



2ARMY

Automated Additive Repair and Manufacturing System

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2nd European Military Additive Manufacturing Symposium

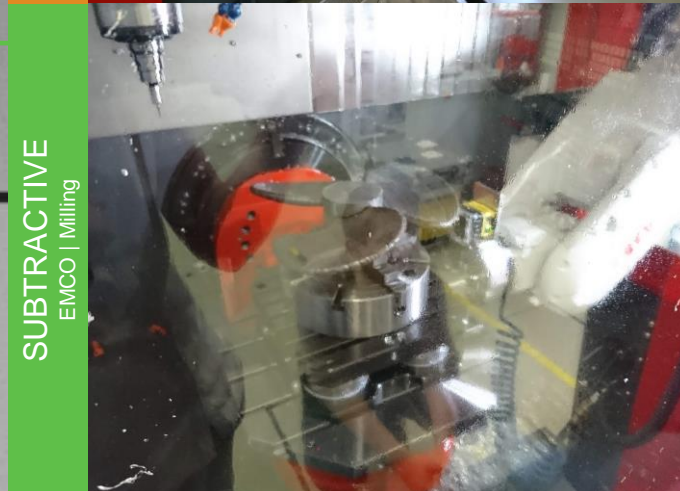
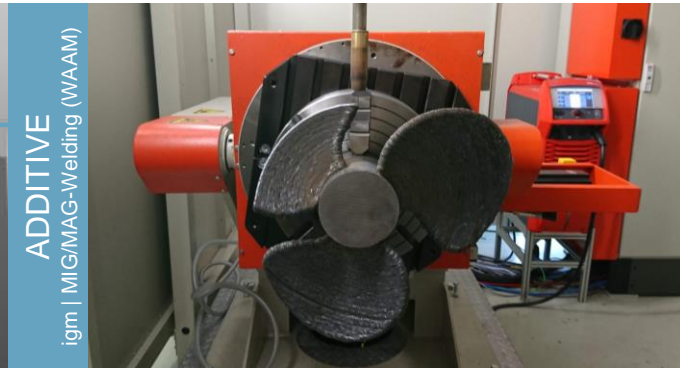
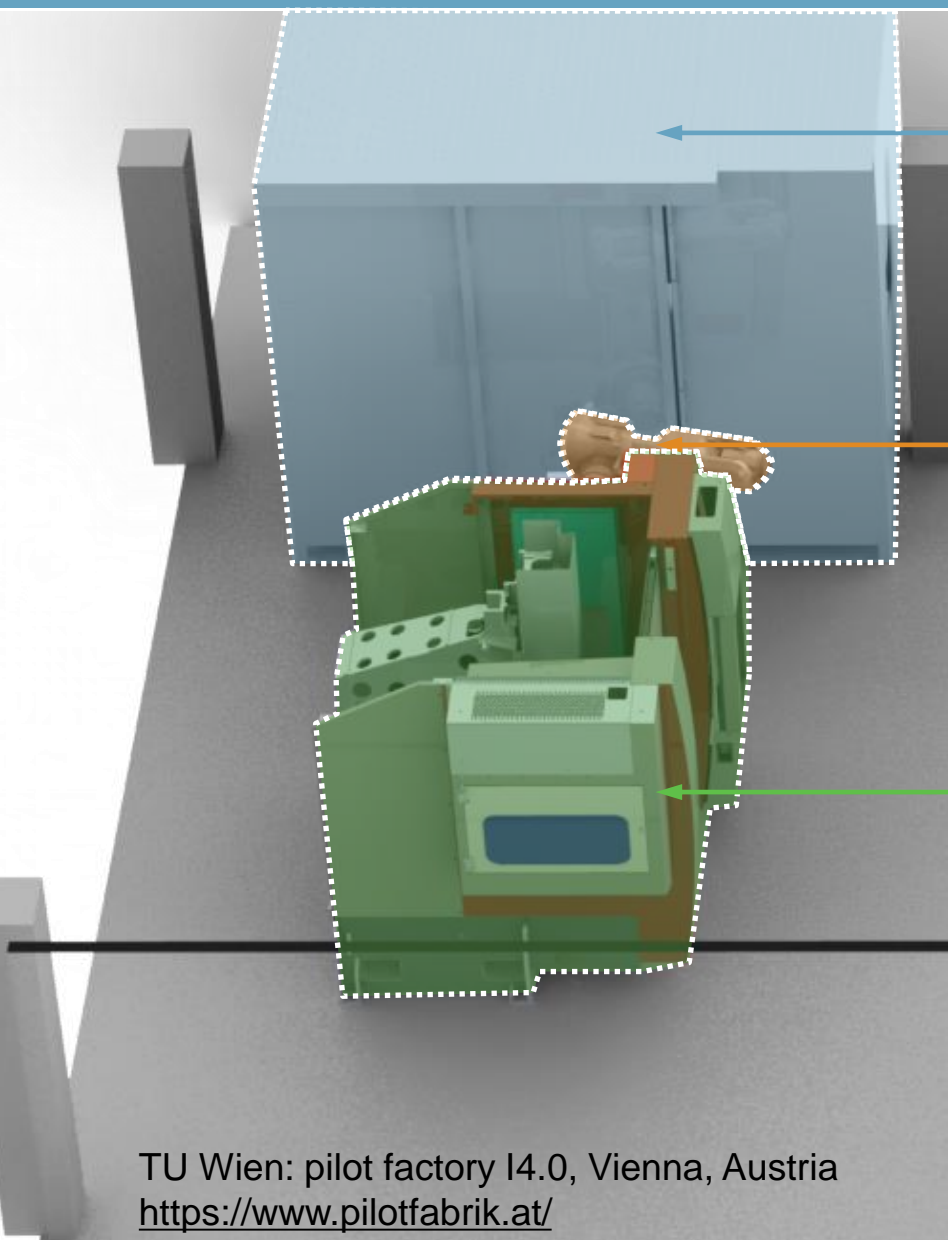
Bonn, 18th October 2023

