Geometric Variation included in computer modelling and a Digital Twin as an opportunity to get adaptive manufacturing

ENBIS 2022 conference in Trondheim

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European Network for Business and Industrial Statistics

Agenda

- GKN Aerospace
- “Make it light”-Light fabrication structures
- SPC Process Improvement
- Process knowledge vs Industry 4.0
- Digital Twin concept- Chalmers View
- Geometry Assurance process vs digital twin
- GKN case: Geometrical variation in fabricated components
- Digital twin for individualized manufacturing
- Ongoing work: Virtual assembly and welding simulation using the RD&T software
- Future work: Test manufacturing with adaptive process adjustment

GKN Aerospace In Numbers

~£2.5BN
SALES

38
SITES

4
GLOBAL TECHNOLOGY CENTRES

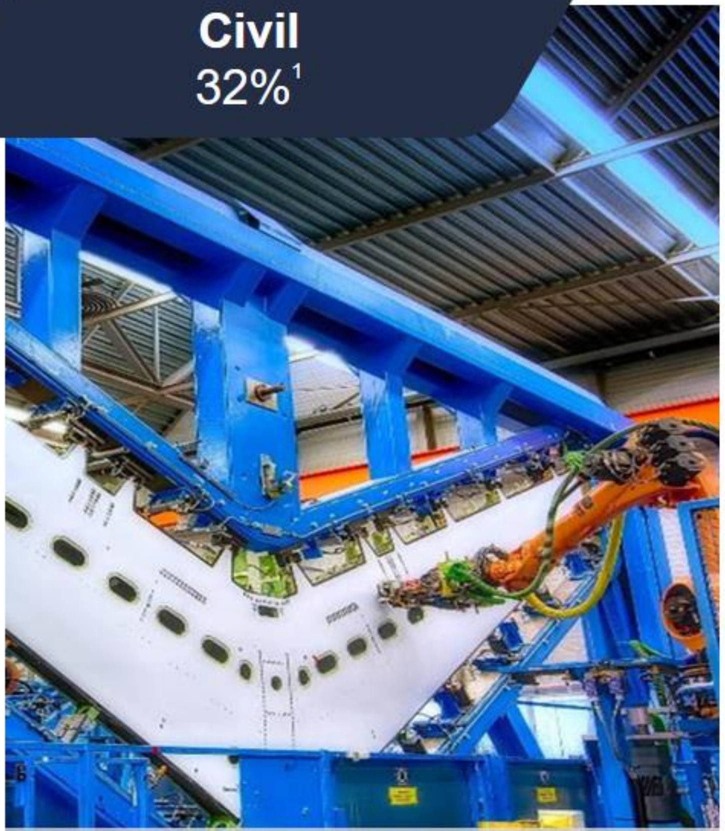
15,000
EMPLOYEES

12
COUNTRIES

ON BOARD
100,000
FLIGHTS A DAY

A Focused Business with Three Core Markets

Civil
32%[1]

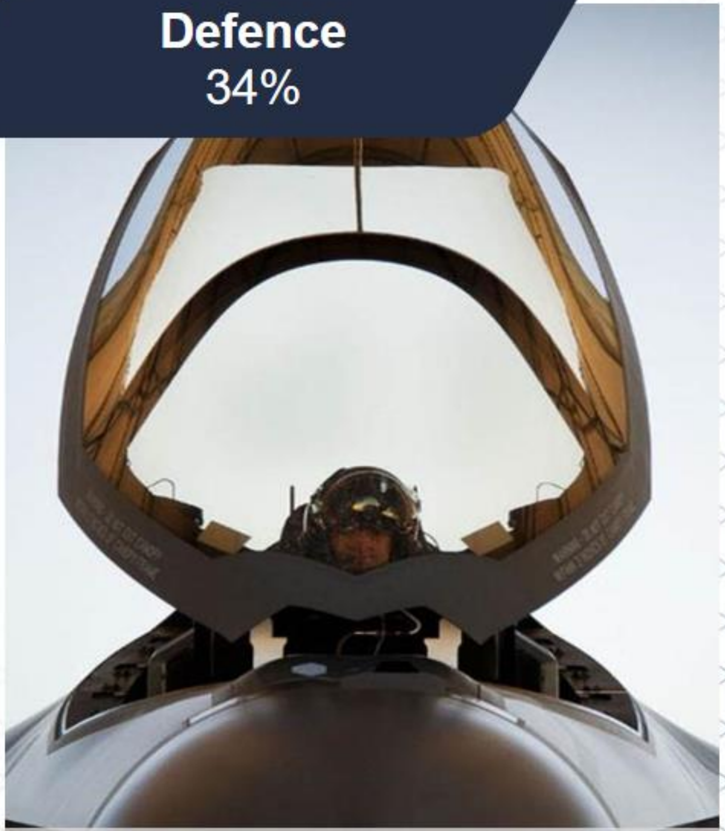


Tier 1 expertise across fuselage, empennage and wing; plus landing gear, wiring and transparencies

Engines
34%

OEM capability for RM12 engine, plus super Tier 1 capability across the entire engine architecture

Defence
34%



Full SSA structure in place to support positions on leading US and European Defence platforms

[1] All percentages relate to total company sales at end 2021

A truly global business, investing for the future

R&D - 4 Global Technical Centres creating a Network of Innovation

- Trollhättan, Sweden
- Bristol, UK
- Oak Ridge, US
- Hoogeveen, The Netherlands

Develop Technology knowledge for exploitation

Industrialise Sustainable Technology

Create an Ecosystem hub

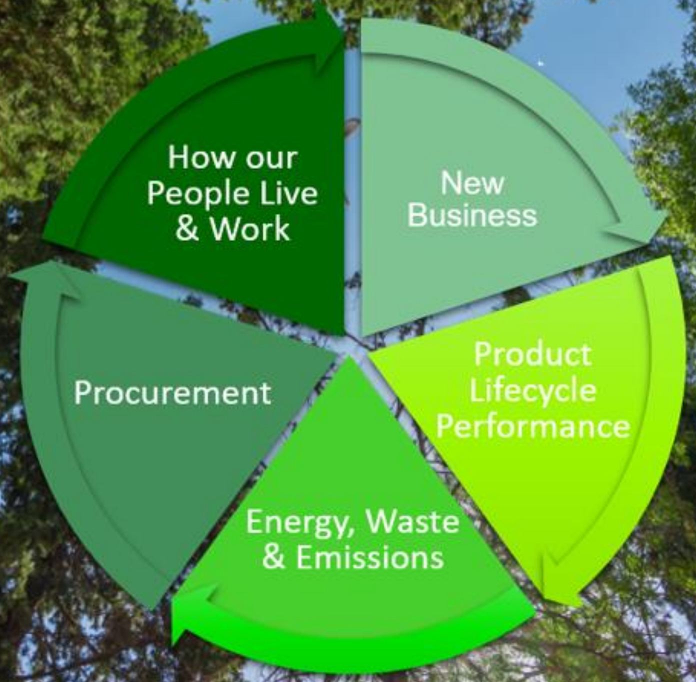
Increase Collaboration

Provide Technical Capability

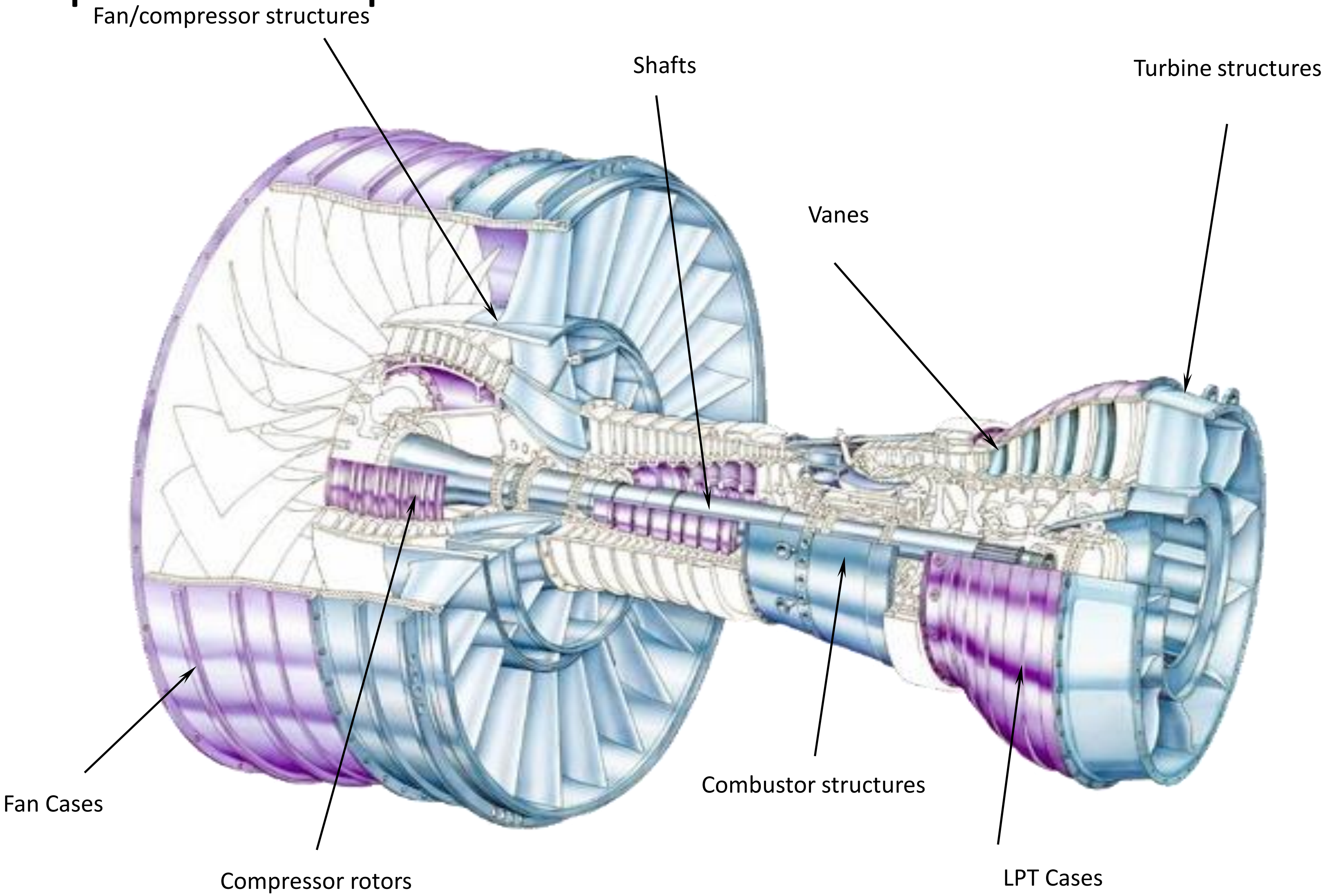
Showcase GKN Aerospace capabilities

Committed to a more sustainable future by:

- Achieving net zero emissions in our footprint
- Developing products enabling net zero emission flight
- Protecting our environment



Our component specialisation



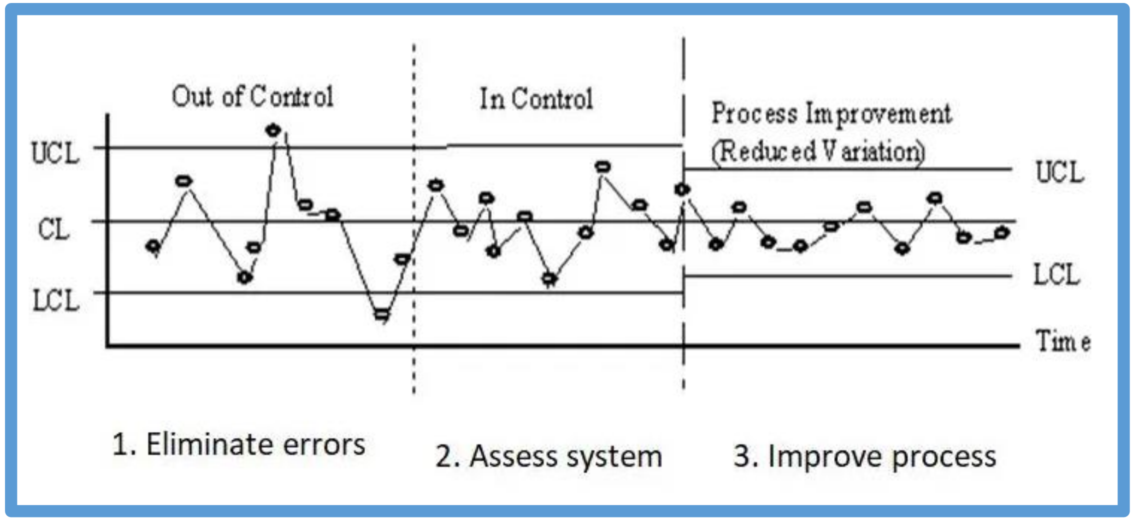
“Make it light” – From heavy casting structures → Light fabrication structures

One-piece manufacturing (skilled craftsman) → Assembly line with Process Controlled Product manufacturing

Challenge for fabrication:
Reach tolerance level of one big casting: 0.1 mm in machining operation

SPC Process Improvement

Walter A. Shewhart



W. Edwards Deming

Process knowledge vs. Industry 4.0
Controlled variation by a Digital Twin?

