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AM-motion

A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES

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D2.1 Selection of Key AM Sectors for Europe

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Abbreviations

Abbreviations	
3DP	3D printing
AM	Additive manufacturing
CAD	Computer-aided design
CT	Computerized axial tomography
EASA	European Aviation Safety Agency
EBM	Electron Beam Melting
EC	European Commission
FDA	US food and drug administration
FoF	Factories of the future
KETs	Key enabling technologies
MRI	Magnetic resonance imaging
OEM	Original equipment manufacturer
RTO	Research Technology Organization
UAV	Unmanned aerial vehicle
VC	Value chain
WP	Work package

1. Introduction

The present document constitutes Deliverable D2.1 "*Selection of Key additive manufacturing (AM) Sectors for Europ*e" in the frame-work of the H2020 project "*A strategic approach to increasing Europe's value proposition for Additive Manufacturing technologies and capabilities*" (Project Acronym: AM-motion; Contract No.: 723560). This document is the result of the activities performed within the framework of work package 2 (WP2): "*Mapping the AM landscape*", and more specifically of Task 2.1 "*Selection of market driven value chains*" led by TWI and with the collaboration and input from TNO, PRODINTEC, CEA, IDEA Consult, AIRBUS, SIEMENS and MATERIALISE.

The main objective of WP2 is to create an overall picture of the current situation of the AM field and community with a view on the development of products or applications in lead markets. It aims to widen the scope of the market study, database, and value chains (VC) established in the FoFAM[1] project and DG Grow 3D printing report[2]. With this in mind, Task 2.1 will analyse preliminary information and VC selections coming from those projects with subsequent validation being undertaken from its findings along with an in-depth review and synthesis of VC related knowledge. Verification of the preliminary VCs for further analysis will be governed by the support of the industrial partners within the consortium (AIRBUS for aerospace, SIEMENS for energy and transport and MATERIALISE for health and consumer) in the first place. In a second step, this selection will be revised and validated by AM Expert's

In subsequent tasks these VCs and collated evidence will be further detailed with technological and non-technological information concerning existing expertise and key actors in the field.

2. General Growth and Impact of AM

Among the most innovative manufacturing solutions of the last decade, **additive manufacturing (AM) technologies** have been identified as one of the most promising production technologies at global level. They are considered to empower the transition from mass production to mass customization in several leading sectors. Moreover, the OECD (Organisation for Economic Co-operation and Development) has identified AM as one of the technologies driving the digital transformation of industrial production and where productivity impact in industry

[1] FoFAM ""Industrial and regional valorization of FoF Additive Manufacturing Projects" H2020 CSA project (2015-2016, nº 636882) www.fofamproject.eu

[2] Report on 3D-printing, 2016, http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8937

is likely to develop[3]. This digital transformation being recognised as the 4th Industrial Revolution holds the promise of increased flexibility in manufacturing, mass customisation, increased speed, quality, and improved productivity. AM technologies are mainly concerned with "high performance manufacturing" and identified as a segment with "particular high growth potential". The global AM industry grew 25.9% (CAGR – Compound Annual Growth Rate) to $5.2Bn in 2015, of which $2.4Bn came from AM products alone[4]. Moreover, if growth continues the worldwide AM industry could expect to exceed $21bn in revenues by 2020.

Europe, at both a political and industrial level, possesses great potential to become a world leader in the development and deployment of these technologies. For instance, in Europe there are currently world-class machine builders, material providers, service bureaus, business model developers, etc., operating at a global level, along with reputable universities and research centres. By the end of 2015 Europe was the second main region in the world of industrial systems installed. Equally, as of March 2016, 28 companies across Europe were manufacturing and selling AM systems, with eight being metal AM systems[5]. From a European research point of view, this desired leadership has been heavily promoted during the last decade. For instance, the European Commission (EC) has been a pioneer in developing AM by providing funding in this area since the first (1984) Framework Programme (FP). Within the **7th FP, the EC funded more than 60 projects based on AM technologies** with a total grant of over **€160 M** and a total project budget of **over €225 M**[6]. In **Horizon 2020**, AM is positioned within the Key Enabling Technologies (KETs) area under the Industrial Leadership pillar, which also plays an important role in helping to meet the Societal Challenges. Under H2020, **at least 27 AM projects have been launched in 2014-16, with over 113M€ in EU funding**, mainly within the Key enabling technologies (70% of total FP7 in only 3 years).

At national and regional level, huge efforts have been made over recent years to reinforce technological capabilities in AM technologies and to speed up its market uptake. National and Regional authorities across Europe are invited to develop and implement **smart specialisation strategies**[7]. These have an aim to stimulate regional research and innovation activities and synergies between different EU, national and regional policies, as well as increasing public and private investments. Since 2013, half of the EU-regions have placed 'Advanced Manufacturing' as one of the key priorities, with a large majority focusing specifically on AM. Such a trend was supported by the EC in the context of its further study in 2016 on the promotion and support

[3] "Industry 4.0 Digitalisation for productivity and growth" Ron Davies, European Parliament briefing September 2015 http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf "Meeting of the OECD Council at Ministerial Level" Paris, 1-2 June 2016 https://www.oecd.org/mcm/documents/Enabling-the-next-production-revolution-the-future-of-manufacturing-and-services-interim-report.pdf
[4] "Wohlers Report 2016 – Annual Worldwide Progress Report" – Terry Wohlers, Tim Caffrey, Ian Campbell, Wohlers Associates, Inc
[5] "Wohlers Report 2016 – Annual Worldwide Progress Report" – Terry Wohlers, Tim Caffrey, Ian Campbell, Wohlers Associates, Inc
[6] "Additive Manufacturing in FP7 and Horizon 2020" Report from the EC Workshop on AM held on 18 June 2014
[7] http://ec.europa.eu/regional_policy/sources/docgener/informat/2014/smart_specialisation_en.pdf

of Advanced Manufacturing Technologies (AMT)[8] through Horizon 2020 and the European Cohesion Policy[9] for supporting investments in KETs. In line with this progressive rise of Advanced Manufacturing and AM technologies on the European and regional agendas, a network of Regions was setup in 2014 to support the re-industrialisation of Europe namely the Vanguard Initiative for New Growth through Smart Specialisation. In that context, more than 30 European Regions politically and economically committed to "join forces" by signing the Milan Declaration[10] and engaging into the implementation of a number of action lines. Several pilots were developed, among which one was fully dedicated to High-Performance Manufacturing through 3D-Printing[11]. In the context of this pilot, eight cross-regional demonstration projects were designed in a bottom-up approach in areas such as automotive, and medical.

To support these regional efforts and to co-invest in the industrial modernisation of Europe, in June 2016, the EC launched the "*Smart Specialisation Platform for Industrial Modernisation*[12]". This Platform supports the emergence of bottom-up partnerships bringing regions with similar interests to undertake targeted collaborations. The recently launched Smart Specialisation Partnerships (SPP) follows a similar logic to that established by the Vanguard Initiative to support the re-industrialisation of Europe. Although this partnership is not intended to directly focus on AM, this technological area was in several cases a main interest and AM was part of the three "*First candidate thematic areas*"[13].

In line with the **European Grand Challenges**, the benefits of AM are numerous over conventional subtractive manufacturing technologies. For example, many AM applications can decrease energy consumption, minimize the use of raw materials, and decrease generated waste during the manufacturing process. AM has the ability to produce lower volumes more economically and allows parts to be individually customised. For example, accurate patient specific parts can be built directly from a 3D CAD model which has been created from a patient's CT scan. This can reduce the removal of healthy bone; enable more efficient surgery planning and consistent execution; and higher acceptance of parts in patients. Also, optimised porous structures which mimic human bone can be created directly from metal powder. Due to the nature of the technology, components can be designed to have material only where it is needed. This not only reduces the overall weight of the part, but any remaining material can be recycled. Also, because many medical parts are made from expensive materials, waste of raw material can be significantly reduced when compared to conventional subtractive technologies. Properties such as decreased time-to-market, production based on just-in-time principles improve the environmental posture of AM technologies over traditional manufacturing. Furthermore, the fact that the AM manufacturing chain is built upon the concept of digitalization and digital data

[8] See for instance http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=9061. September 2016
[9] See https://ec.europa.eu/growth/industry/key-enabling-technologies/eu-actions/investment-support_en
[10] Available at http://www.s3vanguardinitiative.eu/sites/default/files/contact/image/final_declaration_of_milan_final_27_10.pdf
[11] http://www.s3vanguardinitiative.eu/cooperations/high-performance-production-through-3d-printing
[12] https://ec.europa.eu/growth/industry/innovation/smart-specialisation_es
[13] See https://www.alpeuregio.org/images/Trento/Eventi/2016_06_21_Friends_of_eusal/Pantalos.pdf

supports the global actions on reduction of environmental footprints.

Currently, AM is shifting from a pure rapid prototyping technology to **series production readiness** and therefore is **opening new market opportunities** for machine suppliers, manufacturing service providers and designers/OEMs. Manufacturing of components, with virtually no geometric limitations offers **new ways to increase product performance or establish new processes and revenue streams.** Furthermore, AM allows new production solutions (e.g. increased functionality, and complexity, manufacture of batch sizes consisting of just one item, on-demand-production near to the customers…) and novel supply chains s (e.g. inventory and storage reduction, faster delivery time), accelerating the product development process.

Europe is aware of the importance that AM is playing at a global level and its potential as the driver for European reindustrialization shifting towards smart and sustainable manufacturing. Nevertheless, aside from the existing knowledge portfolio and expertise, it has been demonstrated that exploitation of this technology is far from its potential, due to many factors including lack of awareness, limited competences, market access, resources, and limited inter-linking of regions and/or sectors. Therefore, **there is a need to take steps in the strategy** by bridging complementary capabilities and resources across Member States and to boost the results achieved to date, particularly from efforts/funds provided by public-private partnerships.

To enable real AM industrial innovation and deployment the **entire value chain** from modelling, design, process and product development (Fig. 1) to new business models and services, needs to be considered. Successful exploitation of this cooperation and expertise along these chains will not only reinforce the individual's competitiveness of each stakeholder, but also the whole European industry.

Fig 1. *Value chains segments established in AM-motion project*

3. Key Sectors for AM Deployment

As the adoption of the technology grows, the value and potential of AM for promising applications can vary from one sector to another. Equally, industrial deployment for the technology across such sectors becomes complex, resulting in their needs and challenges deviating across the sector VC. For this reason, a comprehensive review is firstly required on what brings those sectors to the fore and outlines an understanding of their current growth and potential impact on both a European and worldwide level. Therefore, this section focuses on outlining evidence relating to the most promising industry VCs for the development of AM innovations. This includes information relating to the most recent and relevant documentation, initiatives, projects and programmes.

The following top level sectors are outlined in detail:

- Health
- Aerospace
- Automotive
- Consumer goods
- Electronics
- Energy
- Industrial equipment and tooling
- Construction

An overview on the market potential, along with the expected economic impacts for specific applications is also included.

3.1 Health

Health is one of the most valuable aspects of anyone's life which makes this sector one of the world's largest and fastest-growing industries, consuming over 10% of gross domestic product (GDP) of most developed nations. Additive Manufacturing offers high added value to a number of applications and has already established itself as strong sector using the technology. For example, early acceptance of applications include visualisation models, hearing aids, hip implants, teeth braces and drilling guides. The AM hip implant cup was one of the first applications used in large production quantities mainly owning to this promotion of bone ingrowth. This is a component selected to reconstruct a hip known as "acetabular" cup to replace the natural socket, which is called the acetabulum. Figure 2 shows an image of a 3D printed acetabular cup with integrated trabecular structures for improved osseointegration (pores into which bone forming cells and supporting connective tissue can migrate).

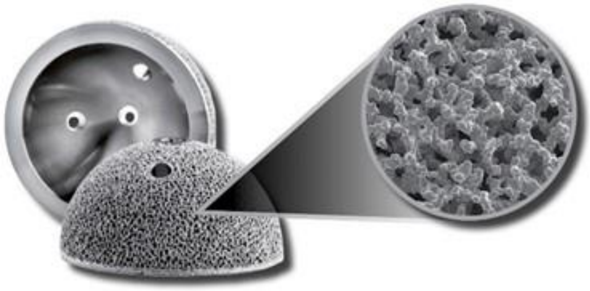


Fig. 2 *3D printed acetabular cups with integrated Trabecular Structures for improved osseointegration (Source* www.arcam.com*)*

Healthcare applications accounted for 12.2% of the related revenue for their AM market[14]. Research suggests by 2020 the market share for AM in this sector will likely reach $450m[15]. Equally, the medical sector has seen 25% compound growth in the AM market every year since 2009[16]. The dental market currently holds the largest share in AM with hip and knee implants becoming the second largest area of the healthcare sector. Although, products for use in the health sector are often critical and need to meet very high standards regarding reliability, safety, bio-compatibility and require certification (e.g. CE mark according EEC/93/42 for Europe or US food and drug administration (FDA-approval for USA)) bio-printing, well-being and food is fast becoming an areas of focus.

There are a number of **key drivers** for the healthcare sector to adopt AM and hence increase the potential impact. These include:

- Personalisation
- Mass customisation
- Efficient bio-compatibility
- Promotion of healthy bone ingrowth after surgery
- Integration of medicine and healthcare through digital innovation
- Increased efficiency of supply chain
- Reduced lead time
- Quicker response times

[14] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.
[15] Global metal additive manufacturing market 2016-2020 Technavio Inifiniti Research Limited 2015
[16] http://www.medicalplasticsnews.com/why-is-2016-the-year-for-additive-manufacturing-in-the-medic/

This sector is a sector where most of the key industrial players that are not 3DP specialists are American companies (Stryker, Zimmer-Biomet…). Still, a few EU players are active and it is clear that Europe's 3D-Printing industry has been developing strongly in the health sector, particularly for medical implants and the one off medical devices.

Over 20 AM medical implant products ranging from hip, spinal and knee implants have received clearance from the US food and drug administration (*FDA)*[17]. The FDA is now working more closely with AM to develop new approaches to assess the quality and safety of AM produced products for the industry but also where they believe the technology will make the most impact[18]. AM applications in the medical sector such as implants can offer exceptional added value. However, the demands regarding medical regulations and industry approvals require a high level of reliability and constraints for biocompatibility. Approval procedures can be stringent and specific requirements set for quality control of materials and processes. In this respect, AM is still a very sensitive process because every pixel of the workpiece material is individually produced. Some examples of progress at this rejects are the FDA-approved cranio and facial implants[19] and approval of a patient-specific titanium craniofacial plate implant[20] in 2014 and 2016 respectively.

At the AM and 3D printing European Conference held in Brussels in May 2016, health was a hot topic and there were many discussions regarding the implementation of certification and standards for the industry. A representative from the company Materialise quoted "*Harmonizing the certification system all over Europe would facilitate the recognition of health and safety standards and boost the use of AM products in sectors such as medical devices*"[21]. This is equally substantiated by the increasing focus of the ISO/TC 261 standards Committee to establish medical requirements for AM and further by the number of patents being issued for the healthcare industry which has increased over the years to where it currently stands as the top industrial sector obtaining patents related to AM.

The reason for this increasing development is due to AM impacting the industry in a number of positive ways, and where AM techniques are being rapidly adopted by the industry. For example in medical applications, **AM is being used for the creation of assistive, surgical and prosthetic devices and implants. In dental, for the production of crowns, bridges, drill guides and dental aligners**. Here, AM is able to bring significant improvements due to the nature of the process allowing for **complex parts to be produced accurately and to the patient's specific needs and profile**. Thus, reducing the removal of healthy bone, eliminating the

[17] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.
[18] Grunewald, S. J. *The FDA's Principal Investigator for 3D Printed Medical Devices is Looking for Industry Feedback and No One is Giving It to Him*. Retrieved July 20, 2016, from 3Dprint.com: https://3dprint.com/142583/fda-3dp-devices-feedback/
[19] http://3dprintingindustry.com/news/opm-gets-fda-go-ahead-3d-printed-facial-implant-31733/
[20] https://3dprintingindustry.com/news/fda-approves-3d-printed-titanium-craniofacial-implants-66136/
[21] "Helping industry and policy makers to build together a European strategy for additive manufacturing". *Additive Manufacturing and 3D printing European Conference.* Brussels: Cecimo, 2016

need for bone grafting whilst promoting effective planning of implantation/surgery and shortening the time of anaesthesia and increasing implant life particularly in an era of an ageing population[22].

- **Assistive, surgical and prosthetic devices and implants**

The 3D-printed surgical guide technology and related market is already at a mature level. As an example, Materialise currently produces over 4000 surgical guides for total knee replacements each month. The use of guides is increasingly expanding towards other orthopaedic surgeries. Typically, the focus is on non-standard, complex or accuracy sensitive cases where models for pre-analysis and even practicing the actual surgery are also used. For knee guides the complete VC is already today highly automated and is often used as the standard example of mass customisation.

