White Paper

Unlocking the potential of Additive Manufacturing

ascent
atos thought leadership

Atos

Additive technology offers the ability to produce personalized products with lower development costs and shorter lead times during manufacturing and less material waste.

It can be used to manufacture complex parts, and enables manufacturers to reduce inventory, make products on-demand, create smaller localized manufacturing environments, and even reduce the cost and complexity of supply chains.

About Ascent Thought Leadership Program from Atos

Atos does more than accompany its clients on their digital journey, the Group actively helps them to stay one step ahead. Through its Ascent initiatives, Atos shares its vision and innovative thinking on the emerging trends and technologies that will shape business in the future.

For further information on Ascent vision, download Ascent publications, and read, share or comment the latest Ascent blog stories, please go to **ascent.atos.net**

About the Atos Scientific Community

Innovation lies at the core of Atos' business strategy and the company has organized itself to think one step ahead to help its clients to reinvent their growth models. The Atos Scientific Community brings together over 120 best-of-breed business technologists from all Atos geographies and businesses, representing a rich mix of skills and backgrounds. Its aim is to help Atos anticipate and craft its vision of upcoming technology disruptions and the future business challenges that will be faced by the markets it serves. By making this vision available to its clients, and by investing in areas related to the findings, Atos intends to help its clients make informed decisions as the Trusted Partner for their Digital Journeys.

The Scientific Community are "creators of change", highlighting the importance of innovation in the dynamic digital services market and taking a proactive approach to identify and anticipate game changing technologies. They are mentors in the Atos IT Challenge, a competition encouraging the next generation of IT talents from universities across the world.

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Executive summary

Additive Manufacturing (AM) is all about creating a 3-dimensional, solid object from a digital model that can have almost any possible shape. The solid object is created by adding layers of material, and not by removing material as in classical manufacturing techniques[1].

AM is one of the potential game changers that could disrupt the complete manufacturing value chain, allowing a shift from mass production to full customization, from centralized to distributed production. As presented in **Figure 1,** AM is one of the basic Key Enablers Technologies (KET) for Industry 4.0. In combination with Internet of Things (IoT) and other KET's, manufacturers can monitor and improve their products, designs and performance.

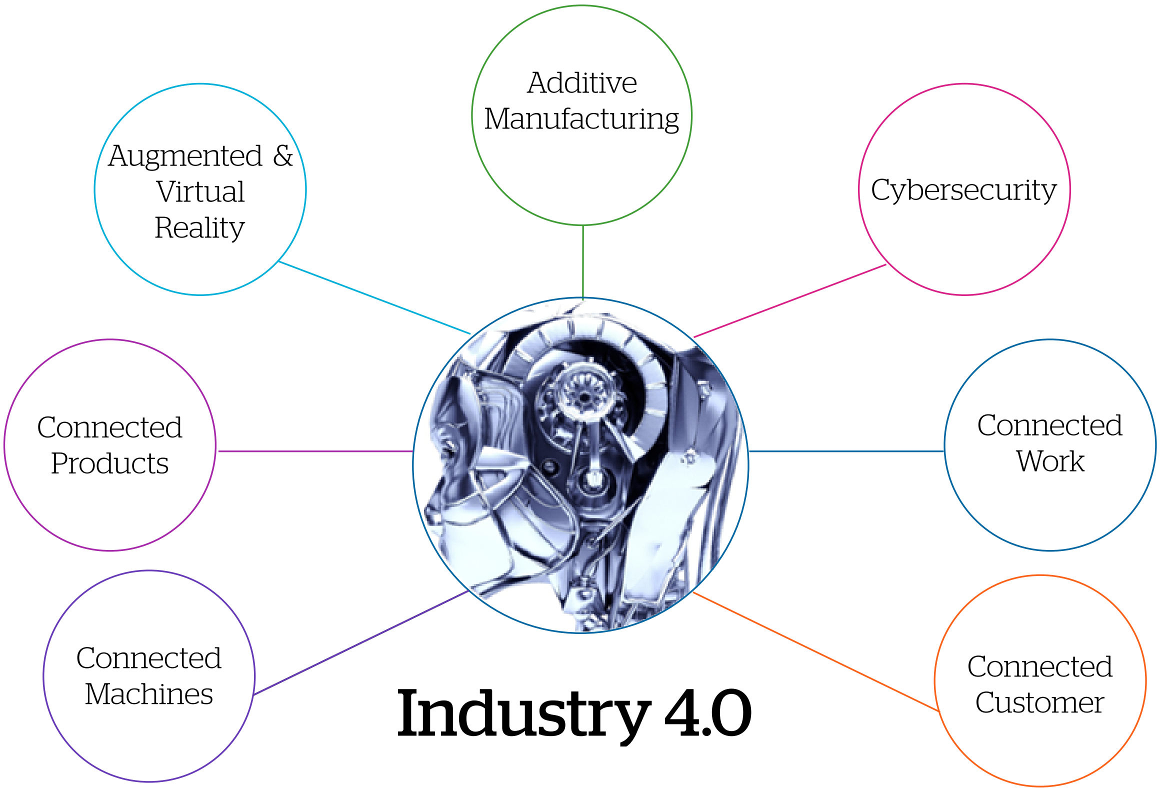

Figure 1 - Additive Manufacturing in Industry 4.0

Atos already analyzed the impact of this technology in 2014, in a white paper[2] on 3D Printing. Up to 2014, the main usage of AM was in creation of prototypes, but its relevance for lightweight parts, the availability of results at the point of use, the instantaneous addressing of customization requirements, the reduced assembly cost, the significantly reduced time to market, the additional functions, the reduced utilization of source material and the positive impact on the supply chain, support a much wider use of AM in the years to come. According to a PricewaterhouseCoopers report[3], about two-thirds of US manufacturers are now adopting 3D printing in some way. Half are using it both for prototyping and final products. And 52% of manufacturers expect 3D printing to be used for high-volume production in the next 3-5 years.

[1] http://www.astm.org/Standards/F2792.htm
[2] http://ascent.atos.net/ascent-white-papers/
[3] http://www.pwc.com/us/en/industrial-products/publications/assets/pwc-next-manufacturing-3d-printing-comes-of-age.pdf

Fully extending the usage of AM requires opening the door of AM for all stakeholders and creating a joint understanding of the benefits, changing processes and roles each should take. This includes the concept of a collaboration platform which will be outlined in this white paper.

In our digital view on the AM environment we see the following stakeholders (see **Figure 2**).