[DOI: zenodo.1000333](https://zenodo.org/doi/10.1000333)

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| | | energy source | | | |
|-----------|------------|----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| | | arc / plasma | laser | electron beam | kinetic / friction |
| feedstock | wire / rod | <p>Wire Arc Additive Manufacturing (WAAM)</p> <p>[DOI: 10.3390/met13050873]</p> | <p>Wire Laser Additive Manufacturing (WLAM)</p> <p>[DOI: 10.3390/app7030227]</p> | <p>Electron Beam Additive Manufacturing (EBAM)</p> <p>[DOI: 10.3390/en15031076]</p> | <p>Friction Stir Additive Manufacturing</p> <p>[DOI: 10.1016/j.msea.2020.139035]</p> |
| | powder | <p>Plasma Transferred Arc</p> <p>[DOI: 10.1007/s00170-021-08643-6]</p> | <p>Laser Metal Deposition (LMD)</p> <p>[DOI: 10.3390/en15031076]</p> | - | <p>Cold Spray Additive Manufacturing (CSAM)</p> <p>[DOI: 10.1007/s40430-013-0030-1]</p> |



igm Rte-496SH

- Active cooled table
- Welding source Fronius TPS500i
- Workpiece up to 320 kg
- Detailed process monitoring

ABB IRB6620

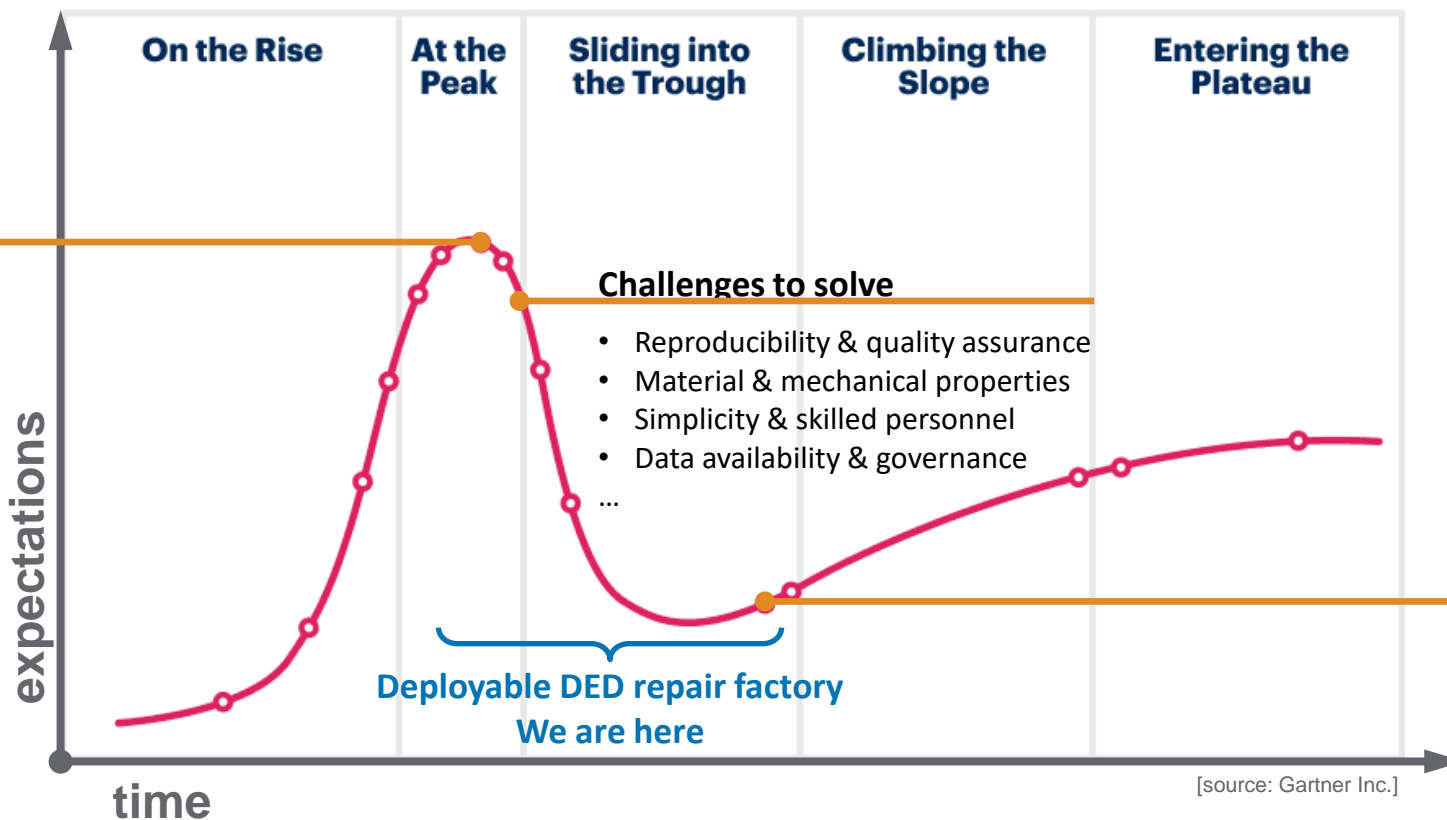
- automatic pallet handling
- 9 pallets in storage
- RFID-tags on each pallet
- up to 150 kg capacity