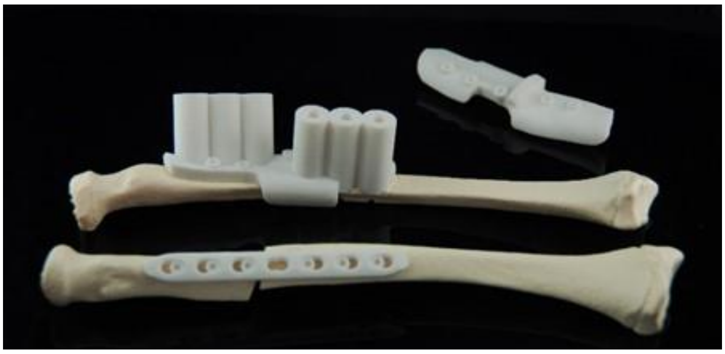


Fig.3 *Combined drill and cutting guide for a corrective surgery on a malunion of a radius (courtesy of Materialise)*

The more traditional applications of AM in the medical area were the production of physical models to visualise complex cases. Today, these models are often used to validate simulations and even practice or learn surgeries. This provides the surgeon with additional insights in what difficulties may occur during the actual surgery. There is however an increasing demand for more realistic models that better mimic the behaviour of real body parts. This is especially the case for organs and blood vessels (soft tissue in general). When practicing a surgery, the surgeon expects a similar "feeling" in order to be better prepared.

During the Materialise World Summit 2017[23] (Brussels, April 2017) it was mentioned by Dr. Morris, from the Mayo Clinic, a pioneer in the use of AM technologies, that the variety of materials available, from clear to sterilizable, allows for a variety of uses for 3D printed models used in the operating room as well as by physicians and patients alike ahead of any procedure. On the patient end, seeing a model of the actual anatomy and issues in question "provides true

[22] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.
[23] https://3dprint.com/171862/co-creation-mws17-keynotes/

informed consent" in a way that difficult-to-understand MRI/CT scans do not offer.

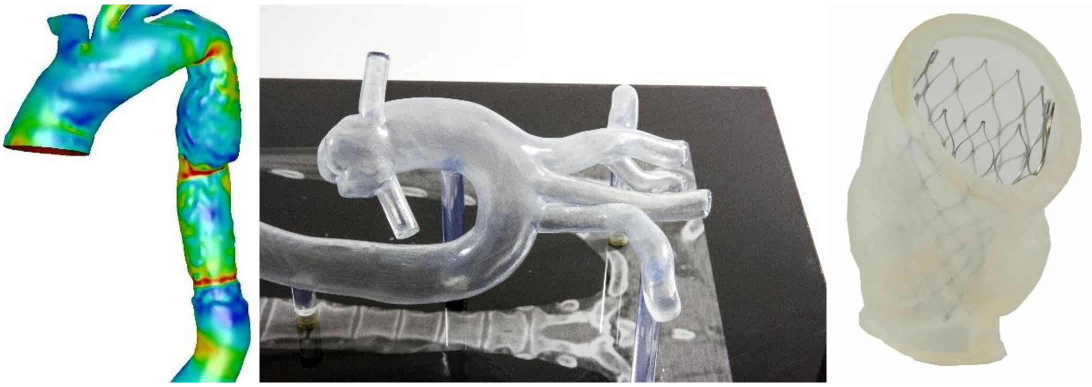


Fig.4 *Patient-specific model of an Aorta to ensure an optimal stent design (courtesy of Materialise)*

The <u>customisation of implants</u> opens up solutions for patients with unique pathologies. A typical market here is the revision of hip implants where detailed mechanical simulation can be used to ensure the required functionality and mobility of the patient. The recent (and hopefully future) advancements in process stability and material characteristics have opened up the <u>orthoses market</u> for the 3D-printing of patient-specific devices. Insoles, braces and Ankle-Foot orthoses (AFOs) are already being printed today. The key towards a further acceptance of AM within this market is the streamlining of the complete value chain.

Fig.5 *Customised hip implant mounted on a (printed) pelvis and 3D-printed orthopaedic insole*

- **<u>Dental</u>**

The dental industry continues to be one of the strongest targets for development of new AM printers, materials, and applications due to the acceptance of digital technologies by dental professionals. Most of the processes within the field of dental technology have already been digitised. Dental work and laboratory-based processes can now be combined into a single, digital workflow to ensure higher productivity, reproducibility and cost-effectiveness. However, there is still the challenge of quality control to contend with[24].

A typical dental restoration application known as a fixed restoration is used to replace a missing tooth by joining an artificial tooth permanently to the adjacent teeth or dental implants. Traditionally an oral impression of the patients mouth is taken and sent to the dental laboratory, where a technician creates a plaster model and hand-carves a wax-up (a wax mould of how the repaired teeth will look), investment casts it (using the lost wax technique), and adds a porcelain or ceramic veneer. This is a labouring and inefficient process which takes a lot of time. There is also a high volume requirement for precision individualised dental implants that are traditionally laboriously fabricated by high-skilled technicians. This high volume requirement cannot always be met due to the shortage of highly skilled technicians which could fulfil the demand. **AM has the potential to take away the intensive nature of the process by simplifying the manufacturing steps**. Also, many dental parts are made from expensive materials, so waste of raw material can be expensive. **AM can reduce costs through material savings** because any remaining powder material can be recycled. Also the **overall weight of the part can be reduced** because material is only placed where it needs to be. AM makes dental restauration affordable for a larger group of Europe's aging population.

- **Bio-printing**

Bio-printing is the process of creating cell patterns in a confined space using AM technologies, where cell function and viability are preserved within the printed construct. In more recent years, significant developments have been made in AM bio-printing and the use of medical imaging data to recreate complex biology. This is where bioengineering and tissue regeneration can be revolutionised. In the future, it is expected that this technology can provide 3D printed organs at affordable cost. Human embryonic, resident stem cells and bone marrow stem cells are within the current technology seen as essential for organ development. Some of the top manufacturers of bio-printing technology are Organovo Holdings inc., 3D systems Inc., 3D Biotek and Nano3D biosciences.

Despite a lack of industrial players and a low TRL, this area is still under construction, and analysis shows that European research is competitive in this area. However, the business area here is seen as immature and only a limited number of companies have to date managed to identify a business niche to sustain their commercial activities. Among other aspects, the technical limitations of the printers currently available appears to be a constraining factors together with the associated cost and complexity of printing human tissue. However, developments are fast moving and in the longer-term could bring potential breakthroughs to patients.

Scientists at Wake Forest institute for Regenerative Medicine have recently unveiled the

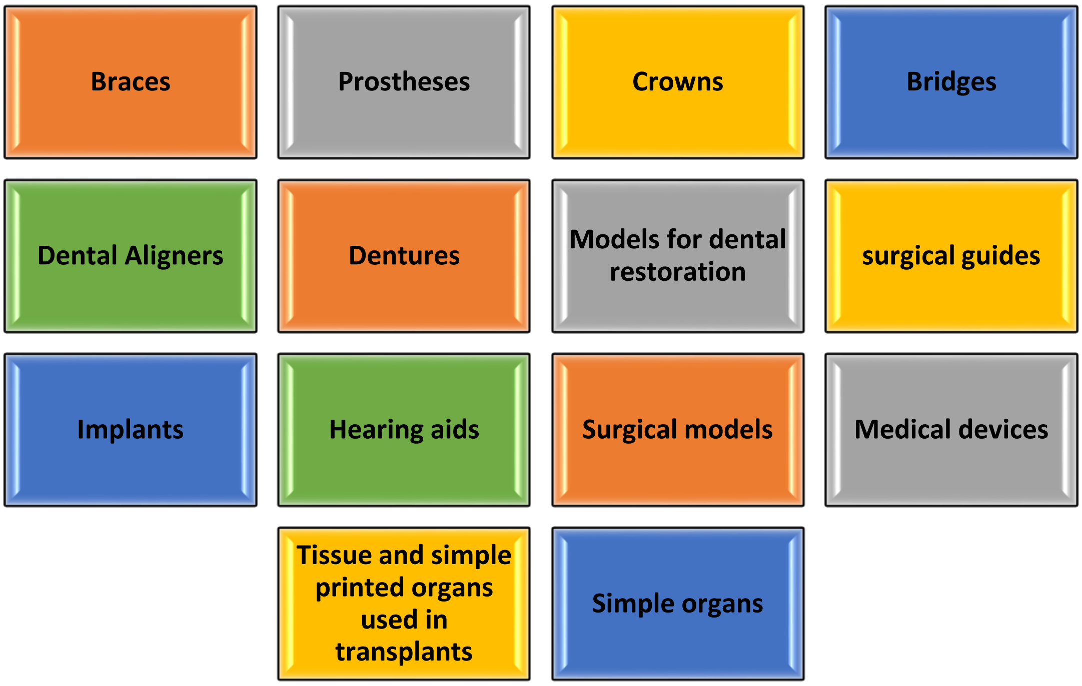
[24] Köster GmbH & Co., Dental Technology trade forum (16 June 2016) at Rapid.Tech

Integrated Tissue and Organ Printing System (ITOP). Clinical experiments have shown the system capable of printing bio-parts that maintain their shape, and form cartilage tissue and blood vessels. Once proven these AM bio printed structures could be used to replace injured, missing or diseased tissue in patients[25].

In terms of bio-printable tissue for transplantation it will provide improvements in not only pharmaceutical testing but subsequent cancer tissue models[26]. Researchers at the University of Pittsburgh Cancer Institute (UPCI) and materials and biomedical engineers at Carnegie Mellon University look to address the over diagnosis and over treatment of a non-invasive precancerous breast tumour. This will be achieved by creating an AM bio-printed breast ductal structure to categorise markers for low-risk premalignant disease[27].

Key innovative products

In the health sector there are a number of **key innovative AM products.** Outlined below is an analysis of the most promising applications areas:



[25] Hyun-Wook Kang, S. J. (2016). A 3D bioprinting system to produce human-scale tissue constructs with structural integrity. *Nature Biotechnology*, 312-319.
[26] Nathan, S. (2015, March 6). *Your Questions Answered: 3D bioprinting*. Retrieved July 20, 2016, from The Engineer: https://www.theengineer.co.uk/issues/march-2015-online/your-questions-answered-3d-bioprinting/
[27] UPMC. (2016, May 25). *3D Bioprinted Model for the Study of Precancerous Breast Disease Aims to Reduce Unnecessary Treatment*. Retrieved July 21, 2016, from UPMC: http://www.upmc.com/media/NewsReleases/2016/Pages/3d-bioprinted-model-precancerous-breast-disease.aspx

Capabilities/interests at regional level

European AM players are very much active in a number of healthcare areas. Key research fronts for Europe are “Biomedical Implants produced by EBM and SLM” and “Mandibular Reconstruction Surgical Planning”[28]. Moreover, strong capabilities in VCs such as the ‘hard and inert implants’ as well as ‘surgical tools’ which are mainly concentrated in Western European regions with either a strong healthcare industry or a strong presence of AM players. For instance Bavaria, Flanders, Asturias, Denmark, Emilia Romagna, are shown to be key regions in the area of surgical planning. Regions such as Bavaria and Baden-Württemberg gather key printer manufacturers, while a region such as Flanders gathers an ecosystem of service providers (Materialise), research and technological entities (K.U. Leuven, Sirris), Printer Manufacturer (Layerwise, now part of 3D Systems) hospitals and medical companies[29].The United Kingdom, the Netherlands and France ae strong when considering areas such as implants printing. Companies such as Renishaw (UK) and ARCAM (SE) have developed clear business lines on the 3D-Printing of implants.

In addition to individual capabilities, networking activities are progressively shaping up. Current developments in the Vanguard Initiative for example relate to the setting up of cross-regional demonstration activities in the areas of 3D-Printed orthoses, implants and prostheses.

[28] Source: http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8937
[29] See the illustrations provided by the current PROSPEROS project, available at http://www.grensregio.eu/projecten/prosperos

Main AM European projects with applications/relation to the Health sector

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acronym	ADDFACTOR BAMOS BOREALIS DREAM CAXMAN ENCOMPASS HI-MICRO HYPROLINE MANSYS NEXTFACTORY SMARTLAM SYMBIONICA TOMAX	ADDFACTOR BAMOS BOREALIS CAXMAN DREAM ENCOMPASS HI-MICRO HYPROLINE MANSYS SMARTLAM SYMBIONICA	3D HIPMAS ADDFACTOR BAMOS BOREALIS DREAM ENCOMPASS FAST HYPROLINE MANSYS TOMAX	3D HIPMAS ADDFACTOR BOREALIS CASSAMOBILE CAXMAN DREAM ENCOMPASS FAST HI-MICRO HYPROLINE MANSYS PHOCAM SMARTLAM SYMBIONICA TOMAX	ADDFACTOR BOREALIS CAXMAN DREAM ENCOMPASS HYPROLINE MANSYS	3D HIPMAS ADDFACTOR BOREALIS CAXMAN DREAM ENCOMPASS FAST HI-MICRO HYPROLINE MANSYS NEXTFACTORY SMARTLAM SYMBIONICA	BOREALIS DREAM MANSYS

- **Well-being and food**

Pharma

There is currently a growing interest on where AM could be applied within the pharmaceutical industry. Key drivers that are motivating this interest, are the possibility for personalisation, rapid experimentation, on demand supply and of having novel functions and forms, offered by these technologies.

Among the possible applications, AM could be used to print drug tables with truly personalised dosages of active pharmaceutical ingredient (API) and/or combining multiple drugs in just a single dose, greatly simplifying the pill intake for polypharmacy patients. The freedom of design in the AM manufacturing process allows for the development of different release profiles of the API in a pill, as well as new structures of the pill itself. By changing the density of the pill for example, the dissolving characteristics can be greatly altered. This was used to produce the first drug by 3DP, Spritam®, accepted for commercialization by the FDA in 2015[30], a rapid disintegration drug with personalised doses. At this moment, there are no other 3DP pharmaceu-

[30] https://www.forbes.com/sites/jenniferhicks/2016/03/22/fda-approved-3d-printed-drug-available-in-the-us/#574cc070666b

ticals on the market, but academic and commercial interest in the topic has been growing rapidly in the last few years.

These advantages will enable a new business model of specification formulations direct to the patient, lowering planning and forecasting activities as production is closer to the customer. Moreover, products can be tracked for example by printing on each pill a barcode plus the company's trademark.

Food

In addition to the well-known technical applications of AM, other sectors like food are also making vast advancements in the application of the AM technology. Most of the AM applications in the food sector use material extrusion (FDM), material jetting and powder bed fusion for the shaping and deposition of the material. Starting in 2011 the development of a prototype pasta printer capable of printing 3D pasta shapes was showcased at EXPO2015 in Milan. This printer is able to create unique pasta shapes and to print eight pasta shapes every two minutes. Linked to this, an app was developed that enables (future) customers to design their own pasta shapes, starting from a number of basic models[31]. The pasta, cooked and eaten as demonstrated in a BBC documentary[32], was shown to have the same properties as regular pasta.

Fig. 6 *3D printed pasta Printed and carrot puree courtesy (courtesy of TNO)*

There is also food with personalised medical nutrition which can be industrially manufactured by 3D printing. A European project named PERFORMANCE[33] developed and validated an holistic, personalised food supply chain for frail elderly facing swallowing and/or masticating problems (a medical condition known as dysphagia). The developed 3D printer turns the purees back to an edible form and are able to make them personalized. For example, a carrot

[31] Link: https://www.tno.nl/en/about-tno/news/2015/5/world-first-for-barilla-and-tno-3d-pasta-printer-at-expo2015/
[32] (http://www.bbc.co.uk/programmes/b06s1rn4)
[33] http://www.performance-fp7.eu/ (FP7-KBBE-2012-6 single stage)

puree can be printed into a shape resembling a portion of carrots (Fig 6). The factors that can be personalized to enable/promote edibility include hardness, size, calorific content, and added nutrients (proteins, fats, but also micronutrients like calcium, vitamins, omega-3 fatty acids). This personalization is something that cannot be achieved by conventional food production routes.

The AM technology can also be used for printing lab-grown meat. The Dutch Maastricht University has been working on 3D printed meat grown from beef stem cells[34]. Although developments are still underway, the technical process begins with stem cells extracted from cow muscle tissue. Taking 3DP into a real industrial context, 3D printing of chocolate is making headway. Chocolate has been a material that has been of interest from the beginning because it can be melted and solidified and thus inherently suitable for food printing. Over the years many organisations have become active in this particular area, as demonstrated by the commercial availability of a number of chocolate printers (typically based on extrusion printing).

AM is also being investigated as a novel and sustainable production process for food products where computational design and innovative building of uniquely structured food can be achieved[35]. Previous work has focussed on the creation of shapes and in some cases personalized recipes, here the focus is texture. Very specific and innovative structures were successfully printed that result in a predictable mechanical and hence textural behaviour. .

[34] http://www.3ders.org/articles/20151020-3d-printed-lab-grown-meat-could-be-in-stores-in-the-next-five-years.html
[35] http://susfood-db-era.net/drupal/sites/default/files/231-cibus-food.pdf

3.2 Aerospace

AM in the Aerospace sector has grown by 4.3% in 2015; is the second largest sector for AM[36] and currently represents over 10% of the global AM market [37]. The market is predicted to reach $1bn by 2021[38]. The aerospace market was an early adopter of AM, with many examples of niche components being made and supplied using various forms of AM[39]. This is mainly owing to the design freedom, near 100% material utilisation, light weighing and short lead times AM enables. This holds for many sectors but is particularly important for the Aerospace sector **because reduced weight and improved fuel efficiency of their engines, whist reducing cost and waste are key**[40].

