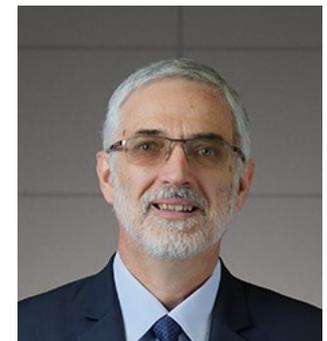




Une vision systémique de la fabrication additive métallique : développements, challenges et tendances pour le futur

Alain BERNARD

Professor Emeritus at Ecole Centrale de Nantes
 Researcher at LS2N UMR CNRS 6004
 Vice-President of France Additive
 Fellow of the Academy of Technologies of France



Outline of the presentation

- 📄 France Additive
- 📄 Additive manufacturing: A systemic approach
- 📄 Main strengths of Additive Manufacturing
- 📄 Main future goals for Additive Manufacturing
- 📄 Conclusions

Outline of the presentation

France Additive

 Additive manufacturing: A systemic approach

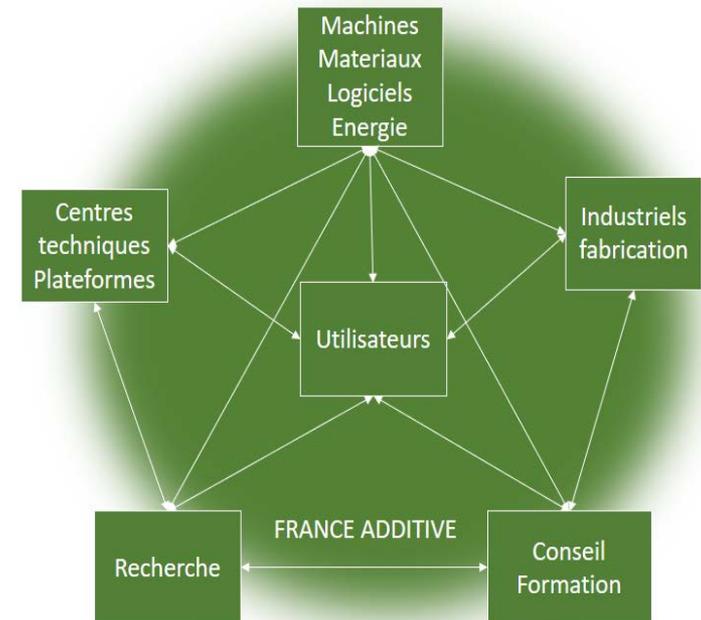
 Main strengths of Additive Manufacturing

 Main future goals for Additive Manufacturing

 Conclusions

About France Additive

- Non profit association dedicated to AM, funded in 1992
- 160+ members. Multisectors, open, neutral
- Federate research and technical centers, education, industrials, services providers and final users
- 360° scope in an open community mode:
 - applications
 - technologies
 - materials
 - skills
 - R&D
 - digital
 - education
 - finance
 - supply chain
 - economic growth



Source: France Additive, 2021

160+ members

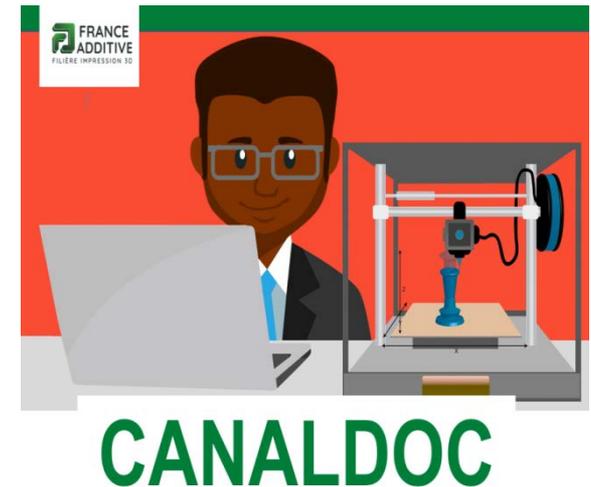


Source: France Additive, 2021

Working groups in open community

Initiated by the members and animated by them, working groups on various topics are being proposed:

- 🔧 Maintenance, repairing and repairability of parts
- 🔧 Luxury – precisions and precious materials – Artisan of the future
- 🔧 Automobile and new mobilities
- 🔧 Large parts – DED and WAAM
- 🔧 Training
- 🔧 Health / Medical
- 🔧 Safety at work
- 🔧 SME executive club
- 🔧 Program managers executive club
- 🔧 Canal Doc (for PhDs and post-docs)
- 🔧 ...



Recent creation of a new Branch Strategic Contract

SOLUTIONS INDUSTRIE DU FUTUR



GOALS

- Accelerate the development of AM in France
- Improve the competitiveness of French AM activities
- Improve the cooperation between all the actors of the ecosystem within complete value chains
- Boost the technical investments in the field of AM

Source: France Additive

Forum France Additive 2023



Source: France Additive

Forum France Additive 2023

MARDI 4 JUILLET

- 9h05 - 9h30 Ouverture Plénière
- 9h30 - 9h55 Future actions for the AM development and successful market uptake: AM European Roadmap
- 9h55 - 10h20 Impression 3D et crypto-objets post-quantiques
- 10h20 - 10h45 Panorama de 5 années de recherche mutualisée en Fabrication Additive Métallique et 22 doctorants.
- 10h45 - 11h10 Cybertron, l'usine à usines 4.0 !
- 11h10 - 11h35 Impression 3D en milieu hostile : quels modèles commerciaux pour un passage à l'échelle ?
- 11h35 - 12h00 Advances in 3D biomanufacturing

- 13h30-14h30 Conception machine hybride open-source
- Développement des polymères techniques en Fabrication Additive
- Les nouveaux matériaux et alliages haute performance métallique en fabrication additive métal
- 14h30-15h30 Alimentaire

- 16h LURPA
- La Fabrique
- AFH Air Liquide
- Arts Numériques

MERCREDI 5 JUILLET

- 8h15-8h40 Fabrication additive métallique ou Impression 3D métal : Etat des connaissances sur les risques pour la santé
- 8h40-9h05 Les normes : un outil pour le développement de la fabrication additive
- 9h05-9h30 La fabrication additive DED fil à Airbus Commercial : développements et perspectives industrielles

- 10h25 Avancées des procédés de fabrication sur lit de poudre
- La recherche française au service de l'industrie
- Formalisation et gestion des connaissances pour la FA

- 13h30 Avancées des procédés de fabrication sur lit de poudre
- La recherche française au service de l'industrie
- Conception et chaîne numérique

- 16h Avancées des procédés de fabrication sur lit de poudre
- Les procédés DED et WAAM montent en maturité industrielle
- Impression 4D
- 17h-19h Post-traitements

- 18h-19h Program Managers
- 18h-19h Club des dirigeants

JEUDI 6 JUILLET

- 8h25 JO (durée et contenu à préciser)
- Construction Robotique pour la FA
- DED et WAAM se chaussent en grande taille

- 10h25 La FA à l'international
- Construction Robotique pour la FA
- Une panoplie d'outils numériques pour le DED et le WAAM

- 13h30 Avancées sur les matériaux céramiques et métalliques
- L'innovation dans les poudres polymères SLS au service des enjeux industriels
- Quoi de neuf en DED et WAAM dans les centres de développement ?

- 15h55 Procédés émergents
- Optimiser les flux de trésorerie grâce à la fabrication additive
- Quoi de neuf en DED et WAAM dans les centres de développement ?

Plénières
 Visites
 Sessions

FRANCE ADDITIVE
FILIERE IMPRESSION 3D

FORUM FRANCE ADDITIVE
Paris Saclay - 4, 5 et 6 juillet 2023

la fabrication additive pour une industrie profitable et durable

FRANCE ADDITIVE

19h-20h Assemblée Générale 20h-23h Cocktail dînatoire et remise des Trophées

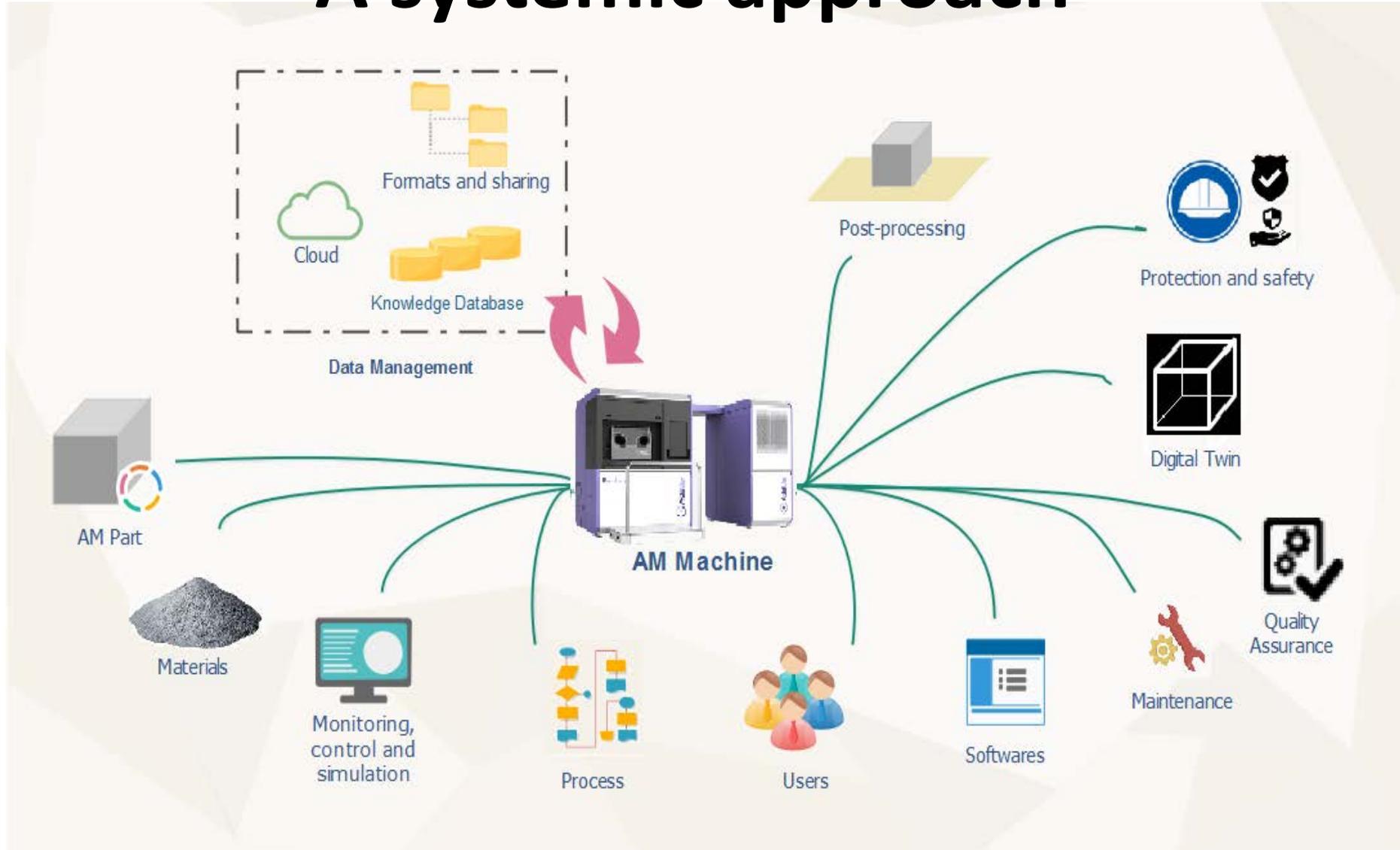
Avec le soutien de

INSCRIVEZ-VOUS DÈS MAINTENANT

Outline of the presentation

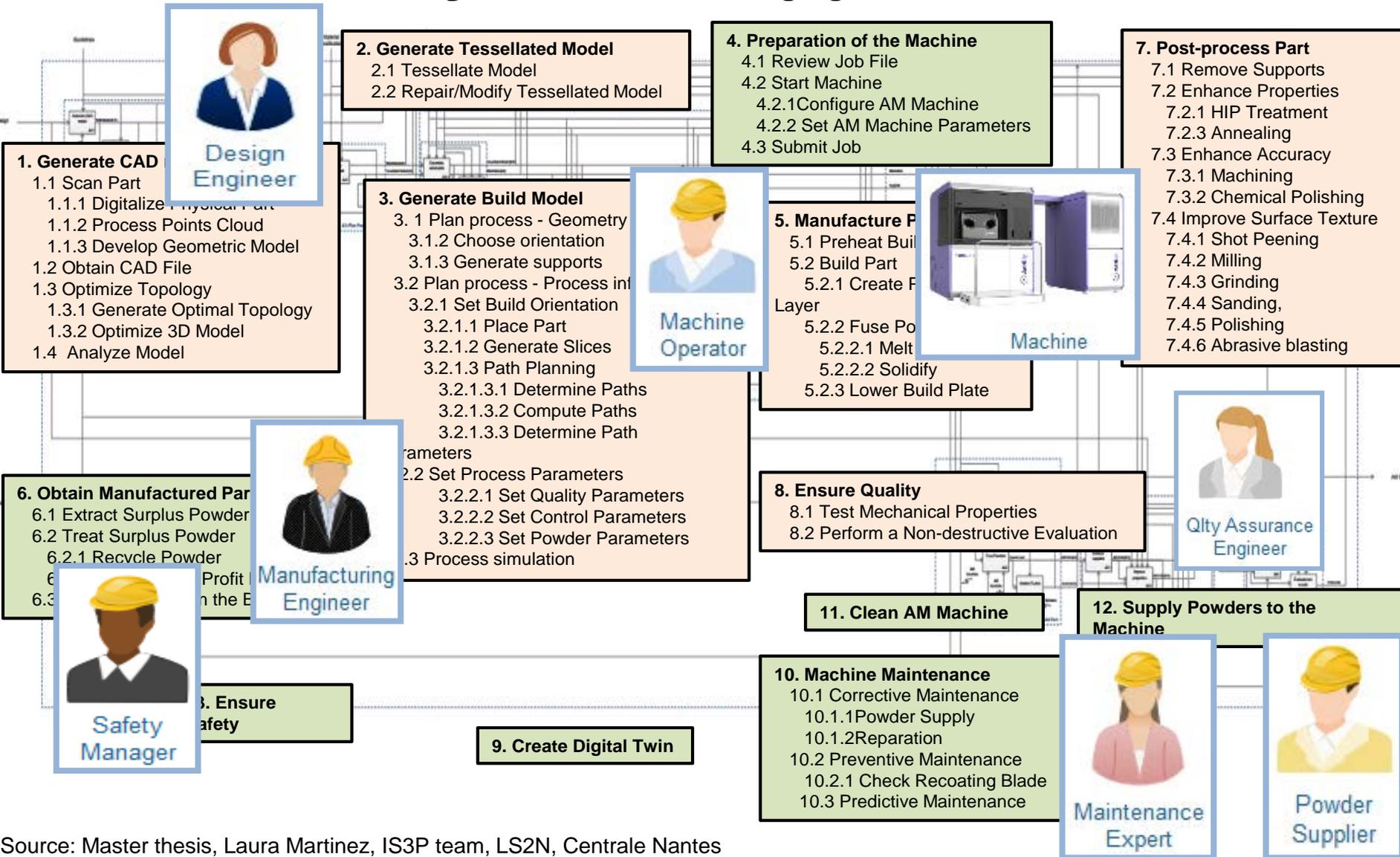
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A systemic approach