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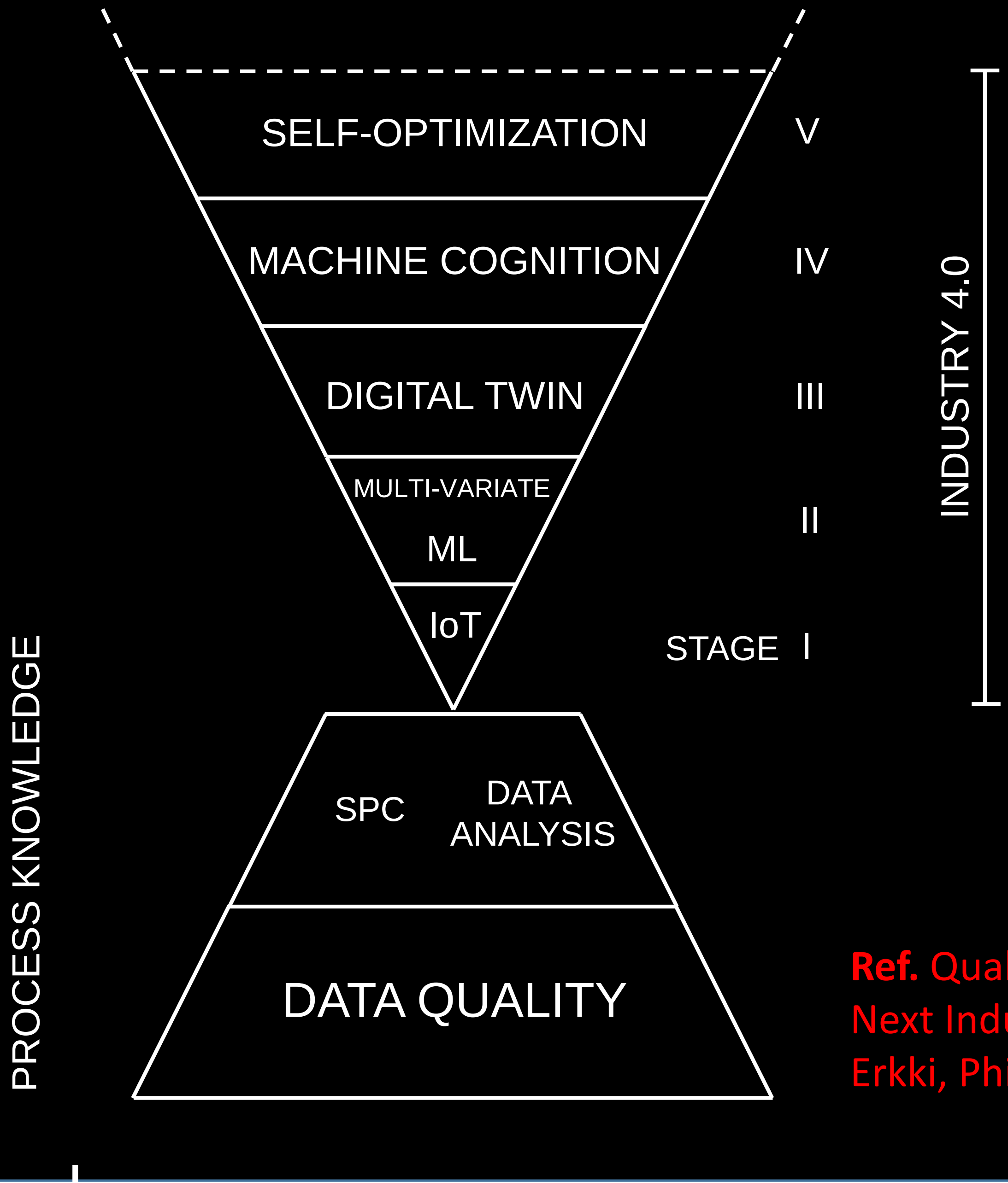
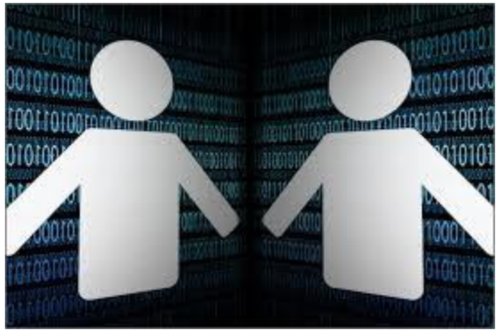
Process knowledge vs. Industry 4.0



Ref. Quality Data Management in the Next Industrial Revolution, Robert Erkki, Philip Johnsson, 2018, LTU

Digital twin



- The **first practical definition of a digital twin originated from NASA in an attempt to improve physical-model simulation of spacecraft in 2010**.[1]
- Digital twins are the result of continual improvement in the creation of product design and engineering activities. **Product drawings and engineering specifications** have progressed from **handmade drafting to computer-aided drafting/computer-aided design to model-based systems engineering**.

In Manufacturing industry

- The physical manufacturing objects are virtualized and represented **as digital twin models (avatars) seamlessly and closely integrated in both the physical and cyber spaces**. Physical objects and twin models interact in a mutually beneficial manner. (ref. Wikipedia)

Towards Digital Twins (Chalmers)

Industrial competition-motivation
- quality
- factory throughput
- flexibility
- individualization
- sustainability

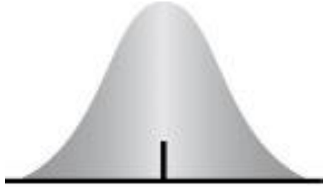
Enablers-tools
- faster optimization algorithms
- increased computer power
- increased amount of available data
- increased connectivity

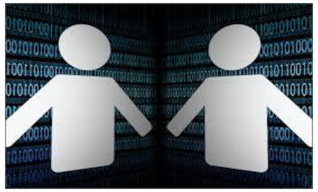
Digital Twins-idea
- **using real-time data**
- **enable real-time control & optimization**
- from mass production to individualized production

Digital twin definition based on ***W. Kritzinger et al., "Digital Twin in manufacturing: A categorical literature review and classification," IFAC-PapersOnLine, vol. 51, no. 11, pp. 1016–1022, 2018, doi: 10.1016/j.ifacol.2018.08.474.***

Digital Twin for Geometry Assurance (Chalmers)

- A digital product description is nominal
- A real product is never nominal (includes variation)
- The manufacturing process adds variation to the final product
- A Digital Twin of the physical system should include impact from manufacturing