The commercial aerospace industry is utilizing metal and polymer AM technologies to produce aircraft engine components and a variety of structural and cabin components.The main **focus markets of this sector** with regards AM **are engines and aircrafts interior parts.** The number of projects in pre-production and flight testing for aircraft engine manufacturing has grown significantly in the last years. Other applications, such as UAV's parts are also fast growing markets.

In 2015 Airbus announced to apply more than 1,000 Stratasys additively manufactured flight parts replacing conventionally manufactured parts for their flagship A350 XWB aircraft in a bid to speed up the manufacturing process. More recently, approximately 350 parts per A350XWB aircraft and around 10,000 parts were manufactured in 2016. The number expected to be printed in 2017 is 30,000 parts.

Another example on the possible use on AM on the aircraft was a titanium fan cowl hinge bracket from an A320 motor with more than 30% weight reduction achieved through topology optimisation. It was designed to fulfil all flying requirements. The original part was traditionally milled out of titanium (Figure 7).

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[36] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.

[37] DeSilva, R. (2015, November). *Debunking the myths of Additive Manufacturing.* Retrieved July 22, 2016, from Additive Manufacturing Summit: http://www.additivemanufacturingsummit.com/media/1003367/34746.pdf

[38] Smartech. (2014, August). *Additive Manufacturing in Aerospace: Strategic Implications.* Retrieved July 22, 2016, from Smartech Publishing : https://www.smartechpublishing.com/images/uploads/general/AerospaceWP.pdf

[39] Additive Manufacturing Platform. (2014). *Additive Manufacturing Strategic Research Agenda.* Brussels : Additive Manufacturing Platform.

[40] *Mapping UK Research and Innovation in Additive manufacturing.* (2016, February). Retrieved July 23, 2016, from GOV.UK: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505246/CO307_Mapping_UK_Accessible.pdf

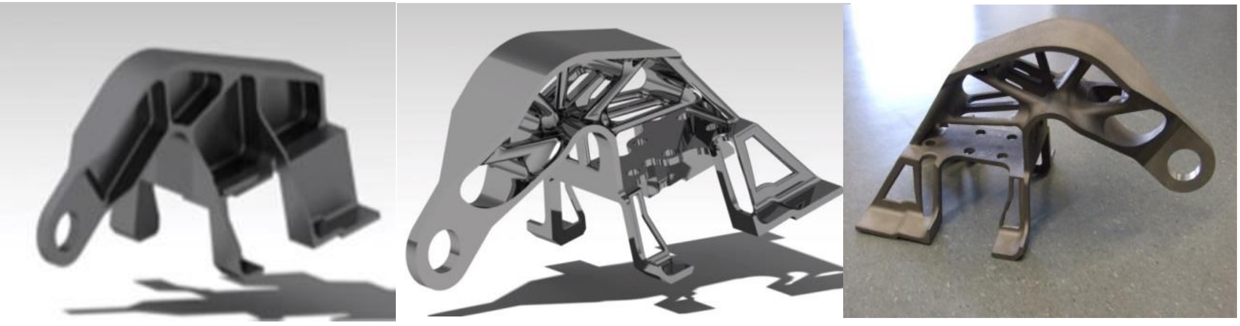


Fig. 7 *Topology optimization of structural hinge and manufacturing in Titanium (courtesy of PRODINTEC)*

This highlights why AM is such an attractive potential alternative manufacturing route, primarily due to its high material use efficiency and ability to process aerospace grade alloys. In more recent times, the industry is making significant moves to qualify AM parts. Norsk Titanium AS recently announced it had received a large order from The Boeing Company to additively manufacture preforms to demonstrate part to part repeatability leading to long term production of structural components for fleet aircraft[41].

Another prime example of the AM benefits being capitalised on by the Aerospace industry, is when Sciaky, on the order of on the sanction of Lockheed Martin Space Systems, developed an Additively Manufactured titanium propellant tank with an 80% reduced manufacturing time, 75% weight reduction and 55% cost reduction. The part met all the performance requirements[42].

A third example of AM application in aerospace sector is the fuel nozzle of the LEAP Engine of the joint venture company between GE Aviation (US) and Safran Aircraft Engines (FR) which attracted over 5,000 orders with a planned production of 1,700 engines by the end of 2018 for a.o. the Airbus A320 and Boeing 737. Each LEAP engine holds 19 fuel nozzles that will be up to 25% lighter, reducing fuel consumption and reducing production and maintenance costs. A remarkable recent acquisition of GE concerns the taking over of two leading AM machine manufacturer companies (ARCAM and Concept Laser).

There are a number of key drivers for the aerospace sector for the adoption and development of AM and hence potential areas of impact. These include:

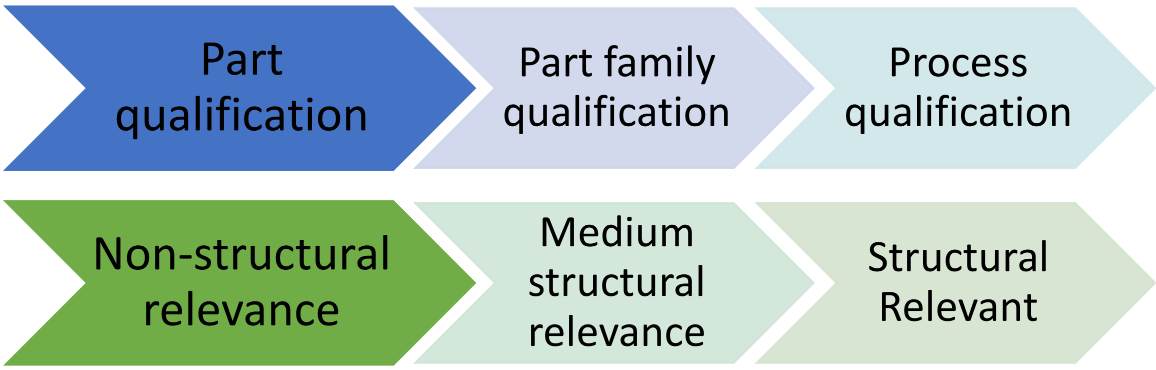
- Light weighting

[41] Norsk Titanium . (2016, July 12). *Norsk Titanium Receives Boeing Engineering Test Article Order*. Retrieved July 23, 2016, from Norsk Titanium AS: http://additivemanufacturing.com/2016/07/12/norsk-titanium-receives-boeing-engineering-test-article-order/

[42] Hewson, M. A. (2016, June 14). *Remarks to Aerospace Industries Association Supplier Management Council Summer Meeting*. Retrieved July 24, 2016, from Lockheed Martin: http://www.lockheedmartin.com/us/news/speeches/0614-hewson-aia-supplier-management-council.html

- Energy usage (improved fuel efficiency)
- Design freedom ‘new’ or ‘optimised’
- Life cycle cost
- Life time extension
- Reducing the buy-to-fly ratio
- Utilisation of materials
- Performance of materials
- Reduction of time to design and test and validate an aero engine
- Validation in full scale engine tests
- Increased efficiency of supply chain
- Production efficiency
- Simplified assembly process

Safety is always the first driver in the aerospace industry; therefore the AM introduction has had to take into account the need to verify the compliance with all existing regulations around the world. The complete strategy is subject to a continuous process of validation, verification and agreement with all applicable Airworthiness Authorities. Currently the activity is based on a step by step approach in order to gain confidence. For example in following schemes:



In the longer term, AM has real potential for the space industry. In this sense, The European Space Agency (ESA) began to study the potential applicability of AM technology[43]. A roadmap, covering around 30 types of AM parts that would strongly benefit from being manufactured using AM and the entire end-to-end AM process, from initial modelling and design of items to material supply and processing and post-processing stages to qualification and standardisation, has been produced by them. Standardisation is a key element is all important for space. To give mission managers sufficient confidence in 3D-printed parts, methods need to be

[43] http://www.esa.int/Our_Activities/Space_Engineering_Technology/Advanced_Manufacturing ; http://www.esa.int/Our_Activities/Space_Engineering_Technology/Ten_ways_3D_printing_could_change_space

in place to ensure that these items perform to a benchmarked, repeatable standard.

One key driver for space structures and equipment is the launching loads. Currently all parts being delivered to the International Space Station, or in a longer term, to the Moon or Mars for example, are launched as finished parts, therefore oversized and under the launching loads. Printing them directly at the destination will save a lot of weight and cost because those parts can be optimized to sustain real operating loads. Extra benefits will be exploited when the printing material is extracted and processed in situ. Here, printing in micro or low gravity needs to be assessed as powder based technologies will present relevant technical difficulties.

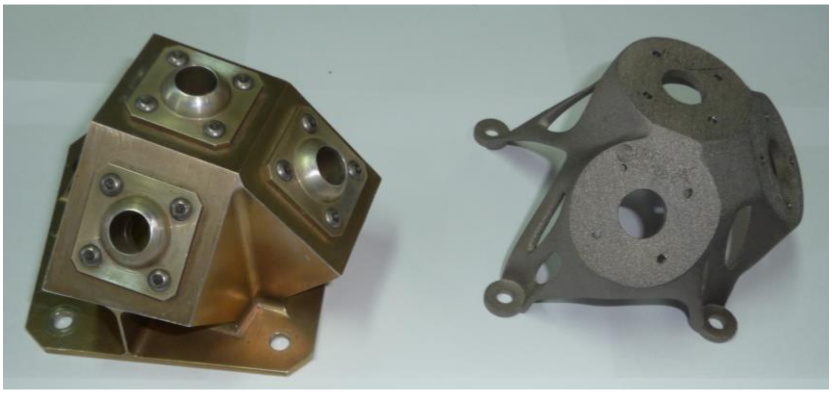


Fig. 8 *Original (from 1986) and optimised AM baffle bracket of ESA's Hipparcos satellite (courtesy of AIRBUS Defence& Space)*

On the other hand, the spares sector has potential for AM in terms of parts being delivered literally to any place in the world (usually at short notice). AM could drastically become a game changer, by reducing the needs of stocks by printing the parts closer to the demand and enabling shortening of lead times for part availability. Business models to be adopted will be a major decision to be taken in the industry. Safety, traceability and IP rights will also have to be secured. In 2016 a spare process has been agreed with EASA and several parts have been subsequently approved and available in case of customer demand.

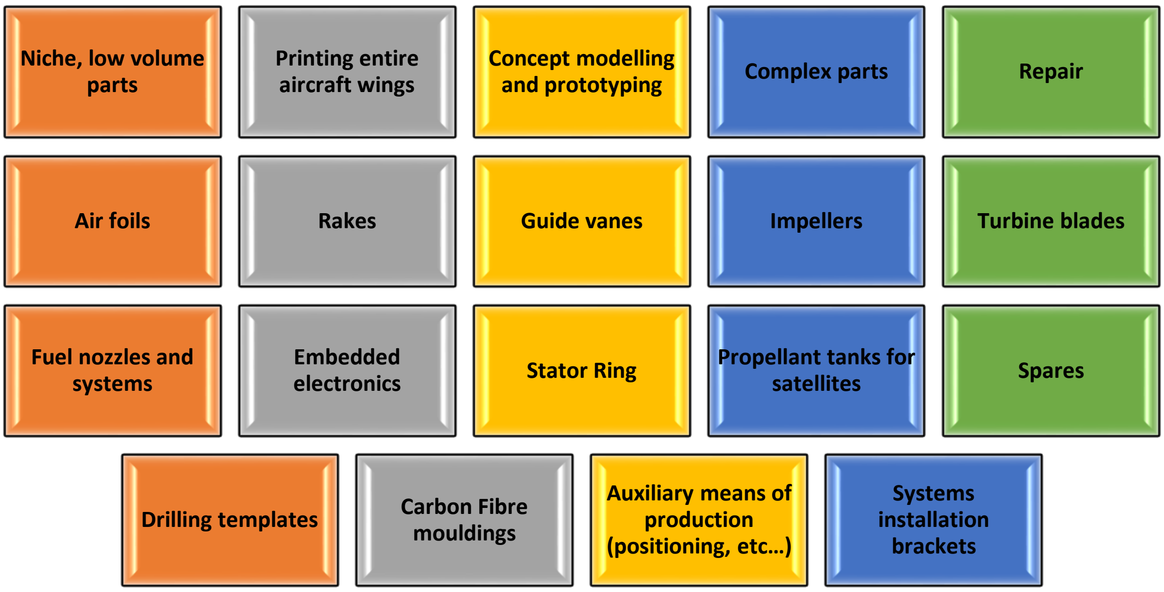
In this market there is a very relevant and specific niche previously mentioned which are the cabin parts. Surface quality and full harmony with the existing non AM parts are extra requirements which current technologies do not fully cover. Therefore very specific post processes are being developed as well in order to ensure that regulations are met (Fumes Smoke and Toxicity (FST) + Heat Release in case of a fire in the cabin) and full customer satisfaction is granted (no visual difference with existing parts).

There are also very ambitious initiatives running to develop customized AM tools like MyShape ® for Airbus, aiming to facilitate the engineers to change the design paradigm and exploit the full capability and benefits coming along with AM by following a seamless process across the traditional design disciplines. Very relevant shortenings of the lead times are envisaged behind this challenging project[44].

Specific alloys are being developed to take better profit of the advantages of the AM and to close some identified technological gaps, such as Scalm alloy[45] ® from Airbus Group Innovation, bringing exceptionally high fatigue properties and the same positive manufacturing propensities as AlMgSc sheet material

Key innovative products

In the aerospace sector there are a number of **key innovative AM products.** Outlined below is an analysis of the most promising applications areas:



Capabilities/interests at regional level

For metallic structural airplane components, the 3DP study on behalf of the EC[46] reports strong capabilities in North Rhine-Westphalia, Flanders, Bavaria, North Holland, Flanders, Auvergne, Cheshire, Ile-de-France, Burgundy, Baden-Württemberg, Midi-Pyrénées, Västergötland, Staffordshire, Schleswig-Holstein, Sør-Trøndelag, Hamburg - Low Saxony, Hesse, Rhône-Alpes, South Holland, Veneto, Emilia-Romagna, Cranfield, Sheffield, Manchester, Nord-Pas-de-

[44] http://www.4erevolution.com/myshape-outil-de-conception-impression-3d-airbus/
[45] http://www.technology-licensing.com/etl/int/en/What-we-offer/Technologies-for-licensing/Metallics-and-related-manufacturing-technologies/Scalmalloy.html
[46] And available at http://ec.europa.eu/DocsRoom/documents/18741/attachments/1/translations/en/renditions/native

Calais-Picardie, Piemonte/(Liguria), and Skirosky (Masovian Voivodeship). The correlation between the presence of industrial aeronautic clusters and the central role of the aforementioned regions in the VCs under the scope is clear. While the main printer manufacturers were found in German Länders (with companies such as EOS, SLM Solutions, Realizer and ConceptLaser), other providers were allocated in Sweden (Arcam AB), the UK (Renishaw), along with a broad range of service providers collaborating with the aeronautic sector in Flanders (Materialise), Ile-de-France, etc.

One of the key drivers of the diffusion of AM across regions in this sector was found to be integrators and Tier-1 suppliers. Their active role in adapting the use of AM to their production chains led those large companies to produce both structural and non-structural components made of different materials as to integrate them into final systems. In addition to GKN and Rolls-Royce, companies such as Safran/SNECMA, Zodiac, and others closely collaborate with each other but also RTOs (FhG, TWI, TNO, PRODINTEC, etc.) and Universities across European regions (Cranfield, Sheffield, etc.).

Despite of the development of AM capabilities by American players (e.g. Boeing, Bombardier and Lockheed Martin), in various European Regions including in Sikorsky or the UK, Airbus most likely remains one of the most important players in the AM industry world-wide. The company is today a key driver of AM industrial developments and developed AM capabilities across Europe (among other in German, French and Spanish regions).

Main AM European projects with applications/relation to the Aerospace sector

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acronym	4D HYBRID AMAZE BOREALIS CAXMAN ENCOMPASS HYPROLINE LASIMM MAESTROMANSYS OPENHYBRID PARADDISE STELLAR TOMAX	4D HYBRID AMAZE BOREALIS CAXMAN ENCOMPASS HYPROLINE LASIMM MAESTRO MANSYS OPENHYBRID REPROMAGSTELLAR	4D HYBRID AMAZE BOREALIS ENCOMPASS HYPROLINE LASIMM MAESTRO MANSYS OPENHYBRID REPROMAG STELLAR TOMAX	4D HYBRID AMAZE BOREALIS CASSAMOBILE HYPROCELL CAXMAN ENCOMPASS HYPROLINE LASIMM MAESTRO MANSYSMODULASE OPENHYBRID PARADDISE REPROMAG STELLAR TOMAX	4D HYBRID AMAZE BOREALIS CAXMAN ENCOMPASS HYPROLINE LASIMM MAESTRO MANSYS OPENHYBRID REPROMAG STELLAR	4D HYBRID AMAZE BOREALIS CAXMAN ENCOMPASS HYPROCELL HYPROLINE MAESTRO MANSYS LASIMM OPENHYBRID REPROMAG STELLAR	AMAZE BOREALIS MAESTRO MANSYS STELLAR

3.2 Automotive

As early adopters of the AM technology, the automotive industry has established itself as a strong sector. The industry is the third largest sector as reported by Wohlers[47] and it is estimated by 2019 the industry will generate over $1.1bn in revenue[48].

