ADDITIVE MANUFACTURING ROADMAP: VISION, CHALLENGES AND ACTIONS

AM-motion

Because AM matters

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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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ABBREVIATIONS

3DP	3D Printing
AM	Additive Manufacturing
CAD	Computer-aided design
CAGR	Compound Annual Growth Rate
EC	European Commission
IP	Intellectual Property
IPR	Intellectual Property Right
RTO	Research Technology Organization
VC	Value chain

1. INTRODUCTION

This document aims at presenting the **Additive Manufacturing (AM)**[1] **implementation map on market driven value chains** and constitutes an open working document, developed in the framework of AM-motion project "A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES " (Grant agreement no. 723560).

The overall aim of AM-motion roadmap is to create a common vision for successful European leadership in additive manufacturing, addressing the societal challenges of our time, and to suggest common goals and specific actions to solve the existing gaps between the current status and the target vision.

AM-motion roadmap is as an evolution of FOFAM[2] Roadmap, which has been further developed and expanded in AM-motion project by means of combination of desk research (integrating the results of key initiatives in AM[3]) and working group sessions, involving around 100 external experts through physical meetings and remote surveys.

The sectors and market addressed in this roadmap have been selected in line with FOFAM initiative and according to AM-motion project need to be relevant to the technological advancements across Europe and their potential to positively influence societal and economic challenges. Therefore, this selection is based on the evidence collated from the sector surveillance activity and the growth and impact analysis performed within the project and the contribution of the external experts attending the AM-motion workshops.

In this framework, AM-motion roadmap focuses on the following sectors:

- Health;
- Aerospace;
- Automotive;
- Consumer goods and Electronics;
- Industrial equipment and Tooling;
- Construction;
- Energy.

The following chapters present a **summary of the roadmap** main findings in terms of roadmap vision and future actions proposed to address the identified challenges.

Annex I reports the lists of target products identified for each sector while Annex II reports a list of AM enablers, i.e. key European stakeholders in additive manufacturing.

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1 **AM technologies** refer to a group of technologies that build physical objects from Computer Aided Design (CAD) data. The main difference between traditional and AM-technologies is that parts produced via AM are created by the consecutive addition of liquids, sheet or powdered materials in layers, instead of removing material to generate a desired shape which is common to traditional technologies such as milling or drilling. Additive Manufacturing has many common names, involving rapid manufacturing, direct manufacturing, 3D-printing, rapid tooling and rapid prototyping. In line with FOFAM, in AM-motion we consider AM as the umbrella term for additive technologies; the terms direct manufacturing, rapid tooling and rapid prototyping refer to the application of AM.

2 https://cordis.europa.eu/project/rcn/193434_en.html

3 E.g. The 3D printing Pilot of the Vanguard Initiative (http://www.s3vanguardinitiative.eu/cooperations/high-performance-production-through-3d-printing); EC Report- EASME Tender "Identifying current and future application areas, existing industrial value chains and missing competences in the EU, in the area of additive manufacturing (3D-printing)". 2016.; Lloyd Register Foundation. Roadmap for additive manufacturing. 2017.

2. AM-MOTION VISION

Global warming, energy transition, population ageing and decreasing resources present us with immense challenges. In order to deal with these, we need fresh approaches, technological advances and clear implementation strategies. In this framework, Additive Manufacturing may play a pivotal role in changing the manufacturing paradigm and contributing to address the societal challenges of our time. For example, lightweight production and functional complexity enabled by AM technologies can help to reduce the consumption of resources for the process and the product itself, streamline manufacturing processes and make more sustainable products.

AM-motion vision for 2030 foresees that Europe will improve its leading role in Additive Manufacturing, greatly impacting on the competitiveness of European industrial sectors. Additive Manufacturing will improve the quality of life of European citizens in terms of retention of high quality jobs in Europe, availability of customised, cleaner, safer and affordable products and increased access to cleaner energy, mobility and effective and personalised medicine.

Figure 2.1 summarises AM-motion Vision for AM in 2030, including the envisaged **opportunities and challenges** as well as the **areas of intervention which are covered by the roadmap** (i.e. technologies, standardisation, certification, skills and education, financing, intellectual properties, safety, communication, cross-regional and international cooperation).

The following lists describes some of the upcoming **opportunities** offered by market uptake of AM technologies:

- Additive Manufacturing is one of the **pillars of the Fourth Industrial Revolution** (also known as Industry 4.0), which is a transformation that makes it possible to gather and analyse data across machines thus enabling faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs with greater agility.[4]. In particular, AM can highly contribute to Industry 4.0 approaches by increasing process automation and the intrinsic digital core of AM manufacturing technologies make them relatively easy to use effectively digital twin approaches[5]. The application of digital twin in AM-enabled value chains can allow companies to have a complete digital footprint of their products from design and development through the end of the product life cycle. The digital twin may help to solve physical issues faster by detecting them sooner, predict outcomes to a much higher degree of accuracy, design and build better products, and, ultimately, better serve their customers. Finally, AM approaches includes recent breakthroughs as 4D Printing, which is a mean to enable **smart and Internet of Things[6] functionalities in AM products**. In fact, 4D Printing is a combination of 3D printing and the fourth dimension, which is time and/or the change of functionalities. This technique allows a printed object to be programmed to carry out shape change while adapting to its surroundings. This allows for mastered self-assembly, multi-functionality, and self-repair and sensoring capabilities.

4 https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

5 The digital twin is a near-real-time digital image of a physical object or process that helps optimize business performance. From https://www2.deloitte.com/insights/us/en/focus/industry-4-0/digital-twin-technology-smart-factory.html

6 The Internet of Things (IoT) is the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and connectivity, which enables these things to connect and exchange data, creating opportunities for more direct integration of the physical world into computer-based systems, resulting in efficiency improvements, economic benefits, and reduced human exertions. More info on: Internet of Things: Science Fiction or Business Fact?" Harvard Business Review. November 2014.

- Bringing **Artificial Intelligence** to the world of AM can lead to faster and more precise processes, by giving smart advice on the choices to make, both in terms of design, of materials and of technologies, especially in presence of control and monitoring systems (including in line and real-time ones) and predictive maintenance approaches. When coupled with robotic arms for printing large/complex shapes, artificial intelligence algorithms enable machine to see, create, and even learn from their mistakes during the printing process, thus being able to produce complex, large and precise patterns without sacrificing speed, as recently showcased by the company Ai Build[7].

- High degree of product customisation and human-centred approach offered by AM will contribute to improve the **quality of life**, with affordable and high quality products built based on customer needs, and also potentially address specific needs of the growing elderly population or of the people with physical impairments, thus building more inclusive societies. Co-creation approaches, involving researchers, industrial end-users and final customers in the design process, will contribute to EC strategies towards more **inclusive and Responsible Research and Innovation** (RRI).

- AM may play a lead role in the **Circular Economy** for example by producing high added-value products from recycled or bio-based powders and enabling full re-use of AM by-products in new products. The exploitation of the full potential of AM will also lead to resource and energy saving in the whole value chain and in particular in manufacturing and transportation, thus contributing to the **environment**.

- AM presents transformative potential manufacturing methods in the health sector being able to provide patient-specific solutions (e.g. from smart wheelchairs to orthopaedic implants), thus enabling **Personalised Medicine** approaches, which in the medium term can be affordable for most of the population. The advent of Bioprinting[8], with its ability to create complex geometries and microarchitectures that mimic tissue complexity, can offer innovative solutions in the field of tissue engineering (i.e. printing biological tissues and potentially even organs) for patient-specific regenerative medicine and drug testing.

- AM full market deployment will offer new employment and investment opportunities in several sectors enabling industries (including SMEs) to compete in highly aggressive and complex commercial environments. Furthermore, the new knowledge gained such multi-disciplinary and multi-sectorial domain will contribute to the improvement of workforce skills and education in **European Knowledge-based economy**, i.e. increasingly based on knowledge and information sharing.

- Finally, AM technologies can contribute to the availability at low cost of highly efficient green energy solutions (e.g. renewable energy components and energy storage solutions), thus contributing to the EC **2050 Low Carbon Economy Roadmap[9], as well as to EC plans for sustainable transportation**[10].

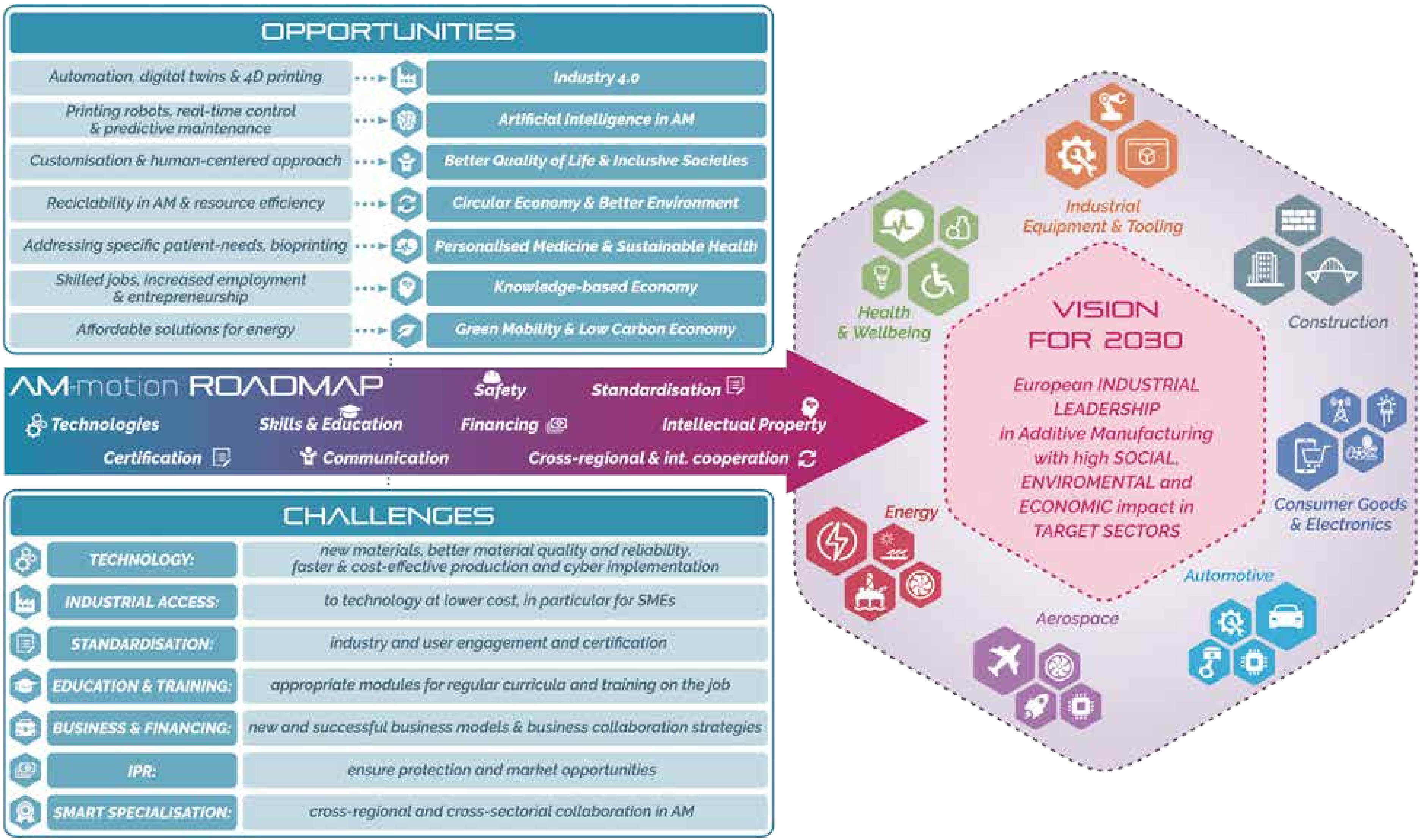
[7] https://www.digitaltrends.com/cool-tech/ai-build-wants-to-change-the-way-we-build-the-future/

[8] Bioprinting can be defined as “the use of 3D printing technology with materials that incorporate viable living cells, e.g. to produce tissue for reconstructive surgery” (https://en.oxforddictionaries.com/definition/bioprinting)

[9] https://ec.europa.eu/clima/policies/strategies/2050_en

[10] https://ec.europa.eu/transport/themes/sustainable_en

Figure 2.1: *AM-motion Vision*



However, Europe must address several **technical and non-technical challenges**, which may hinder AM full development and market success:

- **Technology:** the availability new breakthrough sustainable materials and of advanced materials with better quality, reliability and affordability, together with faster, greener and cost-effective manufacturing processes, integrating effectively industry 4.0 approaches, with focus on energy and resource efficiency, material and product recyclability, automated monitoring and control mechanisms as well as advanced design, modelling and simulations.

- **Industrial access** to technology at low prices. Industries (especially SMEs) in periods of limited resources find difficult to keep pace with the emerging innovation in AM, which may require the use of expensive machines and/or can be used effectively by highly-skilled workforce with multi-disciplinary curricula. There is risk for European SMEs to stay behind without being able to compete in such highly technological arena.

- **Standardisation** requires effort from individual specialists on the short term while the gains will be on the long term for a wide community. From one side, there is need to increase industry engagement on standards development; from another side, standards harmonization will have a significant influence on the long-term perspective. Harmonizing standards can be very time consuming, but standards are needed for the uptake of technologies. Moreover, in order to provide manufacturers with the greatest opportunity to exploit AM and provide confidence to manufactures and end-users that parts are safe, reliable and robust, an early publication of AM Qualification guidelines for product and process **certification** is paramount.

- **Education and training:** industries are currently facing some obstacles to find out the missing necessary people (technicians, engineers, designers and operators) specialized in technical and non-technical aspects of AM. The demands on—and expectations for—AM talent are high, especially because the technical and engineering skills required vary widely and because AM professionals are expected to be at the same time creative, and able to constantly adapt to new developments. There is need for proper communication campaigns, industry involvement in education and training aspects, delivering proper learning contents at all levels, specific educational programmes, workplace training, on-line education and reskilling actions for current work force.

- **IPR:** IPR Regimes should be reflected upon as to ensure protection without hampering market entry. Protection should be further ensured (IPR enforcement) and new IP-based reward systems should be thought of as to foster the development and commercialisation of AM-based products. In particular, it is important to give clearer guidance on defining for example whether a CAD file could benefit from copyright protection or other IP protection and build-up of a set of use cases in which IP can be used as an inclusion tool instead of exclusion tool.

- **Business and Financing:** Bringing prototypes to production by securing the reproducibility of application remains a critical point for the industry. AM is still perceived too much as a technology solution instead of a business solution. Moreover, many companies need to understand how they can gain access to finance: in fact, a survey conducted by The Manufacturer reported nearly two thirds of companies (61%) stated that initial development costs were the key barrier to the start of a new AM-enabled business[11]. There is need for availability of effective business models, able to address all the emerging opportunities (including co-creation platforms, provision of AM as a service etc.). In this framework, effective business collaboration models (e.g. strategic alliances, joint ventures, acquisitions, etc.) as well as an efficient innovation management system are fundamental to ease market deployment of AM technologies. Business collaborations in AM are motivated by several drivers, such as the high cost of AM equipment and materials, the cost and skills needed for certification and marketing activities, the need for high level of technical expertise, the opportunity to open up new markets and business cases and the medium term nature of the Return of Investment opportunities offered by AM (with RoI after 5 or even 10 years mainly due to the lack of the maturity of the technology)[12]. Furthermore the capacity to manage the innovation provided by AM technologies as a system is a critical success factor for companies.

[11] Williamson, J. (2017, May 22). What's holding businesses back from investing in additive manufacturing? Retrieved from The Manufacturer: https://www.themanufacturer.com/articles/whats-holding-businesses-back-investing-additive-manufacturing/

[12] Business collaboration models are treated in details in Deliverable D4.4, which will be publicly available at the project completion at www.am-motion.eu.

- **Smart Specialisation:** as reported in previous studies[13], the European AM landscape however remains fragmented. The concentration of AM capabilities in specific Western European regions leaves a picture of leading regions specializing in particular segments of the AM value chain, covering both supply and demand sides. Eastern (and to some extent Southern) Europe is however at a discovery stage: only a limited number of 3D-printer manufacturers and specialized service providers could be identified in Eastern European regions. In these regions, most efforts are being made in key RTOs where public investments contributes to the absorption and development of AM knowledge and technologies. In order to enlarge industrial research and business opportunities, cross-regional and cross-sectorial cooperation is required. In this framework, collaborations among S3 Smart Specialisation Thematic Platforms - SSTPs (up to now European Commission set up SSTPs for interregional cooperation on Industrial Modernisation, Agri-Food and Energy) would be important to enhance AM penetration in traditional sectors and to foster cross-contamination between western and eastern regions.

AM-motion Roadmap aims to catch the foreseen opportunities and address the described challenges by suggesting recommendations focusing on industrial sectors of high economic, social and environmental impact, described in the following sections.

[13] EC report- "Identifying current and future application areas, existing industrial value chains and missing competences in the EU, in the area of additive manufacturing (3D-printing)". EASME Tender 2016 by IDEA Consult, AIT, VTT, CECIMO

3. AM-MOTION IDENTIFIED ACTIONS

The present chapter provides AM-motion roadmaps on identified actions to foster AM development and market uptake. Such actions are divided into cross-cutting technological and non technological ones, and actions segmented by sector.

For each identified actions, the relevance for the different steps of the value chain (Figure 3.1) have been emphasised in the roadmaps.

Figure 3.1: *Steps of AM value chain in AM-motion roadmap*

AM-motion proposed actions are segmented into short-term actions (suggested actions to be started in 2019-2021), medium term actions (2022-2024), long-term actions (2025-2028), in order to deliver by 2030 the foreseen vision.

For sectorial roadmaps, each action is linked also to specific target product groups. Moreover, the type of foreseen activity has been highlighted, in line with H2020 topics: research and innovation actions (RIA) are actions where the core of activities is in fact research and development with target TRL in general up to 5; innovation actions (IA) are suggested topics which are more focused on validation and demonstration activities, with target TRL up to 6-7. Coordination and support actions (CSA) are suggested topics resulting in enhanced coordination of research initiatives and findings rather than in research outputs.

Some details of each action in terms of identified gap with the description of the current context, description of proposed activities are reported in the present document. The full description of the proposed action is included in the complete Roadmap publicly available at www.am-motion.eu.

3.1. CROSS-CUTTING TECHNOLOGICAL actions

A number of technical actions to solve cross-sectorial challenges were identified as reported in the roadmaps shown in Figure 3.2 and in Figure 3.3, focusing on short term and on medium to long term, respectively. Such actions include also standardisation and certification-related topics.

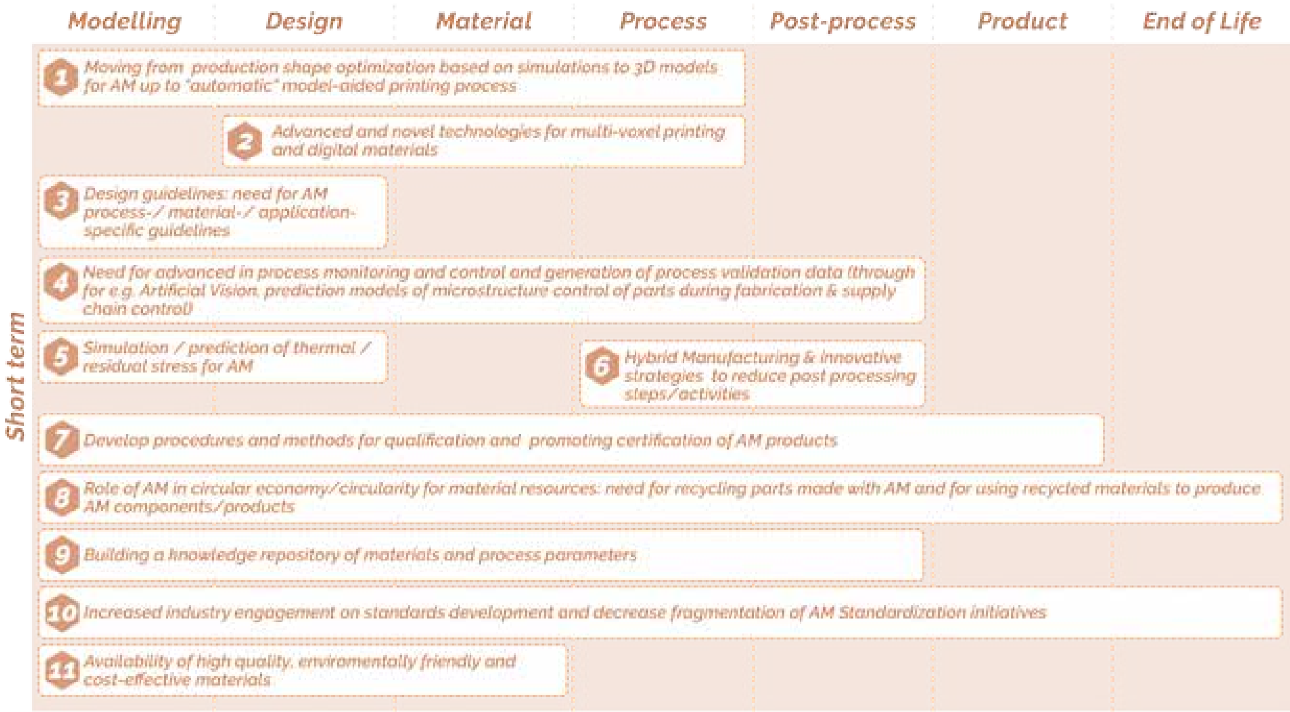


Figure 3.2: *AM-motion Roadmap on cross-cutting technical actions (short-term focus)*

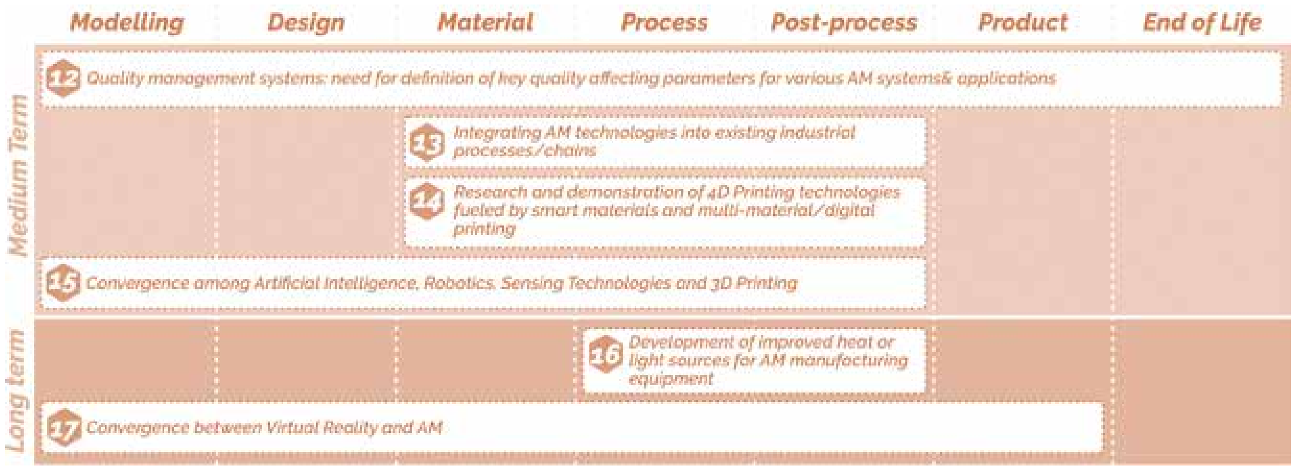


Figure 3.3: *AM-motion Roadmap on cross-cutting technical actions (medium and long-term focus)*

The following tables include key details for each action, in terms of current challenges and proposed activities.

