Additive Manufacturing (R)evolution perspective: from prototype towards mass production

… from “Rapid Prototyping” to “Direct manufacturing”

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- AM evolution impact on manufacturing plants and working force
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Additive Manufacturing evolution

Additive Manufacturing (3D printing) history

Plastic based development

Metal based development

Production

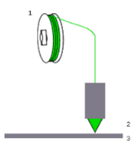
Initial Commercialization of stereolithography
Stereolithography (SL)

first Stereos stereolithography system
EOS

Deposition modeling (FDM)
STRATASYS

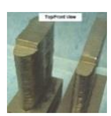
solid ground curing (SGC)
CUBITAL

laminated object manufacturing (LOM)
HELISYS



Selective laser (CO2) sintering (SLS)
DTM

Wax with Inkjet print head
Solidscape



laser (CO_2) additive manufacturing (LAM) for Titanium based powder
AeroMet

ABS parts with FDM technology
STRATASYS

Laser (CO_2) sintering steel based powder
EOS

Laser (Fiber) sintering metal based powder
TRUMPF
EOS

Cusing Laser melting
CONCEPT Laser

New system suitable for thinner wall
EOS

New resins
DSM Somos

small RX-1 metal-based machine [40x60x25 mm]
Ex ONE

Medical protesys

New resins for CRP
3D System

New laser sintering
EOS

New larger EBM (electron beam melting)
ARCAMM

New system for dental application
Solidscape

powder bed by selectively melting powder with a Trumpf disk laser
Trumpf

NanoTool: nanoparticle-filled photopolymer for SL
DSM

Agreement for EBM technology
STRATASYS + EOS

MLS MicroLightSwitch technology
Huntsmann

Larger SLM [250x250x300 mm]
MTT

Titanium grade 2
ARCAMM

High elongation PA
EOS

Consumer Maker 3D printers

Inconel alloy and Al-Si10-M [550x393x300 mm]
EOS + Advanced laser material

New line for medical
Renishaw

New materials, CRFP
MATERIALISE

3D bioprinting software
Autodesk

New metal powders for Additive Manufacturing
Alcoa

LPT Blade

Aero Structures

Drill tool

New filament for FFF (fused filament fabrication) systems
BASF

New metal powders for Additive Manufacturing
GKN Hoeganaes, Voestalpine Steel Division

New Binder Jetting system for metal based technology
MIT / ExOne

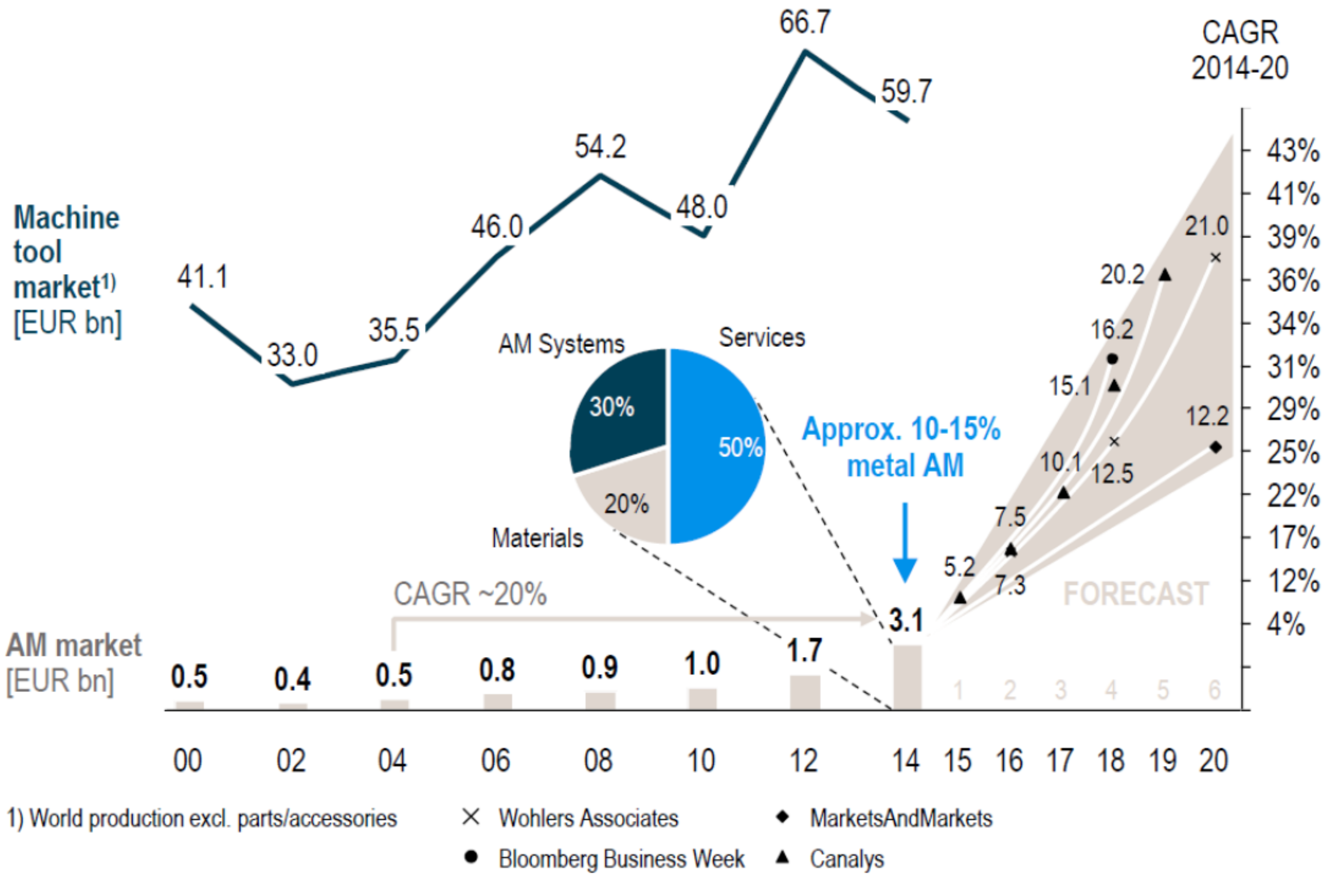
New FFF system for metal based technology / ADAM
Markforge

