NRFP3 SLUTSEMINARIUM – 2018-11-15

DESIGN AND QUALIFICATION METHODS FOR ADDITIVE MANUFACTURING IN SPACE APPLICATIONS

PHD STUDENT: CHRISTO DORDLOFVA

SUPERVISORS: ANNA ÖHRWALL RÖNNBÄCK, PETER TÖRLIND, OLA ISAKSSON

GKN: CLAS ANDERSSON (& STAFFAN BRODIN)

LULEÅ UNIVERSITY OF TECHNOLOGY

GKN AEROSPACE

GLOBAL LAUNCH COMPETITION

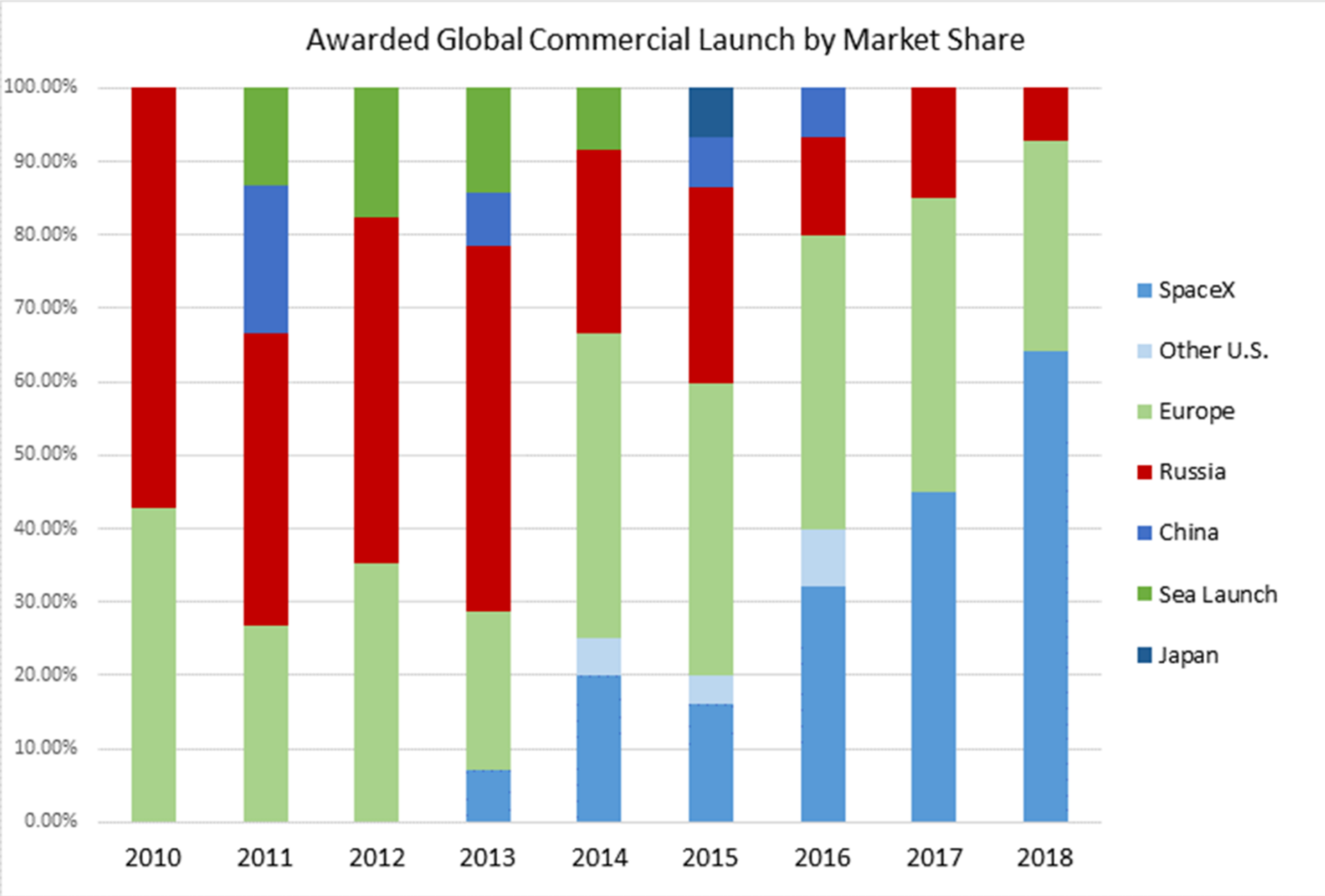
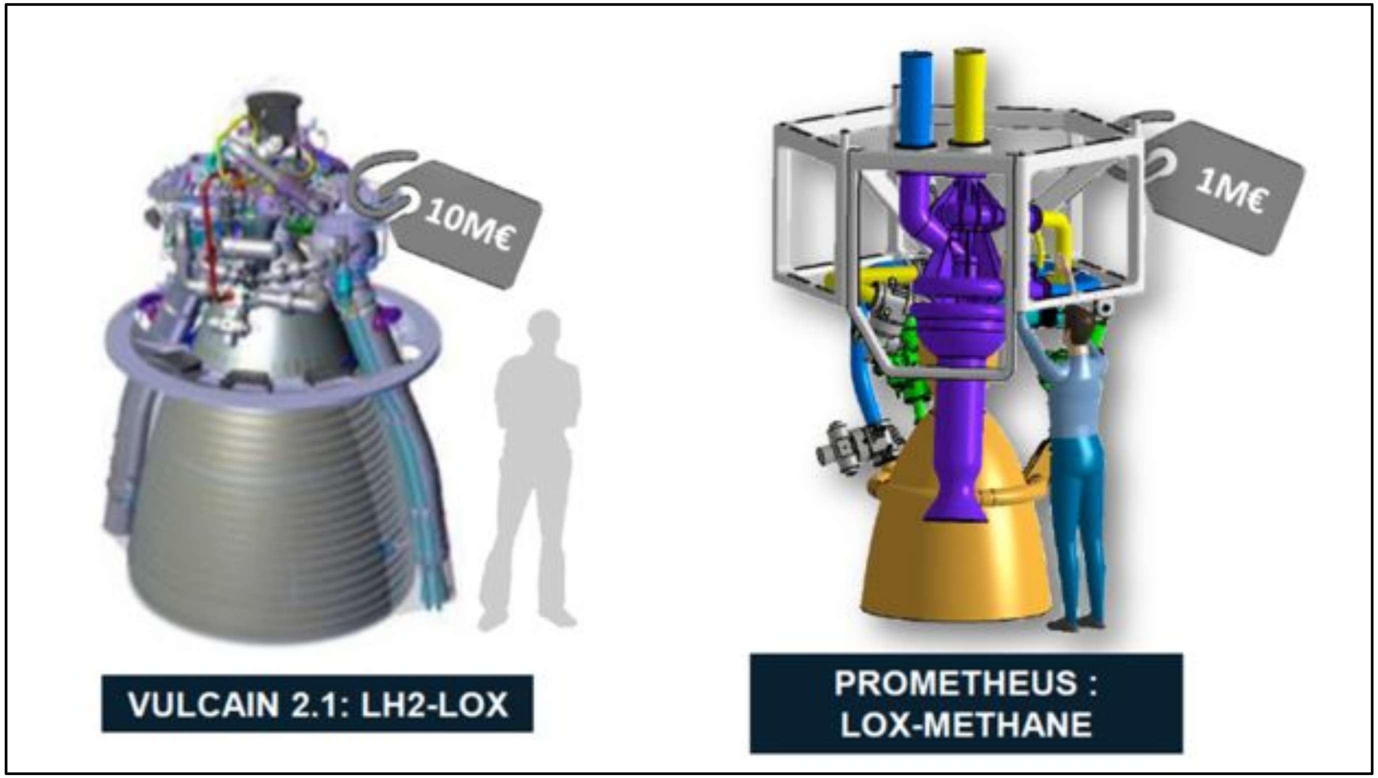