Part variation from stamping

Variation from assembly

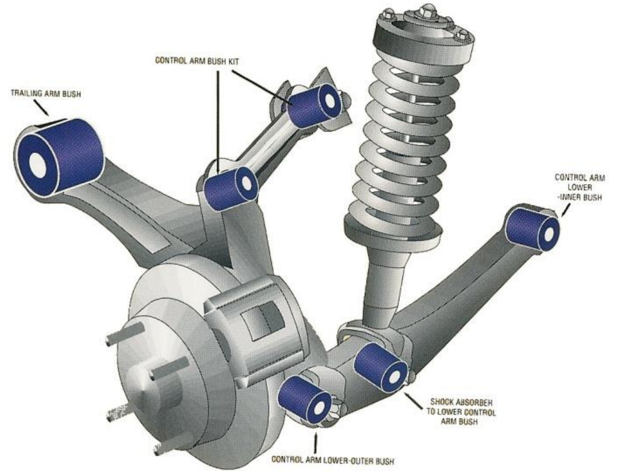
Variation from joining

Variation in final product

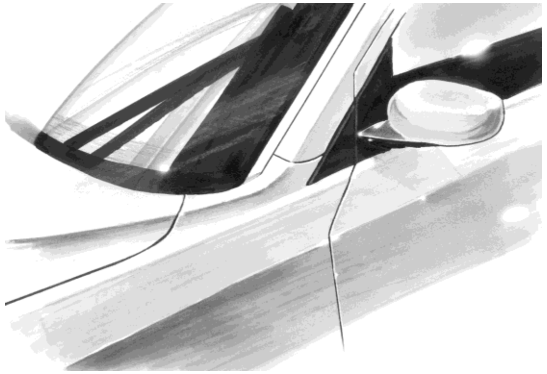
Geometrical Variation

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

Assembly



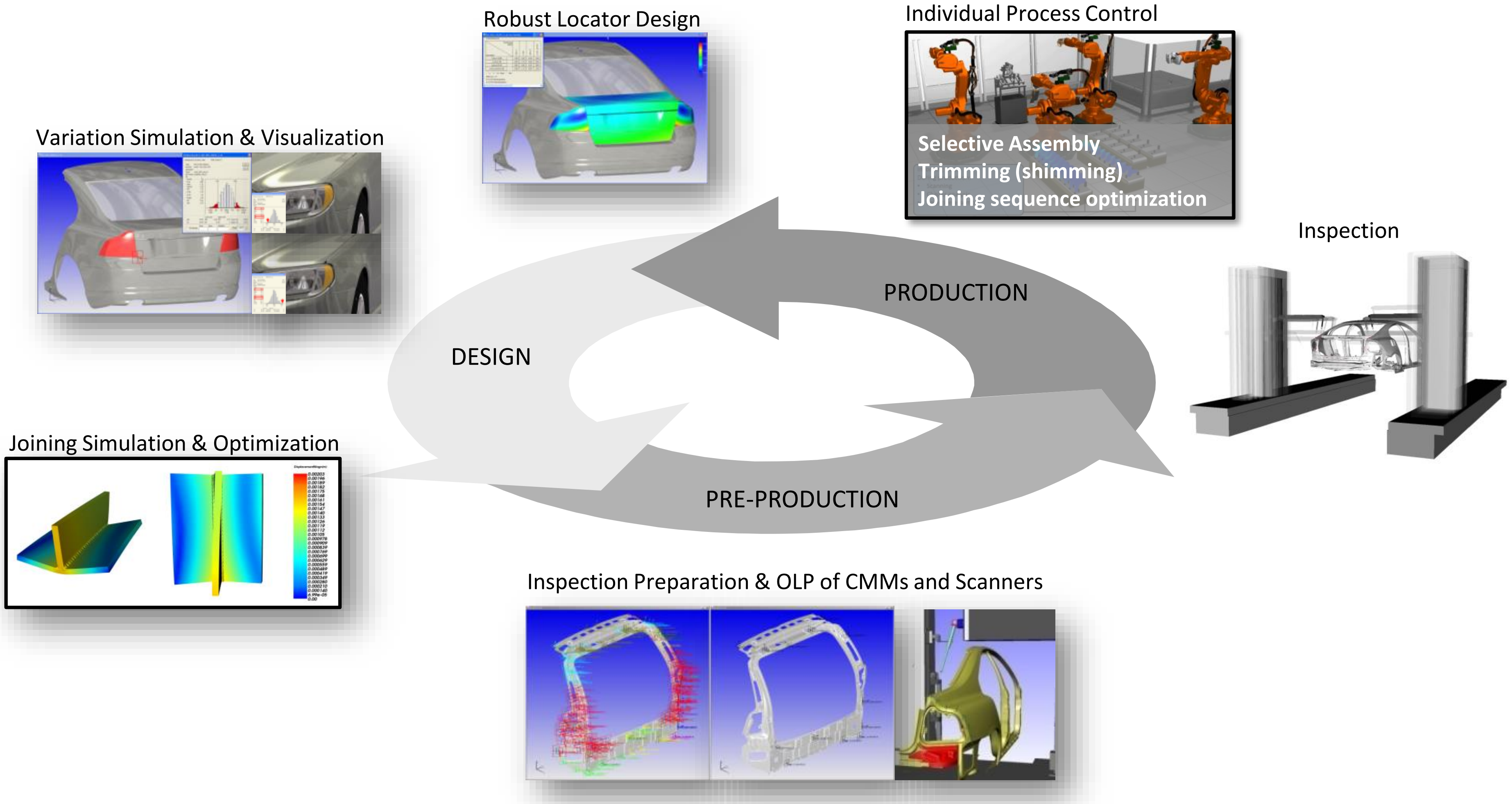
Function



Perceived Quality

RD&T Geometry Assurance Toolbox

- minimizing the effect of geometrical variation



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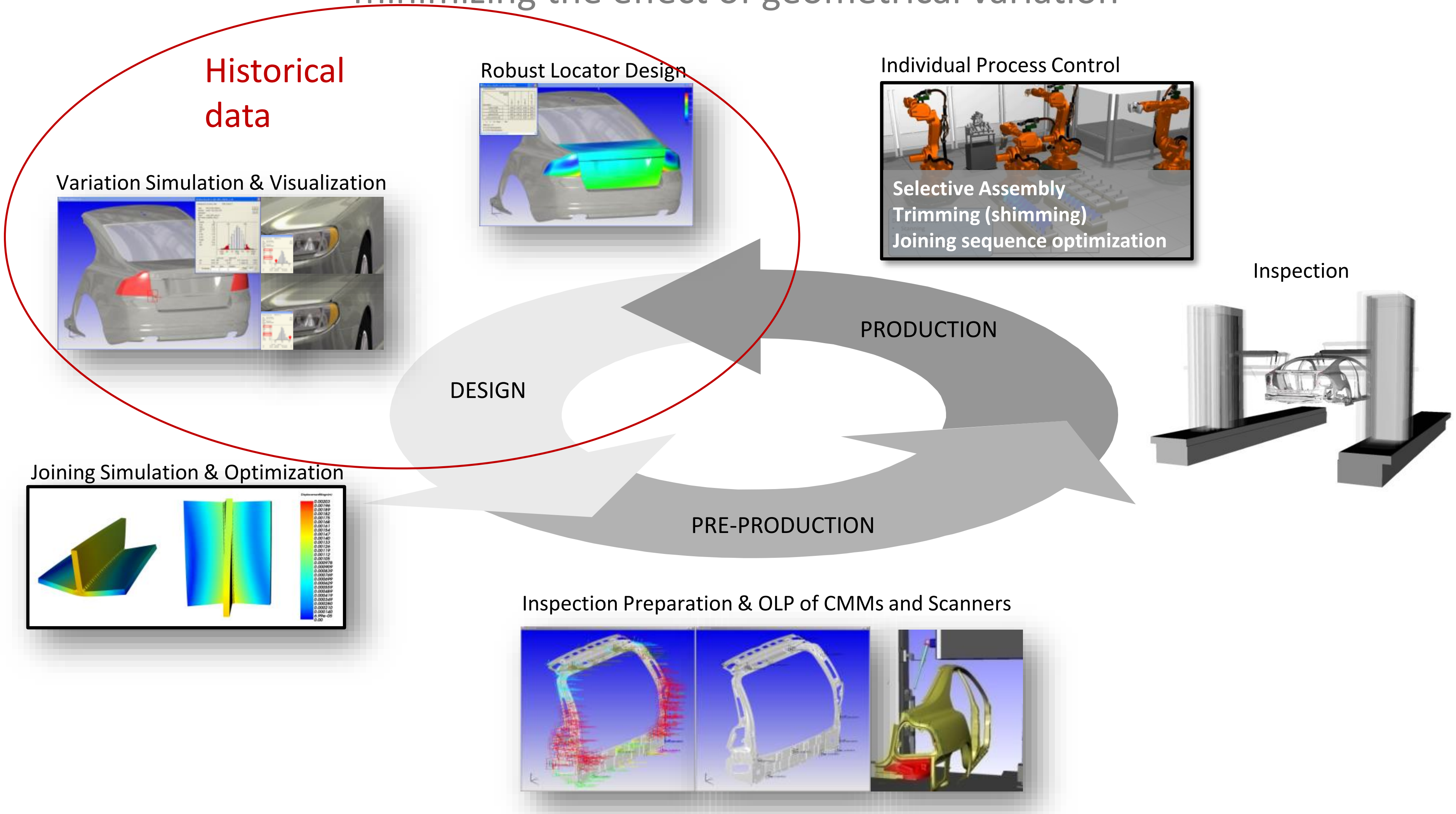
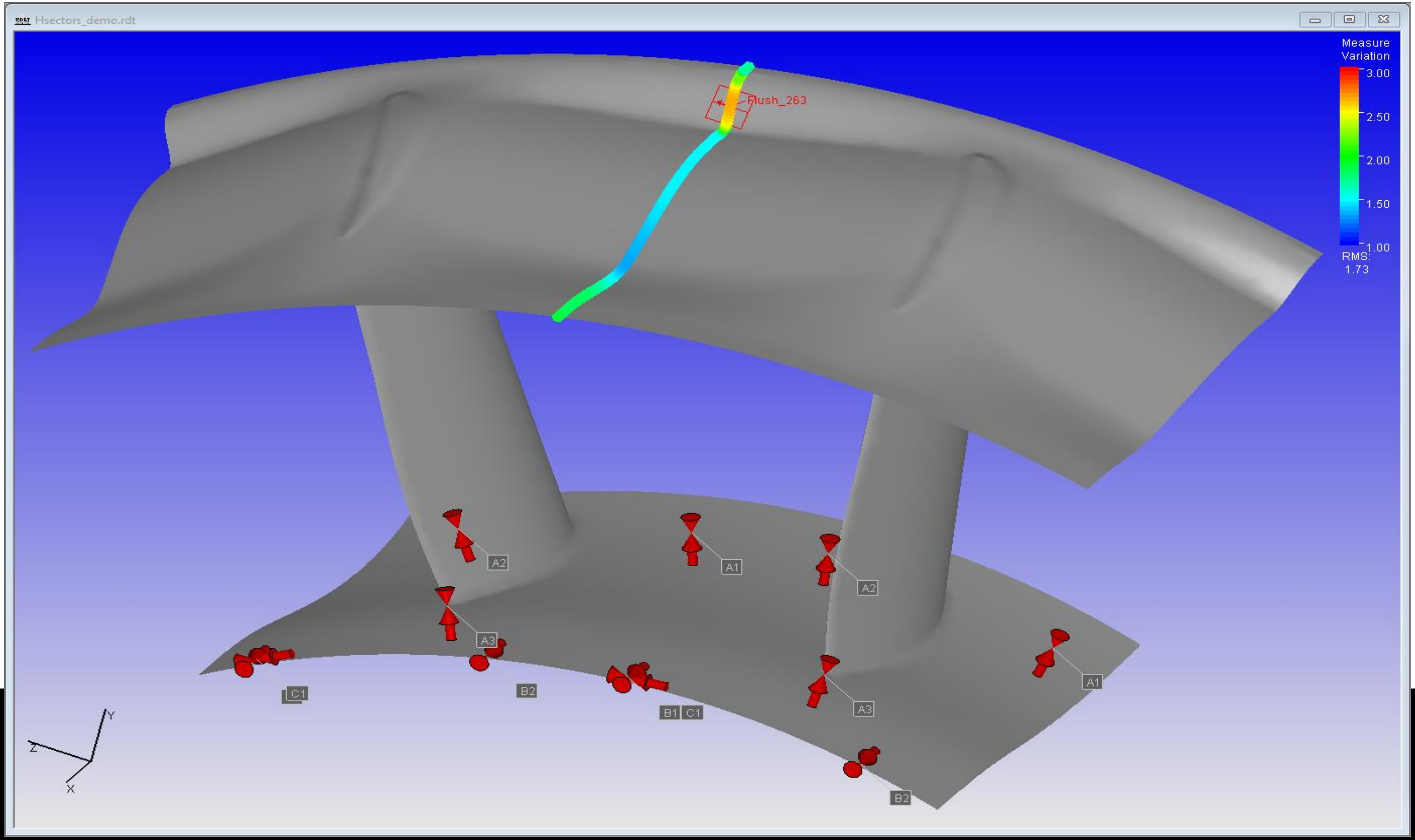
Variation simulation in the design phase