The automotive industry has historically used AM as an integral tool in the design process. The fast-paced design cycles in the automotive industry require a rapid prototyping solution that can produce almost any geometry with a variety of material properties, quickly and cost effectively[20]. Although it has mainly been limited to prototyping, tooling (e.g. injection moulds) or short series (vintage cars, customisation, etc.), AM is still relevant to Automotive. Still, the issue of technology efficiency leaves an interrogation mark on the space it will occupy in the future (besides tooling and prototyping). Whilst sectors such as aerospace are in need of batches ranging from 1 to a few tens of thousands of parts or products, the automotive sector deals with millions of outputs. Automotive companies (whether tier suppliers or integrators) remain among the keys European lead-users of AM world-wide with an absorption capacity similar to the one found in large industrial groups from the aeronautic industry.

Given the significant developments made in AM technology the industry has grown and is now utilising the benefits of AM in new ways. For example in the field of powder bed fusion the largest machine was developed in cooperation between Fraunhofer, Concept Laser and Daimler. With this machine it is possible to produce (functional) prototypes of large aluminium parts for applications involving vehicle and engine technology, but also from other areas.

For fully functional parts in automotive sectors the AM applications are still very limited. The safety requirements on automotive parts are very high as well as other requirements on strength, light weight and costs while the series often are very large. Niche markets for limited series of exclusive cars are starting to apply AM. Besides unexpected breakthrough on the technical side, changes in the end product itself (Smart/Greeb cars) might also affect the type of structural components needed. Moreover, processes are being put in place as to facilitate the characterisation and normalisation of AM in the automotive sector, and very recent progress was made with for instance the new EOS acquisition(s) by Audi in Germany or the promotion of the Canadian URBEE 2 vehicle. BMW began using 3D printing technology to produce end-use parts in series production back in 2012 with their new Rolls-Royce Phantom. Over the next several years, more than 10,000 3D printed components would end up being used to manufacture each Phantom coupe that came off the assembly line[49]. Daihatsu are collaborating with Stratasys to manufacture limited edition skins for the Copen, a two door roadster. These skins

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[47] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.
[48] Smartech Publishing. (2016, December). *Additive Manufacturing Opportunities in the Automotive Industry: A Ten-Year Forecast.* Smartech Publishing
[49] source: https://3dprint.com/142364/3d-printed-parts-bmw/

will be a first towards the mass production of AM parts for the automotive industry[50].

There are a number of **key drivers** for the automotive sector for the adoption and development of AM and hence potential areas of impact. These include:

- (Functional) prototyping
- Light weighting
- Design freedom
- Increased efficiency of supply chain
- Increased quality, reliability and reproducibility
- Reducing vehicle carbon emissions
- Cost effectiveness

The main applications of AM in the automotive market are in prototyping, pre-series manufacturing, concept models, race cars, exclusive cars. Figure 9 shows a typical use of such a concept model of a car interior. Where in the early days of AM (still called Rapid Prototyping at the time) the produced prototypes were very brittle, today most prototypes are functional parts that can be used for testing (see Figure 10Fig.).

***Fig. 9**: The concept model for a Citroen interior (Courtesy of Materialise)*

[50] Newman, J. (2016, June 24). *Daihatsu Partners with Stratasys for Automotive Customization*. Retrieved July 24, 2016, from RapidRady: http://www.rapidreadytech.com/2016/06/daihatsu-partners-with-stratasys-for-automotive-customization

Fig.10: *A functional prototype of a sports car headlight*

In general, the typical large series envisaged in automotive have a negative impact on the cost effectiveness of 3D-printed components. In assembly tooling and other manufacturing aids however, this is not a problem and the automotive industry is an early adopter of 3D-printing in these application. An example of this is shown in Figure x. It is a fixture for a fender used to clamp a produced part to be measured. A large part of the fixture consists of reusable components. The orange parts in the picture are the customised parts, adapted to the shape of the specific fender.

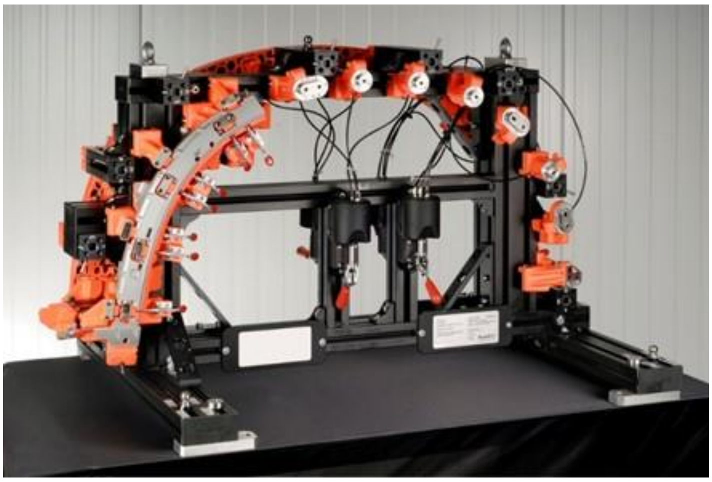
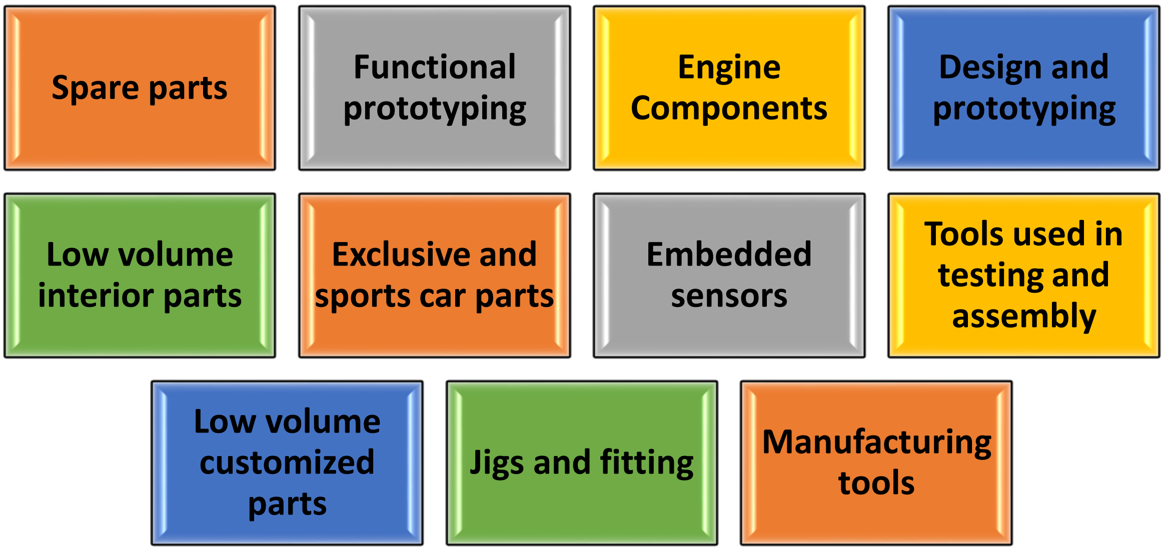


Fig. 11: *a fender measuring fixture (Courtesy of RapidFit+)*

Key innovative products

In the Automotive sector there are a number of **key innovative AM products.** Outlined below is an analysis of the most promising applications areas:



Capabilities/interests at regional level

For various segments identified, capabilities could be reported such as in-service provision (Flanders and Wallonia with Materialise and Sirris) and printer manufacturing (Layerwise and Phoenix System – both now 3DS and respectively operating from Flanders and Ile-de-France, Gorgé in Ile-de-France and Rhône-Alpes-Auvergne). In the automotive area, the role of clusters and RTOs is of key importance, such as demonstrated by the strong presence of the Spanish ASERM and the PEP-IPC cluster. The VC remains driven by OEMs and integrators: besides Rhône-Alpes-Auvergne and Ile-de-France (Renault, Volvo), Piemonte and Lombardy but also Emilia Romagna (where Ferrari or Lamborghini are active in the area) or Ängelholm (Koenigsegg), Västergötland and Bohuslän (Volvo) were listed.

Similar to the aeronautic AM area, one of the key concentrations of all types of players is found in Germany with SLM-Solutions (Schleswig-Holstein), EOS and ConceptLaser (Bavaria) from the side of printer manufacturers, Fraunhofer (Bavaria, Hesse), LZN (Hamburg - Low Saxony) and other players in Baden Wurttemberg from the side of RTOs, as well as the broad range of automotive manufacturers (Audi, BMW, etc.) and OEMs (EDAG in Hesse and the French OEM Faurecia for example).

One of the particularities of the automotive VCs (whether plastic or metal-based) is their outreach to Eastern European regions, such as Polis ones where both research and industrial applications of AM are growing. For plastic-based non-structural car interior components, the 3DP study reports strong capabilities for instance in Flanders, Wallonia, Rhône Alpes, Ile-de-France, Auvergne, Piemonte, Lombardy, Emilia Romagna, Catalonia, Schleswig-Holstein, Bavaria, Hesse, Hamburg - Low Saxony, Baden Wurttemberg, Ängelholm, Västergötland and Bohuslän.

The repartition of the capabilities across these regions follows a pattern similar to the one observed in the aeronautic sector: the value chain segments are mainly located around the key automotive clusters and well-known 3D-Printer manufacturers and service provider. Companies either absorb the technology directly (by means of leasing and/or acquisition) or call upon service provisions from key service providers. An outstanding concentration of different value chain segments (service providers, OEM, integrators and printer manufacturers but also software providers and RTOs) are however in German regions such as Bavaria and Baden Württemberg.

Main AM European projects with applications/relation to the Automotive sector

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acronym	AMAZE AMCOR BOREALIS CAXMAN COMPOLIGHT DREAM ENCOMPASS HIPR KRAKEN LASIMM MAESTRO OPENHYBRID PARADDISE STELLAR	AMAZE BOREALIS CAXMAN COMPOLIGHT DREAM ENCOMPASS KRAKEN LASIMM MAESTRO OPENHYBRID REPROMAG STELLAR	3D HIPMAS AMAZE AMCOR BOREALIS COMPOLIGHT DREAM ENCOMPASS HIPERLAM KRAKEN LASIMM MAESTRO OPENHYBRID REPROMAG STELLAR	3D HIPMAS AMAZE AMCOR BOREALIS CASSAMOBILE CAXMAN COMPOLIGHT DREAM ENCOMPASS HIPERLAM HIPR HYPROCELL KRAKEN LASIMM MAESTRO MODULASE OPENHYBRID PARADDISE REPROMAG STELLAR	AMAZE AMCOR BOREALIS CAXMAN COMPOLIGHT DREAM ENCOMPASS HIPR KRAKEN LASIMM MAESTRO OPENHYBRID REPROMAG STELLAR	3D HIPMAS AMAZE BOREALIS CAXMAN COMPOLIGHT DREAM ENCOMPASS HYPROCELL KRAKEN LASIMM MAESTRO OPENHYBRID REPROMAG STELLAR	AMAZE BOREALIS DREAM KRAKEN MAESTRO STELLAR

3.3 Consumer Goods/Electronics

Consumer goods/electronics is the fourth largest sectors using AM accounting for over 13% of the market (*Wohlers, 2016*). One of the principle uses of AM parts in the consumer goods industry is to produce prototypes, models art, jewellery and gadgets. Although making prototypes remains the main use of additive fabrication, the technology has increasingly spread into 'rapid manufacturing'. One industry projection for the future would involve the use of a single machine for the design, prototype, and creation of a finished part. Within the consumer market AM is seen as playing a very significant and pervasive role in enabling a whole new way of designing and making things in the world of customised consumer products. For example, artists, jewellers and fashion designers are using AM in a range of ways to make one off bespoke pieces[51]. AM of electronic devices and components is also seeing growing interest. Inkjet printing methods are emerging as the front runner for electronic applications using AM technologies.

Fig. 12 *A stool named OneShot by the designer Patrick Jouin for MGX by Materialise because the moving mechanical parts are created and emerge in one go by 3D printing.*

[51] Scudamore, R. J. (2015). *POSITIONING PAPER:The Case for Additive Manufacturing. UK: AM Strategy Development Group.* Sheffield.

Fig. 13 *3D-printed bespoke glasses (courtesy of Materialise and Hoya) and printed customised in-soles (courtesy of Materialise, RSPrint and RSScan)*

An example of the impact AM is making in the industry is when Martyn Harris, a 3T employee, noticed a gap in the market for cycle accessories, in particular the need to mount hardware such as mobile phones, cameras etc. Due to the large variation in handle bar diameters there was potential for AM to offer a solution. As a result, RaceWare Direct was established and now retails for specialist and bespoke cycling accessories[52].

There are a number of **key drivers** for the consumer goods/electronic sector for the adoption and development of AM and hence potential areas of impact:

- Tailored products
- Customisation
- Increased efficiency of supply chain
- Increased functionality
- Enhanced materials
- Sustainability of raw materials
- Higher demand for colourful items
- Demand for innovative products

The customisation of running shoes was investigated, among other, in the FP7 project ADDFactor[53]. Within the project, a method was developed to adapt the mechanical properties locally in a midsole to optimise the pressure distribution on the foot of the customer. The first resulting shoe is shown in Figure 14.

[52] 3T RPD Ltd. (2016, 2016). *From Prototype to Production to Sales in weeks*. Retrieved July 24, 2016, from 3T RPD Ltd: http://www.3trpd.co.uk/portfolio/additive-manufacturing-prototype-production-sales/gallery/consumer-goods-case-studies/
[53] http://cordis.europa.eu/result/rcn/171034_en.html

Fig. 14: *the ADDFactor European project customised midsole*

A new market that is currently adopting AM and the possibility for mass customisation is in eyewear. Spectacles have an enormous impact on the look of the person wearing them. Not surprisingly, the fashion industry plays an important role within this market. It was only a matter of time for AM to break into this market. Materialise has partnered up with different players in this market (Hoya, Hoet…) to offer design as well as manufacturing services in this area. Having a solution for the complete VC is again the key to success here.

- **Jewellery**

The adoption of CAD software among designers is opening the way to AM for manufacturing in the jewellery sector. Annual revenues from 3D-printed hardware, materials, services and software used in the jewellery industry is expected to reach $900 Million in 2026[54]. In traditional jewellery manufacturing with silicon moulds, the initial model is often 3D printed using high-temperature resistant photopolymer resins. Jewellery prototyping for size and shape verification is complemented by the use of directly 3D printed wax and resin patterns for direct casting and serial manufacturing. Materials also include precious metal powders. The next evolutionary step is direct metal 3D printing.

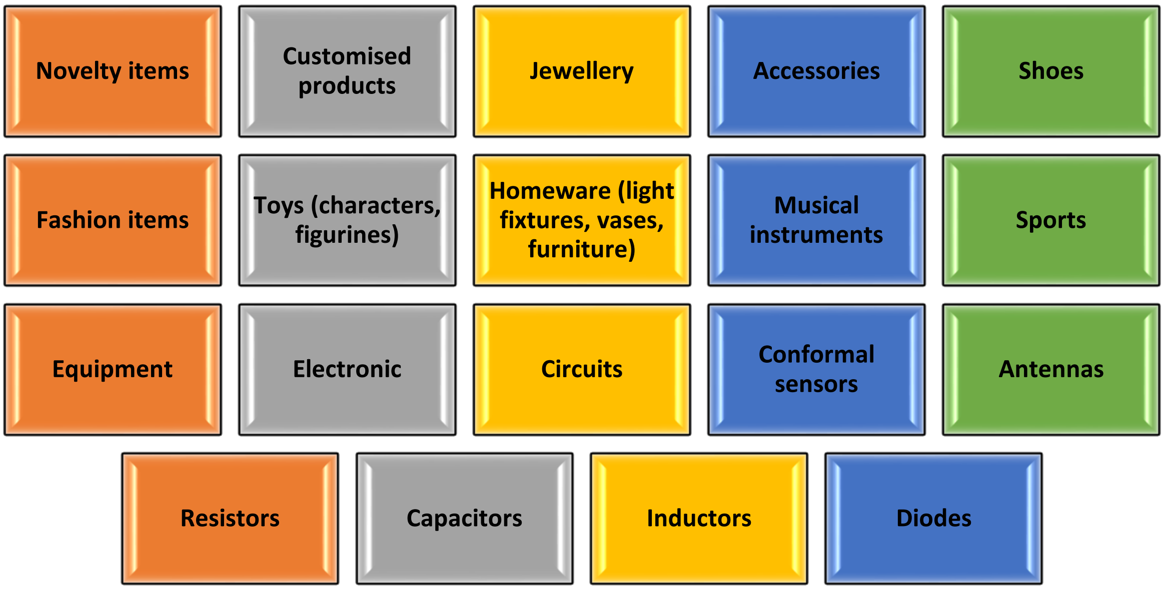
The leading providers of technologies and materials in this sector include Stratasys (Solidscape), 3D Systems, EnvisionTEC, EOS, Concept Laser, Sisma, ReaLizer as well as precious metal powder providers such as Cooksongold, Legor, Progold and Hildebrand[45] .