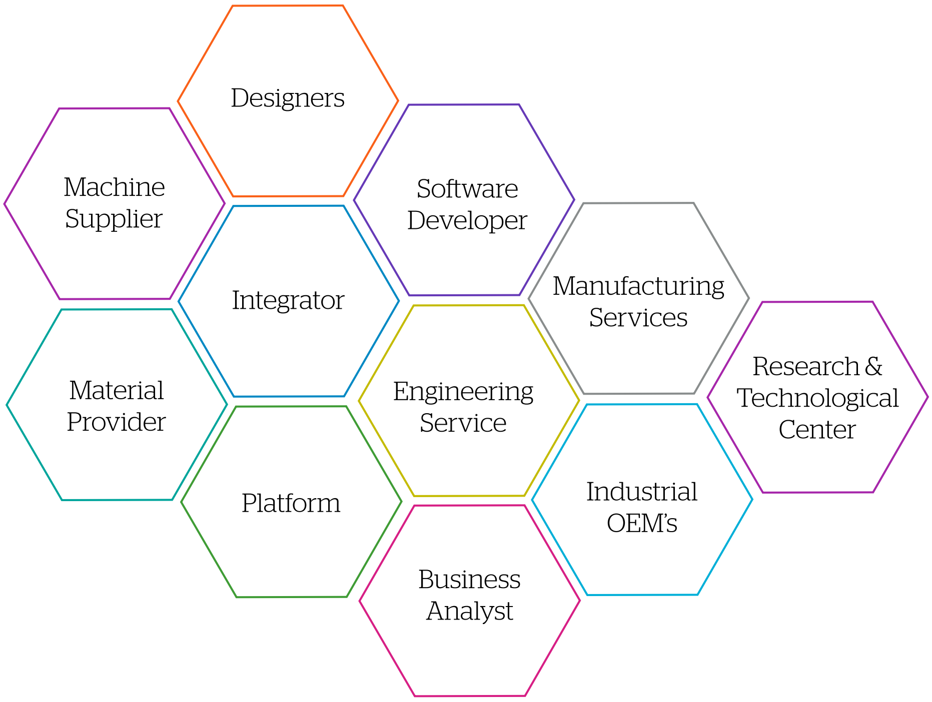

Figure 2 - Additive Manufacturing Ecosystem

To fully realize the potential of this disrupting technology, there are several areas of top priority, which will be outlined in this white paper;

1. AM has an enormous impact on the Product Lifecycle Management (PLM) process: Product design, manufacturing and retail channels as well as products and spare parts distribution models will radically change with this technology.
2. AM requires compatibility of digital models and 3D printers for the industry. This can be looked at from a pure software definition of a digital format that is commonly usable and tools that are accessible as well as usable.
3. Considerations on Intellectual Property Rights. How to ensure that the printer only produces the allowed amount of items, or the allowed changes? How to communicate the model to the printer ensuring that the Intellectual Property is not staying in the memory of the machine?
4. The techniques currently used to manufacture in an additive way vary in their flexibility of speed and combination of materials. Therefore, they are still halfway between mass production and individualization.
5. The economic trade-off between "make or buy" for products, assembly parts or spare parts: How convenient and effective is it to "print" a part rather than getting it from a supplier? And could this be mass production or a "one-off" production?

We will examine these aspects to better understand the usage of AM in a constantly growing, and increasingly more digital market.

Business models and applications

According to the Wohlers Associates Report[4] of 2016, AM and the 3D printing industry reached a market volume of 5 $bn in 2015. This represents a growth of 25,9% compared to 2014. It will see substantial market growth for products and services of approximately 315% between 2013 and 2021, with the market volume increasing to 10.8 $Bn in 2021. Currently the US market has the largest market share with 41% followed by Japan (10%) and Germany (9%). The fastest growing sectors for AM will most likely be automotive and aerospace, but we expect (and see) also dental and medical applications.

From an application point of view the major sector today is R&D i.e. the quick development of prototypes (also known as "rapid prototyping") which allows the developers to easily improve and change their designs based on 3D prints. Italian superbike producer Ducati, for example, used AM in the development of the new motor bike for the Motor GP series. The design process was reduced by 60% from 20 to 8 months because of the ability to print precise prototypes of bike components. AM can also solve some of the long-time outstanding issues of stock management level and rotation, as well as delays in the logistics linked to suppliers that can cause major issues in the production process and deliver spare parts which are no longer being available.

AM will create 3 paths of "disruption":

1 Individualized products:

AM will support the trend of the personalization of products in the way that it is suited for the manufacturing of small series of products as well as "lot size one". This is fueled by the fact that a certain percentage of production costs are independent from the lot size.

2 New geometries, materials and material properties:

AM will provide for new and enhanced functionalities in high tech materials, new materials , new usage and repair strategies

3 Decentralized production:

AM will allow distributed industrial production on demand, home production and outsourcing of production to partners. This will have major consequences on future business models.

[4] https://wohlersassociates.com/2016report.htm

B2C Business Models

With the individualization of consumption and fostered by the cost reduction in the distribution of 3D printers, printing of consumer goods at home becomes feasible. For some simple products, home printing seems to be a feasible option. Makerbot's site http://www.thingiverse.com/ allows you for example to download designs for household products like chess pieces, knives, shelves and various spare parts for household devices.

Nevertheless, experts like those from the German management consulting firm Roland Berger[5] doubt that home printing will be realistic in the future, backed by the following arguments:

- The size of the objects and, in consequence, the products that can be produced at home will be limited by the printer size and type, and therefore, by the price of the printer. Besides, every print needs a 3D model as a source for production. It remains unclear whether consumer goods manufacturers will provide access to the 3D models of their products. Furthermore, the quality of printed objects generated by home-technology printers is not likely to meet customer expectations. The adequate material has to be available, and sometimes this is the limitation.
- The print of complex products featuring functional surfaces will not be possible.
- There will be a lack of possibilities to combine different materials (in a product).
- Limited know-how in CAD design in home users. If the 3D model is not available as send-to-print, designing it requires skills, time and SW tools.

We acknowledge such limitations for certain cases of B2C AM, especially "useful" objects that must serve a critical purpose in a household (knives, shelves, screws, etc.). However, there are fewer limitations in other cases of B2C AM, such as decorative house items, jewelry or clothing.

For the B2C market in AM, experts see three other business models:

- Specialized AM suppliers or 3D printing services
- Internet platforms offering printing services for individual objects from a catalogue[6] and/or local 3D printing shops
- Sharing of 3D printing capacities

Specialized AM suppliers already exist today. The University of Würzburg has identified 43 companies in Europe with the majority located in the UK and Germany[7]. These companies work for consumers as well as institutional clients (B2B). The business model they are following is based on the provision of 2D models by the customer (e.g. photographs and scanned drawings). The provision of 3D models by consumers will remain an exception given their limited knowledge and technical capabilities to develop them. Professional companies can be expected to deliver 3D models. The models are usually uploaded to the service provider`s internet page.

The suppliers will transform the 2D into 3D models. This is followed by the actual 3D print of the object based on the customer's order and payment. Payment is usually effected using credit cards and/or PayPal. The object will then be shipped.

Prices are calculated based on the used material, the volume of the object, the applied 3D printing technology, the necessary rework and the degree of data adaptation. The price is calculated as price per cubic centimeters printed.

Another trend in business models is the advent of so-called 3D printing shops (e.g. Protolabs or 3D Printshop in Germany), comparable to the "copy shop" that we have known for decades. People can walk into these printing shops, where qualified personnel will either print the objects brought by the customer or even design the object the customer is looking for. The target is to attract the public to 3D-printing technology. It is assumed that, with the democratization of Additive Manufacturing, more and more shops will open. In addition, whilst some shops are brand- or object-neutral, established businesses could open their own, branded, 3D-printing shops as an effective way to bridge in-store and digital customer experiences. Nevertheless, 3D designing is still a process that requires time and expertise, what is still an obstacle for this kind of business models.

