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Role of additive manufacturing in medical application COVID-19 scenario: India case study

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ABSTRACT

This paper reviews how the Additive Manufacturing (AM) industry played a key role in stopping the spread of the Coronavirus by providing customized parts on-demand quickly and locally, reducing waste and eliminating the need for an extensive manufacturer. The AM technology uses digital files for the production of crucial medical parts, which has been proven essential during the COVID-19 crisis. Going ahead, the 3D printable clinical model resources described here will probably be extended in various centralized model storehouses with new inventive open-source models. Government agencies, individuals, corporations and universities are working together to quickly development of various 3D-printed products especially when established supply chains are under distress, and supply cannot keep up with demand.

1. Introduction

Mankind has seen different pandemics since the starting where a portion of them were more horrendous than the others to the people. The worldwide emergency of novel coronavirus also referred to as COVID-19 initially detected in the Wuhan region of China. As of August 2020, there is no proven vaccine for COVID-19, but numerous continuous clinical preliminaries are assessing expected medicines [1–3].

3D printing [4–12] is an essentially unique method of creating parts contrasted with conventional subtractive or formative manufacturing technologies. In 3D printing the part is made directly onto the built stage layer-wise, which prompts a novel arrangement of advantages and confinements - more on this beneath. The 3D printing technique needs to think outside the standard for changing human services. In a few words, 3D printing consists of empowering specialists to treat more patients, without sacrificing results. Hence, similar to any innovation, 3D printing has presented numerous favorable circumstances and conceivable outcomes in the clinical field [13–15].

2. Traditional manufacturing vs Additive manufacturing, the best method for the job

Manufacturing industries and investors are continually trying to improve procedures to bring down cost, vitality and grow their ability (Table 1). At this stage, exploration and industry intrigue lie in figuring out where AM can supplant or make new assembling frameworks [16–24].

AM might have the option to assume a job in assisting with supporting modern gracefully chains that are influenced by constraints on conventional creation and imports. Co-ordinations of the supply chain are likely the primary enormous scope business that might be influenced by 3D printing innovation. As shown in Fig. 1(a) Traditional method involves prolonged process starting from taking raw materials, acquiring materials, manufacturing, distributing and selling to end-user. Fig. 1(b) represents changes in the supply chain that quick part production possible through the use of 3D printing [25–28].

Makers are on the whole being compelled to develop and actualize new and coordinated ways to deal with item observing and quality control. One of their greatest calculated difficulties includes guaranteeing their creation lines are running, despite the absence of accessible staff because of social distancing rules [30]. This is the place computerized developments in smart manufacturing [31–33] can offer numerous advantages. The decision of the most appropriate procedure for each kind of model depends on the meaning of the target behind the creation of the model and different factors: innovation, creation time, weight, materials, cost, aesthetic, functional, investigational, surface completion, post processing requirements, assurance, spares and consumables things. Consider the ideal characteristics for your specific

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Table 1
Traditional Manufacturing vs AM.

Methods	Volume	Cost per unit	Time to market	Cost of complexity
Traditional Manufacturing 	Large batch, Not customized	Low variable costs, High fixed costs	Very slow to moderately slow	Much higher than simple parts
Additive Manufacturing 	Small batch, Highly customized	High variable costs, No fixed costs	Very fast (≤ 1 day)	No higher than simple parts

application and contrast them with the available choices in a given manufacturing processes.(Fig. 2)

The present advanced cloud-based innovation services [35–38] and arrangements offer an uncommon degree of adaptability, with factory managers ready to remotely monitor and deal with their creation lines from any area with a web association [39–41].

The designer must realize the deciding components of the finished result so as to have the option to choose the most appropriate assembling strategy, make the essential changes to the geometrical data file (stl or amf), and survey the NC code. The designer must, therefore, have a full outline of the times of the cycle as appeared in Fig. 3.

This highlights the impact of design for additive manufacturing (DFAM), when an item has been intended for a particular machine or cycle [42], just as the significance of print settings to optimize production [43–46].

Key advantages of 3D printing over Traditional Manufacturing are digital storage, quicker creation, detectability of part files, reduction in delivery time and the capacity to deliver segments regardless of the complexity of part geometry. Three ISO/ASTM 3D printing measures, in particular Material extrusion (ME), powder bed fusion (PBF) and Vat photo-polymerization (VP) are most usually used to create medical parts in the current COVID-19 pandemic [47,48].

3. Market available in INDIA for additive manufacturing

The current government has made some excellent strides in pushing for assembling with ventures, for example, Prime Minister Narendra Modi's domestic task 'Make in India', and the nation has seen critical enhancements in its 'Ease of Doing Business' rankings [49]. There still is sufficient time for India to get up to speed, yet lead the world by concentrating on building the next generation of pioneers [50–53].

