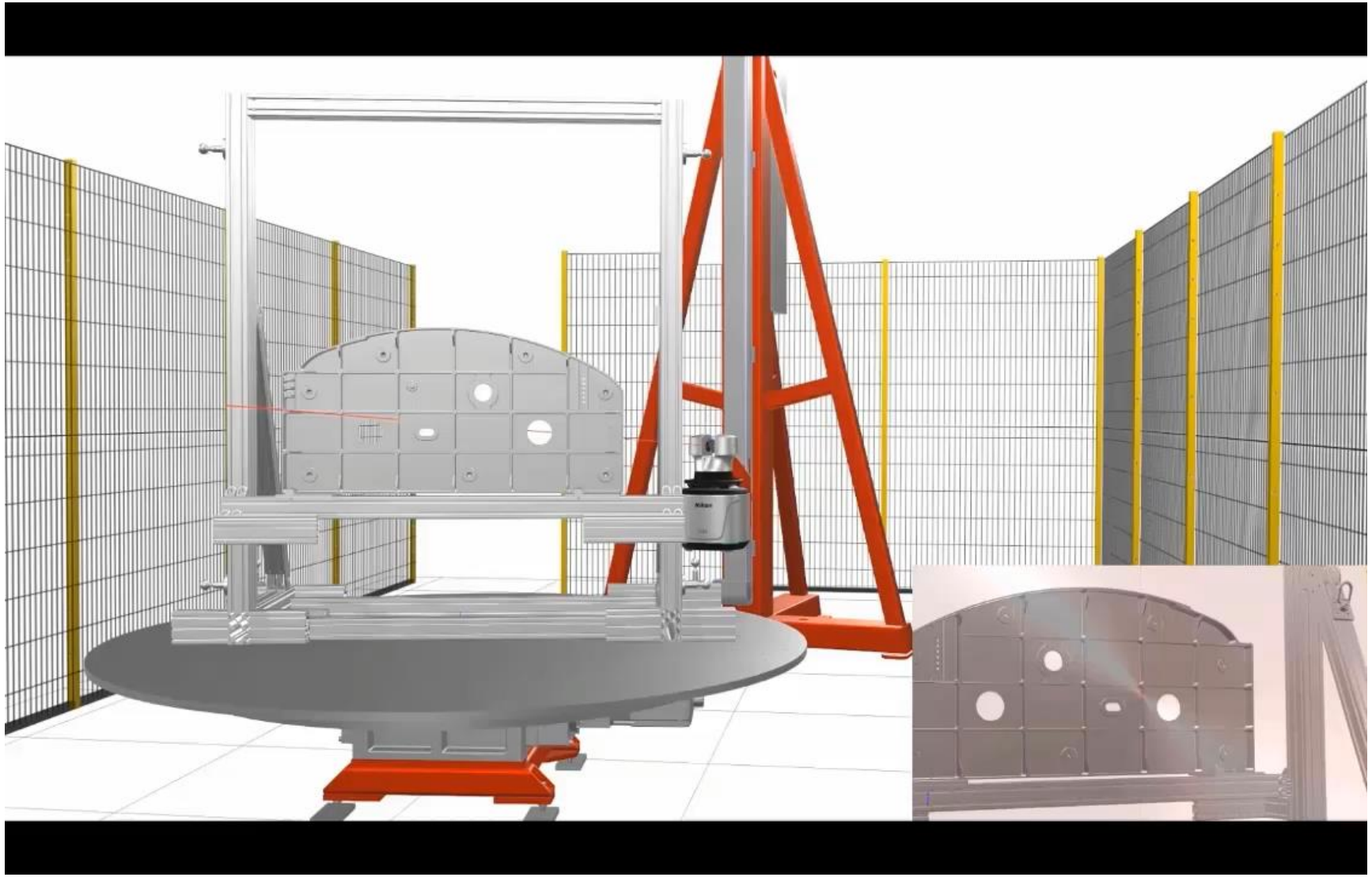

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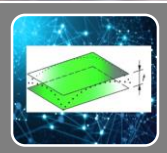
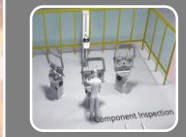
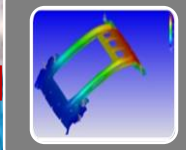
Digital quality assurance for sustainable industry


SPECIFY


FIXTURE


MEASURE


ANALYZE

How to evaluate a part or subassembly virtually?