Another interesting aspect of providing AM services is the concept of shared 3D printers. The idea behind this is that a group of individuals jointly buys a 3D printer for common use among them. The process of forming the group and purchasing the printer is done by providers like the startup "Thinklip". The groups are constituted via an online portal based on criteria such as common interests. A prerequisite for success is that the group reaches a consensus about the printer type and price. Based thereon, the provider issues ownership certificates to the group members and purchases the printer. The printer will be delivered to and operated from one of the providers´ branches. "Business-Chip.de" estimated that a positive business case for such an investment can only be realized if the printer will be used more than 10 times a month.

[5] https://www.rolandberger.com/en/Publications/pub_additive_manufacturing.html
[6] In some of these platforms, like https://www.cgtrader.com/3d-print-models, customers can directly buy the model from a designer
[7] http://cedifa.de/wp-content/uploads/2013/07/02-3D-DruckereienInEuropa.pdf

B2B Business Models

AM promises significant cost, time and resource reductions for industrial companies for both design and prototyping activities, with the latter being a strong lever for cost reduction in the test & simulation area. Furthermore, the major cost advantage lies in the AM lifecycle costs, AM allows for the creation of new opportunities to completely redefine business processes to be faster, safer, more fit-for-purpose, more customer intimate. On the product side, it permits the creation of forms and structures for components and products, which cannot be achieved by "conventional" (mainly subtractive) production procedures.

AM will foster decentralized production and therefore will lead to new B2B business models:

- **Mobile printing:** e.g. the decentralized production of spare parts by the customer rather than the OEM often in the field
- **AM for repair:** cheap and fast printing of simple assembly tools by the maintenance staff onsite
- "**Outsourced" production:** e.g. the production of spare parts and/or product parts at 3rd party/partner facilities or in dislocated OEM AM factories

This will allow for the rapid availability of product/spare parts in remote locations as well as for the fast and cheap production of supporting tools for maintenance.

The market is currently dominated by AM service providers that are mostly small in size, with less than 100 employees. The provider universe is quite small, i.e. the population of metal AM providers worldwide is estimated by Roland Berger[8] with approximately 90 companies. They serve consumers as well as industrial clients. The future will see investments by big industrial companies in AM capacities[9]. The distribution of AM systems is linked to the improvement of manufacturing speeds and therefore the increase of manufacturing quantities. The DMRC (Direct Manufacturing Research Center) estimate that the build speed e.g. for metal AM devices will increase from 10 cubic meter per hour in 2013 to 80 cubic meter per hour in 2020[10]. Although AM will allow for the cost-effective production of individual products in the future (also known as "a lot size of one"), it will only partly substitute conventional production methods. AM is expected to be integrated in the overall production process wherever it can provide its strengths compared to conventional manufacturing.

[8] https://wohlersassociates.com/2016report.htm
[9] That is the example of General Electrics, that in September 2016 has announced plans to buy Arcam AB and SLM Solutions Group, through an investment of 1.4 $bn
[10] Thinking ahead the Future of Additive Manufacturing – Innovation Roadmapping of Required Advancements. http://www.dmrc.de

Transformation approach

Full industrialization of Additive Manufacturing is just a few years ahead, so now is the time to think about the new possibilities this technology will bring in order to prepare robust systems with flexibility and security as key values.

We think the timeline of adoption of the critical mass of AM customers will be around 2020, in a low futuristic scenario. While doing that, we already see additional points to consider such as those related to 4D printing[11], additive manufacturing for smart materials, bio-mimetic design, printing gigantic structures or electronics, or bio-printing of organic tissues.

Modelling to accelerate transformation

AM allows optimization of structures, leaving material only where needed, making products becoming lighter. It allows the 'functionalization' of structures, for example by integrating complex cooling channels. It allows simplification of structures, integrating several parts into one, thus reducing assembly time: we must change the concept of 'installation' and think on integrated designs. A clear example of this transformation is the Atos "structural bearing concept", awarded as best design for additive manufacturing (Additive World Design Awards 2016), that joins integration, optimization and new functionalities in a new conceptual design of integrated and customized support for space application.

The conception of the models must be from a 'space' design given by the boundary conditions, adding mechanical and functional requirements and from there, just place material where it is needed and even, not necessarily solid, we can design internal structures to provide special properties.

Important in AM is how the manufacturing process have influence in the final properties of the parts. Therefore, process simulation should be integrated in the design phase to predict these effects and to adapt the design to ensure that the pieces are and behave as expected. Otherwise, it is run through a trial and error basis.

Figure 3 - Atos won a prestigious award for Additive Manufacturing design

[11] 4D printing: 3D printing of structures that can change their shape in a predefined way, as a response to specific stimulus

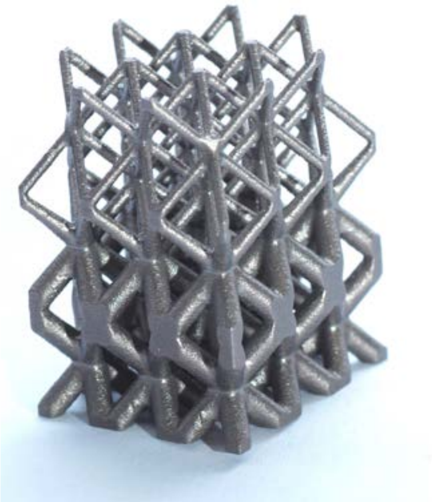

Figure 4 - Adaptable lattice structure

Possibilities here are so vast and exciting that some ideas lead to pure science fiction concepts. In order to afford such a wide scope it is easier to divide possibilities into the chance of using the so called smart materials (those whose properties change triggered by any stimuli such as heat, pressure...) or create our own metamaterials (microstructures engineered in order to find certain properties that differ from those of the base material).

In the first case, using smart materials, the main challenges will be related to multi-material manufacturing and the ability to deal with complex manufacturing processes where the smart properties are not lost. The prediction of operational properties will be also of capital importance as the components will have to behave as expected under different operation conditions. In the second case, creating metamaterials, the challenge is to print at microscopic scale and obtain the expected and desired macroscopic results. Prediction is again key for the final performance.

In both cases the additional complexity will mainly rely on the manufacturing process. It will be necessary to foresee the following issues:

- CAD-CAE systems should be enhanced with new features that enable the complex design these structures need but in an agile way (today it is feasible but not still agile).
- Enriched G-code files that can support parameters related to microstructure and multi-physics phenomena.
- Capabilities for predicting operating and non-operating behavior or even switch-on and switch-off behavior (for transient situations).

Nature mimics

Organisms in Nature have millions of years of “encapsulated experience” in optimizing their structures. Such strong background should be taken into account by human beings when designing components. Additive Manufacturing is an enabling technology but surrounding systems still need more development, with special focus on CAD-CAE systems and their interfaces. Now it is possible to print almost everything, but before we fall into uncontrolled euphoria it is necessary to put the limits in the “almost” and take into account different limits according to the technology to be used. These limits should be flexible and change as the technology evolves.