Key innovative products

In the consumer sector there are a number of **key innovative AM products.** Outlined

[54] “3D Printing Opportunities in the Jewelry Industry 2017” https://www.smartechpublishing.com/reports/additive-manufacturing-evolution-in-healthcare

below is an analysis of the most promising applications areas:



Capabilities/interests at regional level

Although the printing of electronics is US-driven, some technological developments such as UV-laser sintering of silver ink in Germany could provide new pathways for EU players. More potential is however seen in the textile area for fashion products, including sporting goods. The 3DP study[55] analysed in that regard two different landscapes which are the one of the 3D-printed textiles and the one of lighting and other home decoration products[56].

In the former, the role of open-source designs and data as well as of decentralised networks and platforms is of key importance to this niche under development. Although not yet a full level of maturity, this field can be associated to regional capabilities related to the presence of main 3D-printing companies (service providers and printer manufacturers) as well as to key research efforts being performed in different areas across Europe. Such key capabilities are mainly observed in Western European regions and Poland. These also encompass companies which develop their expertise in home decoration printing and that might not be active in other 3D-Printing areas, although the diversity of this particular segment is developing across Europe. From the user side, a more fragmented view can be observed. Areas subject to a high level of urban concentration are one of the main areas of development of consumer printing, whether by individual consumers or through fablabs. Regions NL2, NL, 3, NL 4, BE 1, BE 2, and DEA

[55] See http://ec.europa.eu/DocsRoom/documents/18741/attachments/1/translations/en/renditions/native
[56] Such as furniture, vessels (vases, bowls, cups etc.), sculptures, and others

concentrate around fablabs, which are complemented by a high density of fablabs across France, the UK, Italy and Germany. Poland, Czech Republic and Latvia are also countries where capabilities could be identified, which are rather associated to the supply side (presence of companies providing 3D-printing devices and/or services in the first place).

The textile area is even less mature from a market perspective. New developments however point to a clear evolution from research to commercial successes. Companies and RTOs in Germany, Belgium, the Netherlands and the UK are consolidating their capabilities in this field. In some of the most active fields of textile printing – sportswear, shoe and protective clothing manufacturing – companies such as Nike or Feetz developed commercial approaches and took a market lead. In Europe, they compete with the German player Adidas. The scattered landscape of European designers (mainly located in Denmark, the UK and the Netherlands) is involved in those developments, however not illustrating the presence of structured capabilities yet. A stronger landscape appears when considering Smart Textiles, area where successful research is being conducted in RTOs and Universities in the UK, Italy, Ireland, Germany, Finland, as well as in the Netherlands. When considering this area, capabilities can be extended to the particular value chain in which Smart Textiles are used: an illustration is provided by the Cocoon car produced by EDAG, an automotive OEM located in Germany.

Main AM European projects with applications/relation to the Consumer goods/Electronics sector

VC Seg-ment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-pro-cessing	Product	End of life
Project acronym	ADDFACTOR CAXMAN COMPOLIGHT DIMAP HI-MICRO HIPR IBUS MAESTRO OPTICIAN2020 SMARTLAM TOMAX	ADDFACTOR CAXMAN COMPOLIGHT DIMAP HI-MICRO IBUS MAESTRO OPTICIAN2020 REPROMAG SMARTLAM	3D HIPMAS ADDFACTOR COMPOLIGHT DIMAP HIPERLAM IBUS MAESTRO REPROMAG	3D HIPMAS ADDFACTOR CASSAMOBILE CAXMAN COMPOLIGHT DIMAP HI-MICRO HIPERLAM HIPR IBUS MAESTRO OPTICIAN2020 REPROMAG SMARTLAM TOMAX	ADDFACTOR CAXMAN COMPOLIGHT DIMAP HIPR IBUS MAESTRO OPTICIAN2020 REPROMAG	3D HIPMAS ADDFACTOR CAXMAN COMPOLIGHT DIMAP HI-MICRO IBUS MAESTRO OPTICIAN2020 REPROMAG SMARTLAM	DIMAP IBUS MAESTRO

3.4 Energy

Energy consumption is still growing worldwide and projected to increase further Two thirds of the worldwide energy development was generated by fossil sources in 2010. The global turbine market was valued at USD 135.68 billion in 2013 and is expected to reach USD 191.87 billion by 2020 at a CAGR of 4.89% from 2014 to 2020[57]. The Energy branch is focused on production of energy and its transport and distribution. The topic of energy storage is also being covered and seems to be substantial for further development of the renewable energy system.

There are a number of **key drivers** for the energy sector for the adoption and development of AM and hence potential areas of impact. These include:

- Energy usage (improved fuel efficiency)
- Reductions of emissions
- Complex parts
- Life cycle cost
- High performance materials
- New opportunities for product development process e.g. validation in full scale turbine tests
- Improvement of MRO (Maintenance, Repair and Overhaul)
- Production costs
- AM process efficiency

Reliable, efficient and clean fossil power systems needs innovative technologies. By using innovative fossil power systems, scarce resources can be exploited with maximum efficiency and fossil power generation as environmentally friendly as possible. The development of AM processes in recent years offers the opportunity to produce complex parts by AM with a high accuracy and improved material properties for the use in power turbines[58].

With the AM technology the repair and production of parts for industrial gas turbines can be faster and with full freedom of design possibilities. Within the last years, AM has emerged and is revolutionizing the manufacturing of components. This technology allows design improvement and rapid manufacturing of components, thus enabling quick upgrading of existing assets to the latest part design.

There is great potential for AM to create value by reducing greenhouse gas emissions, use less resources in the production process, reducing the development time, offering flexibility for

[57] http://www.transparencymarketresearch.com/turbines-market.html
[58] http://www.energy.siemens.com/us/en/fossil-power-generation/

design of parts, faster repairs, reduction of lead time and using new fuel mixes. For example, Siemens announced in 2014 they would produce replacement burner components for gas turbines rather than using conventional methods (fig. 15a). Recently, a key development was achieved with the production of additively manufactured turbine blades with a conventional design at full engine conditions[59], standing extreme temperatures (fig.15b).

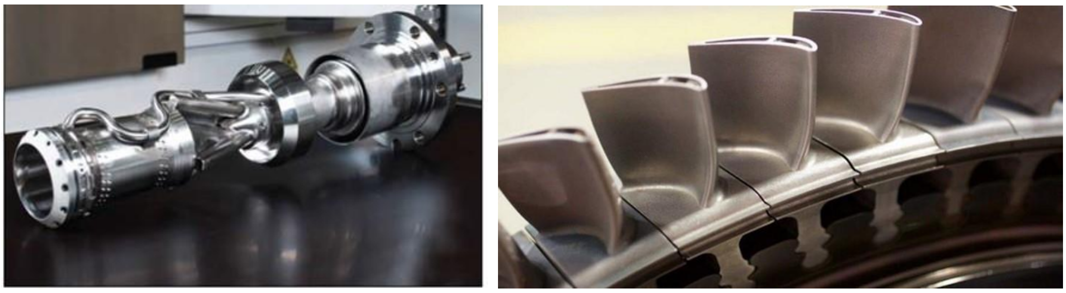


Fig. 15 *a) SGT-700/800 burners were traditionally manufactured with 13 components and 18 welds, b) turbine blade (Source: Siemens)*

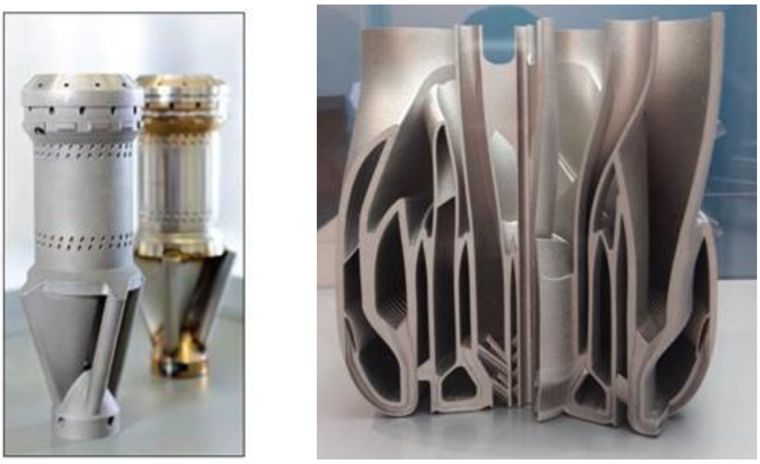


Fig. 16 *AM burner front vs conventional burner front and Burner Design Study. The new SLM manufactured burner front consists of one component and two welds. (Source: Siemens; «Gas Turbine World)*

[59] https://3dprint.com/164121/siemens-gas-turbine-blades/

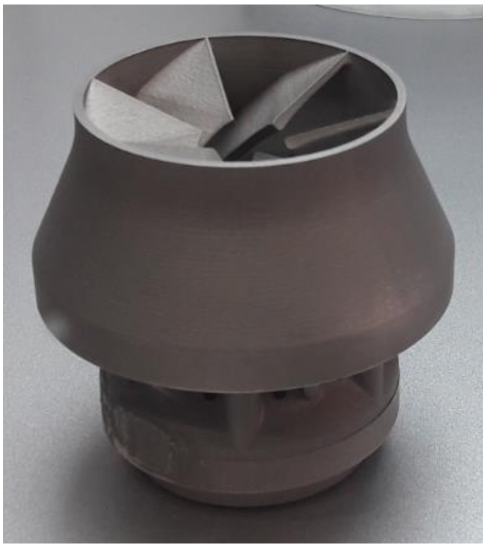


Fig. 17 *Swirler (Source: Siemens)*

While the nuclear sector is also developing Additive Manufacturing knowledge and applications[60], it is believed that the **Oil and Gas Industry** will be the next big adopter of AM technologies to become more efficient in the current low oil price era. Companies are actively exploring the use cases for both rapid prototyping as well as field production of parts- The possibility of printing metal components and increasing opportunities for large print volumes is one of the key drivers[61].

General Electric Oil & Gas are expanding AM use, introducing the first metal 3D printers into their Japanese operations at their Kariwa plant in Niigata Prefecture. There they are using hybrid metal laser sintering 3D printers to manufacture control valve parts, which are used in various applications within the energy industry. The machine (Lumex) combines both additive and subtractive capabilities within a single unit[62]. The freedom to design specific types of valves in shapes was never possible with traditional molding techniques. For instance, intricate shapes, hollow structures, and woven meshes are able to be realized in designs. Additionally time is being saved. Specialty parts can now be designed and fabricated in a matter of a couple of weeks as opposed to the typical three-month wait seen using traditional manufacturing methods.

AM technologies are also gaining interest in the **renewable energy** sector and in particular in **wind energy**. Major players in the wind industry are currently investigating how AM can contribute to the development and manufacturing of wind turbine components. One early example is the 3D printing of a mold for the turbine blades, used in wind energy and tidal energy

[60] See for instance https://energy.gov/sites/prod/files/2016/05/f31/2016%20ADVANCED%20METHODS%20FOR%20MANUFACTURING%20AWARD%20SUMMARIES_0.pdf
[61] https://www.smartechpublishing.com/reports/additive-manufacturing-opportunities-in-oil-gas-markets-2016-a-ten-year-for
[62] https://3dprint.com/47485/3d-print-control-valve-ge/, 2015

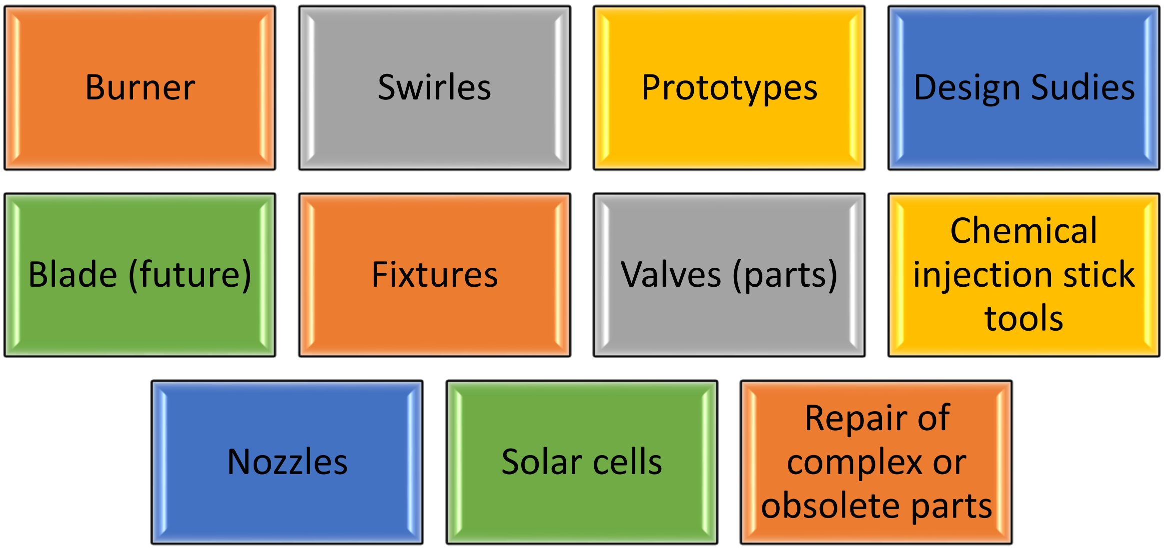
applications for example[63]. Moreover, AM has been used for several years as a rapid prototyping tool by wind turbine manufacturers such as Vestas and GE, and is now being considered as a key enabling technology for manufacturing complex molds, lightweight components (gears, blade parts, …) or spare parts[64].

Similarly, the relatively new sector of **ocean energy** could benefit in the future of progress in AM technologies.

Lux Research developed a methodology to score use cases for this industry based on the value generated by printing them and their suitability for being printed. The analysis identified use cases such as pipeline pigs and sand control screens as forthcoming and liner hanger spikes and drill bits as high-potential applications. Profitable use cases included 3D printing chemical injection stick tools and nozzles for downhole cleanout tools [65].

Key innovative products

In the energy sector there are a number of **key innovative AM products.** Outlined below is an analysis of the most promising applications areas:



[63] http://www.owi-lab.be/content/3d-printing-large-components-offshore-renewable-energy-industry-inspiration-future-cost
[64] http://www.windpowermonthly.com/article/1421837/additive-manufacturing-will-gamechanger#box
[65] 2016, http://www.luxresearchinc.com/content/assessing-opportunity-additive-manufacturing-oil-and-gas-industry

Capabilities/interests at regional level

European capabilities in the area of Additive Manufacturing for Energy are currently scattered. There is a “modest” use of Additive Manufacturing in the oil and gas sector, while more visible developments seem to take place in the energy sector[66].

The most well-known players in this area are most likely companies such as Siemens AG Power Service and General Electrics which recently undertook a strategic move toward the acquisition of the Electron Beam Melting machine manufacturer Arcam AB and prior to that, the French Alstom. Additional actors include for instance ENGIE Lab-Laborelec, TWI and Rolls-Royce Nuclear who joined forces on a new collaboration in July 2016[67]. Other players involved in the energy area include Sirris (in the context of collaboration initiatives undertaken with the OWI application and SLC Labs), the Nuclear AMRC, Materials Solutions, and to some extent Bielefeld and Grabher Günter Textilveredelungs GmbH.

Such spread of capabilities implies that Finspång, Flanders, Bavaria (and to some extent Berlin Brandenburg when considering corporate decision structures[68]), Wallonia, Västergötland, Cambridgeshire, Derbyshire, North-Rhine Westphalia, Worcestershire, Vorarlberg, Yorkshire and the Humber are the regions on the forefront of AM development in the sector.

Main AM European projects with applications/relation to the Energy sector

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acronym	4D HYBRID	4D HYBRID	3D HIPMAS 4D HYBRID	3D HIPMAS 4D HYBRID CASSAMOBILE HYPROCELL MODULASE	4D HYBRID	3D HIPMAS 4D HYBRID HYPROCELL	

66 See http://ec.europa.eu/DocsRoom/documents/18741/attachments/1/translations/en/renditions/native
67 Source: http://www.lr.org/en/news-and-insight/news/ENGIE-lab-laborelec-rolls-royce-nuclear-join-additive-manufacturing-joint-industry-project.aspx
68 Note for instance that a company such as Siemens has Additive Manufacturing capabilities in different locations such as Germany, the UK, Sweden, etc.

