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DIGITAL THREAD FOR ADDITIVE MANUFACTURING

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Abstract: *Additive manufacturing (AM) has been shaping the industrial manufacturing in recent decade due its high performance and benefits over the traditional technologies, especially in the field of prototyping and low volume production. AM transforms 3D models into the physical realm through the several steps know as digital thread, which explain the real digitization nature of this process. This paper intends to emphasis the benefits of AM approach, necessity for creating the digital thread for AM as well as to present some issues related to its applications. Also, some new trends in the development of AM production process (on-line platforms, Manufacturing Execution System, etc) will be briefly explained.*

Keywords: *Additive manufactuirng, 3D printing, digital thread, on-line AM platforms.*

1. INTRODUCTION

In order to stay competitive at the global market companies around the world are trying to find feasibly solutions to improve their products, the way how perform their business, embrace new business models as well as new technologies. Product strategies and new technologies essentially change the process of developing and manufacturing the products.

Survey from [1] highlighted several strategies that companies can leverage to improve their competitiveness: advance product performance, increase product quality, make product smarter, lower cost of ownership for customers (maintenance and energy cost), lower product cost. Same survey further showed that 3D printing, use of new materials, ability to work with scanned data, cloud computing, IoT (Internet of Things), etc, are the technologies that will help companies to execute their strategies.

With previous in mind, it is becoming very clear that 3D printing technologies has taking an important role and this is the explanation why there are so many interests and activity about it. 3D printing or additive manufacturing (AM) are using synonymously but there are the differences. ED term was coin by MIT Institute and it is related to the fabrication of the object through the deposition of materials using print head, nozzle other printing technologies. This definition linking 3D process with binder and material jetting technologies as well as with material extrusion technology. Since the AM is a process of joining material to make objects from 3D models usually layer by layer, it can be stated that 3D printing is sub group of AM technologies.

Starting from the 80-ies years of last century what is count as the appearance of the AM (companies Stratasys and 3D Systems are among the first to develop and apply AM technology), this technology keeps growing at record speed and its adaption increases. As it stated in [2] professionals use AM for two main purposes: 1) as prototyping solution for increase product development and 2) in manufacturing as low-run production.

Same authors further explain the benefits of this technologies are as follows: functional and accessible solution and effective design in prototyping phase, as well as fewer design restriction, on-demand production, mass customization, distributed manufacturing in production phase, AM processes enable minimization of material waste with direct manufacturing and no tooling needs. In addition to these benefits, it should be mentioned that prices of AM technologies are coming down while the speed of the manufacturing is increasing. These two elements have been seen as two main downsizes of AM.

There are the elements of disruption in the emerging of AM. Disruption is observed from the use of new process (adding material instead of subtraction), new services (on-line manufacturing platforms), use of information communication technologies (ICTs), and all together threaten to displace conventional methods (CM) of manufacturing in some fields. CM is not in position to create complex shapes (especially inside structure), there are limitations in use of materials and performances of

products, as well as limitation in further improvements in production process (lead time, cost reduction, quality, etc).

AM is one part of the new digital manufacturing production, and together with digital thread (or CAx chain), digital supply chains and smart factories, forming the new manufacturing landscape. With the embrace of new technologies, it is worth mentioning that many professionals choose on-line manufacturing platforms as the solution to fulfill their 3D printing requirements.

After the introduction that explains the market trends related to AM, next chapter is dedicated to the explanation of basic elements of additive manufacturing, while the 3rd chapter is dedicated to the main topic of this paper – digital thread for AM. The next chapter gives some basic information about new approaches and business models that support industrial/cloud application of AM. In conclusions, brief overview of presented information is given with suggestions for further research in this area.

2. THE BASICS OF ADDITIVE MANUFACTURING

In order to precisely define AM as well as to list the AM categories, almost all authors usually referring to the officially statement and definitions from American Society for Testing and Materials (ASTM) group ASTM F42 and the ISO 17296 committee. With this in mind and according to [3] AM is 'the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

Following the same referring methodology and authors, there are seven categories of AM technologies [3]: 1) vat photopolymerization including Stereolithography (SLA) and Direct Light Processing (DLP) 2) material jetting, 3) binder jetting, 4) material extrusion including Fused Deposition Modelling (FDM) and FFF (Fused Filament Fabrication), 5) Powder Bed Fusion (PBF) including Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Direct Metal laser Sintering (DMLS) 6) sheet lamination including Laminated Object Manufacturing (LOM) and 7) direct energy deposition including 3D laser cladding and Wire Arc Additive Manufacturing (WAAM).