According to the 17th edition of the World Bank's (WB) report on October 23, 2019, "Doing Business 2020-Comparing Business Regulation in 190 Economies", India has ranked 63rd in the list with the score of 71.0. It has improved by 14 places among 190 nations as against 77th position in the 2018−19 list. Industry 4.0 [54–56] has likewise brought the capacity of consistent advanced physical change through robotics and AM innovations like 3D printing. AM advancements are reshaping worldwide worth chains and hold the guarantee of new creation capacities [57].

India right now represents just around 3 percent of the AM introduced base across Asia and Oceania consolidated, however, organizations such as GE, Wipro and Intech are driving 3D printing appropriation in the nation. While the current market size might be little, the future has conceivably numerous situations and the state of the industry relies upon imaginative new use instances of receptions.(Fig. 4)

In the Indian market, there are some limitations in terms of diagnostic kits and a sufficient standard quantity of Personal Protection Equipment (PPE). Presently to change India into a worldwide design and manufacturing hub, it is a powerful call to action to citizens and business pioneers to discover gaps and satisfy the necessity of the customer by Make in India initiative.

The utilization and selection of 3D printing services are expanding step by step. There will be a more noteworthy requirement for training and capability building inside the associations with expanded infiltration of AM. There is additionally a growing concern that AM items can't be copyrighted yet should be patented dependent on obvious differentiation. An industry wide joint effort is required to create clarity on what meets all requirements for patent security to control the multiplication of replica parts. [59]

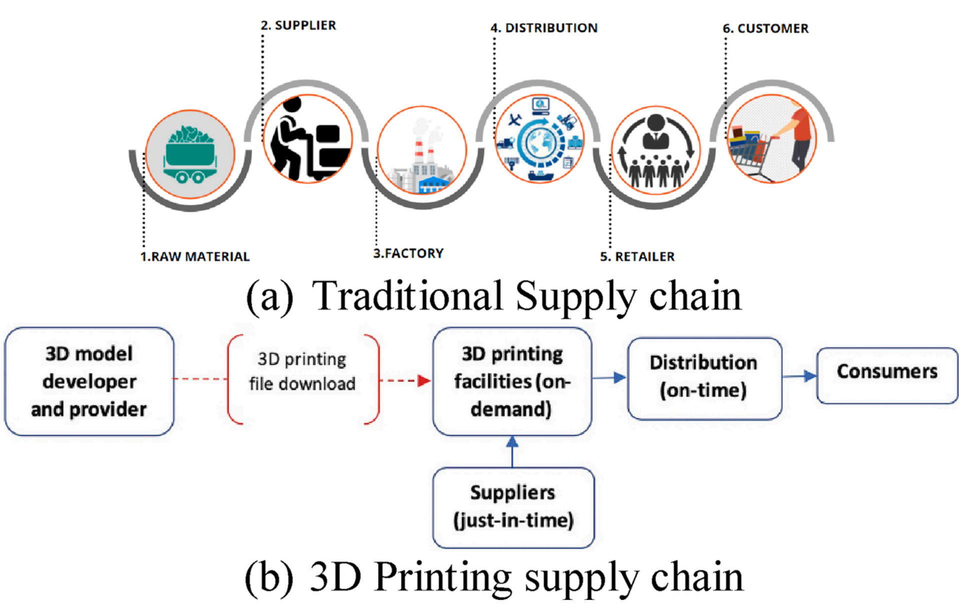
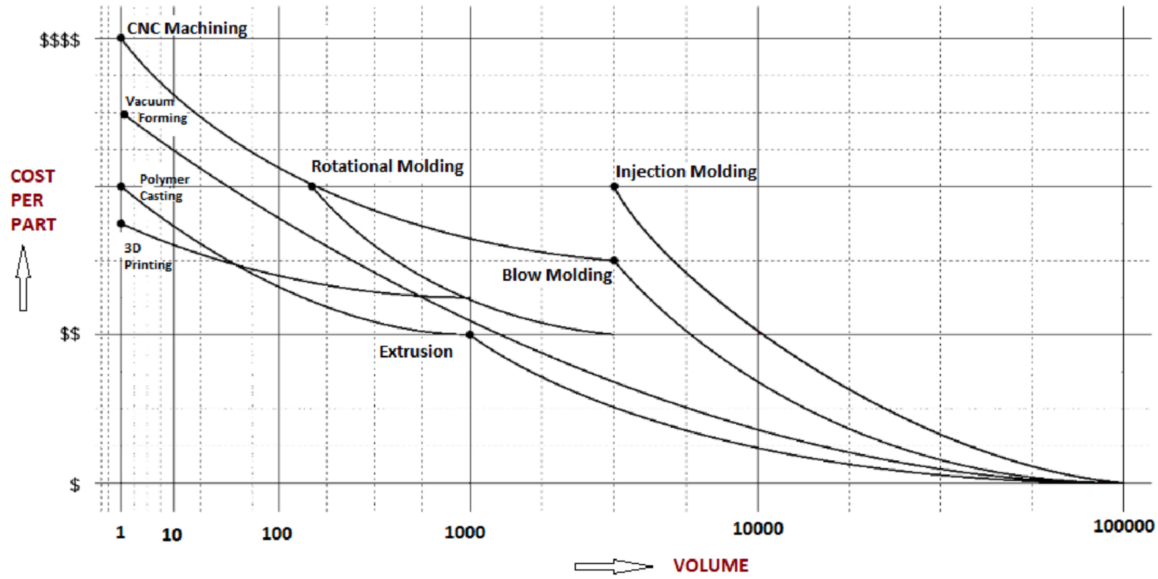


