DEMO or DIE

Develop Engaging Massive Open Online Resources for Designers Innovative Education

DOD Article #2: Benefits of 3D Printing in Sustainable Manufacturing

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DEMO OR DIE (DOD) is a European Commission-funded Erasmus+ programme aiming to promote Open Access to Online Training in 3D Printing to professionals from non-manufacturing backgrounds and students from vocational education and higher education. 3D Printing is the popular name for what is technically termed as Additive Manufacturing (AM) also referred to in the past as freeform fabrication, rapid prototyping, and layer-based manufacturing[1]. 3D Printing is a manufacturing method that creates physical objects by joining materials in a precise and successive layer-by-layer fashion. The manufacturing sector is considered the second highest contributor in greenhouse gas emissions in EU, second to the energy sector[2] and therefore, is of great importance to implement green manufacturing practices to ensure sustainable growth. Green manufacturing is defined as an effort to reduce the environmental impact of human activities, and to create a more resource efficient and competitive economy[3]. Sustainable development is defined as "the simultaneous pursuit of economic prosperity, environmental quality, and social equity"[4]. Sustainable manufacturing employs processes that are non-polluting, conserve energy and minimizes use of natural resources, leading to activities that are economically sound and safe for employees, communities, and consumers alike[5]. 3D Printing has the potential to enable sustainable development through a series of benefits, including, but not limited to efficient design, streamlined manufacturing, improved material efficiency, use of recyclable, biofriendly materials and by-

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[1] Gibson I, Rosen DW, Stucker B (2009/12/30) Additive manufacturing technologies: rapid prototyping to direct digital manufacturing, 1st and 2nd edns. Springer, Berlin

[2] Panagiotopoulou, Vasiliki-Christina & Stavropoulos, Panagiotis & Chryssolouris, George. (2022). A critical review on the environmental impact of manufacturing: a holistic perspective. The International Journal of Advanced Manufacturing Technology. 118. 10.1007/s00170-021-07980-w.

[3] Dornfeld, D.A. (Ed.) Green Manufacturing: Fundamentals and Applications; Springer Science & Business Media: Berlin, Germany, 2012.

[4] Elkington, J., 2013. Enter the triple bottom line. In: The Triple Bottom Line. Routledge, pp. 23e38.

[5] Lozano, R., 2008. Envisioning sustainability three-dimensionally. J. Clean. Prod. 16 (17), 1838e1846.

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products, decentralising manufacturing, increasing supply chain resilience, increasing product affinity while at the same time having a positive social impact.

Efficient Design and Streamlined Manufacturing

Through 3D Printing, parts can be created with shapes and features unachievable with other manufacturing methods, so that we no longer have to worry about sacrificing part functionality to achieve ease of manufacture. The knock-on effect of this design freedom, is optimisation of parts with improved product functionality that can lead to overall higher quality products, both in terms of functionality and aesthetics. Moreover, compared to conventional manufacturing processes, 3D Printing does not require the use of fixtures, cutting tools, coolants, and other auxiliary resources, streamlining the manufacturing process, reducing costs and paving the way for made to order personalised products.

Improved Material Efficiency

Unlike conventional methods of manufacturing where large amounts of material is removed during production, for example in the case of aerospace applications, the "buy-to-fly" ratio is often ranging from 12:1 to 25:1 [6], 3D Printing uses raw materials efficiently by creating parts layer by layer and having the ability to selectively deposit material only where it is needed. This enables the optimization of each design in terms of shape and weight, through the use of topology optimisation and generative design software. Moreover, the added design freedom allows for functionality integration and part consolidation, meaning reducing the total number of product parts by substituting assemblies with single more complex parts without compromising the functionality of the product. In addition to using less raw materials and minimising assembly time and costs, part consolidation and light weighting in the transport industry e.g., in products like aircraft and cars, has a direct effect on the energy they consume during their lifespan, where every kg saved in an aircraft reduces the annual fuel expenses by ~US$3000[7] while also emitting less greenhouse gases such as CO2.