AM technology is capable to produce fully functional parts using a wide range of materials: metal, ceramic, polymers and their combinations, composites or functionally graded materials (FGMs), [4]. For full functional production SLS, SLM and DMLS technologies are by far the best possible solution to do it.

AM technology is applied in various industries: aerospace and automotive industry, military industry, healthcare and medical industry, food industry, architecture, building, and construction industry, fabric and fashion industry, electric and electronic industry, etc.

Many companies' sees in AM process as a replacement for conventional manufacturing process or in some cases augmented it (technology process known as hybrid AM or the combination of conventional and AM techniques).
So, at the first place, the advantage of AM is eliminating the tooling that goes with manufacturing and instead printing parts directly. This leads to the elimination of the time and costs linked with making this type of tool, [5].

AM gives new opportunity for designing of the products, with the introduction of the Design for the AM (DfAM) framework which deals with the design of the product, but at the same time focusing on manufacturing and assembly of that product. As it published in [6] and further explained in details, techniques for optimization of product geometry based on DfAM are: 1) Light-weight design (Complex design) including: topology optimization, application of bionic principles and transformation of shapes from nature and lattice and cellular structures, 2) Component consolidation (design of integrated geometries - several parts connected into one functional unit), 3) Design for functional integration - multifunctionality achieved by shape, 4) Design to improve the function and performance of the work, 5) Tool optimization and 6) Customization.

AM support traditional manufacturing process through the production of fixtures, jigs and tooling setups for machining and operations. These are low volume parts, but they are needed quickly and not need to be metal product (can be plastics, composite materials).

With the use of 3D models as a prerequisite for AM, and since the company beginning to explore what can be done with AM, digital inventories instead of physical ones came as good solution.

AM in form of DDM (Direct Digital Manufacturing) is part of the production of end-use components and products, and in most cases it is not just the extension of the rapid prototyping. With the advantage of the geometric complexity of the AM with DDM it can be produced parts with customized geometries.

3. THE DIGITAL THREAD FOR ADDITIVE MANUFACTURING

Due to the intensive technology development exchange of the information in manufacturing chain has become data intensive and digitalized. Digital thread is the communication framework that enables digitally connections among involved parties (designers, customers, AM providers, OEMs) providing material and manufacturing information, according to [7].

In digital thread information exchange are occurring in both directions, feed-forward and feed-back loops, and connects process stages from design, through simulation and build plan, process monitoring, control and verification [7]. All this information need to be a part of a single digital thread, accessible, traceable and interoperable with all machines within the process chain.

The typical information flow is presented on the Figure 1, (5). Each step uses a different piece of software (one software for design, other for simulation, then for printing, etc). Each of these software often requires a

different file formats, which later require file to be converted causing information to be lost. Beside these issues, researchers in the field of AM digital thread identifies some other challenges: lack of digital standards, disjointed digital thread that can cause the lost of information, etc.

Figure 1: Barriers to industrializing AM, [5]

With previous statement in mind, the importance of having an integrated end to end software solution, as unbroken digital thread of data, is becoming priority. Current markets are limited with new and powerful set of fully integrated solution for AM chain.

AM digital thread: The common vision for the digital, or CAx chain of AM is composed of five principal steps (Figure 2.).

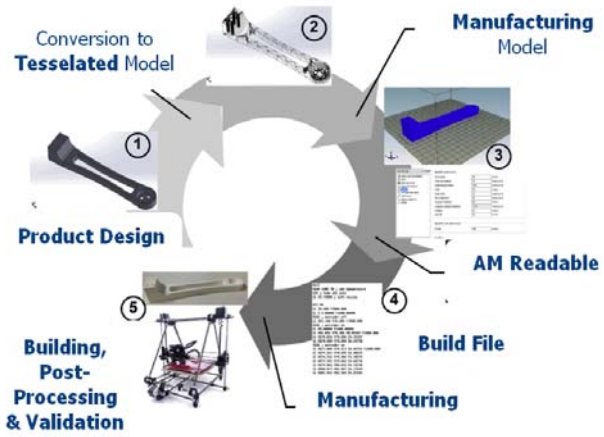

Figure 2: Typical AM digital thread, [3]

Process starting with the creation of a 3D model (by design or scanning) mainly using CAD software. After that, the 3D model is in most cases converted to an STL file format (first known AM format and accepted by almost all AM machine).

In order to overcome some lost of the information during the conversion to STL format, new formats have appeared: AMF (Additive Manufacturing Format) and 3MF (3D Manufacturing Format), Standard for the Exchange of Product model data (STEP), and STEP compliant Numerical Control (STEP-NC), [8, 9].