New large laser-powder AM machine (1mx1mx1m) / (2mx0.6mx0.6m)
GE / Aeroswift

1987 1990 1991 1992 1994 1997 2000 2001 2003 2004 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

Technologies, equipment and materials trend

Global AM market development (Source: Roland Berger)



Details

- Market growth between 2010 and 2014 was higher than 30% p.a.
- Future market growth expected to range between 25 and 40% depending on different sources
- Up to 2014, German manufacturers provided almost 70% of the 1,601 metal AM systems (PBF) sold worldwide

Source: Roland Berger;
Source: Additive Manufacturing –next generation Amnx, Roland Berger, April 2016

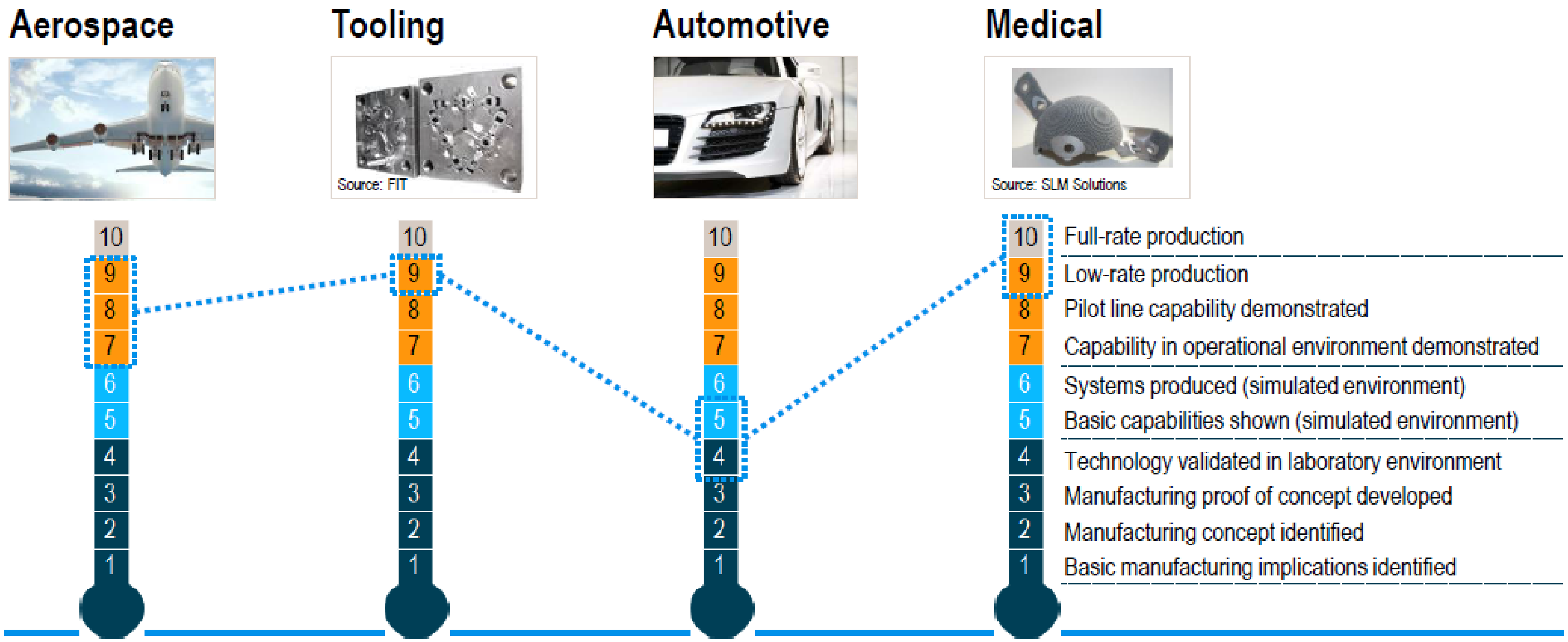
Technologies, equipment and materials trend

Advantages	disadvantages
Complex and arbitrary geometry possible, overhang	Process stability
Shorter time from design to pilot batch	Building time depends on cross-section, higher time with respect mass production target
Customized production	Time consuming process and post processing required
Efficient production: recycling almost the entire powder material	Support structures are necessary
Very thin wall, lattice structure	Risk of deformation during building and cooling down (residual stress)
Cost profitable for small series	Raw material and process cost higher with respect mass production target

TRL in AM

Additive Manufacturing is a step up from rapid prototyping – Series production manufacturing readiness level differs by application

Series production manufacturing readiness level



Examples

Aerospace
- Fuel injection
- Structural elements
- Blades

Tooling
- Tooling inserts

Automotive
- Air ducts
- Formula 1 components

Medical
- Crowns and copings
- Artificial hip joints
- Medical instruments

Source: Roland Berger;
Additive Manufacturing (AM) – Opportunities in a digitalized production, Additive Manufacturing European Conference , Brussels, June 23rd, 2015

Applications (examples automotive field)

Stub axle, configured to optimize load and resources, manufactured by SLM. (Courtesy: Fraunhofer ILT, Aachen, Germany/Volker Lannert)

An exhaust manifold manufactured by Selective Laser Melting at FIT

In year 2015 BMW installs 500th metal AM racing car water pump wheel.
In a **race**, the high-performance powertrains run up to 70% of the time under full load.

