3D Printing for Small Modular Reactors : Technologies and Applications

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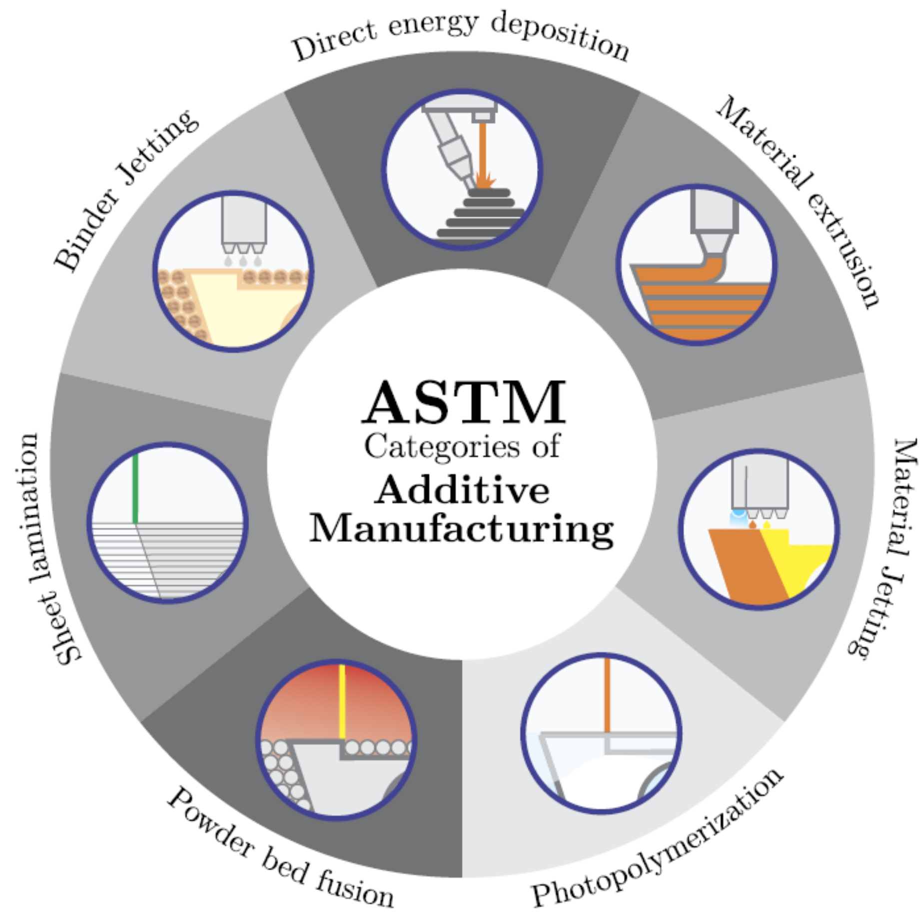
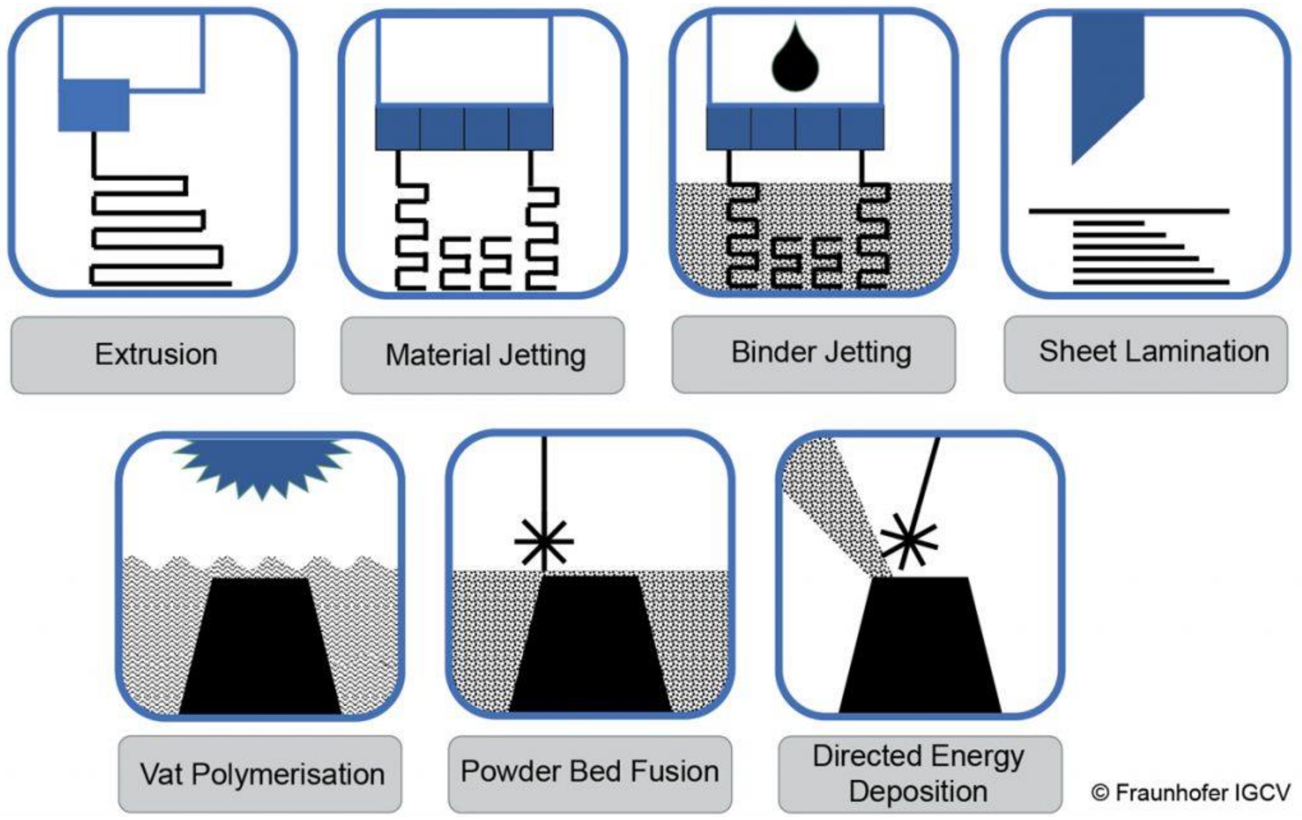
7 Categories of Additive Manufacturing Technologies



