Integration of Additive Manufacturing in Production Systems

Alain Bernard(✉)

Ecole Centrale de Nantes, LS2N UMR CNRS 6004, Nantes, France
alain.bernard@ec-nantes.fr

1 Introduction

Historically, Additive Manufacturing is not considered as a production technology even if many examples are available in different application fields [1]. More than 20 years ago, some specific and niche sectors have adopted additive manufacturing technologies as part of a complete value chain, from 3D scanning and/or CAD modeling to post-processing. With the progress of reliability of additive manufacturing technologies and with respect to the increase of expertise of companies in this field during the last 20 years, some alternative visions have been drawn concerning new designs and new ways of producing products, by integrating functions, by optimizing material quantity, by considering a coherent association of several technologies with respect to a given set of requirements (and not only additive manufacturing technologies). In addition, AM became cost-effective [2] and especially for spare parts. For such parts, one way of progress is to produce on demand parts when and where you need then, with up-to-date digital models. All this progress is supported by national and international associations, like France Additive.

In this short paper, France Additive is first briefly introduced. Then, Additive Manufacturing is positioned as a key player of production systems in the context of the factory of the future and Industry 4.0. Some particular key issues are then introduced with several concrete illustrations. In the last section, examples of industrial facilities and production structures are introduced and commented. Then a conclusion section allows summarizing the content of the paper and highlighting some expected progress for the future.

2 A Key Actor: France Additive

France Additive is a non-profit association, dedicated to Additive Manufacturing and created in 1992 with another name, French Association for Rapid Prototyping (AFPR). In a recent evolution, many activity groups have been created and devoted to the different topics supported by the 180 + members. The main goal of France Additive is to federate research and technical centers, education actors, industrial companies, service providers and final users. The scope of topics of interest is 360° in an open community, from R&D, applications, technologies (physical and digital), materials, skills and education,

J. O. Correia Vasco et al. (Eds.): ProDPM 2021, STAM, pp. 3–11, 2023.
https://doi.org/10.1007/978-3-031-33890-8_1

finance, supply chain, economic growth. Recently, the French government decided to create a new branch strategic contract named "Solutions Industrie du Futur". France Additive is in charge of coordinating the effort in the field of Additive Manufacturing. Part of the action plan is to accelerate the development of AM in France, to increase the competitiveness of French AM actors activities, to improve the cooperation between all the actors of the ecosystem within complete value chains, to boost the technical investments in the field of AM.

3 A Key Player: Additive Manufacturing

At a worldwide level, Additive Manufacturing activities have increased significantly during the last 15 years, mostly. In this context, many technologies have been developed, many standards have been proposed and many companies have adopted AM.

But adopting AM is not only buying and using a AM machine. This is a complete transformation of the value chain, from design to post-treatments, with a real systemic vision. Managing product lifecycle is mandatory, including all the dimensions of the lifecycle (mainly product, process, organization), taking into account the material lifecycle and trying to optimize the material consumption and the material recycling when possible. Two parallel flows have to be "synchronized": physical and digital ones. As shown on the following Fig. 1, many issues have to be taken into account in order to achieve the requested and expected products at the end of the complete value chain process.

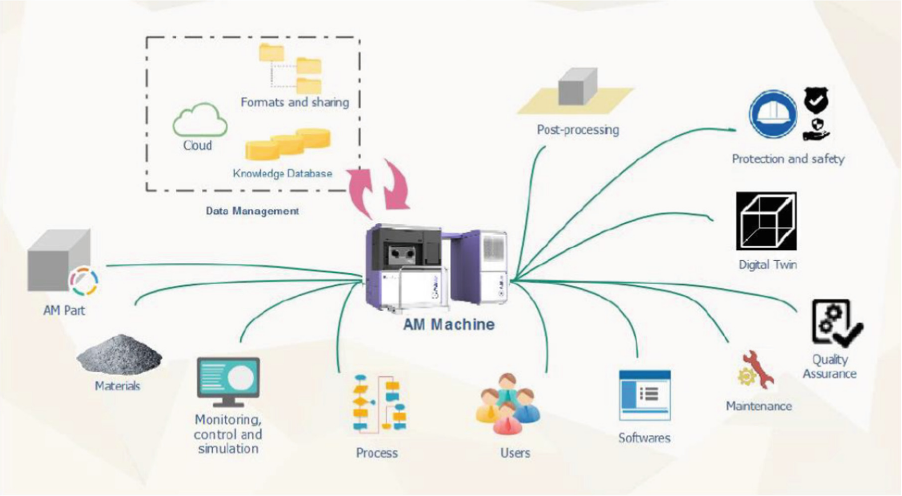


Fig. 1. Global schema of a systemic vision of AM [3].