Today there is a clear separation between CAE and CAD systems when both are part of the design process. The complexity of bionic design needs integrated and agile tooling where iterations and design process do not become a nightmare.

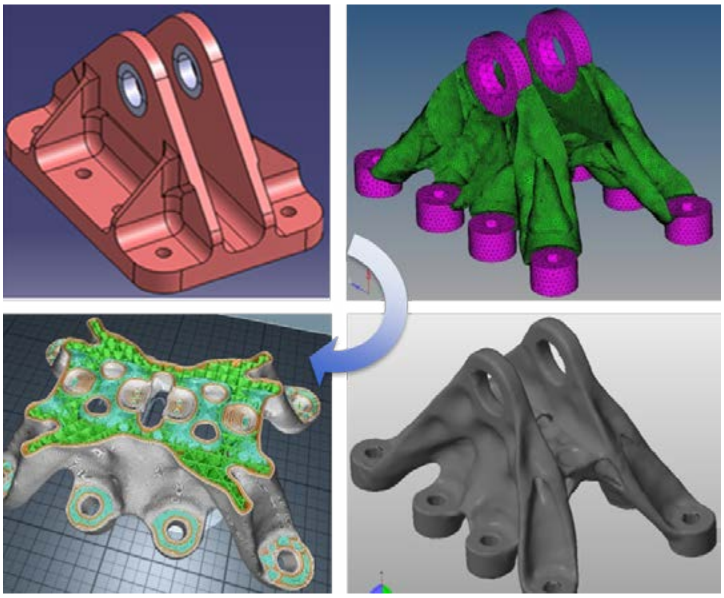

Figure 5 - Topological optimization of an aeronautical component.
Designed by Atos

Printing complexity

Gigantic, biological or edible structures are just a few of the huge amount of "printable" items we will find in the future. The systems put in place should be able to deal with this complexity in terms of:

- Materials: a high variety of materials should be taken into account and, depending on their final usage different properties or conditions should be controlled. Materials data have to be traceable, at least previous to the manufacturing process.
- Interfaces: multi-material printing brings different challenges, related not only to material compatibility (electromagnetic, chemical corrosion...) but also to the properties and capabilities reached at interface level. This complex field will involve material, process and even geometrical and microstructure data that should be taken into account in order to predict and design final part behavior.
- Size: from printed microscopic electronics to even complete houses is possible with AM. The future systems will have to deal with such scale issues.
- Certifications: depending on the field or market, different standards will apply and additional documentation should be generated and managed. The ability to integrate the certification processes or standards is key.
- Conditioning or post-process: in several cases processes additional to the manufacturing by deposition could be necessary; these processes could affect raw materials previous to the manufacturing process (some kind of conditioning) or the component itself in order to improve its capabilities (stress release, hardening...). These adjacent operations could involve traditional machining processes (drilling, milling...) that could be provided in a single machine that integrates the full manufacturing process, what is, hybrid manufacturing.
- Technology: different technologies for different products. Depending on the product a different additive manufacturing technology could be applied.

Some of these data will be part of the G-code files but others should be included in the integrated platform providing the service, from raw materials billing and preservation to recycle or destruction.

Information and collaboration flows

In addition to the creation of products which would take more time and money to produce traditionally, AM allows the creation of complex shapes which are not possible by any other manufacturing mean. Besides, multiple components can be consolidated into a single part, reducing production times and maintenance activities to a minimum .Once the object is created, a variety of finishing activities may be applied.

Data flows

Geometric freedom is such that it facilitates the design and fabrication of lattice structures, designed to exhibit properties that differ from the solid material used in fabrication. The complexity is then replicated in the 3D model and, as a consequence, the size of these files turns to be substantial, typically hundreds of Gigabytes.

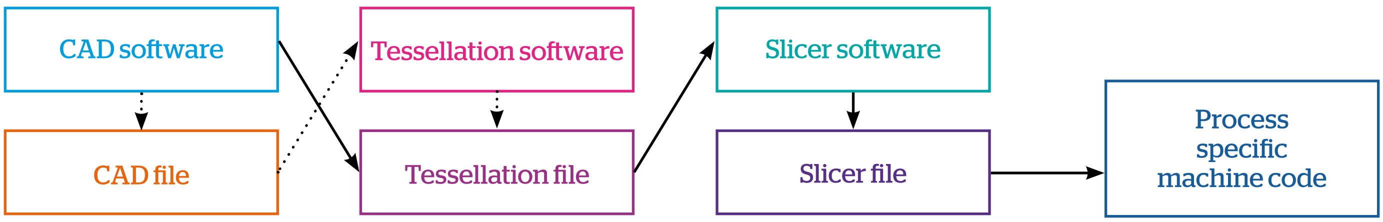

Figure 6 - Conventional design process for additive manufacturing

The AM process traditionally begins with the creation of a three-dimensional (3D) model through the use of computer-aided design (CAD) software. The CAD-based 3D model is then saved as a Standard Tessellation[12] Language (.STL) file, which is a triangulated representation of the model. Software then slices the data file into individual layers, which are sent as instructions to the AM device (G-code Files). The AM device creates the object by adding layers of material, one on top of the other, until the physical object is created. G-code Files contain the information on how the machine will produce the part according to some parameters given, e.g.:

- Part orientation and position;
- Supports and infilling design;
- Parameters related to energy input or laser beam path, etc.

Those parameters have a strong influence on the final appearance and properties of the part. Therefore it is critical that those parameters are controllable by the designer in an earlier stage of the process.

Most software products used today to design parts are not well suited to exploit the advantages of Additive Manufacturing for the creation of complex shapes, especially lattice structure models.

The three clearest restrictions are:

- The design process used to be guided in a traditional (subtractive) way, in which the shape is defined by eliminating material from a bigger plate or billet or by forming a sheet through several operations. Instead, new CAD solutions for 'free shaping' are arising to provide the tools to design parts just adding material (e.g. - Evolve (Altair), Catia Freeform (Dassault), NX Freeform (Siemens), 3-matic (Materialise), Solidworks Freeform (Dassault), Creo (PTC)).

- The conventional data flow from CAD model to a manufactured part involves several conversions between file formats. Most of the times this is a laborious process and with each conversion, a risk of geometric errors that must be fixed before manufacturing is introduced.

- The subsequent steps of CAE analysis and CAM processing of these extremely big CAD models require high capacity systems and even HPC (High Performance Computing) capabilities.

New file formats

New 3D scanning and imaging tools are now emerging as alternatives for traditional CAD programs. In addition, stylus-based and other design technologies that allow consumers to modify digital models themselves— without the need for extensive CAD experience—are expected to drive growth in personal AM.

New file formats that will substitute STL are being developed and the design process is now under evolution in order to support new innovations in AM. The focus is on collecting and defining more properties and parameters at an early stage of the process, and, at the same time, reduce to a minimum the number of file conversions to avoid geometric errors or 'lost in translation' mistakes to occur. Those that are having higher acceptance are AMF[13] and 3MF formats.