EMCO MaxxMill 500

- SINUMERIK 840D
- 5 Axis
- RFID-tags on tools
- Workpiece up to 500x500x475 mm



TU Wien: pilot factory I4.0, Vienna, Austria
<https://www.pilotfabrik.at/>



Technology showcases

Commercial systems

- MaxQ Repair [RAMLAB]
- MX3D
- SPEE3D
- Mobile Smart Factory by METROM & Rheinmetall [VDI]

...

Research projects

- OpenLab Mobile [HSU/UniBw H]
- 2ARMY [TUW]

...

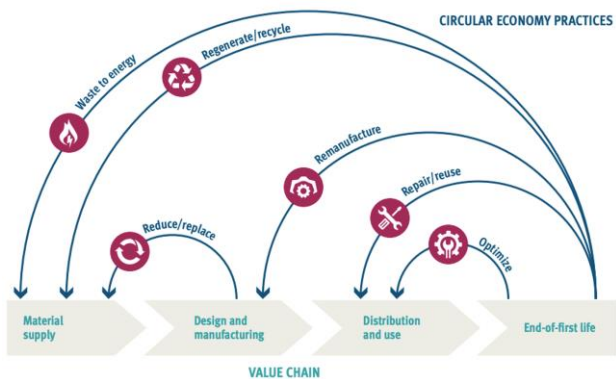
Early adopters & use-cases

- Rapid Equipping Force [U.S. Army]
- Naval Postgraduate School achieves first in-flight 3D printing of medical cast on Osprey [nps.edu]
- AML3D Expands US Navy Submarine Parts Manufacturing with New Order [AML3D]
- DB is using 3D printing to revolutionize maintenance [DB]

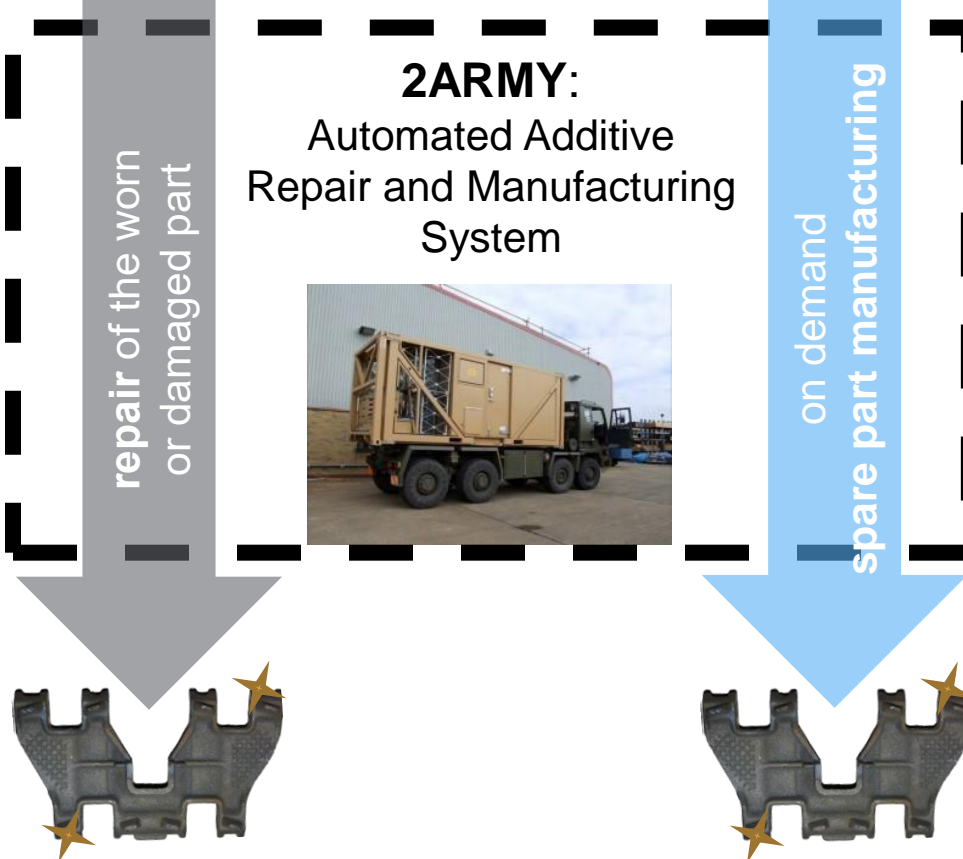
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- The overall feasibility is confirmed
- Important technological challenges are to solve prior to the broad mainstream adoption

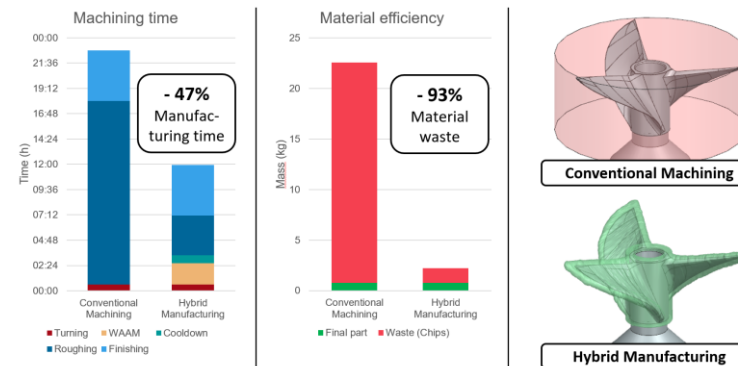
Benefits of repair:



