PAM2

Precision Additive Metal Manufacturing (PAM^2)

MSCA-ITN project

Grant Agreement No 721383

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KU LEUVEN

DTU Danmarks Tekniske Universitet

GE Oil & Gas

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

KIT Karlsruhe Institute of Technology

The LEGO group

MAGMA Committed to Casting Excellence

Università degli Studi di Padova

TU Delft Delft University of Technology

3D SYSTEMS formerly LayerWise

alicona That's metrology!

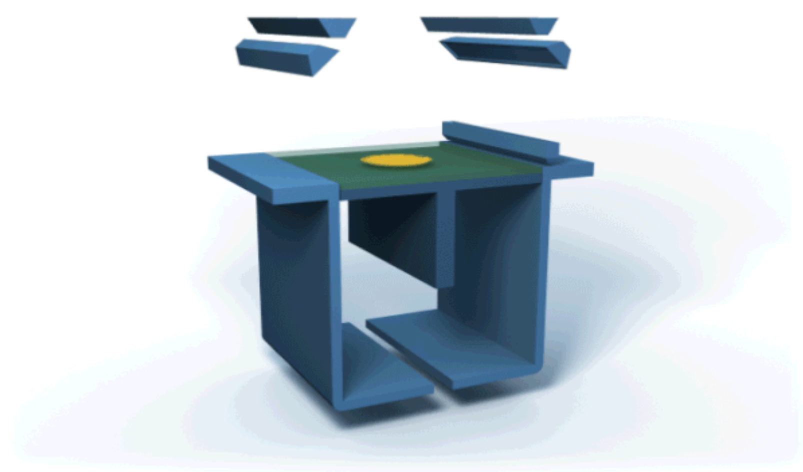
ASML

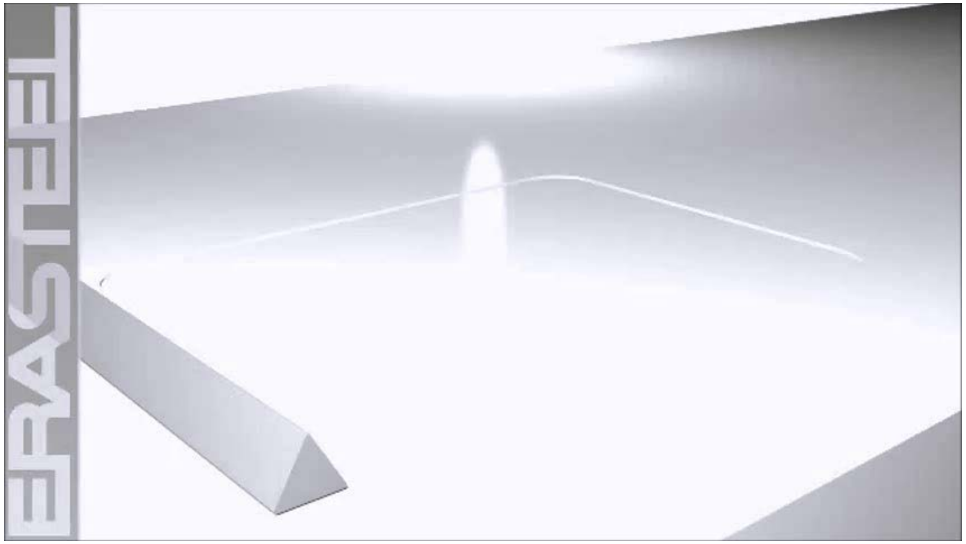
AM Introduction

Within PAM^2:

Selective **L**aser **M**elting (SLM):

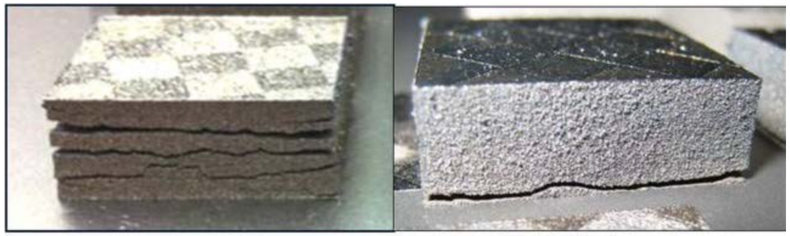
melting metallic **powder** locally by the use of a **laser**





- ➢unlimited design freedom enabling unprecedented levels of functional integration
- ➢produce personalized parts locally and with efficient material use.