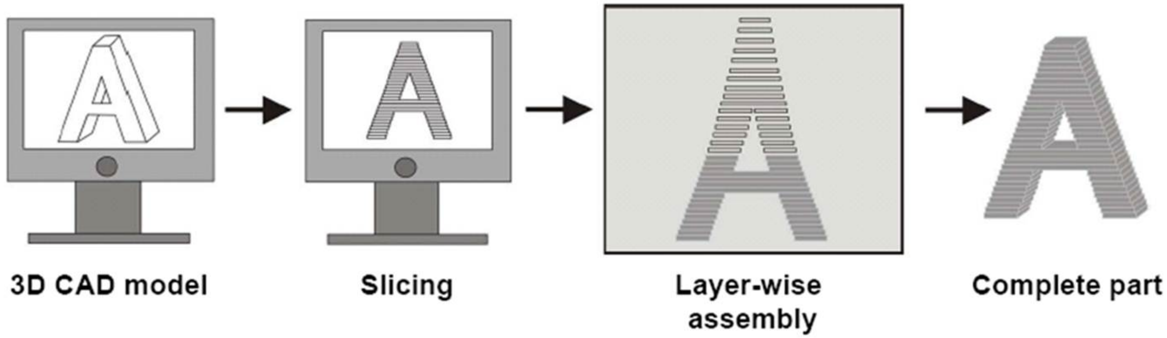
Diagram from Tim Hughes, July 2017 (Space Exploration Technologies Corp.)