DIW

FDM | Polyjet | BJT | SL



SLA | PBF | DED

DLP | SLS | WAAM

SLM

Case Studies

Case Study 1 — ORNL & Kairos Power (3D-Printed Concrete Formwork)

July 23, 2025

Project Overview

- Collaboration between **Oak Ridge National Laboratory (ORNL)** and **Kairos Power**
- Development of **large-scale composite 3D-printed formworks** for casting concrete structures in advanced nuclear facilities

Key Benefits

Lead time reduction

Weeks → days
in producing complex construction molds

Design freedom

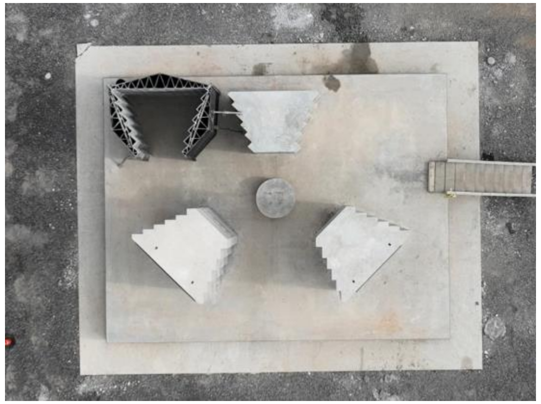
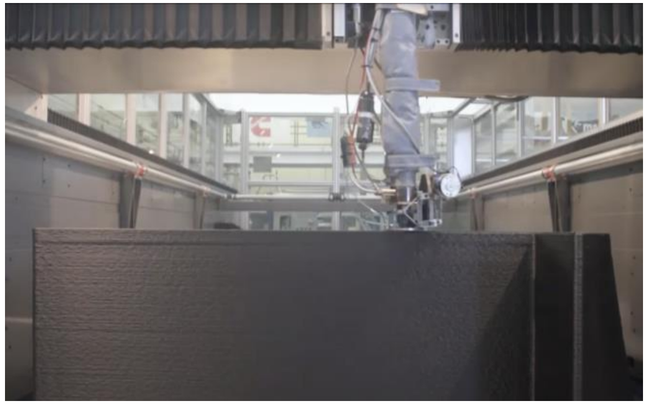
Curved/complex geometries
that are impossible with traditional timber/steel formworks