AMF has been developed by ASTM Committee F42[14] on AM. This format provides the possibility to assign material types to different areas of the design, and smooth grading between material types. With this solution, lattice structures can be defined designing graded materials. Also, it increases the accuracy of tessellated surfaces.

3MF is the result of the initiative of a consortium[15] of large companies launched in 2015, working collaboratively on a new standard in AM. 3MF improves the description of a model keeping an interoperable and open format, allowing additional functionality and information updates in the future. This concept accommodates larger amounts of data in a smaller compressed file size, allowing multi-material and multi-color support, custom metadata or multiple objects within a single archive.

As a complementary change to the new evolutions in file formats alternative to STL, the evolution of the CAD model into a Voxel model is arising. Voxel is, briefly, a cubic pixel. Voxels are more flexible conforming extremely complex geometries, including those but they generate stair-case structures in all directions. As counterpart, they cannot be easily used as the use of vectorized slices is required.

[12] "A tessellation of a flat surface is the tiling of a plane using one or more geometric shapes, called tiles, with no overlaps and no gaps. In mathematics, tessellations can be generalized to higher dimensions and a variety of geometries." https://en.wikipedia.org/wiki/Tessellation

[13] https://en.wikipedia.org/wiki/Additive_Manufacturing_File_Format

[14] http://www.astm.org/COMMITTEE/F42.htm

[15] Some of these companies are: Microsoft, HP, Siemens PLM, Materialise, Autodesk, Dassault Systems, Stratasys, 3D Systems, Netfabb and others. http://3mf.io/

Qualification flows

Despite the numerous potential benefits of AM, there are significant challenges ahead and maturity is still growing. AM processes must be developed to meet the market's requirements and to ensure that products can achieve the performance levels established by traditional manufacturing methods, as well as, comply with the regulation framework.

AM has specific technical aspects different to conventional manufacturing processes that need to be considered in design. Both the system parameters (like the energy source or chamber conditions) and the part specific process parameters (like the power intensity, layer thickness or energy path) have to be considered. In addition, physical phenomena occurring during manufacturing are complex and other factors as material reusability and the need of post-processing are crucial to assure the final properties of the part. All these technical aspects result in a difficulty to ensure the full process is under control. The variables of the manufacturing process have a strong impact on how the final part will be; differences in manufacturing result in differences in final geometry or physical properties. As a solution, more and more AM systems are incorporating solutions to monitorize parameters and melt pool to predict potential appearance of defects in the final parts, but there is still a lack of real-time smart systems capable to reverse the situation by acting over the most effective parameters.

Unlike conventional well-known manufacturing processes, AM is still not sufficiently understood for establishing a combination of fixed process agreements and acceptance testing to confirm adequate part performance. To solve the current situation, novel standards specific for AM are being developed by national and international institutions (CEN[16], ISO[17], ASTM[18]) at the same time that machines improve their process control to guarantee repeatability and homogeneity. That is especially relevant to extend the use of spare parts produced in the point of use, mindless the remote location it could be. In the interim, the most adopted approach for part certification is that of part-to-part practice.

Re-shaping PLM

As the previous sections showed, information and data flow change in the AM framework. But even more importantly, collaboration flows radically change as well. In the traditional manufacturing scheme, the collaboration process is linear and iterative, as shown in Figure 7.

However, with the introduction of AM and the significant changes it brings, the PLM scenario changes quite drastically:

- There is no longer need for tooling and storage of parts (or very little)
- Design and Engineering/Simulation are combined in a continuous iterative process
- The linearity of the workflow is disrupted (you can go from inception and design directly to manufacturing, and back)
- Third parties, including customers, can join forces with manufacturers in design and in printing – with personalization being key.

[16] http://www.cencenelec.eu/standards/Sectors/Machinery/AM/Pages/default.aspx

[17] http://www.iso.org/iso/iso_technical_committee?commid=629086

[18] http://www.astm.org/COMMITTEE/F42.htm

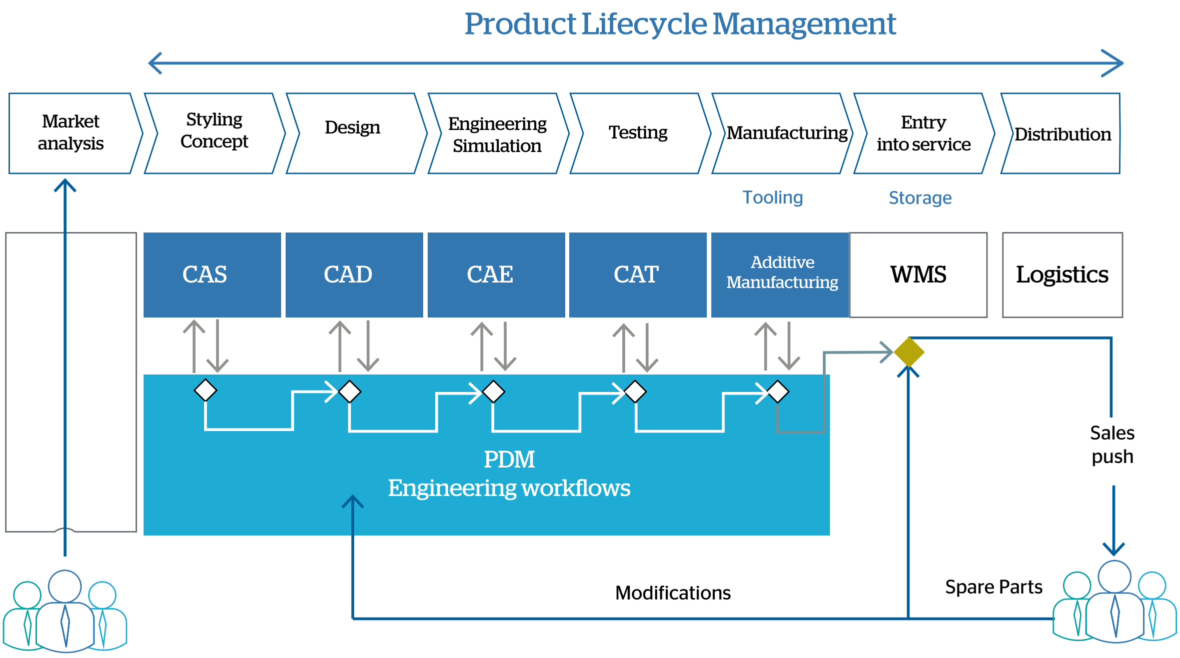

Figure 7 - PLM in traditional (current) manufacturing

But this requires the adaption of current PLM concepts and tools to the introduction of AM as shown in **Figure 9**.