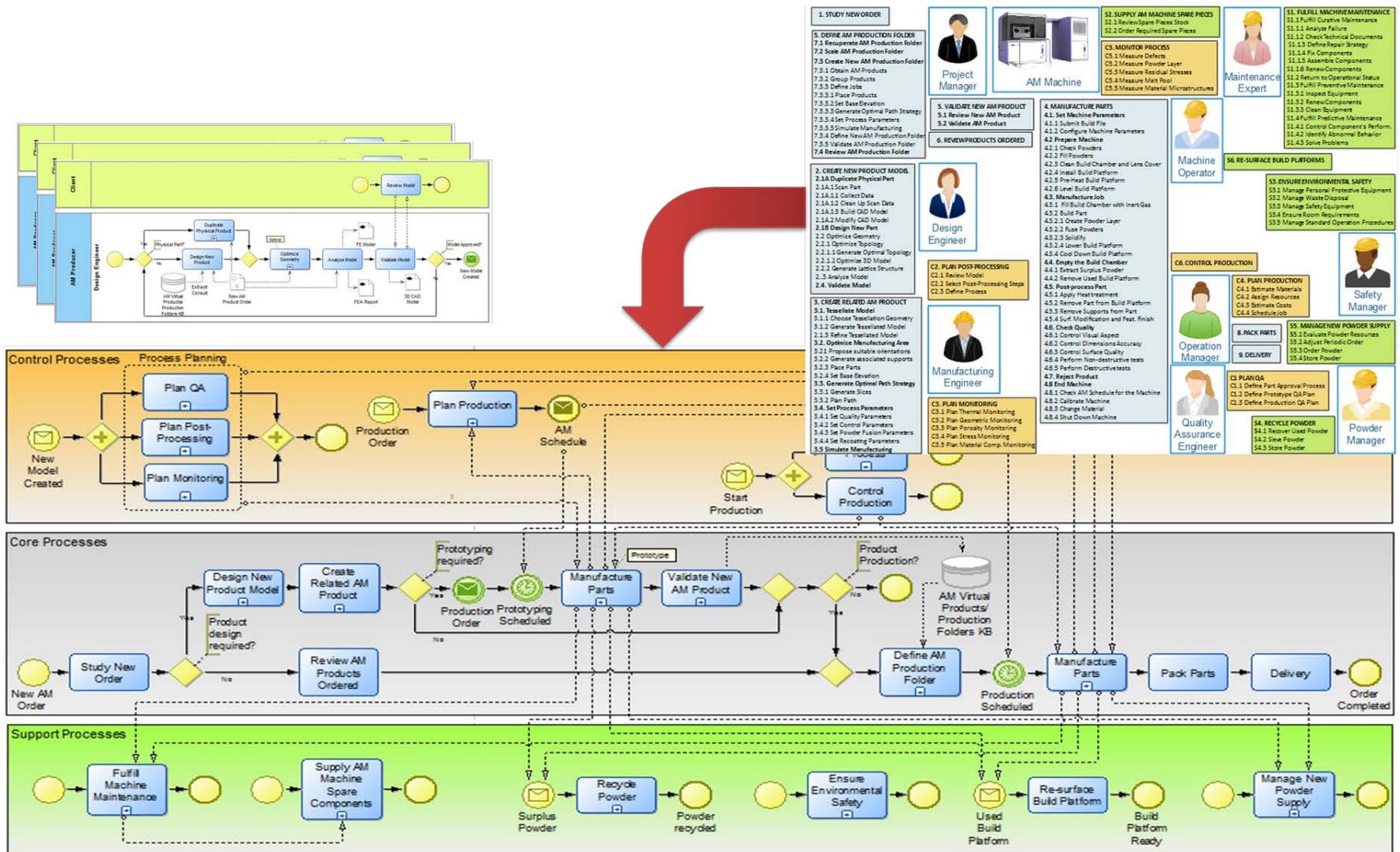
Source: Master thesis, Laura Martinez, IS3P team, LS2N, Centrale Nantes

A systemic approach



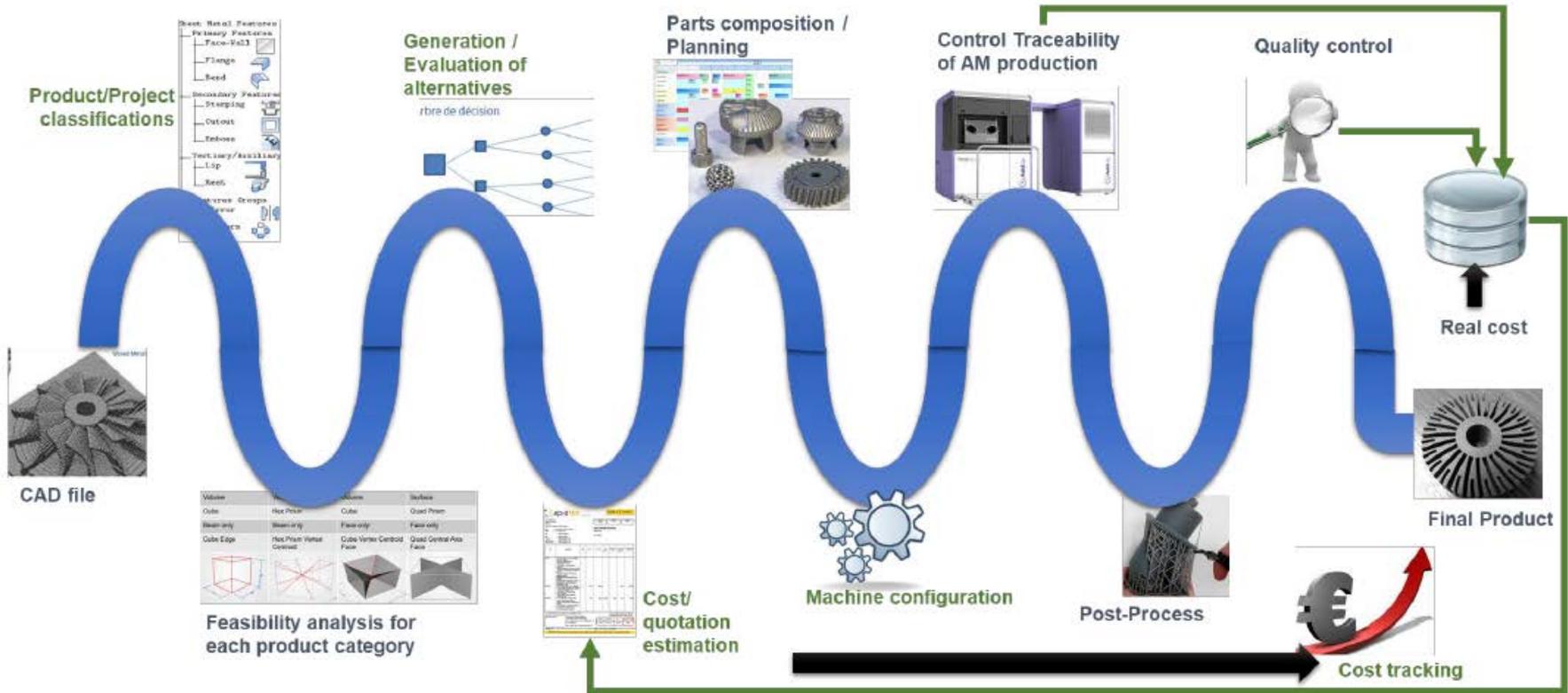
Source: Master thesis, Laura Martinez, IS3P team, LS2N, Centrale Nantes

A systemic approach



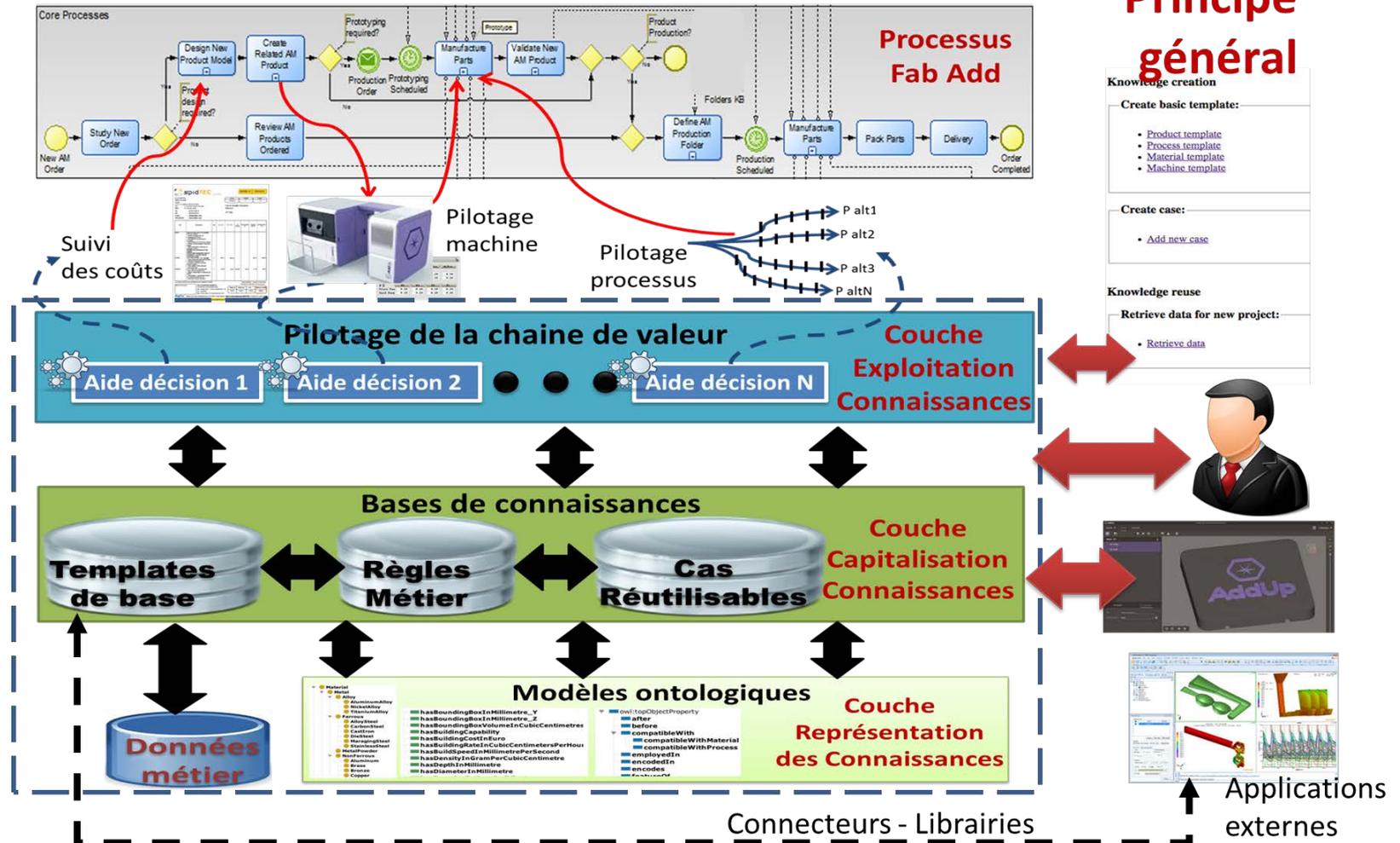
Source: PhD work in SOFIA project, Qussay JARRAR, IS3P team, LS2N, Centrale Nantes

A complete value chain



Source: PhD work in SOFIA project, Qussay JARRAR, IS3P team, LS2N, Centrale Nantes

A framework for value chain control

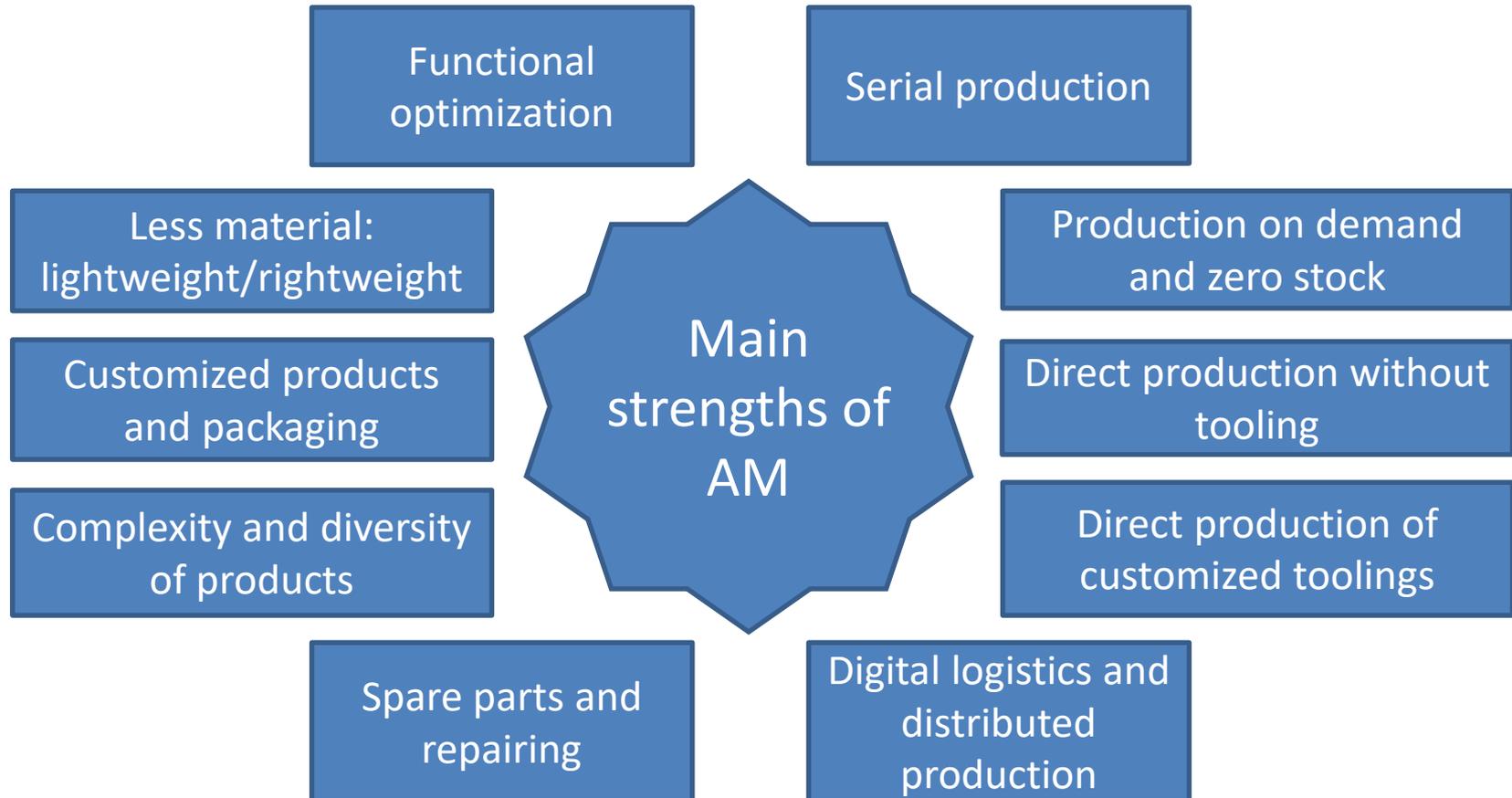


Source: PhD work in SOFIA project, Qussay JARRAR, IS3P team, LS2N, Centrale Nantes

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Main strengths of Additive Manufacturing





Functional optimization

LEAP fuel nozzle tip

20:1
PARTS

30%
COST EFFICIENCY
IMPROVEMENT

95%
INVENTORY
REDUCTION

5x MORE
DURABLE

25%
WEIGHT
REDUCTION

Source: GE Aviation

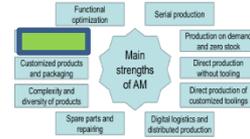
LEAP is a trademark of GE Aviation and a 50% joint venture of GE Aviation and Safran Aircraft Engines. Comparison versus TMS fuel nozzle.