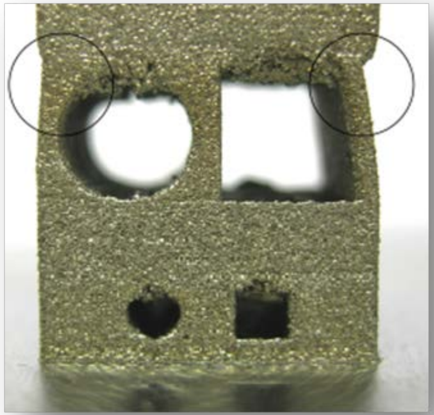
AM challenges



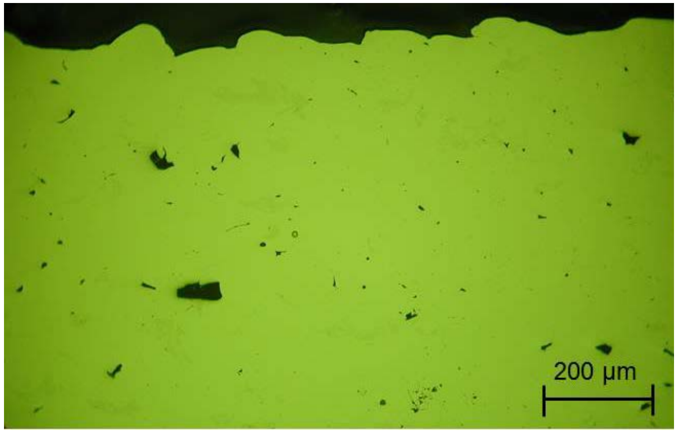
No pre-heating T = 90°C

Cracking& delamination

porosity



Deformation



roughness

Build-in stresses, shrinkage, limited robustness, etc…

AM challenges

For AM to gain a significant market share it must be developed into a true **precision manufacturing** method.

The production of precision parts relies on three principles:

1. Production is robust, i.e. that all sensitive parameters can be controlled.
2. Production is predictable, e.g. the shrinkage that occurs is acceptable because it can be predicted and compensated in the design.
3. Parts are measurable, as without metrology accuracy, repeatability, and quality assurance cannot be known.

Next to these principles ensuring robust & predictable production, we should also work on improving the overall quality of the produced part (density, roughness, precision, ..)