Two Concept Laser M1 cusing systems with a central material supply container are used. The systems, from the medium performance range, have a build envelope of 250 x 250 x 250 mm. The QTD insert drills are created as 10×10 or 11×11 unit solution in this build envelope. 100 to 121 drills are produced in one set-up.

Source: http://www.industrial-lasers.com/articles/print/volume-28/issue-2/features/laser-additive-manufacturing.html

http://www.conceptlaserinc.com/mapal-relies-on-additive-manufacturing-for-qtd-series-insert-drills/

Applications (examples automotive field)

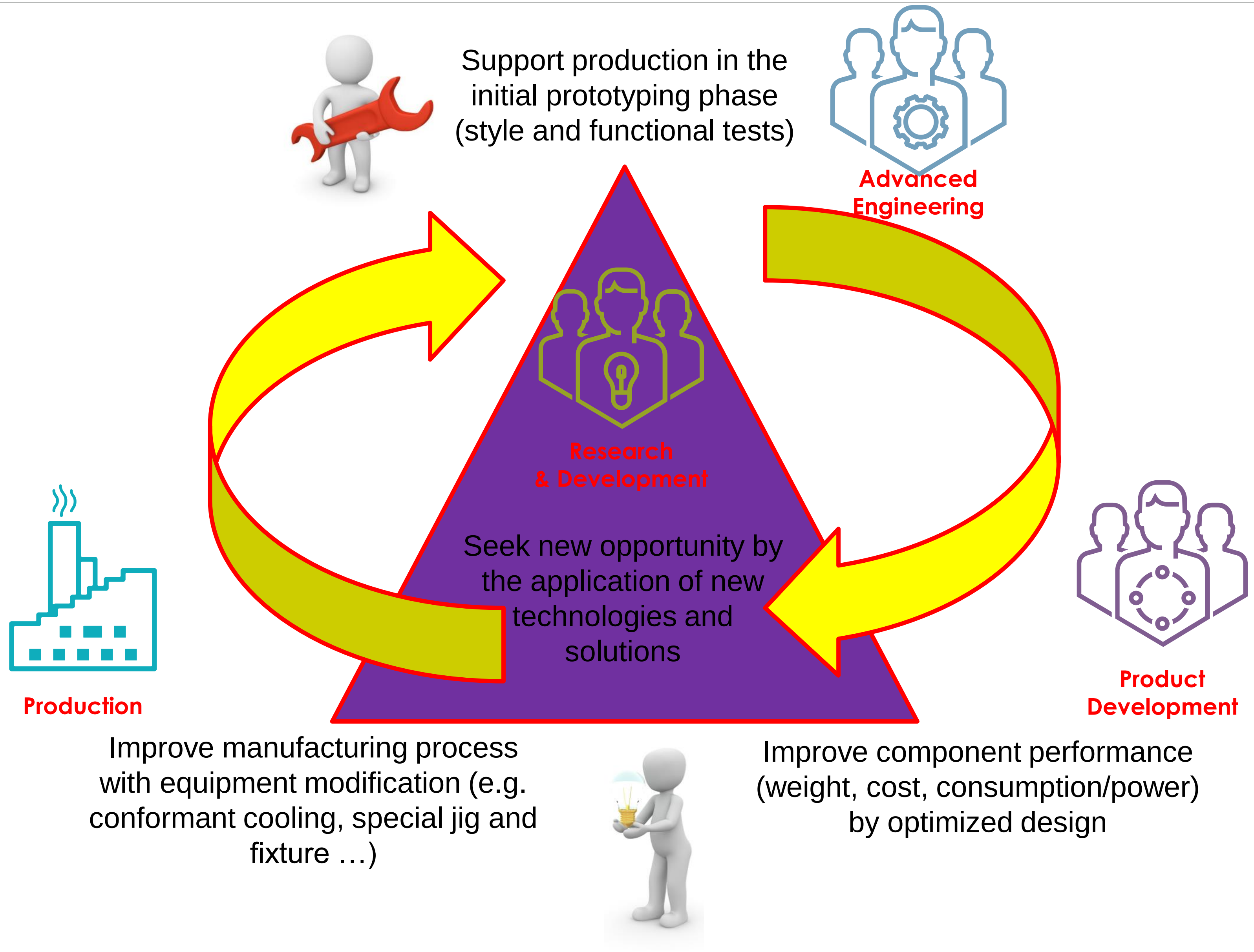
This concept F1 Cylinder Head is manufactured on a SLM 500 machine using AlMg10Si powder by FIT. By applying Additive Design and Manufacturing, FIT used AM technology to significantly increase the surface cooling area while achieving reduced vibration and great weight reduction of the part from 5.1 kg to 1.9 kg, equating to a 66 % weight reduction.

TRL ?