Fig. 1. Traditional versus 3D printing supply chain [29].
(a) Traditional Supply chain.
(b) 3D Printing supply chain.



	3D PRINTING	CNC MACHINING	POLYMER CASTING	ROTATIONAL MOLDING	VACUUM FORMING	INJECTION MOLDING	EXTRUSION	BLOW MOLDING
Complex Shapes	●●●●●	●●●●○	●●●●○	●●○○○	●○○○○	●●●○○	●○○○○	●○○○○
Lead Time	12-36 hours	24 hours-2 weeks	24 hours-1 week	4-6 weeks	4-6 weeks	8-10 weeks	2-4 weeks	4-6 weeks

Fig. 2. Characteristics for Manufacturing process [34].

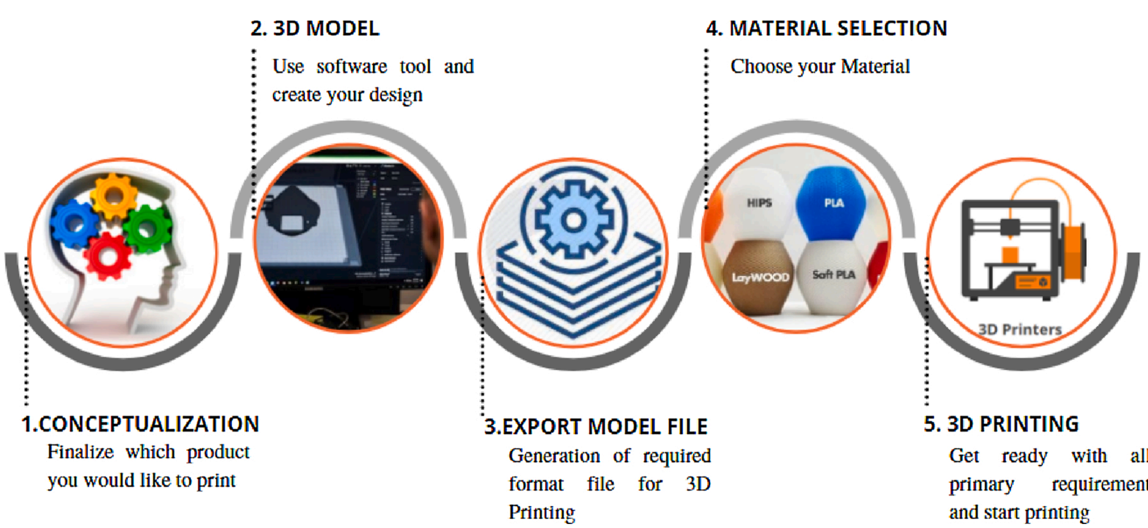


Fig. 3. 3D Printing process flow.

4. Use of additive manufacturing to fight COVID-19

COVID-19 pandemic is the most noticeably terrible unnerving episode of humanity's rule on Earth to date. Not just it has asserted over a hundred thousand lives afterward, however, it has likewise given many restless evenings to clinical and investigates experts over the globe [60]. The AM industry played a key role in stopping the spread of the virus to the health crisis caused by COVID-19 [61–68]. 3D Printing apparatus give concrete solutions for healthcare workers and all those exposed in this time of crisis of lack of medical equipment shortages [69–71].