RD&T Geometry Assurance Toolbox

- minimizing the effect of geometrical variation

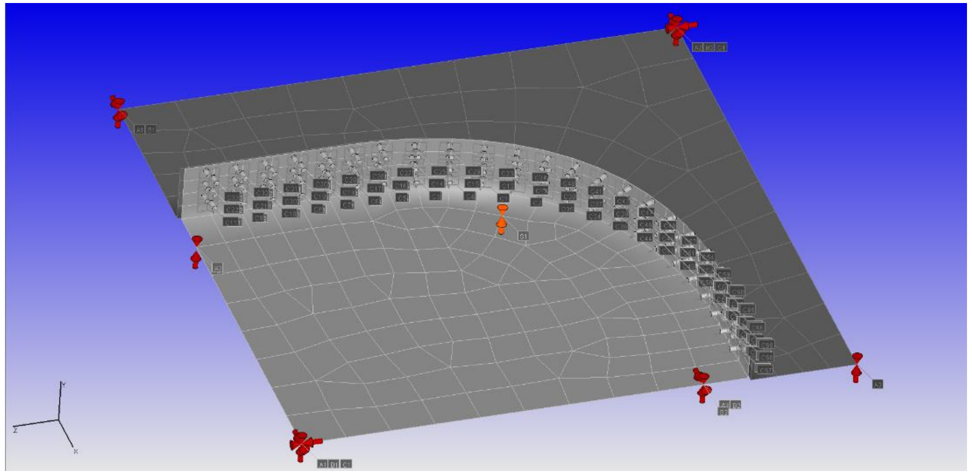


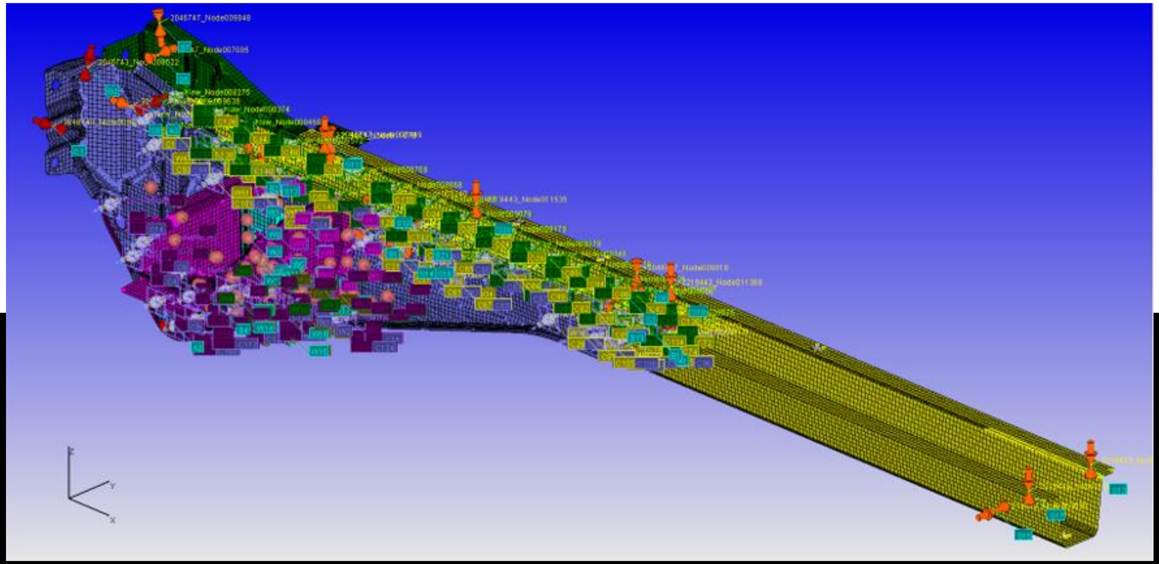
RD&T Statistical Variation Simulation

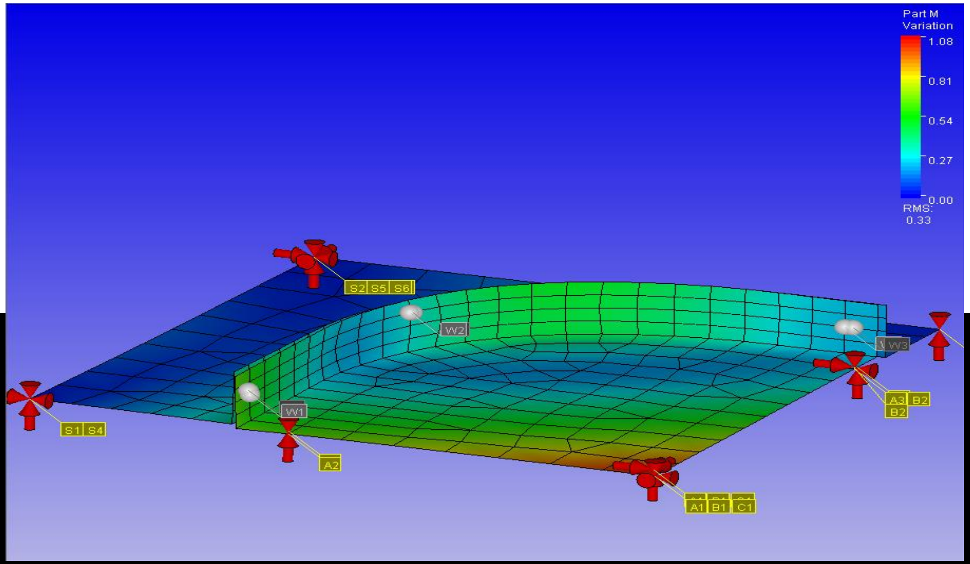


RD&T Non-rigid variation simulation

- *FEA meshes as representations of part geometries*
- *over-constrained locating schemes*
- *contact modelling*
- *spot weld points and*
- *spot weld (joining) sequences*
- *statistical variation simulation*



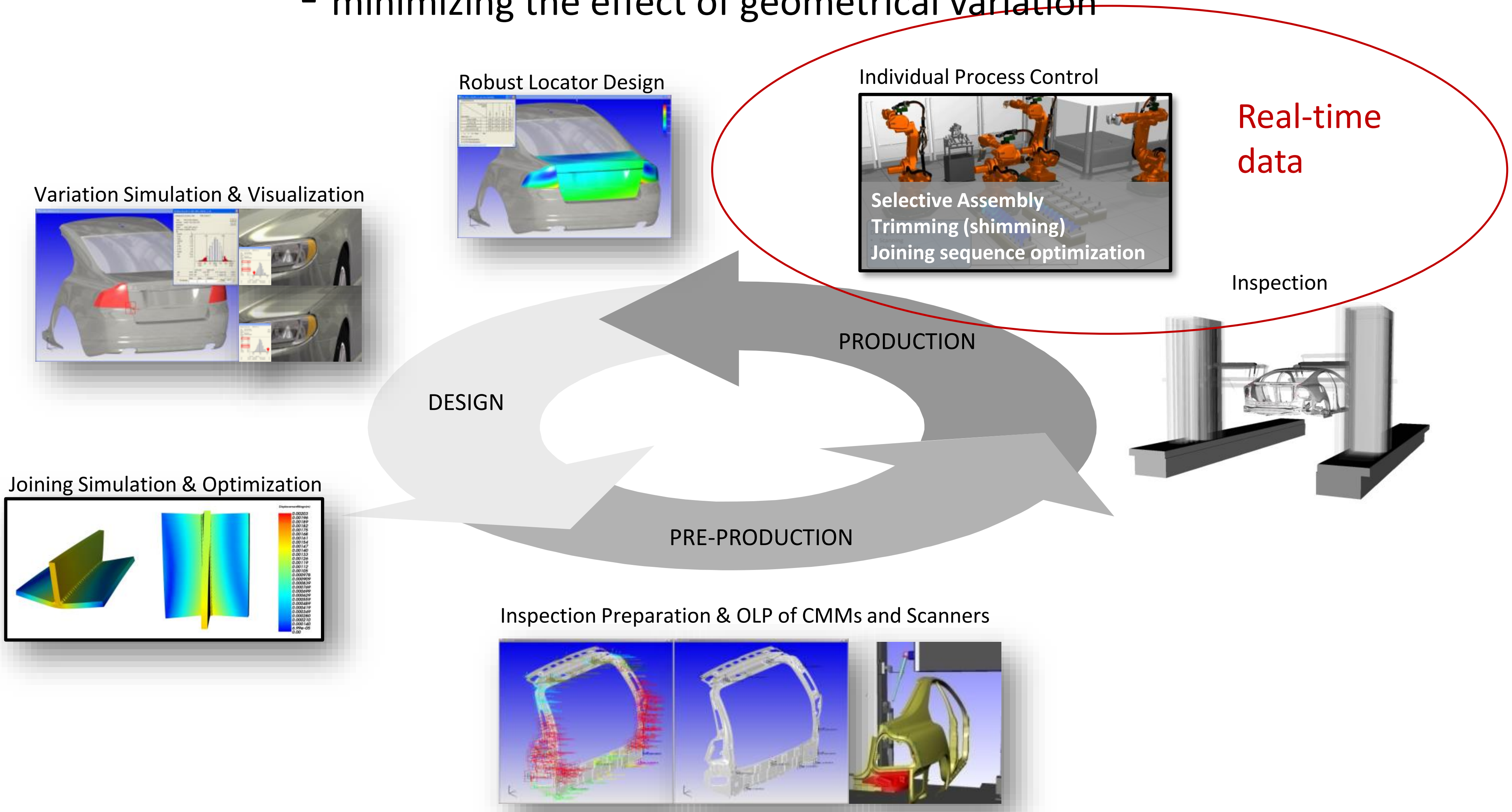




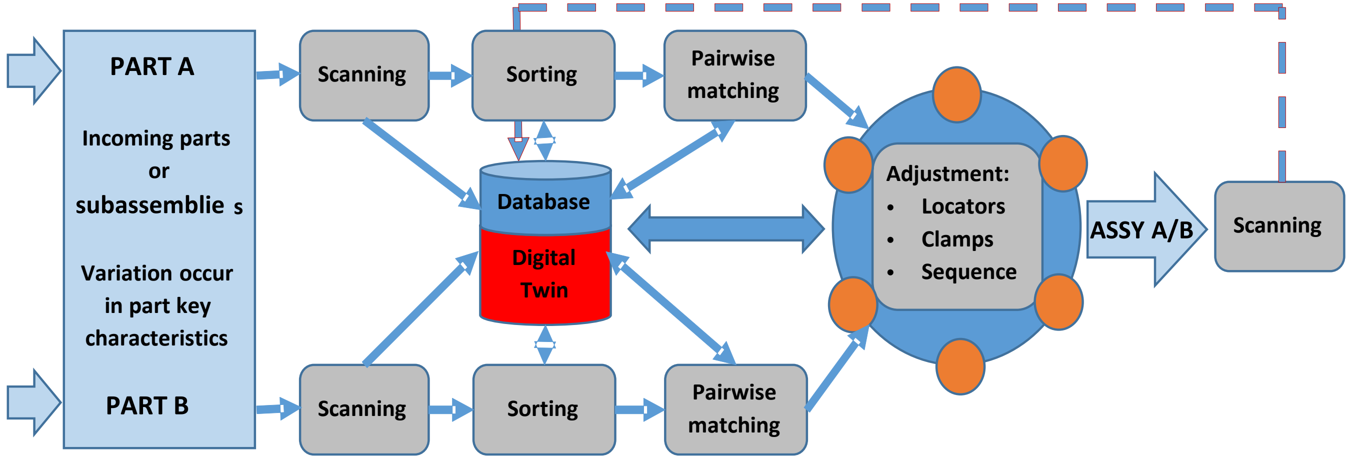
Variation simulation in the production phase

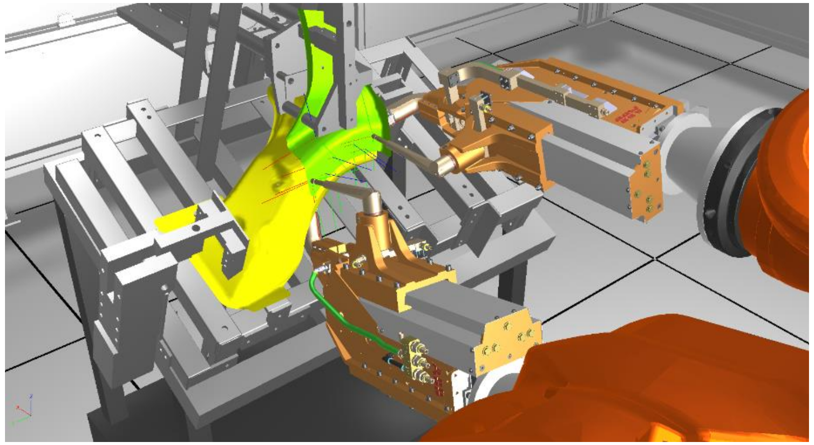
RD&T Geometry Assurance Toolbox

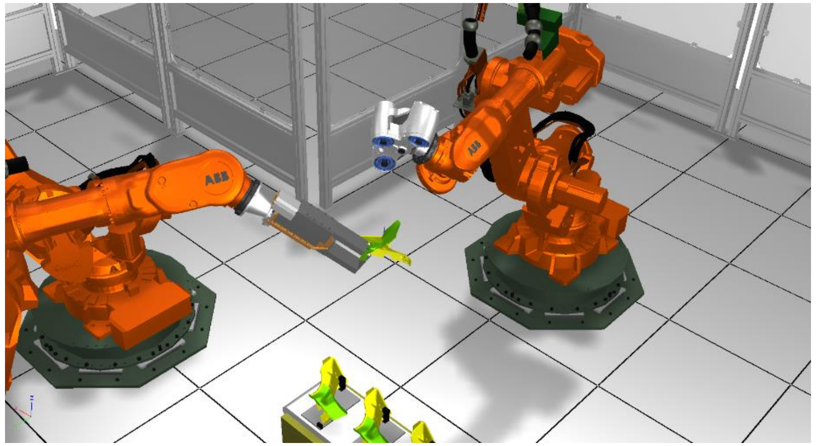
- minimizing the effect of geometrical variation



What if scan data of individual parts were available in-line?