Action n. 1	Moving from production shape optimization based on simulations to 3D models for AM up to "automatic" model-aided printing process
Challenge	Development of accurate modelling and simulation tools is an important fundamental building block. Alignment is needed among mathematical representations in CAD, FEM, simulations and project planning. Fast, economic modelling is required. Some good examples of such activity has been performed (e.g. FIOH in Finland, INRS France) but further efforts are required. One of key aspects is interoperability and continuity.
Proposed activities	● Complete realisation from design to part. Holistic modelling approaches using multi-physics, multiscale simulation and going from process parameters and simulation to product mechanical properties, via thermal mapping/history of the workpiece. ● Integrate software tools with lean management, considering the overall life cycle assessment ● Integrate software tools with increased automation of AM processes (including robotics for manufacturing and packaging) ● Stochastic/empirical modelling techniques utilizing a large volume of data (knowledge repository) ● Development of material databases (material, properties and relation to surface condition) ● Integration of modelling in the general process. Digital twin approaches ● Data Driven Process modelling using experimental and statistical approaches. This helps especially hard to model processes such as powder bed processes to reach the level of a predictive process through modelling and optimisation. ● Develop software tools that enable parametric modelling of lattice structures for design of light-weight products. ● Exploitation of FP7/H2020 projects' outcomes in this field (in alignment with the European Material Modelling Council).

Action n. 2	Advanced and novel technologies for multi-voxel printing and digital materials
Challenge	Multi-material printing is the combination of materials is on the Macro Level. Digital material is a seemingly one material where the combination of materials is on the Voxel level (microstructure), achieving completely new macroscopic properties.Voxel (volumetric pixel) is a volume element representing a value on a regular grid in three dimensional space. Most AM technologies (e.g. SLA, SLS, FDM) are working on a layer level. Working at voxel level will increase 3D printing opportunities enhancing the quality and functionalities of products (e.g. by achieving full color 3D printing, continuous transitions of properties, building new materials etc.). Further research is needed to develop novel incremental technologies able to control both layers and voxels (e.g. based on polyjet) or to work without layers achieving full digital printing.
Proposed activities	● Develop new materials and technologies for multi-voxel printing resulting in 3D printed digital materials ● Demonstrate the technologies in relevant environment and sectors.

Action n. 3	Design guidelines: need for AM process-/ material-/ application-specific guidelines
Challenge	Solid progress has been recently made in standardisation, both in form of ISO International standards, which are normative and include words such as "Shall" and "Can", and Technical reports, which are informative and could include recommendations (typically words such as "should" and "could"). Examples of published standards are ISO/ASTM 52910:2018 "Additive manufacturing -- Design -- Requirements, guidelines and recommendations". Examples of standards at DIS (Draft International Standard, a stage when the standard is first brought to ballot by the technical committee) are: ISO/ASTM DIS 52911-1 Additive manufacturing -- Technical design guideline for powder bed fusion -- Part 1: Laser-based powder bed fusion of metals (title of the standard under revision) and ISO/ASTM DIS 52911-2 Additive manufacturing -- Technical design guideline for powder bed fusion -- Part 2: Laser-based powder bed fusion of polymers (title of the standard under revision). A new work item on Powder bed fusion of metals using an electron beam has recently approved to be started. Example of Technical Reports already

Action n. 3	Design guidelines: need for AM process-/ material-/ application-specific guidelines
	approved and to be published soon is ISO/ASTM CD TR 52912 Additive manufacturing - Design - Functionally graded additive manufacturing, is mainly an overview of publications on functionally graded AM, design and processes. Despite such progress, there is need for process; material, application specific guidelines as well as design standards for AM (such as for light weight structures and low vibration). In parallel there is also need for specific training and educational activities targeting designers in key sectors (e.g. automotive, electronic devices) in order to draw benefits from AM technology.
Proposed activities	●Establishment of a set of generic AM design not-binding recommendations with guidelines integrated with design modelling tools ●Design guidelines should not be limited to just the AM process but also include the entire manufacturing aspects of AM in combination with pre- and post-processing ●Development not-binding recommendations for adressing topology optimization with regards to specific AM processes in the design phase to move from feature-based to function-based design. ●Creation of a central European data bank as base reference ● Collection of best practices and application-specific Design Guidelines in mature industry environments in particular AM applications and delivery of specific training activities.

Action n. 4	Need for advanced in process monitoring and control and generation of process validation data (through for eg. Artificial Vision, prediction models of microstructure control of parts during fabrication and supply chain control)
Challenge	Process monitoring is important for quality and production throughput. Improvement of control technologies are needed to enable effective in process measurement as current ones are not robust enough. Need for in-process monitoring and control to minimize defects and increase reproducibility and process reliability. There is also need for Traceability of AM products.
Proposed activities	● Use of a “knowledge repository” to improve process reliability ●”Prevention of defects” module during the design process .To be linked/incorporated with product build preparation (build direction, nesting, maintenance etc.) ● Investigate the consequence of defects/porosity/surface condition under service load conditions (fatigue loads), and identify the critical defect shape /size that could lead to premature failure. ● Explore effective post-processing methods (e.g. heat treatment, HIPing (Hot Isostatic Pressing), laser peening) to reduce defect size. ● Identify the best manufacturing route for a product ● Definition of the parameters to be controlled ● Development of real-time in-process faster/cheaper measurement techniques to enable total control. Bring inspection techniques more developed in subtractive manufacturing to the world of AM. Integration of artificial vision in in-line monitoring system. ● In-situ process monitoring and of materials processing and allow for product defect detection ● In-line non-destructive testing and/or in-situ analysis on the AM product ● Inspection of welding for thermoplastic materials joining, and section inspections need in production lines through ultrasonic welding vibration during the welding process , infrared inspection, artificial vision inspection. ● Implementation of existing AM manufacturing platforms to be fully integrated with the process ● Automated conformity assessments, and its cross validation with existing standards; for example dynamic certification based on similar parts, processes, designs and material combinations, including big data, data safety and security ● Use design guidelines to support business decisions ● Address the generation of process validation data more than real time control

Action n. 5	Simulation / prediction of thermal / residual stress for AM
Challenge	The selection of optimum process parameters for reducing structural distortion and residual stresses by simulation (e.g. in laser direct manufacturing (LDM))
Proposed activities	● Investigation of thermal distortion of thin walls and substrates to optimize tool paths and deposition strategies to either control or minimize distortion. ● Thermal field mapping (from machine sensors) in order to determine residual stresses and distortion. ● Investigating how the process parameters affect thermal field, microstructure and mechanical properties to enable prediction of material properties. ● study in-process and post-process methods for reduction of residual stresses

Action n. 6	Hybrid Manufacturing and innovative strategies to reduce post processing steps/activities
Challenge	Post-processing involves removal of the part from the platform and/or finishing the part. This segment of the manufacturing VC should be minimised, automated and integrated in the overall process as much as possible. Moreover, post-processing quality and reliability should be improved. There is need for breaktrhough innovations which address such challenges.
Proposed activities	● Development of innovative AM technologies and processes which minimise the need of post-processing. ● Integration of AM technologies with surface modification equipment able to realize an on-line surface modification in 3d printed material ● Strategies for increased automation of post processing and minimisation of manual operations ● Further investigation and evaluation of the effect of different post-processing operations (for example different heat treatments, Hot isostatic pressing (HIP) etc.) ● Integration of the AM process in a single process/hybrid machine to reduce the need of post-processing activities ● In-line process control and development of intelligent fix and handling systems ● Identifying a cost effective and adequate surface finishing method ● Understanding how the removal of material from the surface impacts the oversize of the design ● Investigate how post-processing can be supported via modelling providing a complete digital track of all steps ● Design approaches in am: make functional use of layers/lines in design for function

Action n. 7	Develop procedures and methods for qualification and promoting certification of AM products
Challenge	Qualification process consists in specifying or listing the necessary qualities for a part, or production system, or professional person, for a specific purpose, while certification is to confirm that the part (or production system, of person) actually possess these qualities. Qualification testing for parts is performed to verify the design and manufacturing process, in order to ensure that the component, meets necessary requirements, and thereby to provide a baseline for subsequent acceptance tests for the components. A quick and cost-effective certification process in AM should be developed. There is a need for qualification methods that will increase the number of qualified producers of AM parts, qualified AM proffesionals and certified quality AM producers, proffesionals and parts. The ability to qualify producers and certify parts to existing specifications (e.g. aerospace) is also important. There is need to boost equivalence-Based & model-based qualification routes.
Proposed activities	● Adaptive and flexible qualification for products ● Experimental: development of a matrix of required mechanical tests and acceptance criteria (e.g. tension, bending, fatigue endurance, fatigue crack growth rate, fracture toughness) that comply with certification rules ● Modelling and design: Predictive models that develop and demonstrate the capability of prediction (of strength and fatigue life) to satisfy the requirements that enable certification. These should take account of specific AM material characteristics, such as graded microstructures, residual stresses due to thermal load distribution and anisotropic properties of the final parts ● Adopting/ promoting effective classification and categorization of defects in AM components and creation of an Atlas of defects, in line with the recent standards under discussion by ISO/ASTM

Action n. 7	Develop procedures and methods for qualification and promoting certification of AM products
	JG59 NDT for AM parts (working on ISO/ASTM CD 52905 Additive manufacturing -- General principles -- Non-destructive testing of additive manufactured products) and ASTM E07.10 (working on WK47031 Non-destructive Testing of Additive Manufactured Metal Parts Used in Aerospace Applications). ● Development of a European wide system to qualify and certify companies that carry out AM (for example ISO3834). This is crucial to ensure the quality of the products that are produced ● Ensure that existing knowledge and rules are transmitted to AM players.

Action n. 8	Role of AM in circular economy/circularity for material resources: need for recycling parts made with AM and for using recycled materials to produce AM components/products
Challenge	From one hand, there is a shortage of material recycling services and means for reusing AM materials. From the other hand it is needed to promote reusing feedstock for parts production.
Proposed activities	● Effective Life Cycle Analyses (LCA), Life Cycle Cost Analysis and Social LCA, enabling the application of LC methodologies for accurate analysis of the environmental impact of AM processes, incorporating an environmental perspective into decision-making processes for transitioning to AM. ● Development of Environmental Impact Module/Evaluator acquiring real-time process data from measurement systems ● Definition and quantification of environmental KPIs such as energy consumption, waste streams, heat emission and gaseous emissions ● Development of effective feedstock recycling processes ● Development of regulatory requirements for recycling metal powders and production of functional parts ● Need for standard validation procedure for material properties in parts produced with feedstock that has been subjected tore-use or recycling, as well as guidelines for acceptable material properties and actions that restore the material properties to the original target values.

Action n. 9	Building a knowledge repository of materials and process parameters
Challenge	Databases of process parameters and material properties need to be developed to enable determination of product design and establishment of material design allowances for specific processes. There is need to achieve sustainability of preferred/chosen knowledge repository.This task should align with current efforts (and when necessary include further activities) in setting specifications, i.e. standards for key properties, -and measurement methods, in the feedstock and process equipment, -as well as for the actual manufacturing process, including the entire process chain. The database should takle also aspects of end of life and material reciclaybility.
Proposed activities	● Knowledge generation for the effect of AM parameters (including waste streams), to the energy consumption and environmental footprint (activity connected with life cycle analysis approaches). ● Generation and availability of data regarding mechanical properties, dimensional accuracy, surface roughness etc. coupled with the respective machine characteristics and process parameters. ● AM material information database to enable the correct choice of AM materials ● Investigations on effect of several protective gases / mixtures on material characteristics ● Library of industry cases (successful and failed) ● Open innovation on consortia (e.g. Cambridge pharma) collaborating at pre-competitive stage

Action n. 10	Increased industry engagement on standards development and decrease fragmentation of Am Standardization initiatives
Challenge	To accelerate AM market take up, industry should be further engage in CEN, ASTM, and ISO standards development (e.g. in process certification: -Simulation software for NDF & variation certificaton; -Application specific requirements). Possible barriers concerning time and money to follow this activity should be minimized. Involvement of customers in AM is important.

Action n. 10	Increased industry engagement on standards development and decrease fragmentation of Am Standardization initiatives
	From a logistic point of view ISO/TC261 and ASTM F42 arranges face to face meetings twice annually. These events usually cover four days, but it is getting increasingly difficult to include meetings for all areas of activity within this limited time. These meetings foresee fulltime engagement and could be difficult to combin them with attending a conference or technical exposition. However, the actual work on standards development is mostly done by continuous and repeated work in web-based meetings, but in order to have a continuous and consistent progress in the work it is critically important that the experts working on a project continuously participate in these meetings and allocate the time needed to do this. A work on how to reorganize the structure of work within the ISO/TC261 and ASTM F42 collaboration and enable scalability for the rapid growth of this activity has started this year. One critical discussion point is how to enable a contribution from a wider community but to maintain efficiency and still keep consistency and continuous progress. A very significant barrier is the number of people with enough of the needed expertise available. Many newcomers to AM would very much like to "participate" but in reality, just monitor the work and thus learn from the process. Another challenge is that many people do not really have all the expertise in the wide spectrum of AM processes, which is needed to make standards that are coherent for the entire field of AM and not only for a single process. Yet another challenge is that experts with backgrounds from different fields of technology (besides AM) insists that AM is merely an extension of their own original field and that the AM standards they are interested in should conform to the different fields of technology they are used to, thus working againts coherent standards in AM technology. Finally, there is also need for Open data warehouse on certified designs (with production requirements).
Proposed activities	● To promote the use of AM standards, including the use of a consistent AM terminology in all important documents and communications, including education on AM. This would greatly support and help clear communication and thus understanding of AM technology. ● Lower the barrier to engaging stakeholders by centralization of standardisation activities in specific key meetings/events etc, in line with current efforts in ISO/TC261 and ASTM F42. ● Promote the ongoing activities on standardization at a wider level. . Cooperation & coordination between AM standardization bodies and between industry and NSBs (national standard bodies) with EU-project coordinators. Improving communication, dissemination and the uptake / adoption of standards for good industry practices. ● To boost truly collaborative environments and networks among the regions and Member States following their capabilities (RIS3 strategy) / needs along the value chains segments ● Support further engagement via EC funded projects or other relevant projects with central focus on AM to evaluate possible use of results for standards elaboration. Next framework calls must be adapted to include topics which are relevant for standards development. When suitable a Work Package dedicated to dealing/engaging with standardization should be mandatory. This would require that at least a project partner is member of the relevant technical committees for AM standardization, and have the necessary knowledge of standards and standards development. As an alternative, there is a possibility that some of the results from some of the projects could be published in the form of technical reports. Another alternative could be having EC-funded Coordination Actions for coordination between EU-projects and standardization activities.

Action n. 11	Availability of high quality, enviromentally friendly and cost-effective materials
Challenge	AM community relies on a limited selection of conventional feedstock material. The availability of high quality, environmentally friendly and economically feasible raw materials or feedstocks should be fostered. The range of available materials needs to be expanded (e.g. there is need for high-class powders (Titanium); polymer compounds with tailor made properties (with active funcionalities such as antimicrobic, electrical or thermal conductive…)). It is important to understand to transport these materials (safety issues) to achieve distributed manufacturing and to study the whole life cycle to address environmental sustainability; Strategic support is needed for European powder/material for AM supply chain and growth.

Action n. 11	Availability of high quality, enviromentally friendly and cost-effective materials
Proposed activities	● Developing new polymers (and charge, where relevant) through interdisciplinary actions linking together chemistry, material research, new manufacturing process and user needs. ● Realization of innovative feedstock for FDM 3d printer based on polymer compound with tailor made properties (with active functionalities such as antimicrobial, electrical or thermal conductive…) ● Ultra-high temperature materials (refractory, composite, others). New alloys with high temperature capability ● Research into materials suitable for printing of multifunctional components/ Multi-material for multi-functional parts towards smart system. ● Use of Hybrid AM machine with tools able to improve joining between dissimilar materials (for example atmospheric plasma jet) ● Research on materials compatibility with current and novel AM processing technologies ● Novel materials resulting in fewer undesirable by-products and less waste ● Reinforce collaboration between designers, material producers and AM machine manufacturers ● Increase awareness on existing powder metallurgy solutions ● Life cycle analyses approach to ensure material economic and environmental sustainability and reciclability

Action n. 12	Quality management systems: need for definition of key quality affecting parameters for various AM systems& applications
Challenge	Quality management system covering the whole AM-process chain from materials to the final product, as a basis for part qualification, and AM-process chain surveillance. This includes data gained from pre-process analysis (powder), process monitoring solutions as well as machine data etc. Producing parts with standard properties requires development of standard procedures.
Proposed activities	● Development of AM-process chain monitoring solutions, protocols and data systems, which give indication about the conformance of the AM-process chain with existing standards and rules ● Development of statistically based knowledge about the influence of AM-processing-chain parameters on the final part quality ● Development of specific "AM-quality management" standards. Definition of quality on several levels: microstructure, mechanical properties and discontinuities ● Setup of a qualification label for AM service providers ● Experimentally-validated databases containing standard sets of process parameters per process/machine/material ● Standard materials database ● Standard post-processing (especially heat treatment) temperature profiles

Action n. 13	Integrating AM technologies into existing industrial processes/chains
Challenge	Integration in the shop floor requires attention as AM machines do not stand alone in factories. Combination with other machinery (subtractive, metallization, inspection, assembly) allows complex process chains and highly functional products, thus higher value and possible sale prices. Connect pre-, in- and post-processing for AM parts both physically (automation) and digitally (continuous digital thread)
Proposed activities	● Integration of entire process chains ● Interfaces development ● Evaluate/reconfigure CAD/CAM systems. CAD-CAM Platforms to support the integration of AM processes and equipment. Extension of existing file formats (i.e. STEP-NC) to include AM as well as pre- and post-processing steps in different "blocks" ● Fully automated AM processes connected via ERP and with the other machines in the production lines, to produce single parts in continuous production flow ● Creation of framework for multiple hardware equipment communication and collaboration

Action n. 14	Research and demonstration of 4D Printing technologies fueled by smart materials and multi-material/digital printing
Challenge	4D printing is a combination of 3D printing and the fourth dimension, which is time and/or the change of functionalities. This technique allows a printed object to be programmed to carry out shape change while adapting to its surroundings. This allows for masterized self-assembly, multi-functionality, and self-repair. While 4D printing looks promising for many applications such as the packaging, medical, actuation, construction, and automotive fields, it is still a very raw and new technology with many challenges that require resolution. Significant issues include the development of that possess reversibility (e.g shape memory materials; informed matter); material printability and repeatability of 4D printed objects. Moreover mechanical constraints, time response linked with the desired application, design of structured printing (i.e. smart foam) and mathematical modeling are required for the design of the distribution of multiple materials in the structure
Proposed activities	● Develop and/or optimise new 4 Printing technologies and solutions with smart stimulus-responsive materials (shape/functionality change materials or shape memory materials) able to respond to stimuli such as water, heat, electromagnetic field or light or their combinations. ●Development and application of 4D printing and smart multi-material/digital structures in several sectors (medical, bio-printing, construction, packaging and drug distribution, consumer electronics and automotive).

Action n. 15	Convergence among Artificial Intelligence, Robotics, Sensing Technologies and 3D Printing
Challenge	AI can make 3D printing more productive by for example enabling more people to be designers (translating their needs directly into CAM files) and improving co-creation opportunities in different environments (e.g.health, consumer markets etc.). Robots and disruptive software may enhance 3D printing speed and properties including quality by introducing artificial intelligence algorithms such as computer vision algorithms for in line quality control. Development of new AM technologies that can move away from classical cartesian coordinates and print in more complex spaces is also important. For example in the health sector it is important to create more complex structures that better mimick the architecture of our body parts. Further research is needed in such areas..
Proposed activities	● Development of novel AM technologies, integrating mechatronics, robotics and software development. ● Integrate artificial intelligence in 3D printing design process, promoting co-creation and enhancing design opportunities by involving users and different stakeholders (e.g. patients, surgeons etc.) in health and consumer markets. ● Increase automation, manufacturing speed and in line quality control in 3D printing through robotics and artificial intelligence. ●The developed smart materials and devices will also require qualification for both virgin state and recycled state .

Action n. 16	Development of improved heat or light sources for AM manufacturing equipment
Challenge	The heat or light source (in most) AM equipment is a bottle neck for improved production quantity and accuracy (resolution). This is a very important issue in terms of industries linked to glass manufacturing (not only jewel-lery, but e.g. also optics).
Proposed activities	● Development of improved heat transfer/control/distribution/strategy/new lasers/energy sources etc.