File in the appropriate format is then transferred to the slicing engine (or "CAM system"). After the part positioning/orientation at the build plate, slicing of the part into individual layers starting, with the manufacturing information settings and tool-paths generation (creation of G-code that printer uses to print the file). In complex AM processes, like SLS, SLM, DMLS, all of these steps are processes in different software's.

Post-processing can consist of several process which in basic include separating the print from the build plate and/or removing any support material (by melting or dissolving), and in some cases can comprise CNC machining and thermal treating.

Validation process is part of control, which helps to trace back the settings and conditions used throughout the design and build phase in order to compare it with initial data/design and make corrections.

4. NEW APPROACHES AND BUSINESS MODELS FOR SUPPORT INDUSTRIAL AM

This part is dedicated to the explanation of the Manufacturing Execution System as support for industrial AM production, as well as cloud-based solutions and new business models for AM.

Manufacturing Execution System: In the beginning of its appearance, AM was just a prototyping tool. Now days AM is a viable option for small serial production with intention to reach full serial production capacity in near future. To exploit the full potential of AM technologies and hardware/machines particularly in light of serial production, some issues still need to be resolved, like: organization of AM workflow and information movement, improvement of AM machine efficiency, optimization of AM process, etc.

Manufacturing Execution System (MES) is designed to address these challenges and help to run and monitor lot of more activities in production real time. MES offers running of several AM process simultaneously (even with different machine configuration), data acquisition and processing, scheduling of operation, handles management of the chain of process steps needed to create parts, control of resources and allocation, dispatching production to machines and workers, provides a bidirectional link between the enterprise planning layer and the shop floor, etc, [10].

Some MES solutions (instant quoting, 3D file optimization, and nesting) are specifically designed for additive manufacturing environments, and called Additive MES solutions.

MES features are serving as foundation for implementing Industry 4.0 concept providing manufacturer process to be smarter by supplying on-line data.

Cloud based solutions and new business models for AM: Additive manufacturing is a technology that changes engineering process and production, but also changes how the business is conducting. New business models, following the latest development in ICT technology, are now cloud-based collaboration platforms.

In order to make this business models works efficiently all relevant factors are included in its building and functioning: hardware and software vendors, material

vendors, part buyers, print SME, etc.

Idea behind this solution is to support the industrial business process, speed up the production as respond to customer request, organize the production close to the end user and reduce customer need for AM and IT infrastructure.

Manufacturing service providers and online manufacturing: According to [2] AM service provider sector is one of the fastest-growing sectors within the 3D printing industry, with its participation of 34% in total revenue.

AM service providers offer for businesses outsourcing of their AM production, helped further advancement of the technology, broaden the range of available applications, and provide more choices for OEMs to select AM manufacturers, [11].

World famous and leading hardware manufacturers, well known as the founder of AM technology Stratasys and 3D Systems, also offering AM services as part of their business model.

Particular opportunity for the AM services market is Metal additive manufacturing, and predictions for the revenue in this area is around 9.4 billion dollars by 2025, [11].

The new business models that provide manufacturing services are the "online manufacturing" or "MaaS – Manufacturing as a Services". Beside AM services they also provide conventional manufacturing services as well as injection molding. This is the online platforms and on-demand services, connect world manufacturing suppliers with end users, and automate the procurement and sourcing process. As it stated in [11], 35-45% of AM service providers share can be attributed to "online manufacturing".

5. CONCLUSIONS

Leading world companies in many industrial areas are discovering that the future of digital part production lies in adopting new technologies which transforming it and upgrading to a new capability. One of these technologies that create new and additional value to the product is the additive manufacturing.

Additive manufacturing technologies provide the creation of parts on totally new and innovative way (adding materials in layers), in contrast to traditional manufacturing process (subtractive approach), and with unique design, shape and parameters improvements (lightweight structure, strength and durability).

In order to connect various applications and processes within digital part production companies need to set up the digital thread. Basic frameworks for digital thread is presented in this paper.

Above mentioned parameters improvements can be achieved in digital thread through continuous digitalized communication feedback loop, which enables connection between shop floor, engineering and front-end design process. Digital thread with feedback loop provides data transfer, elimination of duplication of data, inclusion of information from production to design stage, and in general offer the product with highest possible quality. This information exchange is very important in the process of development and production of complex combat systems.

But, with all its benefits and improvements, additive manufacturing technology is not being used to its full potential. Some barriers still exist and can be attributed to the limited know-how among designers, lack of understanding of benefits, price of machines and some type of materials, etc. As it already stated in the introduction of this work, the prices of the AM process are coming down while the speed of the process is increasing.

Nevertheless, there are several AM areas that are currently (and will be in future) subject of wide scientific research like materials, machine technologies, process parameter optimization, sustainable manufacturing, as well as business opportunities and solutions linked with these processes.

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