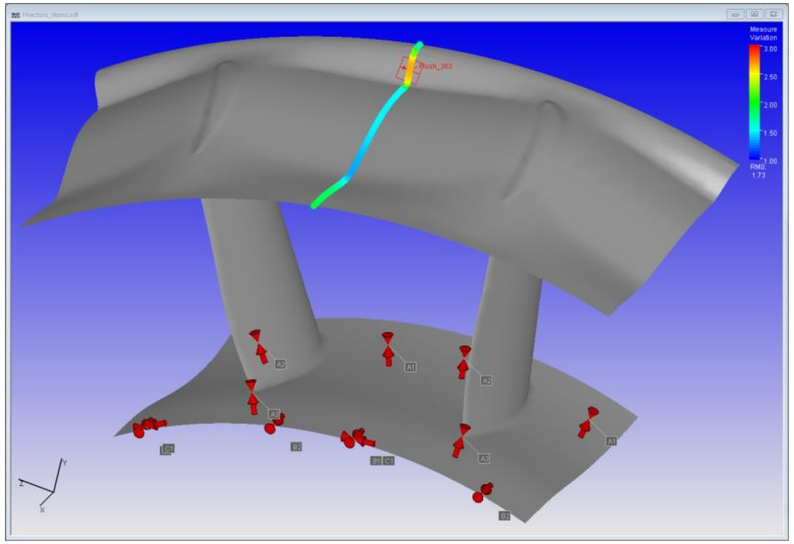




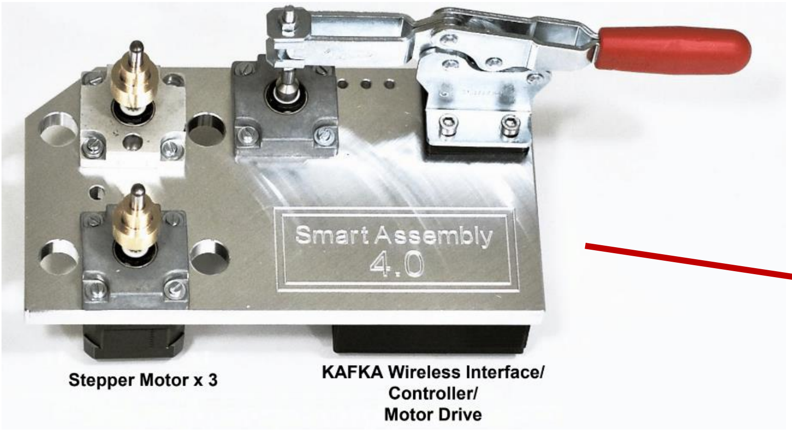


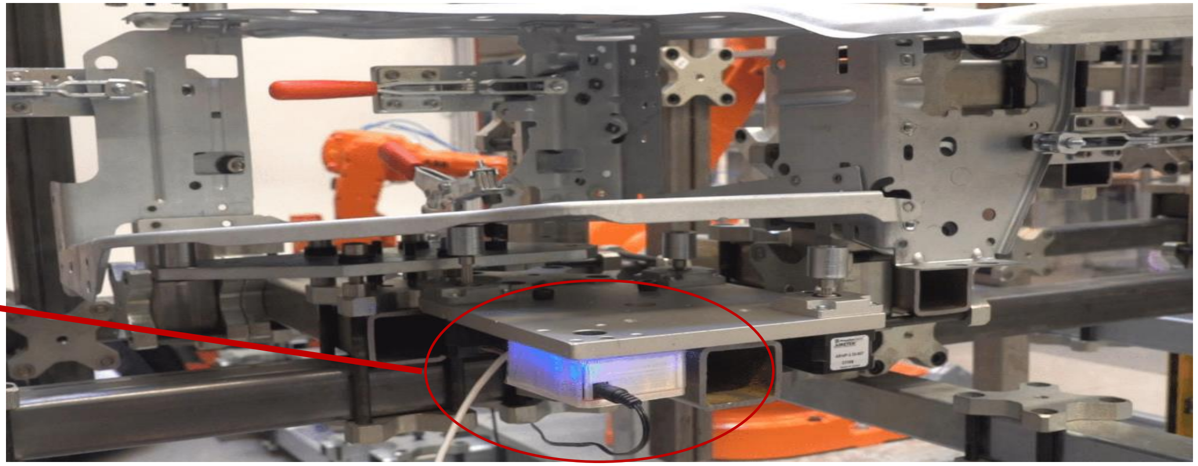
1. Selective Assembly
2. **Locator trimming (shimming) Focus GKN**
3. Weld sequence optimization

2. Locator trimming (shimming)



Form errors on individual parts are compensated by adjusting the position of the locators (for batches or for individual assemblies).

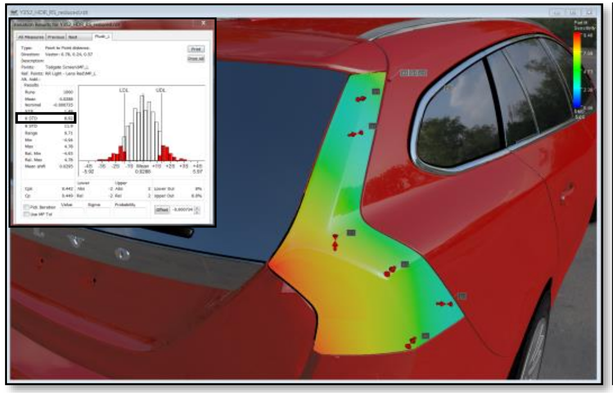


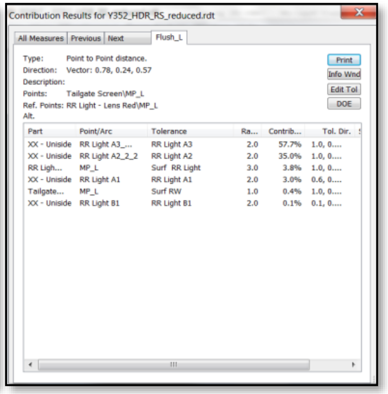


Summary - Chalmers

Digital Twins for Geometry Assurance

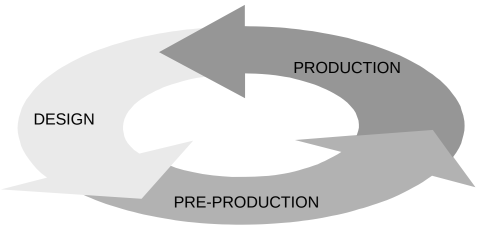
- Increased efficiency and accuracy in modelling, simulation and optimization
- Increased amount of data, bandwidth, computer power and connectivity between systems
- Real-time control & optimization
- ***Should include variation from manufacturing***





The Design Phase (historical data)

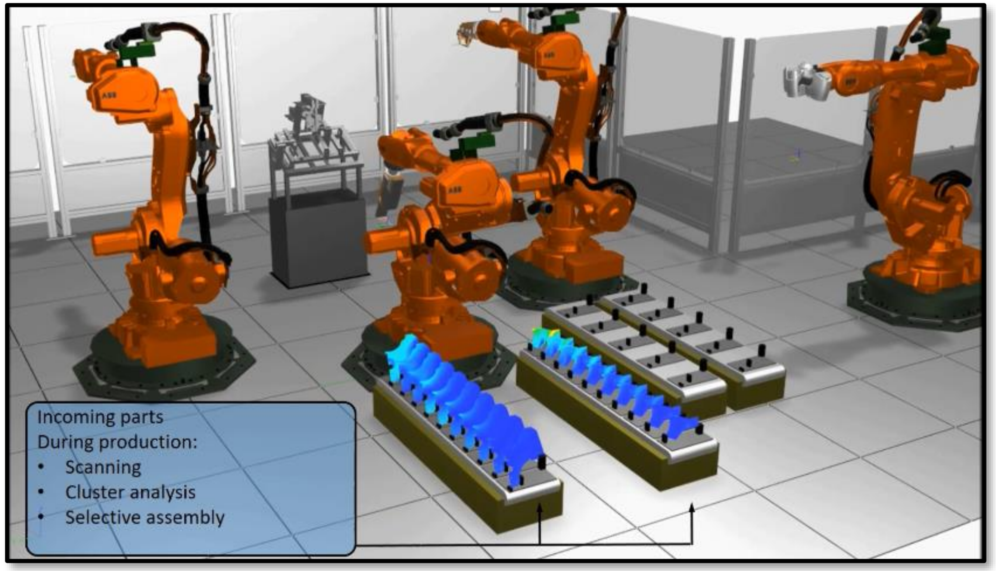
1. Stability Analysis
2. Variation Simulation
3. Contribution Analysis



The Production Phase (real-time data)

1. Selective Assembly
2. **Locator trimming (shimming)**
3. Weld sequence optimization

>50% reduced variation



Söderberg, R., Wärmefjord, K., Carlson, J. S., Lindkvist, L., 2017, Toward a Digital Twin for realtime geometry assurance in individualized production, CIRP Annals-Manufacturing Technology.