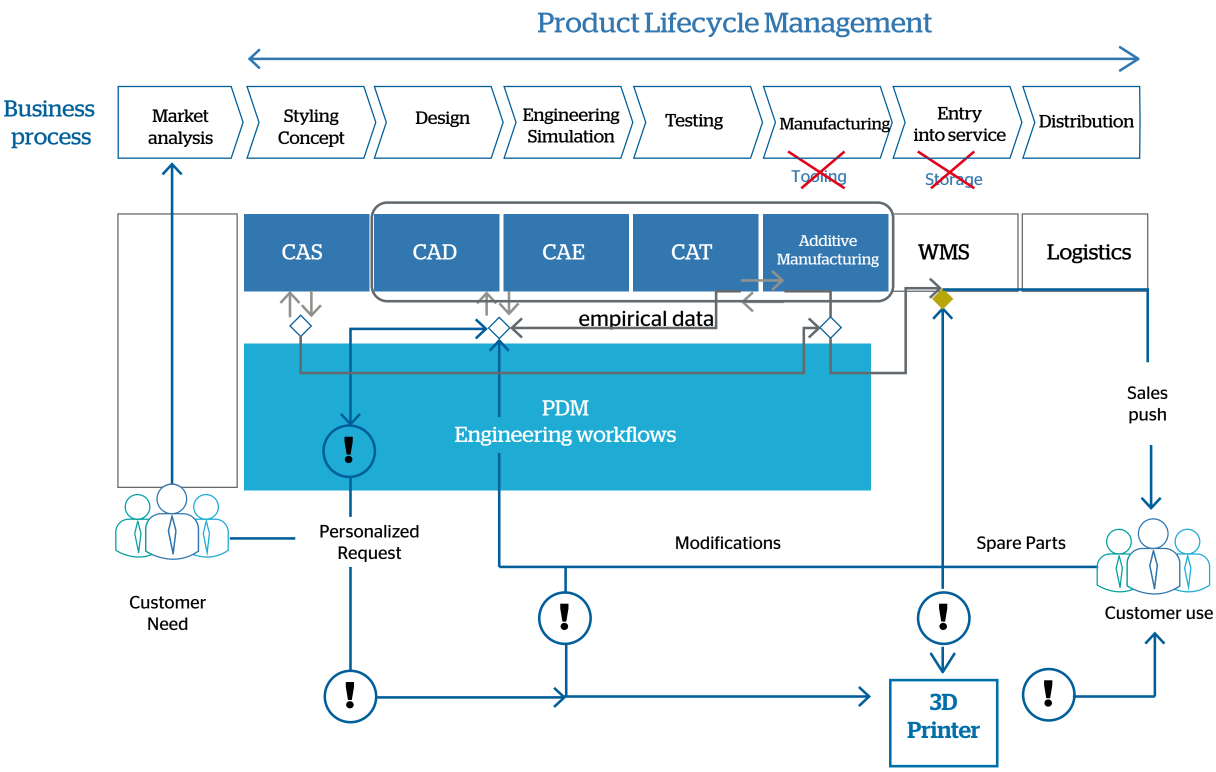

Figure 8 - PLM with Additive Manufacturing.

Security

Providing AM services involves various security and certification[19] aspects. To ensure the trust relationship between manufacturers and the clients, the following essential aspects needs to be secured: Intellectual Property, Digital Right Management, Privacy and IT Infrastructure Security.

Intellectual Property

Manufacturers produce a wide range of products that are often protected by different intellectual properties such as copyright, design right and/or trademarks. According to Bradshaw et al [1] there are four main classes of IP rights that might be infringed by AM, which may be divided into two categories, namely those which require registration and those which arise automatically (unregistered rights):

- **Copyright** - is an unregistered right that protects mainly artistic and creative works.
- **Design Protection** - exists in both registered and unregistered forms and protects the distinctive shape and appearance of items (in particular those that are mass-produced).
- **Patent** - is a registered right that protects novel and innovative products such as mechanisms or pharmaceutical compounds.
- **Registered Trade Marks** - serve to inform consumers of the origin (and by association, reputation) of goods.

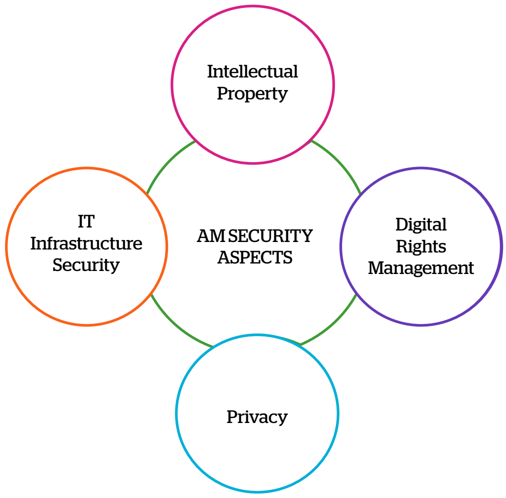

Figure 9 - Security aspects in additive manufacturing

3D printing models are relatively easy reproduced and spread over the internet. Furthermore, an existing solid object might be scanned and reproduced. In a B2B value chain, where many actors are involved, measures need to be put in place to protect manufactures IPs. The important question that needs answer is: who is responsible for protecting manufacturers' IPs? Would it be the cloud service provider? Or would it be the 3D printing service providers? We argue that both actors need to sign legal agreement with manufacturers by the simple fact that both actors have access to 3D models. In order to guarantee protection of IP, smart contract[20] would be a good candidate to help automating IP settlement between the involved parties.

Besides, from a legal point of view, who is the responsible of the quality of the printed part, which guarantees its performance? Is it the designer of the 3D model or is it the manufacturer? What role plays the raw material provider? For example, modifying original copies can lead to lack of robustness of the printed items, hence damaging the manufacturer's reputation. In addition, with current immature regulation, 3D printing service provider run the risk of distributing printed items improperly used.

Digital Rights Management

Digital Rights Management refers to access management of 3D models. It is obvious that a model should not be downloaded and used unrestrictedly. Smart contracts and enabling technologies (e.g. Blockchain) should assure secure management of digital rights. Possible restriction of digital rights depends strongly on the business scenarios:

- Do manufacturers aim to earn money from their 3D model? or
- Do manufacturers sell parts via a 3rd party printer service?
- Do manufacturers use a 3rd party printer service to print prototypes?

The choice between 1, 2 or 3 will require different approaches to digital right management.

[19] This aspect of certified processes and products is addressed with the part-to-part certification process in chapter 2.
[20] https://en.wikipedia.org/wiki/Smart_contract

In the first scenario, a 3D printing service would pay for the usage of 3D models to produce the part with their printer. This implies that 3D models will be transmitted from the cloud to printers. 3D models must be managed in such a way to ensure the full control of model usage. For instance, digital rights management policy should allow the printer to print an object properly, and then it makes sure that the model is removed from the local data base of the printer. Solutions are emerging to enable the streaming of the 3D model to the printer, to difficult the receiving party's access to the whole model. Printing properly means that the printer should be able to print multiple times in case of print error. In the second scenario, digital right management is less necessary because the business model is based on the volume of parts, printed and sold via the 3D printer services. The actors involved would establish commercial agreements in which intellectual IPs are protected instead as to avoid the need for digital right management. In the third scenario the manufacturer would be highly interested that a competitive company would not get hold on the 3D model of the prototype. Digital right management should ensure only the selected 3rd party printer service gets access.

