ADDITIVE MANUFACTURING – INTEGRATION INTO UNIVERSITY EDUCATIONAL PROGRAMS OF UZBEKISTAN.

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Additive Manufacturing (AM), or commonly known as 3D printing technologies, have been first developed for rapid prototyping and now they are being used for rapid manufacturing. The main reason is that the AM technologies have greater advantages compared to conventional manufacturing, allowing production of final products with optimized performance and complex shape. This paper studies the growing attention to the AM by research institutes and the offered AM courses by Politecnico di Torino. Based on this study, the integration into university programs of Uzbekistan and the implimentation of AM centers in the utilisation of the AM benefits are discussed.

Keywords: 3D printing technologies, CAD, CAE, CAM, rapid prototyping, educational program.

Introduction

Technology will play a central role in driving change. Many of the technologies including ICT, sensors, advanced materials, robotics and additive manufacturing that are likely to transform manufacturing into mass customisation, decentralized manufacturing, digitised manufacturing value chains. To prepare us for key opportunities and challenges and to ensure we use this changing manufacturing landscape, those technologies should be studied, developed and adopted locally.

Additive manufacturing, commonly known as 3D printing is the general term for those technologies that are based on a 3D CAD geometrical model, create physical objects by successive addition of materials. The importance of additive manufacturing (AM) to the future of product design and manufacturing infrastructure demands educational programs tailored to embrace its fundamental principles and its innovative potential.

Advantages of Additive Manufacturing

Additive Manufacturing (AM) technologies offer greater advantages compared to conventional manufacturing technologies and the main benefits are listed and briefly described in the Table 1, [1],[4],[5].

Table 1. The advantages of AM

Benefit	Description
Shape Complexity	It is possible to build virtually any shape, including complex cellular structures and hierarchical (from nano to macro scale) constructions, as well as optimized material distributions that is achieved by topology optimization tools.
Material and property tailoring	Material can be processed one point, or one layer, at a time, enabling the manufacture of parts with complex material compositions and designed property gradients.
Functional Integration	It is possible to embed components (e.g., hardware, sensors, actuators), fabricate working kinematic joints, and deposit conductive materials directly using AM processes.
Lightweight Design	Lightweight Design is one of the core advantages of AM parts. Through optimal distribution of materials or cellular structures, the weight of the final product can be reduced significantly, without limiting functional performance and strength. The technology has already proved to be a viable production technology in the aerospace, automotive and medical industries.
Decentral Manufacturing	Decentral Manufacturing describes distributing the production to local production facilities as compared to centralized production facilities. Each small production facility is supplied with the material necessary to produce the required parts, as compared to distributing final parts. The local manufacturing units can specialize on regional product variants. Once large production capacities are required, an intelligent platform distributes build jobs according to a multiobjective optimization.
Mass Customisation	AM allows for the production of small batches, up to lot size one. Customer requirements can be met more specifically, products can be adapted to a single customer. The medical industry takes great advantage in production of custom prostheses. For the manufacturing industry, potentials can be sought in products with many variants and in products which are directly sold to the consumer.
Repairing Parts	Abrasion due to mechanical load or temperature cycles often causes the replacement of whole parts or groups of parts. Here, AM has the potential of printing material onto worn out surfaces via e.g. Laser Melting technology. Repair using AM is especially useful for large components, e.g. aerospace products, which saves time and money for the production of new component.
Rapid Prototyping	Rapid Prototyping describes the production of design or functional prototypes via layer wise manufacturing. Potentials can be sought in complex product development products, volatile customer demand and daring projects which require for fast feedback loops.
Reduce Time to Market	The mega-challenge „shorting product life cycles“ necessitates shorter development cycles. AM has proven to be a viable option in order to shorten development cycles. 1) As a Rapid Prototyping technology, it allows for faster design feedbacks and functional testing and 2) as a Direct Manufacturing technology, the production of additional tools is unnecessary, therefore it enables a production directly from CAD file.