NEXT GENERATION ROCKET ENGINE



Picture from CNES (French Space Agency)

ADDITIVE MANUFACTURING



Powder Bed Fusion

Pictures from ESA, Trumpf, EOS

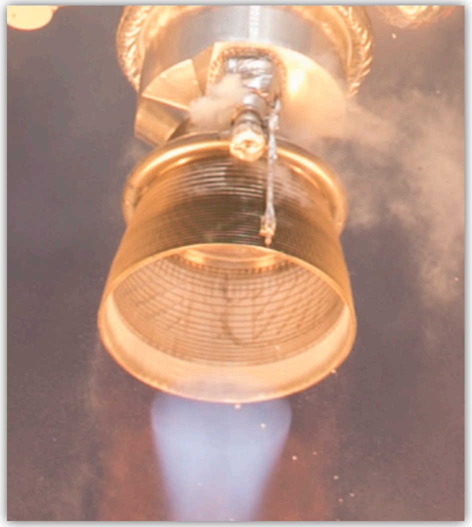
AM IN SPACE APPLICATIONS

Reduced lead time for product development

Reduced lead time for production

Suitable for low volume manufacturing

WHY?



Reduced cost:

- Fewer parts
- Fewer manufacturing processes
- Faster manufacturing

Increased design freedom and optimisation for:

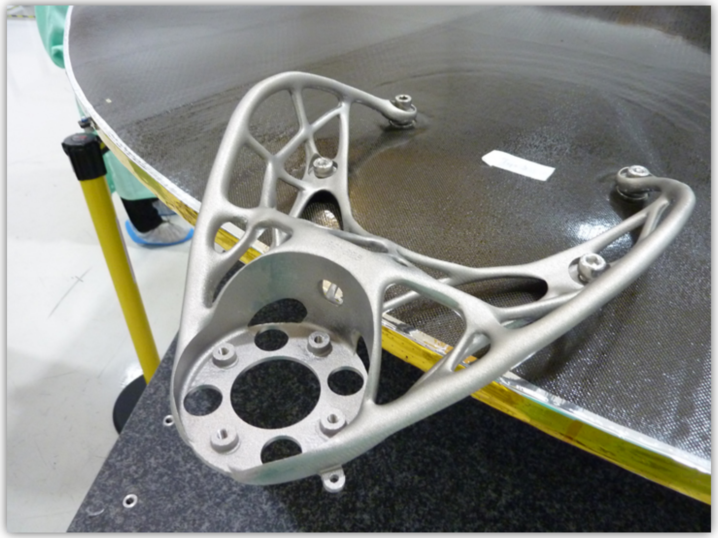
- Weight
- Performance
- Producibility

"AM is a perfect fit"

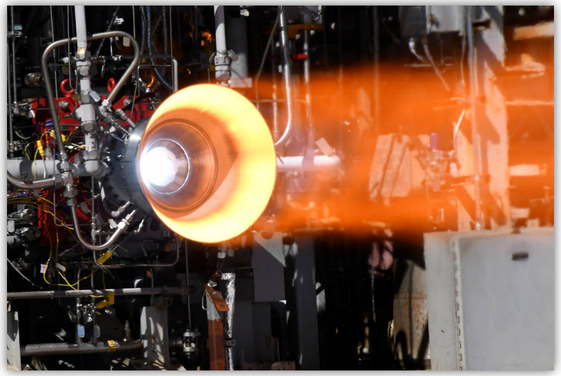
Picture from ESA

WHERE IS AM TODAY?