Rapid deployment

Direct factory-to-site implementation

Limitations & Considerations

- **Structural strength** of printed molds under heavy concrete load
- **Surface finish quality**, which may require post-processing
- **Regulatory approval**: adoption in nuclear-grade civil structures requires extensive certification


Case Studies

Case Study 2 — WAAM Pressure Vessel (ANDRITZ + FAME Ecosystem)

November 6, 2023

Project Overview

- Partnership between **ANDRITZ** and the **FAME ecosystem (Finland Additive Manufacturing Ecosystem)**
- Fabrication of a **300 kg pressure vessel** using **Wire Arc Additive Manufacturing (WAAM)** in stainless steel 316L

Key Benefits

111 bar hydrostatic pressure test

Comparable to operational nuclear conditions

Feasibility of large, safety-critical metal parts

Demonstration of using additive manufacturing

Limitations & Considerations

- **Standardization**: Pressure vessels must meet the pressure equipment directives and EN standardization
- **Post Processing time**: actual production time, including cooling, inspections and measurements, and learning, was about 300 hours

Quantitative Summary

- Build rate: significantly faster than Powder Bed Fusion **(3kg/hr)**
- Vessel mass: **~300 kg**
- Validation: full-scale hydrostatic testing confirmed mechanical integrity

Case Studies

Case Study 3 — Rosatom Pump Impeller

November 6, 2024

Project Overview

- Rosatom (Russia) applied metal additive manufacturing to produce a pump impeller for nuclear chemical plant applications
- Installed in operational nuclear facility infrastructure

Key Benefits

Direct in-service nuclear component

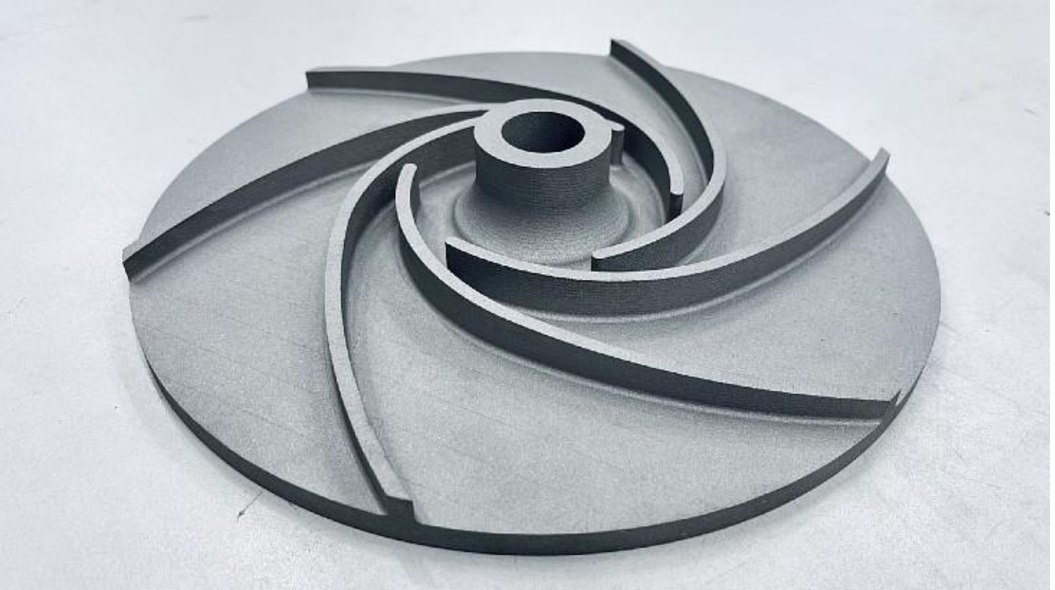
Additive manfunacturing verification

Proof of concept for retrofit parts

Conventional supply chains are limited

Limitations & Considerations

- **Material certification** (meeting nuclear-grade codes)
- **Service life prediction** under irradiation & corrosion
- **Non-destructive evaluation (NDE)** for defect detection



Case Studies

Case Study 4 — Westinghouse Electric Company

November 6, 2020

Project Overview

- A first-of-its-kind 3D printed component has successfully been **installed into a commercial nuclear reactor**
- The part, a 3D printed **thimble plugging device (TPD)**, was installed by nuclear energy company Westinghouse Electric Company at Exelon's Byron Unit 1 nuclear plant