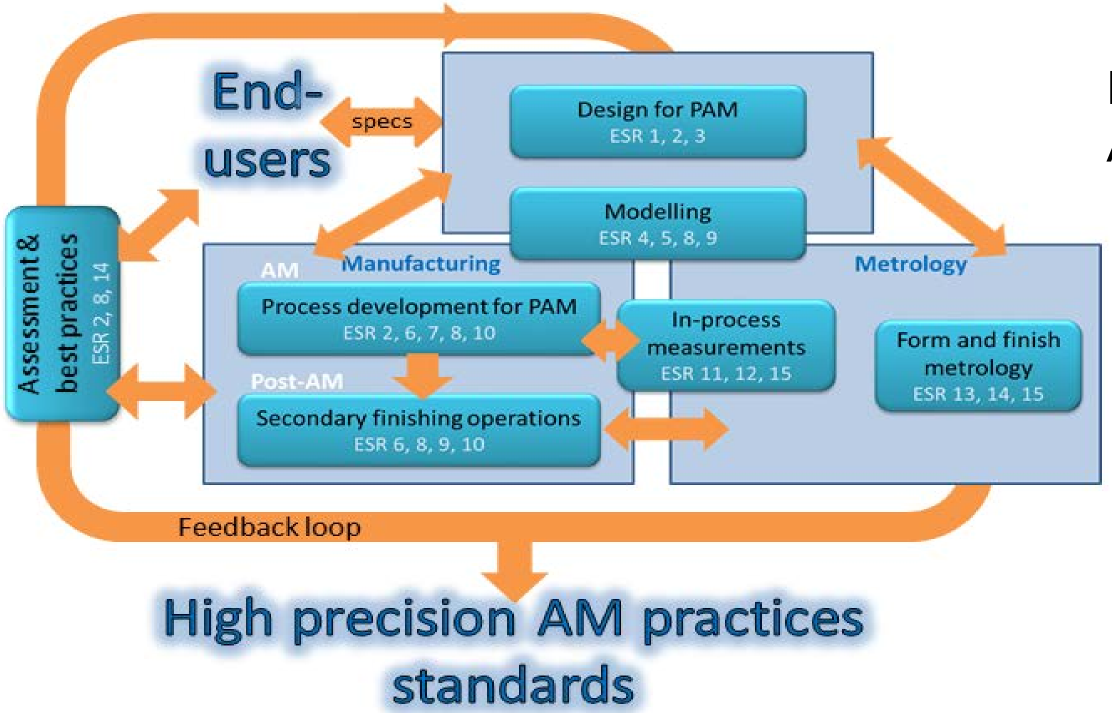
Objectives

The overall objective of PAM^2 is to ensure the availability of high precision AM processes and (computational) design procedures. Detailed objectives to reach this overall goal are:

- to develop advanced (computational) design tools, enabling competitive designs, better use of AM possibilities against minimal design costs and reduced time-to-market
- to develop better modelling tools for first-time-right processing
- to optimise selective laser melting process strategies for improved part precision and feature accuracy
- to understand the link between post-process metrology and in-process observations, creating the basis for in-process quality control and process stability
- To develop innovative in-process and post-process techniques to reduce or remove roughness, porosity and internal stresses and to improve dimensional accuracy and mechanical properties

Project approach

- To quality assure the parts produced, PAM² will address each of the various process stages of AM with a view to implementing good precision engineering practice.
- Cross-linking every step, providing feedback for each stage



End-users: GE, ASML, LEGO

Consortium

ASML
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Close collaboration between industry and academia