Data Protection

AM architectures need to rely on strong identification and authentication measures destined at ensuring the security of access to the model libraries. From that perspective, data protection challenges are relatively standard but need to be duly factored in at the time of creation of the platform regarding the management of logs, monitoring of accesses, etc. In this respect, the definition and implementation of clear information notices and data management policies covering issues such as terms of retention of log files, conditions and purposes for which access to such information should be granted.

The processing of personal data relating to certain 3D models needs special attention. By nature, AM allows for personalization of the 3D models which can be produced. When dealing with standard "commercial" products, data protection matters will essentially focus on the potential re-use of the information gathered about the end-user for marketing or profiling purposes. In medical context where the AM services are used for the creation of medical devices, each 3D model in question will inherently bear personal health information relating to the person for which it is produced. Health information is, under most legal regimes, considered highly sensitive and therefore subject to strict restrictions, ranging from the right to process such data to localization obligations for it. AM providers may therefore face issues regarding the architecture of their AM libraries to ensure compliance with these obligations and may also need to implement specific security measures to these specific libraries. In addition, AM providers will need to ensure that their customers are provided with adequate information so that they can, in turn inform the end-users of the 3D models and, where relevant obtain their consent to such processing of their information.

Regarding the correct manufacturing of a print, there is a possible hack that must be considered for protection. The printer only reads instructions when it is building a 3D model, it does not need to read directly the virtual model, as it only understands instructions like position, speed, power, etc. Also, as explained before in this paper, the final result of the part is very much linked to these parameters. Therefore, a possible hack could be introduced inside the .gcode of the print, hacking these parameters in a way that, without a smart and interlinked CAD/CAE/CAM security procedure, the print would be modified without a trace. To this extent, homomorphic encryption technology looks promising to increase the level of data protection.

IT infrastructure Security

Infrastructure Security in this context refers to the secure exchange of information among the different components of the AM ecosystem, especially the communication between the server side and the 3D print service. Besides pure network based security, end-to-end security across all layers of the system is an absolute requirement for guarantying the confidentiality and integrity of the 3D models transmitted. End-to-end security could be seen as a holistic security concept, which encompasses three major mechanisms in a seamless and integrated manner: authentication and access control, transport security and system security.

Continuing with the end-to-end protection approach in mind, we envisage that the required level of protection could be achieved by encapsulating the 3D models inside cryptographic containers before transmitting them. These protective containers will include protection and usage requirements and policies based on the sensitivity of the data from which it has been created to ensure data security, and in particular that it cannot be accessed by unauthorized users (or lost), and that data privacy is maintained.

Finally, the system must contain the appropriate components to obtain licenses, extract the relevant cryptographic keys and access the data.

Above of all, the most solid security procedure will be the one implemented in the printer. To this extent a 3D printer and its control software needs to be protected by appropriate security measures.

Integration of digital businesses

Creating a printed object requires additional steps and actors. We propose a new approach for the integration of services in the path to the full digital manufacturing concept. It starts with a need, a request which could be created by an individual consumer or a business consumer. Both target the creation of a solid object, either already available as a 3D model or newly designed.

Finding a Designer: It is the first challenge for the customer. Either the designer is positioned within the organization of the manufacturer or the designer is working independently. If the requirement is not concerning any existing object and no manufacturer is known yet, the search of a capable designer gets more challenging and requires specific attention.

A platform that combines at least the manufacturers and designers could be the easy accessible source for a customer.

Accessibility of a Model: To make a model available for the business or individual consumer, a suitable way should be found. It requires security that a model cannot be tampered with, downloaded and/or printed more than agreed, and not be available indefinitely (if a specific time usage was agreed). However, while meeting all those requirements, the model needs to be accessible in an easy manner to connect to a printer immediately.

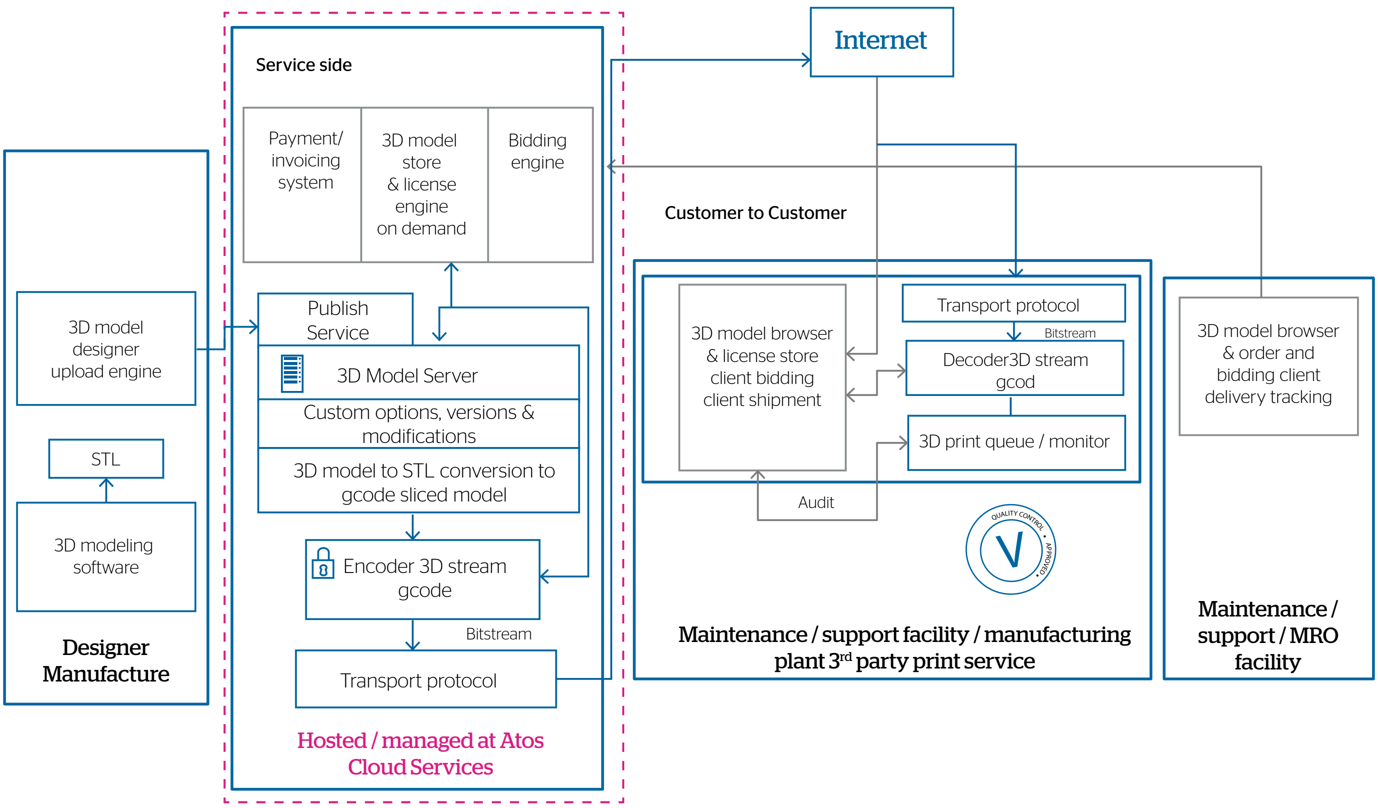

Figure 10 - IT Platform supporting a digital market place

Data format in use: At this stage another challenge shows up: the selected printer could work with a different data format, which would require a conversion to the suitable format. A platform with service function could be the suitable choice if it converts already the manufacturers and designers to use common formats.

