Vision:
Qualification of Additive Manufacturing Components Based on Sensor Data Acquired During Fabrication

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How the vision evolved

My research group has been central in a series of H2020 projects addressing with the role of addressing Additive Manufacturing from the digital perspective:

- CAxMan (2014-2018, Coordinator) Computer Aided Technologies for Additive Manufacturing. https://www.caxman.eu/
- Change2Twin (2020-2024, Coordinator) Digital twins in manufacturing, cascading funding for SMEs (Open calls for experiments). Establishing a European community for digital twins in Manufacturing. https://www.change2twin.eu/
- PULSATE (2020-2024, partner) Laser Based and Advanced Additive Manufacturing, cascading funding for SME (Open calls for experiments). Building a European community within Laser based and Additive Manufacturing. https://www.pulsate.eu/

Need for digital warehouses and on demand manufacturing in the Energy Sector

- Equinor (Oil, natural gas, wind power) has spare part worth 2.8 Billion € in stock
  - Records show that only 15% of the spare parts are ever used
  - Annual cost to maintain the stock 15% of the stock value
- By gradually replacing physical warehouses with digital warehouses
  - Only parts needed are produce, thus lowering the CO2 footprint and use energy and feedstock
  - Reduce the capital used for physical warehouse
- Produce parts close to the place of use (e.g., at supply bases or on an offshore site), decentralize production combining subtractive and additive manufacturing
  - Shorten supply chains, and lead time

Material properties of produced parts

- The material properties of objects produced by additive manufacturing are significantly more complex than material properties resulting from subtractive manufacturing
  - Risk of high/significant (directional) anisotropies
  - Thermal tensions triggering shape distortions or cracks
- A strong need for qualification and certification of additive manufactured parts
  - Qualification is very expensive for one-of-the-kind or small production series
  - Lab base qualification have significant lead time and cost
  - Sensor based part qualification an alternative
- These challenges from the energy sector seems to be also relevant for the space sector

Lab based
verses sensor based qualification

Lab based

- Need to produce additional part for testing
- Shipping to the lab
- Capacity of lab
- Takes time and extra resources

Sensor based

- Sensor data acquired during fabrication, no extra part needed
- Data can be processed during or soon after fabrication
- Qualification directly after production
- Less resources used
- New technology needed

Some observation: CAD-AM workflow

- Design of the object interior
  - For lightweight designs: Cavities, voids and lattice structure
  - B-rep CAD is not suited, interior structures too complex
  - CAD going from B-rep (representation of surface) to V-rep (mathematical representation of volumes)
- What is actually printed is not the CAD-model. Example Powder Bed Fusion
  - The CAD-geometry is converted to STL (triangulation) or ASTM format (approximation)
  - The STL/ASTM model is sliced with planes, areas within are hatched with the laser
  - Print parameters determines what happens during printing: Anisotropies, porosity,…
- Printers are increasingly equipped with sensors
  - Images, thermal sensor,…
  - Trend: As printed model, print error detection

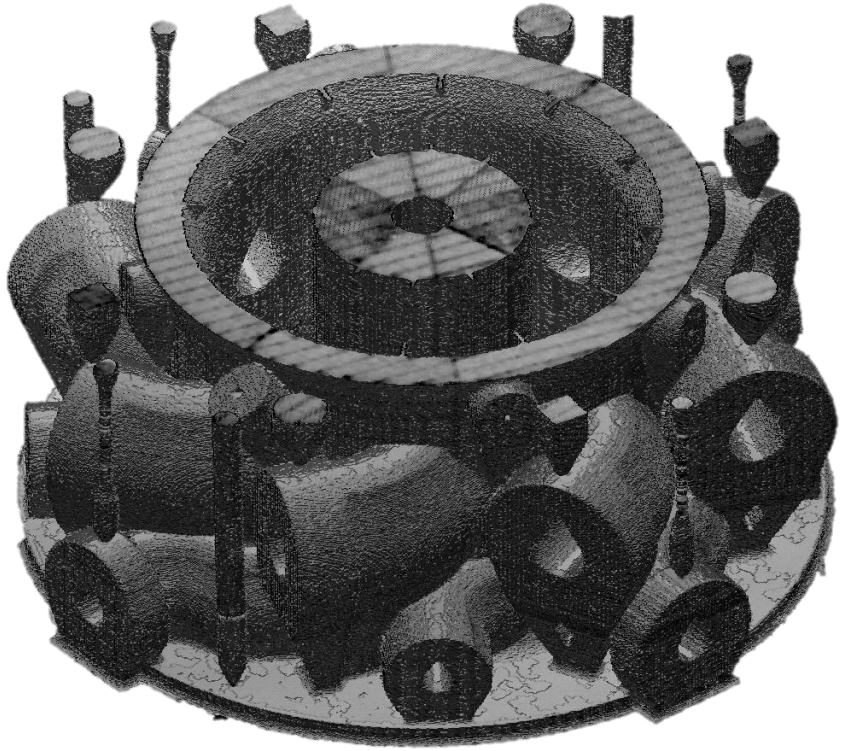
Change2Twin: Layered images to digital twin for additive manufacturing

What?

- Creating 'as-built' models from layered images that can be compared to 'as-designed' models

Why?