Use of Recyclable, Biofriendly Materials and By-products

A wide range of polymer materials are used in 3 Printing, which can be recyclable or biodegradable, while the commitment of using raw materials obtained from natural and renewable resources, as opposed to oil, is increasingly notable [8]. Moreover, recycled materials, waste filament, by-products of other processes such as wood or saw dust from timber processing and even misprinted parts can sit alongside virgin materials for the 3D Printing process[9]. Some notable applications on the use of the above materials are listed below. German automaker Audi has developed an in-house upcycling programme that uses their

[6] https://www2.deloitte.com/us/en/insights/focus/3d-opportunity/additive-manufacturing-in-lca-analysis.html
[7] Hopkinson, N., Hague, R., Dickens, P. (Eds.), 2006. Rapid Manufacturing: An Industrial Revolution for the Digital Age. John Wiley & Sons
[8] https://www.triditive.com/article/what-is-the-environmental-impact-of-additive-manufacturing/
[9] Simon Ford, Mélanie Despeisse, Additive manufacturing and sustainability: an exploratory study of the advantages and challenges, Journal of Cleaner Production, Volume 137, 2016, Pages 1573-1587

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own packaging materials and 3D Prints them into tooling use in assembly lines[10]. Adidas and Parley for the Oceans produced footwear by combining printed midsoles with upper parts made from recycled ocean waste plastic[11]. The Horizon 2020 BARBARA Project[12] (Biopolymers with Advanced functionalities for Building and Automotive parts processed through Additive Manufacturing) developed eight new bio-based materials suitable for MEX 3D printing that were produced by extracting natural dyes, bio-mordants, antimicrobials, and essential oils from pomegranate, lemon, almond shell, and corn.