Behind this schema, there are many actions and many actors that have to be considered, those who are on the critical path dedicated to the direct production of the product, and many other activities that could be considered as services all along the complete development process of a given product. The following Fig. 2 summarizes the set of the main activities and actors concerned for metal layer-based fusion manufacturing value chain.

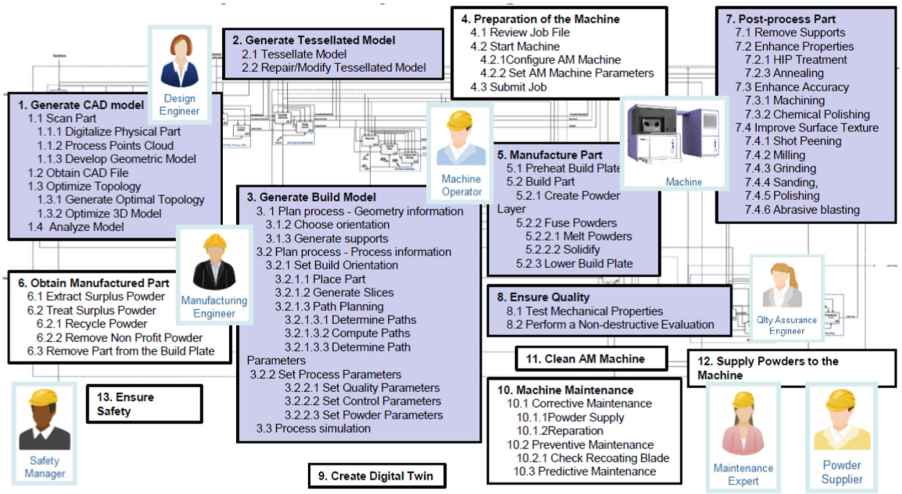


Fig. 2. Interoperability between actors along the value chain.

4 Key Issues of Additive Manufacturing in Relation with Industrial Production

In this context, one major question is to decide to adopt and to integrate AM as a production solution in a company for regular or specific productions. The main issue is to consider all the dimensions that concern the new way of designing, of producing, of managing products along their lifecycle. In this paper, only five key factors will be considered and illustrated. The following Fig. 3 summarizes those five factors: innovative creation of innovative products, spare parts, digital logistics and distributed production, direct production, production on-demand and zero stock. Each of them will be briefly commented and illustrated with some particular examples.

4.1 Innovative Creation of Innovative Products

Design or redesign of parts in the context of a value chain based on AM has new great benefits in the field of design methodology. Design for Additive Manufacturing [4, 5] allows optimizing different factors, in particular part weight by putting the just enough material at the right place with for example topological optimization. But one major advantage is the integration of functions and the use of multi-material for the same part during a given production. In the following Fig. 4, three examples are proposed, two directly relate to function integration, reducing dramatically the number of parts in a

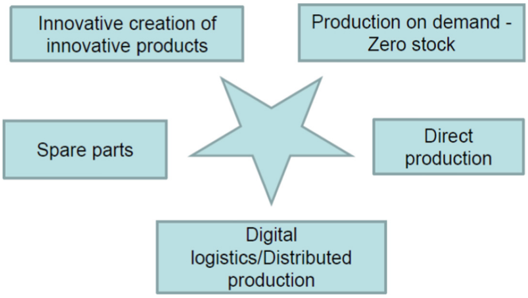
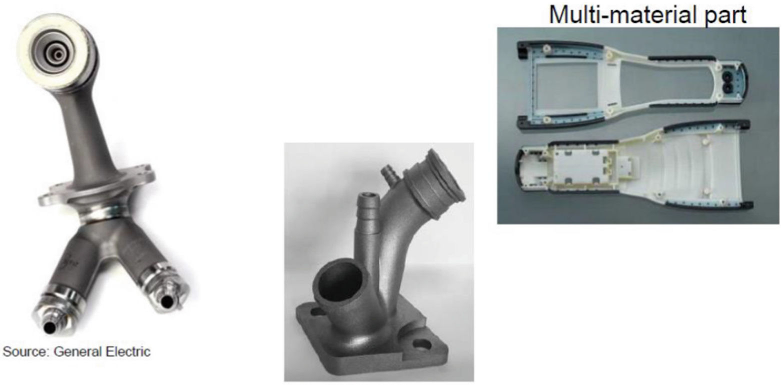