Hospitals around the globe confronted disturbing deficiencies of clinical apparatus basics like face shields and covers, testing swabs, ventilators, and more. While traditional supply chains [72,73] diverse to respond, 3D printing outfits have begun dealing with transient curiosity [74]. Most 3D printers can't produce stock as fast as other assembling techniques like injection molding, however, they can create a wide variety of designs without the need for new molds. By sharing design files and pooling assets, individuals from the 3D printing network have joined together to become something of an assembling hive mind during this pandemic [75,76].

The World Health Organization has published a list of COVID-19 critical items facing a global shortage, grouped into three categories like Personal Protective Equipment (PPE), Diagnostic Equipment and Critical care equipment. Governments around the globe are approaching makers to briefly repurpose their assembling lines to meet this deficit. Normally, various degrees of repurposing are required to produce COVID-19 basic things, depending on the items' level of complexity.

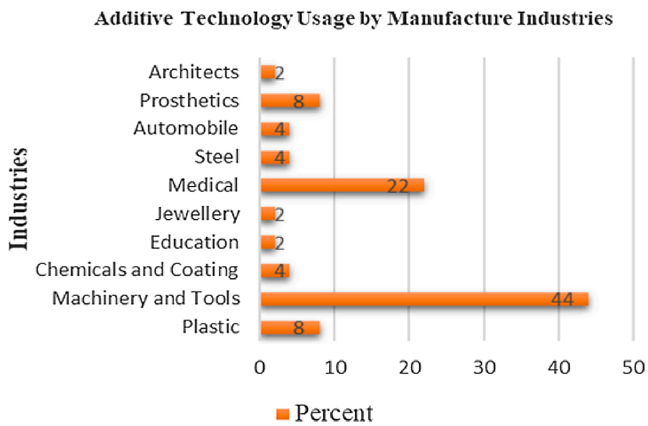


Fig. 4. Additive Technology usage by manufacture industries [58].

COVID-19 is setting off the assembling segment to re-evaluate its conventional creation forms, driving digital transformation and smart manufacturing over the creation lines [77–80].

PPE refers to protective clothing, helmets, gloves, face shields, goggles, surgical masks, respirators, and other equipment designed to prevent wearer exposure to infection or illness in this COVID-19 pandemic. Some of the equipment required for the general public are covered in this article for the benefit of society. A large number of the PPE designs featured here are works in progress, and the viability of privately fabricated subordinates of these gadgets ought to be carefully evaluated locally [13,81].

a) **Face shield**

Face shields are personal protective equipment devices that are utilized by numerous specialists for protection of the facial zone and related mucous membranes (eyes, nose, mouth) from sprinkles, splashes, and scatter of body liquids. In common surgical masks and N95 masks, the assurance is only for nose and mouth, yet eyes are uncovered. These face shields will assist them with protecting their general face for a more extended time without much discomfort [82].

Indian Institute of Technology Madras-bolstered new businesses has created PPE, such as face shields (Fig. 5)from 3D Printers just as generally accessible materials besides to protect healthcare professionals fighting COVID-19 [83,84].

Weighing under 50 gm, the 3D-printed Face Shields utilize an adaptable plastic casing to fit people without the requirement of elastic bands and can be worn for long hours. It utilizes a replaceable transparent sheet, which is cheap and can be handily taken off [86].

b) **Stopgap Face Mask**

The Stopgap Face Mask (Fig. 6) is created as an emergency action to protect frontline workers and secondary support service health care professionals. It consists of two main parts mask body and filter cover [87–101].

The mask and filter cover is printed from a biocompatible nylon material using selective laser sintering technology. The others feature for the attachments are flexible straps and rectangular filter patch are disposed of after every use of this device [103].

c) **Mask Adjuster**

Mask adjuster (Fig. 7) plays an important role for hospital staff who need to wear a face mask for an extended period [104,105].

A designer is fabricating thousands of 3d printed buckles to improve comfort and alleviate associated ear pain for medical workers treating coronavirus patients.

d) **Swabs**

Another critical factor in the battle against coronavirus is widespread diagnostic testing. The common processes consist of inserting a five-inch-long nasal swab along the nasal septum until the nasopharynx is reached. The swab must then be rotated for up to 15 s to collect secretions before being removed and placed in a sterile container for lab testing [107–114].

The 3D-printed swab (Fig. 8) design is thin at the top and gets gradually thicker throughout the neck and handle. It has a well-designed tip for efficacy in sample collection for a medical professional, and also for patient comfort and safety [116].

But for large-scale testing (Fig. 9), medicinal services experts get tired and exhausted of tedious work. The robot has extraordinary potential for mass screening for COVID-19 in the healthcare sector. So to fulfill these gap Robotics researchers from the University of Southern Denmark have built up the world's first completely programmed robot to do throat swabs for COVID-19 [117–119].