- Waste reduction due to:
 - postponed EOL of the product
 - on-demand production
- Reduction of logistic footprint through on-site production
- civil or military usage



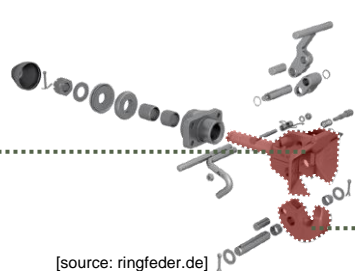
Benefits of AM for spare parts:



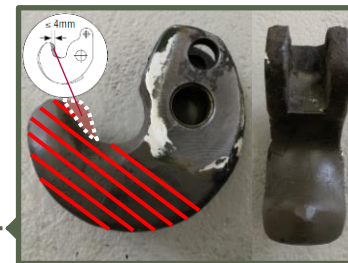
- Material & energy usage efficiency due to near net shape manufacturing
- Waste reduction due to on-demand production
- Reduction of logistic footprint through on-site production
- civil or military usage

Repair application example

Pull rod of the ringfeder type 663 KA1 truck coupling



[source: ringfeder.de]

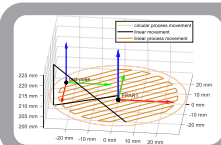


Spare part application example

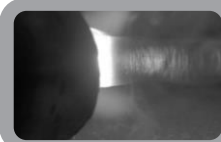
Hook of the ringfeder type 663 KA1 truck coupling



3D shape acquisition



toolpath generation



quality assurance



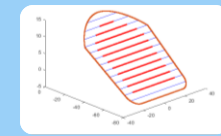
+CAD

+CAD

CAD model

- ⚠ Challenge: where users will get it from?
- ⚠ Challenge: legal aspects & intellectual property
- Approach: EU Commission's right to repair + Gaia-X

toolpath generation



quality assurance



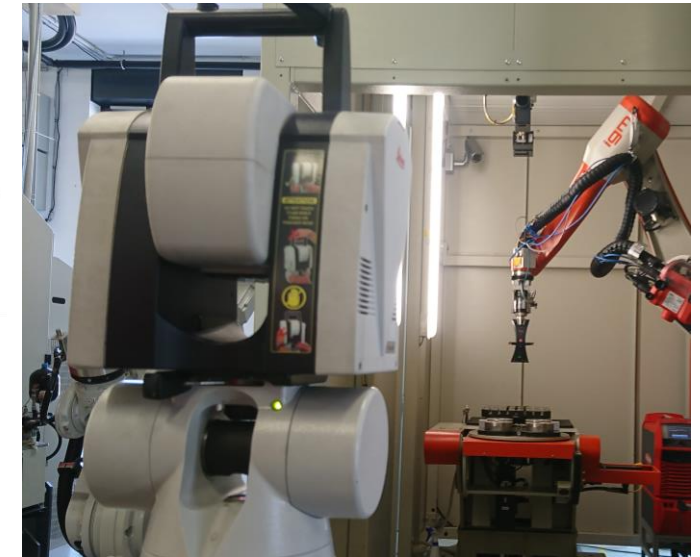
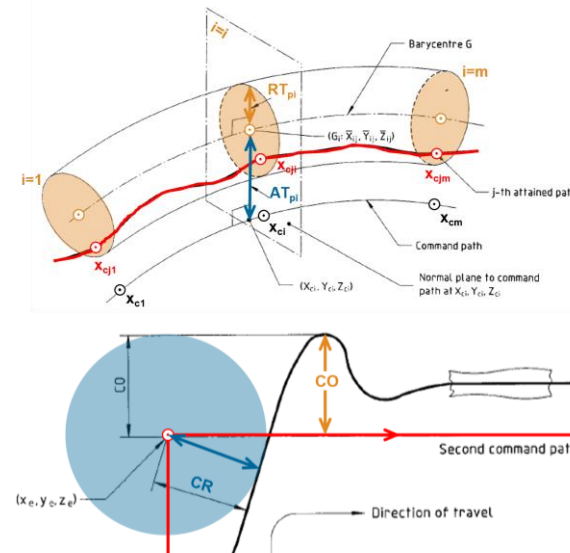
Full-sized prototype + pilot phase @TUW