3.5 Industrial Equipment and Tooling

AM industrial equipment is a significant sector and a growing one for the European market. In March 2016, as many as 28 companies in Europe were manufacturing and selling AM equipment. Eight of these are metal powder bed fusion system manufacturers. Wohlers reports industrial machines as those selling for more than $5,000 which aims to provide the distinction between 'industrial' and 'desktop'. Within Europe these equipment manufacturers include ARCAM, Sweden (acquired by GE); Concept Laser, Germany (75% acquired by GE); DWS, Italy; Envisiontec GmbH, Germany; EOS, Germany; Lithoz, Austria; Mcor, Ireland; Prodways, France; Realizer, Germany (acquired by DMG MORI); Renishaw, UK; Sisma, Italy; SLM Solutions, Germany; Trumpf, Germany and Voxeljet, Germany[69]. Many of these companies are also developing new AM systems to bring to the market. A total of 12,558 industrial systems unit sales were estimated worldwide during 2015. In 2015, Europe position in system unit sales grew to 31.7% in 2015.

AM can be used to produce tooling, moulds, fixtures and patterns with enhanced functionality. Moreover, temperature regulation is a key issue for industrial equipment in the process industry and injection moulding. Because AM enables the ability to produce parts with complex internal structures improve heat transfer can be applied. For example, conformal cooling channels inside moulds can reduce cycle times up to 40% when using AM. This is particularly important when equipment needs to operate at very high temperatures (e.g. burners) and internal cooling channels are able to cool the parts improving the life span of the parts and the mechanical properties of the part when operating at these high temperatures. Product examples are special heat exchangers and manifolds for the process industry, robot grippers and test rigs. An example of a special 'heat exchanger' (cooling plate) is given below see (figure 18). The cooling plate is equipped with a grid of thermal pixels each having individual supply of cooling liquid that can keep the temperature gradient of the plate within very narrow limits.

Fig. 18 *Thermal stabilised table by means of free form cooling structure (source TNO)*

AM can be applied for complex shaped light weight parts. The shape of the part can be

[69] Wohlers, T. &. (2016). *Wohlers Report.* Colorado: Wohlers Associates Inc.

optimised using FEM analysis and topology optimisation in which internal lattice structures can increase the stiffness.

Conventional manufacturing technologies, such as milling, are limited in producing complex parts due to tool access and fixturing restrictions. At the present, complex parts are normally produced out of full dense material and divided up into several, easier to produce, simple parts that are then assembled together. This strategy introduces the need for milling accurate reference planes and applying mounting elements resulting in relative high production costs needing extra materials and energy. Secondly the parts are made out of dense materials not using the advantages of structural optimization.

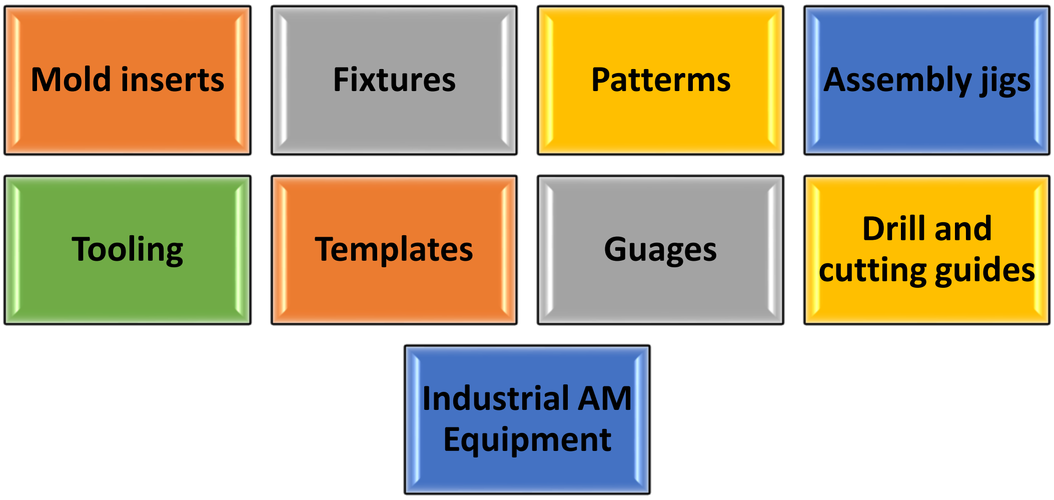
With additive manufacturing each "pixel" of the material could be placed exactly at the spot where it is most effectively used. In this way parts with multiple integrated functions can be realised and structural optimised materials can be applied, using the material and energy only where it is really needed with near zero material waste. In this way, AM enables opportunities for a drastic improvement of the performance of the part by a lighter weight with more functions integrated in the part.

As a secondary service market, tooling produced using AM grew from 13.1% to $1.859 billion in 2015[70]. As a horizontal industry, tooling is a major industrial sector producing endless products to be assembled using various jigs, fixtures and moulds. To produce these products conventional CNC machining is widely used, however these techniques can be expensive with long lead times. This is where more manufacturers are now looking to AM for a more cost effective method particularly for producing low volume or one off complex parts. Equally this opens the opportunity for improving tooling design which in turn offer improved functionality of the products produced[71].

Key innovative products

In the industrial equipment and tooling sector there are a number of **key innovative AM products including industrial equipment itself.** Outlined below is an analysis of the most promising applications areas:

[70] Wohlers Report 2016: 3D Printing and AM state of the industry. Annual worldwide progress report.



Capabilities/interests at regional level

The equipment and tooling sector is diverse in nature: the printing of components for machines will greatly vary from the printing of tools such as mould inserts, cutting guides, jigs and fixtures.

The printing of mould inserts reached a clear level of maturity. Here however comes a second challenge: the particularity of such area as mould printing is that it can be associated to a wide range of value chains. Mould inserts can indeed be printed for automotive companies, toy makers, or in the packaging industry, involving different industrial players and different modus operandi. In addition to RTOs and taking the example of metal AM for injection moulding, capabilities on the following value chain segments were identified[72]:

- In terms of material provision, (mainly Western) European regions include North Rhine-Westphalia, Flanders, Skåne, and Cheshire in the first place and face a tough competition from American companies.
- Regions where key Printer manufacturers are located in Europe included Warwickshire, Staffordshire, Schleswig-Holstein, Bavaria (most likely the leading region in this area due to the presence of several industry leaders), BadenWürttemberg, as well as Auvergne. Although these are not the only players at stake, they are known to be at the core of the manufacturing of 3D-printers used to manufacture metal injection moulds.
- Regional capabilities are then scattered when coming to the segment of mold makers. Mould-making companies are often small companies, except for OEM and a selected number of Tier suppliers of different industrial sectors. The industry is therefore characterized by a high level of fragmentation which is coupled to a high level of specialization.

[72] See http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8937

- Region where key service providers were located include for instance Flanders, Scotland, Bavaria, Rhineland-Palatinate, Northern Ireland, Rhône Alpes, Ile-de-France. One of the particularities of those companies is that they sometimes are even seen as competitors to the mould-making industry.
- Examples of end-users were also referred to as to illustrate the broad outreach potential of the mould-making industry. These include for instance LEGO (Jutland, DK), Berker (North Rhine-Westphalia, DE), car manufacturers located in Germany (Bavaria and Baden-Wurttemberg), French and Swedish car manufacturers such as Renault and Volvo (both active in Rhône-Alpes).

These are illustrative of the complexity and wide spread not of the supply side of AM in Europe, but rather of the demand- and lead-user sides. Being a very horizontal industry, and given that a sector-focused approach is currently missing in AM for industrial machines, there currently emerge difficulties in identifying regional capabilities. Examples were mentioned in this area, with Dutch, Italian and German companies (such as Atlas CopCo, ASML, IMA.it, Schunk and Siemens for instance) implementing initiatives for the printing of spare parts that find direct links with industrial machinery.

<u>Main AM European projects with applications/relation to the Industrial Equipment & Tooling sector</u>

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acronym	AMAZE COMPOLIGHT DREAM	AMAZE COMPOLIGHT DREAM	AMAZE COMPOLIGHT DREAM	AMAZE CASSAMOBILE COMPOLIGHT DREAM HYPROCELL	AMAZE COMPOLIGHT DREAM	AMAZE COMPOLIGHT DREAM HYPROCELL	AMAZE DREAM

3.6 Construction and building

The construction industry is one of the oldest in the world and has accompanied humans along the years since the beginning of the humanity and its evolution. It has been recognized as one industry that consumes considerable amount of resources and poses significant environmental stresses. Over the past few decades, studies on construction innovations have been conducted to address the productivity, environmental, and other issues in terms of two forms. One form of construction innovations is a response to external needs (e.g. the clients' needs) and the other form of construction innovations originates from other industries. However, the main emphasis for innovation strategy in the construction industry is to use technology from elsewhere to reinforce other competitive advantages.

Freedom of forms, unconventional buildings, curves, innovative designs and personalized creations are some of the features that AM can bring to this sector. In construction virtually every wall, floor, panel, partition, structure and facade is unique in dimension, which means either standard sized materials are cut down to fit, or bespoke moulds are created to form each component. In the latter case economies of scale drive the need to design multiple copies of identical elements on a project. There is a clear cost-based opportunity to save time and materials by reducing waste and the need for formwork/mould making. There is also significant potential to reduce the quantity of materials used through optimisation of form and the implementation of additional 'engineering function' within components. The computational design environment promises the freedom to design around individuals and the environment. Furthermore, AM may remove the need for replication of components, giving designers freedom to make each part unique[73].

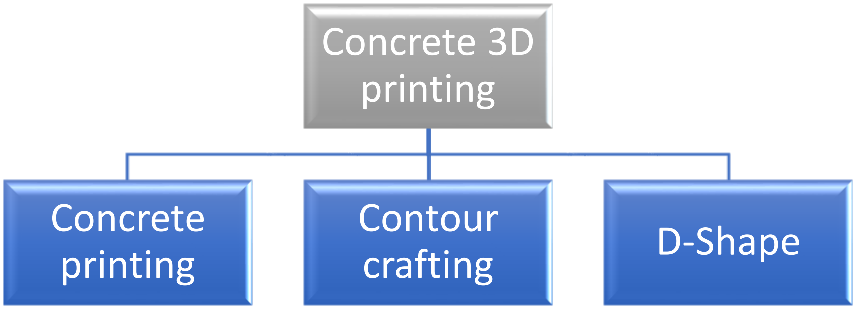
The integration of AM technologies in the construction sector has the main advantages:

- Manufacturing of new structures, complex shapes, integrated channels with flexibility and adaptability:
- To build more accurately and with a better final appearance
- Pollution reduction and consumption of natural goods.
- Decreasing energy consumption and waste products obtained while manufacturing.
- Decreasing of the manufacturing and production time, with a manufacturing processes automatization, obtaining by this way functional structures faster with a lower cost.
- Decreasing of labourer's accident hazards due the increase of automatization.
- Total process control while manufacturing layer by layer any structure. Can be checked at every second all variables of the constructive process.

The first attempt at using cement based materials in an approach to AM was suggested by

[73] Wu, P., Wang, J. & Wang, X. Automation in Construction A critical review of the use of 3-D printing in the construction industry material Finished. *Autom. Constr.* **68,** 21–31 (2016)

Pegna[74]. Currently there are three large-scale AM processes targeted at construction and architecture in the public domain, namely: Contour Crafting, D-Shape (Monolite)[75] and Concrete Printing[4]. All three have proven the successful manufacture of components of significant size and are suitable for construction and/or architectural applications.



Contour Crafting is based on extruding a cement-based paste against a trowel that allows a smooth surface finish created through the build-up of subsequent layers. It has been developed to address the issue of high-speed automated construction, and the current deposition head is capable of laying down material to create a full width structural wall with the minimum use of material. This technology was developed by Dr. Khoshnevis (University of Southern California) in 1996 concerning the 3D-printing based on extrusion of concrete. It has a great potential for automating the construction of whole structures as well as sub-components (with different designs) may be automatically manufactured in a single run, embedded in each house all the conduits for electrical, plumbing and air-conditioning. Currently, NASA is interested in this kind of process, in order to build up structures on the Moon and Mars ground with the aim of next human colonization.

Concrete Printing is also based on the extrusion of cement mortar, however the process has been developed development has been to retain 3-dimensional freedom and has a smaller resolution of deposition, which allows for greater control of internal and external geometries.

The **D-Shape** process uses a powder deposition process, which is selectively hardened using a binder in much the same way as the Z-Corp 3Dprinting process.

[74] Pegna, J. Exploratory investigation of solid freeform construction. **5,** 427–437 (1997).
[75] D-Shape Technology. Available at: http://d-shape.com/what-is-it/.

	Pegna [14]	Contour Crafting	Concrete Printing	D-Shape
Process	*3D Printing*	Extrusion	Extrusion	3D Printing
Use of mould	*No*	*Yes* (Becomes a part of component)	*No*	*No*
Build material	*Sand*	• Mortar mixture for mould • Cementitious material for build	In-house Printable Concrete	Granular material (sand / stone powder)
Binder	Portland cement (activated by water)	None (Wet material extrusion and backfilling)	None (Wet material extrusion)	Chorline-based liquid
Nozzle diameter	1 mm	15 mm	9–20 mm	0.15 mm
Nozzle number	unknown	1	1	6 300
Layer thickness	unknown	13 mm [21]	6– 25 mm	4–6 mm
Reinforcement	*No*	*Yes*	*Yes*	*No*
Mechanical properties	*Tested* with zero degree (0°) of layer orientation, which means the force was given *from the top* of the printed surface			
Compressive strength	28.30 MPa	unknown	100 110 MPa	235 242 MPa
Flexural strength	14.52 MPa	unknown	12–13 MPa	14–19 MPa
Print size	>1 m dimension	>1 m dimension	>1 m dimension	>1 md dimension
Pre / Post processing	• Removal of *unused material*	• Reinforcement *per* 125 mm vertically • Backfill the mould with a cementitious material per 125 mm height	• Reinforcement after printing	• Compression of the powder for next layer by a roller with light pressure prior to the deposition • Removal of unused material
Pros	• First attempt for freeform construction	• Smooth surface by trowel	• High strengths • Minimum printing process; deposition & reinforcement	• High strengths
Cons	• Massive material placement • Removal of unused material	• Extra process (moulding) • Weak bonding between batches due to segmented backfilling batches by one hour interval	• Limited printing dimension by the printing frame, 5.4 m (L) × 4.4 m (W) × 5.4 m (H)	• Slow process • Rough surface • Limited printing dimension by the printing frame • Massive material placement • Removal of unused material

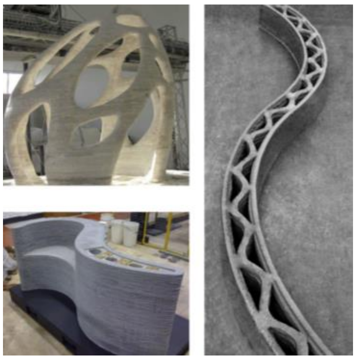


Fig. 19 *Comparative between different 3D printing construction processes*[76]

Currently the TRL-level of AM with regard to application in the construction sector within the specific area of the printing of structural building elements (e.g. walls) is low in which the integration of reinforcing steel to reach the required strength is a fundamental problem.

A complicating factor for application of 3D-printing in the construction area is that the requirements in this sector are tough with respect to e.g. durability (typical required life span 50 years), safety and strength (compressive stress) while some parts of the building are exposed to outside weather conditions and heavy loads. Another issue is the sizes of buildings. These are often in the range of tenths of meters which is enormous compared with the building area of most traditional 3D-printers that have working areas in the range of e.g. 300 mm. This means that the volume of workpiece material used in buildings can be in the order of 1 million higher compared to 'traditional' parts produced by AM. The part complexity of building elements is relatively low as most elements are flat and rectangular shaped.

Nowadays, on a European perspective, AM technologies applied on construction sector

[76] Lim, S. *et al.* Developments in construction-scale additive manufacturing processes. *Autom. Constr.* **21,** 262–268 (2012).

with several projects, developers. Some examples are described below.

EU H2020, leader, Spanish company VIAS,"HINDCON[77]: Hybrid INDustrial CONstruction" through a 3D printing "all-in-one" machine for large-scale advanced manufacturing and building processes uses concrete to build up components for use in construction. A prototype is planned for 2018. HINDCON project aims to adapt manufacturing technologies to the construction sector, advancing towards industrialisation and overcoming the limitations of actual approach for introducing Additive and Subtractive Manufacturing in construction activities. This type of manufacturing could be used to build almost every element of a building, from panels and internal walls to roofs, without being constrained by their size. There is no point in using this to build regular, plain walls of fixed dimensions as traditional techniques can already do that efficiently. The biggest potential of this type of manufacturing is creating elements with complex shapes, from the architecture of non-conventional buildings such as museums to bespoke or complicated features within a conventional building.

Consortium performed by "Cementos Tudela Veguin (concrete company)", "Coprosa (construction company)" and PRODINTEC on the national project "*CON3D: development of an automatized process for structure manufacturing using 3D printing technologies for the construction sector*", had developed a constructive process based on 3D printing using concrete materials (fig.20). Nowadays, their further developments include an integral building solution that includes the concrete printing technology and steel reinforcement structure integrated in a real scale machine is under development. The machine prototype will ready to use mid-2017.