The 3D printed robot swabs the patients with the goal that human services experts are not presented to the danger of contamination.

e) **Ventilator parts**

HP has declared achievement in empowering frontline workers and communities to react to the difficulties of COVID-19 through 3D printing. HP has collaborated with Redington 3D in India, to effectively create 120,000 ventilator parts for AgVa Healthcare (Fig. 10). As a major aspect of this activity, 12 classes of parts have been 3D printed, to make 10,000 ventilators [120–131].

These ventilators are being sent across India for the treatment of COVID-19 patients. The parts incorporate breathe in and breathe out connectors, valve holders, oxygen nozzles and solenoid mounts among

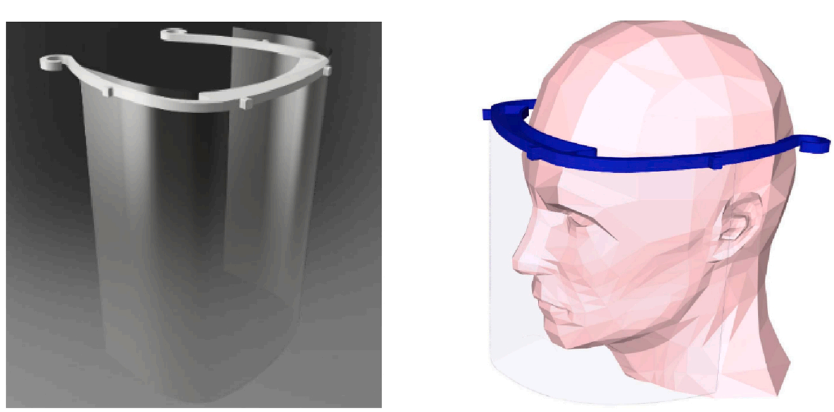


Fig. 5. 3D Printable Face shield [85].

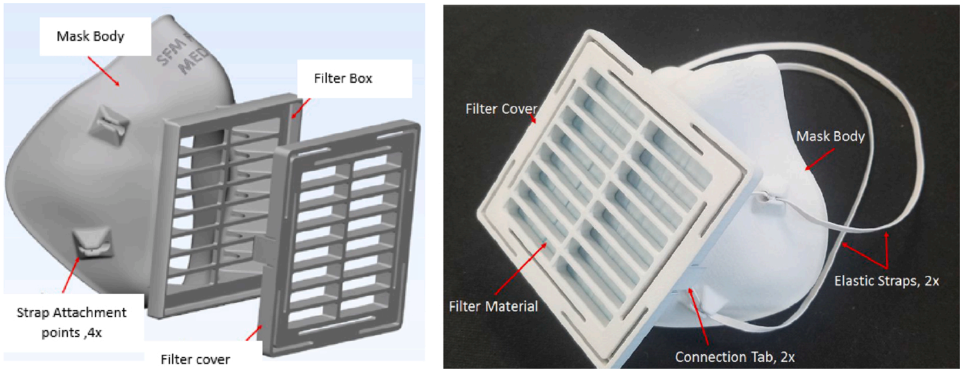


Fig. 6. 3D Printable Stopgap Face Mask [102].

Fig. 7. 3D Printable mask adjuster [106].

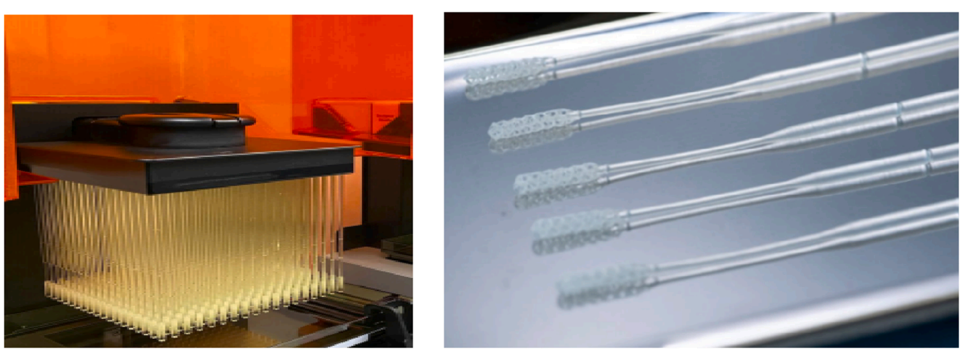


Fig. 8. 3D Printable swab [115].