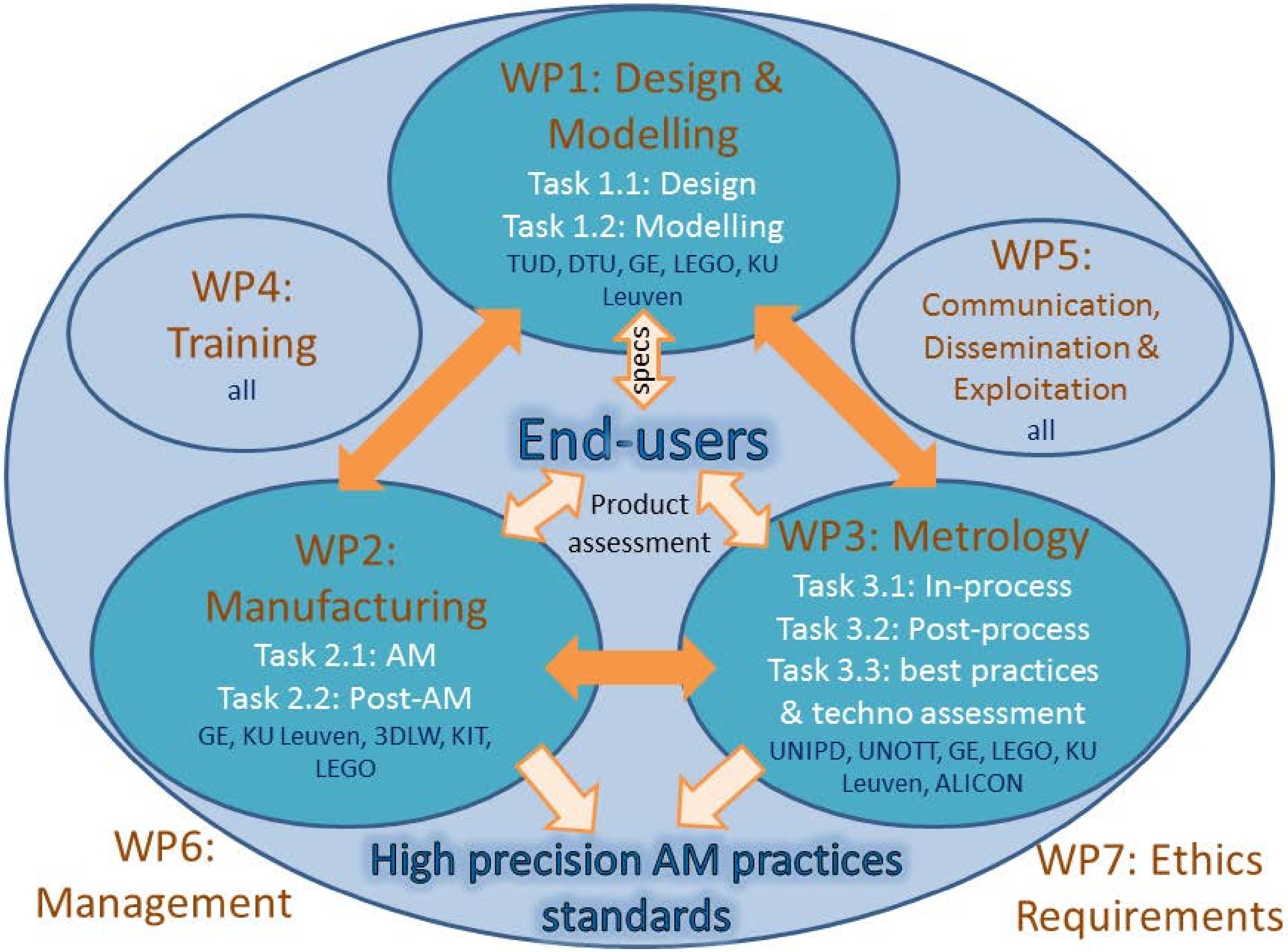
Research topics

15 innovative & interconnected research projects for Early Stage Researchers:

ESR No.	Title
1.	**Topology** optimisation for precision components produced by additive manufacturing
2.	Develop a novel **process** approach to improve the precision of inner features
3	Develop **design** guidelines for Precision AM based on scientific understanding
4.	**Modelling** the thermo-metallurgical-mechanical conditions in precision additive metal manufacturing
5.	Numerical **modelling** of heat treatment of additive manufactured metal parts
6.	Selective laser melting **process** strategies for improved part precision and feature accuracy
7.	In-situ laser-based subtractive **manufacturing** for increased inner and outer precision of AM parts
8.	Integrated **process** chains based on AM precision technologies for production of high accuracy mould components
9.	Laser based secondary **finishing processes** of AM manufactured metal parts
10.	**Process** optimisation of the AM process and all related **post processing** steps of SLM parts
11.	In-process **metrology** for high-precision AM: vision system and defect engine development
12.	In-process **metrology** for high-precision AM: focus variation system development
13.	Optical form **measurements** of complex rough surfaces to improve the precision of AM manufactured parts
14.	Best practices in X-ray **computed tomography** to improve the precision of additive manufacturing
15.	Improved control of the AM **process** by **in-process** monitoring and feedback

Still open vacancies, see: www.pam2.eu/vacancies!

Pert diagram



Result

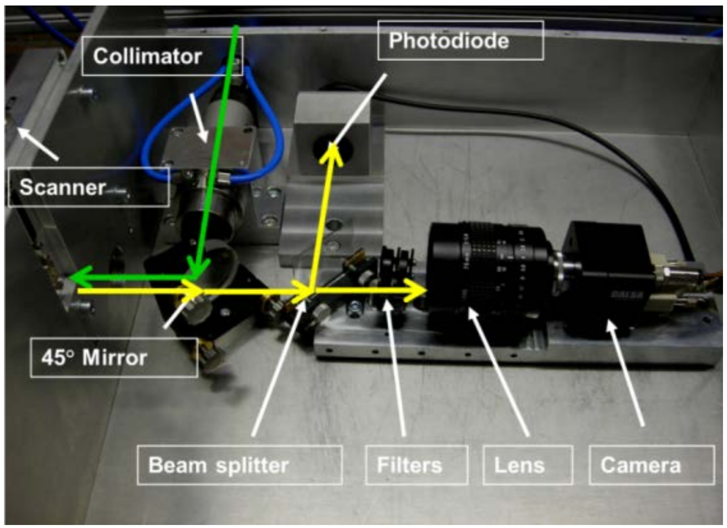
- Expected result: The availability of high precision AM processes through:
  - improved layout rules with better use of AM possibilities
  - better modelling tools for first-time right processing
  - possibility for in−situ quality control ensuring process stability and
  - if still needed, optimised post-processing routes.