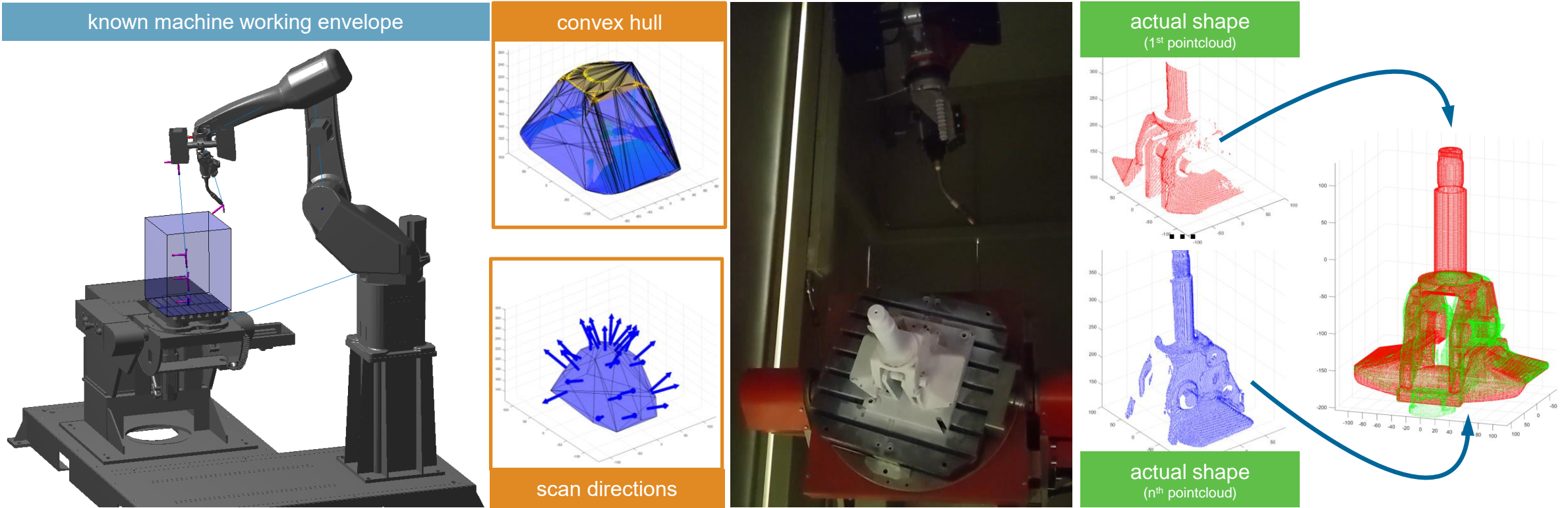
- ⚠ Challenge: skilled personnel, necessary skills
- Approach: Automate as much as possible
- Approach: Students will beta-test own examples



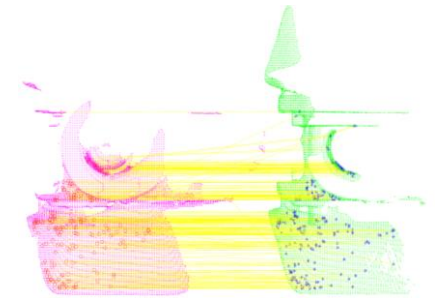


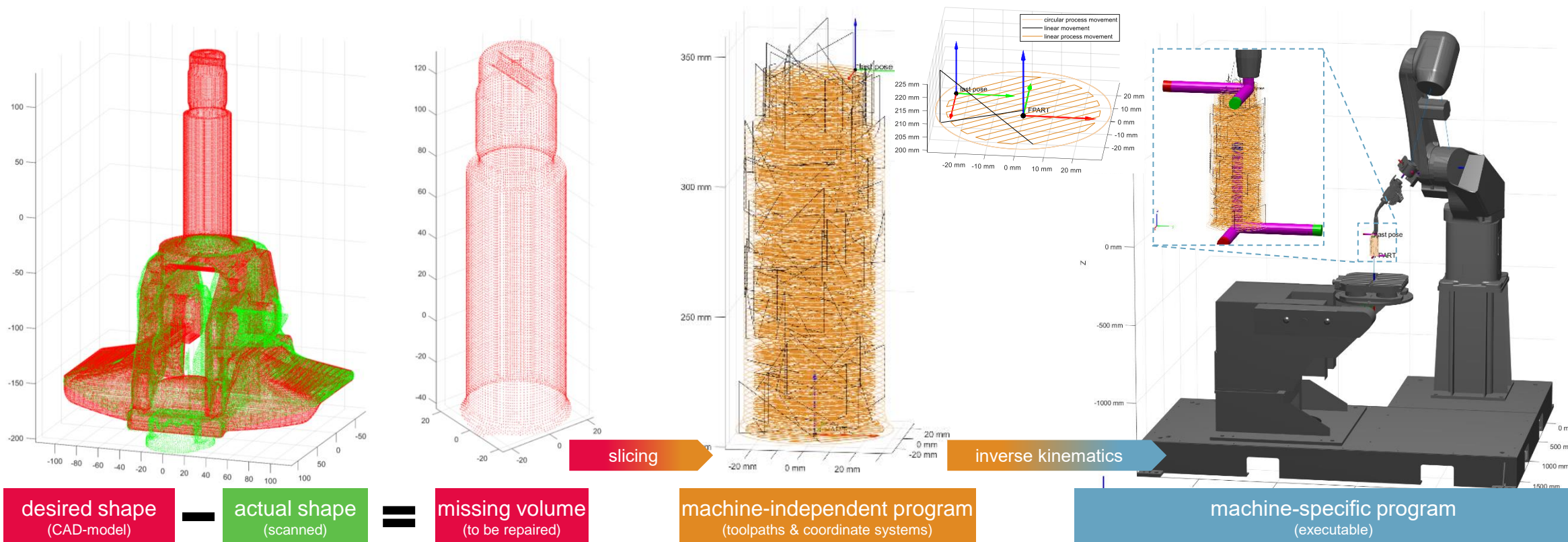
- Possible impact of transportation on machine's accuracy expected
 - Transport fixture will be designed
 - Prototype's accuracy before and after transportation will be evaluated according to ISO 9283:1998
- Special requirements on vibration resistance of the electric cabinet