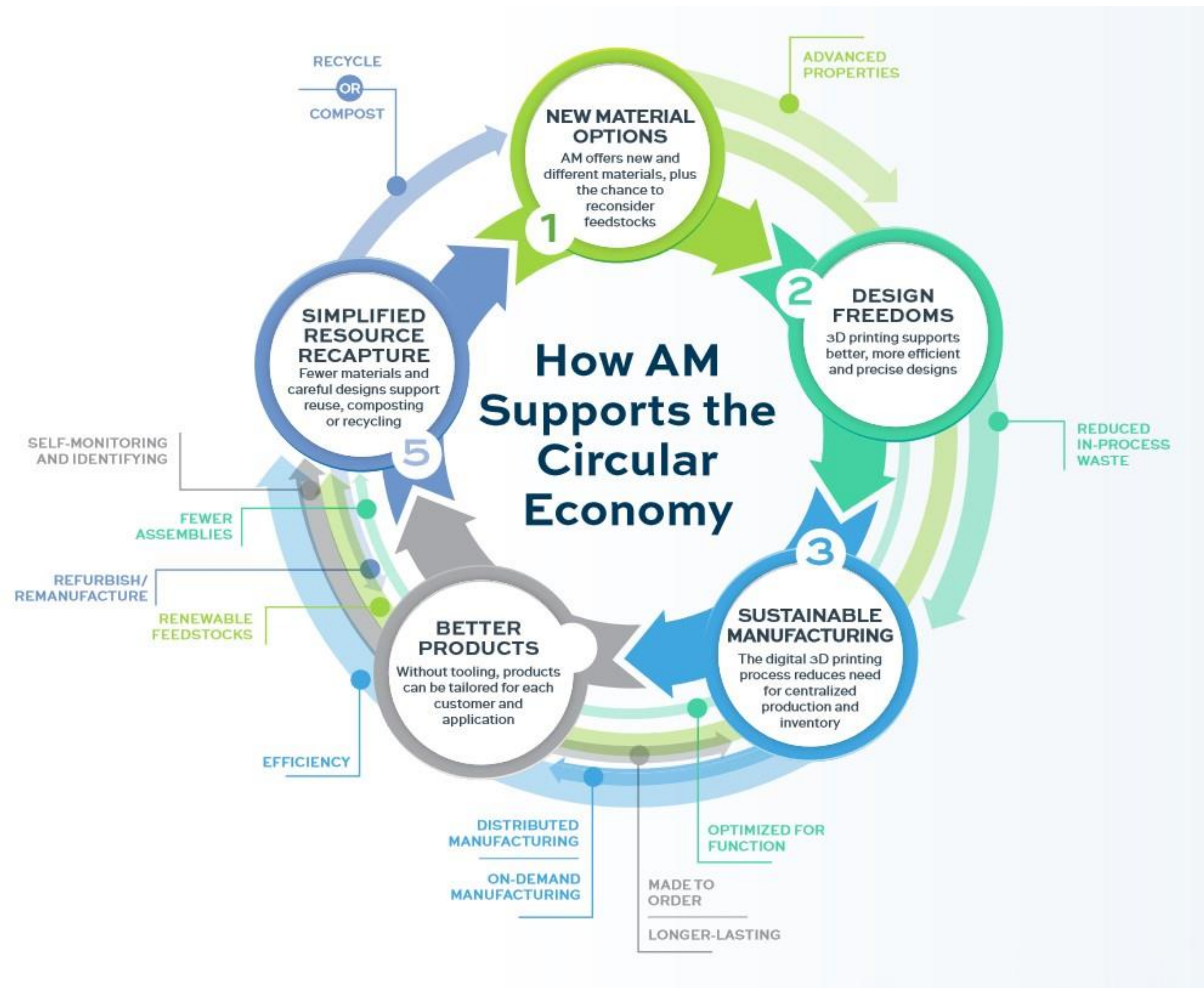

Figure 1: Benefits of AM on Sustainability (https://www.additivemanufacturing.media/cdn/cms/AM%20CircularEconomy.pdf)

[10] https://3dprinting.com/automotive/audi-3d-prints-their-packaging-trash-into-new-parts/
[11] https://www.3dprintingmedia.network/am-for-sustainability-3d-printing-a-better-tomorrow/
[12] https://www.barbaraproject.eu/

Decentralized Manufacturing and Supply Chain Resilience

3D Printing enables decentralized manufacturing of products, that means manufacturing products near the customers, where the net effect is the reduction in transportation and warehousing costs with great impact on the environment. According to the 2020 Advance of Greenhouse Gas Emissions by the Ministry for the Ecological Transition and the Demographic Challenge, 17.6% of GHG emissions are linked to transport[13]. Traditionally, supply chains have existed using the three modalities of logistics: ground, air and sea, while AM creates a fourth, vastly more efficient modality: the Cloud, where physical storage can be replaced with Virtual Warehouses. Moreover, 3D Printing machines do not require costly setups and are hence is economical in small batch production[14], enabling a lean supply chain through just-in-time (JIT) manufacturing. This reduces the risk of excess inventory, instead of producing and holding large volumes of product, the manufacturer only starts production after an order is received from the customer. An added benefit is the shortening of the supply chain, which increases its resilience, an effect that was prevalent during the Covid-19 pandemic or the blockage of the Suez Canal, where long supply chains were disrupted causing a myriad of problems.

An area where all the above benefits materialize is the spare parts supply chain. Traditionally, when a component in a product breaks the consumer will either discard or repair the product depending on the value of the product and the cost and ease of its repair. But for the companies maintaining an inventory of replacement parts is costly and there is great uncertainty over future demand for replacement parts, where 3D Printing provides the capability of repairing, upgrading, and remanufacturing of products, enabling a reduction in energy consumption and costs[15]. An interesting case study is Renault's Re-Factory, a factory that retrofits vehicles rather than building new ones, where Renault's engineers will work to extend the lifespan of second-hand cars by efficiently managing and recycling the materials and spare parts it has on-site. [16].

Increased Product Affinity and Social Impact

From a sustainability point of view, product quality has a direct effect on the product longevity. The term design quality includes both technical quality and desirability of a product[17] and products that not only function pleasingly but are also customized for the individual needs of the customer, create lasting objects of desire, pleasure and attachment increasing the loyalty of the customer to that specific product[18]. Finally, in an increasingly homogenised world 3D Printing has the potential to improve sociocultural

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[13] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690579/EPRS_BRI(2021)690579_EN.pdf

[14] Huang, Samuel & Liu, Peng & Mokasdar, Abhiram & Liang, Hou. (2012). Additive manufacturing and its societal impact: A literature review. The International Journal of Advanced Manufacturing Technology. 67. 10.1007/s00170-012-4558-5.

[15] Morrow, W., et al. (2007). Environmental aspects of laser-based and conventional tool and die manufacturing. Journal of Cleaner Production, 15(10), 932–943.

[16] https://www.renaultgroup.com/en/news-on-air/news/re-factory-the-flins-site-enters-the-circle-of-the-circular-economy/

[17] Mehrpouya, Mehrshad & Vosooghnia, Alireza & Dehghanghadikolaei, Amir & Fotovvati, Behzad. (2021). The benefits of additive manufacturing for sustainable design and production. 10.1016/B978-0-12-818115-7.00009-2.