Mockup of a V8 engine block (proportion 1/3) produced by LAM on a Concept Laser machine. In the future, these automotive parts can be produced full scale and with significant higher build-up rates by using more powerful lasers < 1 kW. (Copyright: Fraunhofer ILT, Aachen, Germany)

In 2016 Fully functional additively manufactured automotive cylinder block produced for Volkswagen. Built in 300 hours on a Concept Laser X 1000 R system

AM in CRF/FCA


Support production in the initial prototyping phase (style and functional tests)
Advanced Engineering
Research & Development
Seek new opportunity by the application of new technologies and solutions
Production
Product Development
Improve manufacturing process with equipment modification (e.g. conformant cooling, special jig and fixture …)
Improve component performance (weight, cost, consumption/power) by optimized design

Product development: EMEA prototypes

Fattibilità di massima

Progettazione componenti

Verifiche di processo

1 2 **3** 4 5 6 7

1° Concept della vettura

Approvazione dello Stile

Attrezzamento definitivo

Inizio produzione

Fase 3

EMEA Product Development

Prototypes

Missione:
Essere partner di Centro Stile per l'attività di sviluppo modelli di stile e rendering

Product development: EMEA prototypes

Fattibilità di massima

Progettazione componenti

Verifiche di processo

1 | 2 | 3 | **4** | 5 | 6 | 7

1° Concept della vettura

Approvazione dello Stile

Attrezzamento definitivo

Inizio produzione

Fase 4

EMEA Product Development

Prototypes

Missione:

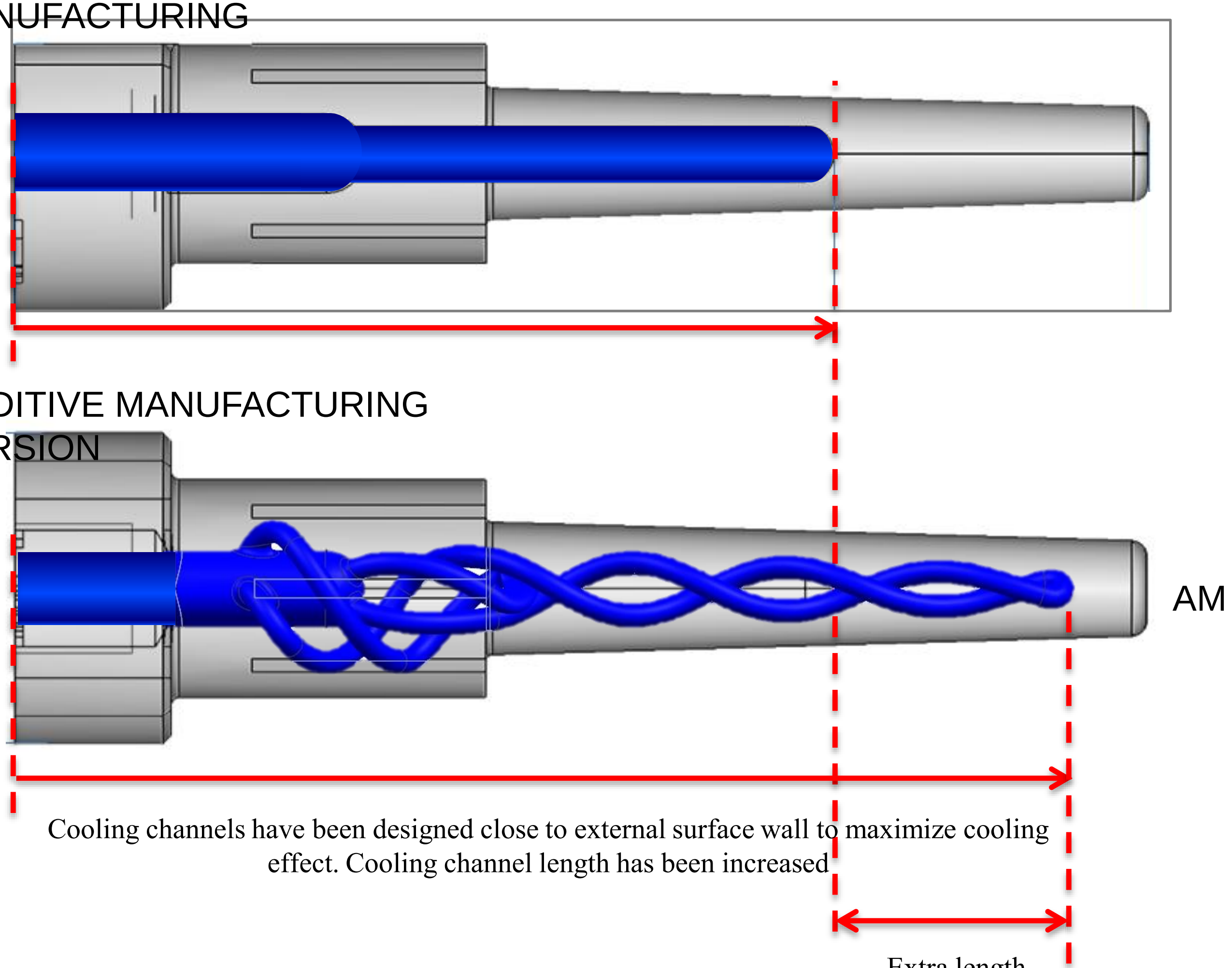
Produrre componenti per muletti e prototipi al fine di testare la **soluzione ottimale** in tempi ridotti e dare al cliente prodotti sempre più **innovativi e di qualità**.

Case studies CRF/FCA

Heat extractor tool for metal casting, redesigned for conformant cooling.