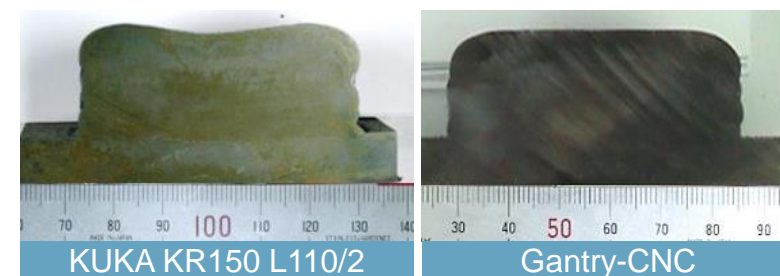


- **3D shape acquisition process may be carried out completely automatic & agnostic**
- **Structured light 3D scanner have been found best suitable (resolution, available interfaces)**

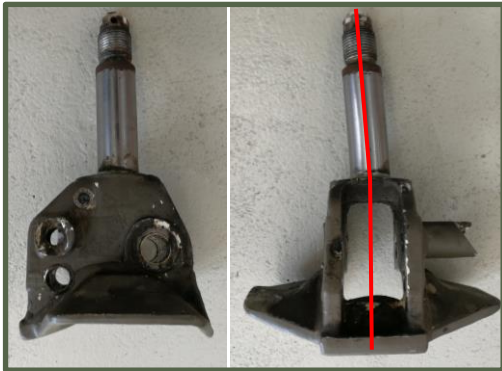
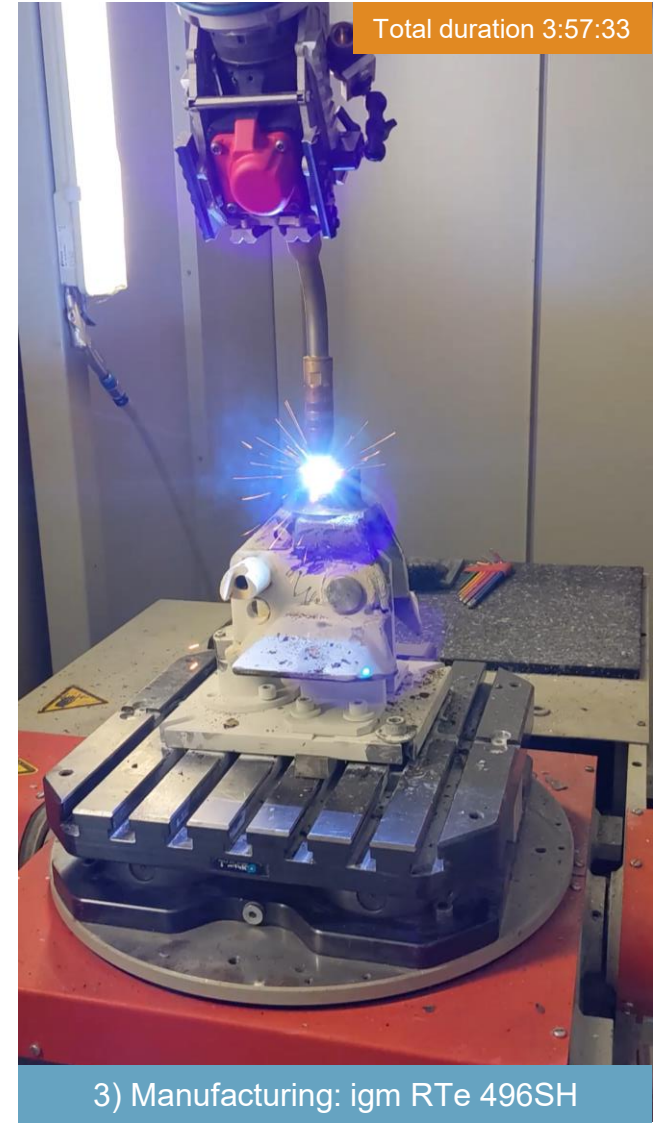
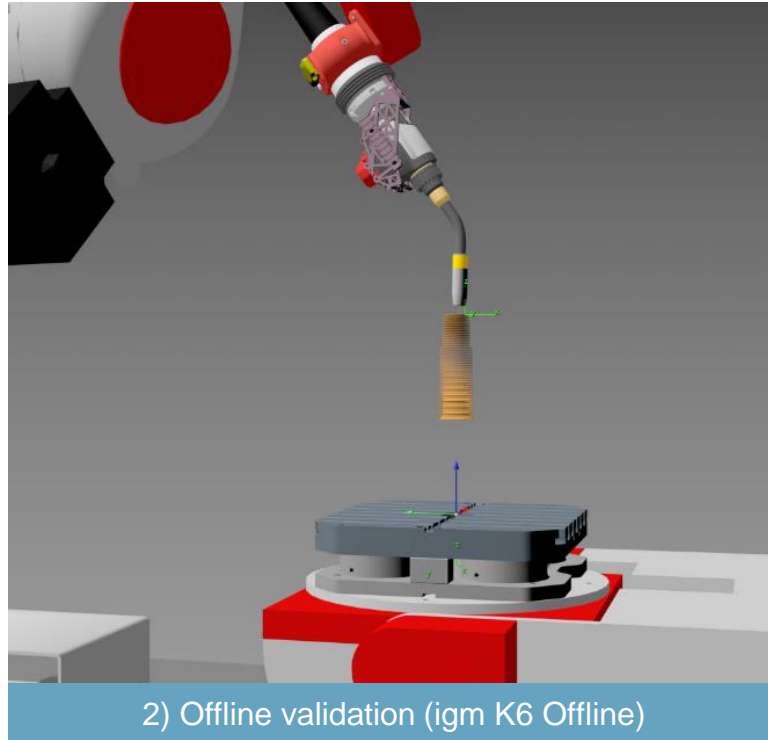
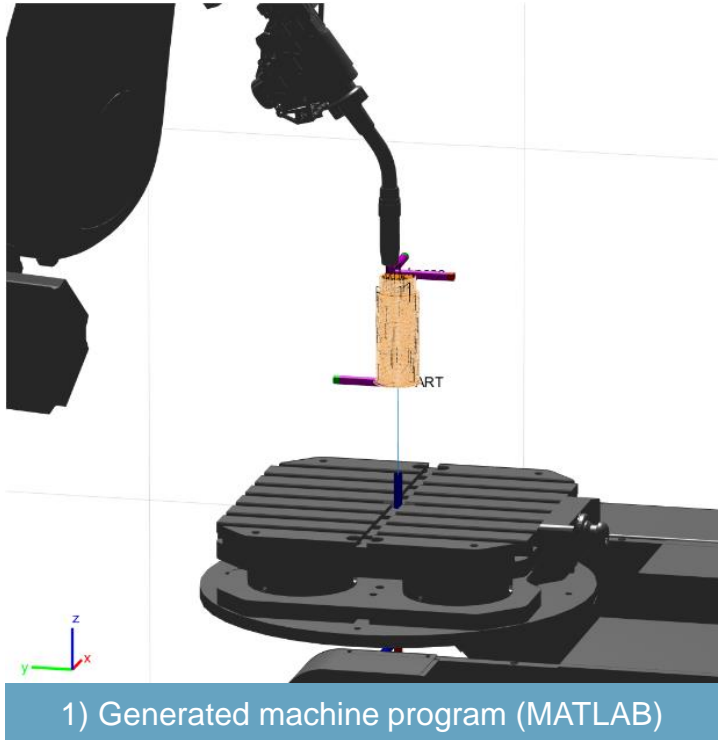