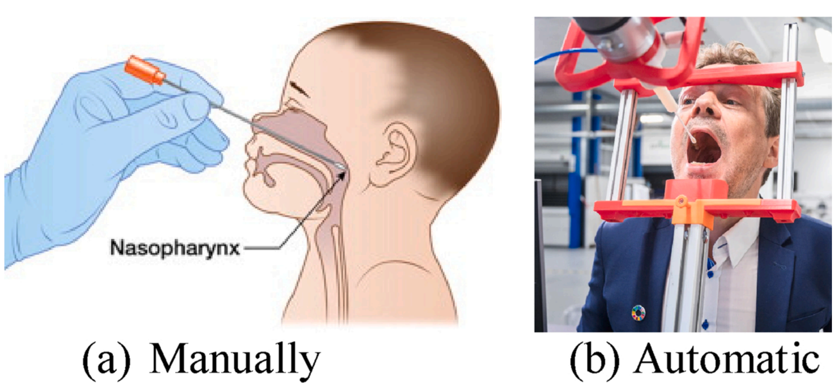


Fig. 9. Swab testing.
(a)Manually (b) Automatic

Fig. 10. 3D Printable Ventilator Parts.

others. By using the conventional process to prepare such types of complex parts it requires 4–5 months to manufacture theses quantities but with HP 3D printing innovation, these parts were printed in only 24 days [132–137].

f) **Hands-Free 3D-Printed Door Opener**

The infection that causes COVID-19 can live on surfaces for a long time which implies it may infect yourself by reaching a contaminated surface. People often have to enter and exit rooms so it may be possible to infect yourself by touching the door handle [138].

To shield from such kind of polluted surface a 3D Printable Door Opener (Fig. 11) can be fitted onto entryways in clinics and organizations, permitting individuals to open entryways without hands.

g) **Quarantine Booths**

There has been an increased need for facilities to quarantine oneself in this critical situation of COVID-19. In this demand, Winsun, a 3D printing firm has found an ingenious solution [140].

By using 3D-printing powers on an architectural scale firm is preparing 15 coronavirus isolation wards (Fig. 12) in a single day. The isolation wards are also furnished with electricity and water supplies. This will help overcome the shortage of Hospital rooms at a time when the country and the world are facing the COVID-19 crisis.

h) **Drone Technology**

The FICCI Drone Committee comprehend that drones (Fig. 13) are playing a huge job in a battle against the coronavirus in help to the accompanying activities undertaken by Police, healthcare and municipal authorities like Surveillance and lockdown enforcement, public broadcast, checking monitoring body temperatures, medical & emergency food supplies delivery, surveying & mapping, spraying disinfectants, etc [141–149].

“Corona Killer”, as now popularly known, the Quick Sanitization Drones possess the capacity to cover almost 20 km/day and it is 5 times more efficient than manual sprayers and cost-effective, and got its recognition from the Government of India. 3D printing shortens lead

Fig. 12. 3D Printable isolation wards [140].

times during product development, brings down creation expenses, and engages designers and manufacturers to face more challenges with new 3D printed drone structures that give new expected applications to the innovation [150].

Digital Aerolus, a worldwide innovator in autonomous advancement has developed the essential indoor drone (Fig. 14) to fight the spread of the COVID-19 contamination with a 99 % cleansing rate.

5. Recommendations and conclusions

The battel against Coronavirus elimination requires a multi-sectoral approach by focusing on treatment, supportive care, prevention and quickly initiate research projects on medical equipment and vaccine development. As per the World Bank data shown in the below Figs. 15 and 16point to the strong possibility that the strength of the healthcare system and the base level of health in the general population are two other important factors that matter crucially.

Numerous articles have been written in the clinical field identified with the COVID-19 flare-up that has encircled the World and killed numerous individuals. Around the world, the episode brought about by COVID-19 makes individuals have restricted social opportunity. General wellbeing activities, for example, social distancing, can cause individuals to feel confined and desolate and can build pressure and nervousness. However, these activities are important to decrease the

Fig. 11. 3D Printable Door Opener [139].

Fig. 13. Drone for COVID-19 [150].

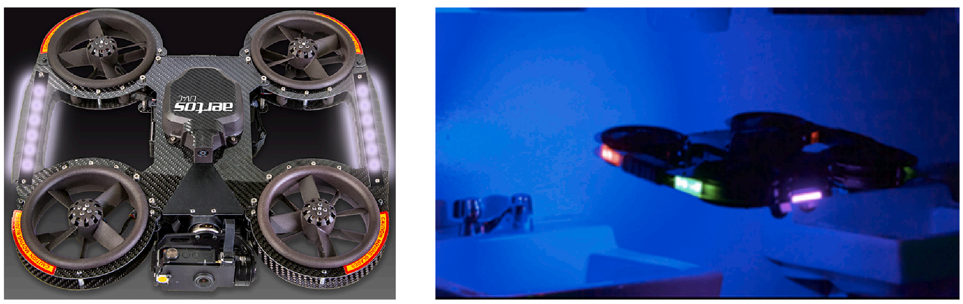


Fig. 14. Indoor Disinfection Drone [151].