Action n. 17	Convergence between Virtual Reality and AM
Challenge	Virtual reality (VR) is defined by the Virtual Reality Society as: "the term used to describe a three-dimensional, computer generated environment which can be explored and interacted with by a person. That person becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions. The application of virtual reality in additive manufacturing would have several implications: engineers are able to design better products while customers can see final products pre-production, ultimately saving everyone precious time and money. By designing and simulating production lines virtually, a production manager can identify bottlenecks, maximize efficiencies and reduce total waste before any physical work begins
Proposed activities	●Application of virtual reality for enhanced AM design and predictive analytics and optimisation of the manufacturing chain. ● Develop AM smart objects which can be on-site inspected with a cell phone and smart glasses. ●Application of virtual reality for enhanced AM design and predictive analytics and optimisation of the manufacturing chain.

3.2. CROSS-CUTTING NON-TECHNOLOGICAL actions

A number of cross-cutting non-technical actions were identified as reported in the roadmap shown in Figure 3.4. Such actions cover different topics such safety, communication, education and training, business models, IPR and financing issues.

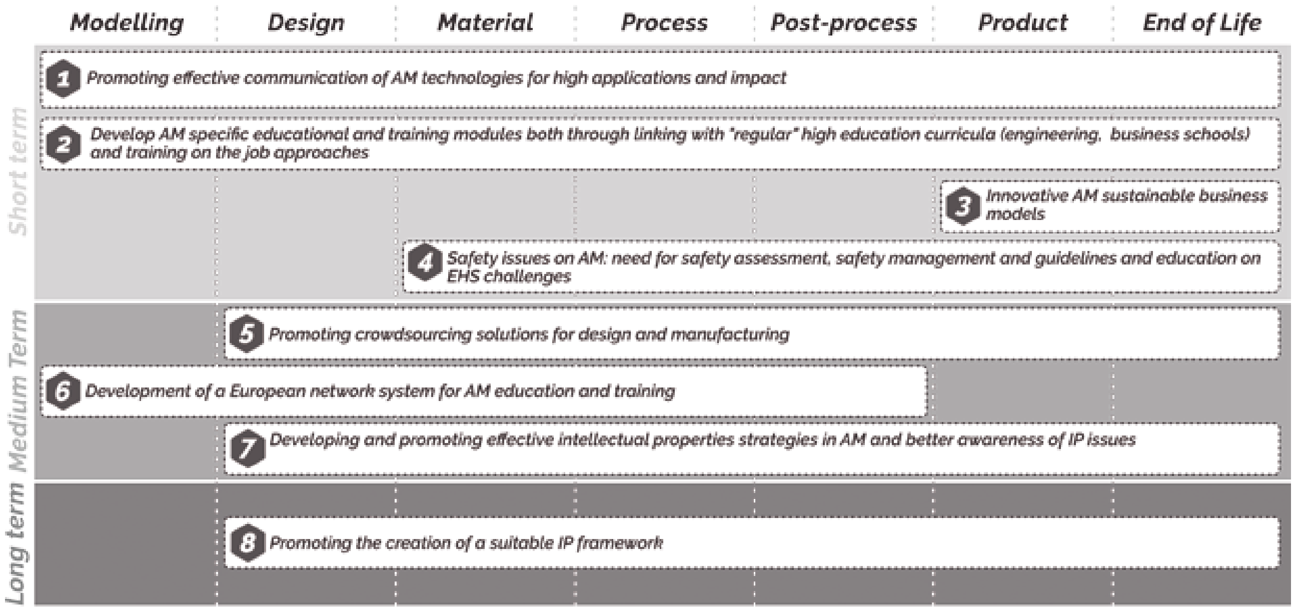


Figure 3.4: *AM-motion Roadmap on cross-cutting non-technical actions*

The following tables include key details for each action, in terms of current challenges and proposed activities.

Action n. 1	Promoting effective communication of AM technologies for high applications and impact
Challenge	In some cases, the AM technology/term has been over-characterised and described by excessive media hype and expectations. This has brought serious damage to the credibility and development of the AM industry. To ensure rapid and effective guides, real benefits and impact need be communicated to industry as well as basic and practical AM knolewdge should be disseminated. At the same time, it will be useful to discuss on the effect of the short lifetime of new machines which are for too short time used, linking the discussion with new business strategies and models.
Proposed activities	● Use of existing communication networks of reference (e.g. Platforms, industrial associations, standardisation committees…) to inform the different communities and foster dialogue between them. Moreover, to reach the general public and policy maker, sector magazines, newspapers and 2.0 tools (Twitter, You Tube) should be further exploited. ● Emphasis on design for AM and special considerations (overhangs/ supports/solid structures or latticed/post-processing requirements required for AM) ● Coordination with local industrial chambers and organisation, including umbrella organizations, of training days/seminars including practical workshops ● Screening of existing/ organisation of events, conferences to present the novelties, bringing examples of good collaborations, success stories in industrial implementation, and societal impact. This includes bringing together different stakeholders (policy makers, industry, end-users etc.) and adopting a 'correct' communication channel for each of them ● Attention to the development of "use" cases where businesses in application sectors can have access to technology facilities and use AM equipment, thereby improving their practical understanding of this technology. This would tackle the problem related to overall conservative attitude towards AM in industry ● Learning-by-doing support action for industry (including deep-learning and artificial intelligent elements)

Action n. 2	Develop AM specific educational and training modules both through linking with "regular" high education curricula (engineering, business schools) and training on the job approaches
Challenge	New jobs around AM will be created. Finding the workforce with the right competences is a challenge. Thus, knowledge gaps and educational needs for the AM workforce need to be identified and addressed. Training and education establishments need to preserve and develop the employability of workers. Industry and other employers (e.g. Standardisation bodies, IPR entities etc.) should be also engaged in the process in order to align their needs with regard to skills with the educational contents. AM education and training requires an integrated and interdisciplinary approach to prepare the current and future workforce to boost AM's real potential. It is important to define new jobs and skill sets, while addressing the current uncertainty about their education domain (engineering, design, processes etc.). Finally, there is lack of engineering & design specialists in Europe. The complexity of interdisciplinary processes has to be mastered…which is quite difficult as reported in previous works.
Proposed activities	● Map existing Educational programs and actors in Academic and Industry ● Promote collaboration of educational bodies with industry and governments at regional, national and EU levels towards the inclusion of AM aspects on the educational curricula in an effective way ● Map existing Educational programs and actors in Academic and Industry ● Promote collaboration of educational bodies with industry and governments at regional, national and EU levels towards the inclusion of AM aspects on the educational curricula in an effective way ● Emphasise design for AM and special considerations (overhangs/ supports/solid structures or latticed/post-processing requirements required for AM) ● Ensure that AM curricula addresses employer's needs, address multidisciplinarity and includes both technical (AM and traditional manufacturing processes, materials, design for AM, safety, etc.) and business related aspects. They should target different levels: management, engineers, shop floor, etc. - from University level to the operator level, focusing not only in preparing a new workforce but also in re-skilling the existing one to work and implement AM ● Introduce new means of teaching: For example practical modules held at industrial or specialized R&D centres. ● Provide AM training programs to gain AM knowledge and experience for workers seeking alternative employment pathways ● Use of standards as a base for all training materials and courses (certification by professional bodies) from industry training to higher education ● Offer support for collaborative and community-oriented maker spaces/events that, as informal learning environments, promote awareness of AM among society ● Introduce AM to curricula of Elementary and High schools in all EU ●CSA for promotion of AM technologies to wide public -Support Fablab initiative ● AM promotion through the organization of competition for AM design (free form design) for young people (high school pupils, students) and public promotion of their design ● These activities should be supported by popular lectures and workshops

Action n. 3	Innovative AM sustainable business models
Challenge	The capability of the organizations to innovate is recognized as one of the main factors driving economic growth, increasing wellbeing levels and the development of society. Innovation depends not only on the internal competences of the organizations, but also on their ability to interact with other interested parties, transforming knowledge into value realization. The capacity to manage innovation as a system is a critical success factor. In this contexts business cases and models are still needed to show decision makers what is possible with AM and how it could impact their business (for parts, for prototyping, for production processes). Accessibility to AM technology for newcomers should be easier and cost effective. There is need to understand the effect of new supply chains on companies 'business models? We should not confuse that AM is often not the need, but rather the means.

Action n. 3	Innovative AM sustainable business models
	It is important to learn how to incorporate presumption and (autonomous) co-creation in business models as well as find sustainable business models for direct manufacturing and distributed manufacturing. The general idea of redesign of part is probably a good route for promoting AM..
Proposed activities	● Adopt an Innovation Management System approach including detection and response to changing situation in its context, to pursue new opportunities, to leverage the knowledge and creativity of people within the organization and other interested parties, and to promote a culture supporting innovation activities and in particular AM capabilities. ● Evaluation of AM capabilities for new products and structures. Identification of appropriate use cases, right applications and markets, and development of practical solutions for the production and distribution of the products. ● Success models for business collaboration, realising current bottlenecks and best practices for transferability of novel technologies ● Explore existing AM manufacturing platforms and materials to evaluate suitability as an alternative manufacturing solution ● Business and economic model analysis using also a life cycle cost analysis approach. Ability to calculate the total increase in manufacturing cost vs. the benefits arising from its use during the lifecycle. ● Consideration of 3D parts models access and IPRs possible issues ● Assessment of value creation by AM in industrial applications ● AM as service: -Business model based on uptime; -Flexible attitude towards temporary parts. ● Consideration of maintenance/replacement of AM parts, especially in the case of function-integrated structures ● Creation of a decision-support tool able to quantify benefits of introduction of AM during the lifecycle of a product

Action n. 4	Safety issues on AM need for safety assessment, safety management and guidelines and education on EHS challenges
Challenge	Need for Rules/Guidelines/ Education on EHS challanges with AM. In relation with protection of Machine Operators: there is a need for standards to address EHS in the AM process. Typical hazards to be addressed include: guarding from moving parts that are not protected from contact; chemical handling (liquids, powders, wires); air emissions (dusts, vapors, fumes); noise (cleaning apparatus); electrical (water wash systems, electro-static systems); flammable/combustible cleaning materials; solid waste; laser use (sintering processes); and UV light (may require eye and skin protection based on design)
Proposed activities	● Adopt safer-by-design approaches: consider safety aspects into the early design stages in order to reduce potential hazards (e.g. the post processing safety concerns can be minimised). ●Recommend creating a standard addressing EHS issues relative to additive machines (power, laser, safe handling, air quality, etc.). Physical measurement of operator exposure to AM materials is one of the most critical needs and can be leveraged from existing industry standards and guidelines. ●In case of use of nanomaterials during the AM process safe by design approach is relevant in respect of European Nanosafety Cluster ● Understanding the potential of the operation to generate fine powders, the exposure and the effect of volatile powders on the individual and surrounding environment during the life cycle. ● Develop sufficient protective equipment around AM (ventilation, powder handling stations, etc.) ● Development of technical solutions to minimize contact between operator and material (e.g. Solvent Damp Powders - There should be sufficient solvent that the powder cannot form a dust cloud; Large Particle Size Materials and Blends - Concentration of fine powder within the bulk of the material) ● Exploring the potential for charging powders into Flammable Atmospheres ● Promote education and training activities related to EHS challenges in AM with focus on powder handling.

Action n. 5	Promoting crowdsourcing solutions for design and manufacturing
Challenge	There is need for self-sustainable co-creation platform with easy to use softwares
Proposed activities	● Connect data and available tools and platforms, integrating existing applications, systems and enterprise processes. ● Involvement of software companies/ computational services providers.

Action n. 6	Development of a European network system for AM education and training
Challenge	AM is a fast developing technology constantly changing, and educational contents and training guidelines need to be updated at the same speed and in a sustainable way to ensure the system tackles immediate and future needs. Moreover, new educational partnerships are needed to deliver broad education covering innovative and interdisciplinnary aspects. Specific focus should be given on 21st century skills: - Deep learning, use of AI in education; - Communication & collaboration; - Industry 4.0, big Data, -AI/Robotization and IoT.
Proposed activities	● Creation of a European network for AM education as a central reference hub for training and educational purposes, covering VET, HE etc. ● Development of harmonized qualification and certification system for AM, covering all European Qualifications Framework (EQF) levels. The system would address the needs for training and qualification (and re-qualification) of personnel at all levels. Consideration also of different training needs of the different end-users sectors industrial, educational and consumers in order to generate suitable support material ● Quality assurance system to guarantee the quality of the training provided along with standard best practices ● Resource and facilities sharing, good quality course materials and other contents provided to create and sustain AM education across Europe ● Promote students/workers/teachers exchange among educational establishments and practices in companies/R&D centres ● Coordination with local industrial chambers and organisation of training days/seminars and practical workshops. ● Dialogue with applied science HEI Networks to develop new curricula ● Involvement on MAJOR HE interest organizations ● Focus ALSO on vocational training in AM

Action n. 7	Developing and promoting effective intellectual properties strategies in AM and better awareness of IP issues
Challenge	Intellectual property implications of AM should be reviewed to avoid that it hinders. Implications of AM on the intellectual property system should be mapped and monitored to avoid that IPRs hinder innovation. Short term key IPR issues relate to AM designs and copyrights. Designs could be stolen and thus, reproduced. Open innovation strategies should be further exploited. There should be greater awareness in the IP law community on how AM is impacting client´s business models Among current challenges there are also: -need for digitalization of patent law (Not only copyright) + Digitalization of design rights and trademarks - Territoriality of IPRs vs. Global nature of digitalization - Protection of information included in CAD file via exclusive rights such as IPRs - Legal Nature of CAD file (Software? Work of art? Database? something else? - IPR protection of new materials like for Bioprinting - Limits to apply patent law due to possible ethical issues involved - Enforcement issues of IPRs related to digitalization - Use of technical protection measures (e.g. blockchain) to increase efficiency of enforcement of IPRs
Proposed activities	● Development of a strategy to identify possible IP rights and issues that may arise taking into account the interests of all stakeholders

Action n. 7	**Developing and promoting effective intellectual properties strategies in AM and better awareness of IP issues**
	● New forms of protection mechanisms; clearer guidance on defining whether a CAD file could have IPR protection ● Involvement IPR related entities as EPO (European Patent Office) ● Learn lessons from the past; look at past digitisation waves and avoid doing the same mistakes ● Joint tech/non-tech actions aiming at raising awareness ● Solving IP issues by implementing new business models.

Action n. 8	**Promoting the creation of a suitable IP framework**
Challenge	Currently there is no case law about AM/ 3D-Printing in Europe. Knowing the real implications of AM will take some time and it will most likely happen that legislation comes after the act. On the one hand, it is important to understand how the existing IP framework can be used in a suitable manner. On the other hand, the IP system might need to shape itself to be able to meet the needs of AM technology.
Proposed activities	● To explore aspects that might be further regulated or regulated differently, and liability aspects ● To explore the need of regulating AM specifically and separately ● To assess applicability and efficiency of current protection tools : copyright, Patents, Design Rights, Utility Models, Trade Secrets ● Research needed to address challenges and understand: -What field of IPRs (Status Quo) can currently apply to CAD Files + need for new ad hoc types of tools -What legal nature should we "assign" to CAD files ● IPR Helpdesk workshops focusing on iP challenges related to AM

3.3. HEALTH gaps and actions

Health-specific actions were identified as reported in the roadmap shown in Figure 3.5. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-1. The roadmap reports only the key target products linked to each specific action, whilst the table list all the relevant target products.

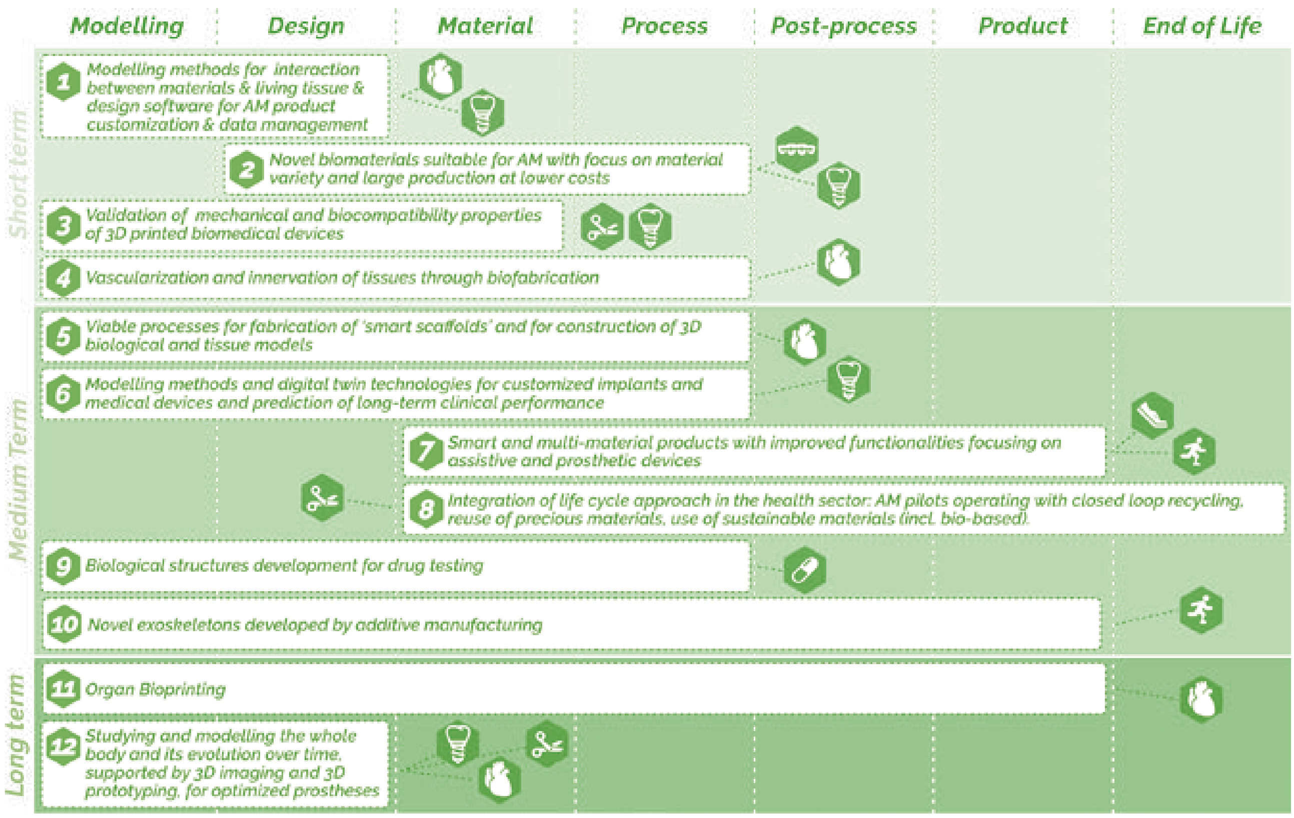


Figure 3.5: *AM-motion Health Roadmap*

Table 3-1: *AM-motion Health actions details*

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Target Products: Assistive and Prosthetic Devices	Target Products: Surgical Guides, Tools & Models	Target Products: Medical Implants	Target Products: Other Dental Products	Target Products: Other Customised Products	Target Products: Living Tissues & Organs	Target Products: Pharmaceuticals Products
1	Modelling methods for interaction between materials & living tissue and Design Software for AM product customization and data management	RIA	3-4	5-6	⬢	⬢	⬢			⬢	
2	Novel biomaterials suitable for AM with focus on material variety and large production at lower costs	IA	4-5	6-7		⬢	⬢	⬢	⬢	⬢	
3	Validation of mechanical and biocompatibility properties of 3D printed biomedical devices	IA	5-6	7-8	⬢	⬢	⬢	⬢		⬢	
4	Viable processes for fabrication of 'smart scaffolds' & for construction of 3D biological & tissue models	RIA	1-2	3-4						⬢	⬢
5	Vascularization and innervation of tissues through biofabrication	RIA	3-4	5-6						⬢	⬢
6	Modelling methods and digital twin technologies for customised implants and medical devices and prediction of long-term clinical performance	RIA	2-3	4-5		⬢	⬢			⬢	⬢
7	Smart products with improved functionalities	RIA	2-3	4-5	⬢	⬢	⬢	⬢		⬢	
8	Integration of life cycle approach in the health sector: AM pilots operating with closed loop recycling, reuse of precious materials, use of sustainable materials (including bio-based ones)	RIA	2-3	4-5	⬢	⬢	⬢	⬢			
9	Biological structures development for drug testing	RIA	2-3	4-5						⬢	⬢
10	Novel exoskeletons developed by additive manufacturing	RIA	2-3	4-5	⬢						
11	Organ Bioprinting	RIA	2-3	4-5						⬢	
12	Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses	RIA	1-2	3-4	⬢	⬢	⬢			⬢	⬢

The following tables include key details for each action, in terms of current challenges and proposed activities.

Action n. 1	Modelling methods for interaction between materials and living tissue and design software for AM product customization and data management
Challenge	Modelling can be an effective tool to test advanced, breakthrough research solutions. As an example, orthopaedic implants can be modelled to best match the hosting bone, and fine mesh structures of AM can even promote osteointegration in these customized implants . Then, analysis and simulation of cell responses and cell tissue growth behavior is required within more realistic environments.
Proposed activities	● Increase knowledge on in-silico models of human body systems (musculoskeletal, cardiovascular, respiratory etc.), also in the recent attractive perspective of "in-silico clinical trials". ● Increase research and knowledge of bio-AM in cell response and tissue growth behaviour. ●Data management of modelling methodologies for AM product customisation. ● Investigate the robustness of models including repeatability. ● Converging biotechnology, biomedical engineering and medical expertise. ● Material models for controlled drug release.

Action n. 2	Novel biomaterials suitable for AM with focus on material variety and large production at lower costs
Challenge	Novel bio-functional materials capable of supporting the use of printing in current and novel human and diagnostic applications are needed. Materials for medical applications (e.g. implants, dental elements, chirurgical instruments) must meet high demands on biocompatibility and reliability. It is important to look for lowest cost according to the goal (cost-benefit analysis). Interdisciplinary aspects and convergence of disciplines should be addressed.
Proposed activities	● New or adapted processes for bio-functional powder production. ● Adapted equipment for bio-functional powder use ● Development of new machine concepts e.g. for graded material properties and multi material combinations ● Development of new composites based on polymer/ ceramic and ceramics reinforced metal (metal matrix composites, i.e. MMCs) ● New materials: e.g. magnesium, copper, biodegradable polymers, etc. ● Focus on biocompatibility and required performance properties ● Mechanical characterisation comparison with traditional materials.

