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A critical review of an additive manufacturing role in Covid-19 epidemic

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ABSTRACT

In 2019, a massive and deadly coronavirus pandemic known as the COVID-19 pandemic has swept through more than 180 nations, causing a massive strain on already overtaxed health systems around the globe. Global demand for medical equipment has put a strain on traditional manufacturing methods, resulting in the need for an efficient, low-cost, and speedy mode of production. Additive manufacturing, or 3D printing, has been used by manufacturers to bridge the gap and enhance the production of medical products. Some designs that had been previously or conventionally fabricated have been revised to meet the 3D printing requirement for combating COVID-19. A variety of designs were created, and they are now in use in hospitals by patients and healthcare professionals. However, because some gadgets must adhere to rigorous standards, it is possible that some items will not meet these requirements. As a result, in order to protect the health of the user, it is necessary to understand each gadget, its usage, and industry standards. An investigation of the usage of additive manufacturing during the COVID-19 epidemic is presented in this paper. It brings together the manufacturers of a variety of 3D-printed products, including face shields, face masks, valves, nasopharyngeal swabs, and others, to debate their application and regulatory concerns in the medical field. The primary shortcoming of technology, discussed in reference to the next pandemic, is addressed here. It also looks at some of the ways that additive manufacturing could be used in the future during an emergency.

1. Introduction

The first case of coronavirus disease 2019 (COVID-19) was discovered in Wuhan, China, in December of this year. This has all happened because of that fateful day, when the virus broke out. This started the worldwide outbreak and later, on March 11th, the World Health Organization (WHO) classified the virus as a pandemic. According to the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), the virus spread about nine months after patient zero was detected, on October 9th, across 188 nations and regions, with 36.6 million confirmed illnesses and 1,063,000 worldwide fatalities [1,2]. This virus, known as SARS-CoV-2, may be transferred via droplets, aerosols, and direct and indirect physical contact with infected surfaces where the virus can survive for up to 72 h [3,4]. Research on the droplet and aerosol transmission mechanisms is currently ongoing, and no consensus has been established yet. Aerosol transmission has recently been found to be more than previously thought. Symptomatic individuals may have severe acute respiratory syndrome (SARS), but may also be asymptomatic, leading in ICU admission. Individuals, corporations, and institutions created a manufacturing drive to assist hospitals and individuals confronting the device and equipment scarcity [5–7]. The several gadgets designed to assist in activities such as facemasks, face shields, test swabs, door handle attachments, and valves are commonly being shared via social media. A 3D printing technique that is rapid, easy, and versatile for producing complicated or monolithic pieces or even mechanical systems has emerged as notable. In addition, people that work with AM are open-minded, creative, and work in an interdisciplinary way with both conventional and unconventional partnerships and applications. Thus, AM technology enables the user to generate components from an STL file format (a CAD-created file), which is easy to locate and distribute [8]. Lastly, desk-

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top 3D printers have gotten more affordable due to patents expiring, allowing open access initiatives to drastically cut the prices and entry barriers for the lower-end AM equipment. However, even for the same STL project, various 3D printed items may have varied characteristics and finishes due to changes in the materials used, the technique utilized, and the particular machine software and calibration, among other factors. Because of this, it is necessary to understand each device, its usage, and its standards in order to guarantee that these goods are in fact useful for the purpose intended while posing the least amount of risk to patients and healthcare professionals [9,10]. To give an example, 3D printed parts may exhibit differences in properties and finishes, even for the same STL project, because of different materials, technology, and individual machine calibration. So in order to keep patients and healthcare providers safe, there must be a knowledge of each item, usage, and standards in order to be sure these goods actually meet the goal and have the lowest risk for patients and healthcare providers. This project seeks to identify COVID-19 pandemic additive manufacturing application. It focuses on diverse PPE, medical equipment, and other applications, and includes the information about where the item can be purchased and how it may be used and regulated. Finally, a framework for how AM may best support emergency events is offered [11–13]. Different designs that take into account the present global epidemic of COVID-19 are examined in this perspective, as well as how 3D printing may assist the global community combat the current and future circumstances.