FRAUNHOFER CHALMERS RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

VOLVO Volvo Car Corporation

LK Scandinavia

polyworks scandinavia

IPS

RD&T Technology

SAAB TECHNOLOGIES SAAB

wingquist LABORATORY

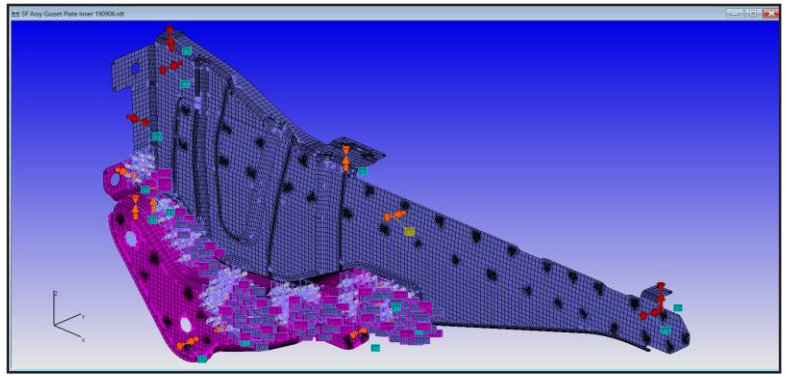
RD&T Variation Simulation/Tolerancing

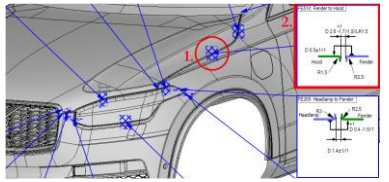
1. Define part tolerances → **2. Build model to predict assembly variation** → **3. Run M.C., evaluate assembly results**