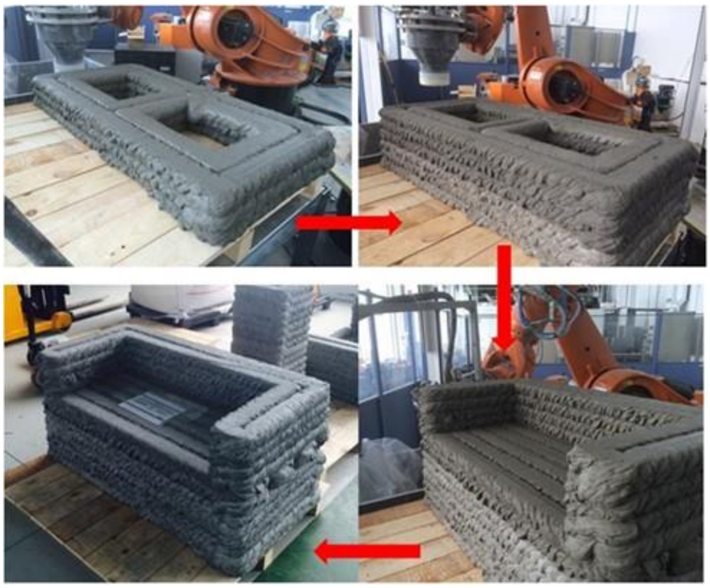


Fig. 20 *Final structure developed by CON3D Project (source: PRODINTEC)*

[77] HINDCON H2020 project http://www.hindcon3d.com/

Further European, and also Spanish, AM projects for the construction industry is as shown "First Printing Concrete Bridge[78]", designed by Institute of Advanced Architecture of Catalonia (IAAC) and built up by Acciona Construction in Madrid, Spain, last December 2016. Bridge placed has a length of 12 meters and a width of 1.75 meters and allows pedestrians go across a river. So far, there was no application of AM technology in the field of civil engineering (fig. 21). Another example of bridges, in this case made in steel, is the Dutch "Canal Bridge" project lead by the company MX3D[79].

Fig. 21 *The first printing concrete bridge by ACCIONA*

The School of Civil and Building Engineering from University of Loughborough have developed computer controlled 3D printers that deposit successive layers of concrete to form complex structural components – such as curved cladding panels and architectural features – that cannot be manufactured by conventional processes. The technique also facilitates the inclusion of increasingly complex building services infrastructure from the outset instead of time-consuming and costly on-site retrofitting[80]. They are collaborating with the construction group Skanska in the creation of a commercial printing robot.

The Eindhoven University of Technology is building a 3D printed concrete home in the Netherlands[81]. The 3D printer was developed in collaboration with Dutch company ROHACO as part of the project 3D Concrete Printing (3DCP). The completed machine features an extrusion print head that can move in all directions will attached to a concrete mixer and pump, featuring a 9 x 4.5 x 2.8m build volume.

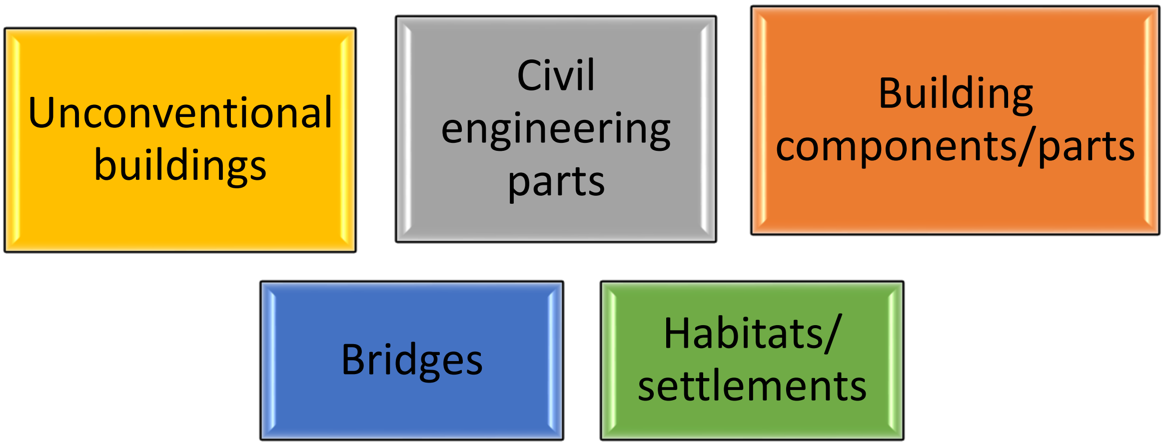
Furthermore, this technology can make possible for people who cannot purchase their own houses to have a home. The technology can be used to rebuild cities that were devastated by war or natural disasters in a shorter period of time, using less money, and it can also reuse

[78] 3 Source: http://csp-world.com/news/20161214/002700/worlds-first-3d-printed-concrete-bridge-has-been-put-place-spain
[79] http://mx3d.com/projects/bridge/
[80] http://www.lboro.ac.uk/enterprise/case-studies/3d-concrete-printing/
[81] http://www.3ders.org/articles/20161027-eindhoven-plans-to-built-europes-first-3d-printed-concrete-house.html

the waste generated in the harmed city, transforming it into construction material[82].

Key innovative products

In the construction sector there are a number of **key innovative AM products.** Outlined below is an analysis of the most promising applications areas:



Capabilities/interests at regional level

In the process of emerging, the market of 3D-Printed houses and buildings is facing key technical challenges. Taking a time-to-market perspective, the European Commission study[83] highlights the potential of 3D-printed affordable housing, area in which capabilities are currently manly located in RTOs and Universities when considering Europe.

Additional capabilities could be identified in the UK, Italy the Netherlands for instance. From a regional perspective, the study refers to most capabilities being spread across The Netherlands (North Holland, South Holland, North Brabant, and Utrecht), the UK (London, North-West England, West Midlands, East Midlands, South-East England), Germany (Bavaria, Hessen, Baden-Württemberg, Rheinland-Palatinate, Nordrhein-Westfalen) and Switzerland (Zürich). Key players are also located in Italy (Tuscany), Sweden (Västerbotten, Skåne), Belgium (Flanders) and Finland (Uusimaa, South-Carelia).

[82] "3D Printing The Next Five Years" Mariana Duarte, InovaHouse3D"

[83] Available at http://ec.europa.eu/DocsRoom/documents/18741/attachments/1/translations/en/renditions/native

Main AM European projects with applications/relation to the Construction sector

VC Segment	Modelling & simulation	Design	Materials	Process, equipment, ITC	Post-processing	Product	End of life
Project acro-	AMCOR CAXMAN KRAKEN	KRAKEN	AMCOR KRAKEN	AMCOR KRAKEN	AMCOR KRAKEN	KRAKEN	KRAKEN

3.7 Summary and conclusions

This document is the result of the activities performed within the framework of work package 2 (WP2): “Mapping the AM land-scape”, and more specifically of Task 2.1 “Selection of market driven value chains”. Task 2.1 has successfully analysed preliminary information and VC selections of key interest to the adoption of AM. This preliminary information was subsequently verified by the support of the industrial partners within the consortium (AIRBUS for Aerospace, SIEMENS for Energy and Transport and MATERIALISE for Healthcare and Consumer).

Additive manufacturing (AM) technologies have been identified as one of the most promising production technologies on a global level. They are considered to empower the transition from mass production to mass customization in several leading sectors and identified as one of the technologies driving the digital transformation of industrial production known as the 4th Industrial Revolution. The global AM industry is growing and is expect to exceed $21bn in revenues by 2020.

Europe, at both a political and industrial level, possesses great potential to be-come a world leader in the development and deployment of this technology. There are world-class leaders operating in specific areas of AM at a global level, the EC has provided over €330M in funding in the technology, and huge efforts are being made on a regional and national level to rein-force capabilities in AM technologies and to speed up its market uptake.

Europe is aware of the importance that AM is playing at a global level and its potential as the driver for European reindustrialization. However, it has been demonstrated that exploitation of this technology is far from its potential and there is a need to take steps in the European strategy to:

- Bridge complementary capabilities
- Align resources across Member States
- Boost the results already achieved to date

To enable real AM industrial innovation and deployment, the entire value chain needs to be addressed to only reinforce the competitiveness of each stakeholder, but also the whole European industry. For this reason this deliverable has identified and recommends the following key sectors for further AM deployment:

Health

This sector is one of the world's largest and fastest-growing industries. AM offers high added value to a number of applications and has already established itself as strong sector using the technology. Healthcare applications accounted for 12.2% of the related revenue for their AM market. Research suggests by 2020 the market share for AM in this sector will likely reach $450m. Key innovative areas are in:

- Assistive, surgical and prosthetic devices and implants
- Dental
- Bio-printing
- Pharmaceutical and food

Aerospace

Aerospace is the second largest sector for AM and is predicted to reach $1bn by 2021 . The aerospace market was an early adopter of AM, with many examples of niche components being made and supplied using various forms of AM. Key innovative areas are in predominately in aerospace parts but also space.

Automotive

The automotive industry has established itself as a strong sector. The industry is the third largest sector for AM and it is estimated by 2019 the industry will generate over $1.1bn in revenue. Given the significant developments made in AM technology the industry has grown and is now utilising the benefits of AM in new ways.

Consumer Goods/Electronics

Consumer goods/electronics is the fourth largest sectors using AM accounting for over 13% of the market. One of the principle uses of AM parts in the consumer goods industry is to produce prototypes, models art, jewellery and gadgets.

Energy

The Energy branch is focused on production of energy and its transport and distribution. The topic of energy storage is also being covered and seems to be substantial for further development of the renewable energy system. With the AM technology the repair and production of parts for industrial gas turbines can be faster and with full freedom of design possibilities.

Industrial Equipment and Tooling

AM industrial equipment is a significant sector and a growing one for the European market. Tooling, also a part of the sector, is where AM is being used to produce tooling, moulds, fixtures and patterns

Construction and building

The construction industry is one of the oldest in the world and AM enables the manufacture of tailor wall structures including e.g. honeycomb structures for optimal thermal behaviour as well as the embedding of cable harnesses and switches. Currently the TRL-level of AM with regard to application in the construction sector within the specific area of the printing of structural building elements (e.g. walls) is low in which the integration of reinforcing steel to reach the required strength is a fundamental problem. A complicating factor for application of

3D-printing in the construction area is that the requirements in this sector are tough with respect to durability, safety and strength. A second complicating factor is the sizes of buildings.

Annex 1: European AM projects' details

1. Projects under FoF PPP

PhoCam	PHOCAM	Photopolymer based customized additive manufacturing technologies	www.phocam.eu www.cordis.europa.eu/project/rcn/94812_en
HYPROLINE	HYPROLINE	High Performance Production line for small series metal parts	www.hyproline.eu www.cordis.europa.eu/project/rcn/104393_es
AMAZE	AMAZE	Additive Manufacturing Aiming Towards Zero Waste & Efficient Production of High-Tech Metal Products	www.amazeproject.eu www.cordis.europa.eu/project/rcn/105484_en
SL SMARTLAM	SMARTLAM	Smart production of Microsystems based on laminated polymer films	www.smartlam.eu www.cordis.europa.eu/project/rcn/104542_en
3D-HiPMAS	3D-HIPMAS	3D-HIPMAS.Pilot Factory for 3D High Precision MID Assemblies	www.3d-hipmas.eu www.cordis.europa.eu/project/rcn/104687_en
Hi-Pr	HIPR	High-Precision micro-forming of complex 3D parts	www.cordis.europa.eu/project/rcn/105489_en
Hi-Micro	HI-MICRO	High Precision Micro Production Technologies	www.hi-micro.eu www.cordis.europa.eu/result/rcn/177882_en
AMCOR	AMCOR	Additive Manufacturing for Wear and Corrosion Applications	www.amcor-project.eu www.cordis.europa.eu/project/rcn/105488_en
optician2020	OPTICIAN2020	Flexible and on-demand manufacturing of customised spectacles by close-to-optician production clusters	www.optician2020.eu www.cordis.europa.eu/project/rcn/109550_en

	CASSAMOBILE	Flexible Mini-Factory for local and customized production in a container	www.cassamobile.eu www.cordis.europa.eu/project/rcn/109055_en
	ADDFACTOR	ADvanced Digital technologies and virtual engineering for mini-Factories	www.addfactor.eu www.cordis.europa.eu/project/rcn/108701_es
	MANSYS	Manufacturing decision and supply chain management system for additive manufacturing	www.mansys.info www.cordis.europa.eu/project/rcn/108896_en
	STELLAR	Selective tape-laying for cost effective manufacturing of optimised multi-material components	www.stellar-project.eu www.cordis.europa.eu/project/rcn/109190_en
	NEXTFACTORY	All-in-one manufacturing platform for system in package and micromechatronic systems	www.nextfactory-project.eu www.cordis.europa.eu/project/rcn/108892_en
	BOREALIS	The 3A energy class Flexible Machine for the new Additive and Subtractive Manufacturing on next generation of complex 3D metal parts	www.cordis.europa.eu/project/rcn/193449_en
	TOMAX	Toolless Manufacturing of Complex Structures	www.tomax-h2020.eu www.cordis.europa.eu/project/rcn/193185_en
	REPROMAG	Resource Efficient Production Route for Rare Earth Magnets	www.repromag-project.eu www.cordis.europa.eu/project/rcn/193433_en
	FOFAM	Industrial and regional valorization of FoF Additive Manufacturing Projects	www.fofamproject.eu/ http://cordis.europa.eu/project/rcn/193434_en.html

	CAXMAN	Computer Aided Technologies for Additive Manufacturing	www.caxman.eu www.cordis.europa.eu/project/rcn/198363_en
	SYMBIONICA	Reconfigurable Machine for the new Additive and Subtractive Manufacturing of next generation fully personalized bionics and smart prosthetics	www.symbionicaproject.eu www.cordis.europa.eu/project/rcn/198346_en
	KRAKEN	Hybrid automated machine integrating concurrent manufacturing processes, increasing the production volume of functional on-demand using high multi-material deposition rates	www.cordis.europa.eu/project/rcn/205448_en
	LASIMM	Large Additive Subtractive Integrated Modular Machine	http://www.lasimm.eu/ www.cordis.europa.eu/project/rcn/205464_en
	OPENHYBRID	Developing a novel hybrid AM approach which will offer unrivalled flexibility, part quality and productivity	www.openhybrid.eu www.cordis.europa.eu/project/rcn/205504_en
	AM MOTION	A strategic approach to increasing Europe's value proposition for Additive Manufacturing technologies and capabilities	www.am-motion.eu www.cordis.europa.eu/project/rcn/205499_en
	MODULASE	Development and Pilot Line Validation of a Modular Re-Configurable Laser Process Head	www.modulase.eu www.cordis.europa.eu/project/rcn/205598_en
	ENCOMPASS	ENgineering COMPASS	www.encompass-am.eu www.cordis.europa.eu/project/rcn/205599_en

	PARADDISE	A Productive, Affordable and Reliable solution for large scale manufacturing of metallic components by combining laser-based ADDItive and Subtractive processes with high Efficiency	www.cordis.europa.eu/project/rcn/205478_en
	MAESTRO	Modular laser-based additive manufacturing platform for large scale industrial applications	www.maestro-project.eu www.cordis.europa.eu/project/rcn/205398_en
	DREAM	Driving up Reliability and Efficiency of Additive Manufacturing	www.dream-euproject.eu www.cordis.europa.eu/project/rcn/205518_en
	HIPERLAM	High Performance Laser-based Additive Manufacturing	www.hiperlam.eu
	HYPROCELL	Development and validation of integrated multiprocess HYbrid PROduction CELLs for rapid individualized laser-based production	www.hyprocell-project.eu http://cordis.europa.eu/project/rcn/205596_en
	HINDCON	Hybrid INDustrial CONstruction	http://www.hindcon3d.com
	4D Hybrid	Novel ALL-IN-ONE machines, robots and systems for affordable, worldwide and lifetime Distributed 3D hybrid manufacturing and repair operations	http://4dhybrid.eu/

2. Projects under other Framework Programme calls

	COMPOLIGHT	Rapid Manufacturing of light-weight metal components	http://cordis.europa.eu/project/rcn/89909_en

SASAM Standardization in Additive Manufacturing	SASAM	Support Action for Standardisation in Additive Manufacturing	www.sasam.eu www.cordis.europa.eu/project/rcn/104749_en
iBUS	IBUS	An integrated business model for customer driven custom product supply chain	www.h2020ibus.eu www.cordis.europa.eu/project/rcn/196843_en
DiMAP DIGITAL MATERIALS FOR 3D PRINTING	DIMAP	Novel nanoparticle enhanced Digital Materials for 3D Printing and their application shown for the robotic and electronic industry	www.dimap-project.eu www.cordis.europa.eu/project/rcn/198812_en
FAST	FAST	Functionally Graded Additive Manufacturing Scaffolds by Hybrid Manufacturing	www.project-fast.eu/en/home www.cordis.europa.eu/project/rcn/198809_en
A_MADAM	AMADAM	Advanced Design Rules for Optimal Dynamic Properties of Additive Manufacturing Products	www.mfkv.kg.ac.rs/a_madam www.cordis.europa.eu/project/rcn/206769_en
Bamos	BAMOS	Biomaterials and Additive Manufacturing: Osteochondral Scaffold innovation applied to osteoarthritis	www.risebamos.eu www.cordis.europa.eu/project/rcn/207034_en