- Detect defects and/or deformations
- Support process engineers in controlling processes



*Data courtesy of Additive Industries

Work performed by Oliver Barrowclough, Sverre Briseid, Konstantinos Gavriil, Georg Muntingh (all SINTEF)

Change2Twin Pilot: Digital twins from layered data

Per layer image*

Format: PNG

Image processing

Artificial intelligence

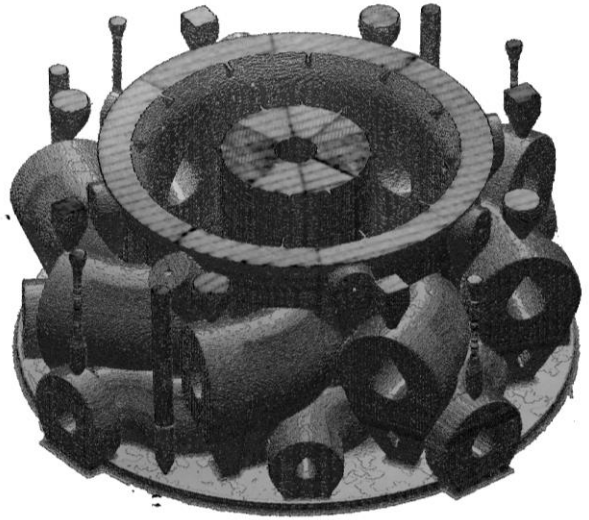
Per layer binary mask

Format: PNG

Voxel rendering

Marching cubes

3D



Format: NRRD (voxels)

*Data courtesy of Additive Industries

Pulsate : ADDINSPECT – Digital in-process NDT for Laser based powder AM

- PULSATE Experiment: ADDINSPECT (selected as one of the first 10 Technology Transfer Experiment)

  https://www.pulsate.eu/success-stories/addinspect/

- Lead company: www.amiquam.ch
- AIM of Experiment:
  - *To facilitate "in process" controlled layer by layer using eddy-current sensors for parts fabricated by laser-based powder Additive Manufacturing (L-PBF)*
  - *Eddy-current sensor looks beyond the top layer*

Pulsate : ADDINSPECT

Porosity measurements

- The porosity is a KPI of the LPBF process quality.
- The porosity can be measured from the AMiquam sensor response for all metals manufactured with LPBF.
- Absolute porosity of the part measured in situ with an accuracy of 0.1%.

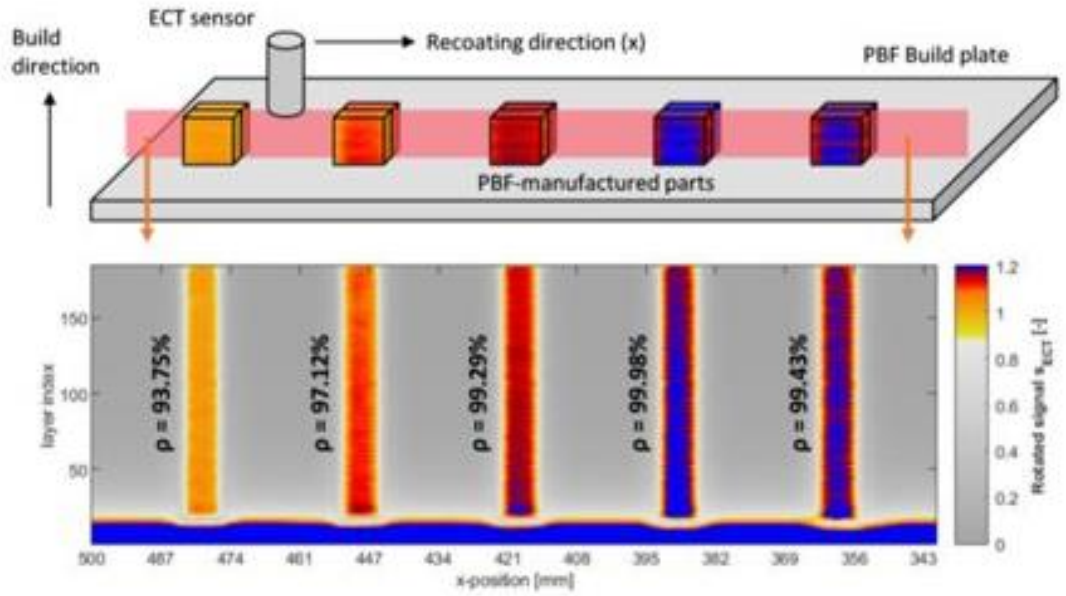


Image an information courtesy of amiquam.net

A network exists that want to pursue this vision

- We need the convergence between and further development of many competences and technologies. Some examples
  - Sensor: Layered images, thermal images, eddy current sensor data, other sensors,..
  - Digital technologies: Sensor data fusion, digital twins, data analysis, AI, simulation,…
  - Material characterization: Comparing results of lab based and sensor based material characterization
  - Additive manufacturing: Can sensor data be used to modify parameters during fabrication to improve quality?
- The vision is ambitious, so we try to address selected challenges through collaborative projects funded from different sources. E.g., HEU, National projects,….
  - Question: Is this vision of interest in the space sector?

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