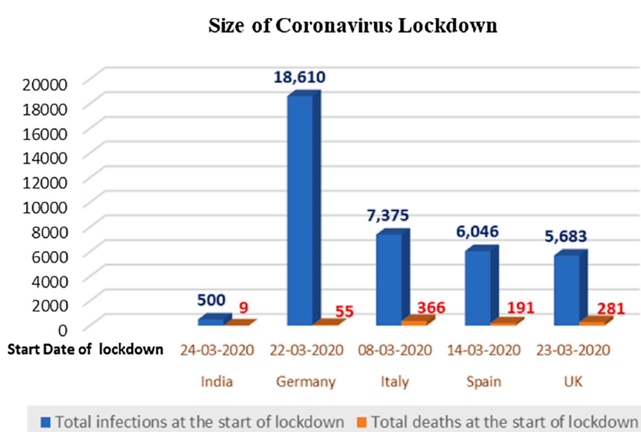


Fig. 15. Size of Coronavirus Lockdown [152].

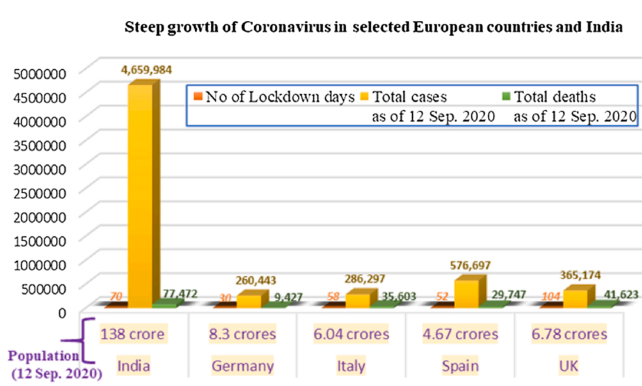


Fig. 16. Steep growth of Coronavirus in selected European countries and India [153].

spread of COVID-19 [154,155].

Then again, reductions in greenhouse gas emissions are seen because of altogether reduced street transport, reduced industrial, educational and other activities. With restrictions on up close and personal clinical meetings in the COVID-19 pandemic and the difficulties looked by medical care frameworks in conveying patient care, innovations like telemedicine and smartphone are playing a key role [156–158].

To avoid a potential pandemic-level outbreak of Coronavirus, recommendations to utilize advanced manufacturing resources to provide hospital services in a short duration of time. Medical parts are available but because of logistical and supply issues, they may not reach at requiring place in time. 3D printing has gotten an opportunity to prove itself as an answer for the quick creation of basic segments for life-saving machines in the tragedy of COVID-19.

The government of India (GoI) launch different schemes/services (Fig. 17) to raise funds and adopt new technologies in manufacturing and another sector. India is an important player and tremendous potential for diffusing new technology in the Indian market and get

Fig. 17. Government of India schemes / Services [159–161].

economic benefits with affordable additive technology price, and future possibilities continue to rise.

In this context, the objective of the study is to scrutinize the motivational factors of entrepreneurs that encouraged to adopt additive technology and how its function as responsible innovation. Additive manufacturing society of India's vision for 2020 aims to put a 3D printer in every educational institute in India, so its help to education is a practical based. In this regard, they organize a business summit such as Gujarat Vibrant, the plastic summit, etc. Moreover, the examination additionally looks at specific chances and difficulties that impact the adjustment procedure; and describe explicit plans of action contributes towards reliable development.

Portuguese specialists are working with Lisbon University, Fan3D and others to create formats and legitimate systems to bring resident drove 3D printing into clinical arrangement. Elsewhere in Europe, the European Commission is working with the European Association for AM on ventures to deliver clinical hardware for medical clinics handling the COVID-19 epidemic. The U.S. Division of Health and Human Services is additionally making similar examinations for COVID-19 pandemic [162, 163].

AM has the upside of facilitating the production of complex building structures, for example, clinical gadgets including PPE that can't be easily produced using traditional methods. Customization is tedious and costly when by conventional manufacturing techniques. This is the place AM makes well and aides in the plan of customized product.