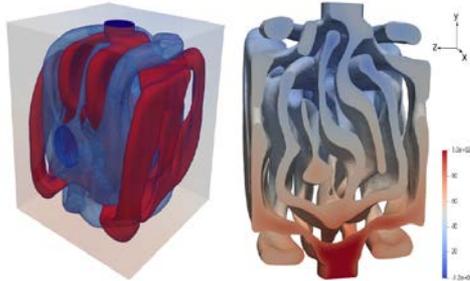
Source: Farinia Group

Source: General Electric/Ian Gibson, 25th European Forum on Additive Manufacturing, 8-10 June 2021

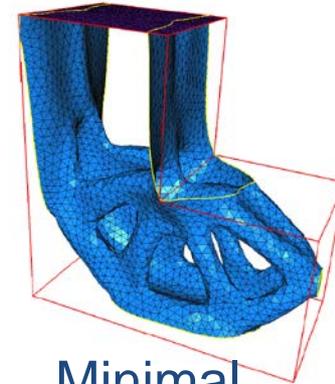
Less material: Lightweight/rightweight



Heat exchanger design



Source: Grégoire Allaire, Laboratoire CMAP, Ecole Polytechnique



Minimal weight and compliance

Hydraulic blocs



Source: Yicha Zhang, UTBM

Heat exchangers



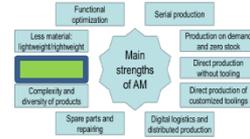
Source: Olaf Diegel, Aukland, New Zealand



Source: Olaf Diegel, Aukland, New Zealand



Customized products/packaging



Automotive Interior

Direct Production Parts

- Mirror housing**
Nylon 12 CF, ULTEM 9085
- Parking Sensor in Front/Rear Bumper**
Nylon 12 CF, ULTEM 9085
- Decorative Cover with texturing**
Nylon 12 CF, ULTEM 9085
- Door Panel**
Nylon 12 CF, ULTEM 9085
- Sun Shade**
Nylon 12 CF, ULTEM 9085
- Air Duct**
ULTEM 9085, ULTEM 1010
- Personalized Gear Shift**
Nylon 12 CF, ULTEM 9085 with metal plating
- Cup Holder**
Nylon 12 CF, ULTEM 9085 with direct coating/painting



Personnalized Packaging
Pack&Strat (patented by CIRTES)
Source: CIRTES

Source : Stratasy



Complexity and diversity of products/bio-inspired



Deluxe Tapware by American Standard



Source : « imprimer le Monde » exhibition, Centre Pompidou, mars 2017



Bio-inspired design



Parts manufactured by Volum-e company



Spare parts and repairing



- **Additive Manufacturing (AM)** allows the production of spare parts:
 - **Short lead time (even on demand)** → **reduced inventory level & decreased supplier dependency**
 - Close to the point of use → **reduced environmental footprint**
- **Increasing interest** in AM for spare parts production, but:
 - **High Production costs** → can be offset by the decreased inventory costs
 - **Uncertain reliability** → main limitation of AM

➔ To what extent does the uncertainty in the reliability impact the choice between AM and Conventional Manufacturing (CM) based on economic considerations?

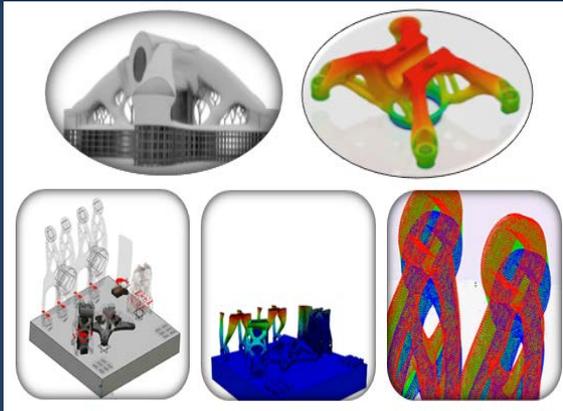


Source : Additive or Conventional Manufacturing for Spare Parts: Effect of Failure Rate Uncertainty on the Sourcing Option Decision
Mirco Peron, Rob Basten, Nils Knofius, Francesco Lolli, Fabio Sgarbossa, BEST PAPER AWARD, MIM 2022 IFAC conference

Digital logistics/ distributed production



4 Process Definition & Simulation



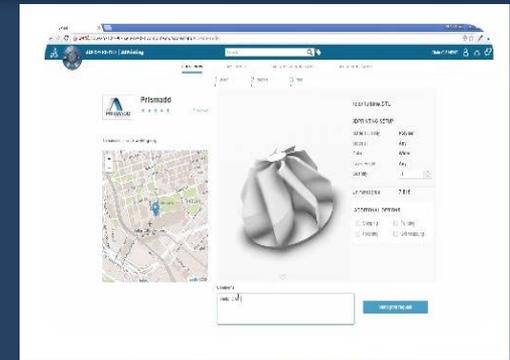
3 Design for Additive Manufacturing



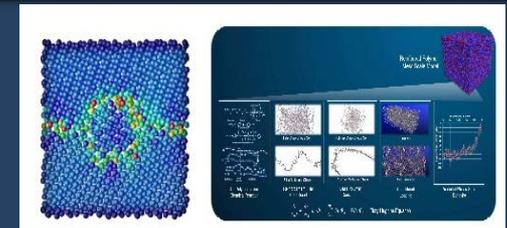
5 Global Production System



1 3DEXPERIENCE Marketplace



2 In-Silico Material Engineering



Source: Daniel Pyzak, Dassault Systèmes Additive Manufacturing solutions 3DEXPERIENCE

Digital logistics/ distributed production



ON DEMAND MANUFACTURING

1. How to get started with on demand manufacturing?

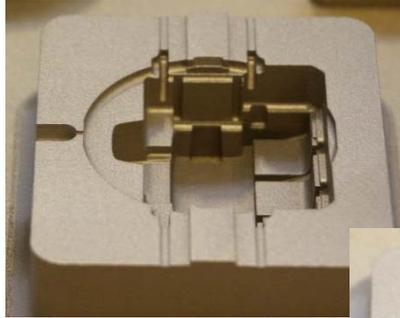


2. Operational phase

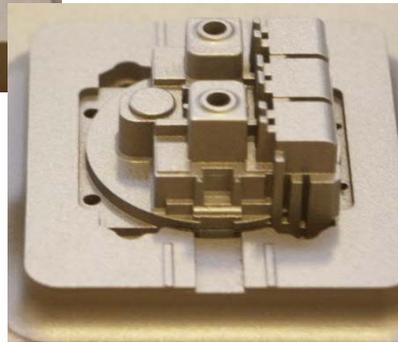




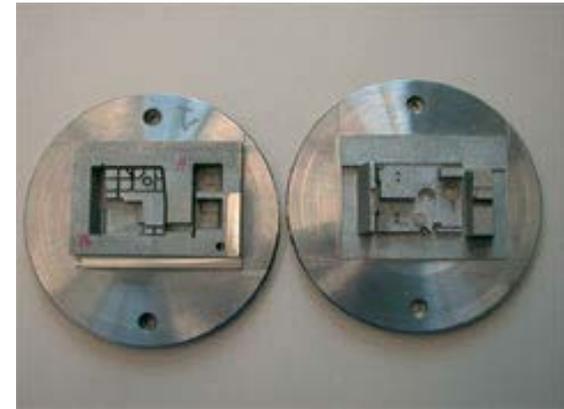
Direct production of customized toolings



Inserts in molds
Source: PEP



Blowing tools
Source: CIRTES

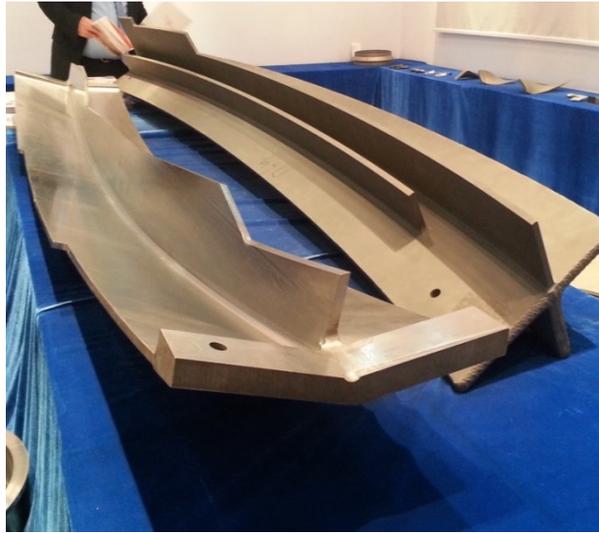
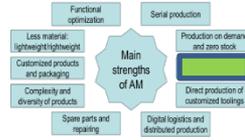


Inserts in molds
Source: Realizer



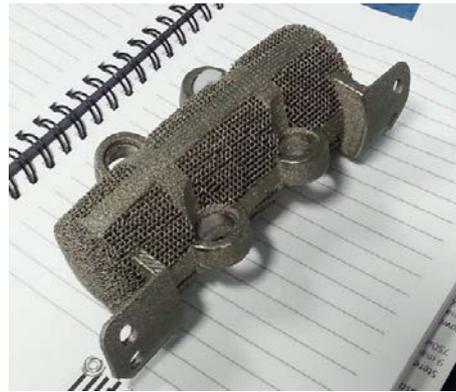
Injection molding toolings - PS Application PMP
R&D contract PSA / CIRTES
(Aluminium)

Direct production without tooling



Source: Georges Fadel, AEFA 2015

Credit photo for these four pictures: Alain Bernard



Source: Volum-e, Courtesy: Airbus defense and space

Production on demand and zero stock



cambox isis

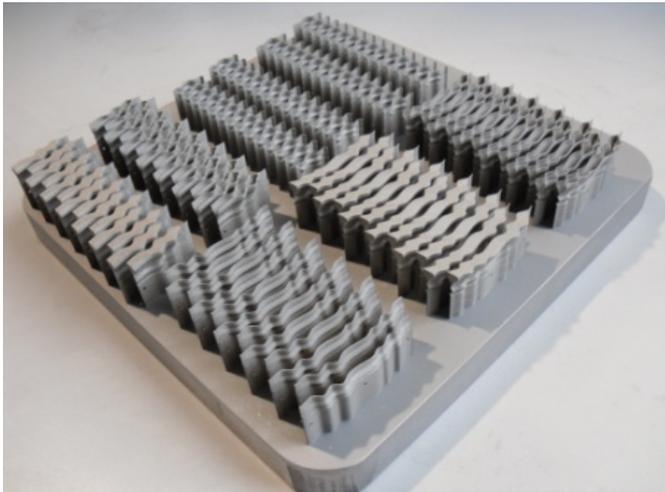


Source: <http://www.camboxisis.fr/shop/fr/content/16-3dprinting>

Serial production



Source: Georges Fadel, AEFA 2015



Source: Phenix Systems



Batch production of a propeler
Source: Naval Group

Serial production



CURRENT

Fluid handling

Applications: Pumps, valves
AM technology: Selective laser melting, electron beam melting
Materials: Aluminum alloys

Exterior/exterior trim

Applications: Bumpers, wind breakers
AM technology: Selective laser sintering
Materials: Polymers

Manufacturing process

Applications: Prototyping, customized tooling, investment casting
AM technology: Fused deposition modeling, inkjet, selective laser sintering, selective laser melting
Materials: Polymers, wax, hot work steels

Exhaust/emissions

Applications: Cooling vents
AM technology: Selective laser melting
Materials: Aluminum alloys

FUTURE

Powertrain, drivetrain

Applications: Engine components
AM technology: Selective laser melting, electron beam melting
Materials: Aluminum, titanium alloys

Frame, body, doors

Applications: Body panels
AM technology: Selective laser melting
Materials: Aluminum alloys

OEM components

Applications: Body-in-white
AM technology: Selective laser melting, electron beam melting
Materials: Aluminum, steel alloys

Electronics

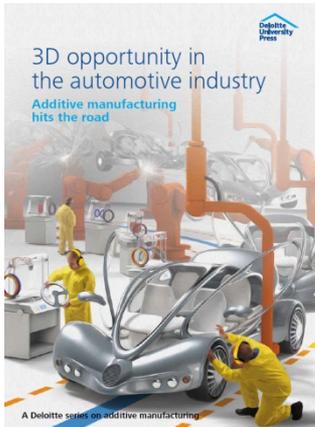
Applications: Embedded components such as sensors, single-part control panels
AM technology: Selective laser sintering
Materials: Polymers

Wheels, tires, & suspension

Applications: Hubcaps, tires, suspension springs
AM technology: Selective laser sintering, inkjet, selective laser melting
Materials: Polymers, aluminum alloys

Interior & seating

Applications: Dashboards, seat frames
AM technology: Selective laser sintering, stereo-lithography
Materials: Polymers