[18] Diegel et al., 2016, Additive manufacturing and its effect on sustainable design. Handbook of sustainability in additive manufacturing (pp. 73–99). Springer.

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sustainability, retaining social and cultural diversity as a factor of sustainability[19]. The simple process of 3D Printing enables developing economies to bridge the gap to high-tech manufacturing methods and to join this new emerging market along with advanced countries[20] while at the same time being able to support the practice of the individual designer-maker, providing an effective mechanism for an artisan to compete in a global market.

Challenges

While 3D Printing can potentially be a truly eco-friendly technology, not all is green. 3D Printing still has an impact on the environment by producing waste such as through support materials, excess resin material or even failed prints and consuming energy. Raw materials processable with AM technologies often require additional processing steps and not all materials are recyclable or biodegradable. Another important issue is the long post-processing times that can reduce the sustainability of an operation by a great factor. In terms of health and safety, a wide assortment of materials that are compatible with, 3D Printing such as resins, cyanoacrylates, polycarbonates, acrylates, elastomers, acrylonitrile butadiene styrenes and nylons (polyamides) have been introduced in the industry but their effects are not fully understood. Emissions of ultra-fine particles (UFPs) have been reported, together with other potentially toxic odor emissions. The industry is constantly implementing solutions to optimize the process and reduce waste and energy consumption, new systems are being developed such as a five-axis AM systems that can print parts with no supports[21], while also new materials like plant-based materials, biodegradable materials, recycled materials, materials that include waste from other industries in their composition and materials with new formulations are constantly introduced to the market.

DEMOorDIE Course

Through the training offered by the DEMOorDIE course, participants will go through five different competence units, namely: CU(A): 3DP MEX Overview, where they will learn about all the compatible polymer materials with the MEX process and how to choose eco-friendly materials for their projects, CU(B): Introduction to CAD and CU(C): Design for MEX, where they will learn to both create and optimize their designs for printing and CU(D): Printer Operation and Practical Applications, where they will learn how to troubleshoot all kinds of printer-related problems, ensuring their prints are successful and no waste from failed print is generated. The complete learning part of the DEMOorDIE course is illustrated below.

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[19] Loy, Jennifer & Canning, Samuel & Haskell, Natalie. (2016). 3D Printing Sociocultural Sustainability. 10.1007/978-981-10-0549-7_4.

[20] Khorram Niaki, M., Nonino, F., 2018. The Management of Additive Manufacturing: Enhancing Business Value. Springer, Cham.

[21] Mohammed A. Isa, Ismail Lazoglu, Five-axis additive manufacturing of freeform models through buildup of transition layers, Journal of Manufacturing Systems, Volume 50, 2019

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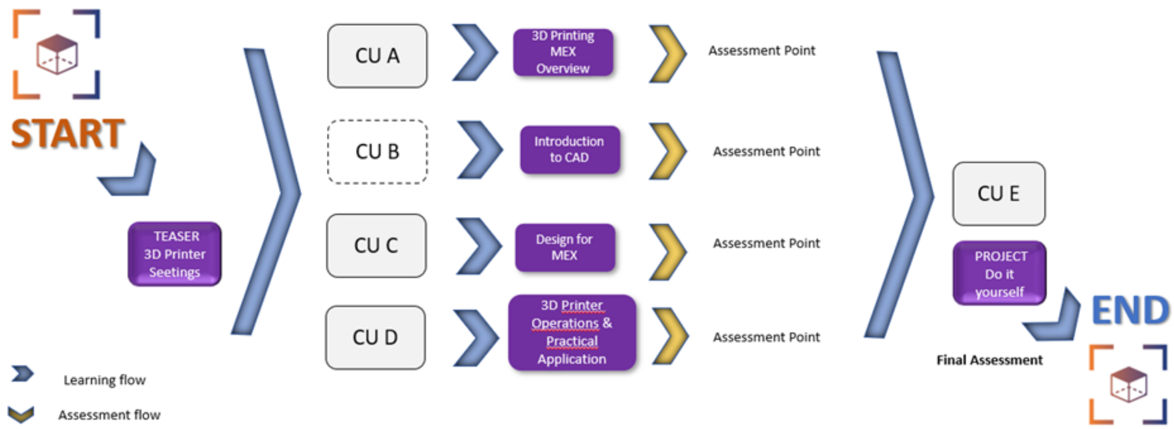

Figure 2: DEMOorDIE Course Learning Path

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