Action n. 3	Validation of mechanical and biocompatibility properties of 3D printed biomedical devices
Challenge	Material quality control and high reliability materials are key issues for medical applications that require validation. As basic requirement is fundamental to develop material targeting to at least replicate the mechanical and biocompatible characteristics of traditional implantable parts.
Proposed activities	● Significant experimental effort needed and population of corresponding databases. ● Develop models and reference data to capture more realistic working conditions of devices in the living environment (kinematics, loading, fluidodynamics, vibration, temperatures, biological, chemical etc.). ● Establish the effects of geometries, morphologies, manufacturing parameters etc. on the final mechanical properties of the products. ● Improve process stability. Brittle fracture is a key property to be assessed, i.e. fracture toughness and effect of small defect on the fracture property. ● Implement methods to improve quality across batches of used and raw materials. ● Develop best-practice for machine and feed-stock handling, round-robin testing and mapping of process parameters vs. material properties. ● Research the effects of heat treatment and post processing operations. ● Protocols for certification of AM process for medical devices (modelling, sensors, mechanical & biological tests, etc.).

Action n. 4	Vascularization and innervation of tissues through biofabrication
Challenge	In biofabrication, a lot of effort is placed to create vascularized tissue constructs. Innervation is often forgotten, despite being also a very important network to maintain tissue functionality.
Proposed activities	● Exploration of materials and biological factors to create conditions similar to human physiology ● Converging biotechnology, engineering and medical expertise.

Action n. 5	Viable processes for fabrication of 'smart scaffolds' and for construction of 3D biological and tissue models
Challenge	One of the key issue is the knowledge of biological processes (epistemiology) before taking actions. Then, the production of parts for medical applications requires special processes and equipment.
Proposed activities	● Development to enable industrial fabrication and implementation for medical applications ● Encourage synthesis of multi-material porous structure for impregnation ● Novel equipment supporting printing of biocompatible fabrication including multi-material and printing of living cells.

Action n. 6	Modelling methods and digital twin technologies for customised implants and medical devices and prediction of long-term clinical performance
Challenge	Advanced modelling tools combining various medical imaging methods with modelling and design to support AM production are needed for efficient use of AM. Knowledge of long term clinical performance of AM implants will help to optimise their efficacy.
Proposed activities	● Compilation of specifications and identification of current capability gaps in available software ● Development of scanning and surgical methods; for example the development of multi-physics, multiscale modelling tools to ensure functionality and safety of parts and increase the understanding of how it will perform after surgery (from grain size or molecule to component level). ● Development of file compatibility between imaging and AM modelling software. ● Fabrication of new porous structures for weigth reduction and elevated bio-integration. ● Development of modelling tools that recognise how implants will perform after surgery (from the tissue to the material and implant). ● Experimental testing of implants for replaced joint mechanics, but also corrosion, fatigue and wear of the single components of the prosthesis. ● Long term clinical observations that aim to understand the health related performance. This should use a case approach in which the full financial impact on the value chain is detailed. To include participation of all stakeholders (medical, biomechanical, organisational, financial, insurance, patients supply etc.). ● Apply digital twin technologies to constantly improve performance and monitor behaviour. ● Transfer information to meta-models.

Action n. 7	Smart and multi-material products with improved functionalities focusing on assistive and prosthetic devices
Challenge	Materials for introducing new functionalities and/or producing integrated electronics to broaden the application of AM
Proposed activities	● Development of "smart" parts by embedding sensors and/or effectors ● Use of nanomaterials and nanotechnologies to improve material properties.

Action n. 8	Integration of life cycle approach in the health sector: AM pilots operating with closed loop recycling, reuse of precious materials, use of sustainable materials (including bio-based ones).
Challenge	Recovery and reuse of expensive AM materials without compromising reliability and safety of produced critical parts. Use of sustainable materials (including bio-based ones) whenever appropriate.Linked with cross-cutting gaps.
Proposed activities	● Demonstration of pilot line operating with closed loop recycling and reuse of precious materials ● Set up of exemplary processes through demonstration projects (including re-use of materials, use of bio-based materials, development of recyclable materials) ● Development of automated conformity assessment protocols/systems to secure entry status and in-process validation of the quality, safety and security of the designs, (recycled) material, differentiated for use categories in the Medical arena ● Integrating life cycle analysis and life-cycle cost analysis, use a case approach to estimate the full financial and environmental impact on the value chain when making use of recycled materials, including risk assessments and financial impact of those risks.

Action n. 9	Biological structures development for drug testing
Challenge	Biological structures that can mimic key biological functions can help improving drug's development and replacing animal testing.
Proposed activities	● Exploration of materials and biological factors to create conditions similar to human physiology ● Converging biotechnology, engineering and medical expertise ● Upscaling of biofabrication technologies to reach human scale dimensions.

Action n. 10	Novel exoskeletons developed by additive manufacturing
Challenge	Personalised prototypes for disabled patients (focusing on children) to improve their quality of life (e.g. for walking, playing etc.).
Proposed activities	● Optimisation of materials and technologies and demonstration in working prototypes. ● Validation in terms of human motion and power performances. ● Integration of robotics, sensoring and artificial intelligence aspects.

Action n. 11	Organ Bioprinting
Challenge	Bioprinting hold the promise to be a game changer for the fabrication of organ replacements. Yet, up to today only very simple and rudimentary small models have been developed. To explore the full potential of organ bioprinting, functional full organ or (as minimum) organ patches should be developed
Proposed activities	● Exploration of materials and biological factors to create conditions similar to human physiology ● Converging biotechnology, engineering and medical expertise ● Upscaling of biofabrication technologies to reach human scale dimensions.

Action n. 12	Studying and modelling the whole body and its evolution over time, supported by 3D imaging and 3D prototyping, for optimized prostheses.
Challenge	Current medical imaging methodologies (computed-tomography, magnetic resonance, ultrasound etc.) coupled with 3D modelling and prototyping may lead to virtual and physical reconstruction of human body and its evolution over time from youth to old age. Coupling such systems with modelling and advanced parametric design has the potential to develop optimised patient-specific orthoses and prostheses.
Proposed activities	● Perform long-term studies /have access to medical data with the evolution of the human body over time and develop parametric design and modelling; ● Develop techniques for scanning external aspects of the human body, for patient-specific prosthetics and orthotics; ● Develop processing algorithms, 3D reconstructions and diagnostic capacity from the medical images; ● Establish new techniques and new standards for modern instrumentations (7T MRI, weight-bearing CT, etc.); ● Demonstrate the potential of the tool in critical prostheses (e.g. Cardiovascular or orthopaedic devices).

3.4. AEROSPACE gaps and actions

Aerospace-specific actions were identified as reported in the roadmap shown in Figure 3.5 ***AM-motion Health Roadmap*** Figure 3.6. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-2.

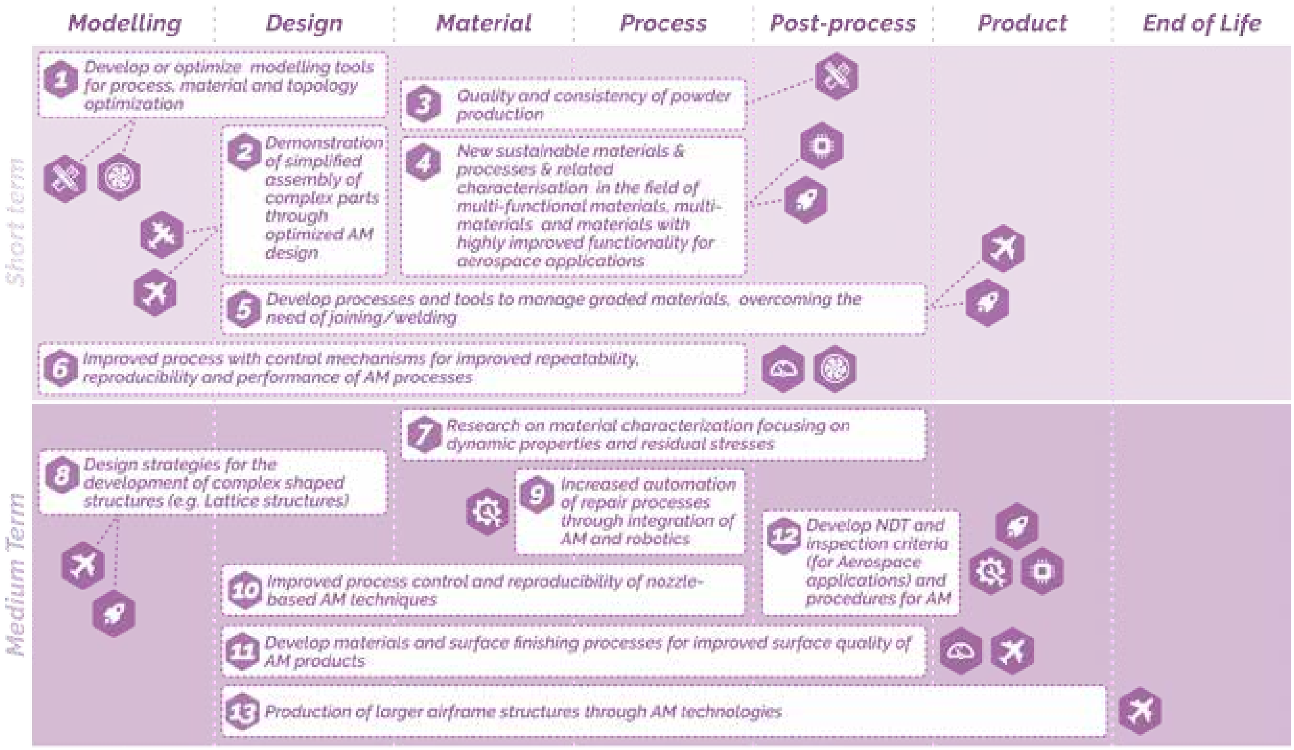


Figure 3.6: *AM-motion Aerospace Roadmap*

Table 3-2: *AM-motion Aerospace actions details*

N	Action Name	Type of Activity	TRL		Target Products								
			Initial TRL	Target TRL	Turbine Parts, Engine	Small aircraft wings & fuselage and their components	Cabin & Cockpit parts	Other omplex parts	Components of large aircraft wings and fuselage	Spare parts & repair	Concept modelling, prototyping and advanced moulds	Niche, low volume parts	Embedded electronics
1	Develop or optimize modelling tools for process, material and topology optimization	RIA CSA	5-6	7	●	●		●	●	●	●	●	●
2	Demonstration of simplified assembly of complex parts through optimzed AM design	IA	6	7	●			●	●	●	●	●	●
3	Quality and consistency of powder production	IA	6	7	●	●		●	●	●	●	●	●
4	New sustainable materials and processes and related characterisation in the field of multi-functional materials, multi-materials and materials with highly improved functionality for aerospace applications	IA	4-6	7	●	●	●	●	●	●		●	●
5	Develop processes and tools to manage graded materials, overcoming the need of joining/welding	RIA	2-3	5	●	●		●	●	●		●	
6	Improved process with control mechanisms for improved repeatability, reproducibility and performance of AM processes	IA	4-6	7	●	●	●	●	●	●	●	●	●
7	Research on material characterization focusing on dynamic properties and residual stresses	RIA	4-5	6	●	●	●	●	●		●		
8	Design strategies for the development of complex shaped structures (e.g. Lattice structures)	IA	5-6	7	●	●		●	●		●		
9	Increased automation of repair processes through integration of AM and robotics	IA	5-6	7	●			●		●		●	●
10	Improved process control and reproducibility of nozzle-based AM techniques	RIA	4-5	6	●	●	●	●	●	●	●	●	●
11	Develop materials and surface finishing processes for improved surface quality of AM products	IA	6	7	●	●	●	●	●	●		●	
12	Develop NDT and inspection criteria (for Aerospace applications) and procedures for AM	CSA IA	6	7	●	●	●	●	●	●			●
13	Production of larger airframe structures through AM technologies	RIA	3-4	6					●		●		

The following tables include key details for each action, in terms of current challenges and proposed activities.

Action n. 1	Develop or optimize modelling tools for process, material and topology optimization.
Challenge	Design optimization in combination with process reliability: there is need for: - full integration of AM process modelling in state of the art software systems for efficient and optimized modelling. - evaluation of correlation between process parameteres and part properties, understanding how defects form and why (advanced melt pool modelling and simulation is necessary).
Proposed activities	● Address simulation of the thermal conditions in the aerospace part in combination with topological optimization of the support structure and fixtures ● Conduct a state-of-art literature survey of existing models and models that are currently being developed. Integration of state of the art tools emerging from FP7 and H2020 programs ● Encourage modelling using machine parameters as entry parameters and build orientation, and establish links with mechanical properties ● Funding of HPC resources ● Publish Public Material properties database relevant in AM ● Knowledge transfer from Academia to Industry ● Web-based platform of reference test models including experimental results. A rating of the models should be possible.

Action n. 2	Demonstration of simplified assembly of complex parts through optimzed AM design
Challenge	Advanced design tools to help utilize the advantages of AM
Proposed activities	● Introduce topology optimization methodologies in the design phase to move from feature-based to function-based design ● Integrate AM Design constraints (overhangs, etc..)and rules into topology optimization to minimize supports ● Demonstrate topology optimization approaches leading to CAD files for complex products

Action n. 3	Quality and consistency of powder production
Challenge	Identification of powder properties that are critical to obtain a "good" part during processing in AM machine (e.g. Shape, chemical composition, porosity, etc..). Moreover, having the right requirement for powder batch acceptance is required for certification compliance. Understanding of the limits of recycling powders. Connected with automotive action n. 2
Proposed activities	● Work on material quality, shape for powder and size in order to have a well-controlled material for the 3D process, including feedstock management and handling including recycling of powders. ● Quality and consistency of powder production. Improve processes for powder production with better distribution size control ● Define powder testing and validation criteria which can depend on each machine (feeding, laser source, etc.)

Action n. 4	New sustainable materials and processes and related characterisation in the field of multi-functional materials, multi-materials and materials with highly improved functionality for aerospace applications
Challenge	Reliability of AM produced parts during their life time is essential for aerospace applications. Reliable high performance materials (light weight, strong, high temperature, reliable) and special materials (ceramic/metal) or materials that include multifuncional capabilities on the materials (e.g. sensorng conductivity), Another challenge is enabling the use of multi materials and graded materials. This may be achieved also through reliable modeling tools and optimized processes.

Action n. 4	New sustainable materials and processes and related characterisation in the field of multi-functional materials, multi-materials and materials with highly improved functionality for aerospace applications
	Sustainability aspects should be addressed considering also the end of life /reciclability of such materials and products.
Proposed activities	● Development of shape memory alloys (thermal and magnetic), piezoelectric actuators and electro active polymers ● Lightweight materials (e.g. titanium alloys) ● Extreme operating temperatures superalloys for turbine components ● Improved dynamic (fatigue) materials properties: development of new alloys with improved dynamic properties and the development of advanced composites including high mechanical resistance ceramic particles in metal matrix ● Development of materials with improved creep and oxidation resistance ● Development of new routes for powder production to enable cheaper powders ● Development of wire feedstock value chain with chemistry tailored for AM applications ● Welding filler metal supplier ● Development of “smart” parts by embedding sensors and/or effectors ● Development of new machine concepts e.g. for graded material properties and multi material combinations and the development of modelling tools to support this activity ● Fatigue and fracture toughness properties; effect of defects ● Residual stress in materials, caused by AM process and miss-match of different material properties (i.e. elastic modulus and coefficient of thermal expansion). ● Study of environmental and economic sustainability as well as reciclability aspects through life cycle analysis and life cycle cost analysis..

Action n. 5	Develop processes and tools to manage graded materials, overcoming the need of joining/welding
Challenge	Machining and welding of super alloys produced by AM (Ni and Ti based) can be very difficult. Develop processes to manage graded materials to overcome the need of joining/welding parts manufactured with different methods. Necessary to have a fast and accurate measuring method to adapt new geometry to the already existing.
Proposed activities	● Establish methodology with machine parameters through defined design of experiments ● New optimized cutting tools (in terms of materials and geometry) for AM parts ● Use of ceramics ● Development of appropriate modelling tools to support this activity ● 3D optical in-process measuring and data tranfer.

Action n. 6	Improved process with control mechanisms for improved repeatability, reproducibility and performance of AM processes
Challenge	Current building processes often perform the printing without recognizing errors during the fabrication. It is required to demonstrate that the key process parameters are under control for certification in this sector. Repeatability, reproducibility and performance of AM processes can be improved using knowledge and tools, in order to get predictable outcome of the process. Lack of availability of suitable monitoring systems for AM; Incorporation into existing machines to control quality during building process. Control mechanisms for yield optimised processes. This is necessary for processing and equipment right performance, and the ability to qualify and certify parts and processes..
Proposed activities	● Implement real thermal field mapping (from machine sensors) to determine residual stresses. ● Data regarding mechanical properties, dimensional accuracy, surface roughness etc. coupled with the respective machine characteristics and process parameters ● Efficient modelling tools to provide intelligent feedback control

Action n. 6	Improved process with control mechanisms for improved repeatability, reproducibility and performance of AM processes
	● Make use of established know-how in polymer fused deposition modelling (FDM), injection moulding and powder injection molding (PIM) ● Interaction with the "design" and "modelling" VC segments, i.e. design and process iterations ● Structural integrity analysis: design against fatigue and design for damage (defect) tolerance ● Develop in-situ multiscale analysis methods by vision systems and image processing ● Create in line control systems with feedback capabilities

Action n. 7	Research on material characterization focusing on dynamic properties and residual stresses
Challenge	Study dynamic properties of metal materials, for different materials and AM technologies; Study residual stresses in AM parts
Proposed activities	● perform fatigue tests in order to determine fatigue limit and construct S-N curves for various materials and AM technologies ● derive distinction between the influences of properties of the material, the technology and layered structure to the observed dynamic behaviour ● perform studies of influence of technological supports to residual stresses ● study influence of technology process parameters to residual stresses ● study in-process and post-process methods for reduction of residual stresses

Action n. 8	Design strategies for the development of complex shaped structures (e.g. Lattice structures)
Challenge	The ability of AM to produce optimised complex shapes can only be utilised if these shapes can be designed.
Proposed activities	● Develop algorithms to automatically generate stress optimized lattice structures (preliminary design) ● Develop automated plausibility checks for structures under constraints (preliminary design). Integrate CAD packages with AM process (conceptual design) ● Integration of simulation into the design phase (both in the preliminary and detailed design) ● Include material properties taking into account process defects in design loop ● Extension of topology optimization tools (including dynamic loads, cyclic loads, vibrations, shock absorption, optimal weight) ● Structural Integrity & Durability assessment (detailed design)

Action n. 9	Increased automation of repair processes through integration of AM and robotics
Challenge	Process integration, CAM for automated repairing -> CNC (computer numerical control) robots. Repair of expensive parts (eg turbine blades) by adding new material at worn regions.
Proposed activities	● Develop and adapt the process chain for repair approach in order to have an easy process and a final product with the best properties ● Develop fully automated repairing processes through CAM (computer-aided manufacturing), robotics and AM: NDT defect detection / Gouging machining / AM / Final inspection. ● More advanced repair operations through selective re-application of advanced alloy materials (e.g. IN718). Possibly in combination with some hybrid manufacturing solutions, this should be a part of industrial process development, evaluation and demonstration projects. ●Support such automation strategies with development of appropriated standards.

Action n. 10	Improved process control and reproducibility of nozzle-based AM techniques
Challenge	It is required to demonstrate that the key process parameters are under control for certification in this sector. Repeatability, reproducibility and performance of AM processes can be improved using knowledge and tools, in order to get predictable outcome of the process. Lack of availability of suitable monitoring systems for AM; Incorporation into existing machines to control quality during building process.

Action n. 10	Improved process control and reproducibility of nozzle-based AM techniques
Proposed activities	● Create advantage by combining small complex and functional AM parts with large volume parts with only stability as a function ● Development of combined AM/subtracting with very good control of final product geometry and properties ● Hybrid solutions should not necessarily be implemented within the same machine: develop techniques for AM integration in the industrial production system and/or Hybrid fabrication processes using multiple AM and other processes ● Joining technologies, e.g. by welding, to join AM with AM or conventional materials to form a larger or complex geometry part

Action n. 11	Develop materials and surface finishing processes for improved surface quality of AM products
Challenge	Complex lattice structures are difficult to reach for post process surface treatments. Surface finishing can improve the fatigue properties of a workpiece as cracks can start at the surface of the part.
Proposed activities	● Research into the effect of post processing operations and automation of post processing. ● Development of materials (cermet/metcer) ● Develop new cost-effective surface finishing processes for example combination of AM and subtractive manufacturing ● Reduce and control particles size of powder ● Optimisation of post-processing, e.g. on balance of cost (time, money) vs. material quality (residual stress, defect size, strength)

Action n. 12	Develop NDT and inspection criteria (for Aerospace applications) and procedures for AM
Challenge	Are the "classic" NDT methods applyed in the aerospace valid and sufficient also for AM?
Proposed activities	● Networking, coordination and research activities in the following aspects: − Defect classification − Analysis of influence on static and fatigue performance − Analysis and measurement of residual stresses − Defect detection techniques (CT, UT) − Acceptance criteria

Action n. 13	Production of larger airframe structures through AM technologies
Challenge	Increasing the size of envelopes mean increases the productivity of the "printers" including DED (directed energy deposition) processes with wire, at a reasonable cost with the same quality. Also, methods to perform quality control/NDT on large AM parts are to be furthermore investigated.
Proposed activities	● Development of new machines with larger build envelopes, high deposition rate for higher productivity, and integrated post-processing ● Assembly operations to be reduced towards the end of the production line ● Address critical issues such as reliability of the process both over a large area, and over long building times. For example detection and elimination of faults with 100% certainty, achieve consistency of properties and minimize tension over a large build area and volume. ● Secure good printing conditions like heating in the whole printing area ● High deposition rate keeping good quality

3.5. AUTOMOTIVE gaps and actions

Automotive-specific actions were identified as reported in the roadmap shown in Figure 3.7. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-3.