2. 3D printing in pandemic

The fast growing market for medical devices at the same time as the COVID-19 pandemic boosted demand and brought new goods to the general public has had different supply chain interruptions, which has led to a scarcity of essential medical supplies [14]. Following this situation, corporations, organizations, and individuals all started to work together to meet people and medical facilities who are suffering shortages of necessary supplies. In this sense, AM has shown itself to be a feasible option for producing different sorts of these products locally, as demonstrated by AM's ability to handle a variable supply of strategic items. Because of the large number of people, especially highly skilled, inventive, and creative people, the usage of AM was critical during the epidemic. In the recent decade, desktop 3D printers have been available at lower price points because of the decline in the cost of CPUs and the expiry of patents [15].

Additionally, filament polymers for these 3D printers are at decreasing prices. For example, part production for the disease pandemic shortfall is not limited to industry. Entrepreneurs, who have access to 3D printers or similar quick manufacturing tools, have been shown to contribute considerably during the crisis. Also, having a 3D printer does not require you to have expertise of computer-aided design to create parts. There are many places in the internet where you may find printable 3D files [16–18]. A third factor is that complicated manufacturing procedures which would need a lengthy time to prepare might be expedited by AM. The delivery period for small batches of components is extremely short, making it nearly instantaneous in the event of a crisis. People who got STL files were thus able to aid as soon as media started distributing information on shortages [19,20]. The first ideas and machine prototypes were able to be rapidly prototyped using the method capability for rapid prototyping. Additionally, low-end machine AMF facilities do not require extensive planning or infrastructure. This study is a good illustration of the effect, as described above, as given in the COVID-19 pandemic report published by François et al. Within a four-day span, they reportedly had purchased, received, and completed the installation of 60 FF machines [21–23].

3. 3D printed appliance

The next sections cover a wide range of AM solutions used during the COVID-19 epidemic and examine them in detail.

3.1. Personal protective equipment—PPE

According to data, PPE is the most commonly printed equipment in the event of a pandemic because to their low geometric tolerance requirements and their lower risk categorization when compared to complicated devices like ventilators and valves. One of the most common types of PPE is the face shield. In situations where masks are in low supply, WHO and the FDA see face shields as an alternative to medical masks. The frame consists of a transparent plastic sheet worn on the head to protect the user from the accidental contact with contaminants such as sprays and splashes. Additional criteria include the fact that they must be simple to clean, comfortable to wear for extended periods, robust, and able to accommodate more PPE. It is critical to remember that the face shield should be used alongside other PPE equipment in high-risk scenarios. A basic geometry is used in the construction of the frame, which can simply be 3D printed. Another method involves using SLA to build a hollow frame which may be utilized in conjunction with an external airflow, clearing the visor and keeping outside air from infiltrating. Manually cut plastic sheets are made using scissors and an office puncher, or made using laser cutters. In some cases, an elastic band may be acceptable [24]. The duration and price of face shields may be specified according on the design, machine, material, and specific factors. Fig. 1 demonstrates a wide collection of 3D printed facial shields modelled using various AM methods and materials. Face shields come in several designs.

The goggles function as eye shields by blocking the eyes' line of sight. To avoid infection, you should use eye protection while caring for infected patients. Two sizes of safety googles created, validated, and made available for download by Farsoon, Huaxiang, and LEHVOSS businesses were developed, produced, and made accessible via SLS, SLA, or FFF techniques. In acrylic material, the lenses must be cut individually.

Surgical masks give reduced protection to the same level as N95 respirators, but they can drive different nations and governments to provide citizens financial or legal incentives or penalties to use even handmade masks in order to cut the contamination ratio. Diverse 3D printed projects and designs were presented because of the vital function and strong demand. Adaptor valves made of 3D-printed plastic that can be attached to full-face snorkeling masks and a HEPA filter were recommended for use by health professionals [25,26]. 3D printing and a half-face mask that doesn't require premade masks are two different approaches that function as substitutes for surgical masks. An appropriate AM method, print quality, body anatomy, and filter material must be selected for maximum mask efficiency [27,28]. Tino et al [29] conducted an in-depth literature analysis of five distinct kinds of half-face masks from FFF and discovered certain models were infeasible due to printing or sealing issues. Swennen, Pottel and Haers presented a 3D mask concept proof made up of two reusable SLS components and two single components (head band and filter membrane) [30]. They are supportive of employing 3D smartphone face scanning to create a 3D model of anatomy to enhance the fitness of the mask. The need for regulatory permission is crucial to note that these masks. Nevertheless, the NIH 3D Print Exchange, the Veterans Healthcare Administration and the USA have collaborated to educate 3D printing solutions whose models have passed examina-

