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# 3D printing workflows for printing individualized personal protective equipment: an overview

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*Abstract: Sars-Cov-2 pandemic has taken hold over the globe in the last months. Even the best healthcare systems all over the world are overwhelmed by the number of patients and the lack of personal protective equipment (PPE). Medical operators are exposed at high risk for contracting COVID-19. Additive manufacturing techniques allow to produce protective masks and facial shield. Thanks to 3D scans of the face, open-source files and software, many researchers and clinicians can print individualized PPE. This method paper aims to illustrate the key-aspects for producing individualized protective masks and face shields*



## I. Introduction

A novel coronavirus, named Sars-Cov-2 started to diffuse from the region of Wuhan, China at the end of 2019.[1] On March 11, the World Health Organization (WHO) declared COVID-2 a pandemic, due to the global spread of this new disease. This virus provokes a parainfluenza syndrome characterized by symptoms like choke, fever, cough, fatigue, headache, gastrointestinal discomfort, dyspnea and muscle ache. In the most severe cases, the infection may cause pneumonia, severe acute respiratory syndrome and even death.[2,3]

This coronavirus spreads mainly through contact with the respiratory droplets of infected people, via saliva droplets, direct contact and infected material. [4] It has a long period of incubation and also asymptomatic patients can transmit it. [5,6] Thus, personal protection equipment (PPE) is crucial. Recommended PPEs are face shield, filter masks (FFP2/N95/FFP3), gowns and disposable cuffs and gloves. Due to the huge quantity of PPEs required to protect from the virus, PPE supplies were stressed and prices increased.

Additive Manufacturing (AM) processes represent a possible way to overcome the shortage of filtering masks and facial shields for healthcare providers.[7] Among all AM techniques, 3D printing is already available in the medical field for many scopes, like anatomical models, dental and orthopedic prosthesis or scaffold for tissue regeneration. [8]

Many researchers, industries and "makers" have published their own method to print frames for face shields. Regarding the masks, AM is not useful to fabricate filters, but it can be used to fabricate custom-fit mask, thanks to a facial scanner, that can be fitted with a commercial particle filter.[9] Individualizing a mask can lead to produce a comfortable mask that can show an airtight fit for prolonged use. These masks can be loaded with filtering cartridge, which minimum standard filtering capacity is defined by UNI EN 143.

Before printing an object, the critical steps are the choice of a printer and the selection of printing material and software. The object's final properties are strictly dependent to the chosen material. Moreover, not all printing techniques work with the same printing materials and different 3D printing workflows show different ratio cost-benefit. Due to a large amount of methods available, the objective of this article was to pinpoint the critical issues to consider before printing PPEs for the Sars-CoVid-2 related emergency situation.

## II. Material and methods

### II.I. Printer

Face shields and masks can be fabricated using different types of 3D printers. Material jetting printers are fast and accurate, but they are the most expensive. Laser Sintering 3D printers (LS) can be used to obtain rigid metallic frames, as well as biocompatible nylon objects. Fused Deposition Modeling (FDM) printers are the cheapest and most diffused, and therefore appear a first-line tool to accomplish the task. FDM printers are less accurate than other technologies, but their accuracy is sufficient to produce adequate PPE. Besides the low cost, they present a wide choice of compatible materials and they usually have a large working platform, i.e. they can produce large objects. VAT photopolymerization printers work with resin materials and they can lead to good results. Also, their

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production time is short and their cost is reduced. (Figure 1)

*Figure 1: 3D printed masks with a Vat Polymerization printer and elastic resin.*

### II.II. Materials

Material properties are fundamental to achieve a good result. The best material must be hypoallergenic, sterilizable, biocompatible (ISO 10993) and light. For the fabrication of custom masks, the PPE material must be elastic, and it must be rigid for creating face shields.

A shore hardness of 70-80A is suggested by the authors to create a custom mask: it is achievable with thermoplastic elastomeric (TPE) materials that exist in medical grade. Further studies investigating the filtering capacity and the comfort of a 3D printed masks are needed Other groups suggested to print masks in nylon or antimicrobic polylactic acid (PLA). Based on our experience, elastic materials show clear advantages. Some commercial printable resins show elastic properties, but they usually lack a certification for skin contact. For these materials, we suggest to use a medical-grade coating that can stabilize the resin and maintain its mechanical properties. To produce face shield frames, Nylon, PLA or acrylonitrile butadiene styrene (ABS) are perfectly suitable.

### II.III. Computer-Aided Design

In the last months, many researchers and industries have released free STL files on the web to give everyone the possibility to print masks and face shields. Among all these available possibilities, the open-source Blender's add-on called "MyFaceMask" software developed by Werg (Werg, Italy) to make protective masks is innovative: this software permits to design a mask based on the facial scan of the subject. (Figure 2) These data can be acquired through a stereophotogrammetric scanner to be accurate. It results in a mask with an improved fit. A Polyshape3D (Polyshape3D, Italy) scanner was involved in this study. Otherwise multiple commercial devices permit to take an STL of the face. Moreover, a wide choice among different types of commercial filters is available.

### II.IV. Type of Filter

Particles filters are categorized by the European standard in P1, P2, and P3 (UNI EN 143). This classification is made on their filtering capacity. The most protective are the P3 filters that can filter 99% of particles up to 0,6 µm. The P2 filters the 94% of particles up to 0,6µm. P1 filters are not adequate to stop this novel coronavirus, because they filter the 80% of particles that sized up to 0,6µm. P3 filters are considered the gold standard in fighting this battle. Due to the shortage of P3 filters and considering that Sars-Cov-2 is transmitted via droplets, P2 filters are declared sufficient to protect medical operators. [10]

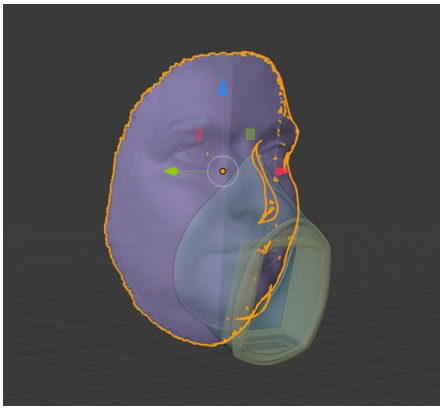

*Figure 2: Integration between facial scan and "MyFaceMask" add-on on Blender to produce tailor-made 3D printed filtering masks.*

## IV. Conclusions

Thanks to AM techniques it's possible to create PPEs that can help healthcare providers to be protected against the COVID-19. While for the face shield just the mechanical characteristics are important, a protective mask has to be atoxic, biocompatible, sterilizable and well-fitting to the face' anatomy. The most cost-effective way to produce these masks is through FDM printers, using a 70-80A elastic and biocompatible material. To obtain a comfortable mask with an airtight fit for prolonged use, it is suggested to design it on the face scan of the subject that will wear it with at least a P2 filter.

#### AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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