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The Versatility and Rapid Mobilization of 3D Printing Technology in Today's Pandemic and Tomorrow's Lifestyle

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Additive manufacturing, more commonly known as 3D printing, is a rapidly growing technology that has earned a special interest in the past several months in the COVID-19 pandemic [1]. It is an enabling technology that has the potential to not only revolutionize rapid prototyping and manufacturing in industry but also completely transform the fields of medicine and education [2],[3]. The main concepts of the technology are also not very difficult to grasp, and online communities on platforms like Reddit and Thingiverse are extremely helpful and friendly to flatten the learning curve for beginners to enter the 3D printing world. These are the very communities that sparked the immediate mobilization of engineers, hobbyists, students and artists all over the world with access to 3D printers in universities, houses, and businesses to aid in the fight against COVID-19 with emergency respirator devices, masks, face shields, and other accessories [1].

So what exactly is 3D printing? How does it work? 3D printing is a broad term that refers to building any object from a computer aided design (CAD) model by translating the model's geometry into lines of code that a machine can execute to build that object layer by layer. There is a number of very different principles of operation behind such machines: the most common technologies right now are stereolithography (SLA), selective laser sintering (SLS), laminated object manufacturing, and fused deposition modelling (FDM) [4]. FDM is the most prominently utilized technology for making 3D printers now because of its versatility, low cost, and ease of use [5], and for that reason it will be my focus in this discussion. FDM simply uses a motor to force a type of plastic into a hot end that almost instantly melts that plastic. More motors allow the hot end to move in two directions above a bed that moves in the third direction to slowly create a three-dimensional object layer by layer in a bottom-up fashion. The best thing about this is the fact that the firmware that allows the synchronization of these motors along with its user interface is fully open source, which allows the users to continuously streamline it for a better experience and higher quality for lower prices. In fact, a full-fledged, decent quality FDM printer can now sell for as low as 200$.

What is even better is the fact that FDM technology has reached a point where tinkerers, hobbyists, and engineers can easily build their own FDM machines for even less than that price. Towards the end of our fourth year in our mechanical engineering degree at AUC, my colleagues and I were exposed to more advanced concepts of mechanical design and manufacturing. I luckily stumbled upon this technology during that same time. In a craze of enthusiasm and excitement about my robust comprehension of the workings of such a machine I was able to build my own FDM machine in a couple of weeks. A month later the first COVID 19 wave had started, and it was then when I started to realize the enormous impact that such a technology can have on our community. Designers from all over the world began using numerous online platforms to publish their 3D printable designs of ventilator valves, mask connectors, face shields, and mask holders [2] for anyone to easily print. Students and professors in universities began developing their own emergency mechanical ventilators [6],[7],[8],[9] and publishing their designs to allow as much people as possible to help supplement the dire need for such devices. This effort inspired a group of my colleagues and I to collaborate with two of our faculty members to use our senior project at AUC to create *AUCVENT*- AUC's very own ICU grade emergency mechanical ventilator with fully 3D printed structural components to help with Egypt's fight against COVID-19. A fully 3D printed casing and structure components means that the entire design can be uploaded to an online platform to allow people all over the world to replicate and improve it. This is exactly why 3D printing is a very powerful technology.

I think the main driver behind the success of 3D printing in a time of crisis like this lies in the very nature of the technology. Most 3D printers are extremely simple to set up, and many FDM printers can be easily modified to print larger volumes as the only limit on the printing volume is the frame of the printer and not the physics of the technology. Moreover, the printing process only requires a digital file to be uploaded to the printer without the need for any prior preparation typically required in traditional manufacturing techniques. Pair this feature with the fastest means of communication in the world like social media or the internet in general and we get a light speed mobilization of people from all over the world to manufacture necessary components in any crisis. The accessibility of the technology is also another major factor that distinguishes it from traditional manufacturing techniques. A typical 3D printer will usually occupy less than a cubic meter of space, meaning that it can be installed in a small room in a house for an individual.