Current Research Institutes in the world

The impact of AM and its increasing adoption in many fields are also supported with the initiatives to open research centers taken by governments of many countries and the integration into conventional undergraduate and graduate programs. The main aims of the research centers and institutes are to develop new 3D printing technologies and products, to bridge research and product development gaps while educating 3D printing technologies to students, engineers, companies, and designers [2],[3]. Leading 3D printing research centers in the world are:

- **The Engineering and Physical Sciences Research Council (EPSRC) Center for Innovative Manufacturing in AM in the United Kingdom.**
  The center has a total fund of £8.1 million from the government and numerous participating companies and is focused on the development of multimaterial and multifunctional products.
- **National Additive Manufacturing Innovation Institute (NAMII) Institute (subsequently known as America Makes) in the United States of America.**
  A fund of USD 70 million from the government and participating companies was initially awarded to the institute which is a consortium of 40 companies, 9 research institutes, 5 colleges, and 11 nonprofit organizations.
- **Singapore Centre for 3D Printing (SC3DP) in Singapore.** It is a nationally funded center that provides world class 3D printing facilities with close to SGD 150 million funding. The four key industries that SC3DP is focusing on are: (1) Aerospace and Defense, (2) Building and Construction, (3) Marine and Offshore, and (4) Future of Manufacturing.
- **The Direct Manufacturing Research Center (DMRC) in Germany**. It was founded in 2008 involving several industries and academia, namely: (1) Boeing, (2) Electro Optical Systems (EOS), (3) Evonik Industries, (4) SLM Solutions GmbH, and (5) University of Paderborn.

Politecnico di Torino – Additive Manufacturing Courses

Politecnico di Torino offered the first biennial Master Course in Additive Manufacturing, which started in January 2016. It is a second level Master Course that delivers 400 hours of classroom training and 800 hours on the field, with partner companies: Comau, Ellena, GE Avio, Iris, Prima Electro, Prima Industrie. The objective of the Master Course is the training of young and motivated, newly-graduated engineers in order to create a new generation of high-level specialists in the Additive Manufacturing process field. The disciplines that are studied and applied in the field include:

- **Design for Additive Manufacturing.** The objective of this course is to illustrate the advantages of AM in order to fabricate complex geometry using topology optimization tools or cellular structures with the aim to maximize part performance and minimize the weight of the part. Design for Additive Manufacturing guidelines are explained and discussed in detail taking into account the specific requirements of different technologies and materials (plastics or metals).
- **Materials for Additive Manufacturing**. For each AM technique, available materials and innovative ones are presented and deeply described. In addition, in the case of selected products an evaluation of the microstructural features will be presented, underlying their role on the identification of the best process parameters.
- **Additive Manufacturing systems.** The module provides an overview of the systems for additive manufacturing (AM). Starting from the description of the basic principle of additive manufacturing, the developments over the past decades are outlined , illustrating the current application fields and analyzing the potential and limitations of AM, considering the impact on production management and possible future advances.
- **Advanced sensors for the control of Additive Manufacturing systems**. First, the issues concerning the use of sensors for the control of additive manufacturing systems and the basic knowledge of the theory of sensors are analyzed. Then, the different types of existing sensors and advanced sensors based on the principle of Micro Electro Mechanical Systems (MEMS) are studied.
- **Integration of Additive Manufacturing technologies with conventional processes for parts' finishing.** Additive manufacturing technologies allow the production of metal components without the use of tools and fixtures. However, current AM products have poor surface quality, that is solved by hybrid machines that are able to deposit the material but also to remove it.
- **Systems for the evaluation of products made using Additive Manufacturing**. The general principles of Metrology together with the description of the most common instruments, principles and methods of measurement in additive manufacturing systems. Through studying the basis for designing and implementing a system for quality control in a production context, the module concludes with the current standards for Quality Management (ISO 9000 family), their implementation in a production organization and the obtainment of the relevant certification.