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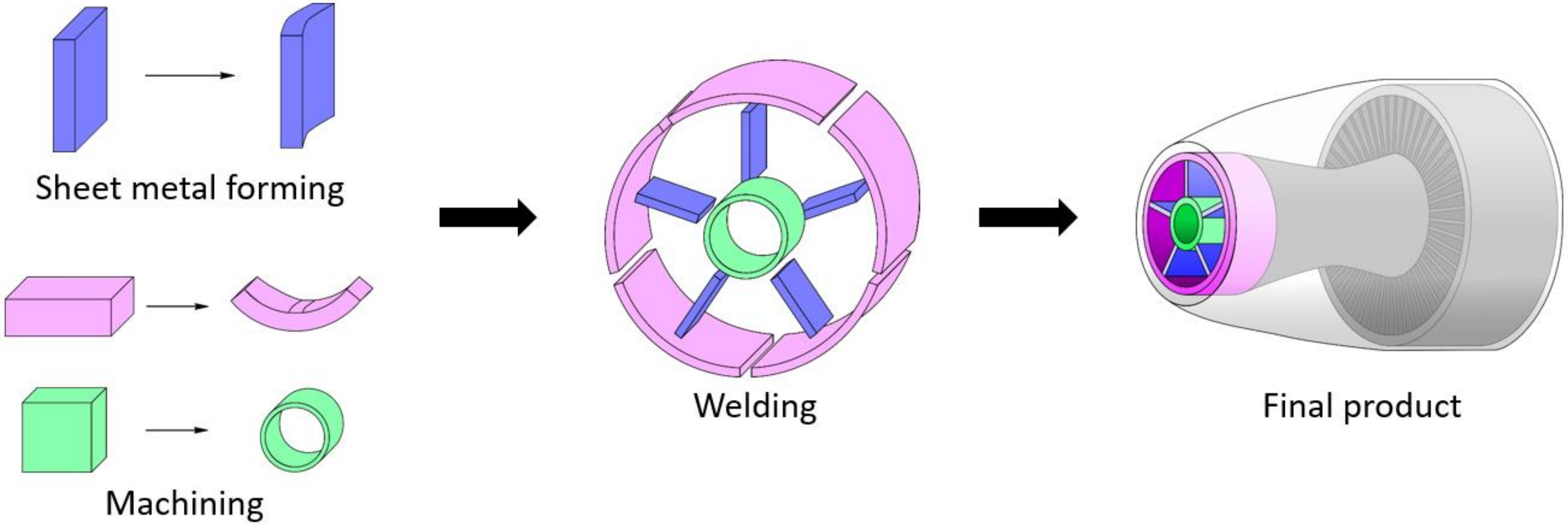
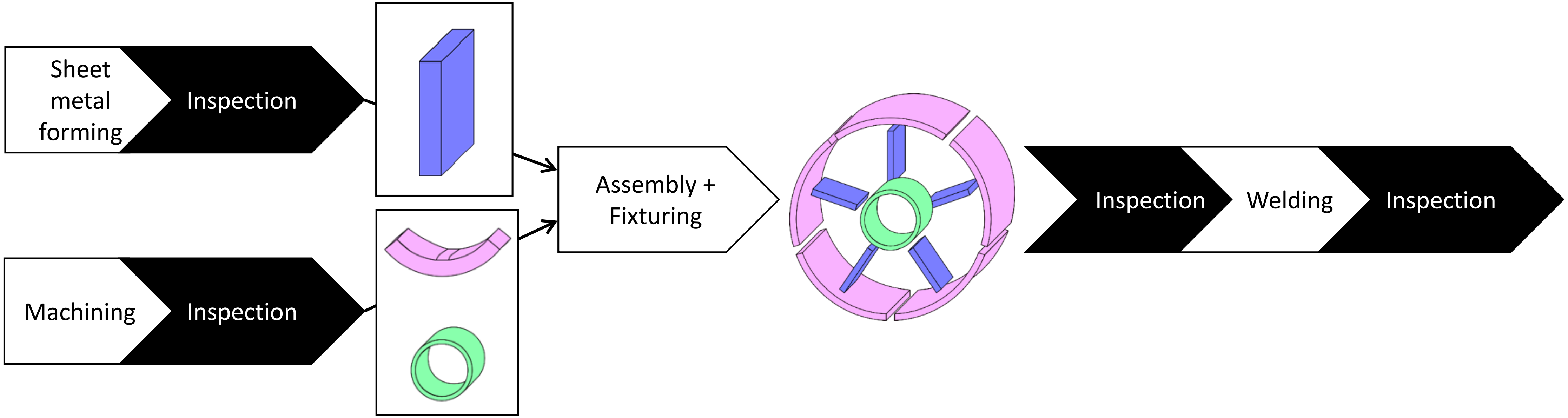
GKN case:
Geometrical variation in fabricated components

- **Fabrication** is a manufacturing method where an assembly of smaller parts are joined into a final product
- Compared to the traditional approach of starting with a large casting and removing material, fabrication provides flexibility for choosing how each part is made and from what material
- Fabrication can be challenging when it comes to **geometry assurance**, since each part provides a **unique amount of geometrical variation** to the final component, increasing the complexity of the process
- **How can we leverage the possibilities of data collection and simulation to increase the geometrical quality of fabricated components?**



Digital twin for individualized manufacturing

- During manufacturing, it is possible to **inspect and measure the parts**
- This is creating an opportunity for a **digital twin**, an emerging technology that works by creating a **virtual representation of a physical process**



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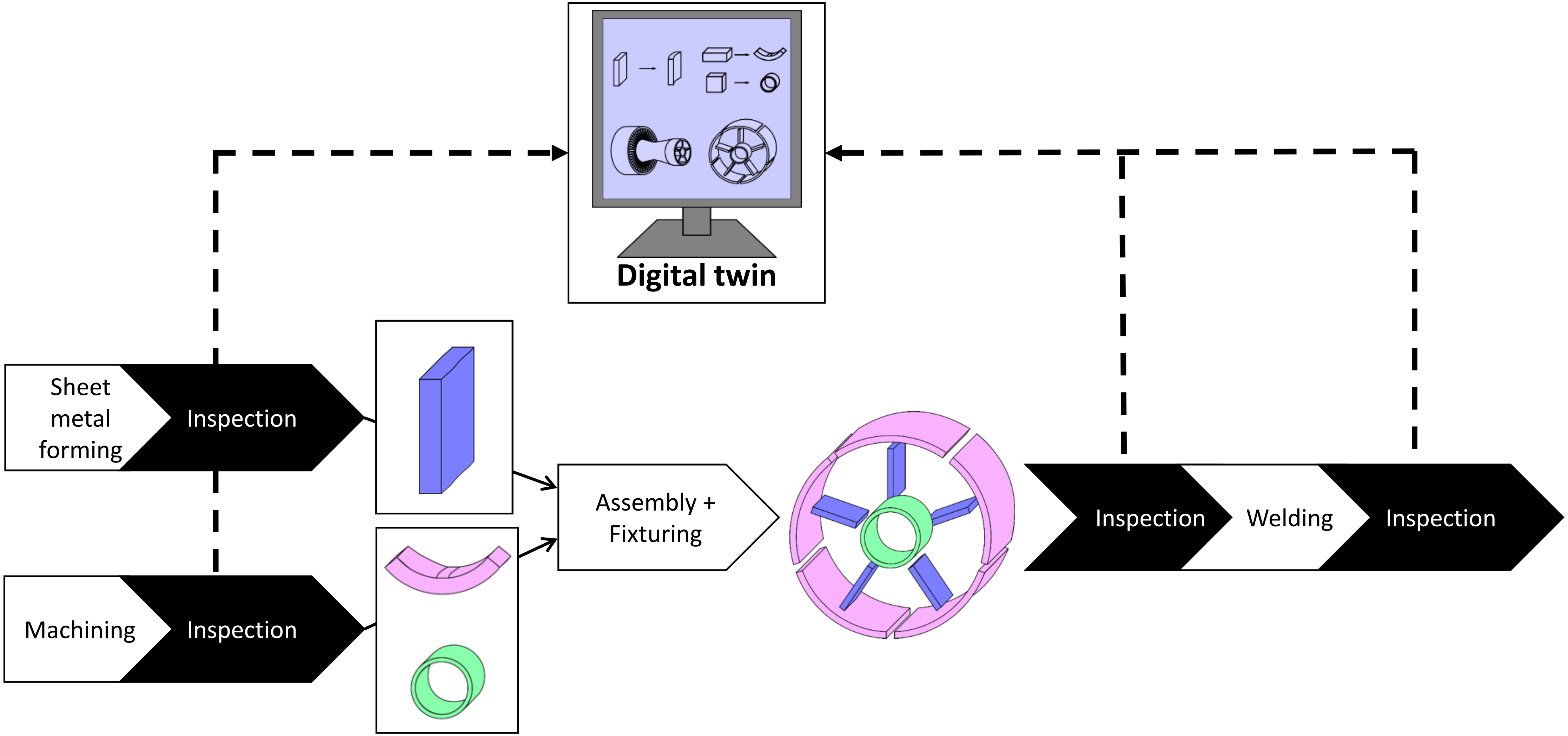
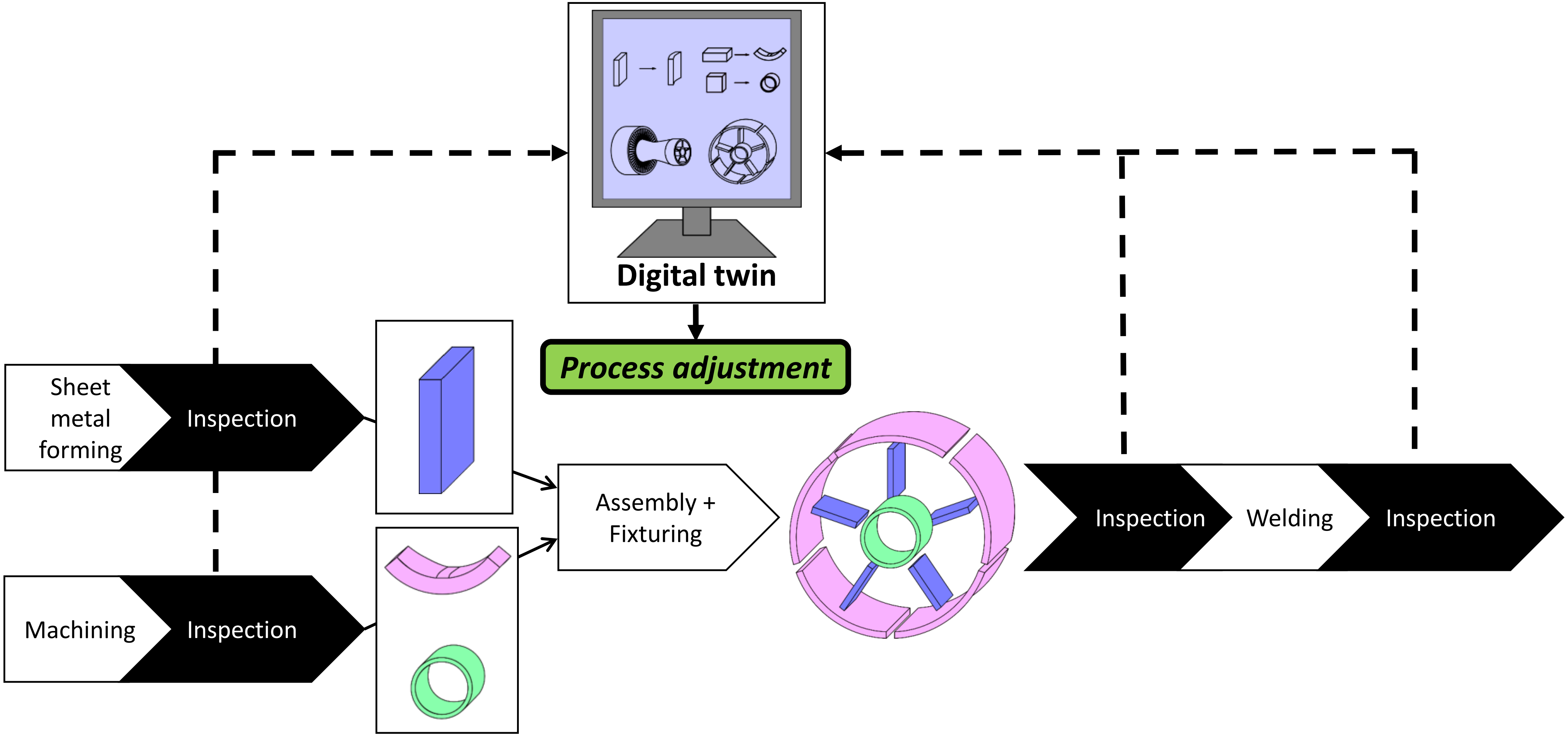
Digital twin for individualized manufacturing