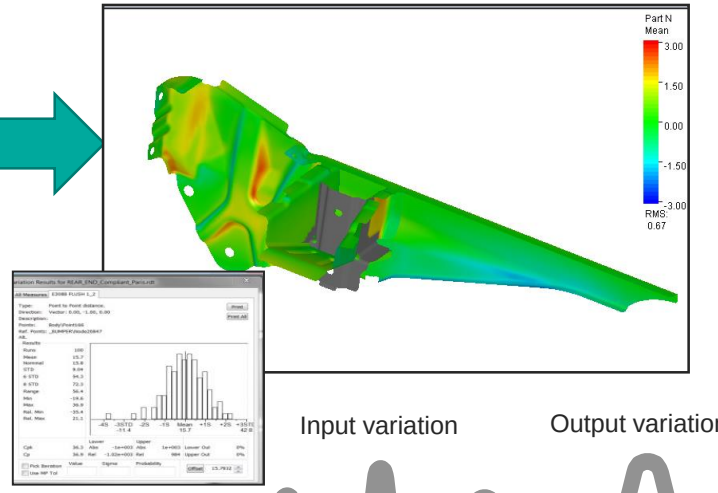
Tolerance/ assumed variation

AND/OR

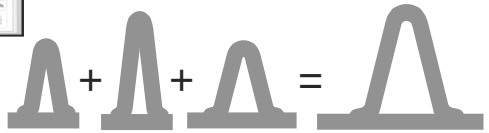
Inspection data



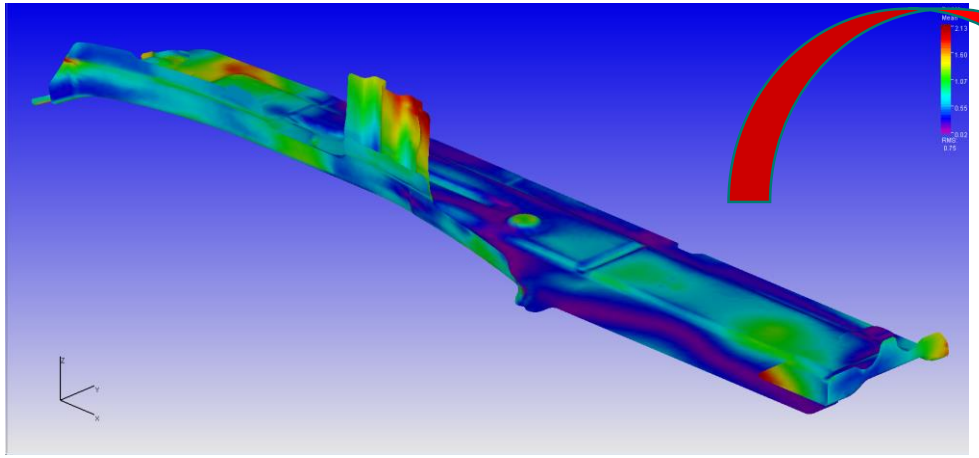




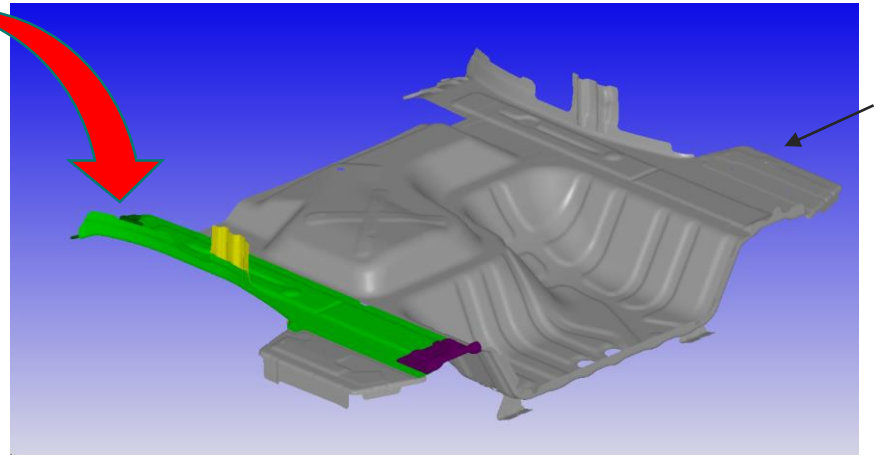
Input variation Output variation



Evaluation of variation in flexible parts/assemblies

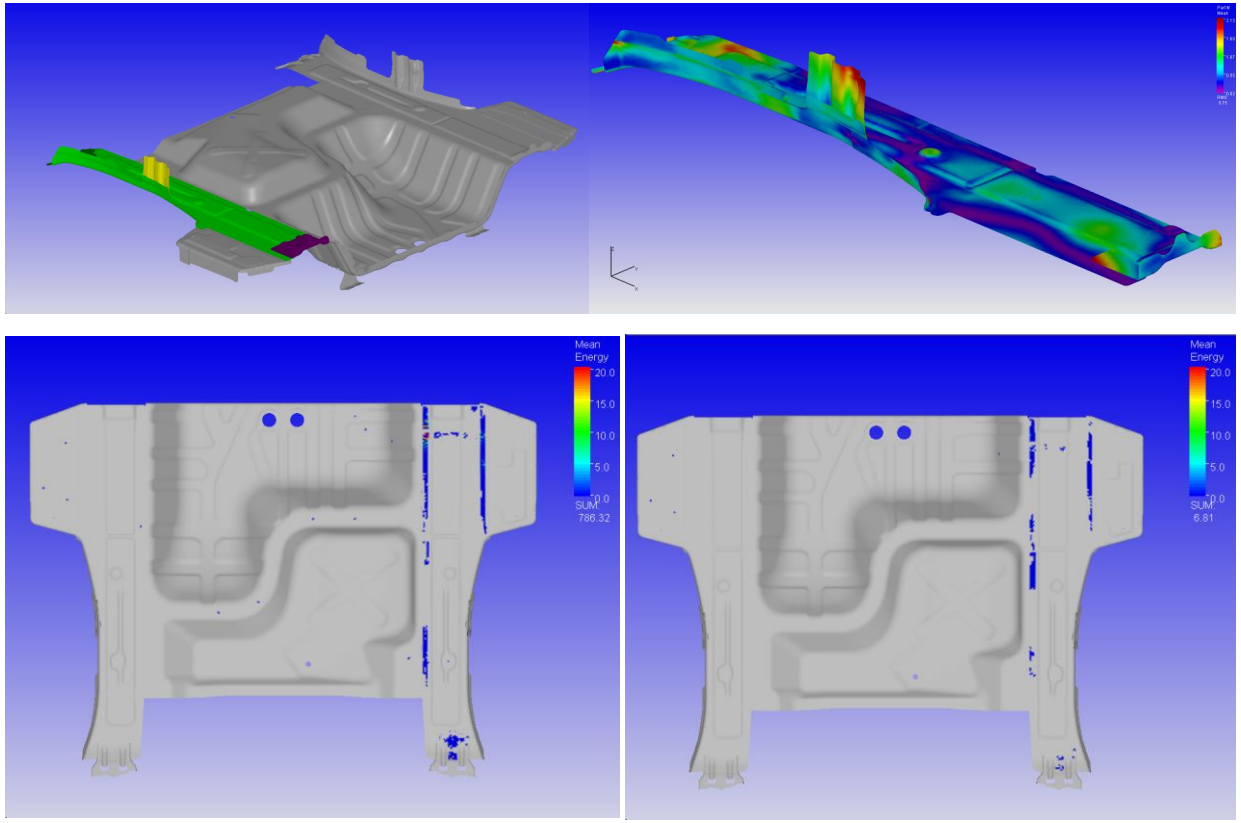


Variation in Subassembly 1



What if Subassembly 2 is much stiffer than Subassembly 1?

Evaluation of geometric tolerances using strain energy density



The color-coding shows the subassembly deviation from nominal values

$$\mathbf{W} = \frac{1}{2}\mathbf{u}^{\mathbf{T}}\mathbf{K}\,\mathbf{u}$$ Strain energy density

Left: Assume sheet metal subassy. **W=786** Nmm

Right: Assume plastic subassy. **W=7** Nmm

Wärmefjord, K., Lindkvist, L., Söderberg, R., Lindau, B., & Andrén, M. (2023). Evaluation of geometric tolerances using strain energy density. CIRP Annals.

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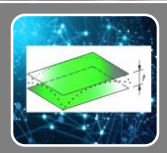
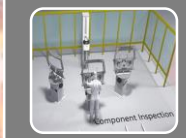
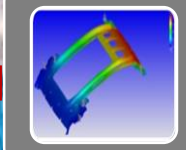


SPECIFY

FIXTURE



MEASURE



ANALYZE

How to specify geometrical requirements digitally?

How to verify geometrical requirements fixture-independent?

How to configure and optimize an inspection cell automatically?

How to evaluate a part or subassembly virtually?