Key Benefits

1st applications installed in a commercial nuclear reactor

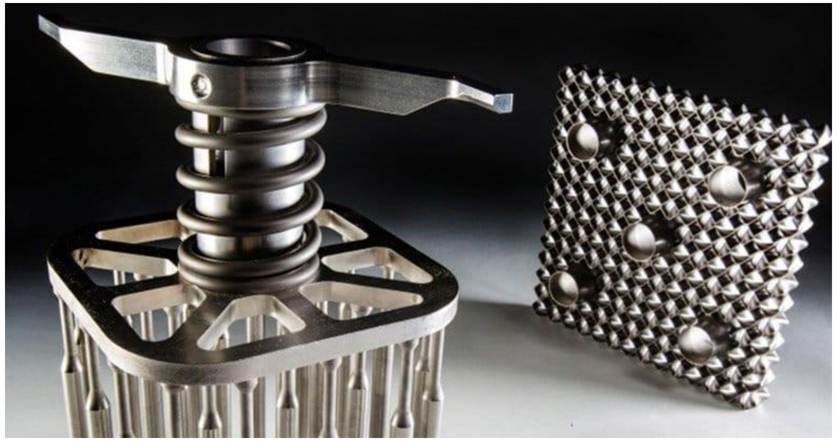
Additive manfunacturing verification

Hybrid approach

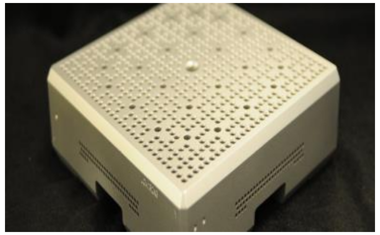
the AM plug was grown (built) onto an existing conventionally manufactured baseplate. This mitigates risk because the interface and mounting remain conventional

Expanded AM efforts

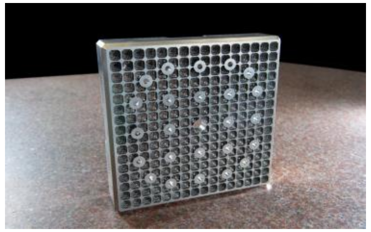
- **[February 3, 2021] Additively manufactured debris-filtering bottom nozzle (ADFBN)**
  for fuel assemblies to mitigate debris fretting
- **[July 3, 2024] 3D printed bottom nozzles in a test assembly for PWRs**
  ~30 % improvement in resistance to debris
- **[March 26, 2024] 1,000th 3D printed fuel flow plate for VVER-440 fuel assemblies**
  from prototyping to full-scale production



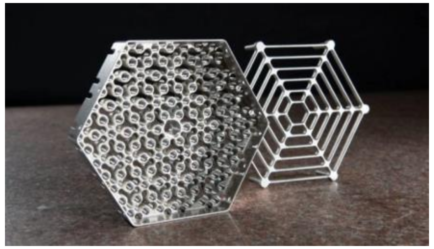
[2020] Thimble plugging device



[2021] Debris-filtering bottom nozzle



[2024] Debris-filtering bottom nozzle



[2024] Fuel flow plate

Case Studies

Case Study 5 — Silicon Carbide FCM fuel

Project Overview

- Nano Nuclear's FCM concept embeds TRISO (tri-structural isotropic) fuel particles (uranium oxycarbide or similar) into a **silicon carbide** (SiC) matrix rather than a soft graphite or carbon matrix

- The SiC matrix is manufactured via **binder-jet 3D printing** of SiC powder + binder into a "green" porous shape, then densified by **chemical vapor infiltration (CVI)** to fill pores with SiC and achieve structural integrity.