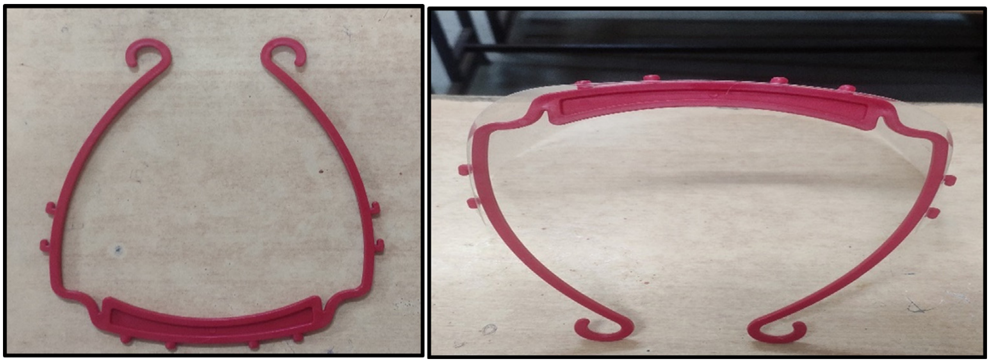

Fig. 1. Face shields designs.

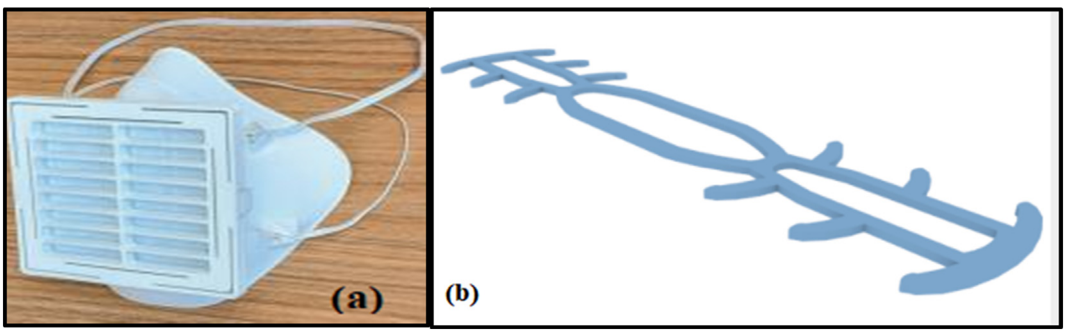

Fig. 2. (a) Face mask and support parts made Stopgap surgical face mask [35] (b) Ear saver designed by NIH 3D Print Exchange [36].

tion in a clinical context and have been determined to be relevant for the manufacturing of the parameters indicated [31]. The Stopgap surgical facial mask, to be made using SLS or MJF, depicted in Fig. 2 is one evaluated and verified model. It comprises of two 3D-printed components that are also sterilizes, plus elastic straps and a filter material, all of which must be discarded after each usage. However, Bezek et al [32]. examined three products that were pre-printed, one of which was the Stopgap, and the other two were Montana face masks and La Factoria 3D COVID-19 that were manufactured using powder bed fusion industrial and FFF industrial equipment. Overall filtering effectiveness for particles between 100 and 300 nm was nearly always lower for masks without post-processing processes. An efficiency of 90–95% was seen in the Montana design that was manufactured utilizing the ULTEM material and an industrial FFF 3D printer. Additionally, post-processing procedures allow masks to have an increased filtering effectiveness [33]. Their research suggests that more rigorous testing and validation of 3D printed PPE is needed, and moreover, developing and standardizing post-processing processes that aid in increasing the mask efficiency is in order. When prior work agreed, Gierthmühl et al [34] discovered that La Factoria's mask model, which is a home-made vacuum cleaner bag mask model, could only filter 39% of the vapors (70 percent). Fitting the masks properly is critical to getting the best performance from them. Some of the components were specifically developed to be used as supplemental PPE. It is important and mandatory PPE for healthcare personnel to use N95 or surgical masks. This process begins with the wearing of the mask bands, which causes the sensitive skin behind the ears to get damaged. In addition to wearing hearing protection, employees and those who work for long hours wearing face masks 3D printable ear savers and mask extenders have been created to enhance the wellbeing of health professionals and workers who wear face masks for extended periods. A variety of contributed models is available in the NIH 3D Print Exchange repository, such as the one displayed in Fig. 2.