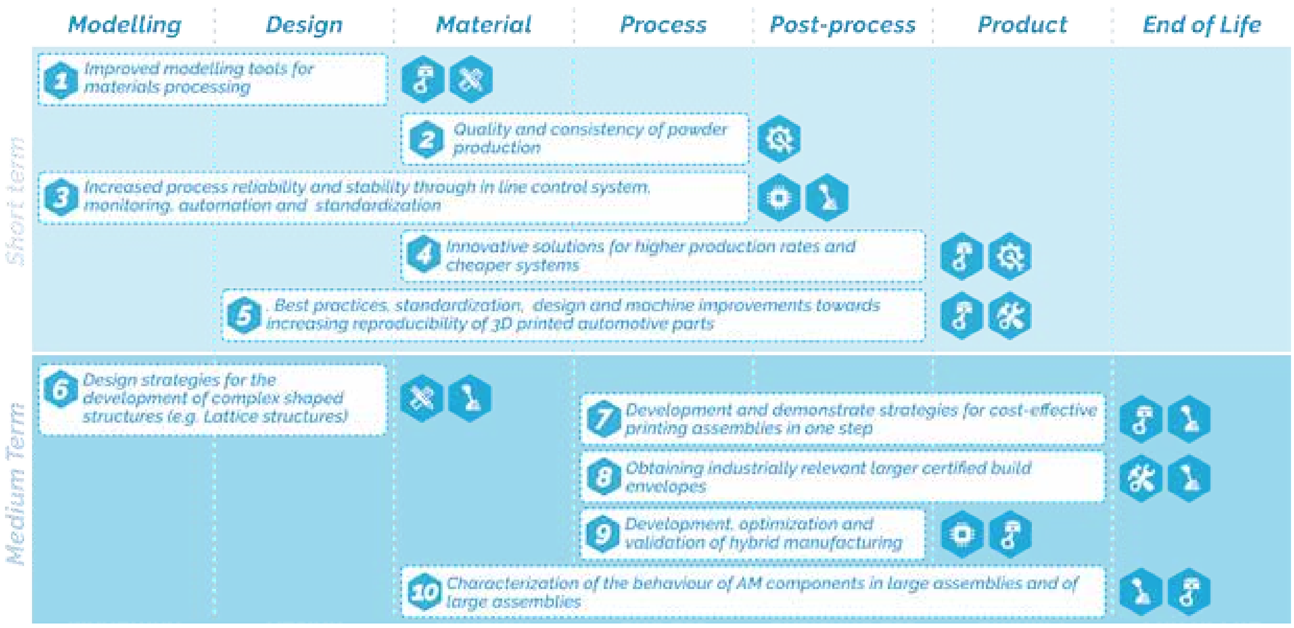


Figure 3.7: *AM-motion Automotive Roadmap*

Table 3-3: *AM-motion Automotive actions details*

N	Action Name	Type of Activity	TRL		Target Products					
			Initial TRL	Target TRL	Engine Components	Embedded Electronics	Auxiliary means of production & supports	Concept modelling, prototyping & design	Spare parts & Repair	Niche, low volume parts
1	Improved modelling tools for materials processing	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
2	Quality and consistency of powder production	IA	5-6	7	⬢	⬢	⬢	⬢	⬢	⬢
3	Increased process reliability and stability through in line control system, monitoring, automation and standardization	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
4	Innovative solutions for higher production rates and cheaper systems	IA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
5	Best practices, standardization, design and machine improvements towards increasing reproducibility of 3D printed automotive parts	IA CSA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
6	Design strategies for the development of complex shaped structures (e.g. Lattice structures)	IA	5-6	7				⬢		⬢
7	Development and demonstrate strategies for cost-effective printing assemblies in one step	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢
8	Obtaining industrially relevant larger certified build envelopes	CSA IA	5-6		⬢	⬢	⬢		⬢	⬢
9	Development, optimization and validation of hybrid manufacturing	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢
10	Characterization of the behavior of AM components in large assemblies and of large assemblies	IA	5-6	7	⬢			⬢		⬢

The following tables include key details for each action, in terms of current challenges and proposed activities.

Action n. 1	**Improved modelling tools for materials processing**
Challenge	Need for modelling and simulations prior to production to enable first time right and minimal lightweight design (structural computational modelling, thermal history, porosity modelling, multiphysics, topology optimization, AM material properties table).
Proposed activities	● Increase understanding of the microstructure-material properties relationships. Foster the academic structure in the simulation of material microstructure (coarse grained, Monte Carlo, random walk) ● Develop multiphysics, multiscale modelling, from grain size or molecule towards components ● Holistic modelling approaches using multiphysics simulation going from process parameters and simulation to product mechanical properties, via thermal mapping/history of the workpiece ● Stochastic/empirical modelling techniques utilizing a large volume of data (knowledge repository)

Action n. 2	**Quality and consistency of powder production**
Challenge	The AM industry need to define relevant properties and improve understanding and handling of powders. Material quality and - control is a key factor for a quality controlled AM manufacturing process. Implement new developments and benefit and encourage close links/cooperation with feedstock manufacturers. Connected to aerospace action n. 3
Proposed activities	● Involvement of powder and resin manufacturers in AM Platform ● Work on material quality, shape for powder and size in order to have a well-controlled material for the 3D process ● Encourage developments based on nanotechnologies and nanomaterials texturing, coatings, spheroidization, etc. ● Standard for measuring relevant properties ● Training in Powder handling ● Recycling improvement

Action n. 3	**Increased process reliability and stability through in line control system, monitoring, automation and standardization**
Challenge	Process reliability and stability are key for a successful industrial process. Improvement of control technologies are needed to enable effective in process measurement as current ones are not robust enough
Proposed activities	● Monitoring and automation of the process, including loading/unloading, support removal and post processing ● Develop in-situ multiscale analysis methods by vision systems and image processing ● In process measurements (e.g. Insert sensors in the AM machine in order to monitor the quality of parts during the process) ● Study new solutions to improve the software that control the process ● Study the effect of process parameters on built components mechanical parameters ● Standardization of all process steps ● Methods to reduce the magnitude of residual stress ● Reduce porosity and surface defects ● Design of Experiments (DOE)

Action n. 4	**Innovative solutions for higher production rates and cheaper systems**
Challenge	Economic use of AM requires lower cost per part, i.e. higher productivity or lower machine cost as well as reduced post processing material cost. One envisioned route is the hybridization, where more than one process is engaged in one machine. This development should be encouraged by market interests and competition
Proposed activities	● Process planning considerations. ● Encourage machine and equipment manufacturers from outside the AM scene to engage and develop concepts/demo projects needed for studying feasibility ● Process parameters optimization ● Machine speed improvement ● Software optimises deposition paths to minimise delays for cooling / curing and maintain stable thermal field ● Machine producers: increase the numbers of laser sources/workheads ● Development of low price materials (e.g. powder size distribution - wider to reduce cost). ● New design to have an AM design for minimal support requirements, resulting in decreased post processing. ● Arrayed AM heads on a common machine structure. ● Parallel AM

Action n. 5	**Best practices, standardization, design and machine improvements towards increasing reproducibility of 3D printed automotive parts**
Challenge	The reproducibility of parts achieved by AM should be assessed and improved. Producing parts with standard properties requires development of standard procedures.
Proposed activities	● Create standards and certifications ● Definition of parameter exchange to get a higher reproducibility of the process ● Development of best-practice in feedstock and machine handling ● Round-Robin testing of materials and process parameters ● Machine accuracy and capability improvement ● Novel design approaches for AM. ● Experimentally-validated databases containing standard sets of process parameters per process/machine/material ● Standard post-processing (especially heat treatment) temperature profiles

Action n. 6	**Design strategies for the development of complex shaped structures (e.g. Lattice structures)**
Challenge	The ability of AM to produce optimised complex shapes can only be utilised if these shapes can be designed.
Proposed activities	● Develop algorithms to automatically generate stress optimized lattice structures (preliminary design) ● Develop automated plausibility checks for structures under constraints (preliminary design). Integrate CAD packages with AM process (conceptual design) ● Integration of simulation into the design phase (both in the Preliminary and detailed designs) ● Include material properties taking into account process defects in design loop ● Extension of topology optimization tools (including dynamic loads, cyclic loads, vibrations, shock absorption, optimal weight) ● Structural Integrity & Durability assessment (detailed design)

Action n. 7	Development and demonstrate strategies for cost-effective printing assemblies in one step
Challenge	Alignment and rolling out of design methodologies, training (demonstration material) and certification of design methods is suggested
Proposed activities	● Development of new design strategies and tools, for the new material class, e.g. anisotropic properties and inhomogeneous microstructure, presence of residual stress. Select parts that are suitable for AM production. ● Benchmark costs (use expensive titanium fasteners vs. AM-driven one-piece design) ● Training of AM capabilities (including novel approaches for component fabrication). ● Team design for Multi-functional parts.

Action n. 8	Obtaining industrially relevant larger certified build envelopes
Challenge	While AM processes are maturing, "conventional" machine manufacturers might come in and help to take current machines to the next level of machine design and engineering.
Proposed activities	● Encourage machine and equipment manufacturers from outside the AM scene to engage and develop concepts. This development is already in progress. ● Collaboration with the AM industry and research community is highly recommended ● Study and design new solutions for the use of more than 1 energy source in the build envelope ● Expand to other AM tech (B.J). ● Implement R&D results in high TRL industry solutions (focusing on hybrid manufacturing)

Action n. 9	Development, optimization and validation of hybrid manufacturing
Challenge	Exploiting the capability of AM by integrating or combining AM with other processes in the manufacturing stream
Proposed activities	● Create advantage by combining small complex and functional AM parts with large volume parts with only stability as a function ● Development of combined AM/subtracting with very good control of final product geometry and properties ● Hybrid solutions should not necessarily be implemented within the same machine: develop techniques for AM integration in the industrial production system and/or Hybrid fabrication processes using multiple AM and other processes ● Processing of inlays ● Joining technologies, e.g. by welding, to join AM with AM or conventional materials to form a larger or complex geometry part. Attention should be paid to the interface of the joints and residual stress in the heat affected zones due to property mismatch and/or forced fitting ● Have a manufacturing deployment assigning to AM only some finishing add on standard optimised parts

Action n. 10	Characterization of the behavior of AM components in large assemblies and of large assemblies
Challenge	To test the whole structure, to simulate/molding to integrate AM properties
Proposed activities	● Assembly guidelines. ● Access the AM properties. ● Implementation of AM Properties in FE/CAD. ● Check current testing rules. ● Manufacturing process in components integrating AM assembling parts.

3.6. CONSUMER and ELECTRONICS gaps and actions

Consumer and electronics-specific actions were identified as reported in the roadmap shown in Figure 3.8. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-4.

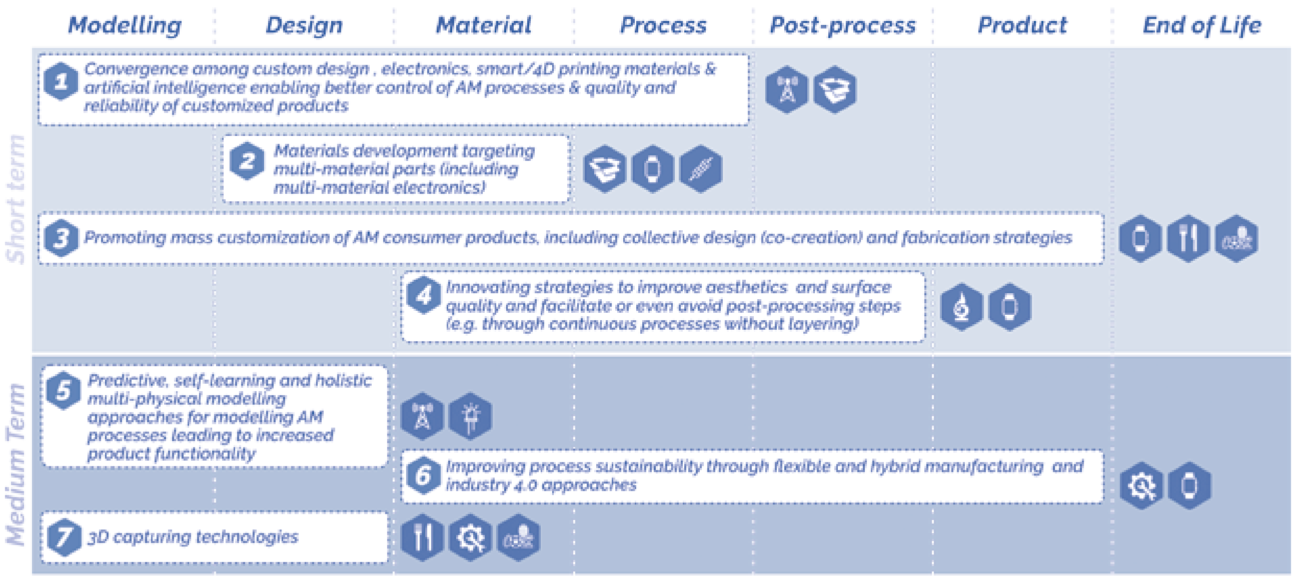


Figure 3.8: *AM-motion Consumer and Electronics Roadmap*

Table 3-4: *AM-motion Consumer and Electronics actions details*

N	Action Name	Type of Activity	TRL		Target Products								
			Initial TRL	Target TRL	Wearebles	Sensors and Antennas	Basig electronic components	Other electronic parts	Household utensils	Entertainment	Spare parts and repair	Packaging	Art
1	Convergence among custom design , electronics, smart/4D printing materials and artificial intelligence enabling better control of AM processes and quality and reliability of customized products	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
2	Materials development targeting multi-material parts (including multi-material electronics)	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
3	Promoting mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies	IA CSA	5-6	7	⬢		⬢		⬢	⬢	⬢	⬢	⬢
4	Innovating strategies to improve aesthetics and surface quality and facilitate or even avoid post-processing steps (e.g. through continuous processes without layering)	IA	6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
5	Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality	IA	5-6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
6	Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches	RIA	4-5	6	⬢	⬢			⬢	⬢	⬢	⬢	
7	3D capturing technologies	IA	5-6	7	⬢	⬢			⬢	⬢	⬢	⬢	⬢

Action n. 1	**Convergence among custom design , electronics, smart/4D printing materials and artificial intelligence enabling better control of AM processes and quality and reliability of customized products**
Challenge	The use of design possibilities of AM in customization is not optimal. Actions needed to help implement this benefit for the sector(s). Also the link with intelligent AM parts (with embedded electronics) needs to be established. In order to allow for full-scale flexible electronics a stronger linkage between materials, design and advanced electronics is necessary as one of the key enablers in this segment. In this context an important challenge is open innovation.
Proposed activities	● Use customization supported by automated software tools to bring AM into the products/parts ● Drafted pre-CAD files depending on product families allowing further enhancement of design features. (Application independent) ● Process chain modelling concepts ● Improved topology optimisation tools ● Establish linkages between electronics design and AM geometry design in one design system towards first time right production of intelligent (IoT) AM products ● Establish linkages between materials, design and advanced electronics ● Implementation of demonstration projects

Action n. 2	**Materials development targeting multi-material parts (including multi-material electronics)**
Challenge	New developments in this area should be made to enable AM of functional parts. Material properties such as optical, magnetic, conductive, fluidics, are not implemented in AM well enough today. Broader availability of multi-material parts could lead to higher demand from consumers. Environmental and economic sustainability aspects should be considered.
Proposed activities	● Development of higher performance polymer material able to produce 3D components with the same or enhanced properties as injected parts e.g. metallic, high tech ceramics ● Development of multi-materials e.g. coated coloured material or parts local properties ● AM materials that are comparable to established materials: materials like metal, ceramics and glass, where still important gaps (apart from polymers) in terms of properties exist. ● Conductive materials in AM ● Advanced materials with new material and atomistic models ● Sustainability aspects addressed through life cycle approaches, looking also at the end of life /reciclability of materials and products.

Action n. 3	**Promoting mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies**
Challenge	AM enables the involvement of the consumer in the design of their tailor made product. Tools should be developed / rolled out to unlock this capability. The perspective of the "creative industry sector" (fashion, art, sports, jewellery) has a strong focus on this aspect. It is important to develop new curricula (linked to cross-cutting actions), appropriate tools platform to simplify customisation. In order to meet clients requirements, it is important to undestand why a particular product should be customised. It is important to promote collective design and fabricatio and connect ART/design/engineering to imagine new products
Proposed activities	● Creation of an online platform able to manipulate CAD data, allowing both engineers and customers to interact with the final product geometry ● Use customization supported by automated software tools (including multi-material, conductivity, electronic functionality) to bring AM into the products/parts. Not only for design, but also directly to relevant manufacturing & logistics processes as integrated approach ● Mechanisms for modularisation of products ● Analysis of process chains, allowing "configuration" of products in a detailed manner ● The creation of good product databases ● Demonstration projects

Action n. 3	Promoting mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies
	● Customisation perspectives should include both B2C, but also B2B perspectives (focus not only on consumer side) ● Introduce AM/3D printing to design schools, develop curricula ● Integration of design software used in ART and design with engineering AM software.

Action n. 4	Innovating strategies to improve aesthetics and surface quality and facilitate or even avoid post-processing steps (e.g. through continuous processes without layering)
Challenge	AM for consumer puts high requirements for surface quality. Mostly post processing is needed to achieve acceptable level of part quality. Use of the characteristics of materials and manufacturing processes to produce functional and aesthetically pleasing objects. Aesthetics play obviously a key role regarding clients and it is an important factor for product acceptance and commercialization.
Proposed activities	● Development of parts with a specific “look and feel” ● Introduction of new process concepts related to continuous processes without layering (e.g. by learning from and further developing Carbon 3D and Printvalley machines) ● Improved topology optimization tools ● Reduction of surface roughness (also for internal structures) ● Utilizing products made by conventional technologies as inserts/basis for Additive & subtractive tailoring ● Colouring, nano-structuring to enhance surface properties wear, wettability, antifouling, dust free ● Work on material and process with material ageing behaviour ● Develop processes for post processing but also the AM process in such a way that post processing becomes more obsolete. Innovative support solutions. Role of automation and support infrastructure in this field (e.g. robotics).

Action n. 5	Predictive, self-learning and holistic multi-physical modelling approaches for modelling AM processes leading to increased product functionality
Challenge	Part final properties are directly linked to material properties and part design. Predictive modelling. Guidelines & tools for first time right minimal design (including design history and structural modelling and simulations) must be developed.
Proposed activities	● Develop models able to predict final properties and process parameters ● Predictive modelling: model material, processes leading to first time right production of products. Self-learning models with iterative corrections will yield first time right products. ● Develop holistic modelling approaches using multiphysics simulation and going from process parameters and simulation to product mechanical properties, via thermal mapping/history of the workpiece. ● Implement stochastic/empirical modelling techniques utilizing a large volume of data (knowledge repository). ● Electronics design and AM geometry design in one design software system

Action n. 6	Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches
Challenge	New developments including the manufacturing processes in this area should be made to enable AM of functional parts. Flexible and hybrid processes, incl. incorporation in existing production processes or adaptation to existing interfaces, are essential. Economic use of AM requires lower cost per part, i.e. higher productivity or lower machine cost

Action n. 6	Improving process sustainability through flexible and hybrid manufacturing and industry 4.0 approaches
Proposed activities	● Development of more flexible/combination 3D processes ● Develop hybrid process, incl. incorporation in existing production processes or adaptation to existing interfaces, with high throughput ● Equipment for integration of conductive tracks, Pick and Place of electronic components ● Process comprises: multi-material, conductive tracks, electronics, ● Intelligent/IoT AM parts drive the manufacturing cycle (which will be hybrid) themselves (4.0 approach). ● Processes for thermally conductive & fire retardant, composite, Cermets, metal, carbon AM made products Develop convergent processes towards smart devices with multi-functionalities ● Increase production speed for 3D printers, nowadays big pieces (20 cm x 20 cm x 20 cm) can take many hours (>10H). Should be nice print faster

Action n. 7	3D capturing technologies
Challenge	When personalised data is used in the AM design to provide tailored, personalised AM built products, (personal) 3D data capture (in an easy, accessible but safe way) needs to be established
Proposed activities	● Creation of algorithms/tools that will enable usage of low-cost commercially available equipment in order to capture 3D geometry e.g. SW/APP to 3Dscan / capture from mobile device and create the 3D cad model. Then further elaborate. Cheap/Easy to use for high market penetration.

3.7. INDUSTRIAL EQUIPMENT and TOOLING gaps and actions

Industrial equipment and tooling-specific actions were identified as reported in the roadmap shown in Figure 3.9. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-5.