Key Benefits

Multiple inherent safety barriers

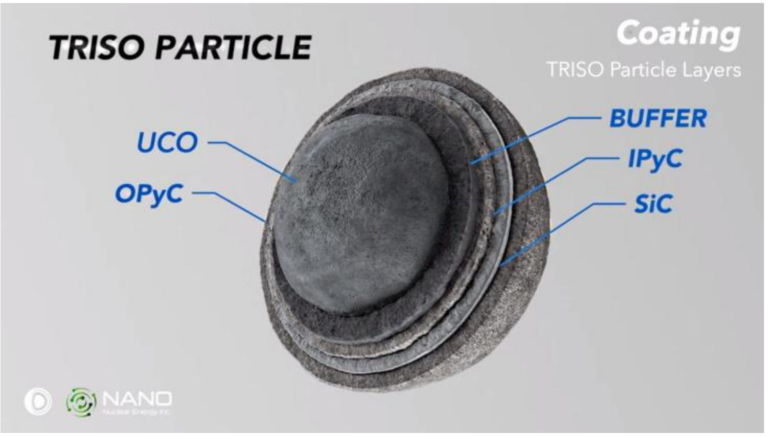
SiC is refractory, stable, corrosion/oxidation resistant, and the TRISO particles already have multiple ceramic coatings

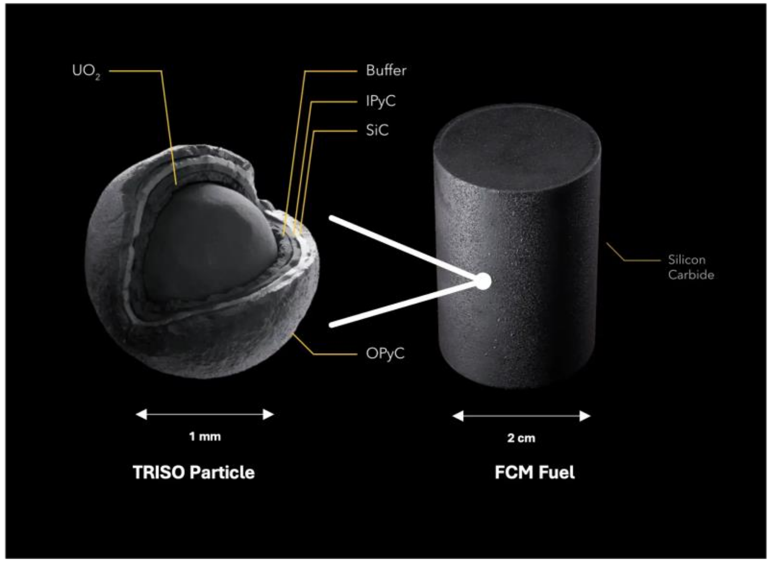
High temperature stability & structural integrity

SiC can withstand high temperatures, has low swelling, low chemical reactivity, and good mechanical strength in harsh environments

Geometric freedom & complex internal features

Allows internal cooling channels, custom shapes, non-standard geometries (which are hard or impossible by conventional machining)