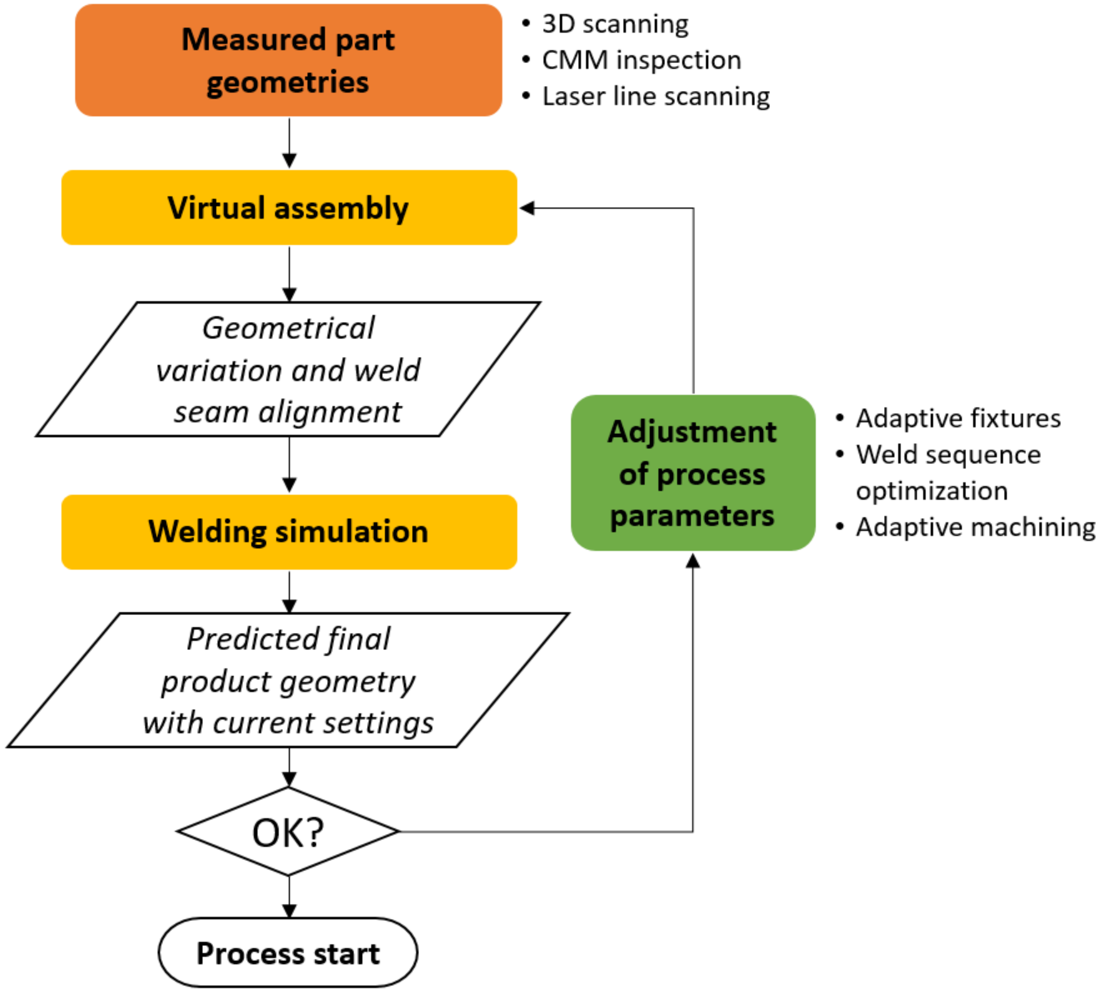


Digital twin for individualized manufacturing



Digital twin for individualized manufacturing: Proposed functionality

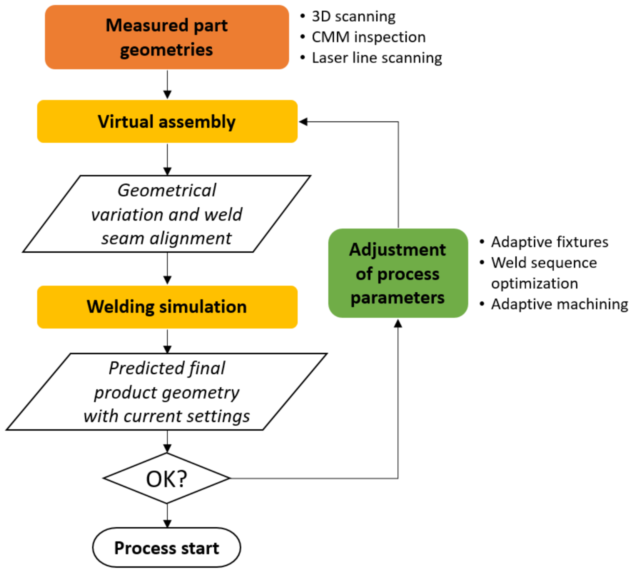
- The digital twin for manufacturing is proposed as an **analysis loop** that takes **measurement data** as input and predicts the results based on specific **process parameters**
- The loop will run through multiple iterations in order to find the process parameters that result in the least amount of **geometrical variation** in the **final product**



Digital twin for individualized manufacturing: Basic requirements

MEASUREMENT → **ANALYSIS** → **ADJUSTMENT**

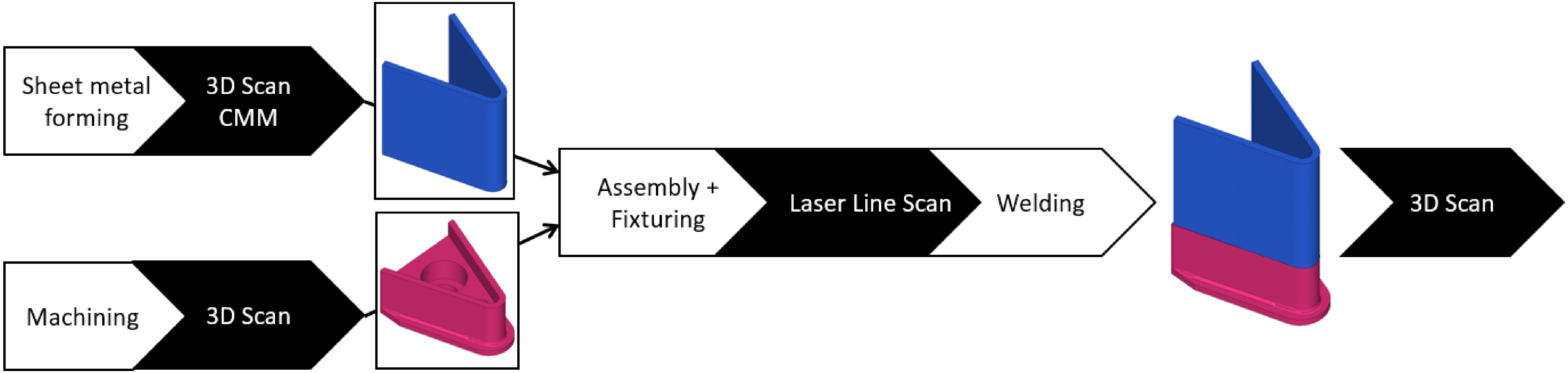
- To complete the proposed analysis loop, **three steps** are required:
- **Measurement** to collect data from the parts
- **Analysis** to predict how the measured parts will behave in the manufacturing process
- **Adjustment** of the process that can compensate and reduce the predicted variation



Ongoing work: Test manufacturing with extensive data collection

MEASUREMENT | **ANALYSIS** | **ADJUSTMENT**

- A manufacturing process has been set up in a lab environment
- The process has basic similarities to a real fabrication process at GKN
- After each step, data is being collected through different measurements



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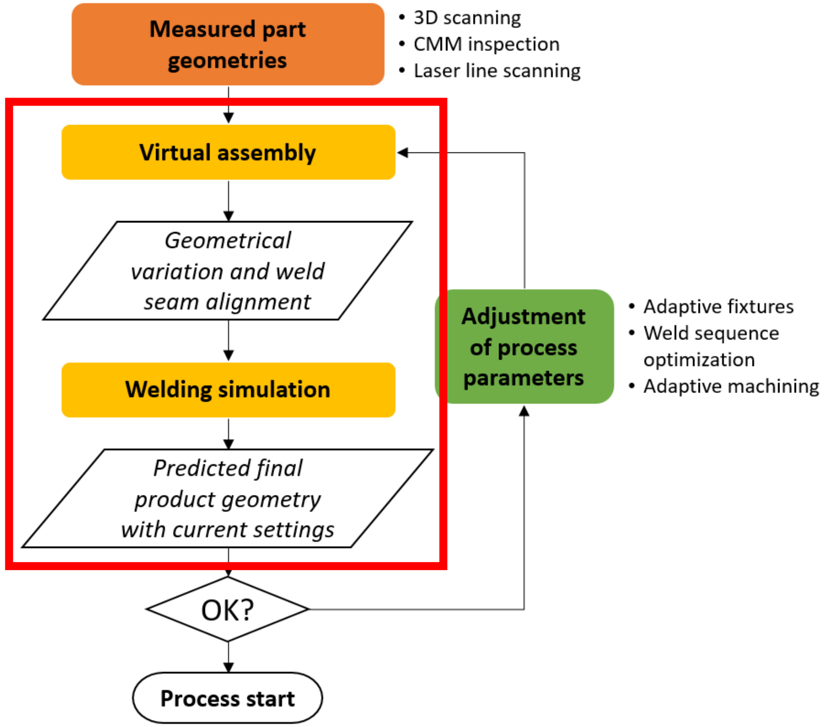
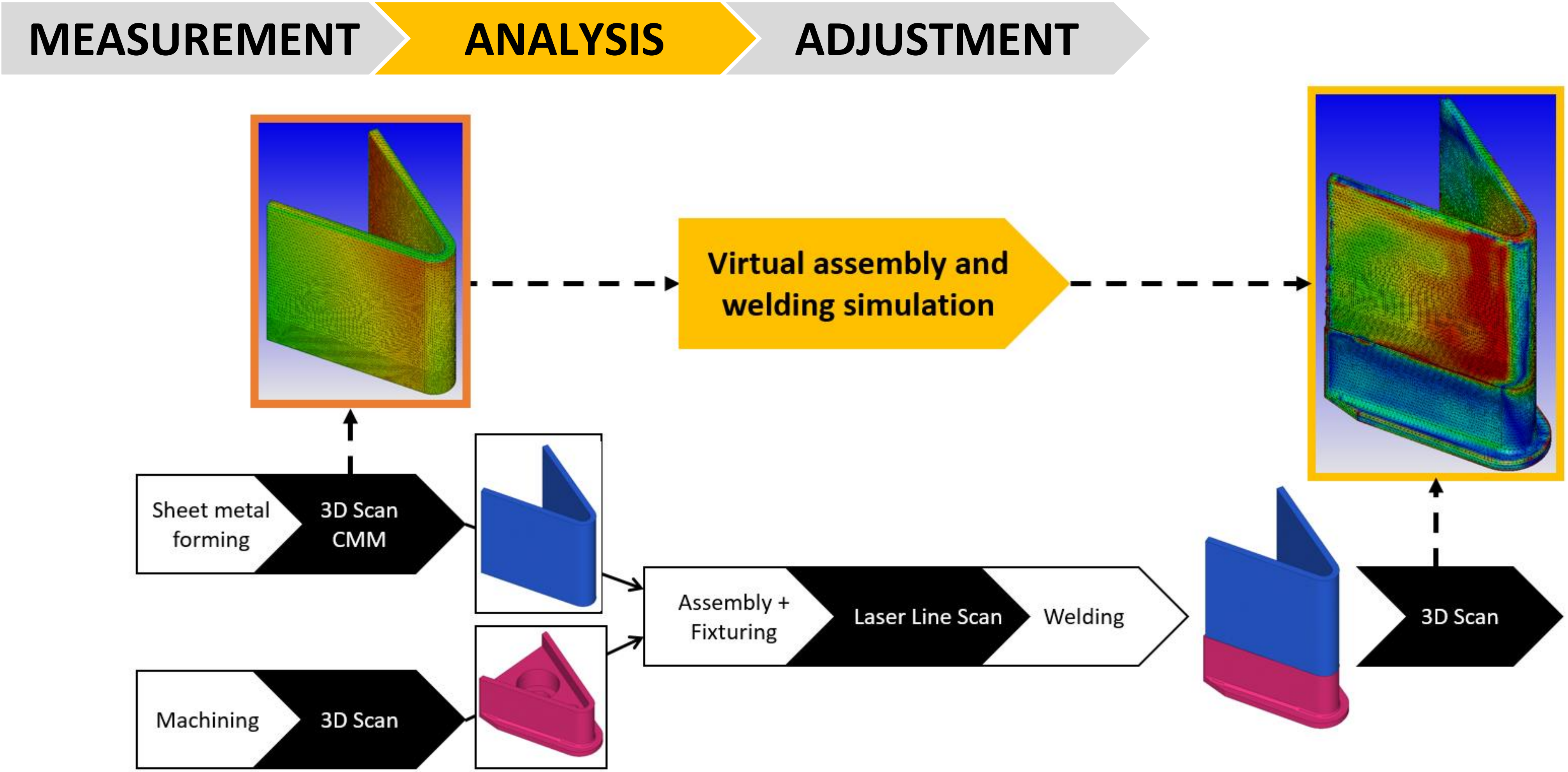
Ongoing work: Virtual assembly and welding simulation using the RD&T software