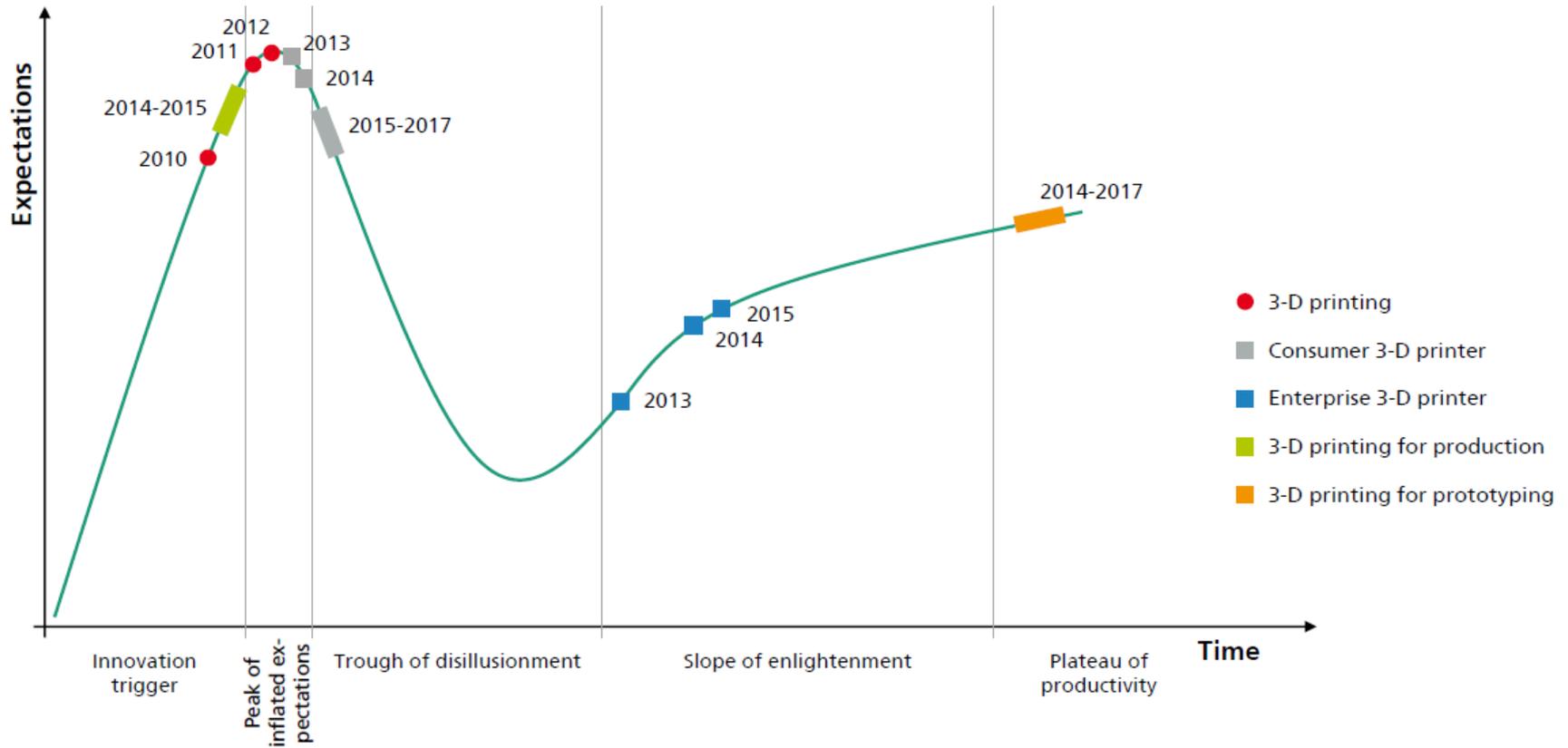


Source: A Deloitte series on additive manufacturing

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Gartner's Hype cycles for emerging technologies (2010-2017)



Source: Jochen LOOCK, Head of Academy, Fraunhofer-Einrichtung für Additive Produktionstechnologien IAPT Hamburg

The TRL in Aeronautic Industry

TRL 6-7: Titanium (Airbus)

- First civil application are going to serial production

TRL 9: FDM Ultem (Airbus)

- Fully certified flying cabin parts in serial production and after sales + tools & customized solutions

TRL 9: Polyamide 22FR (Boeing)

- Used since years for venting & air ducts on many programs

TRL 9-10: Cobalt-Chrome (GE)

- Fuel Nozzle flight tested and in mass production

TRL 9: Inconel (MTU)

- Ramp-up of serial production for the engines

First players on the verge of (part specific) TRL 10



Technology Readiness Level (TRL)

10	Full rate production
9	Low rate production
8	Pilot line capability demonstrated
7	Production in production environment demonstrated
6	Systems produced (near production environment)
5	Basic capabilities shown (near prod. environment)
4	Technology validated in laboratory environment
3	Manufacturing proof of concept developed
2	Manufacturing concept identified
1	Basic manufacturing implications identified



The TRL in Medical and Dental sectors

TRL 10: Titanium

- More than 100.000 Hip Implants were manufactured using SLM & EBM technology.

TRL 10: Cobalt-Chrome

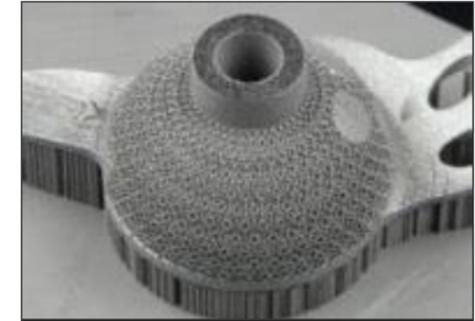
- >12.000 Crowns and Copings for dental usage are produced daily

TRL 10: Polymers

- Around 50% of all hearing aids are today manufactured
- Mass production of Surgical Guides in SLS

TRL 9: (Stainless) Steel

- Customized medical instruments for surgeons



Technology Readiness Level (TRL)

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Most advanced industry; driver → customization

The TRL in Automotive Industry

TRL 6-8: Metals

- Focus on product development (prototyping), Tooling and exotic small series
- Broader usage in motor sports & Formula 1 (e.g. gearboxes & exhaust systems)
- First application ins after-sales (esp. classic cars)
- Lightweight parts are examined for electrical cars
- First applications on luxury cars at Bugatti, Audi and BMW are on the verge to serial production

TRL 6-9: Polymers

- Rolls Royce Phantom is using 10.000 parts in small serial production (e.g. hazard flush, sockets and other polymer clips)
- Daimler is starting 2016 to use SLS for small series and repair of Trucks
- PA12 & ABS: Prototyping for interior parts (dashboard, doors,...)
- BMW is customizing e.g. interior for Mini

First automotive application are going to serial production



Technology Readiness Level (TRL)

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The TRL in Tooling and Machine building

TRL 9: Steel

- Tool manufacturer Mapal is using steel (1.2709) for serial production of hybrid drills with optimized cooling channels
- LBM enables smaller drills (8-12mm diameter) compared to traditional manufacturing
- Additive steel tools for deep drawing, stamping and moulding applications

TRL 9: Aluminium & Polymers

- Used for various applications in final part production



Technology Readiness Level (TRL)

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Lower qualification burdens lead to greater adoption

Industrial maturity

Thalès created a new plant in Morocco



Safran is creating a new competence center in Bordeaux



Lamborghini produced more than 20 000 parts in 2020



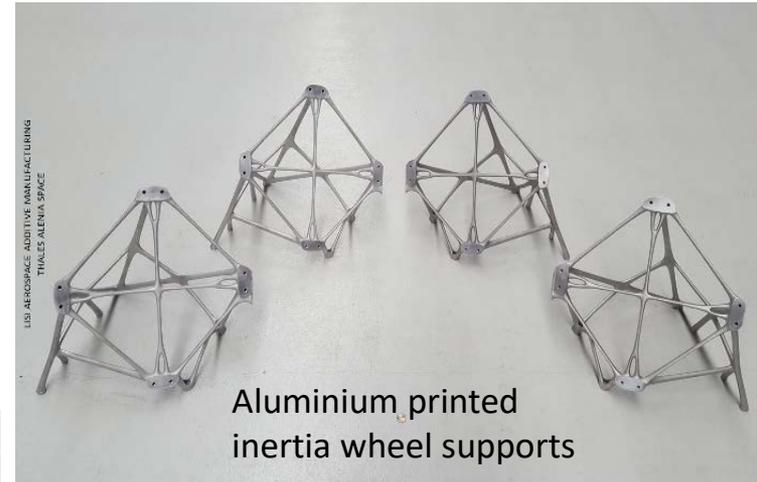
Tank cap (EPX 82)



Fixing element for air duct (EPX 82)



Ventilation grid (EPX 82)



US AEROSPACE ADDITIVE MANUFACTURING
THALES ALenia SPACE

Aluminium printed inertia wheel supports

LISI Aerospace Additive Manufacturing



Anti-condensation for canopy

Anti-condensation for Canopy
First Aluminum Additive Manufacturing (LBM) serial parts flying on Rafale

Dassault Aviation

Recent progresses

Magnetic materials



À Nancy,
Le 4 juin 2021

COMMUNIQUÉ DE PRESSE

Un premier procédé direct d'impression d'aimants en 3D

Les équipes de l'Institut Jean Lamour - IJL (CNRS / Université de Lorraine) viennent de relever un véritable défi technologique : intégrer des propriétés magnétiques à des matériaux imprimés en 3D, sans post-aimantation. Il s'agit là d'une première mondiale avec ce niveau de performance et ces travaux ouvrent la voie à l'impression 4D d'objets magnéto-actifs. Ce procédé de fabrication d'aimants avec une imprimante 3D grand public est en cours de transfert au sein d'une entreprise du Grand Est.

Une prouesse technologique

Cette innovation technologique associe différentes compétences présentes à l'IJL : celles de l'équipe de recherche technologique Matériaux et Procédés Additifs, dirigée par Samuel Kenzari, ingénieur de recherches CNRS, et celles du Centre de Compétences Magnétisme et Cryogénie dirigé par Thomas Hauet, maître de conférences à l'Université de Lorraine. Le défi qu'ont relevé les chercheurs et ingénieurs est celui de concevoir une imprimante 3D de type FDM (dépôt de filament fondu) avec son fil magnétique composite pour imprimer des pièces elles-mêmes magnétiques.

Pour fabriquer le fil, ils ont utilisé des matériaux ferromagnétiques avec des formulations propres à les rendre imprimables. Pour ce qui est du dispositif d'impression, ils sont partis d'une imprimante 3D traditionnelle, à laquelle ils ont ajouté des composants permettant la mise en forme de l'aimant pendant l'impression. Les pièces produites par cette imprimante possèdent une ou plusieurs orientation(s) magnétique(s) permanente(s) sans nécessiter l'application d'un champ magnétique a posteriori pour les aimanter.

Une commercialisation prévue pour l'automne 2021

Une déclaration d'invention¹ a été déposée en 2019 et un contrat de licence de savoir-faire a été passé avec l'entreprise BB Fil basée à Heiligenberg en Alsace. La commercialisation d'une version grand public du procédé d'impression (imprimante et filament d'impression) est prévue pour l'automne 2021 : il deviendra ainsi possible d'imprimer des aimants personnalisables chez soi.

Ces travaux ouvrent la voie à l'impression 4D d'objets magnéto-actifs, qui pourront être déformés, activés ou commandés par un champ magnétique.

Ces travaux ont bénéficié du soutien du CNRS, de l'Université de Lorraine, de Lorraine Université d'Excellence, de la Région Grand Est et d'ICEEL.

¹Matériaux et procédé direct d'impression 3D d'objets magnétiques mono- ou multi-orientés* référencée à la SATT SAYENS avec le n°DISATTGE-275.

CONTACT PRESSE

Capucine François
Chargée des relations presse
06 71 00 07 80

Desktop Metal becomes first to qualify 4140 steel for binder jet 3D printing technology



Fully dense sinterable 6061 aluminum alloy parts

Source : <https://3dprintingindustry.com/news/desktop-metal-becomes-first-to-qualify-4140-steel-for-binder-jet-3d-printing-technology-191116/>



Digital Metal® first in the world to offer pure copper as printing material.

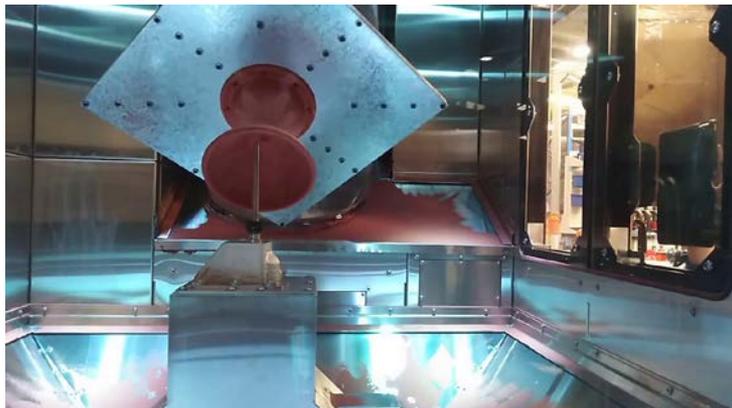
Other materials: stainless steel 316L and 17-4PH, tool steel DM D2, super alloys DM 625 (Inconel 625), DM 247 (MAR M247) and Titanium Ti6Al4V.

Source : Université de Lorraine

Recent progresses

WarpSPEED3D cold spray machine
Speed of building: 100 g/min

Cold spray with
supersonic air
flow (Aluminum
and copper)



18 kg / 3 hours



Copper over aluminum

Source : <https://www.spee3d.com/elementum-3d-adopts-award-winning-cold-spray-metal-3d-printing-technology/>



Velo3D End-to-End Metal AM Solution



Velo3D with support free solution

Design freedom, consistency, reliability, repeatability and greater control



Velo3D Opens New Categories of Metal AM Parts

Static and Rotational Parts Optimized to Control Flow of Fluids and/or the Transfer of Heat



SupportFree™ Processes - Freedom of Design

Bulk

Vertical walls

Low angle closures

- Funnel inward
- Funnel outward

Low angle walls

Lattice



Flow™ offers a sophisticated way of applying parameter sets from a standardized library of specialized parameters

Produces a Velo3D Golden Print File

As Printed on Velo3D's Sapphire

| Confidential & Proprietary

Source : Velo3D company

Recent progresses

Hybrid manufacturing – multi-material parts

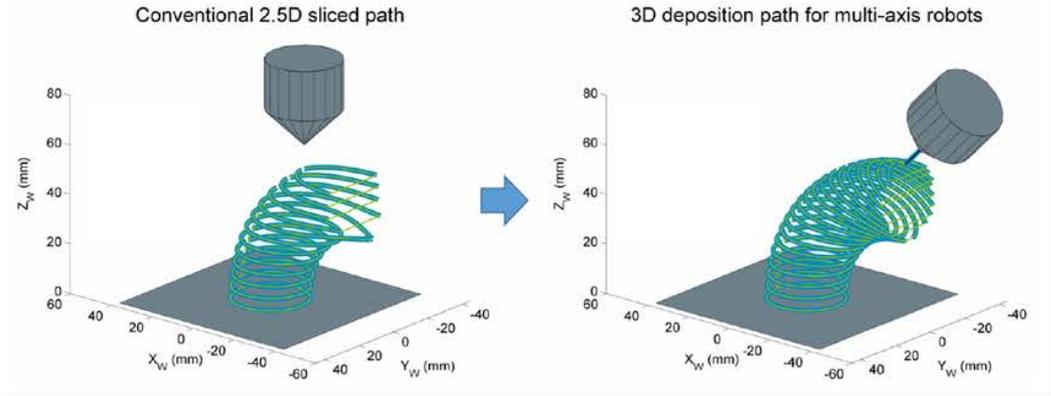
CLAD® + SLM: ANOTHER EXAMPLE

- Modification of the model for CLAD work
 - Locating adding
 - Tube for clamping
- CLAD manufacturing
 - Adjustment of the beam path on the tube edges to take the distortion of the tube into account
 - Firsts layers with larger wall thickness to compensate the weakness of the CLAD-SLM interface (geometry)