Fig. 3. Five key factors to be considered for AM integration and success.

unique one and considering new opportunities to design and manufacture tubes, channels or hydraulic blocs. Instead of drilling blocs of materials, the idea is to put material around the tubes and channels and to connect them with free forms very easy to fabricate with AM. Using multi-material is also an opportunity to get in a unique part different material characteristics instead of assembling different parts, each of them dedicated to a given function and fabricated with a different material. In that case, design tools have to propose additional functions because usually, material is a unique characteristic of a given part.


Multi-material part

Source: General Electric

Source: Farinia Group

Fig. 4. New designs with integration of functions and use of multi-material technologies.

And as it may be seen I the following Fig. 5, design may be as complex as needed with respect to compactness of shapes of parts. New opportunities are offered to heat exchangers ad also to hydraulic blocs, as previously mentioned. At the same time, what is expected is to get a design without any support because some shapes are just inaccessible to be cleaned. Applied mathematics and optimization software modules have been recently developed/improved and proposed to designers in order to really get all the benefit of using AM in a given value chain. Obviously, topological optimization is seen as one major tool to define or predefine the 3D complex shapes of the parts. What is still complex is to take into account all influential factors from the manufacturing technologies when designing the part and not only the constraints related to the future use of the product. Major progresses in this field are expected during the next ten years based on a better understanding of the physical phenomena and on the proposition on new optimization models and approaches.

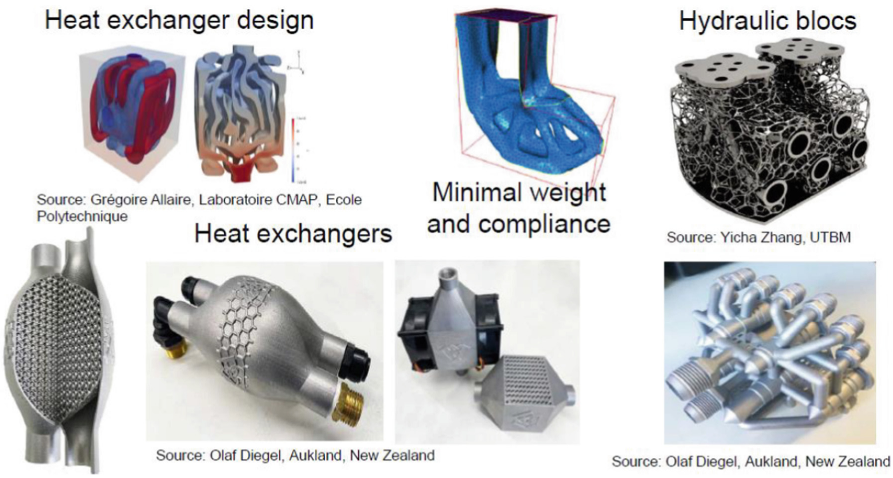


Fig. 5. Topological optimization of shapes, optimized heat exchanges and hydraulic blocs.

In addition, all these new opportunities of design and manufacture allow defining aesthetic and artistic designs, unique or with a set of customized / personalized parts, all different, without any additional cost because of complexity of diversity, even if produced during the same production batch. As shown in the following Fig. 6, some interesting applications have been industrialized during the last twenty years, like hearing aids for example.

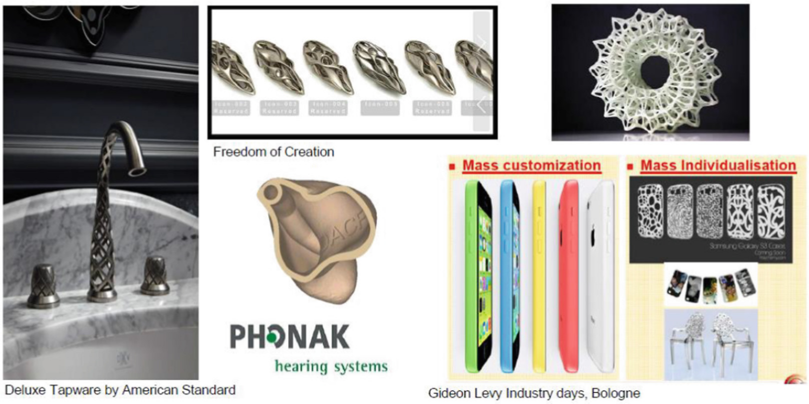


Fig. 6. Examples illustrating zero additional cost for complexity and diversity.