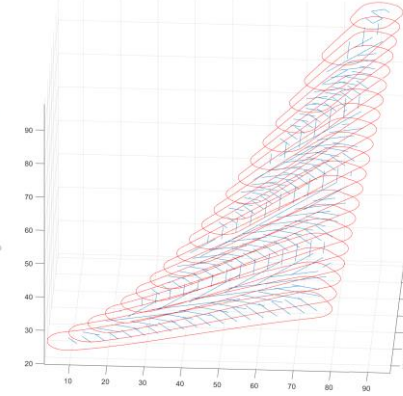
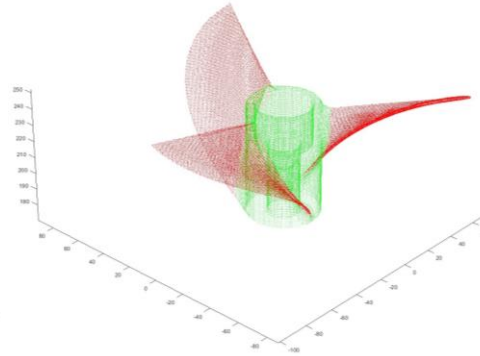
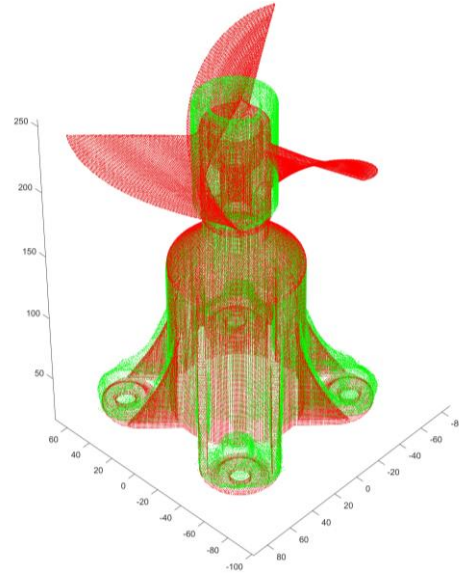
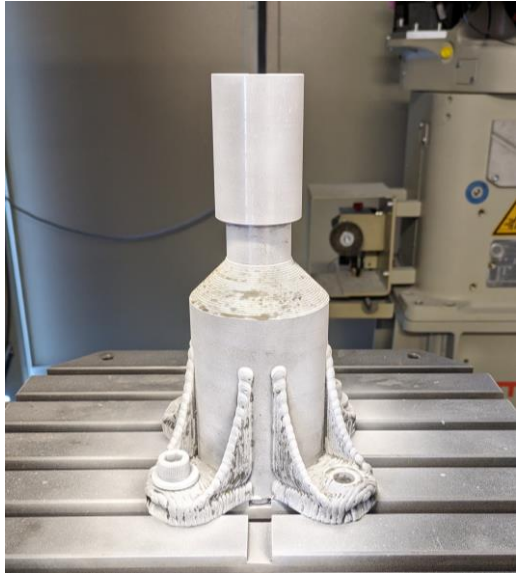


- Provided **CAD model will not necessarily match the real part**, making automation more difficult
- **“Machine-to-machine variability must be understood and controlled.”**
[W.E. Frazier 2010, p. 15]