- Next: example from KU Leuven concerning in-situ quality control (ESR topic 15)

Quality control in-process vs. post-AM

In-process

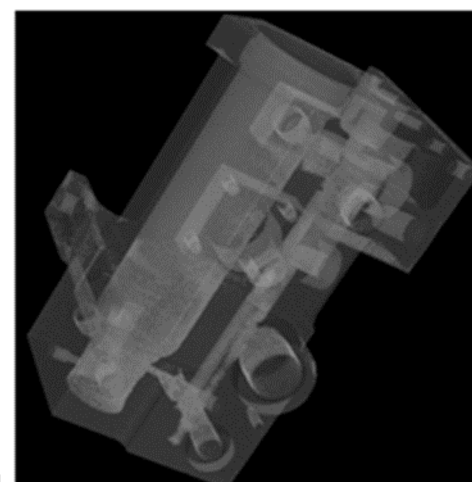
- Optical system
  - Laser scanning& monitoring



Post-AM (final part)

- OM/SEM

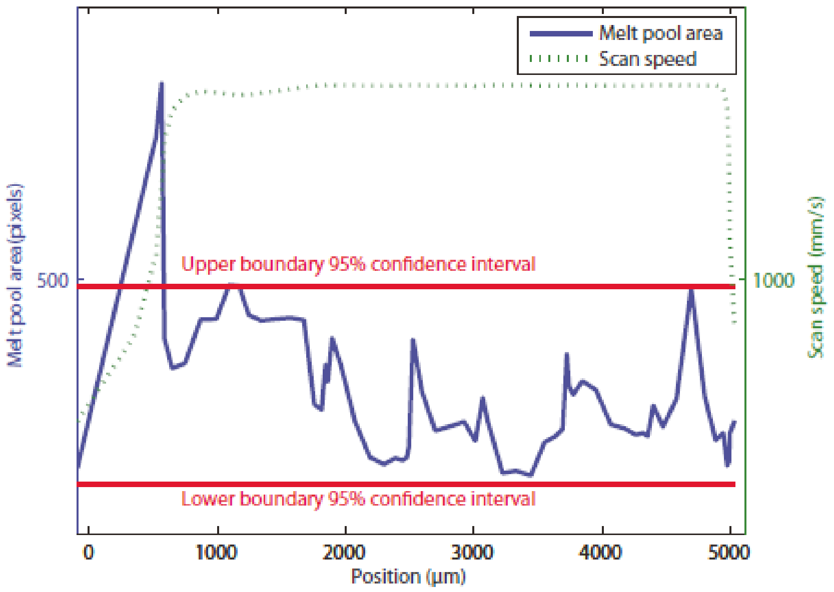
- X-ray CT

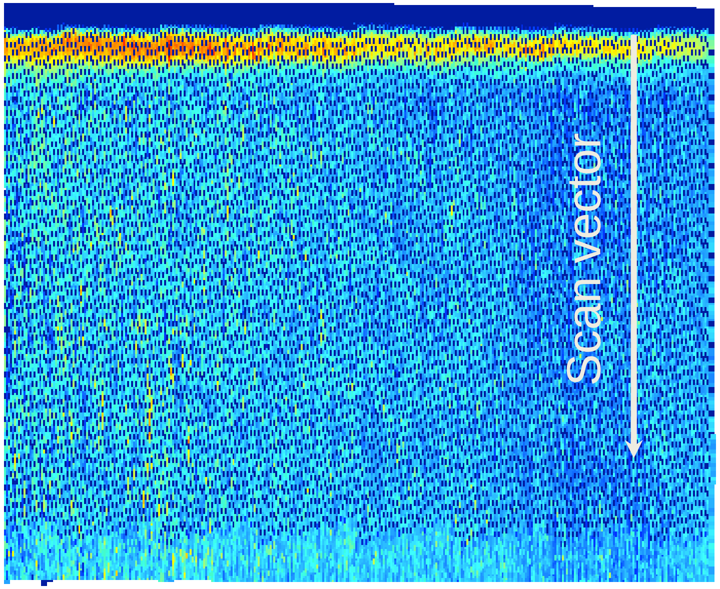