CONVENTIONAL DESIGN AND MANUFACTURING

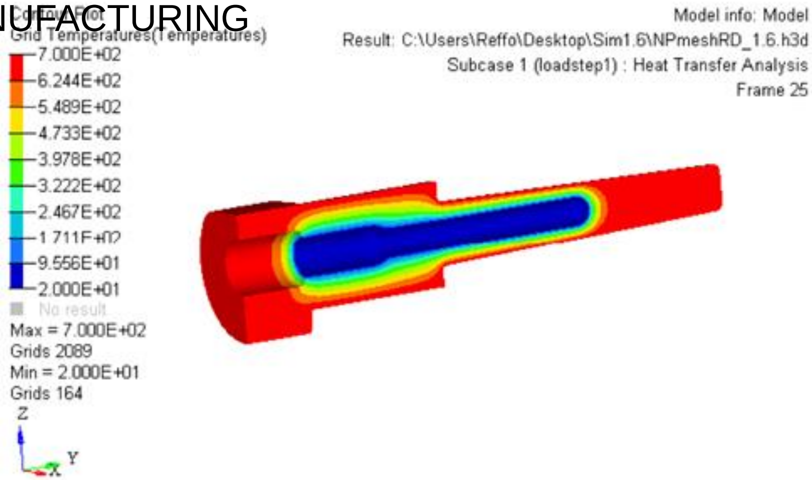
ADDITIVE MANUFACTURING VERSION



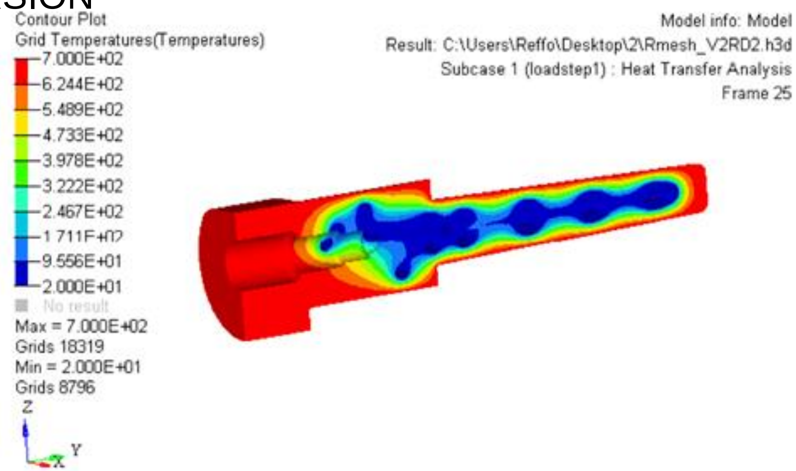
Cooling channels have been designed close to external surface wall to maximize cooling effect. Cooling channel length has been increased

Case studies CRF/FCA

CONVENTIONAL DESIGN AND MANUFACTURING



ADDITIVE MANUFACTURING VERSION



Prototype manufactured on **Concept Laser** equipment

Benchmark and scouting with international collaboration

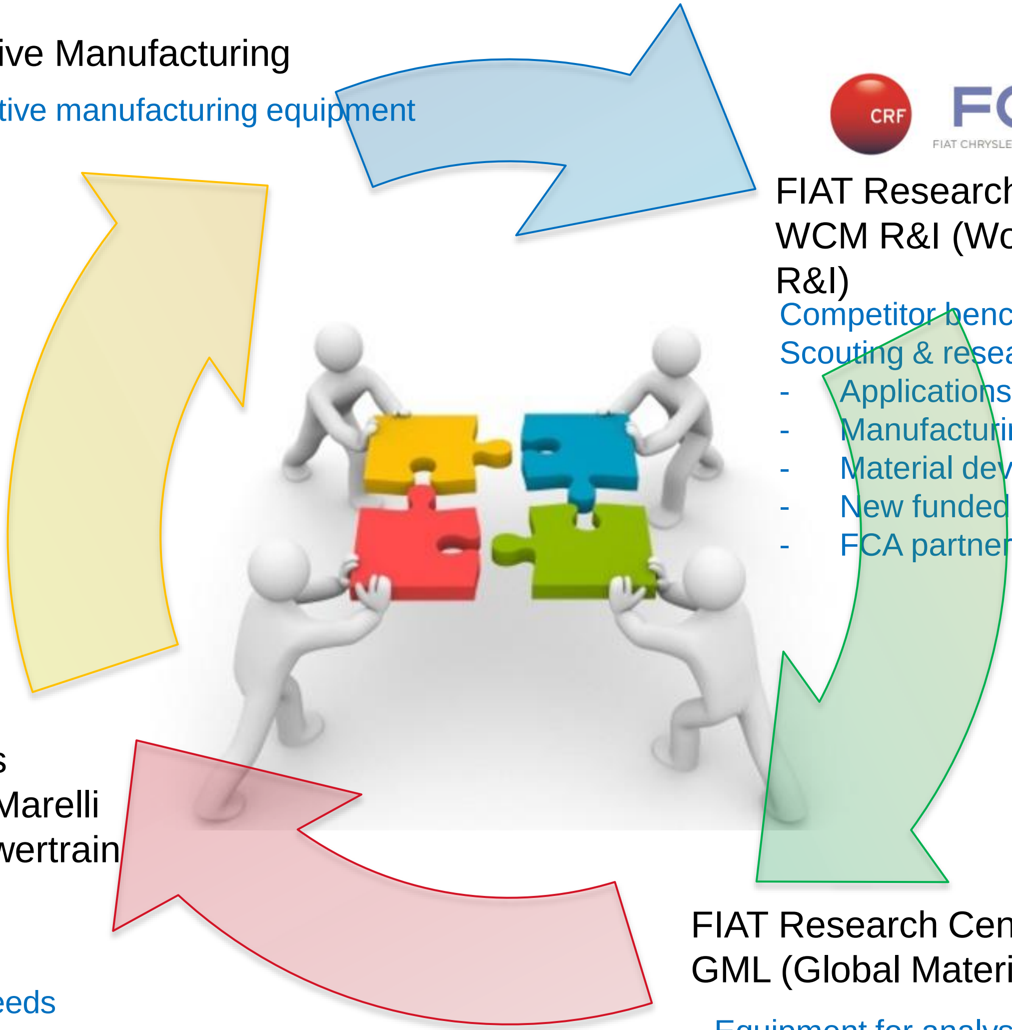
1. Co-funded Projects on AM technologies:
   - A. European H2020 framework:
     1. ENCOMPASS project (July 2016-June 2019):
        - Integrated Component and Process Design tool which will be a comprehensive integrated additive manufacturing (AM) process chain decision support
     2. OpenHybrid project (July 2016-June 2019):
        - developing a novel hybrid AM approach which will offer unrivalled flexibility, part quality and Productivity
     3. PALMS project (July 2017-December 2019):
        - Investigate new surface coating procedure for AM component
   - B. Piattaforma Piemonte:
     1. STAMP project (2016-2018):
        - Process evolution, application benchmark, new AM architecture investigation
2. International cooperation:
   1. Research Institutions: MTC (UK), Fraunhofer (DE), …
   2. Supplier: Renishaw (UK), Concept Laser (DE), EOS (DE) … new companies
   3. University: POLI Torino (IT), UNI Fisciano (IT), RWTH Aachen (DE), …
   4. SW house: Altair (IT), ESI (DE), Autodesk …