3.2. Isolation chambers and wards

Preventing the spread of SARS-CoV-2 infections is done by isolating infected patients. Patients in hospitals can spread the virus via aerosols and droplets, as demonstrated previously. Thus, there are certain gadgets that help keep the environment pollution-free. A negative air flow isolation chamber was created by Cubillos et al [37] for COVID-19 patients. A complete frame chamber is wrapped in a clear plastic bag. A negative air flow flows through the chamber to keep contaminants out of the surrounding environment [38–39]. The system utilizes 3D-printed air inlets, which makes suction, oxygen delivery, and nebulization possible. AM production glove grommets were created as part of a partnership between the University of Wisconsin – Madison Department of Surgery, Dr. Hau Le, and the UW-Madison College of Engineering [40]. In contrast to isolation chambers that are more sophisticated, more rudimentary isolation chambers were created at Texas A&M University. The chambers are made from CNC cut vinyl and 3D printed components to provide a physical barrier to infected patients [41,42].

3.3. Nasopharyngeal swabs

It is vital to do intensive testing in order to combat the COVID-19 epidemic. The types of samples for which testing is required include those from the upper respiratory tract and this process is applied using reverse transcription polymerase chain reaction (RT-PCR). Because nasopharyngeal swabs have the best sensitivity for viral detection, nasopharyngeal swabs are considered the most sensitive. These devices, marked as class 1 under the FDA, are rod-shaped with a head made of short synthetic filaments or spun fiber and is utilized to collect secretions from the upper respiratory tract from the patient. In the swab, the breakpoint is used to make the head storage tube for vial transfer material available. Afterward, the vial is submitted to the lab for testing.

3.4. Valves

COVID- One-hundred-and-nineteen people might show up with the symptoms of SARS, which include rapid breathing and low oxygen levels. Patients presenting with these significant hypoxemic symptoms undergo IMV procedures. Droplets and aerosols are emitted from the patient during this operation, producing a propitious setting for health-care professionals to be contaminated [43,44]. In these instances, patients spend a lengthy time in an induced coma, which increases the risk of mortality and the occupation of ICU beds [45–47]. These are important health worker facts. Using noninvasive breathing techniques, such as continuous positive airways pressure, may help reduce the rate of intubation (CPAP). For patients at increased risk of complications, the WHO recommends using NIV first and using endotracheal intubation as a last alternative.

The research conducted by Wang et al. looked at 27 individuals who had presented with SARS and used NIV. Only four of these patients had to be intubated from these individuals [48–50]. NIV with inadequate sealing should not be utilized, even if it can be delivered by aerosols and droplets. Because of this, exhaled air from patients undergoing NIV can be screened using a HEPA filter or else cannot be returned to the environment [51]. There are alternatives to the mechanical ventilators that are not yet available, such as 3D-printed splitters (class II devices by the FDA). These splitters allow two patients to use a single mechanical ventilator. Moreover, 3D printed valves might be used as ports in Bubble Helmet's open-source NIV helmet project [52].