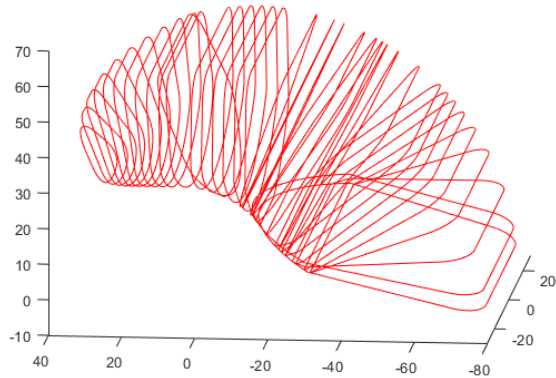
[Y. K. Bandari, 2016]



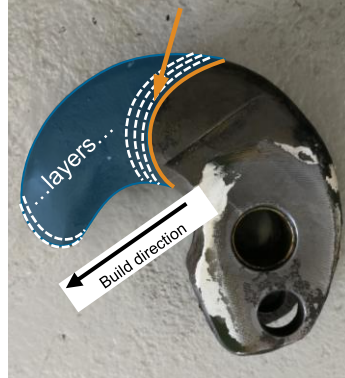


Challenges for automation:

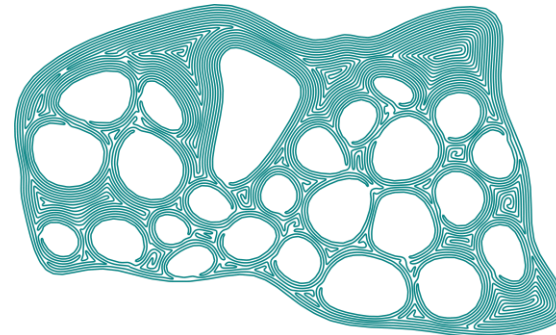
variable layer distance in curved shapes



non-planar base surface



continuous infill patterns

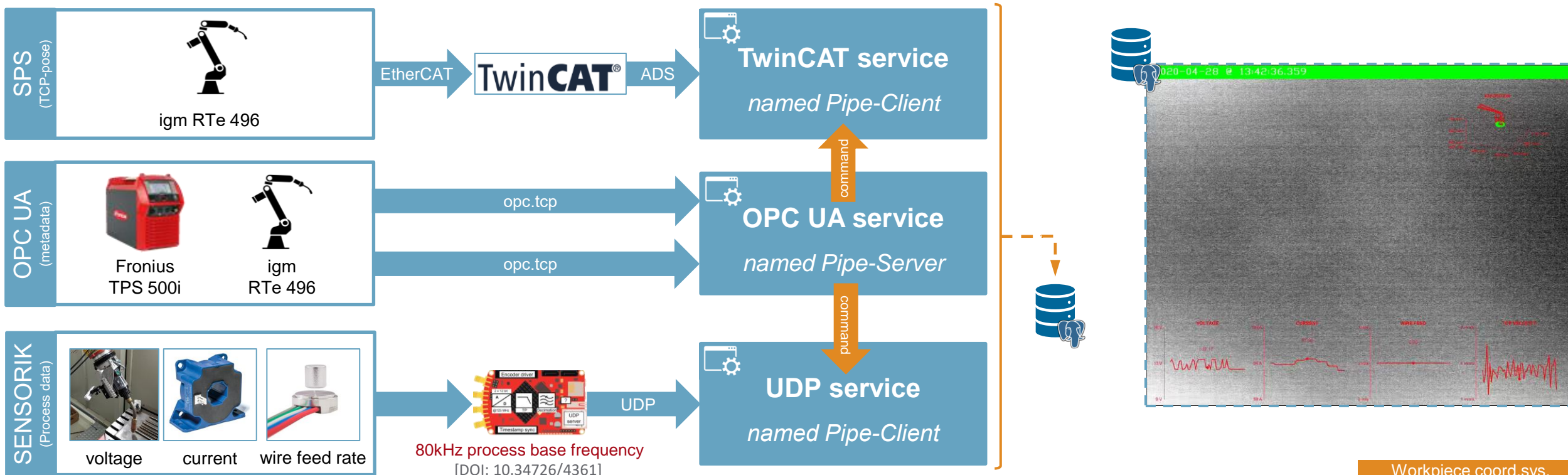


[DOI: 10.1145/2897824.2925958]

hierarchically ordered segments



[source: lincoln electric]

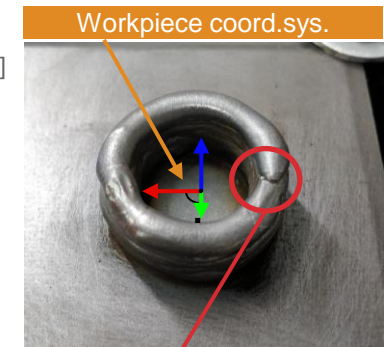


“The highest priority should be given to developing integrated in-process, sensing, monitoring, and control technologies.” [W.E. Frazier 2010, p. 15]

- Every **AM-part is unique** per definition → destructive tests on samples are not representative
- **Non-destructive testing** of entire part is **time-demanding** (if even possible)

Localized process data allow selective local inspection:


- **SPS** → Tool pose and timestamp
- **OPC UA** → Metadata (program name, coordinate frame definition, process characteristic, etc.)
- **Process data** → primary (I, U, WF) and secondary (energy input, material deposition rate, processability, etc.)



EMERGENCY STOP occurred



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