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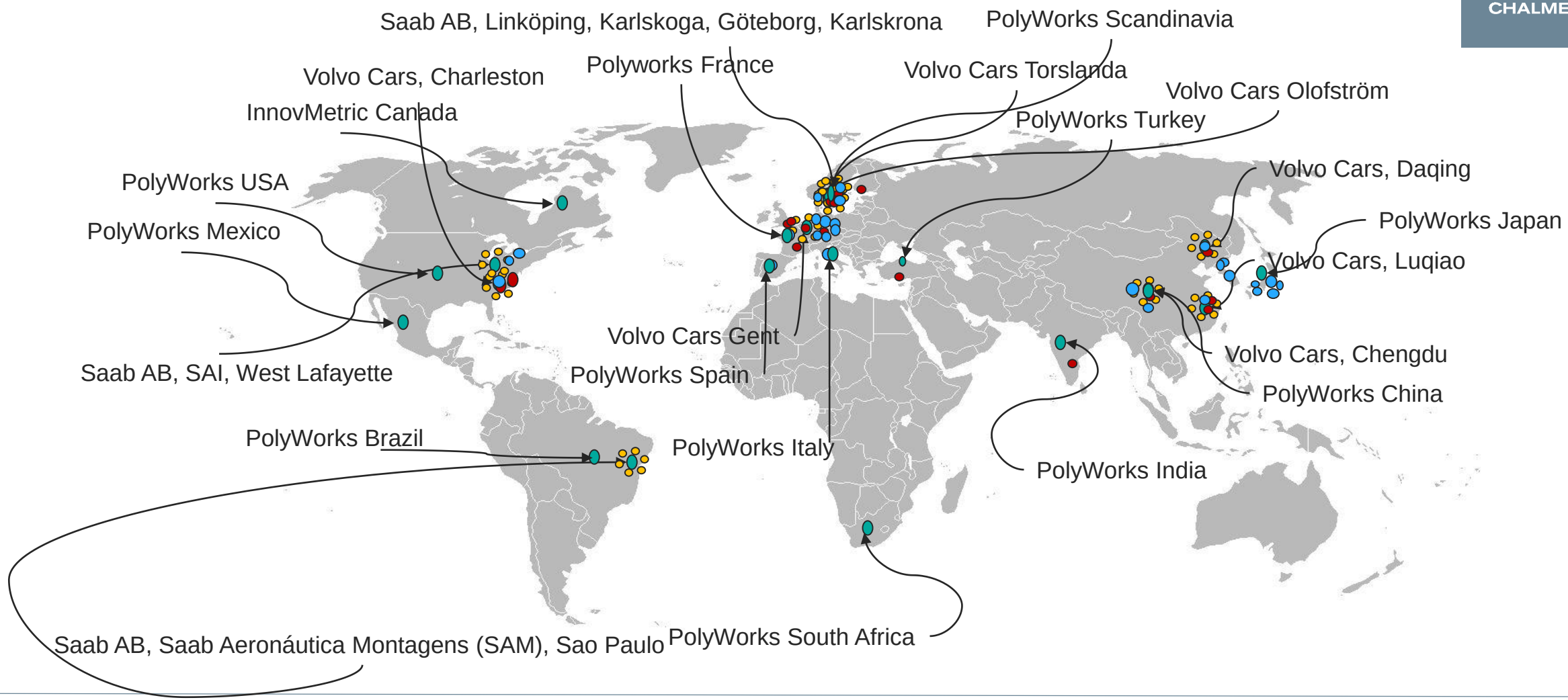
Transfer of results



Towards sustainable production

- Increased opportunity for **climate-neutral and circular production through increased degree of digitization and automation** of the geometry assurance process
  - Reduced transport of physical details (local suppliers)
  - Reduced travel
  - Reduction of physical test series
- Increased opportunity for **resource-efficient and resilient value chains** through better material utilization, fewer discards, increased traceability and higher quality
  - reduced variation in final product
  - reduced lead times in the geometry assurance chain
  - reduced programming time for OLP
  - reduced need for physical documents
  - reduced need for expensive fixtures
- Increased **global competitiveness** for Swedish OEM/SME through participation in effective global networks and value chains