3.5. Hands free tools

For periods ranging from 72 h to two weeks, the COVID-19 virus may persist on many surfaces. To prevent the spread of infection, staying away from public and medical facilities is the best way to go. It is possible that some items, such as buttons, door handles, and switches, might transmit viruses because of how many people use them [53–62]. Direct hand contact was reduced with the invention of different hands-free tools. François and his colleagues created and produced a wide range of automated equipment for use in university hospitals and other places around greater Paris [63–71]. While door openers do really allow people to open and close doors using their elbows or forearms, some of these gadgets have sensors built into them and will also automatically unlock the door if someone releases their grip on the door handle [72–79]. Fig. 3 shows the hand safety tool designs. Materialise Ltd., the creators of a variety of various types of hands-free door openers, such as cylindrical, rectangular, circular, and spherical ones, among others, have 3D-printed openers that are created with technologies such as FDM, SLA, and SLS.

4. Training and education

In the education sector, one use of AM is to support student learning. It is beneficial in many stages of education, including as a child-focused, basic version as well as a complicated replica that helps to diagnose, prepare for surgery, and educate patients. They developed a manikin to assist in teaching healthcare personnel with less expertise in diagnosing COVID-19 using nasopharyngeal swab testing. Following the growth of Industry 4.0, educational institutions have seen an increase in the usage of AM, according to Hervás-Gómez et al [80]. The potential to utilize the AM attention during the COVID-19 epidemic is used by Moreno Martínez and Morales Cevallos [81] to empower students and raise their curiosity, engagement, and involvement with experimentation and manipulation [82–90]. As a further aid to communication, 3D printed tactile models can also be useful to those who are visually impaired [91–100]. Simple approaches, such as 3D-printed mounts to position cameras [101–110], may be able to help educators introduce board-based pedagogy.

5. Conclusion

COVID-19 pandemic has brought additive manufacturing (AM) to the forefront. Various equipment, such as face shields, face masks, valves, and nasopharyngeal swabs, were scarce because of the supply chain interruption. These health personnel, patients, and members of the general public all benefited from AM's quick and creative design, as evidenced by the fact that all of these people survived because of AM. If a project file is shared or projected over a worldwide network, local production might be practically immediate. Another big advantage AM used in responding to the epidemic was the widespread availability of 3D printers throughout the world, including in poor nations. This makes it simple to share and download components, which expedites the design and development process. In a mass manufacturing of gadgets, many businesses, organisations, and individuals from all around the world have come together to aid people in need. Once the production became famous, it also stirred up difficulties that had to be dealt with prior to the next crisis. In the absence of central regulatory standards and norms, many groups, organisations, and individuals produced non-validated components based on their own expertise. However, it is worth noting that AM is very new as a technology. New technologies, materials, methods, and software are developed constantly. To continue with current trends, this is

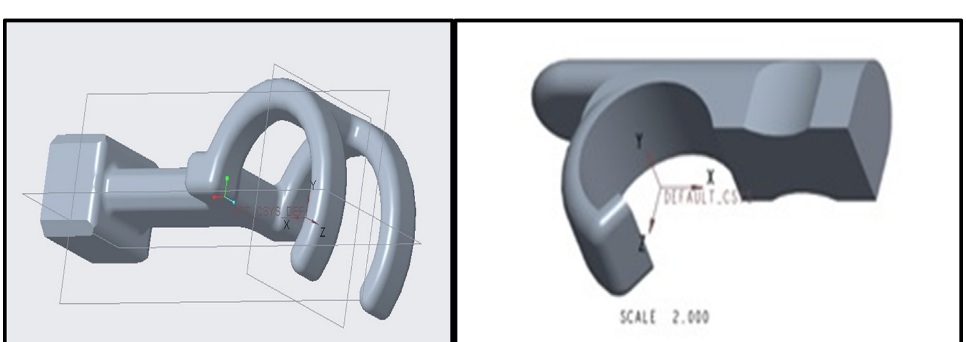

Fig. 3. (a). Hand safety device design (b) Hand safety device design.

necessary to guarantee that additive manufacturing remains important to assist us combat the next epidemic.

CRediT authorship contribution statement

Jinka Rupesh Kumar: Conceptualization, Writing – original draft. **K. Mayandi:** Project administration, Resources. **S. Joe Patrick Gnanaraj:** Supervision. **K. Chandrasekar:** Resources, Writing – original draft. **P. Sethu Ramalingam:** Investigation, Validation.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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