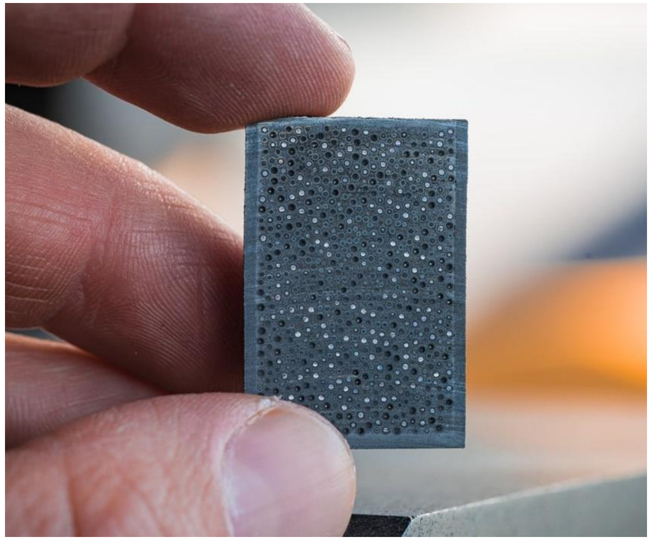


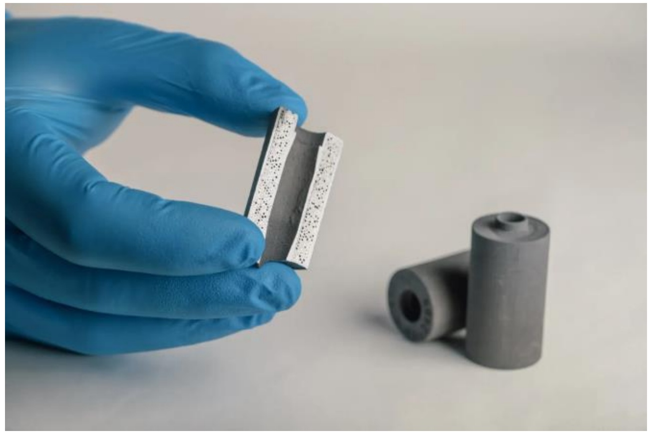
Case Studies

Case Study 5 — Silicon Carbide FCM fuel

Sol-Gel Process

SiC 3D Printing





Technical Details

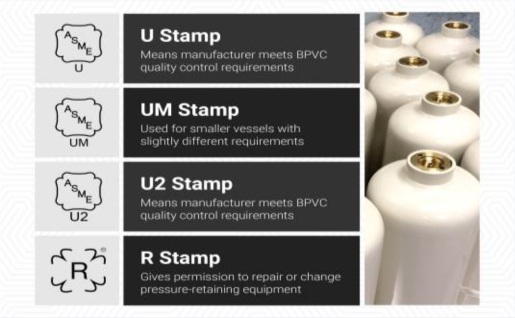
Quantitative Comparison

Metric	Conventional Manufacturing	Additive Manufacturing (AM)	Improvement
Lead time	6–12 months (casting/forging)	Weeks to months (WAAM / Binder Jetting)	Up to 80–90% faster
Cost	High (tooling, logistics, machining)	Lower (tool-less, localized)	30–70% reduction
Design	Limited by casting/forging	Complex geometries possible	New functional designs
Materials	Forging-grade steels, alloys	Stainless steel, Inconel, SiC, Tungsten	Expanding portfolio
Nuclear demo	Limited pilot projects	ORNL, Rosatom, ANDRITZ, Vattenfall, INL	Rapidly increasing

Technical Details

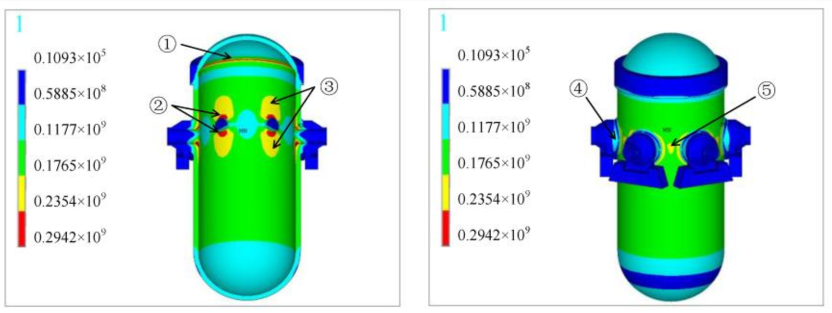
Technical Risks & Challenges

Material certification under ASME Boiler & Pressure Vessel Code

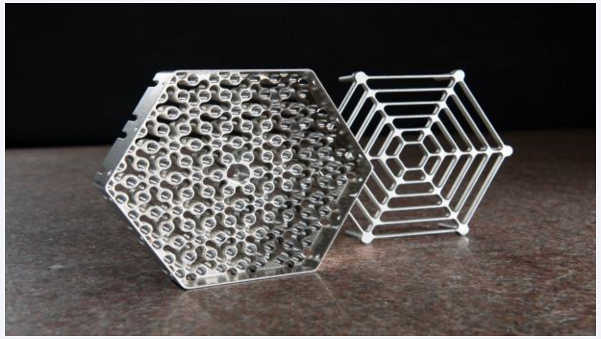


Non-Destructive Examination (NDE/NDT) challenges (CT scanning, in-situ monitoring)

Irradiation & thermal fatigue performance still under evaluation



Governance gap: lack of fully established AM design codes for nuclear



Conclusions

Value Proposition of Additive Manufacturing in Nuclear Applications

Shortens Supply Chains

Less Time

X 9

Reduces Costs

Less Cost

X 3

Enables New Nuclear Designs

Design

NEW

Conclusions

*FCM : Fully Ceramic Microencapsulated

MADDE: Delivering Integrated Additive Manufacturing Solutions

SiC 3D Printing :
FCM* shells or high thermal applications

Wire Arc Additive Manufacturing :
Large-scale metal products

Freedom in Manufacturing

We Print Universe