MEASUREMENT | **ANALYSIS** | **ADJUSTMENT**

- The **RD&T software** is used for analyzing the measurement data and predicting the outcome of the process
- RD&T **combines variation simulation and welding simulation**, making it possible to create a virtual assembly and then simulate the weld process
- The **point cloud** produced by the 3D scan of the sheet metal part is positioned with an appropriate target system, and is then **used to warp a nominal mesh** so that it mimics the real part geometry
- The **non-nominal mesh** is then used in a **welding simulation** to predict how this unique part is going to deform during welding
- **The goal is to achieve an accurate prediction of the real welding outcome**, while keeping the simulation time **fast** enough to allow for multiple iterations with different process parameters



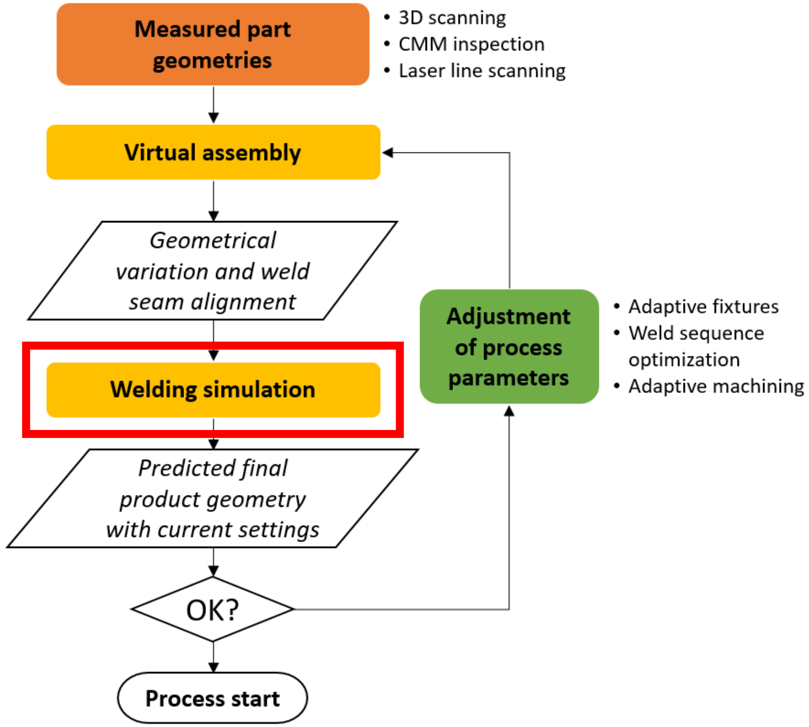
Ongoing work: Virtual assembly and welding simulation using the RD&T software



Ongoing work: Virtual assembly and welding simulation using the RD&T software

MEASUREMENT ANALYSIS ADJUSTMENT

- Results were analyzed to investigate whether the welding simulation can be done by simulating with a nominal mesh and then adding the deformation to a scanned part
- Results show that **the welding deformation is coupled to the geometrical variation of the part**
- This means that welding simulation needs to be an active part of the analysis loop in order to avoid loss of accuracy



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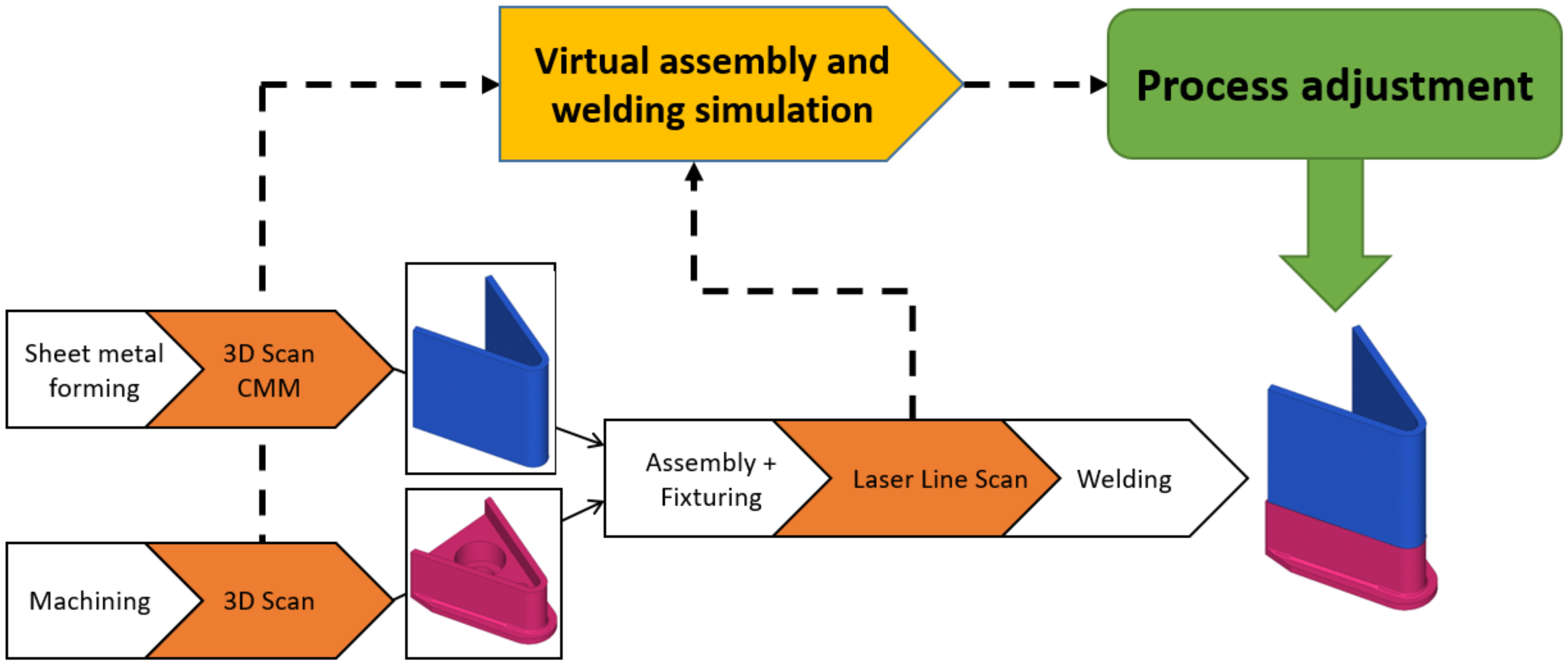
Future work: Test manufacturing with adaptive process adjustment

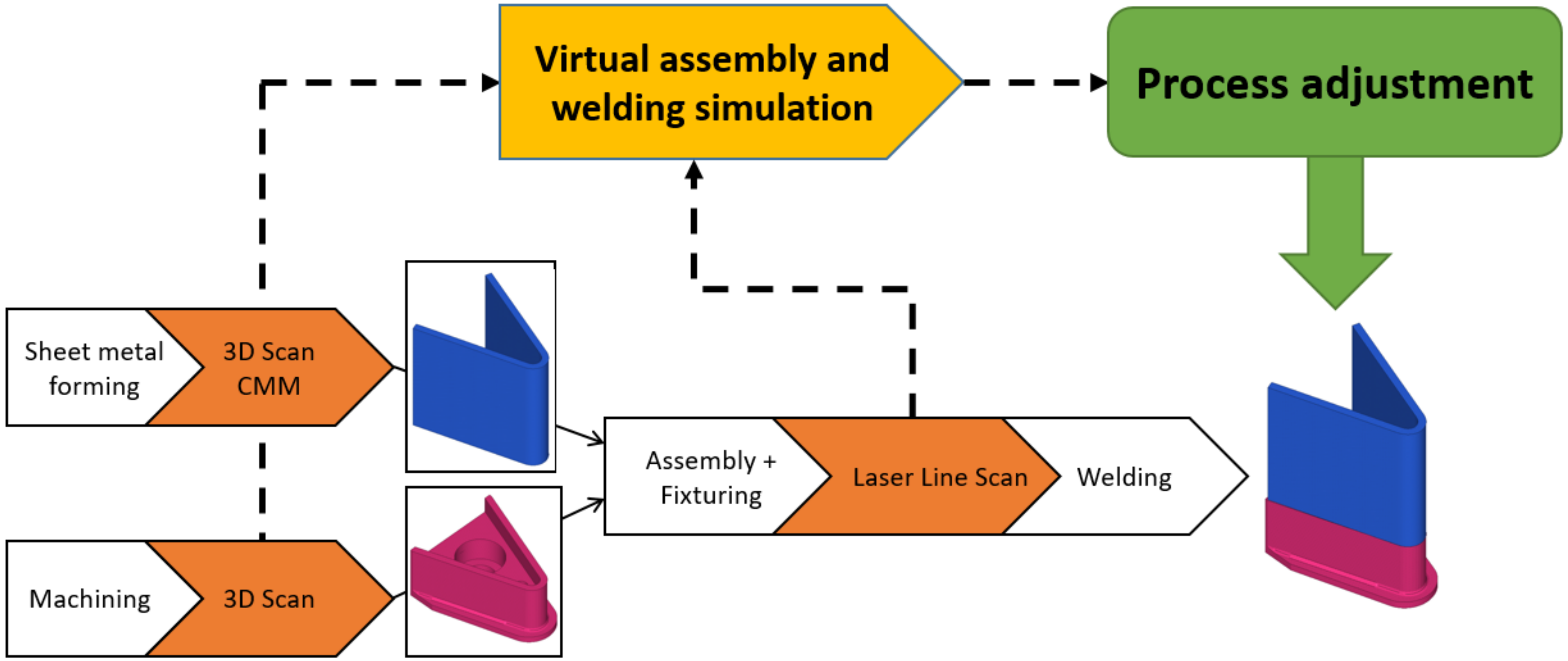
MEASUREMENT | **ANALYSIS** | **ADJUSTMENT**

- Once accurate prediction is achieved, the result needs to be brought back into the physical process, to **compensate** the predicted non-conformance
- This could be done by adaptive machining or by adjusting the locators in the fixture



Conclusion-GKN

- Digital twins for manufacturing is an opportunity to make better use of measurement data to improve geometrical quality
- Work is ongoing to demonstrate a functional digital twin in a lab environment, long term goal is full implementation in GKN fabrication processes



THANKS FOR LISTENING

QUESTIONS?

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