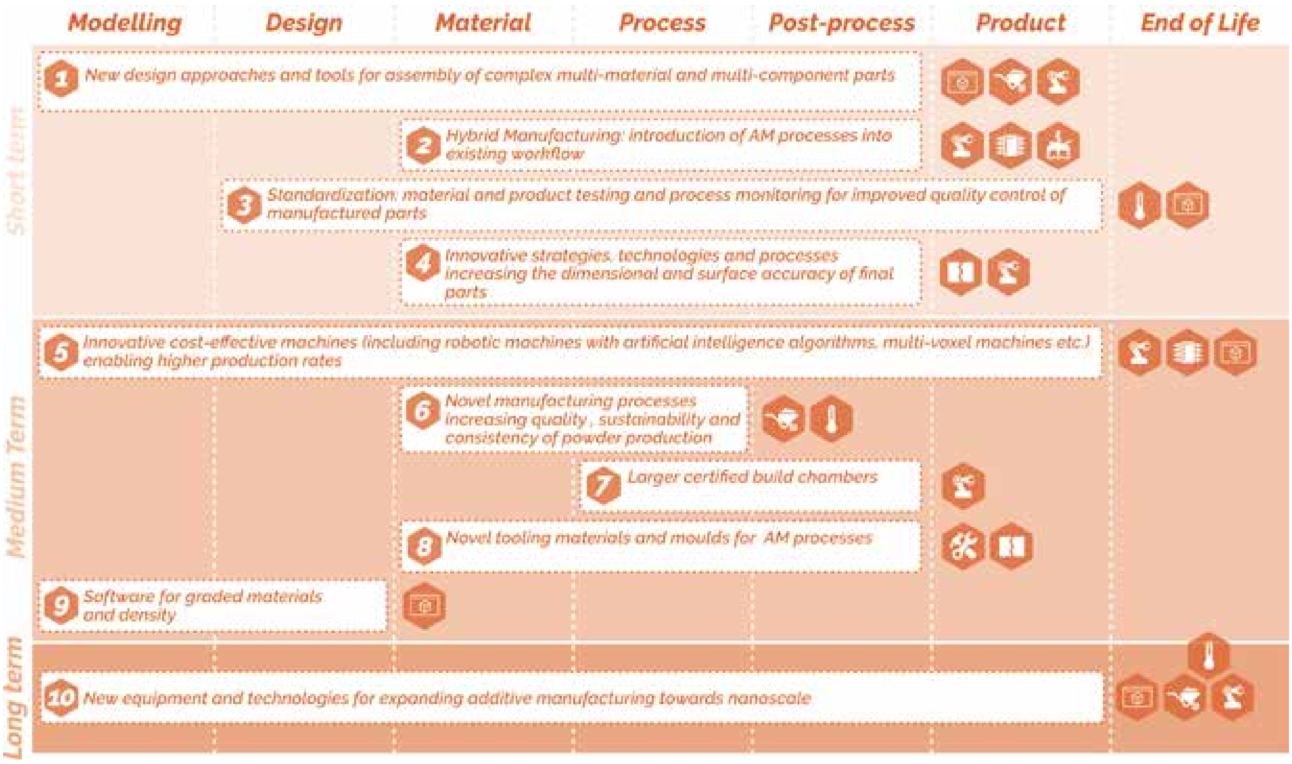


Figure 3.9: *AM-motion Industrial equipment and tooling Roadmap*

Table 3-5: *AM-motion Industrial equipment and tooling actions details*

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Target Products: Mold Inserts	Target Products: Subsea/Deep Sea Industrial Equipment	Target Products: Tooling and guides	Target Products: Scientific & Measurement Instruments	Target Products: Integrated Electronics	Target Products: Spare Parts	Target Products: Industrial AM equipments	Target Products: High Performance Tool Materials	Target Products: Industrial AM Software
1	New design approaches and tools for assembly of complex multi-material and multi-component parts	IA	5-6	7	●		●	●			●	●	●
2	Hybrid Manufacturing: introduction of AM processes into existing workflow	IA	5-6	7			●	●			●		
3	Standardisation: material and product testing and process monitoring for improved quality control of manufactured parts	IA CS	6	7				●			●	●	●
4	Innovative strategies, technologies and processes increasing the dimensional and surface accuracy of final parts	IA	5-6	7	●			●			●		
5	Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi-voxel machines etc.) enabling higher production rates	RIA	4-5	6							●		
6	Novel manufacturing processes increasing quality , sustainability and consistency of powder production	IA	6	7				●			●	●	
7	Larger certified build chambers	IA	6	7							●		
8	Novel tooling materials and moulds for AM processes	RIA	4-5	6	●		●					●	
9	Software for graded materials and density	IA	6	7								●	●
10	New equipment and technologies for expanding additive manufacturing towards nanoscale	RIA	4-5	6							●		

Action n. 1	**New design approaches and tools for assembly of complex multi-material and multi-component parts**
Challenge	Design and modelling to integrate behaviours between forged and AM parts.
Proposed activities	● Create a new design approach and tools that include every part of a sub-system and support the merging process of the components ● Quantify and create new behaviour models ● Increase the chamber dimension in order to produce larger parts, which in turn will allow several components to be merged together without an assembly step.

Action n. 2	**Hybrid Manufacturing: introduction of AM processes into existing workflow**
Challenge	Industrial implementation of AM requires inclusion with and embedding with other technologies in a hybrid setting
Proposed activities	● Development of a higher number of solutions that cover different combination of AM processes and other technologies such as subtractive ones (i.e. Laser cladding and milling processes and turning process, etc.) ● Create/use standards for alignment of systems for complete workflow. Integration of the software system (Hybrid - cutting - deposition technologies - cleaning and re-deposition). ● Understanding the effects of the mix of 'hot' and 'cold' process

Action n. 3	**Standardisation: material and product testing and process monitoring for improved quality control of manufactured parts**
Challenge	To cope with the hesitation of AM in this sector, a guideline/route for guaranteeing quality should be presented
Proposed activities	● Outline a series of standard tests (non-destructive), specific for AM able to evaluate the quality of the manufactured parts ● Material properties at the microstructure. Process monitoring with closed loop parameters adaptation

Action n. 4	**Innovative strategies, technologies and processes increasing the dimensional and surface accuracy of final parts**
Challenge	In order to develop net shaped parts, most of the time post processing is required; how to optimize this? In parallel, search for new techniques leading to higher surface properties while avoiding/reducing post-processing.
Proposed activities	● Try to understand if requests on surface finishing and dimensional tolerances are necessary ● Innovative techniques, which reduce/avoid post processing. ● Consider these limits during the design phase, in order to better understand the parts and overcome the problem. ● Develop solutions for finishing of internal channels ● Find solutions to reduce or tailor residual stress during process (consolidation objectives for thermal treatment) and process simulation ● Investigate process parameters to improve surface parameters, in particular on down-skin regions.

Action n. 5	**Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi-voxel machines etc.) enabling higher production rates**
Challenge	Economic use of AM requires lower cost per part and further development of advanced machine (eg. direct deposition machines, machines for finishing large structures, robotic machines with artificial intelligence algoritms, assisting laser or electron beam with sources with alternative cheaper technologies etc.).

Action n. 5	**Innovative cost-effective machines (including robotic machines with artificial intelligence algorithms, multi-voxel machines etc.) enabling higher production rates**
Proposed activities	● Teach users how to design the part position into the build envelope ● New machine conception: Machine producer to increase the numbers of heat sources/workheads; Multi-voxel machines; Integration of artificial intelligence and robotics ● New technology development - Patents ● EU Community to encourage investment in the second generation of AM Machines.

Action n. 6	**Novel manufacturing processes increasing quality , sustainability and consistency of powder production**
Challenge	Material quality and control is a key factor for a quality controlled AM manufacturing process. Environmental and economic sustainability aspects should be considered.
Proposed activities	● Optimization of the feedstock manufacturing process in order to narrow the properties range and increase the economic and environmental sustainability ● Ceramic filled resins development for large size parts ● Deepest monitoring of the quality control parameter during the manufacturing process. ● Powder characterisation and definition of powder properties by process machine.

Action n. 7	**Larger certified build chambers**
Challenge	AM processes building box quality and - control is a key factor for a quality controlled AM manufacturing process
Proposed activities	● Understand what could be defined as "large part" and the relative market (is it worth it to do it in AM?) ● Study and design new solutions for the use of more than 1 energy source in the build envelope ● Development of multi laser array light engine process and associated equipment ● Equipment development for large size (filled) resin based materials ● Evaluate the value to cost of an AM large part – is it cost effective to manufacture large parts using AM?

Action n. 8	**Novel tooling materials and moulds for AM processes**
Challenge	New classes of material required Specific compositions for specific AM processes (Laser - EB). Cost-effective plastic mould materials are also required for small series (e.g. In injection molding)
Proposed activities	● Define the actual bottleneck with actual materials ● Define new materials for tooling ● Treating the outer surface of plastic mould, that could have different from the inner microstructures. ● Develop a composite materials based on plastic matrix with high thermal conductivity and low thermal expansion.

Action n. 9	**Software for graded materials and density**
Challenge	It is important to develop/optimise softwares tuned for graded materials and hybrid process that can be easily integrated in open platform
Proposed activities	● Design and simulation of graded materials and hybrid processes ● Prediction of material part specification based upon powder, technology, parameters

Action n. 10	New equipment and technologies for expanding additive manufacturing towards nanoscale
Challenge	To expand the additive technology towards micro and nanoscale, processes and equipment serving that scale should be further developed.
Proposed activities	● Development of materials and associated health and safety protocols suitable for nano-scale production. ● Understand what could be defined as "small feature" and the relative market ● Development of equipment for nano-scale 3D structures ● Technologies like 2 photon polymerisation deliver micro structures, to be expanded and extended

3.8. CONSTRUCTION gaps and actions

Construction-specific actions were identified as reported in the roadmap shown in Figure 3.10. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-6.

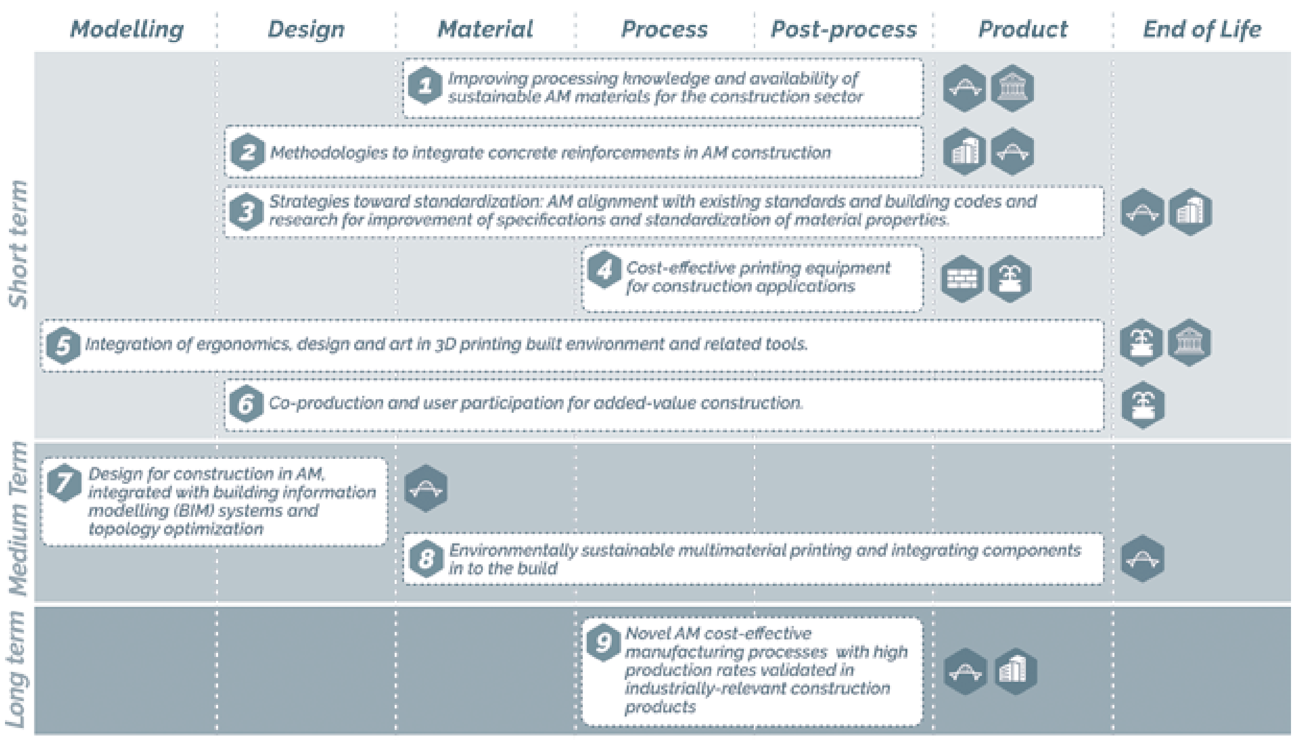


Figure 3.10: *AM-motion Construction Roadmap*

Table 3-6: *AM-motion Construction actions details*

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Target Products: Low risk parts with complex shapes e.g. for garden and landscape decoration	Target Products: Unconventional buildings (prototypes, decorative facades, art, design, heritage reconstruction)	Target Products: Special buildings (army, nuclear disaster, army buildings, lunar base)	Target Products: Structural parts like bridges, floors, walls	Target Products: Organic shaped complex (structural) parts with integrated functions
1	Improving processing knowledge and availability of sustainable AM materials for the construction sector	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢
2	Methodologies to integrate concrete reinforcements in AM construction	RIA	4-5	6		⬢	⬢	⬢	⬢
3	Strategies toward standardisation: AM alignment with existing standards and building codes and research for improvement of specifications and standardisation of material properties.	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢
4	Cost-effective printing equipment for construction applications	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢
5	Integration of ergonomics, design and art in 3D printing built environment and related tools.	IA CSA	5-6	7	⬢	⬢		⬢	⬢
6	Co-production and user participation for added-value construction.	IA CSA	5-6	7	⬢	⬢	⬢	⬢	⬢
7	Design for construction in AM, integrated with building information modelling (BIM) systems and topology optimisation	RIA	4-5	6		⬢	⬢	⬢	⬢
8	Environmentally sustainable multimaterial printing and integrating components in to the build	RIA	3-4	5-6	⬢	⬢	⬢	⬢	⬢
9	Novel AM cost-effective manufacturing processes with high production rates validated in industrially-relevant construction products	RIA	4-5	6			⬢	⬢	⬢

Action n. 1	Improving processing knowledge and availability of sustainable AM materials for the construction sector
Challenge	Knowledge on interaction between process and material to develop materials with the right properties for the process like mixing, pumping, applying by extrusion, spraying or binder jetting, drying. The possibility to use waste materials and/or industrial by-products should eb investigated. End of life aspects should be taken into account. Note: Most production processes in the construction sector are far more robust then AM processes and are far less sensitive for small changes of material properties. AM feed stock materials need to meet narrow specifications with which the industry is not familiar. Development of sustainable materials, processes and design rules are strongly related.
Proposed activities	● Study on interaction between material properties and AM process like rheology, shear rate, fast solidification, binding between layers, shrinkage, etc. Determination of characteristic materials properties (e.g. particle size distribution and consistency for optimal AM processing). ● LCA and LCCA comparative studies between conventional and AM-enabled construction processes.

Action n. 2	Methodologies to integrate concrete reinforcements in AM construction
Challenge	Concrete reinforcement to withstand tensile and bending forces is mostly not possible in combination with AM. Development of methodologies to integrate reinforcements in to the AM-materials is needed. Note: New lightweight (natural) fibre materials are available and might be a solution for an alternative braiding - integration into the construction. Out of the box concepts for hybrid solutions should be encouraged.
Proposed activities	● Investigation and assessment of reinforcement materials (e.g. steel, glass, carbon, natural fibres) and development of applying these fibres/rods into/onto the construction. Simulation of optimal fibre distribution w.r.t. tensile (and bending) properties. Hybrid technologies such as post processes like placing external and internal tensile rods should be considered.

Action n. 3	Strategies toward standardisation: AM alignment with existing standards and building codes and research for improvement of specifications and standardisation of material properties.
Challenge	From one side, existing norms and building codes will continue to exist. AM needs to adapt/improve to be able to meet their requirements. From another side,current material specifications are not accurate and discriminatory enough for AM. New standards should be prepared and drafted. Materials with accurate specs are required in order to obtain reproducible AM-processes.
Proposed activities	● Find ways to specify the materials properties that are of importance to get a reproducible AM-process and introduce them into a new version of the standard.

Action n. 4	Cost-effective printing equipment for construction applications
Challenge	Currently used concrete printing equipment is basic but functional. An improvement step in the direction of speed, control, accuracy, adaptability, size, adaptability, transportability etcetera is still to be done. There is need to learn from experience in other sector.
Proposed activities	● Assessment of currently used printers and development of improved versions which better need the requirements (speed, cost, control, accuracy, adaptability, size, adaptability, transportability, cleanability)

Action n. 5	Integration of ergonomics, design and art in 3D printing built environment and related tools.
Challenge	Involvement of stakeholder to include ergonomy, art, design and esthetic aspects in 3D printed construction.For example, art would bring invaluable dimension to 3D printed constructions. Similarly the consideration of ergonomy in tools is very big opportunity for safer tools.
Proposed activities	● Demonstrate the co-creation and multidisciplinarity process in relevant environment promoting ergonomy, art, design and aesthetic aspects.

Action n. 6	Co-production and user participation for added-value construction.
Challenge	Customer/Multi-Stakeholders participation in design of the building/structure.
Proposed activities	● Development of procedures and tools. Application of parametric design rules.

Action n. 7	Design for construction in AM, integrated with building information modelling (BIM) systems and topology optimisation
Challenge	New design rules coupled with process/materials/functionality need to be drafted. Integration with the currently used Building Information Modelling (BIM) system is required. Note: Tool functionalities include: New level of knowledge including graded structures, honeycomb structures, integration of new materials & reinforcements, sensors functions (acoustic, isolation, piping, wiring, topology optimization. New functionalities will be incorporated when they become available. BIM is a digital representation of all physical and functional properties of a builing, A BIM model is a shared knowlegde repository/source with information of the building and is used as a reliablie bassis during the whole lifecyle of the building.
Proposed activities	● Integrate design requirements, material performance and process requirements into design tools. This should be coupled to simulations on FEM to ensure topology optimization (lightweight, minimal material use, optimal reinforcement meshing).

Action n. 8	Environmentally sustainable multimaterial printing and integrating components in to the build
Challenge	Currently used concrete printing equipment is monomaterial only and a single process is applied. Reciclability aspects should be taken into account.
Proposed activities	●Development of new processes/hybrid processes to integrate components and multi material in to the build is required.

Action n. 9	Novel AM cost-effective manufacturing processes with high production rates validated in industrially-relevant construction products
Challenge	Economic use of AM requires lower cost per part, i.e. higher productivity or lower machine cost. One envisioned route is the hybridization, where more than one process is engaged in one machine. This development should be encouraged by market interests and competition
Proposed activities	● Process planning considerations. ● Encourage machine and equipment manufacturers from outside the AM scene to engage and develop concepts/demo projects needed for studying feasibility ● Process parameters optimization ● Machine speed and precision improvement ● Users: learn how to design the part positions ● Software optimises deposition paths to minimise delays ● Mixing different materials (different properties each one) having by this way different applications with the same new material obtained.

3.9. ENERGY gaps and actions

Energy-specific actions were identified as reported in the roadmap shown in Figure 3.11. Key actions details (type of activity, initial and target TRL, related target product groups) are reported in Table 3-7.

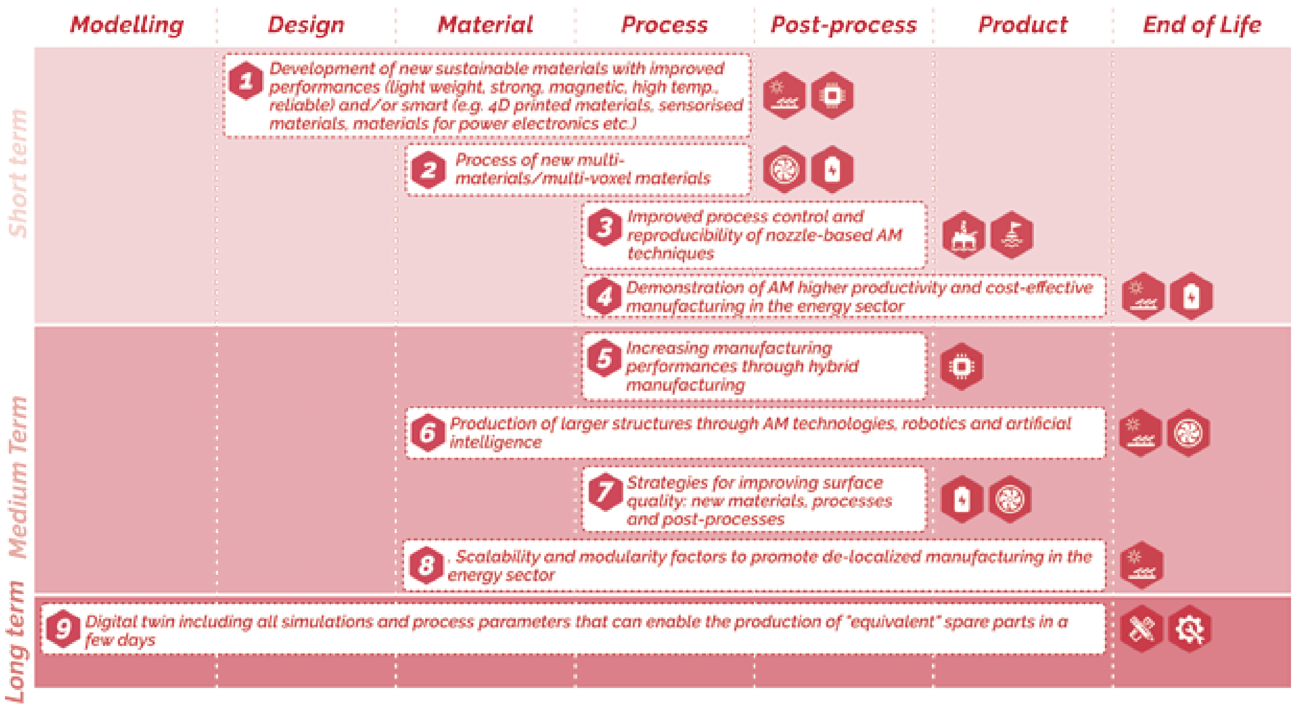


Figure 3.11: *AM-motion Energy Roadmap*

Table 3-7: *AM-motion Energy actions details*

N	Action Name	Type of Activity	TRL: Initial TRL	TRL: Target TRL	Target Products: Turbine Parts	Target Products: Oil and gas industry products	Target Products: Renewable Energy industry components	Target Products: Energy storage	Target Products: Electromechanical and 3D electronic components	Target Products: Floating Platforms components	Target Products: Concept modelling, prototyping and design	Target Products: Spare parts & repair
1	Development of new sustainable materials with improved performances (light weight, strong, magnetic, high temp., reliable) &/or smart (e.g. 4D printed materials, sensorised materials, materials for power electronics etc.)	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
2	Process of new multi-materials/multi-voxel materials	RIA	2-3	4-5	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
3	Improved process control and reproducibility of nozzle-based AM techniques	IA	4-6	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
4	Demonstration of AM higher productivity and cost-effective manufacturing in the energy sector	RIA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
5	Increasing manufacturing performances through hybrid manufacturing	IA	5	6-7	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
6	Production of larger structures through AM technologies, robotics and artificial intelligence	RIA	4-5	6	⬢	⬢	⬢	⬢		⬢	⬢	⬢
7	Strategies for improving surface quality : new materials, processes and post-processes	IA	4-5	6	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
8	Scalability and modularity factors to promote de-localised manufacturing in the energy sector	RIA	1-3	4-5		⬢	⬢	⬢		⬢		⬢
9	Digital twin including all simulations and process parameters that can enable the production of "equivalent" spare parts in a few days	IA CS	5	6-7							⬢	⬢

Action n. 1	**Development of new sustainable materials with improved performances (light weight, strong, magnetic, high temperature, reliable) and/or smart (e.g. 4D printed materials, sensorised materials, materials for power electronics etc.)**
Challenge	Material quality (e.g. powder composition morphology) and reliability of AM produced parts during their life time is essential for energy applications. Development of reliable, cost-effective, high performance materials (light weight, strong, magnetic, high temperature, reliable) and special /smart materials. The action may include advanced research on 4D printed materials. End-of life aspects and environmental sustainability should be taken into account.
Proposed activities	● Mapping/Database of alloys already explored/validated for AM processes, also to identify gaps of alloys to be explored Development of programmable materials by 4D printing, starting for example by carbon fibre, rubber, fabrics, and wood. ● Lightweight materials (e.g. titanium alloys) ● Extreme operating temperatures superalloys for turbine components ● Magnetic materials and materials for power electronics ● Improved dynamic (fatigue) materials properties: Development of new alloys with improved dynamic properties and the development of advanced composites including high mechanical resistance ceramic particles in metal matrix ● Development of materials with improved creep and oxidation resistance ● Development of new routes for powder production to enable cheaper powders ● Development of wire feedstock with chemistry tailored for AM applications ● Expanding material research towards broad industry and low or medium-value applications. High grade metals will not become viable for e.g. the renewable sector with shorten product life cycles. ● Reciclability studies, LCCA and LCA analysis of manufacturing processes and related products.