Production of the object: An AM printing factory could be the next step to make it easy for the consumer to get the required object produced. The factory consists of several providers, which have several 3D printing machines with different materials and free capacities. The platform supports the process of choosing the right provider using parameters like size, date, material, region, etc. It searches the providers who match the requirements and gives a list to the customer. The customer can choose the AM service provider and ask for an offer and order the printing. Communication between the platform and the factory should be encrypted to ensure the right number of objects printed, the secure communication, and the correct allocation to one specific client. Using protocols and codes through the platform would enable such a security concept.

In the printing factory itself, the platform could further be involved into the licensed model being used by the manufacturing queue, monitoring that the correct object being is handed over to the correct consumer.

Maintenance : In the factory environment, the platform could also be the connection to maintain and support the machines used. Through the maintenance area, manufacturers and technicians could be addressed. This would leverage the investments as well as the operating cost of the factory while using such experts across various independent factories.

Value adding : The platform could also enrich the AM experience by providing further services, e.g. software to evaluate and repair the designs or 3D models. It could include experts who advice the customers which technology or material to use. Besides, the platform could also serve to connect consumers with similar requests at one AM provider to create synergies and optimize labor and machine costs by building several parts in the same production shot.

All connections and roles defined would have difficulties to connect among themselves individually and would need to have specific individual agreements to interact; using a platform and an AM Service Provider could be the integration enablement. Securing Intellectual Property Rights, providing suitable data formats and connecting demand and supply is the main goal of such platform provided by the AM Service Provider.

The system architecture of this platform must be developed for a service-oriented distributed working environment using the most advanced IT technology available, which is core business of an IT company but is not at the focus of manufacturers, designers and AM providers.

In summary, the core of such platform will be an IT management platform which will support the supervision of the overall supply chain process, the parts library management and the information exchange flow between the actors.

Conclusions

The main adoption drivers of the AM technology (personalization; new materials, structures and properties; and decentralized production) will originate game-changing innovations in the next years.

AM will provide opportunities with regard to new products, new product formats, and new product characteristics that are superior to conventionally manufactured ones; as well as new business models and participants. Not only parts production but spare parts management will change dramatically, all over the world and as well in space. The main changes AM will enable are:

- AM will enable new business models :
- Dislocation of spare parts and small product production (towards the final customer)
- Further individualization of supply by allowing for lot size one in a cost effective way, thereby meeting the trend to more individualized demand
- New opportunities like printing human tissue (to "produce" organs), edible printing...
- AM will not substitute conventional production methodologies but will complement them, wherever necessary and beneficial for the manufacturer
- B2B will see a mix of AM service providers and own production by OEMs
- B2C will see internet platforms and "copy shops" providing printing services and design services

However, security issues concerning the misuse of intellectual property have to be solved, especially if the printing of a part is not done by the OEM but a third party. The developments to create standard formats and exchangeability, the certifications and the opportunities of platform concepts will lead to a firm integration of AM into the manufacturing area. This will not succeed unless a new mindset change occurs in the conception and design of the products, to take fully advantage to the possibilities of the new technology.

Addendum: Basics of AM Technology

Additive Manufacturing is the process of joining materials to make objects from 3D model data, usually layer upon layer. Also known as "3D printing", both terms are usually used interchangeably, although the term AM is more related to the use of the technology in an industrial environment and 3D Printing is identified more with the consumer goods and home appliances.

The most extended AM technologies for polymeric materials are "Fused Deposition Modelling" (FDM) for consumer applications, "Stereo lithography" (SLA) for models and prototypes of high complex geometries and "Selective Laser Sintering" (SLS) for industrial applications. The two main AM technologies for metallic materials are "Direct Metal Laser Sintering" (DMLS), and "Electron-Beam Melting" (EBM).

Fused deposition modelling (FDM) is one of the earliest technologies and is based on the principle of melting a plastic material in heating system and delivered through a nozzle on a platform. This principle is used in industrial FDM machines and, as this process is mature and well understood, it is used in many industrial applications. As the patents have already expired, in the last years many home machines came on the market using the same (but much simpler) principle.

Figure 11 shows the principle of an FDM-machine. A head moves horizontally over a platform which is lowered layer by layer so the part moves down step by step.

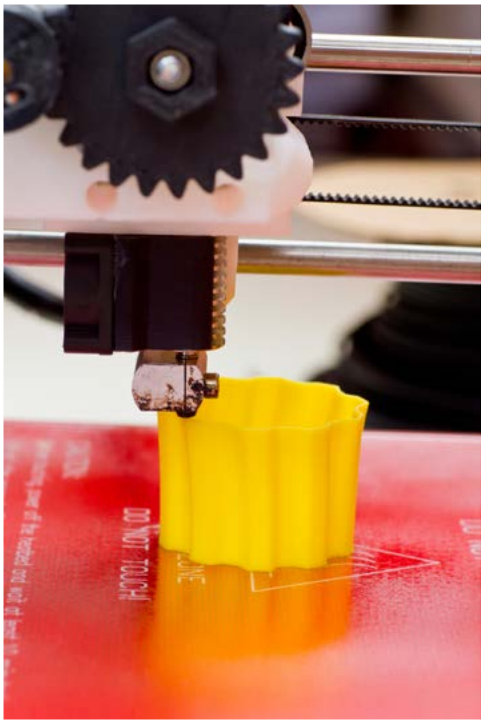

Figure 11 - FDM process

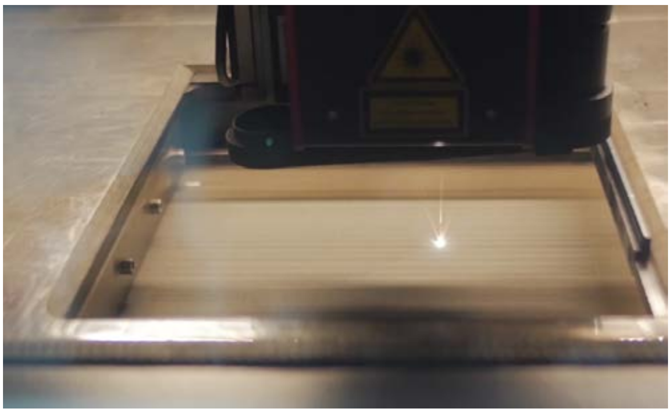

Figure 12 - Laser / Powder based / SLM / LS – proces to process

Laser Powder based processes (SLS, SLM) are based on the use of metalic and/or plastic powder and the energy source of a laser. In this case, a coating system covers a platform with a layer of powder and the laser "writes" the information out of the 3D model (**Figure 12**). The main difference with the Electron Beam Melting (EBM) technology is that, in this last case, the energy source is an electron beam.

About Atos

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