3. Other EU projects

3DPRISM 3D Printing Skills for Manufacturing	3DPRISM	3DPRinting Skills for Manufacturing	www.3dprism.eu
METALS MachinE Tool ALliance for Skills	METALS	MachinE Tool ALliance for Skills	www.metalsalliance.eu
Interreg Sudoe SAMT SUDOE	SAMT SUDOE	Spread of Additive Manufacturing and Advanced Materials Technologies for the promotion of KET Industrial Technologies in plastic processors and mould industries within Sudoe Space	www.samtsudoe.eu

Annex 2: Enablers' list

Legend:
Sectors: H=health; AE=aerospace; AU=automotive, CG=consumer goods; E=electronics, EN=energy; E&T= Industrial equipment &tooling; C= construction; O=other
VC segments: M&D=modelling and simulation; D=design; M=materials; P=process; PP=post-processing; Pr=product; EL=end of life
Process: PBF=Powder Bed Fusion; VP=Vat Photopolymerization; MJ=Material Jetting; ME=Material Extrusion; SL=Sheet Lamination; DED=Direct Energy Deposition; BJ=Binder Jetting; O=Other
Non technology activities: STD=standardisation; L=legislation; EDU=education/training; IE=business, commercialisation, industrial exploitation; IPR=intellectual property rights; TT=technology transfer

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
RTOs								
3C ACADEMY	R&D; service Bureau, design	-	BULGARIA/ Yugozapaden	H,CG,E,EN,E&T,C	M&D, D, P, PP, Pr	PBF, VP, MJ, ME, DED, BJ	Metal, Polymer, ceramic	STD, EDU, IE, IPR, TT
AITIIP	R&D; service Bureau; Materials provider; design; end user	www.aitiip.com	SPAIN/ Aragon	ALL	ALL	PBF; VP; ME;	Metal, polymer, biomaterials	STD;EDU;IE; IPRS; TT
ANDALTEC	R&D, design, Prototyping	www.andaltec.org/en/	SPAIN/ Andalucía	AE, AU,CG, E, Food Packaging	M&D, D, M, Pr, EL	VP, MJ, ME, BJ	Polymer, Bio-Materials	EDU, TT
BMC	R&D, OEM, Materials provider	www.brightlandsmaterialscenter.com	NETHERLANDS /Limburg	ALL	ALL	PBF, VP, MJ, ME	Polymer, Bio-materials	TT
CEA	R&D	www-liten.cea.fr	FRANCE / Rhône-Alpes	ALL	M, P, EL	PBF, VP, MJ, DED	Metal, polymer, ceramic	TT
CEITEC-BUT	R&D, Materials provider	www.ceitec.eu	CZECH REPUBLIC/ Jihovychod	H, AE, AU	M, P, PP	ME	Metal, Polymer, ceramic, Bio-Materials,	EDU, TT
CETIM	R&D	www.cetim.fr/fr	FRANCE/ Rhône-Alpes	ALL	ALL	ALL, 3D printing metal	Metal, Polymer, Bio-Materials	STD, EDU, IE,TT
COVENTRY University	R&D, Design	www.coventry.ac.uk	UNITED KINGDOM/ West Midlands	ALL	ALL	PBD, DED	Metal, Polymer	STD, EDU, IE, TT
CSM	R&D	www.c-s-m.it	ITALY/ Lazio	AE, AU	M, PP, Pr	PBD, VP	Metal, ceramic	EDU, TT
CTTC	R&D, Materials provider	www.cttc.fr	FRANCE/ Limousin	H, AE, CG, E, EN	M, P, PP, Pr	VP, MJ, ME, SL, DED, BJ	Ceramic	EDU, TT
DTI	R&D, Service Bureau, OEM,	www.dti.dk	DENMARK/ Hovedstaden	ALL	ALL	PBF, VP, MJ, ME,	Metal, polymer,	STD, L; EDU, IE,

	design, end user					BJ	food, bio-materials	TT
ECN	R&D	www.ecn.nl/expertise/engineering-materials/	NETHERLANDS / Noord-Brabant	ALL	M, P, PP, Pr	PBF, VP, DED	Metal, ceramic, catalysts	IE, TT
EURECAT	R&D, Pilot and testing, Training	www.eurecat.org	SPAIN/ Cataluña	H, AU, CG E&T	M&S, M; P; Pr	PBF, ME, SL	Metal, polymer, food	EDU, IE, IPRs, TT
IK4-TEKNIKER	R&D	www.tekniker.es	SPAIN/ Pais Vasco	AE,AU, E; EN, E&T, C	M&S, D, P, PP	DED	Metal	TT
IMDEA	R&D; Materials provider	www.materials.imdea.org/groups/pm	SPAIN/ Madrid	ALL	M&S, D, M, PP	ME, SL	Metal, polymer, biomaterials	EDU, TT
IMR	R&D, Design	www.imr.ie	IRELAND/ Southern and Eastern	ALL	ALL	ALL	ALL	STD, L, EDU, IE, TT
INSPIRE AG	R&D, Design	-	SWITZERLAND	ALL	M&D, D, M, P, PP, Pr	PBF, DED	Metal, polymer, ceramic	STD, EDU, IE, TT,
ITAINNOVA	R&D, Service Bureau, Design, End user	www.itainnova.es	SPAIN/ Aragon	AE, AU, CG, E, EN, E&T, C	M&S, D, M; P	PBF, MJ	Polymer	TT
IPC	R&D, Service Bureau, Design	http://ct-ipc.com/	FRANCE/ Rhône-Alpes	ALL	M&S, D; M; P; PP; Pr	PBF, VP, ME	Metal, polymer	EDU, IE, TT
KIMAB	R&D	www.swerea.se/kimab	SWEDEN/ Stockholm	ALL	M&S, M, P	PBF	Metal	EDU, TT
KMWE	R&D, Service Bureau, OEMs, Design	www.kmwe.com/Capabilities/Additive-Manufacturing.htm	NETHERLANDS /Noord-Brabant	H, AE, Semiconductors, Industrial Automation	ALL	PBF, DED, EBAM	Metal	IE, TT
LMS	R&D, Design, Modelling and simulation, experimentation	http://lms.mech.upatras.gr/	GREECE/ Δυτική Ελλάδα	AE, AU,CG	ALL	PBF, VP, ME, SL, DED	Metal, polymer	STD, EDU, TT
Lurederra	R&D, Materials provider	www.lurederra.es	SPAIN/ Navarra	ALL	M, Pr	materials technology, nanotechnology	Metal, polymer, ceramic, nanomaterials	STD, IPRs, TT
M2i	R&D, Services Bureau	www.m2i.nl	NETHERLANDS /Zuid-Holland	AE, AU, O (maritime and offshore)	M&S, M	PBF, DED	Metal	IPRs, TT
PRODINTEC	R&D, Services Bureau, Design	www.prodintec.com	SPAIN/ Asturias	ALL	M&S, D, P, PP, Pr	PBF, VP, SL	ALL	STD, EDU, IE, IPRs, TT
PROFACTOR	R&D	www.profactor.at	AUSTRIA/ Oberösterreich	ALL	M&S, M, P; PP	VP, MJ, ME	Polymer	EDU, IPRs, TT
IQS. Ramon Llull University	R&D	www.iqs.edu	SPAIN/ Cataluña	own R&D	M&S, D, M, P	VP, ME	Polymer, Ceramic, Bio-Materials	EDU, TT
TECNALIA	R&D	www.tecnalia.com	SPAIN/ País Vasco	ALL	ALL	DED	Metal	L, IE, IPRs

TNO	R&D, Design	www.tno.nl	NETHERLANDS /Noord-Brabant	ALL	ALL	PBF, VP, MJ, ME, BJ, continuous SLS or material jetting in carousel	Metal, polymer, ceramic, food	STD, EDU, IE, IPRs, TT
TUKE	End user	www.sjf.tuke.sk/kppt/	SLOVAKIA/ Východné Slovensko	ALL	M, P, PP	ME	Polymer	EDU, TT
TWI	R&D	www.twi.co.uk	UNITED KINGDOM/ South Yorkshire	ALL	ALL	PBF, DED	Metal	STD, EDU, TT
VIVES	Educational Establishment, R&D, design	www.vives.be/onderzoek-ontwerp-productietechnologie	BELGIUM	CG, O (mechanics)	M, D, PP, Pr	PBF, ME,	Metal, Polymer	EDU, TT
Industry								
NAME	**SUPPLY CHAIN**	**WEBSITE**	**COUNTRY/ Region**	**Sectors**	**VC segments**	**AM processes**	**AM Materials**	**Non Tech.**
+90	R&D, Services Bureau, OEMs, Design, End User	www.arti90.com	TURKEY	ALL	D, M, P, PP, Pr	PBF, MJ, ME	Polymer	STD
ADMATEC	R&D, Service Bureau, OEM	www.admateceurope.com	NETHERLANDS /Noord-Brabant	H, AE, AU, E, ALL	M, P, PP, Pr	VP	Metal, Polymer, Ceramic, Biomaterials	-
AIM Sweden	R&D, Services Bureau, OEMs, Design	www.aimsweden.com	SWEDEN/ Mellersta Norrland	H, AE, AU, O (industrial)	M&S, D, M, P ,PP, Pr	PBF, Electron beam melting	Metal	EDU, IE, TT
AIRBUS	R&D, Design, End user	www.airbus.com	SPAIN	AE	M&S, D, M; PP; Pr	PBF, MJ; DED	Metal, Polymer	STD, LE, EDU, IE, IPRS, TT
ALTRAN Deutschland SAS & Co. KG	R&D, OEM, Software provider, design	www.altran.com	GERMANY/ Hamburg	ALL	ALL	PBF, ME	Metal, Polymer, Biomaterials	STD, EDU, IE, IPRS, TT
ATLAS COPCO	OEM	www.atlascopco.com	BELGIUM/ Antwerpen	O (industrial applications)	M&S, D, P, PP, Pr	PBF, ME, BJ	Metal, polymer	L, EDU
ATOS SE	R&D, OEMs, Materials & Software provider, design, End user		FRANCE/ Ile de France	ALL	M&S, D, P, Pr	-	-	STD, EDU; IE, IPRs, TT
D'APPOLONIA	R&D, D, Engineering consultancy; operation and maintenance	www.dappolonia.it	ITALY/ Lazio	ALL	ALL	ALL	Metal, polymer	STD, EDU, IE, IPRs, TT, roadmapping, safety
CRIT	R&D	www.crit-research.it	ITALY/ Emilia-Romagna	AE, AU, E	D, M, P	PBF	Metal, polymer	EDU, IE, TT
EOS	R&D, OEM, Materials & Software provider, End user	www.eos.info	GERMANY/Oberbayern	ALL	ALL	PBF	Metal, polymer	STD, IE, IPRs

ESI Group	R&D, Software provider, Design	www.esi-group.com	FRANCE/ Île de France	ALL	M&S; D	PBF, DED	Metal	STD; EDU; TT; IPRs; IE
Granutools	R&D, OEMs, Materials provider, End user	www.granutools.com	BELGIUM/ Liège	ALL	P	PBF	Metal, polymer, ceramic	STD, EDU, IE, TT
KIWA	R&D	www.swerea.se/kimab	SWEDEN	ALL	M&S, M, P	BPF	Metal	EDU, TT
LCV	R&D, Services Bureau, Design	www.lcv.be	BELGIUM/ Antwerpen	ALL	D, M, P, Pr	DED	Metal	STD, TT
LINDE France	Materials provider, Process gases for AM + powder production + post-treatment	www.linde-gas.fr	FRANCE/ Rhône-Alpes	ALL	M, P, PP, Pr	PBF, MJ, SL, DED, BJ, Cladding, deposition	Metal	-
MATERIALISE NV	R&D, Service Bureau, software provider, design, end user	www.materialise.com	BELGIUM/ Prov. Vlaams-Brabant	H, AE, AU, CG	M, D; M; P; PP; Pr	PBF; VP; MJ; ME	Metal, polymer, ceramic, biomaterials	STD; L; IE; IPRS; TT
MBN	R&D, Materials provider	www.mbn.it	ITALY/Veneto	H, O (cutting tools)	M	PBF, DED, O	Metal, polymer, composite, intermetallic	-
OCE	R&D, OEMs, Design	http://oce.com/	NETHERLANDS / Limburg	ALL	M&D, D, M, P, PP, Pr	MJ	Metal, polymer, ceramic	IE
PRIMA	OEM	www.primaindustrie.com	ITALY/Piedmont	E, EN, E&T, C	P	PBF, DED	Metal	STD, IE
PwC	R&D Business Consultancy	www.pwc.nl	NETHERLANDS / Noord-Holland	ALL	ALL	ALL	ALL	L, EDU, IE, IPRs, TT
SAFRAN	R&D, OEMs, End user	www.safran-group.com	FRANCE/Île de France	AE	All	PBF, DED	Metal, polymer, ceramic	IE
SCHUNK	R&D, Design	www.schunk.com	GERMANY/Stuttgart	O (mechanical, engineering, automation)	M, D, PR	PBF, O (laser sintering plastics)	Polymer	IE, IPR
SIEMENS	R&D, Software provider, Design, End user	www.siemens.com	GERMANY/Berlin	H, E	All	PBF, VP, ME, DED	Metal, polymer, ceramic	STD, L, EDU, IE, IPR, TT
TRIDITIVE	R&D, Services bureau, Design	www.dynamics.tridi-tive.com	SPAIN/Asturias	All	M&S, D, P, PP, PR	VP, ME	Polymer	EDU, IE, TT
Other								
NAME	**SUPPLY CHAIN**	**WEBSITE**	**COUNTRY/ Region**	**Sectors**	**VC segments**	**AM processes**	**AM Materials**	**Non Tech.**
AD GLOBAL	Human Resources	www.alexanderdanielsglobal.com	SPAIN AND UK/Barcelona and Birmingham	ALL	ALL	ALL	ALL	EDU, Hiring AM talent
BERENSCHOT	Consulting company	www.berenschot.com	NETHERLANDS /Utrecht	ALL	ALL	ALL	ALL	STD,EDI, IE, IPRs, TT

IDEA CONSULT	Consulting company	www.ideacon-sult.be	BELGIUM/ Brux-elles-Capitale	ALL	ALL	ALL	ALL	L, IE, TT
ISONORM	Consultancy on standardisation	-	ITALY/ Pie-monte	ALL	ALL	O	ALL	STD
Clusters/networks/associations								
NAME	**SUPPLY CHAIN**	**WEBSITE**	**COUNTRY/ Region**	**Sectors**	**VC seg-ments**	**AM pro-cesses**	**AM Ma-terials**	**Non Tech.**
3C ACADEMY	R&D; Service Bureau; design provider	-	BULGARIA/ So-fia-grad	H, AU; CG, E, EN; E&T, C	M&S, D, P, PP, Pr	PBF, VP, MJ; ME; DED, BJ	Metal, pol-ymer, ce-ramic	STD, EDU, IE, IPRs
3DPA	Service Bureau	www.the3dpri ntingassocia-tion.com	NETHERLANDS / Zuid-Holland	ALL	ALL	ALL	ALL	STD, L; EDU, IPRs
ADDIMAT	ALL	www.addimat. es	SPAIN/ Pais Vasco	ALL	ALL	ALL	ALL	-
CECIMO	R&D; Materials & software pro-vider	www.cec-imo.eu	BELGIUM/ Brux-elles-Capitale	O (machine tool)	D, M, P, PP; Pr	PBF	Metal	STD, L; EDU; IE
EPMA	All Metal AM supply Chain	www.epma.co m	BELGIUM/ Brux-elles-Capitale	O (powder met-allurgy)	ALL	PBF	Metal	EDU, TT, Network-ing; Syn-ergy
ERRIN	Network sup-porting regional Innovation and implementation of Smart Spe-cialisation Strategies.	www.errin.eu	BELGIUM/ Brux-elles-Capitale	O (AM and nanotechnolo-gies)	-	-	-	EDU, TT, Networking
EWF	Education & Training, Standardization	www.ewf.be	BELGIUM/ Brux-elles-Capitale	AE, AU, CG, E, Manufacturing	M, P	PBD, DED	Metal, pol-ymer	STD, EDU, IE, IPRs, TT
FLAM3D	cluster, net-work, associa-tion	www.flam3d.b e	BELGIUM/ Flan-ders	ALL	ALL	-	ALL	ALL
MATIKEM	R&D; service Bureau; Materi-als provider; design; end user	en.matikem.co m	FRANCE/ Nord - Pas-de-Calais	H, AU, CG	D, M, P, Pr, EL	VP, ME	Polymer, ceramic, food, bio materials, o	STD, EDU, IE, IPRs, TT