compare

Quality control in process

Intensity peaks and pores

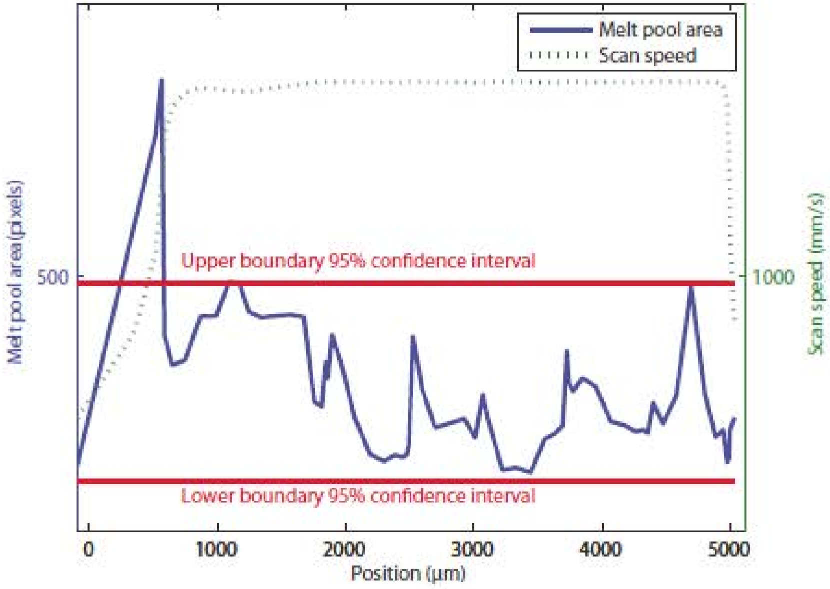


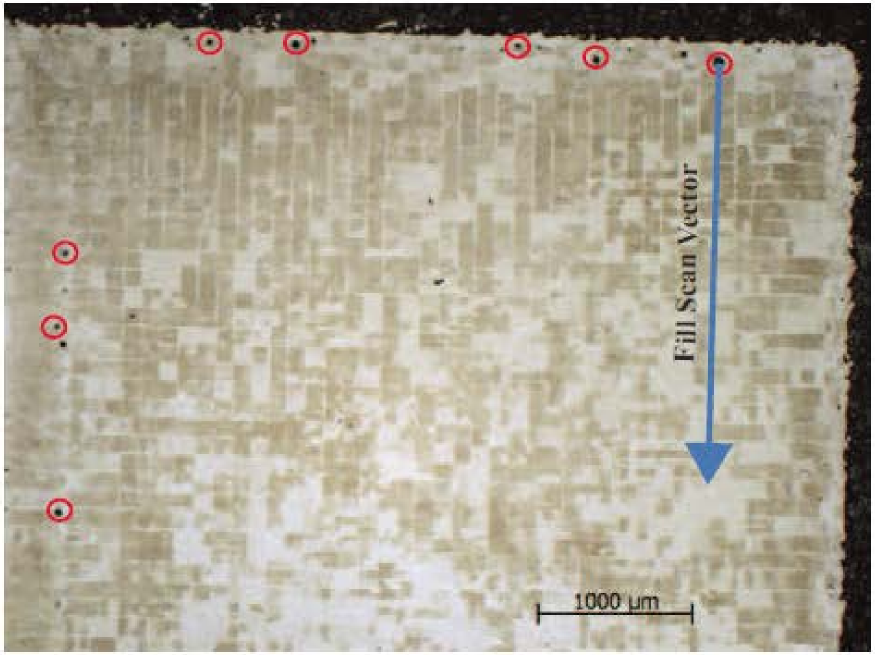


S. Clijsters, T. Craeghs, S. Buls, K. Kempen , J.-P. Kruth, (2014) In situ quality control of the selective laser melting process using a high-speed, real-time melt pool monitoring systemInt J Adv Manuf Technol