4.2 4–2 Spare Parts

Manufacturing spare parts is a very promising opportunity for AM application. This can be applied because it is sometimes impossible and always costly to maintain an inventory of spare parts along many years. The main idea is to produce spare parts when and where needed, transforming physical flow into digital flow. The following Fig. 7 shows some examples in different fields. A recent evolution would be that the CAD files of some critical parts of appliances, like washing machines, could be accessible for free in order to let customer manufacture them by themselves. But the main industrial challenge concerns spare parts for many industrial fields like transports, energy, aeronautics and space, agriculture, etc. In fact there is a double challenge: to be able to repair parts or if not possible to manufacture new ones.

Source: http://3dprint.com/tag/ebm/

Source : Leolane,
Courtesy : PWC(PriceWaterhouseCoopers)

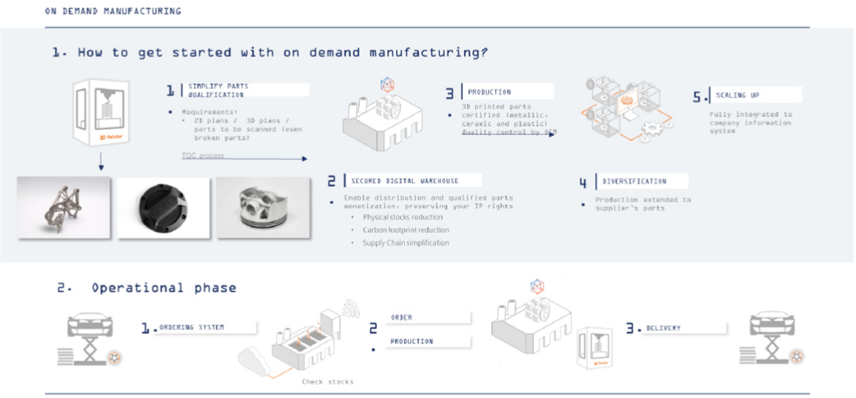
Source : Beam, Courtesy : Chromalloy

Source : Leolane,
Courtesy : Mercedes Benz truck

Fig. 7. Examples of spare parts in different fields.

4.3 4–3 Digital Logistics and Distributed Production

As mentioned before, manufacturing of spare parts is expected when and where it is needed. But at a more general level, the same concept could be developed for many productions. When it is possible, in order to avoid to transport parts/products and to minimize carbon foot print, production could be processed in a distributed manner and not centralized. Some software platforms and market places are able to propose a complete integration of data from design to end-of-life. At the same time, it is necessary to secure the digital chain in order to be sure that the manufacturing process of a give part/product is the right one. This is crucial for parts that are certified in given field, and it is also highly expected when considering counterfeiting trademarked goods. In that case, block chain technology may help in improving the complete traceability and certification of a given specific process of a part/product all along the supply chain. An example of solution available on the market is given in Fig. 8.



Source: Alexandre Pedemonte, Vistory Company

MainChain by VISTORY

Fig. 8. Example of a block chain solution (MainChain from Vistory company).

4.4 4–4 Direct Production

As mentioned before, many operational solutions are available to allow industry to distribute production around the World, based on digital logistics and block chain solutions for example to secure the manufacturing processes, instead of centralizing production and distributing the physical products. So, what is really expected for the future is direct production based on AM technologies and value-chains. Many examples of parts in different fields illustrate the direct production capabilities offered by AM, not only for parts but also for tools and toolings. One of the main issues related to productivity. Metallic parts could be obtained using AM but manufacturing time is still very long. Some recent solutions have been proposed by machine manufacturers to decrease manufacturing time, to increase the number of energy sources (for example 4 to 12 lasers in laser-bed fusion machine for metals), to optimize the management of energy distribution (de-focalization, beam shaping for example) or more generally, to minimize the building time for each layer. Decreasing manufacturing time while decreasing also material cost while improving the design to minimize cleaning post-process operations, all these progresses let hope a bright future for industrial applications of AM in a near future (5 to 10 years) in many fields.