Secondary structures: in flight



Primary structures: in test

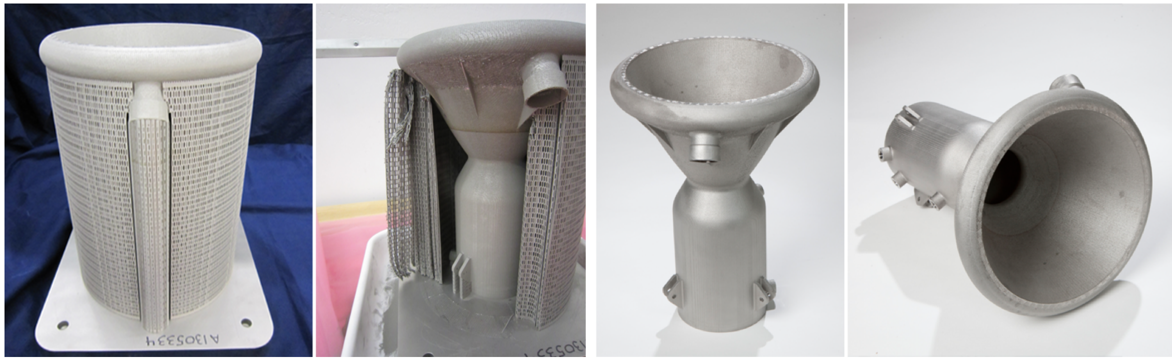


Pictures from Thales Alenia Space and NASA

PROJECT SCOPE

- **Purpose**
  - Focus on design and qualification methods for AM in space applications

- **Objectives**
  - Develop the product development process to facilitate the use of AM capabilities
  - Define qualification strategies for AM in space applications
  - Identify prerequisites and limitations with AM technologies
  - Reach Licentiate



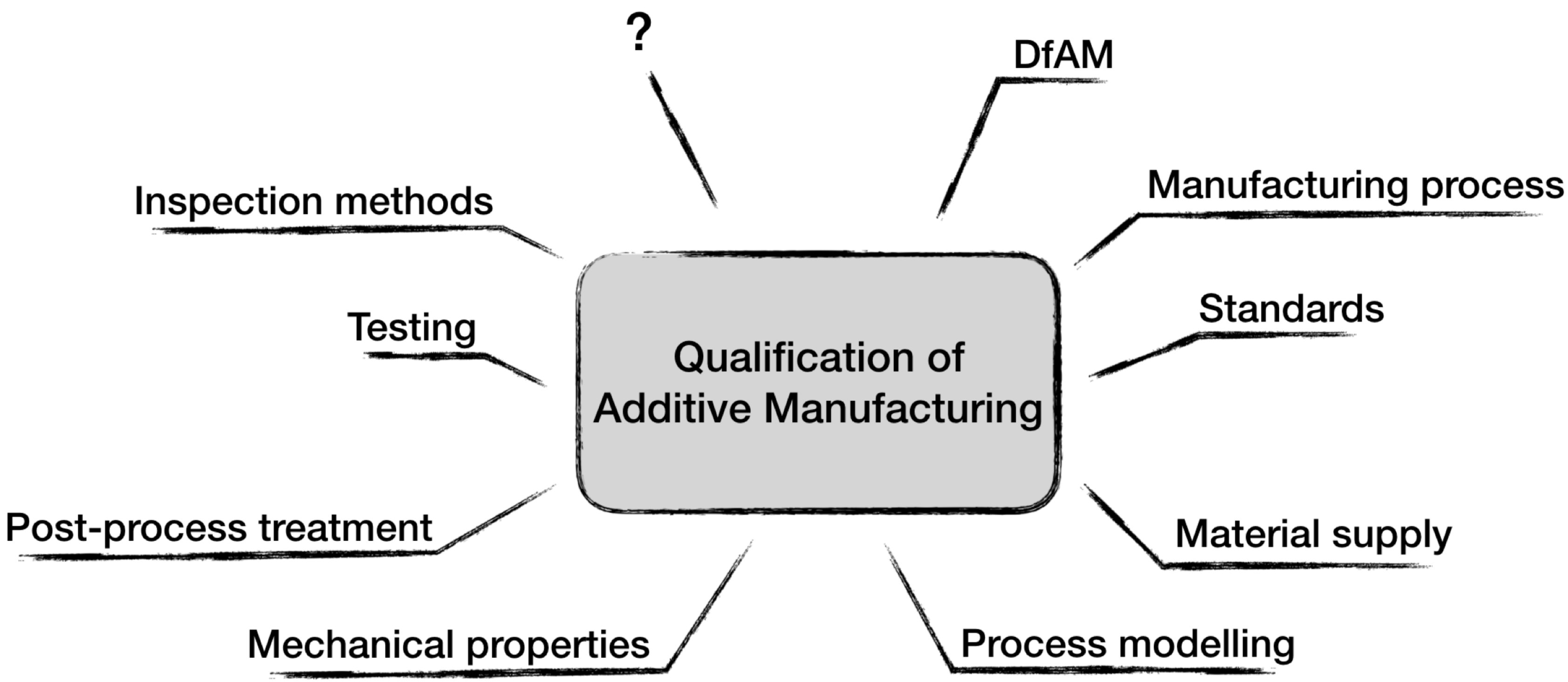
Picture from Lawrence Livermore National Laboratory