IPPA LASER
L'ÉCOLE NATIONALE D'INGÉNIEURIS

LA Laser (Didier BOISSELIER)

Development in collaboration with Dassault Aviation and BV Proto

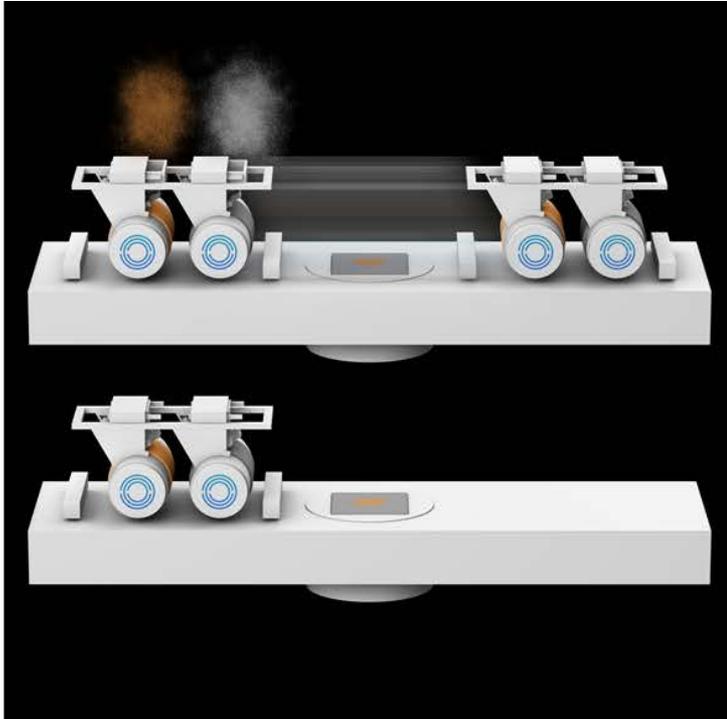


Source : Campocasso, 2017: S. Campocasso, V. Hugel, B. Vayre. *Génération de trajectoires pour la fabrication additive par dépôt de fil robotisé multi-axes- Application à une tubulure torique.* 15ème Colloque national AIP-Primeca, 2017.



Crédit photo : Alain BERNARD

Recent progresses



Desktop Metal –
Aerosint with
be-material
deposition

Example of
heat exchanger



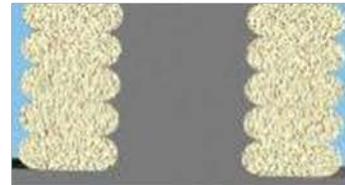
Source : Desktop Metal - <https://aerosint.com/>

New materials for realistic models



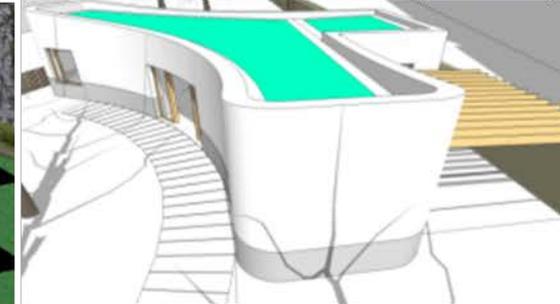
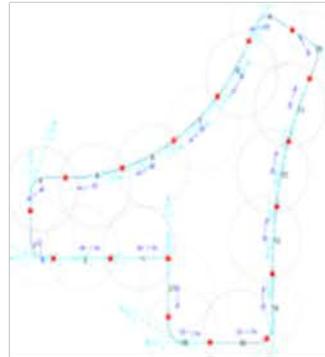
Source : Olaf Diegel, Auckland, New Zealand

Direct production in construction



BATIPRINT3D™

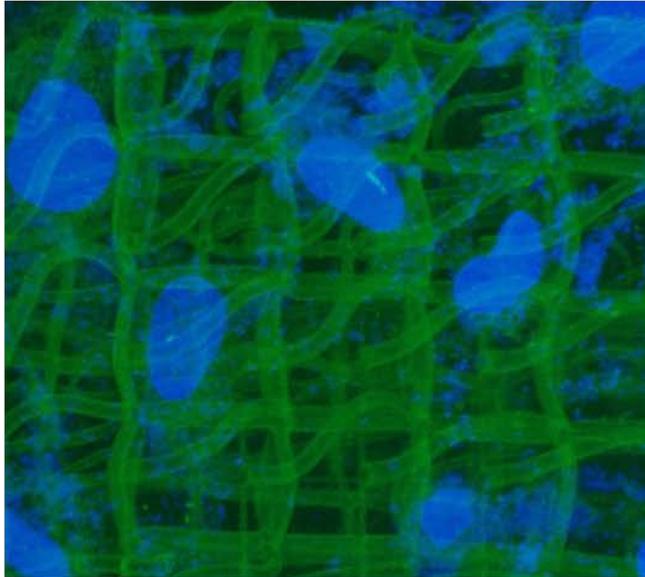
**A new 3D printing method for building
Combination of foam and concrete 3D printing.**



Projet Yhnova

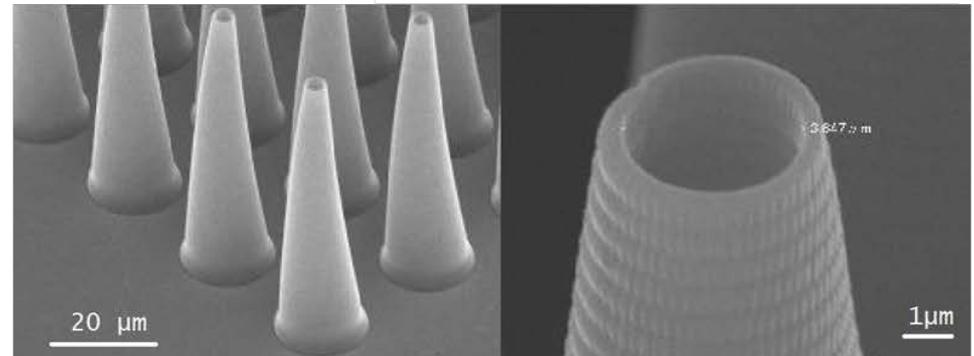
Source: Benoit FURET, Université de Nantes

Direct production at microscale



Collagen structure 3D bio-printed

Microlight-3D
micro-printing
machine



Micro-implosion by photopolymerisation 2 photons

Source: Microlight, <http://www.microlight.fr/fr/master.html>

Direct production in other fields

Food - Drugs



Source :
<https://www.businessinsider.com.au/3d-printed-chocolate-coming-to-european-consumer-market-after-hype-2020-2>

Bio-printing - implants - organs



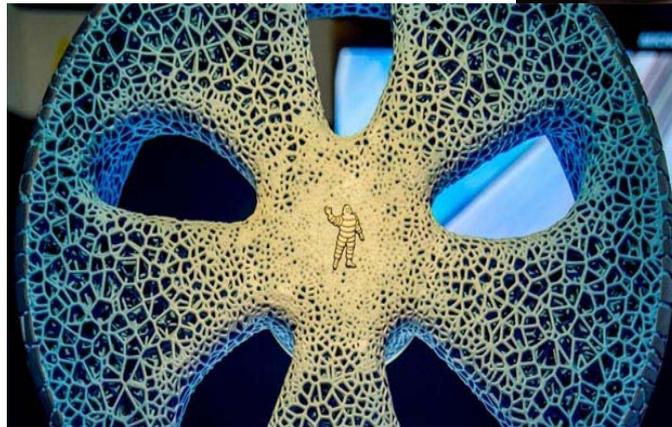
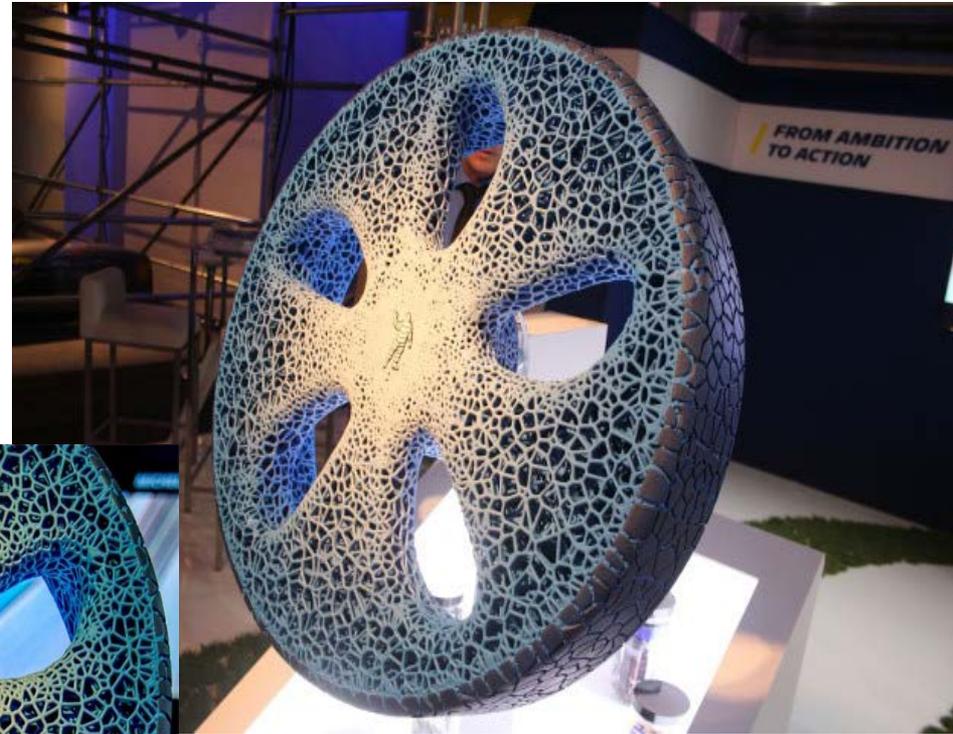
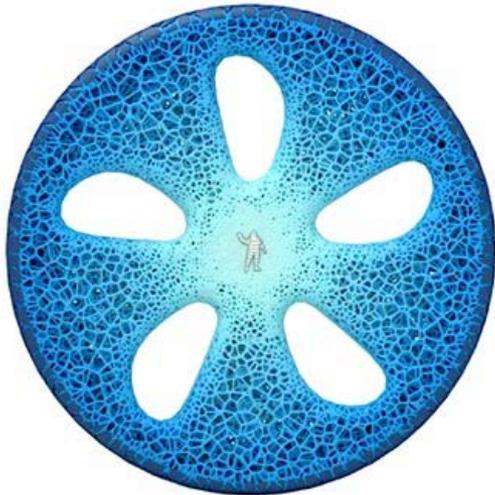
Source: <https://www.3dnatives.com/bio-impression-18052017/>