The influence of 3D printing also transcends beyond the realm of the industrial and medical worlds. The technology has the potential to drastically change the high school and college education experience that we know today [3]. The fundamentals of CAD modelling for 3D printing can be introduced to high school students as a necessary tool for a modernized educational experience. This will introduce an extra element of creative thinking and analytical reasoning in the design and troubleshooting of 3D printed parts that can intertwine with the very core of the educational material. Subjects like geology, for example, can integrate fully colored 3D printed plate tectonics and rock formations in student projects for a far superior and more intimate contact with the subject that will more firmly establish its foundations in the students' minds. Subjects like history and paleontology in colleges can have their students 3D print extremely detailed and anatomically precise replicas of fossils. Such models already exist on online platforms like Thingiverse [10]. I have even printed and assembled all 40 parts of one of these models, and the level of involvement in every detail of undertaking such a project was nothing short of phenomenal to me- let alone a paleontology student. The technology can also be used to produce replicas of human skeletons for anatomy courses for students in medicine. This was already done in multiple universities and studies [11],[12],[13], and the resemblance between 3D printed and authentic bones was uncanny.

This discussion raises the important question of the impact that such printers can have on the environment. Scaling a technology that essentially creates objects out of molten plastic to fit our everyday life introduces a number of concerns. This is, however, far from the whole story. To understand the full picture one must grasp the idea that different 3D printing methods can utilize a wide array of materials with drastically different environmental impacts. FDM in particular can use plastics like polylactic acid (PLA), acrylonitrile-butadiene-styrene (ABS), polyethylene terephthalate glycol (PETG), and nylon [14]. The most commonly used material is PLA not only because of the relatively low temperatures (of around 185 to 205 ℃) required to print it, but also because it is made from corn starch and is fully biodegradable, so disposal is not an environmental issue [15]. Parts made from PLA are also very easy recyclable with water as the main reactant and a moderately high temperature [15]. The problem, however, remains with aerosol emissions *during* the printing process which can also potentially harm the environment and the user. It turns out that the number of emitted particles is a function of the temperature used in the printing process, and, as a result, PLA emits the least amount of such particles compared to other 3D printing materials [16]. However, placing the printer in an enclosure during printing can effectively neutralize the effect of these emissions as they deposit on the enclosure's inner walls [16]. These advantages have made PLA the prime candidate for mixing it with stronger reinforcing materials to further advance the technology's versatility. Iron, copper, carbon fiber, and even wood reinforced PLA materials are available in today's market, and further research in nano particle reinforced PLA materials was conducted [17]. This can revolutionize the integration of the technology into our lifestyles in the future by opening the door for much stronger 3D printed parts to fit into our everyday lives.

The main barriers that hinder the adoption of 3D printing as a main manufacturing process are the economic considerations that govern such a process. While it is indeed cheaper and easier to produce one-off parts with complex geometries by 3D printing, it is a lot more difficult to adopt the technology for large scale production volumes [18]. This is primarily because 3D printing a complicated part takes a much longer time than traditional manufacturing techniques, which separate the complex part into smaller simpler parts that can be assembled later. However, as the 3D printing technology is getting cheaper and quicker it can start to become more economical to bypass the cost of material waste and assembly in traditional manufacturing. An economically clever use of the process involves transferring the manufacturing to the retailer's side, which bypasses the transportation costs as well [18]. This idea was partially implemented in UPS stores across the US where the stores had 3D printers to immediately manufacture any missing supplies if the wait time for these supplies exceeded a certain amount of time [18].

All in all, 3D printing is a technology that has the potential to revolutionize our lifestyles in the very near future. The technology's swift mobilization, versatility, and low entry barrier made it an unquestionably very powerful solution to shortages of everyday small items in the current pandemic. This solution will undoubtedly progress to become integrated into our everyday lives and educational experiences on a massive scale very shortly. While it may never be economically viable to mass produce geometrically simple parts by 3D printing, it will remain an invaluable rapid prototyping tool that has the potential to surpass the traditional manufacturing of large-scale production of complicated parts because of its ease of setup and lower environmental impact.

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