RESEARCH APPROACH

Study I	Literature; Study tour	11 study visits
Study II	Company A	8 semi structured interviews Company documents
Study III	Company A; Company B; Company C	3 workshops
Study IV	Company A	15 semi structured interviews Company documents

L

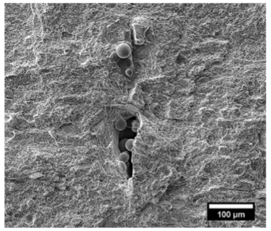
QUALIFICATION CHALLENGES



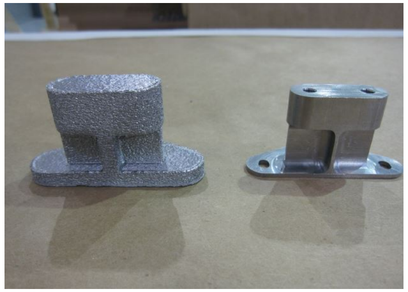
AM MATERIALS

How do you design for an unknown process?

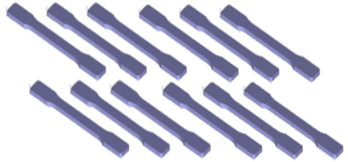
Anisotropy



Defects



Rough surfaces



Representativeness of test coupons?

? →

- **Lack of understanding for AM processes today**
  - Simulation of AM process is still rudimentary
  - Difficult to know how to analyse AM materials
  - Non-Destructive Testing (NDT) methods are not standardised

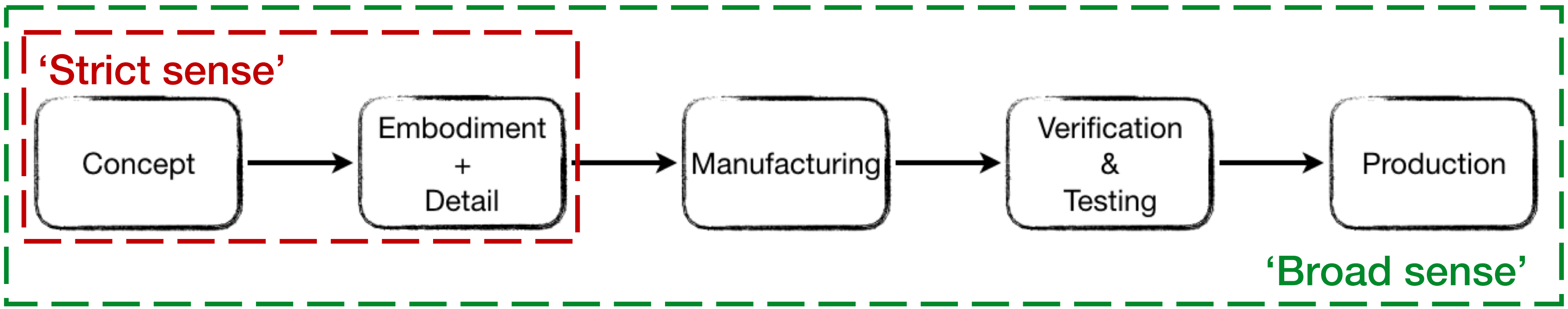
→ Testing is necessary
→ Test artefacts have to be part-representative

Pictures from Neikter et al. (2017), Seifi et al. (2016), Lockheed Martin, EOS/RUAG

Gorelik (2017). Additive manufacturing in the context of structural integrity. International Journal of Fatigue, 94.
Martukanitz (2014). Toward an integrated computational system for describing the additive manufacturing process for metallic materials. Additive Manufacturing, 1–4.
Seifi, et al. (2017). Progress Towards Metal Additive Manufacturing Standardization to Support Qualification and Certification. Jom, 69(3).
Taylor et al. (2016). Certification Strategy for Additively Manufactured Structural Fittings. In 27th Solid Freeform Fabrication Symposium.