Textiles - Clothes



Source : salon Formnext 2021
Crédit photo : Alain BERNARD

New biodegradable and regenerable materials



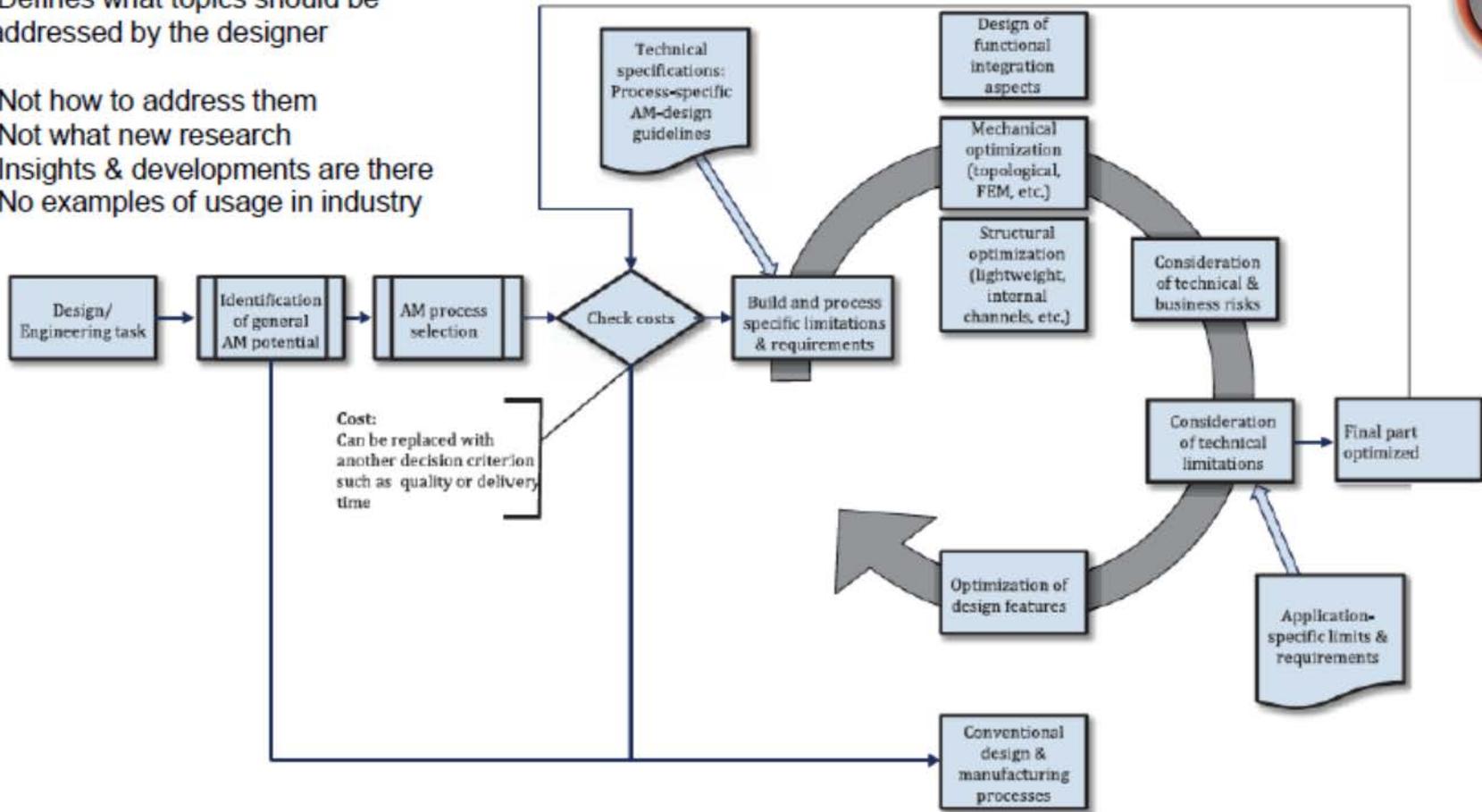
Source : Michelin



DfAM: A methodological approach

ISO/ASTM 52910:2018

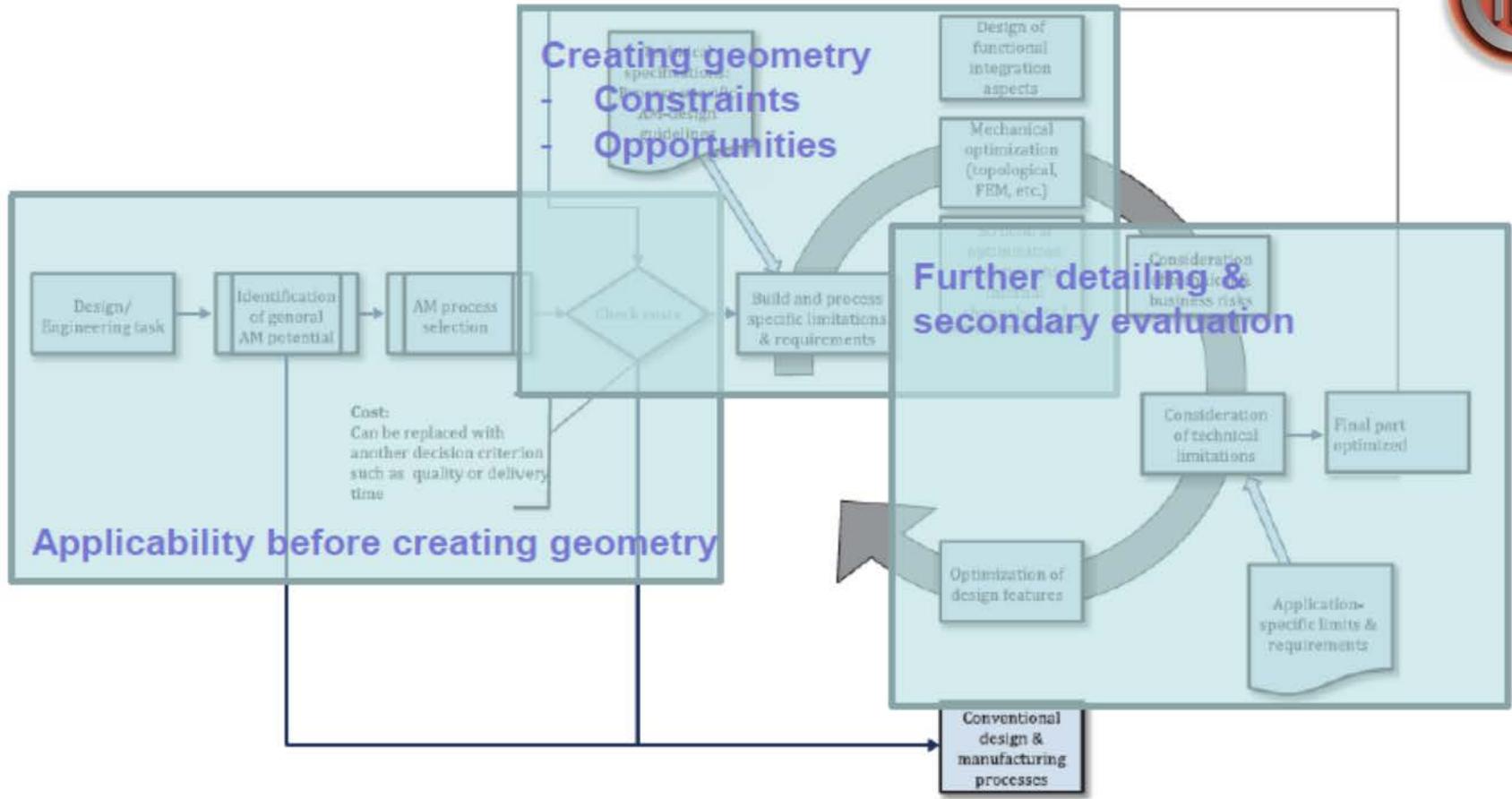
- Defines what topics should be addressed by the designer
- Not how to address them
- Not what new research
- Insights & developments are there
- No examples of usage in industry



Source: CIRP STC Dn Keynote paper, T. Vaneker, A. Bernard et al., 2020



DfAM: A methodological approach

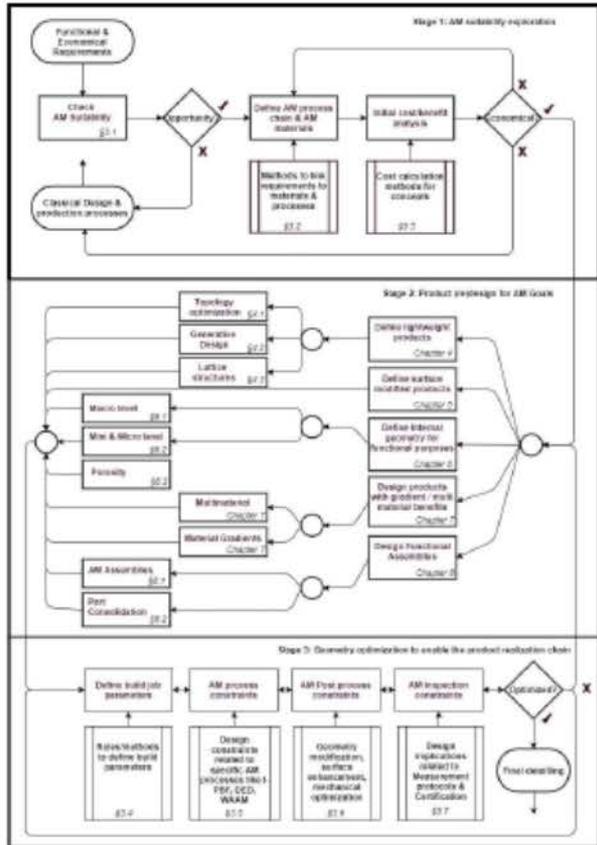


Source: CIRP STC Dn Keynote paper, T. Vaneker, A. Bernard et al., 2020



DfAM: A methodological approach

2. The design framework

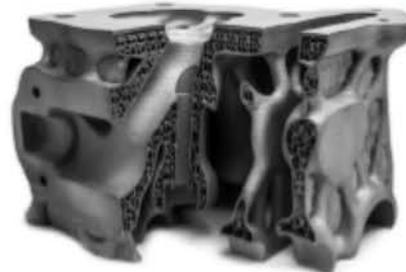


Stage 1: Evaluation of AM suitability



AM metal bridge, printed by mx3d (www.mx3d.com) Picture courtesy of M2i (www.m2i.nl)

Stage 2: Product redesign to enhance functionality



Hull filled with lattice structures [131]

Stage 3: Geometry optimization for the supply chain

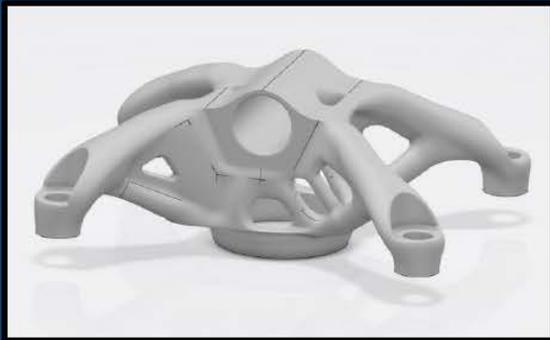


Image source: <https://metrology.news/metrology-with-high-energy-industrial-computed-tomography/>

DfAM: Comparison between as-designed and as-manufactured models

The Gap between “As-Designed” and “As-Manufactured”

“As-Designed” Part



- ▶ Designed geometry without stresses or distortions
- ▶ Standard material property assumptions

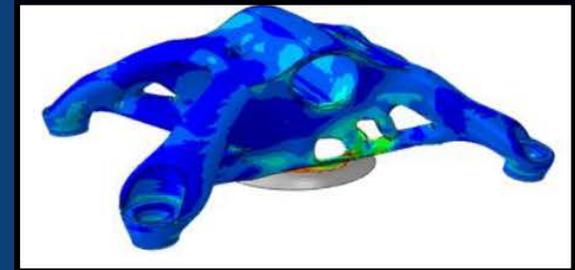
- Materials
- Deposition Path
- Build Definition
- Heat Input



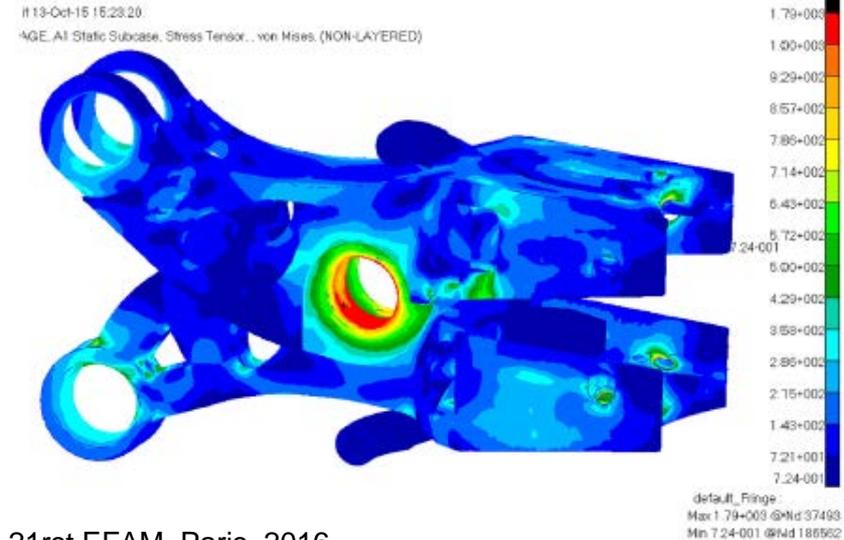
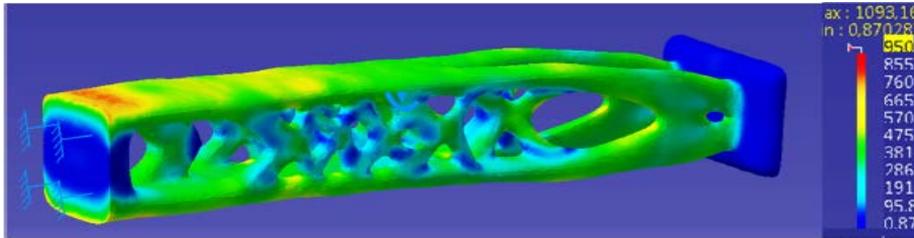
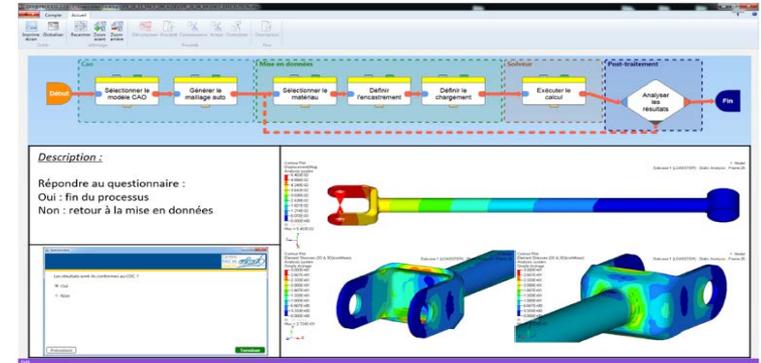
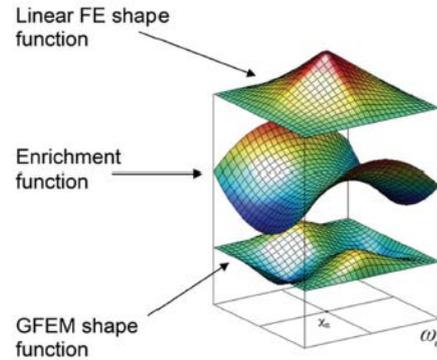
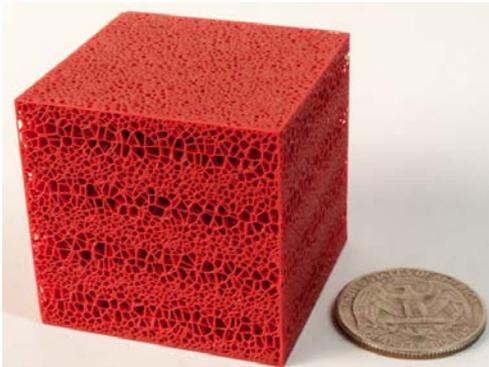
- Residual Stresses
- Distortions
- Altered Properties

“As-Manufactured” Part

- Residual stresses built up from thermal process
- Deformations causing tolerance issues
- Material properties are a function of manufacturing process