But this is not so simple. Design methods and tools have to be adapted and designers have to be trained for new skills and new design principles. New specific skills are also needed in the shop floors for manufacturing, control and maintenance.

4.5 4–5 Production on Demand – Zero Stock

The general tendency is to use appropriate manufacturing structures able to be efficient, resilient, flexible, agile and adaptable. But when these characteristics are mentioned, it is not so easy to convert them into reality. This means that production on demand should be mostly adaptable to personalization issue. Production systems which include AM machines need to develop new automation functions in order to increase productivity even if what has to be produced is not repeatable. However, in many cases, the products are similar, even always the same with some few customized items. So, this is difficult, often impossible, to plan production batches very early. Efficient design and production management systems are the keys of a great success for such kind of production. Then, the post-treatment and shipping systems have to be also efficient in order to minimize the global lead time and to increase customer satisfaction.

5 Conclusions

Many other factors are I favor of the integration of Additive Manufacturing in production systems. However, a lot of progress is expected in a near future to really help in switching to a real economic reality of AM usage. But R&D centers should not stop their efforts in favor of continuous improvements, in particular concerning productivity and robustness of the global value chain processes. As mentioned in this paper by Schmidt et al. [6], enhancement of material portfolio is a major expectation in metallic parts production, including graded materials and multi-material alloys. Predefinition of global processes, including hybrid combinations of conventional and non-conventional technologies, is also a challenge with respect to the best compromise between all major requirements, in particular lead time, cost and quality. New key performance indicators should be taken into account by optimization and simulation modules in order to really anticipate the best strategies in a given context. Learning about physical phenomena but, more widely, about real limits of technologies is absolutely necessary at a general level and in specific contexts and application fields. Specific in-process control systems could help for closed-loop auto-correction systems, helping in adjusting the process parameters in real time, in detecting and correcting main well-known possible defaults along manufacturing process. This could provide real quality assurance systems helping for certification matters. When speaking of production, this also means large volumes of production in many cases. So, enlarging production capacities as well as accelerating material transformation are two main goals that are proposed for future developments. Prost-process and finishing technologies are essential to assure the final quality of the product. Many progresses have to be done in this field in order to minimize the cost and efforts dedicated to these critical phases of the global process. And finally, control technologies, mostly non-destructive ones, have to be improved as well as quality assurance approaches.

So, definitively, AM is a real key player for future production systems. Real changes will allow creating products only manufacturable with AM technologies. It is already the case today but, as soon as much more actors will be confident in the robustness and productivity of AM technologies, associated to efficient post-processes, a significant evolution will be possible at a large scale. As described in this short paper, many advantages are offered by AM technologies and AM-based value chains. But this evolution will come day after day, in parallel of other technologies that have already shown their efficiency for production. Construction, medical sector, and other sectors have already started to adopt AM but significant progresses have also to be seen with the specific regulations and certifications.

Obviously, Additive Manufacturing is a field of interest that is promised to a bright future.

References

1. Ahuja, B., Karg, M., Schmidt, M.: Additive manufacturing in production – challenges and opportunities, laser 3D manufacturing II. In: Helvajian, H., Piqué, A., Wegener, M., Gu, B. (eds.) Proceedings of SPIE, vol. 9353, 935304 (2015). SPIE · CCC code: 0277-786X/15/$18. https://doi.org/10.1117/12.208252
2. Thomas, S., Gilbert, S.W.: Cost and cost-effectiveness of additive manufacturing: a literature review and discussion. NIST special publication 1176. https://doi.org/10.6028/NIST.SP.1176
3. Martinez, L.: A generic systemic vision and modelling of additive manufacturing processes. Master thesis, Ecole Centrale de Nantes, IS3P team of LS2N UMR CNRS 6004 (2016)
4. Thompson, M.K., et al.: Design for additive manufacturing: trends, opportunities, considerations, and constraints. CIRP Ann. **65**(2), 737–760. https://doi.org/10.1016/j.cirp.2016.05.004
5. Vaneker, T., Bernard, A., Moroni, G., Gibson, I., Zhang, Y.: Design for additive manufacturing: framework and methodology. CIRP Ann. **69**(2), 578–599. https://doi.org/10.1016/j.cirp.2020.05.006
6. Schmidt, M., et al.: Laser-based additive manufacturing in industry and academia. CIRP Ann. **66**(2), 561–583. https://doi.org/10.1016/j.cirp.2017.05.011