DESIGN FOR AM

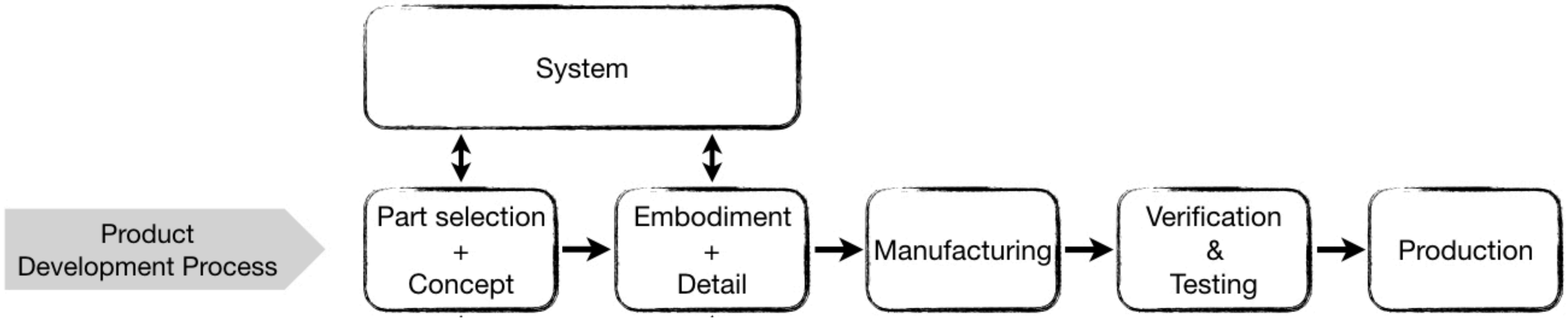
- **AM is an 'end-to-end manufacturing process'**
  - Material supply, early design, manufacturing, post-processing, qualification are linked



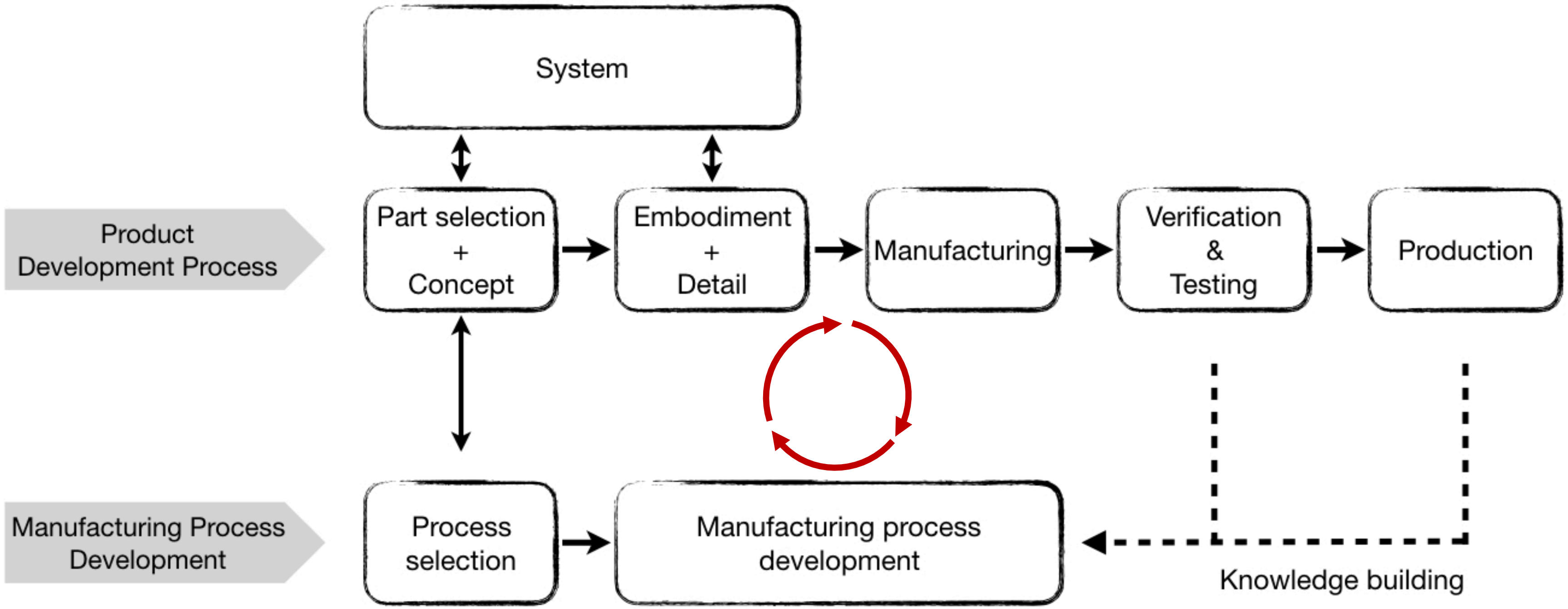
- **DfAM in the 'strict sense' – How to design a part utilising AM potentials (e.g. guidelines)**
- **DfAM in the 'broad sense' – Considerations for manufacturability, process suitability etc.**