Action n. 2	**Process of new multi-materials/multi-voxel materials**
Challenge	Enabling the use of multi material /multi-voxel materials, graded material including reliable modeling tools and optimized processes
Proposed activities	● Development of new machine concepts (new printing heads) e.g. for graded material/multi-voxel properties and multi material combinations and the development of modelling tools to support this activity ● Fatigue and fracture toughness properties; effect of defects ● Development of process parameter required for multi-materials AM ● Residual stress in materials, caused by AM process and miss-match of different material properties (i.e. elastic modulus and coefficient of thermal expansion) ● New data-format to overcome STL format and be able to define voxels of the part (important for gradient structures)

Action n. 3	**Improved process control and reproducibility of nozzle-based AM techniques**
Challenge	Repeatability, reproducibility and performance of AM processes can be improved using knowledge and tools, in order to get predictable outcome of the process. Lack of availability of suitable monitoring systems for AM; Incorporation into existing machines to control quality during building process. Linked with cross-cutting gap.
Proposed activities	● Implement real thermal field mapping (from machine sensors) to determine residual stresses. ● Data regarding mechanical properties, dimensional accuracy, surface roughness etc. coupled with the respective machine characteristics and process parameters ● Develop in-situ multiscale analysis methods by vision systems and image processing ● In line control towards zero defects ● Make use of established know-how in polymer fused deposition modelling (FDM), injection moulding and Powder Injection Moulding (PIM) ● Interaction with the “design” and “modelling” VC segments, i.e. design and process iterations ● Structural integrity analysis: design against fatigue and design for damage (defect) tolerance

Action n. 4	Demonstration of AM higher productivity and cost-effective manufacturing in the energy sector
Challenge	Economic use of AM requires lower cost per part, i.e. Higher productivity or lower machine cost.
Proposed activities	● Higher throughput, by intelligent process management precision = slow, large structures = speed, design for better productivity and cost efficient use of AM technology - All these will be encouraged by the development and demonstration of market ready AM processes. ● Development of low price materials. ● Reduction of production/printing time.

Action n. 5	Increasing manufacturing performances through hybrid manufacturing
Challenge	Exploiting the capability of AM by integrating or combining AM with other processes in the manufacturing stream
Proposed activities	● Development of a higher number of solutions that cover different combination of AM processes and other technologies such as subtractive ones (i.e. Laser cladding and milling processes and turning process, etc.) ● Reliable interfaces for optical measuring-systems for automatic change from a technology to the other.

Action n. 6	Production of larger structures through AM technologies, robotics and artificial intelligence
Challenge	Increasing the size envelopes and the productivity of the printers at a reasonable cost is needed.
Proposed activities	● Development of new machines with larger build envelopes, higher productivity, and integrated post-processing ● Assembly operations to be reduced towards the end of the production line ● Address critical issues such as reliability of the process both over a large area, and over long building times, integrating robotics, in-line control system and artificial intelligence. For example detection and elimination of faults with 100% certainty, achieve consistency of properties and minimize tension over a large build area and volume.

Action n. 7	Strategies for improving surface quality : new materials, processes and post-processes
Challenge	Surface finishing can improve the accuracy and also fatigue properties of a workpiece as cracks can start at the surface of the part. New materials, processes (e.g. Avoiding the need for post-processes), more effective post processes.
Proposed activities	● Research into the effect of post processing operations and automation of post processing. ● Development of new materials and processes avoiding the need for post-processing ● Develop new cost-effective surface finishing processes for example combination of AM and subtractive manufacturing ● Reduce and control particles size of powder ● Optimisation of post-processing, e.g. on balance of cost (time, money) vs. material quality (residual stress, defect size, strength)

Action n. 8	Scalability and modularity factors to promote de-localised manufacturing in the energy sector
Challenge	Equipment and machinery for accelerated and large scale AM production should be developed with scalability and modular behaviour in mind. For future energy needs, de-localised manufacturing will become the standard in order to lower costs and accelerate projects.
Proposed activities	● Research should highlight the scalable/modular expansion constraints and opportunities for certain AM processes, based on broad parameters (material types, deposition methods, part characteristics, electric control, software limits, simulation limits, build strategies, physical constraints, environmental boundaries, sustainability and energy needs, etc.) ● System and machine development has to meet cost and size goals by looking beyond immediate system delivery - and build strategy for further development and relevance to large, medium-value products. ● For practical development; determine system interfaces that are influenced or will influence scalability/modularity. Define steps to overcome or initiate new research.

Action n. 9	Digital twin including all simulations and process parameters that can enable the production of "equivalent" spare parts in a few days
Challenge	Today digital representation of the part produced has conflicting representations: the CAD-model, the STL file and possibly a point of cloud of scanned coordinates. All these has to be taken care of in long term storage structures (LOTAR-type). Today no such storage system using standards apparently existy
Proposed activities	● Coordination between ISO 10303, ASTM, etc.. Looking at the object in a lifecycle perspective allowing info and all aspects related to the object creation process are available for the future to understand and improve or reproduce the part. ● Development of digital twin technologies for rapid and cost-effective spare part manufacturing

4. DISCUSSION AND CONCLUSION

The current report describes a summary of AM-motion roadmap aimed at identifying future actions for the AM development and successful market uptake. The full roadmap was publicly presented at "AMEF2018 Additive Manufacturing European Forum" (Brussels, 23-24 October). The final version of the document has been broadly disseminated through European and international channels (ETPs, associations, partners' networks etc.) and is available at www.am-motion.eu. The roadmap focuses on high impact sectors and related target product groups, includes a vision for 2030 and based on identified challenges and opportunities, proposes a set of sectorial and cross-cutting actions for short, medium and long term. The complete roadmap includes also a mapping of regional capabilities by sectors, considering AM-related national and regional projects.

The roadmap was developed involving around 100 external experts through physical meetings and remote surveys. The Roadmap was also validated through a public online survey (July- September 2018), collecting positive feedback from European experts and stakeholders.

The performed impact assessment enabled the Consortium to group the high impact actions, thus identifying **a short list of AM-motion priorities to be implemented in short and medium term through Horizon Europe**. The Consortium focused mainly on Horizon Europe Pillar 2 "Global Challenges and Industrial Competitiveness, which is structured in five "Clusters": Health; Inclusive and Secure Society; Digital and Industry; Climate, Energy and Mobility; Food and natural resources[14]. Nonetheless, some priorities are relevant also for the other two pillars (i.e. Pillar 1 - Open Science or Pillar 3 - Open Innovation).

The tables below summarise AM-motion top priorities, grouped in technical and non-technical ones. For each priority, relevance for Horizon Europe Pillars and Clusters is provisionally considered. Target sectors were also specified.

[14] Jan Ramboer. "Commission Proposal for Horizon Europe - THE NEXT EU RESEARCH & INNOVATION PROGRAMME (2021 – 2027)", presented at AMEF18, 26 November 2018. Horizon Europe proposed by the EC (version - November 2018) is structured in three Pillars: Pillar 1 (Open Science), Pillar 2 (Global Challenges and Industrial Competitiveness) and Pillar 3 (Open Innovation).

Table 4-1: *AM-motion top technical priorities*

Term	Priority Description	Relevance for Horizon Europe	Target Sectors
Short Term (2021-2022)	1. Availability of advanced materials with better quality, reliability, social and environmental sustainability and economic affordability. Advanced material characterisation and testing and availability of material databases.	• Digital & Industry	
Short Term (2021-2022)	2. Development and validation of holistic modelling approaches and digital twins covering the whole production chain from AM design and material selection through optimisation of manufacturing processes up to simulation-aided product qualification.	• Digital & Industry • Open Innovation	
Short Term (2021-2022)	3. Demonstration of novel AM processes (including hybrid manufacturing and strategies for reducing post-processing steps) focusing on cost-effective performances, in-line quality control and industry 4.0 approaches.	• Digital & Industry • Open Innovation	
Short Term (2021-2022)	4. Promotion of industry engagement in standardization processes. Development of procedures and methods for qualification and promoting certification of AM products.	• Digital & Industry • Open Innovation	
Short Term (2021-2022)	5. Validation of mechanical and biocompatibility properties of 3D printed biomedical devices (medical implants, assistive and prosthetic devices, surgical guides).	• Digital & Industry • Health	
Short Term (2021-2022)	6. Pilots on AM processes in the field of multi-functional materials, multi-materials and graded materials for energy, mobility and electronic applications	• D&I • Climate, Energy& Mobility • Open Innovation	
Short Term (2021-2022)	7. Methodologies to integrate concrete reinforcements in AM construction	• Digital & Industry • Climate, Energy & Mobility	
Short Term (2021-2022)	8. Promoting mass customization of AM consumer products, including collective design (co-creation) and fabrication strategies	• Digital & Industry • Inclusive & Secure Society	
Medium-Long Term (2023-2027)	9. Research and demonstration of 4D Printing technologies fuelled by smart materials and multi-material/digital printing.	• Digital & Industry • Open Science	
Medium-Long Term (2023-2027)	10. Convergence among AM and Artificial Intelligence, Robotics and Sensing Technologies for the energy and transportation sector, targeting large areas and/or complex shaped components.	• Digital & Industry • Climate, Energy & Mobility	
Medium-Long Term (2023-2027)	11. Vascularization and innervation of tissues through biofabrication / bioprinting. Development of relevant 3D tissue models for regenerative medicine and/or drug testing.	• Digital & Industry • Health	

1 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (actions n. 8, 9 and 11); Health (n. 2 and 3); Aerospace (n.3 and 4), Automotive (n.2), Consumer and Electronics (n.2), Industrial Equipment and toolings (n. 6), Construction (n. 1) and Energy (n. 1).

2 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (actions n. 1, 3, 5 and 7); Health (n. 1); Aerospace (n. 1 and 5), Automotive (n.1), Consumer and Electronics (n.3), Industrial Equipment and toolings (n.1) and Construction (n.5).

3 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (actions n.4, 6 and 12), Aerospace (n. 5 and 6), Automotive (n.3 and 4), Consumer and Electronics (n.1 and 3), Industrial Equipment and toolings (n. 2, 4 and 5), Construction (n. 4) and Energy (n. 3 and 4).

4 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (actions n.3, 7 and 10); Health (n.3) Automotive (n.5), Industrial Equipment and toolings (n. 3), Construction (n. 3).

5 - The priority was mainly derived from actions n. 2 and 3 of the Health Roadmap.

6 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (action n. 2), Aerospace (n. 4 and 5), Consumer and Electronics (n.2) and Energy (n. 2).

7 - The priority was mainly derived from action n. 2 of the Construction Roadmap.

8 - The priority was mainly derived from action n. 3 of the Consumer and Electronics Roadmap.

9 - The priority was mainly derived from action n. 14 of the Technical Cross-Cutting Roadmap.

10 - Group of AM-MOTION actions related to the following roadmaps: Technical Cross-cutting (action n.15), Aerospace (n. 8, 9 and 13), Automotive (n.6, 8 and 10) and Energy (n. 6).

11 - The priority was mainly derived from actions n. 4, 5, 9 and 11 of the Health Roadmap.

Relevance Legend:

- **Pillar 1** Open Science
- **Pillar 2** Global Challenges and Industrial Competitiveness
- **Pillar 3** Open Innovation

Table 4-2: *AM-motion top non-technical priorities*

	Priority Description	Relevance for Horizon Europe	Target Sectors
Short Term (2021-2022)	1. Improving SME access to AM technologies and market through cross-regional cooperation, innovative business models and promotion of effective innovation management approaches	• Digital & Industry • Open Innovation	
	2. Promoting safety in AM: safety assessment, safety management and guidelines and education on EHS challenges.	• Digital & Industry	
	3. Development of educational and training modules both through linking with higher education curricula (engineering, business schools, etc.) and on-the-job training approaches.	• Digital & Industry • Open Science	
Med. Term (2023-2027)	4. Developing and promoting effective intellectual properties strategies in AM and better awareness of IP issues. Promoting the creation of a suitable IP framework.	• Digital & Industry • Open Innovation	

1 - The priority was mainly derived from action n. 3 of the Cross-cutting Non-Technical Roadmap.
2 - The priority was mainly derived from action n. 4 of the Cross-cutting Non-Technical Roadmap.
3 - The priority was mainly derived from action n. 2 of the Cross-cutting Non-Technical Roadmap.
4 - The priority was mainly derived from actions n. 7 and 8 of the Non-technical Cross-Cutting Roadmap.

Relevance Legend:
Pillar 1 – Open Science
Pillar 2 – Global Challenges and Industrial Competitiveness
Pillar 3 – Open Innovation

Future plans for implementation of AM-motion actions and further development of the Roadmap, including the expansion towards other sectors (e.g. railway, maritime), are going to be performed mainly by the European Technology Platform on Additive manufacturing "AM-Platform" in alignment and strong cooperation with other key European initiatives, such as CECIMO, EPMA and the standardisation bodies.

On the regional side, cooperation with the Vanguard Initiative, ERRIN and key regional/national cluster/networks will continue for the identification of a short list of AM-motion actions to be carried out also at regional and national level, in alignment and complementarity with EU priorities.

ANNEX 1: TARGET PRODUCTS

Here below are reported the target products for each sector.

HEALTH

Sector	Target products
Medical Implants	• Dental implants (Stems, Crowns, Bridges) • 4D Biocompatible Implants • Biodegradable Implants • Other endo-prostheses: Orthopaedic & Cardiovascular Implants
Living Tissues & Organs	• Bioprinted constructs for tissue engineering • Bioprinted organs for transplantation • 3D printed scaffolds for tissue engineering • Bioprinted cartilages • Bioprinted organs for transplantation* * High challenging and long term target; under scientific discussion
Assistive & Prosthetic Devices	• Flexible supports (instead of rigid casts), i.e. orthoses, splints, orthopaedic braces, thoraco-lumbar corsets etc. • Prosthetic limb • Advanced hearing aids • Esoskeletons • Bespoke assistive devices for elderly & disability (crutches, wheelchairs etc.)
Surgical Guides, Tools & Models	• Customised surgicals guides and tools (e.g. guides for drilling and for seaming) • Case-specific surgical models (focus on soft tissues) • Models for communication with patients and surgical planning
Other Customized Products	• Special soles, insoles and other shoe parts for sports and orthopaedics
Other Dental Products	• Crowns • Bridges • Braces • Dental aligners • Dentures • Osteotomies • Tweezers
Pharmaceutical Products	• Drugs • Drug Delivery Systems with Smart Biocompatible Materials
Food	• 3D Cooked food • Consumable "food inks" • In-house 3D Printers • Personalised Diet

AEROSPACE

Turbine Parts, Engine	• Turbine Blades, Guide Vanes • Nozzles • Stator Rings • Impellers • Non structural parts
Small Aircraft Wings, Fuselage & Their Components	• Design of Entire Wings
Cabin & Cockpit parts	• Interior parts • Airco • Covers • Seats • Door handles • Hinges
Other complex parts	• Bionic design parts • Integration of parts
Components of Large Aircraft Wings and Fuselage	• Air Foils, Brackets • Landing gear parts
Spare parts & repair	• Carbon Fibre Printing For Spare And Repair • Repair of engine components
Concept Modelling, Prototyping & Advanced Moulds	• Carbon Fibre Mouldings • Components with vibration dampening geometries
Niche, Low Volume Parts	• Circuits For Flight Test Installation • Customised Cabin Applications (Seats Etc.)
Embedded Electronics	• Structural health monitoring • Circuits for power supply • Embedded sensors (both in the structure and within engines)

AUTOMOTIVE

Engine Components
- Chassis Components
- Moulding dies repair
- Gear box parts
- Rotating/ reciprocating parts (small complex)
- Conrod
- CAM Shafts
- Batteries for E-cars

Auxiliary Means of Production & Supports
- Manufacturing Tools
- Tools For Testing And Assembly
- Jigs And Fittings
- Tooling for precise positioning during assembly

Embedded Electronics
- Sensors

Concept Modelling, Prototyping & Design
- Carbon Fibre Mouldings
- Customised lights - Concepts Lenses and Glassprinting

Niche, Low Volume Parts
- Exclusive And Sports Car Parts
- Low Volume Interior Parts
- Customized Parts

Spare Parts & Repair
- New parts to upgrade
- Assembly of new sensors
- New liquid parts/ airducts (plasma)

CONSUMER GOODS & ELECTRONICS

Wearables	• Glasses / Eyewear • (Fashion) Clothing • Sports Products	• Shoes • Jewellery • Accessories	• Protective masks (sport/professional)
Household Utensils	• Light Fixtures • Vases	• Furniture • Cutlery	
Entertainment	• Toys	• Musical instruments	• Consoles accessories
Sensors & Antennas	• Sensors integrated in 3D printed parts • Exo selections		
Basic Electronic Components	• Resistors • Capacitors	• Inductors • Diodes	• Circuits
Spare Parts & Repair	• Plastic covers • Repair parts • Objects/parts no longer fabricated	• Conformal cooling inserts • Multimaterial inserts (e.g. Fe-Cu) • Aluminium inserts for small batches	
Other Electronics	• Cooling of Electronic and LED lamps	• Audio components	
Packaging	• Smart packaging for consumer goods/electronic parts,	• On-demand and customised packaging	
Art	• Complex Sculptures		

INDUSTRIAL EQUIPMENT & TOOLING

Mould Inserts	• Hot Summers • Large Moulds (>Ø250mm) Copper/Steel Parts • Re-Configured Moulds • Insert with Enhanced Materials • Conformal Cooling Inserts • Multimaterial Inserts (e.g. Fe-Cu) • Aluminium Inserts For Small Batches
Subsea/Deep Sea Industrial Equipment	• Motor & generator parts • High pressured pumps • Drilling, cutting, moving, transporting equipment • Welding robots
Scientific & Measurement Instruments	• Gauges, • Fixing devices for temp. measurement, chemical analysis etc. with special features, eg. cooling. • Microscopes accessories • Thermometers
Tooling & Guides	• Assembly Jigs • Drills And Cutting Guides • Other Templates • Indexable Inserts (Cutting Tools) • Pressing Dies & Punches • Fixtures
Integrated Electronics	• Sensors integrated in 3D printed parts
Industrial AM equipments	• Hybrid AM machines • Grippers • Mixers (mixing chemicals) • High deposition rate systems for 2x2x2meter components.
Industrial AM Softwares	• Solutions to enable sintering processes also for prototyping • Topology optimisation with capability to create shell structures/sandwich structures • Solutions for designing customised parts; for hybrid manufacturing, graded materials; designed engineering metals (ultra high cooling rates...) • 3D Printing of smart materials
Spare Parts & Repair	• Parts to replace broken parts in existing industrial equipment. Audio components
High Performance Tool Materials	• AM Hard Materials for Tooling (powders & granules): Hard metals/cemented carbides; tool steels/metal matrix composites; engineering ceramics; enabling technologies • Materials specialised in high wear

CONSTRUCTION

Unconventional buildings (prototypes, decorative façades, art, design, heritage reconstruction)

- Mock ups and 1:1 proto types
- Sewage water treatment component
- Ergonomics and customizations in unconventional buildings
- Restauration, local substitute elements combine with scanning
- Restauration historical building details
- Integrated facades / insulation

Structural parts like bridges, floors, walls

- Precise precast with no moulds
- Nodes (steel) for steel frame works build on site (potential)
- Bespoke plastic fittings
- Reinforced "concrete" structures (potentially build on site)
- Structural component for freeform building
- Reinforced / locally reinforced structures
- Complex joints (hinges)
- Combined load bearing, piping, acoustics, insulation, aesthetics and other function integration

Low risk parts with complex shapes e.g. for garden and landscape decoration

- Low risk parts for e.g. garden decoration, landscape, art
- Special elements to close gaps

Special buildings (army, nuclear disaster, army buildings, lunar base)

- Temporary emergency building (after disaster)
- Quick solutions in case of emergencies (cracks / broken pipes / etc)
- Customized components optimised for temporary needs

Organic shaped complex (structural) parts with integrated functions

- Light weighting topological optimised organically esthetical shaped structural free form elements
- Topologically optimized structures
- Indoor partitions (walls, flexible rooms, indoor enclosures, etc.) with integrated functionalities for temporary functions
- Panels with integrated functions (thermal insulation, acoustic insulation, lighting, daylight, etc.)
- Kinematic structures out of flexible and stiff materials
- Special solar elements

ENERGY

Turbines parts	• Static Vanes • Turbine Blades (rotating) • Nozzles • Burners • Swirls
Oil and gas industry products	• Chemical Injection Stick Tools • Nozzles for Downhole Cleanout Tools • Valves • Connectors • Filters • Interface parts (T-connections) • Push button • Heat Exchangers • Propellers, Impellers and pumps components • Flow control parts (including Subsea Xmas tree, valves) • Subsea processing equipment
Renewable Energy industry components	• Solar Cells (including films and flexible PV) • Solar thermal Plant towers (including Mirrors Frames) • Windmill towers • Wind Turbine Blades
Energy storage	• Batteries (including microbatteries) • Fuel cells • Geothermal piping
Electromechanical & 3D electronic components	• Sensor system for temp; • Visual analysing; • Smart Control Devices
Floating Platforms Components	• Anchors • Connections • Mooring • Floats
Concept modelling, prototyping and design	• Heat exchanger injection function integration
Spare Parts & Repair	• Repair of complex or obsolete parts • Burner repair • Swirler repair • Turbine blades, vanes • Processing equipment • Fin seals