Working team / resources

FCA

EMEA prototypes Additive Manufacturing

Rapid prototyping and additive manufacturing equipment
Prototyping manufacturing
Technology testing



FIAT Research Centre
WCM R&I (World Class Manufacturing R&I)

Competitor benchmark (Patent search / Papers)
Scouting & research activity:
- Applications selections vs AM
- Manufacturing technologies improvement
- Material development
- New funded R&D projects preparation
- FCA partner hub for collaboration

FCA partners
- Magneti Marelli
- CNHi powertrain
- Teksid
- COMAU

Application needs

FIAT Research Centre
GML (Global Material Lab

Equipment for analysis (tensile, metallurgical)
Material analysis, qualification

Prototypes features

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Machines, using 4 different technologies

10

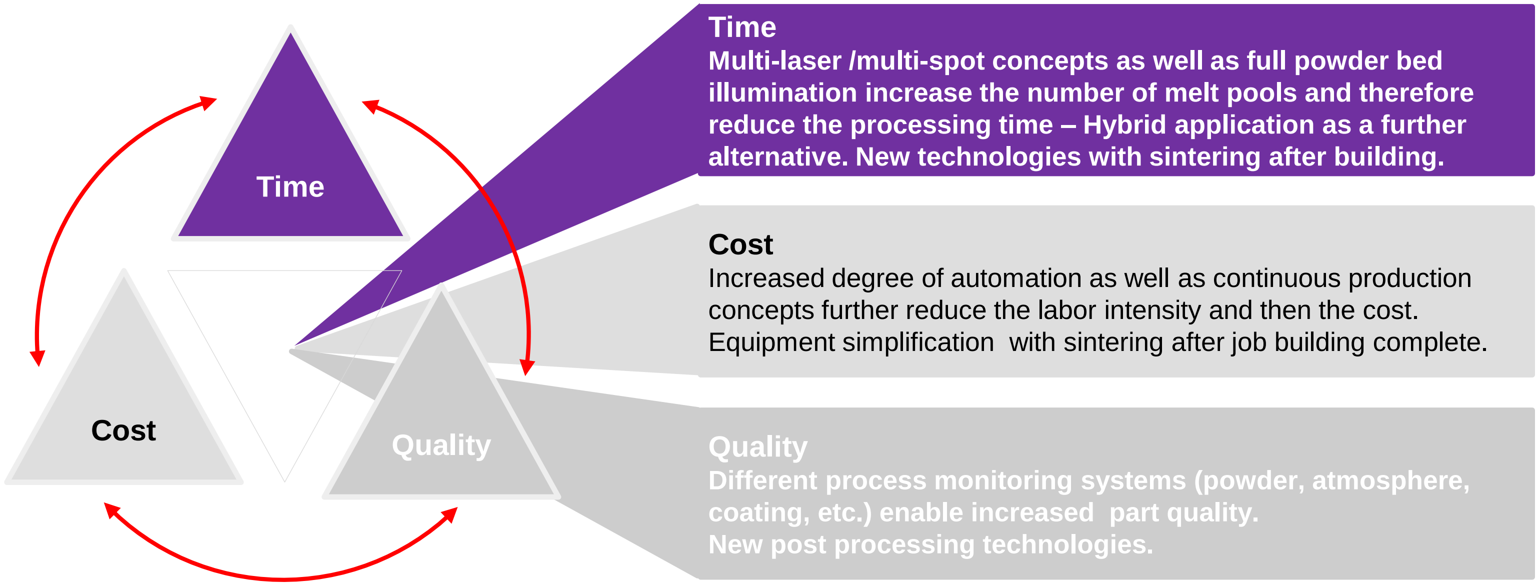
Plastic and metallic materials

Centre for Additive Manufacturing for the realization of **plastic** and **metal** parts for both prototyping and small batch production.