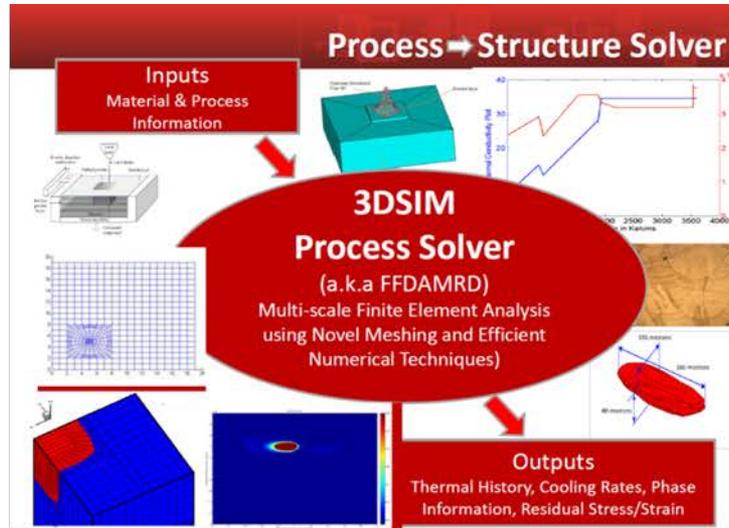


Multiscale modeling and simulation

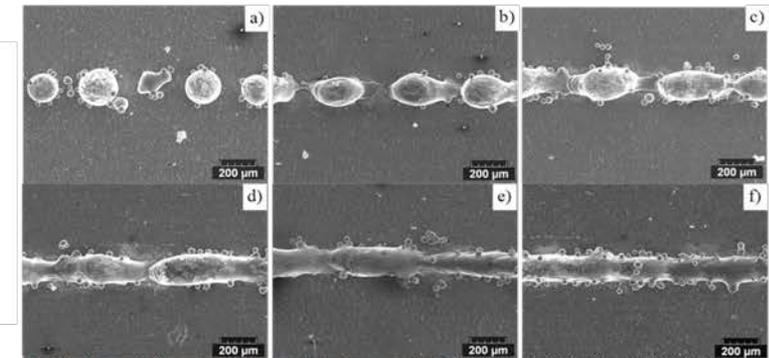
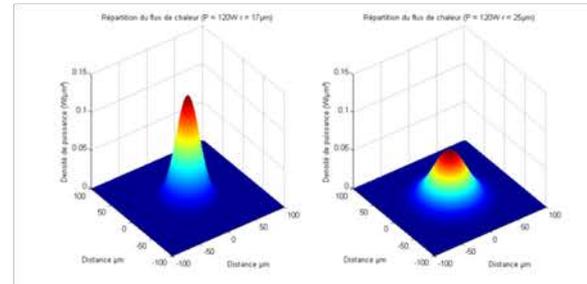
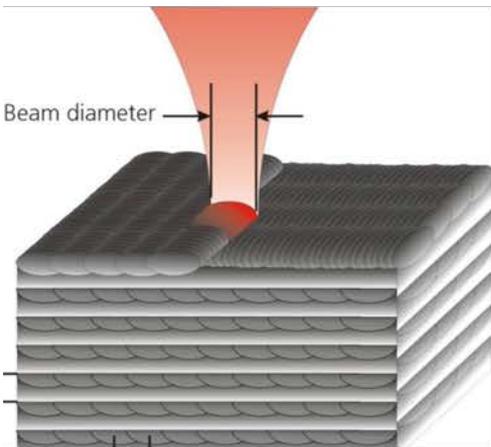
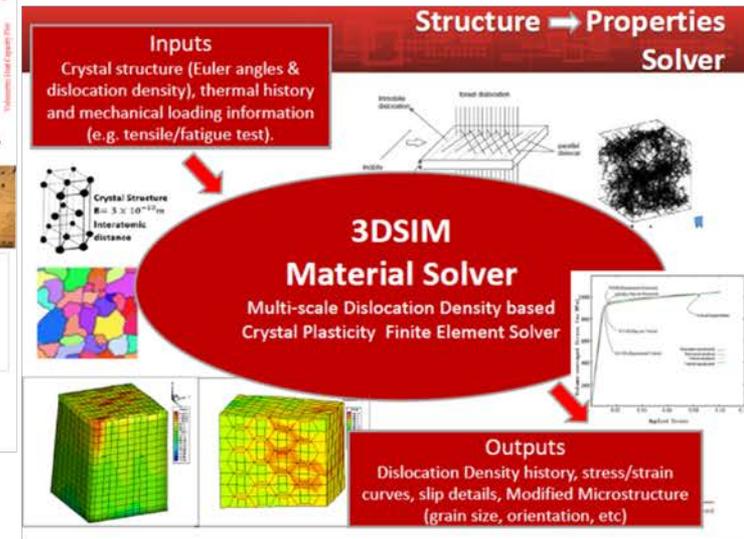


Source: session on digital applications, moderated by Nicolas GARDAN, 21st EFAM, Paris, 2016

Multiscale modeling and simulation



Courtesy: Brent STUCKER, <http://3dsim.com>

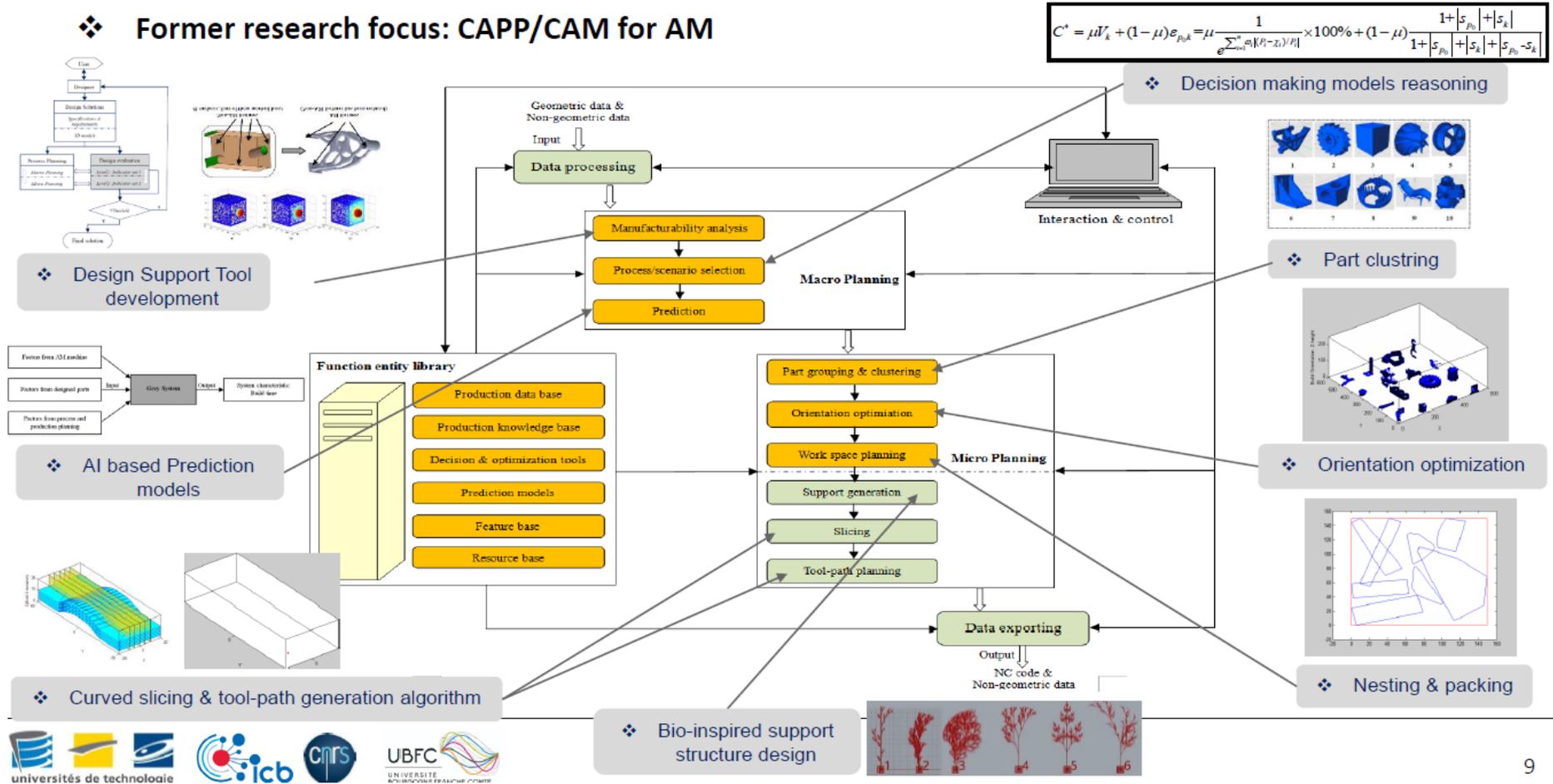


➤ Diminution progressive de la vitesse

a) $0,7 \text{ m}\cdot\text{s}^{-1}$, b) $0,47 \text{ m}\cdot\text{s}^{-1}$, c) $0,35 \text{ m}\cdot\text{s}^{-1}$, d) $0,28 \text{ m}\cdot\text{s}^{-1}$, e) $0,23 \text{ m}\cdot\text{s}^{-1}$, f) $0,2 \text{ m}\cdot\text{s}^{-1}$

Courtesy: Lucas Dembinski, UTBM, IRTES, technical workshop, CNRS, Autrans, october 2015

Beyond CAPP for AM

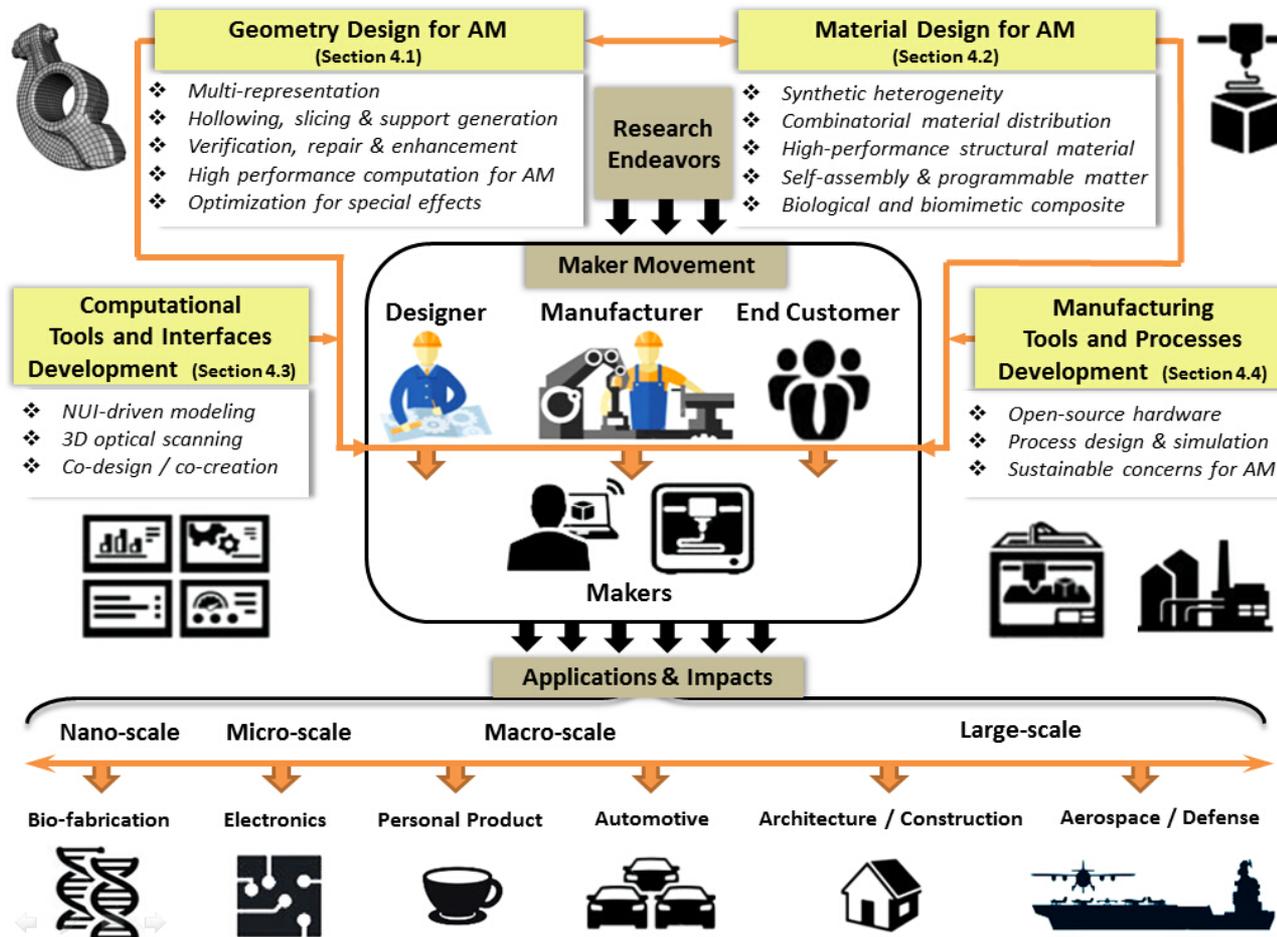


Source : Development of an integrated KBE CAPP system for qualified AM, Y. Zhang (UTBM), A. Bernard (ECN)

Outline of the presentation

- 📄 France Additive
- 📄 Additive manufacturing: A systemic approach
- 📄 Main strengths of Additive Manufacturing
- 📄 Main future goals for Additive Manufacturing
- 📄 **Conclusions**

A large impact at all scales and sizes



Source: <https://engineering.purdue.edu/cdesign/wp/the-status-challenges-and-future-of-additive-manufacturing-in-engineering/>

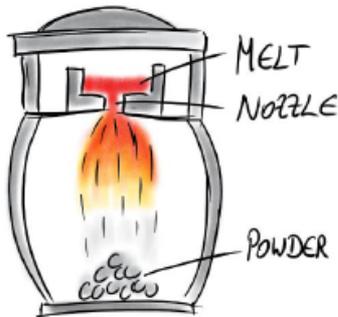
Next stage of Additive Manufacturing

➤ Main expected evolutions

Material

Enhancement of material portfolio

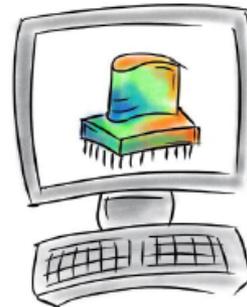
- High performance materials
- Multi-material and in-situ alloying



Data preparation and process simulation and modeling

Pre-defined processing strategies

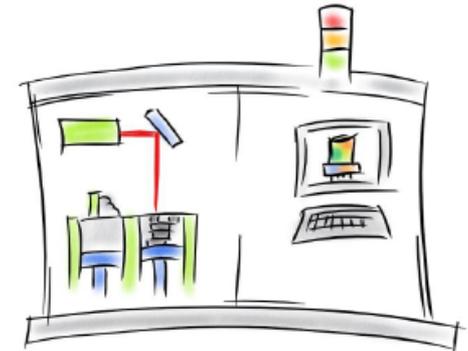
- Combining data preparation and process simulation
- Multiscale simulations & iteratively running optimization strategies



System technology

Automation of AM systems with increased build-up rates

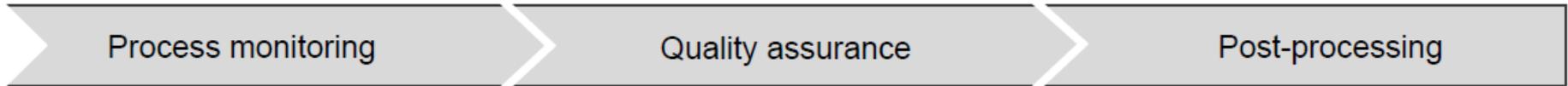
- Multi-beam systems
- Enlarging build envelopes
- Beam shaping
- Integration in process chain



Source : Laser based Additive Manufacturing in industry and academia, M. Schmidt at al., Cross-STC Kn, CIRP Annals, 66/2/561-583

Next stage of Additive Manufacturing

➤ Main expected evolutions



Development of closed loop feedback control systems

- Prediction of process irregularities
- Adjusting the processing strategy in-situ



Quality assurance

Development of in-process quality assurance

- From data preparation & simulation to post-processing
- Documentation and non-destructive testing



Post-processing

Individualized post-processing

- Adjusting final part properties
- Safe and automated routines for part finishing



A new publication to come



Contents lists available at [SciVerse ScienceDirect](#)

CIRP Journal of Manufacturing Science and Technology



Vision on metal additive manufacturing: Developments, challenges and future trends

Alain Bernard^(a), Jean-Pierre Kruth^(b), Jian Cao^(c), Gisela Lanza^(d), Stefania Bruschi^(e), Marion Merklein^(f), Tom Vaneker^(g), Michael Schmidt^(h), John W. Sutherland⁽ⁱ⁾, Alkan Donmez^(j), Eraldo J. da Silva^(k)