- **Production management in Additive Manufacturing systems.** The course deals with the analysis of how additive manufacturing impacts on production management and hence how production management must be changed with respect to traditional manufacturing systems.
- **Supply chain management in Additive Manufacturing systems.** This course introduces the main supply chain management topics and applies them to Additive Manufacturing (AM) systems. Comparisons between traditional and AM supply chains are made by discussing real applications.
- **ICT platforms for facilitating the integration of Additive Manufacturing in traditional manufacturing processes.** This course provides the basic notions concerning sensing and actuation devices, their interconnection and embedding in advanced AM systems. In addition, it offers an overview of state-of-the-art techniques, algorithms and tools for image processing and pattern recognition, which are at the core of ICT platforms that enable an improvement of the performance (speed, quality of the product, etc.) of AM systems and facilitate their integration into traditional manufacturing processes.
- **Managerial training processes.** The training module aims to develop "soft skills" and will cover the following topics: Communication, Leadership and Teamworking, Problem Solving & Decision Making, Economics, Project Management, Cross cultural management.

Additive Manufacturing integration into university curricula in Uzbekistan

To prepare engineering people in Uzbekistan to the changing manufacturing landscape, technical universities in Uzbekistan could also include AM related courses to their academic curriculum. The study of Additive Manufacturing technologies include multidisciplinary subjects from mechanical and material science to electronics and computer engineering.

Possible program of mechanical engineers that may include topics related to additive manufacturing is as follows:

Engineering Drawing	The fundamentals of engineering drawing and computer aided design could be followed by design guidelines for AM technologies. Orientation of the part, support structure generation, topology optimization tools and cellular structure types could be discussed.
Technology of metallic materials	Metal AM trend is increasing, but requires further understanding of microstructure, in-process material properties to control residual stress distortion and in-process material consistency.

Science and technology of materials	A comprehensive understanding of the material properties that most affect micro-structure and those that can cause material deviation is essential to designing new materials for AM (e.g., faster solidification rates with new high-temperature alloys). Polymeric, ceramic materials for AM can be discussed.
Manufacturing Processes	Description of the AM systems' basic principle, types, application fields, advantages and limitations, and the impact of future products development and manufacturing. Comparison between conventional and AM machines are also useful to determine optimal manufacturing process for a specific product.
Industrial Plants and Project Management	The influence of AM on production management and supply chain management and the adoption to AM systems could be a part of the course.

The realisation of additive manufaturing centers can be usuful to gain practical skills related to AM and facilitate the learning process. For example, "Metrology" or "CAD/CAM/CAE" center can provide tools as topology optimization software, cellular structure building software, product simulation and analysis through CAE. The expertise can share skills to design products for AM and offer courses related to this for engineering staff of the manufacturing field. "Technopark" is equipped with various machines including CNC and 3D printing machines, where the digital product model can be directly produced. The study of the usage of AM machines, AM related postprocessing techniques can be implemented and final product properties can be studied in the "Technopark". AM machines are also useful to produce robotic parts in very fast and efficient way, and this can be done in the "Mechatronics" center of the universities.

Conclusion

Today, the manufacturing landscape is changing due to technological advancements including additive manufacturing technologies, robotics, advanced materials and ICT. Therefore, most of the leading universities are paying attention to the study and integration of those technologies into their academic curriculum, including Politecnico di Torino to prepare young generation for the global challenge. The Additive Manufacturing courses of Politecnico di Torino can be adopted to the curriculum of technical universities of Uzbekistan. The educational universities of Uzbekistan aims to cooperate with foreign universities and to establish international educational standards within the university. The development strategy of educational system of Uzbekistan also includes the creation of new courses based on the global demand and

future potential. Therefore, it is also recommended to create the AM related centers where AM related practical skills can be developed and research can carried out.
In any case, the results are affected by some limitations worth being considered by readers.

- Insufficient available information about the AM related courses in university's curricula in Uzbekistan
- Future work will be necessary to consider greater number of AM related courses in university programs worldwide and adopt the best practice into national educational programs

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