Metal cutting pioneer, Sandvik Coromant [164], has built up another 3D demonstrating procedure that can 3D print up to 200 plastic face shields in the time conventional methods require to print one. This innovation makes ideal fit of the customized product, saves time as well as cost [165]. A short review identified with the most recent 3D printing endeavors against COVID-19 is represented in Table 2.

Overall information from this examination shows that face shields are essentially faster to 3D print than face masks, requiring less material, less 3D printed parts, and along these lines costing less to 3D print, which might be contributing variables to the prominence of face shields among producers compared to face masks.

Subsequently the determined 3D printing potential on the globe is in truth moderately assessed to be in any event 10–100 times bigger, and along these lines can huge affect the lack of clinical flexibly in the current circumstance. Moreover, it ought to be noticed that specific 3D printing advances are better for assembling explicit kinds of items than others.

Based on the discoveries, our investigation gives measurable proof that the most potential medical services items that can be fabricated utilizing 3D printing are those that have a high profitability with a single set of equipment and with boundless accessibility of hardware in the market. In any case, this new unregulated flexibly chain has additionally opened new inquiries concerning product certification and IP. There is a squeezing need to create 3D printing clinical norms for current and future pandemics.

Indian Governments are likewise observing all the points and effectively reassuring advancement in this space. The **first** impact is to improve as-is forms by quickening the structure period of new item advancement, upgrading quality by different rounds of testing of models well in time and modifying the manufacture of tooling to improve profitability. The **subsequent** effect is on item development by decreasing driving weight, production cost and assembly process through part simplification and empowering quick customization of parts. The **third** effect is to investigate the reduction of after-market part inventory through disseminated producing and improving business sector responsiveness and reducing lead time for customization of embellishments or elite parts. At long **last**, overall disruptions in the plan of action are normal as AM can help the worth creation portion of Original Equipment Manufacturer (OEMs) and investigate choices for on location manufacture to quicken support and fix for costly segments.

In such manner, a forward-thinking survey has been led to decide the capacity of AM for giving elite advantages to mankind inside the clinical medical services supplies division. Notwithstanding the numerous advantages identified with utilizing AM in medical care applications, there are some significant limitations, and consequently the focal points and impediments of this innovation have been introduced. The findings show that experts and investigators who used to with AM can focus on the current situation of AM from their perspective. It brings another change in perspective in shaping and performing creative thoughts for designers and innovators.

Table 2
Companies respond to COVID-19 [166].

Sr. No.	COVID-19 products	Organization(Country): Production Capacity	Number of parts produced Approximately
1	Face shield	Nissan (Japan) [167]: weekly	1,00,000
		Ricoh 3D (Printing, U.K.) [167]: weekly	40,000
		Nexa3D (U.S.) [167]: weekly	10,000
		Voodoo Manufacturing (U.S.) [167]: weekly	2500
		Boson Machines(India) [168]: Daily	5000–7000
		Fabheads Automation(India) [169]: Daily	5000
		Azul3D (USA)) [167]: Daily	1000
		Y Soft 3D (Czech Republic)) [167]: Daily	500
		3D Usher(India) [170]: Daily	200
		Omni3D (Poland)) [167]: Daily	120
2	Stopgap Face Mask	Carmaker BYD joint venture between SAIC, General Motors, DaddyBaby, Foxconn & Sinopec (China) [171]: Daily	10,00,000
		Indian Institute of Technology (INDIA) [172] : Daily	25,000
3	Safety goggle & Mask adjuster	PERA CD- N95 mask lining bracket—Farsoon Technologies (China)) [167]: Daily	2000
4	Swabs	Formlabs(U.S.)) [167]: nasophryngeal swabs: weekly	40,00,000
		Nexa3D (U.S.)) [167]: Test swabs: weekly	5,00,000
		Stratasys & Origin (U.S.)) [167]: Nasopharyngeal swabs: Daily	1,90,000
		Voodoo Manufacturing(U.S.)) [167]: Test Swab: weekly	50,000
		Protolabs (U.S.)) [167]: Every quarter	20,000
5	Ventilator parts	Airon GE Healthcare(U.S.) & Ford (U.S.) [173] : Monthly	30,000-50000
		Bharat Electronic Limited(India) [174]:Daily	300–500
		AgVa healthcare & Maruti suzuki (India) [175]: Monthly	10000–20000
6	Door Opener	DRDL & DRDO (India) [176] : Every quarter	15000
		Stratasys(USA) [139]: Monthly	1600
7	Quarantine Booths	Winsun (China) [140] : Daily	15
8	Drone	Garuda Aerospace (India) [150] :Monthly	100
		3D Printing center(Poland) [177]:Monthly	500–1000

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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