Additive Manufacturing Technological Evolution

How far is Additive Manufacturing from mass production?
Which are weak points? What are still the open demand from the market?
… Production time, cost and quality (including part dimension, material type, post processing operation, properties homogeneity) …

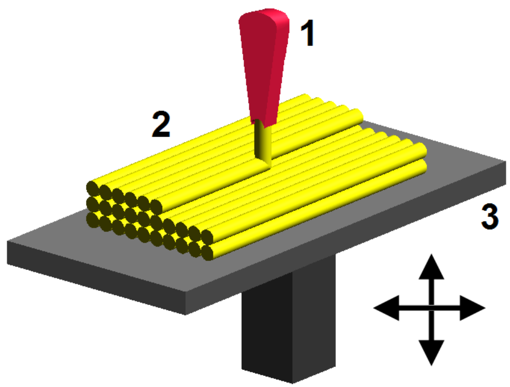
Next generation of Additive Manufacturing systems will approach an optimum in the triad of time, cost and quality

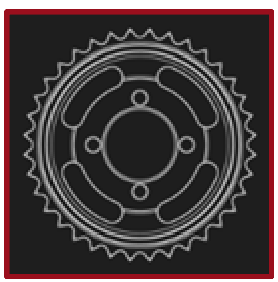


Current process with layer deposition and sintering suffers from longer manufacturing time and material properties limitation due to continuous sintering and cooling steps over the layer by layer component construction. ***Breakthrough approach: contamination by different technologies and sintering process decupling from material addition process***.

Breakthrough in Metal Additive Manufacturing: AM with metal filament

New equipment based on Fused Filament Fabrication (FFF) technology evolution for metal: ADAM (Atomic diffusion additive manufacturing) is an ***intersection of AM and Metal Injection Molding.***





DESIGN

CAD with design for AM part

GREEN PART

Like Metal Injection Molding printed part are "green"

SINTER

Remove binder and sinter metal powder into fused solid metal

FINAL PART

Pure full metal and 99,7% dense

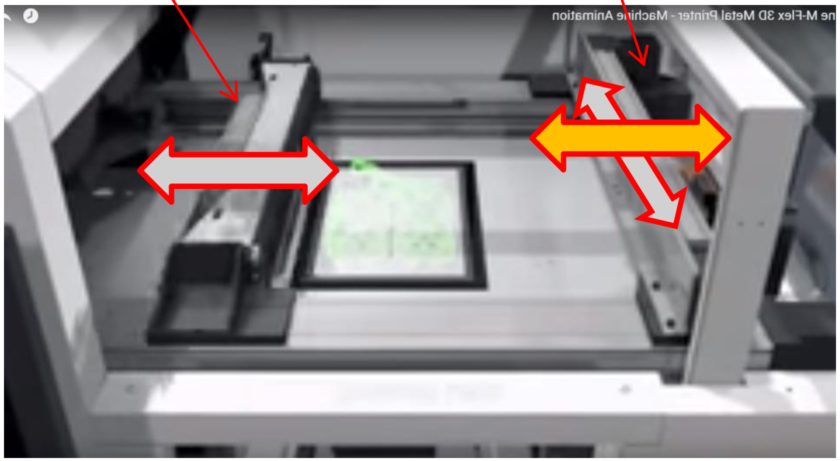

80 μm
RESOLUTIO
N
$12.56
PART COST
CAMSHAFT SPROCKET

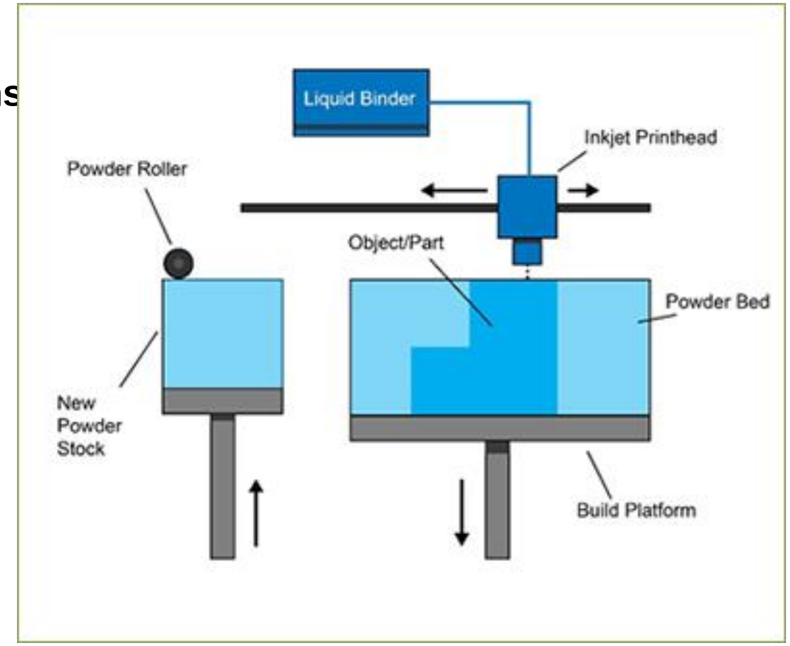
Breakthrough in Metal Additive Manufacturing: binder jetting technology

CRF

New binder jetting, ***based on Inkjet technology*** *where metal powder and binder are used. Layer by layer, a* ***liquid binding agent*** *is selectively deposited by a printhead to join powder particles to form an object.*
Materials are typically cured and sintered and sometimes infiltrated with another material, depending on the application. Hot isostatic pressing may be employed to achieve high densities in solid metals.