Quality control post-AM

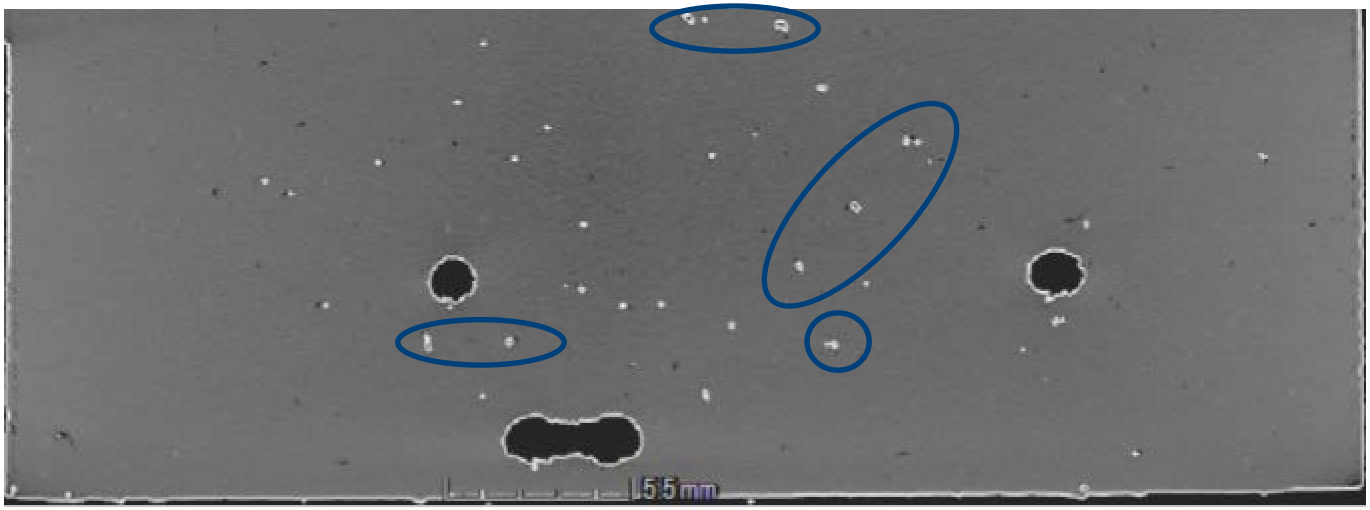
Intensity peaks and pores





Quality control in-process vs. post-AM

Photodiode – CT comparison



Take appropriate in-situ real-time (~20 kHz) control actions based on comparison in-process vs. post-AM observations

Case studies common project theme

Figure 2.1a: Proposed applications to guide the PAM² research: an impeller (left, GE), a typical manifold for conditioning water, with interfaces for temperature sensors in TiAl6V4 (middle, ASML) and prototypes of injection moulding tool inserts in maraging steel (right, LEGO, alternative designs with lattice structures to save materials & speed up the process)

- Process: selective laser melting (SLM)
- Materials: TiAl6V4, Inconel 718 and tool steel
- Products provided by the industrial end-users GE, ASML and LEGO
- From design over simulations, processing, post-processing, measuring and validation/assessment

Case studies related deliverables

Deliverables related to the case studies from the end-users

Deliver-able #	Deliverable Title
D1.1	Report on needed design and **requirements** based on input from **end-users**
D1.2	AM-ready and topology **optimised designs** for AM parts of **end-users**
D1.3	Thermo-microstructural-mechanical **model** for precision AM and secondary processing
D2.1	Case studies with new topology optimised designs **manufactured and assessed**
D3.1	Review and selection of appropriate post-process **instrumentation** and its use for the end-user case studies