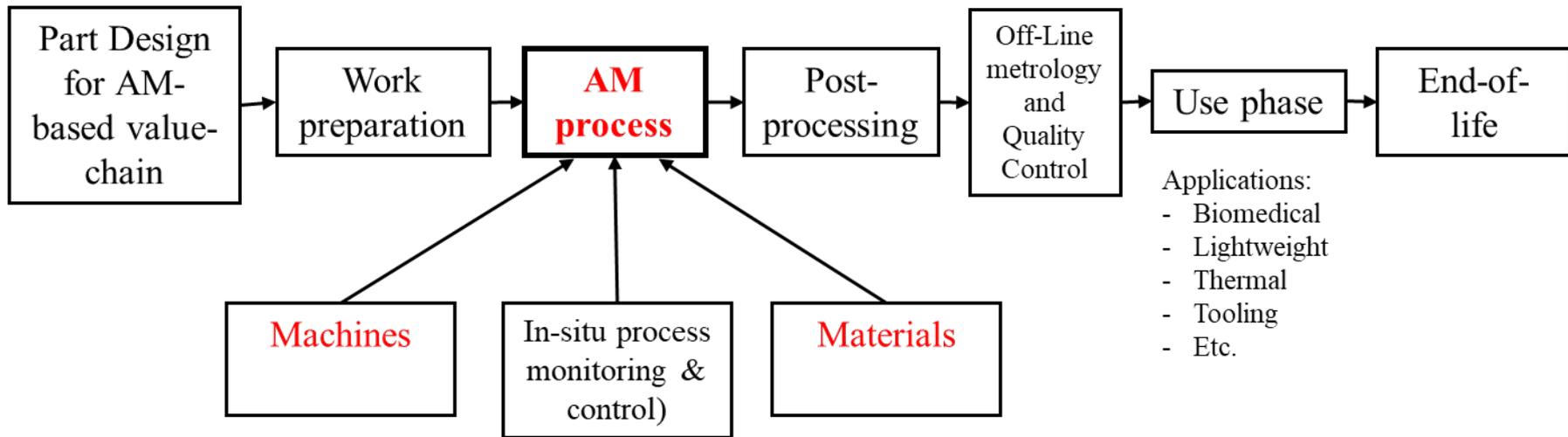
- (a) *Nantes Université, Ecole Centrale de Nantes, Laboratoire des Sciences du Numérique de Nantes UMR CNRS 6004, Nantes, France*
- (b) *KU Leuven, Department of Mechanical Engineering, Member of Flanders Make, Leuven, Belgium*
- (c) *Department of Mechanical Engineering, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208-3111, USA*
- (d) *wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany*
- (e) *Dept. of Industrial Engineering, University of Padova, via Venezia 1, 35131, Padova*
- (f) *Institute of Manufacturing Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Egerlandstraße 13, 91058 Erlangen, Germany*
- (g) *Department of Design, Production and Management, University of Twente, Drienerlolaan 5, 7522 NB Enschede, Netherlands.*
- (h) *Institute of Photonic Technologies, Friedrich-Alexander-Universität Erlangen-Nürnberg, Konrad-Zuse-Str. 3/5, 91052 Erlangen, Germany*
- (i) *School of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN 47907, USA*
- (j) *Engineering Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899, USA*
- (k) *University of São Paulo, São Carlos School of Engineering, Av. Trabalhador São-carlense, 400. 13566-590, São Carlos-SP, Brazil.*

Abstract: Additive Manufacturing (AM) is one of the innovative technologies to fabricate components, parts, assemblies or tools in various fields of application due to its main characteristics such as direct digital manufacturing, ability to offer both internal and external complex geometries without additional cost, and the potential of varying materials at the voxel level. However, despite high anticipations, AM as a real revolution for serial production of metal components has yet to be seen, mostly due to lacks of fundamental understanding, design engineering tools, and the global robustness of the value chains. This paper aims to provide a vision about the future of metal AM based on the collective knowledge of all ten scientific and technical committees of the International Academy of Production Engineering (CIRP).

Additive Manufacturing, 3D printing, Innovative manufacturing technologies, metal AM processes

Source: Vision on metal additive manufacturing: Developments, challenges and future trends, Bernard et al., resubmitted CIRP JMST

Systemic integration for AM



Transversal issues

(interoperability, cybersecurity, digital logistics, certification and qualification, sustainability, KPIs, training and education)

Benefits/Weaknesses of AM

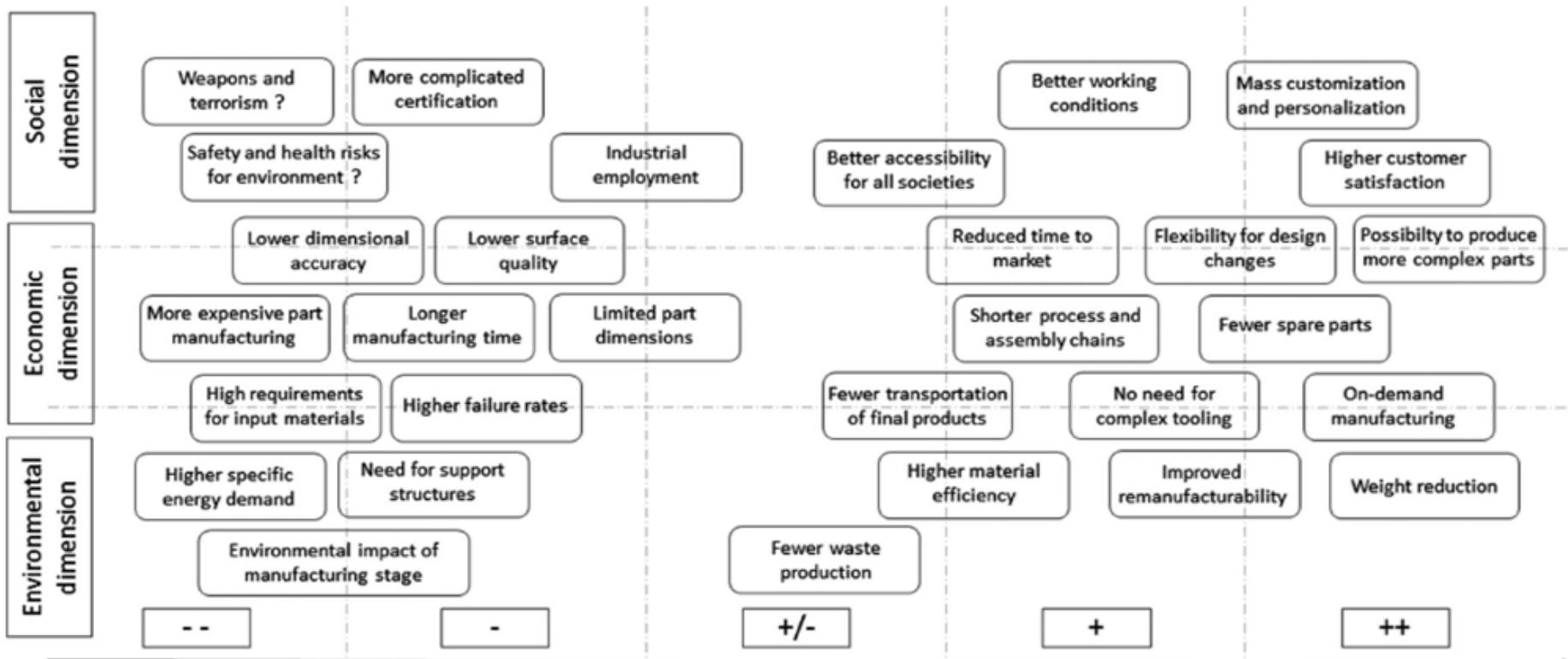


Figure §8.1 Benefits (++) and weaknesses (-) of additive manufacturing processes compared to conventional manufacturing processes [Kellens et al., 2017].

Source: Vision on metal additive manufacturing: Developments, challenges and future trends, Bernard et al., resubmitted CIRP JMST

Sustainability benefits using AM

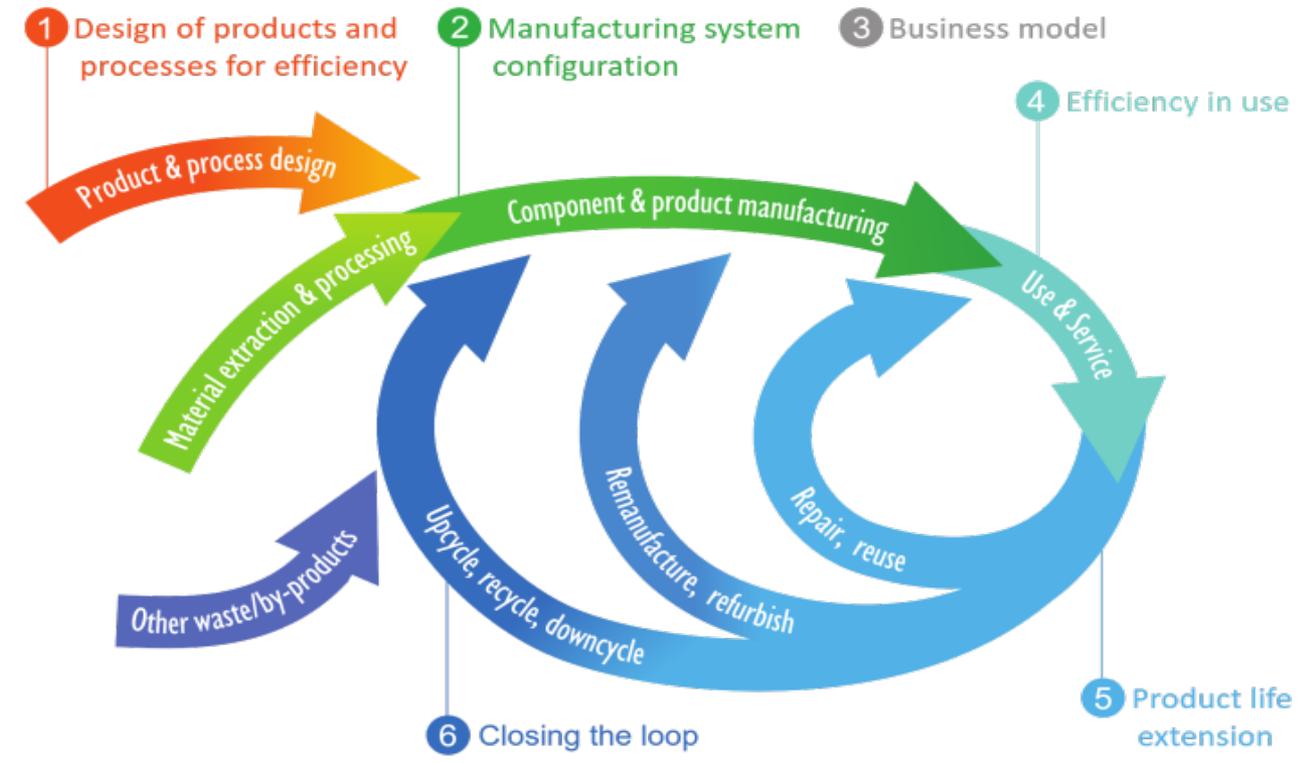
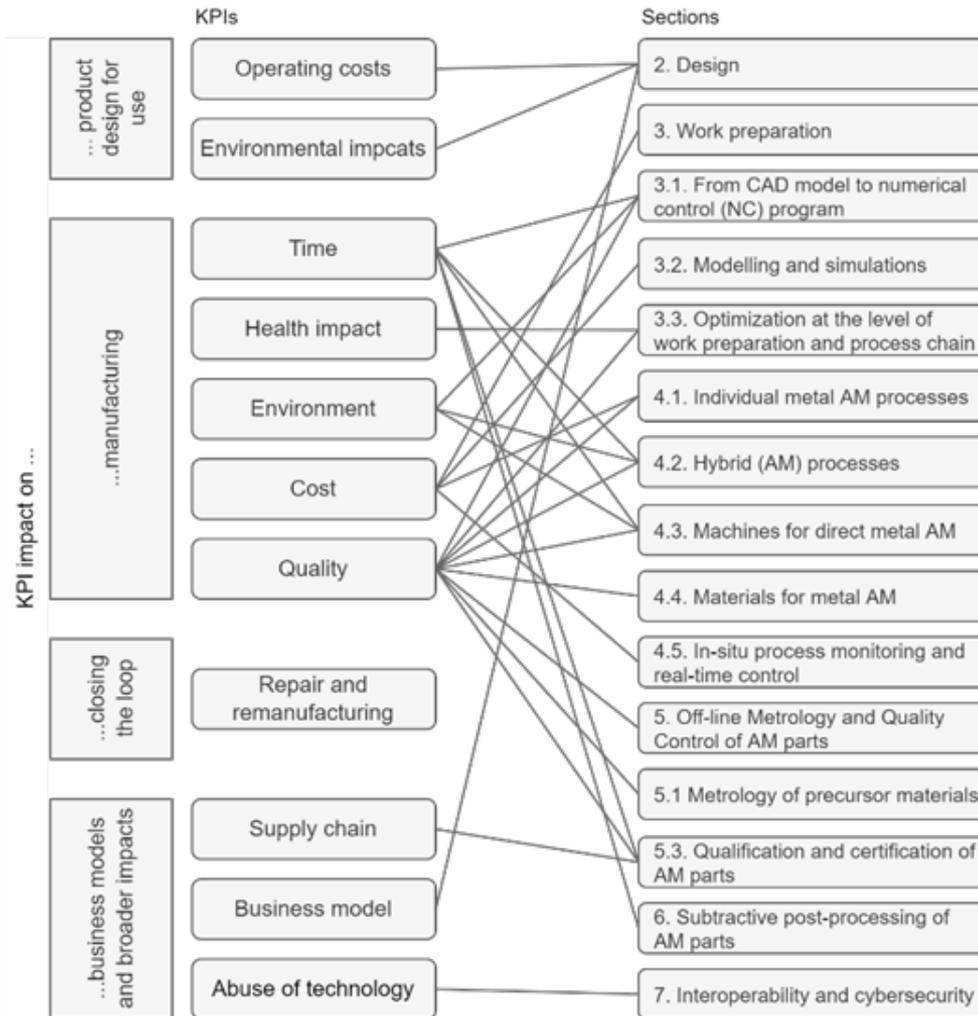


Figure §8.2 Six areas for sustainability benefits across product life cycle using AM [Despeisse et al., 2017]].

KPIs across Lifecycle with AM



Source: Vision on metal additive manufacturing: Developments, challenges and future trends, Bernard et al., resubmitted CIRP JMST

Main strategic challenges



An industrial challenge



An environmental challenge



A societal challenge



A disrupted industrial value chain. AM is intended to:

- Increase performances
- Decrease costs
- Reduce Time to market

A profound reorganisation of the 'supply chain'.

Production:

- On-demand
- Close to end-use
- With the right material

Redistribution of added value across the value chain :

- National sovereignty
- Relocalisation
- Train and retain talents

CNRS <https://rdm.prod.lamp.cnrs.fr>

**9ème école technologique
du Réseau Des Mécaniciens**

Fabrication Additive :
Quelles finalités pour quels
matériaux et procédés ?

Limoges:
12 au 16 juin 2023

Date limite d'inscription:
5 mai 2023

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Une vision systémique de la fabrication additive métallique : développements, challenges et tendances pour le futur

Thank you for your kind attention.

Any question?

alain.bernard@ec-nantes.fr