Metal powder dispenser ***Printhead with*** **binder dispens**

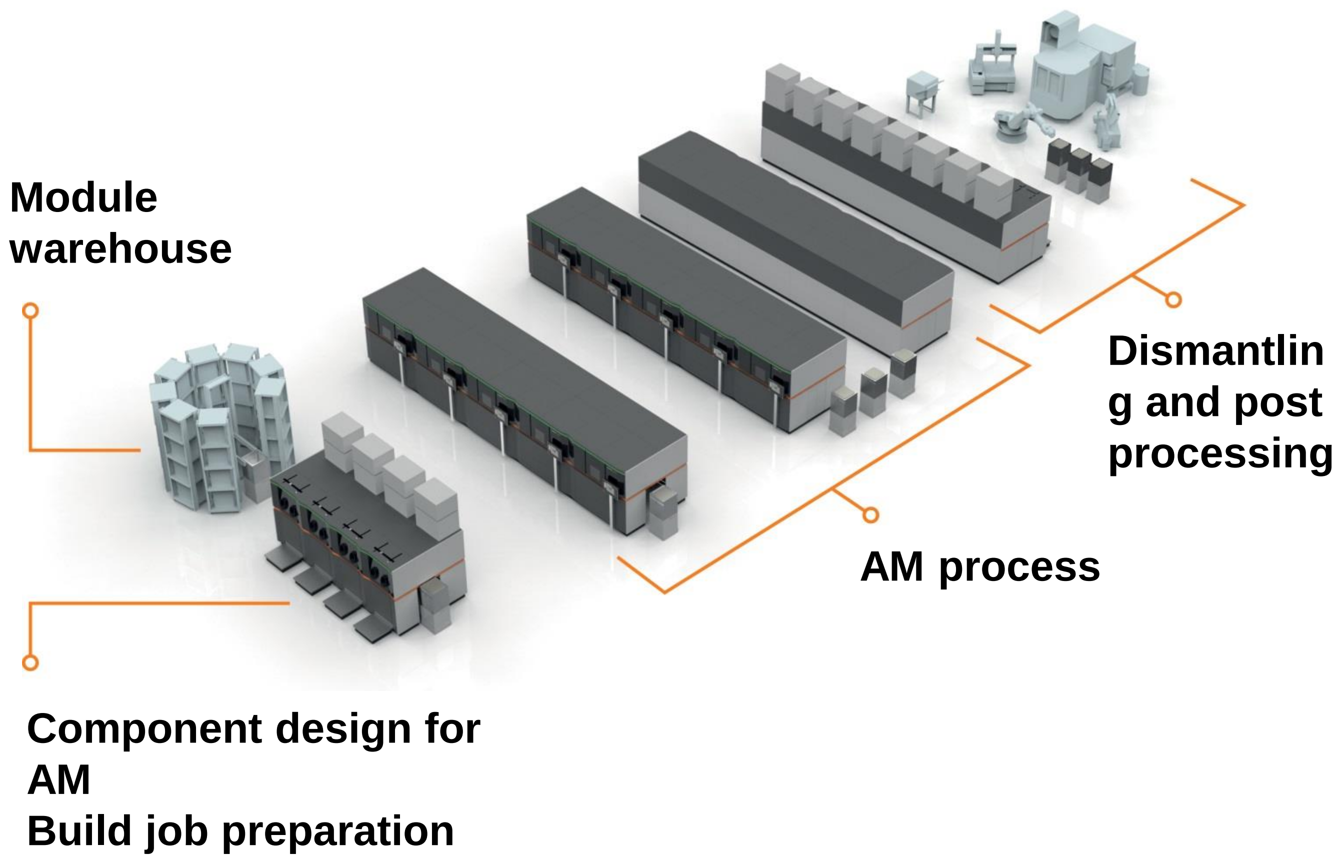




Binder Jetting is similar to traditional paper printing. The binder functions like the ink as it moves across the layers of powder, which like paper, forms the final product.

Impact on factory

Smart factory is highly scalable and modular. Can provide a quick response to a changed production program of products.



Impact on working force

Invest on software solutions and expertise to maintain competitiveness

Importance of software and skills for the further industrialization of AM to enable a fully digital value chain. In terms of expertise, digital capabilities were recognized as fundamental to accelerate the adoption of additive techniques.

Academia

- Fundamentals of 3D printing with a focus on laser beam melting and other technologies
- Design for additive manufacturing principle

Skills Improvement

Academia / SW house

- Understand the full process chain for lightweight design
- Bionic design principles
- 3D print your own design and take it home with you!

Design for AM

Industry

- Exploit the know-how in a real contest
- Work with industrial metal 3D printers along the end-to-end process chain

Skills Improvement

Labs / Research Centre

- Hand on learning experience
- Business case on additive manufacturing

Skills Improvement

Conclusion

- Market demand increase AM solution development.
- Current AM technology limitations will be overcome by continous technology evolution:
  - New approaches with solution to reduce cost, time, and increase quality and dimension available: recent breakthrough technology, still to be validated…
- Continuous innovation and technological research in needed:
  - Impact on society with new skills: academia and industries together to form and exploit the new generations

Working team acknowledge

Daniele Bassan
Project Manager
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EMEA – Manufacturing – Premium Brands
World Class Manufacturing Research & Innovation

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CAD/CAM & Innovation Manager
FCA
EMEA – Product Development
Prototypes, Services & Proving Ground
Prototypes - CAD/CAM & Innovation