Brandão et al. (2017). Challenges in Additive Manufacturing of Space Parts: Powder Feedstock Cross-Contamination and Its Impact on End Products. Materials, 10(5).
Kumke et al. (2016). A new methodological framework for design for additive manufacturing. Virtual and Physical Prototyping, 11(1).

PROCESS MODEL FOR DFAM



PROCESS MODEL FOR DFAM



- Build AM process experience
- Explore the design freedom
- Understand part criticality

➡ **Enabler for innovation!**

CONCLUSIONS

- Given the maturity of AM processes, learning by doing is inevitable and companies have to invest in **process development and process understanding** to fully utilise AM

- The ”rapid manufacturing” is an enabler to build this understanding through **concurrent process and part development**

- **Design for AM** is an integral part of using AM in product development, **also for qualification.** Challenges are:
  - Finding the right part design for the chosen AM process
  - Define the right level of requirements for the part

- **System knowledge** should be utilised in the development of space parts for AM, and in setting the right requirements for parts and their qualification

Picture from 3D Systems

OBJECTIVES REVISITED

- **Develop the product development process to facilitate the use of AM capabilities**
  - The proposed DfAM process model builds on findings from studying product development and qualification in the space industry. The model is currently being further developed in collaboration with industry in the RIQAM project (also NRFP3).

- **Define qualification strategies for AM in space applications**
  - Qualification strategies for AM are presented and discussed in the academic publications. In general, a deeper understanding of the process-part relationship and other qualification drivers are needed in order to qualify critical space components.

- **Identify prerequisites and limitations with AM technologies**
  - A literature review of AM Powder Bed Fusion processes is presented and discussed in the academic publications. Specifically, challenges for AM in space applications are emphasised.

  - Master thesis at GKN: *A Cost Breakdown and Production Uncertainty Analysis of Additive Manufacturing*

ACADEMIC CONTRIBUTIONS

Dordlofva, C., Lindwall, A. & Törlind, P. (2016). Opportunities and Challenges for Additive Manufacturing in Space Applications, Proceedings of NordDesign 2016, Trondheim, Norway.

Lindwall, A., Dordlofva, C. & Öhrwall Rönnbäck, A. (2017). Additive Manufacturing and the Product Development Process: Insights from the space industry, Proceedings of the 21st International Conference on Engineering Design (ICED 17), Vancouver, Canada.

Dordlofva, C. & Törlind, P. (2017). Qualification Challenges with Additive Manufacturing in Space Applications, Proceedings of the 28th Annual International Solid Freeform Fabrication Symposium, Austin (TX), USA.

Lindwall A. & Törlind P., (2018), Evaluating Design Heuristics for Additive Manufacturing as an Explorative Workshop Method, Proceedings of the Design Conference 2018, Dubrovnik, Croatia.

Thank you for listening!

christo.dordlofva@ltu.se

GRADUATE SCHOOL OF
SPACE TECHNOLOGY

Rymdstyrelsen
Swedish National Space Agency

RIT RYMD FÖR INNOVATION OCH TILLVÄXT

Co-funded by the European Union

GKN AEROSPACE