ANNEX 2: LIST OF ENABLERS

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&S=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								
Aalto University Digital Design laboratory	R&D, design, end user	www.aalto.fi	FINLAND/ Helsinki-Uusimaa-Etelä-Suomi	ALL	ALL	ALL	ALL	STD; L, EDU; IE; IPRS, TT
ACAM	R&D; Materials; Design	http://acam.rwth-campus.com/	GERMANY/ Aachen	ALL	ALL	-	Metal, polymer	STD, L, EDU, IE, IPR, TT
AIDIMME	R&D, design	www.aidimme.es	SPAIN/ Comunidad Valenciana	ALL	ALL	PBF, VP, MJ, ME	Metal, Polymer, O: wood, natural materials	STD; EDU; IE; IPRS, TT
AIJU	R&D, Service Bureau	www.aiju.info	SPAIN/ Comunidad Valenciana	CG	M, Pr	PBF, MJ, ME	Polymer	STD; EDU; TT
AIMEN	R&D, Service Bureau	www.aimen.es	SPAIN/ Galicia	AE, AU, E, I&T, C	M&S, D, P	ME, DED	Metal,	STD; EDU; IE; IPRS, TT
AIMPLAS	R&D; service Bureau; design	www.aimplas.net	SPAIN/ Comunidad Valenciana	ALL	M; P; PP; Pr, EL	ME	Polymer, food, bio-materials	STD; L; EDU; TT
AITIIP	R&D; service Bureau; Materials provider; design	www.aitiip.com	SPAIN/ Aragon	ALL	ALL	PBF; VP; ME;	Metal, Polymer, Ceramic y Bio-materials	STD; EDU; IE; IPRS; TT
AMSyst-HTSC-TU/e	R&D	https://www.tue.nl/en/	NETHERLANDS/ Noord-Brabant	ALL	ALL	ALL	ALL	EDU, IE, TT
ANDALTEC	R&D, design, Prototyping	www.andaltec.org/en/	SPAIN/ Andalucía	AE, AU,CG, E, Food Packaging	M&S, D, M, Pr, EL	VP, MJ, ME, BJ	Polymer, Bio-Materials	EDU, TT
BMC	R&D, OEM, Materials provider	www.brightlands-materialscenter.com	NETHERLANDS/ Limburg	ALL	ALL	PBF, VP, MJ, ME	Polymer, Bio-materials	TT
Brunel	R&D, design	www.brunel.ac.uk	UNITED KINGDOM/ Outer London - West and North West	ALL	M&S, D, M, P, PP, Pr	PBF; VP; ME;	Metal, Polymer, Composites	STD; EDU; IE; IPRS; TT
CAMPT-FPC	R&D, service bureau, design	www.camt.pl/index.php/en/home-en/	POLAND/ DOLNOSLASKIE-	H, AE, AU, CG, EN, I&T	ALL	PBF, VP, MJ, ME, DED, BJ	Metal, polymer, ceramic, bio-materials	EDU, IE, TT

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
CEA	R&D	www-liten.cea.fr	FRANCE / Rhône-Alpes	ALL	M, P, EL	PBF, VP, MJ, DED	Metal, polymer, ceramic	TT
CEIT-IK4	R&D, Materials provider; design	www.ceit.es	SPAIN/ Basque Country	ALL	M&S; D;M; P; PP	PBF, MJ	Metal, polymer, ceramic	EDU; 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
CENTIMFE	R&D; service Bureau; ; design	www.centimfe.com	PORTUGAL/ Centro	ALL, packaging	M&S, D, M, P, PP, Pr	PBF, VP, MJ, ME, DED	Metal, Polymer	EDU, IE, IPRS, 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
CIDETEC	R&D, Service Bureau	www.cidetc.es	SPAIN/ País Vasco	H, AE, AU, EN	PP	-	Metal, Bio-materials	EDU, IE, IPRs, TT
CNES	R&D end user	cnes.fr	FRANCE/ Midi-Pyrénées	AE	ALL	ALL	Metal, Polymer, ceramic,	STD, 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
CU	R&D	www.cranfield.ac.uk/	UNITED KINGDOM/ Bedfordshire and Hertfordshire	AE, AU, E, EN, E&T, C	M&S, M, P, Pr	PBF, DED	Metal	STD, EDU, IE, TT
DEMI, FCT NOVA	R&D	https://www.fct.unl.pt/	PORTUGAL/ Área Metropolitana de Lisboa	H, AE, AU, EN, E&T, Non Destructive Testing (NDT)	M&S, D, M, P, PP, Pr	MJ, ME, DED	Metal, Polymer	EDU, TT
DMRC	R&D, Design	www.dmrc.de	GERMANY/Detmold	ALL	ALL	PBF, MJ, ME, Arburg Plastic Freeforming	Metal, polymer	STD, EDU, IE, TT
DTI	R&D, Service Bureau, OEM, design, end user	www.dti.dk	DENMARK/ Hovedstaden	ALL	ALL	PBF, VP, MJ, ME, BJ	Metal, polymer, food, bio-materials	STD, L; EDU, IE, TT
ECN	R&D	www.ecn.nl/expertise/engineer-ing-materials/	NETHERLANDS/ Noord-Brabant	ALL	M, P, PP, Pr	PBF, VP, DED	Metal, ceramic, catalysts	IE, TT
ENGIN	R&D, Design, end user, Education	http://www.cardiff.ac.uk/engineering	UNITED KINGDOM/ East Wales	H, AE, AU, CG, EN, E&T	ALL	PBF, VP, ME	Metal, Polymer	EDU, 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
Flanders Make	R&D	www.flandersmake.be	BELGIUM/ Vlaams-Brabant	AE, AU, CG,	P, PP	PBF, DEP	Metal, Polymer	TT
Fontys CoE HTSM	R&D, Design	https://fontys.edu/	NETHERLANDS/ Noord-Brabant	ALL	M&S, D, M, P, PP, Pr	PBF, VP, MJ, ME	Metal, Polymer	EDU, IE, TT
Fraunhofer IFAM Bremen	R&D, Materials provider, Design	www.ifam.fraunhofer.de/en/Profile/Locations/Bremen	GERMANY/ Bremen	H, AE, E, EN; E&T, C	M&S, D, M, P, PP	PBF, VP, ME; BJ	Metal, Polymer, Ceramic	STD; EDU, IE, IPRs, TT
Fraunhofer IFAM Dresden	R&D, Materials provider, Design	www.ifam.fraunhofer.de/en/Profile/Locations/Dresden.html	GERMANY/ Dresden	H, AE, AU, E, EN, E&T, C	M&S, D, M, P, PP	PBF, ME, BJ, 3D screen printing	Metal, Ceramic	STD, EDU, IE, IPRs, TT

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
Fraunhofer ILT Aachen	R&D, Materials provider, Design	https://www.ilt.fraunhofer.de/en.html	GERMANY/ Aachen	H, AE, AU, EN, E&T, C	M&S, D, M, P, PP, Pr	PBF, SL; DED; O	Metal, Ceramic	STD, EDU, IE, IPRs, TT
Fraunhofer iGCV Augsburg	R&D, Materials provider, Design	https://www.igcv.fraunhofer.de/en.html	GERMANY/ Augsburg	H, AE, AU, EN, E&T, C	M&S, D, M, P, PP, Pr	PBF, SL; MJ; O	Metal, Ceramic	STD, EDU, IE, IPRs, TT
Frederick University	R&D	www.frederick.ac.cy	CYPRUS/ Kýpros	H, AU, E&T, C	M&S, D	BJ	Metal, Polymer, bio-materials	STD, EDU, TT
Friuli Innovazione	R&D, Service Bureau	www.friulinnovazione.it	ITALY/ Friuli-Venezia Giulia	ALL	ALL	-	-	STD, L, EDU, IE, IPRs, TT
I-Form	R&D	www.i-form.ie	IRELAND/ SOUTHERN AND EASTERN	H, AE, AU, CG, E, I&T	ALL	PBF, VP, MJ, ME, SL, BJ	Metal, Polymer, Ceramic	EDU; IE; TT
IK4-LORTEK	R&D, Design	www.lortek.es	SPAIN/ Pais Vasco	AE, AU, CG, E&T	M&S, D, M, P, PP, Pr	PBF, DED	Metal	EDU, TT
IK4-TEKNIKER	R&D	www.tekniker.es	SPAIN/ País 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, bio-materials	EDU, TT
IMR	R&D, Design	www.imr.ie	IRELAND/ Southern and Eastern	ALL	ALL	ALL	ALL	STD, L, EDU, IE, TT
INEGI	R&D, Design	http://www.inegi.pt/inicial.asp?k=z&L-N=EN	PORTUGAL/Norte	H, AE, AU, E&T	ALL	VP, MJ, ME, DED, BJ, Composite materials AM	Metal, Polymer, Ceramic, Composite materials	TT
INSPIRE AG	R&D, Design	-	SWITZERLAND	ALL	M&D, D, M, P, PP, Pr	PBF, DED	Metal, polymer, ceramic	STD, EDU, IE, TT,
IOR	R&D, Software Provider, Design, End User	www.ior.it	ITALY/ EmiliaRo-magna	H, Biomedical research	M&S, D, M, P, PP, Pr	PBF, VP, ME	Metal, polymer, bio-materials	STD, EDU, TT, Ortho-paedic treatments and their validation
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
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
ISQ	R&D	www.isq-group.com	PORTUGAL/Area Metropolitana de Lisboa	ALL	M, P, EL	DED	Metal	STD, EDU, TT
ITC	R&D, Service Bureau, End user	http://www.itc.uji.es	Spain/Comunidad Valenciana	CG, EN, C, Ceramic	ALL	ME, BJ	Ceramic	STD, 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
LEITAT	R&D, Design	www.leitat.org	SPAIN/Catalonia	H, AE, AU, CG, EN	ALL	PBF	Metal, Polymer, bio-materials	IE, IPRs, TT
LMS	R&D, Design, Modelling and simulation, experimentation	http://lms.mech.upatras.gr/	GREECE/ Δυτικη Ελλαδα	AE, AU,CG	ALL	PBF, VP, ME, SL, DED	Metal, polymer	STD, EDU, TT

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
LBORO	R&D, Design	www.lboro.ac.uk/	UNITED KINGDOM /Leicestershire, Rutland and North-amptonshire	C	D, M, P, PP, Pr	ME	Concrete	STD, EDU, IE, IPRs, 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
NLR	R&D, Design	www.nlr.nl	NETHERLANDS/ Flevoland	ALL	M&S, D, M, P, PP, Pr	PBF	Metal	EDU, TT
POLIMI-Departmenrt of Mechanical Engineering	R&D	www.polimi.it	ITALY/ Lombardia	ALL	ALL	PBF, ME, SL, DED	Metal, polymer, ceramic, bio-materials	STD, EDU, IE, IPRs, TT
PRODINTEC	R&D, Services Bureau, Design	www.prodintec.com	SPAIN/ Asturias	ALL	M&S, D, P, PP, Pr	PBF, VP, MJ, ME, SL; BJ O: direct light processing	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
PSI	R&D, End User	www.psi.ch	SWITZERLAND/ Aargau	H, AE, AU, E, EN, C	M&S, M, PP, Pr	PBF	Metal, Polymer, Ceramic, Bio-materials	-
SIRRIS	R&D, Services Bureau	www.sirris.be	BELGIUM/ Prov. Liège	ALL	D, M, P, PP, Pr	ALL	Metal, Polymer, Ceramic	STD, L, IPRs, 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	Metal, polymer, ceramic, food	STD, EDU, IE, IPRs, TT
TUD	R&D, Design	http://www.hyperbody.nl/research/projects/robotic-building/	NETHERLANDS / Zuid-Holland	AE, AU, E, EN, E&T, C	M&S, D, M	ME	Polymer, Ceramic	EDU
TU Delf	R&D, Design, End user	http://designinformatics.bk.tudelft.nl/	NETHERLANDS / Zuid-Holland	C	M&S, D, P	PBF, VP ME	Polymer	EDU, 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
University of Extremadura	R&D	http://materiales.unex.es	SPAIN/ Extremadura	ALL	M&S, M, P	ME	Polymer, ceramic, biomaterails	EDU, TT
University of Sheffield	R&D, Design,	www.sheffield.ac.uk/materials	UNITED KINGDOM/ SOUTH YORKSHIRE	H, AE, AU	M&S, M;	ALL	Metal, Polymer, Ceramic	EDU
VIVES	Educational Establishment, R&D, design	www.vives.be/onderzoek-ontwerp-productie-technologie	BELGIUM	CG, O (mechanics)	M, D, PP, Pr	PBF, ME,	Metal, Polymer	EDU, TT
VTT	R&D, Material Provider, Design	www.vtt.fi/powder	FINLAND	ALL	ALL	PBF, ME, DED, Powder production	Metal, Ceramic	L, EDU, IE, IPRs, TT

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				Industry				
3DStep	R&D, Service Bureau, Design, AM training, Innovation services	www.3dstep.fi	FINLAND/Tampere	AE, EN, E&T, C, Food	ALL	PBF, ME	Metal, Polymer, Bio-materials, Composite materials, Chocolate	EDU, IE, TT, Community development
3DCeram Sinto	Service Bureau, OEMs, Materials Provider	www.3Dceram.com	FRANCE/Limousin	H, AE, AU, E, EN	M, P, PP, Pr	VP	Ceramic	IE, TT
+90	R&D, Service 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, Bio-materials	-
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, EBM	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
CAM	R&D, Services Bureau, OEMs, Design, End user	www.croftam.co.uk	UK/Cheshire	AE, AU, CG, E, EN, E&T, C	D, PP, Pr	PBF	Metal	EDU, IE
CRIT	R&D	www.crit-research. it	ITALY/ Emilia-Romagna	AE, AU, E	D, M, P	PBF	Metal, polymer	EDU, IE, TT
Digital Metal	Services Bureau, Equipment supplier	www.digitalmetal. tech	SWEDEN/ Sydsverige	H, AE, AU, CG, EN, E&T	D, M, P, PP, Pr	BJ	Metal	STD, IE, IPRs
EOS	R&D, OEM, Materials & Software provider, End user	www.eos.info	GERMANY/ Ob erbayern	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
FADDTORY	R&D, Service Bureau design, end user	www.faddtory.com	BELGIUM/ Namur	H, AE, AU, CG, E, EN, E&T	ALL	PBE, VP, ME, DED, BJ	Metal, Polymer, Ceramic	EDU, IE, TT
GFMS	OEM, pre- and postprocessing equipment	www.gfms.com	SWITZERLAND/ Geneva	ALL	D, P, PP	PBF, DED	Metal	IE
GOCERAM AB	Materials provider	www.goceram.com	SWEDEN/ Västsverige	ALL	M	ME, Feedstock provider	ALL	TT

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Granta	R&D, Software provider	www.grantadesign.com	UNITED KINGDOM/ East Anglia	ALL	ALL	ALL	ALL	STD, EDU, IE, TT
Granutools	R&D, OEMs, Materials provider, End user	www.granutools.com	BELGIUM/ Liège	ALL	P	PBF	Metal, polymer, ceramic	STD, EDU, IE, TT
HAMUEL	Machine tool builder	www.hamuel.de	GERMANY/ Oberfranken	E&T	P	Laser Metal Deposition (LMD)	Metal	EDU, TT
HILTI	End User	www.hilti.group	LIECHTENSTEIN	E&T, C	M&S, M, Pr	PBF, MJ, BJ	Metal, Ceramic, Hardmetals (cemented carbide composites)	IE
Höganäs	R&D, Materials provider	www.hoganas.com	SWEDEN/ Sydsverige	ALL	M	PBF, DED, BJ	Metal	STD, EDU, IE, IPRs
IMA	R&D, Design, End User	www.ima.it	ITALY/ Emilia-Romagna	Industrial machines for packaging	D. Pr	PBF	Polymer	IE, TT
IMR	Materials provider	www.imr-group.com	AUSTRIA/ Kärnten	AE, AU, CG, EN, E&T	M	PBF, MJ, BJ	Metal	IE
InnoSyn B.V.	End User	www.innosyn.com	NETHERLANDS/ Limburg	E, (Chemical)	P	PBF	Metal	IE
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	-
Lithoz	R&D, Materials provider, design, technology provider	www.lithoz.com/en/	AUSTRIA/Wien	ALL	D; M; P; PP	VP	ceramic, biomaterials	EDU; IE, IPRs, TT
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	-
MCI	Service Burerau, Communication and Dissemination partner	www.mci-group.com	BELGIUM/ Région de Bruxelles-Capitale	ALL	ALL	ALL	ALL	STD; L; EDU, IE; IPRS; TT
MIMETE	Materials provider	www.mimete.com	ITALY/Lombardia	ALL	M	Gas atomization of metal powders for AM	Metal	-
Melotte	Service Bureau, design	www.melotte.be	BELGIUM/ Prov. Limburg	ALL	M&S, D; PP; Pr	Selective Laser Melting	Metal	EDU, IE

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N-ABLE	Service Bureau	www.n-able.io	FRANCE/ Rhône-Alpes	ALL	ALL	ALL	ALL	STD, L, EDU, IE, TT, R&D/ Demonstration and market policy
OCE	R&D, OEMs, Design	http://oce.com/	NETHERLANDS/ Limburg	ALL	M&D, D, M, P, PP, Pr	MJ	Metal, polymer, ceramic	IE
Oceanz B.V.	R&D, Service Bureau, OEM, Materials provider, Design, End user	http://oceanz.eu/	NETHERLANDS/ Gelderland	ALL	M, P, PP, Pr	SLS	Polymer, Food	EDU, IE
Oerlikon AM GmbH	R&D, Service Bureau, Materials; Design	www.oerlikon.com	GERMANY/ Oberbayern	H; AE; AU; I&T	M&S; M; P; PP; Pr	PBF; BJ	Metal	STD; EDU; IE; IPR; TT
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
RINA Consulting S.p.A.	R&D, D, Engineering consultancy operation and maintenance	www.rina.org	ITALY/Genova	ALL	ALL	ALL	Metal, polymer	STD, EDU, IE, IPRs, TT, roadmapping, safety
RINA Consulting - Centro Sviluppo Materiali S.p.A.	R&D, D, Engineering consultancy; Materials, processes	www.rina.org	ITALY/ Lazio	ALL	ALL	ALL	Metal, polymer	STD, EDU, IE, IPRs, TT, roadmapping, safety
Rosswag	R&D, Services bureau, Materials provider, Design	www.rosswag-engineering.de	GERMANY/ Karlsruhe	EN, E&T, C	ALL	PBF	Metal	STD, EDU, 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
Sintertech	OEM	-	FRANCE/ Rhône-Alpes	AE, AU, CG, EN	Pr	PBF, BJ	Metal	-
SWEREA KIWAB	R&D	www.swerea.se/ kimab	SWEDEN/ Stockholm	ALL	M&S, M, P	BPF	Metal	EDU, TT
TRIDITIVE	R&D, Services bureau, Design	www.dynamics. triditive.com	SPAIN/Asturias	All	M&S, D, P, PP, PR	VP, ME	Polymer	EDU, IE, TT
TRUMPF	R&D OEM, Materials provider,Software provider	www.trumpf.com	GERMANY/ Baden-Württemberg	AE, AU, CG, EN, E&T	M&S, D, M, P, PP, PR	PBF, DED	Metal	EDU, IE
ZiggZagg NV	R&D Service bureau, Design	www.ziggzagg.be	BELGIUM/ porv. Osst-Vlaanderen	H, AE, AU, CG, EN, E&T	M&S, D, M; PP, Pr	PBF, VP; MJ, BJ	Metal, polymer,	STD, EDU, IE

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
Other								
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.ideaconsult.be	BELGIUM/ Bruxelles-Capitale	ALL	ALL	ALL	ALL	L, IE, TT
ISONORM	Consultancy on standardisation	-	ITALY/ Piemonte	ALL	ALL	0	ALL	STD

NAME	SUPPLY CHAIN	WEBSITE	COUNTRY/ Region	Sectors	VC segments	AM processes	AM Materials	Non Tech.
Clusters/networks/associations								
3C ACADEMY	R&D; Service Bureau; design provider	-	BULGARIA/ Sofia-grad	H, AU; CG, E, EN; E&T, C	M&S, D, P, PP, Pr	PBF, VP, MJ; ME; DED, BJ	Metal, polymer, ceramic	STD, EDU, IE, IPRs
3DPA	Service Bureau	www.the3dprintin-gassociation.com	NETHERLANDS/ Zuid-Holland	ALL	ALL	ALL	ALL	STD, L; EDU, IPRs
AM Platform	ALL	www.am-platform.eu	EUROPE	ALL	ALL	ALL	ALL	All
ADDIMAT	ALL	www.addimat.es	SPAIN/ Pais Vasco	ALL	ALL	ALL	ALL	-
CECIMO	R&D; Materials & software provider	www.cecimo.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.com	BELGIUM/ Bruxelles-Capitale	O (powder metallurgy)	ALL	PBF	Metal	EDU, TT, Networking; Synergy
ERRIN	Network regional Innovation and of Smart Specialisation Strategies.	www.errin.eu	BELGIUM/ Bruxelles-Capitale	O (AM and nanotechnology)	-	-	-	EDU, TT, Networking
EWF	Education & Training, Standardization	www.ewf.be	BELGIUM/ Bruxelles-Capitale	AE, AU, CG, E, Manufacturing	M, P	PBD, DED	Metal, polymer	STD, EDU, IE, IPRs, TT
FLAM3D	cluster, network, association	www.flam3d.be	BELGIUM/ Flanders	ALL	ALL	-	ALL	ALL
IAM 3D Hub	R&D OEM, Design, Business development	-	SPAIN/ Catalonia	ALL	ALL	PBF, VP, ME	Metal, Polymer	STD, EDU, IE, IPRs, TT
MATIKEM	R&D; service Bureau; Materials provider; design; end user	en.matikem.com	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
PRODUTECH - Production Technologies Cluster	ALL	www.produtech.org	PORTUGAL/ Norte	ALL	ALL	ALL	ALL	STD, L, EDU, IE, IPRs, TT

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ERRIN European Regions Research and Innovation Network

IDEA CONSULT thinking ahead

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AIRBUS

EPMA european powder metallurgy association

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