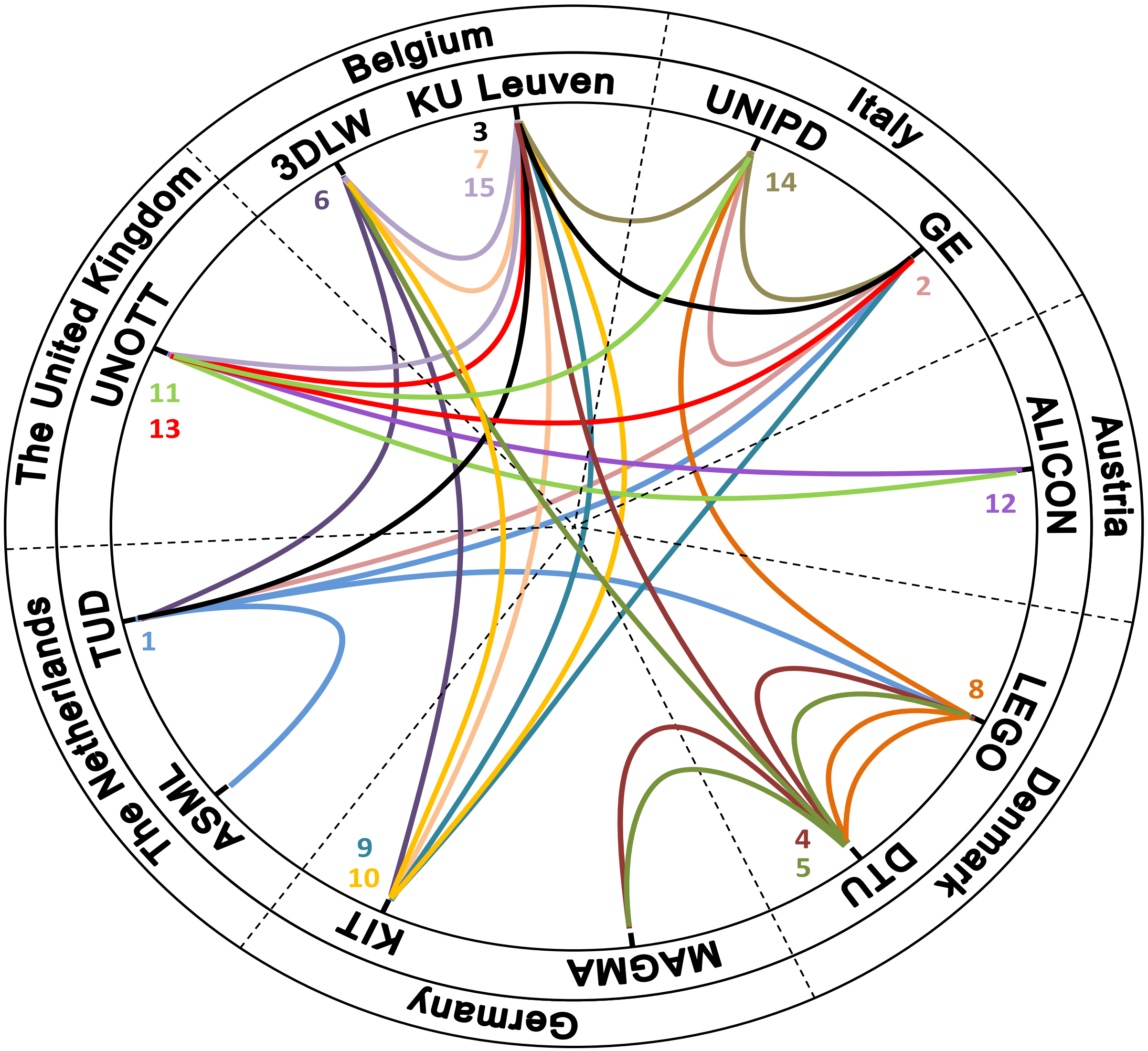
Training

- ESRs will be immersed in the whole AM production chain through hands−on workshops where they will design, model, fabricate, measure and assess a specific product.
- ESRs also participate in local programs, secondments, summer schools, conferences

	Main training events & conferences	Host	Early recruit
1	Workshop 1: AM basics	KU Leuven	June or Sept/17
2	Workshop 2: Basic system design, specs and computational design (+ FEM intro)	TUD	Sept or Oct/17
3	Workshop 3: Process modelling (more advanced FEM)	DTU	Nov/17
4	Workshop 4: Manufacturing and in-process metrology	KU Leuven	Feb/18
5	International Conference (euspen 2018)	UNOTT	Jun/18
6	Summer school 1: Leadership course	GE	Sept/18
7	Workshop 5: Post-processing	KIT	Dec/18
8	Workshop 6: Post-process Metrology	UNOTT	Mar/19
9	Summer School 2: In-depth AM tutorials and tour of facilities incl. demo's	UNIPD	Jul/19
10	Workshop 7: Assessment (geometry and functional assessment), revisit design and modelling	LEGO	Feb/20
11	International Conference (euspen 2020) rejoining fellows	UNOTT	Jun/20

Some of these events open for the public; see: www.pam2.eu for the next event!

Secondments



Conclusions

- To quality assure the parts produced, PAM² will, through a close collaboration between industry and academia, address each of the **various process stages** of AM with a view to implementing **good precision engineering** practice.
- To ensure the availability of trained personnel, ESRs will, next to their individual research and complementary skills training, be **immersed in the whole AM production chain** through **hands−on** workshops where they will design, model, fabricate, measure and assess a specific product.

Conclusions

The expected impact of PAM² thus is:

- The **availability** of intersectoral and interdisciplinary **trained professionals** in an industrial field that's very important for the future of Europe, both enhancing the ESR future career perspectives and advancing European industry.
- The **availability** of **high precision AM processes** through improved layout rules with better use of AM possibilities, better modelling tools for first-time right processing, possibility for in−situ quality control ensuring process stability and, if still needed, optimised post-processing routes.
- As a result: an **increased market** acceptance and penetration of AM.
- Through the early involvement of European industry: a **growing importance of the European industrial players** in this fast-growing field. This will help Europe reach its target of 20% manufacturing share of GDP.

Thank you for your attention..

Any questions?

www.pam2.eu

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