Journal of Production, Operations and Systems Management
e-ISSN: 1984-2430
Open Access
Editor-in-chief: Paula de Camargo Fiorini
Received:02/02/24 Approved: 16/10/24

PRODUCTION OF FACE PROTECTORS BY 3D PRINTING: DISTRIBUTION OF PPE TO FACE THE CORONAVIRUS

PRODUÇÃO DE PROTETORES FACIAIS POR IMPRESSÃO 3D: DISTRIBUIÇÃO DE EPI PARA ENFRENTAMENTO DO CORONAVÍRUS

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ABSTRACT

Purpose: The aim of this study is to produce face shields using 3D printing, contributing to the personal protection of healthcare professionals from both public and private health institutions amid the coronavirus pandemic.
Theorical framework: At the beginning of the Covid-19 pandemic, it became common for health professionals to report on the scarcity of Personal Protective Equipment (PPE) in their work, which resulted in the high level of contamination of those involved in the front line. The face shield stood out as one of the missing PPEs, important for the health and safety of workers as they offer a physical barrier to contamination by secretions.
Methodology/Approach: For this purpose, through the Center for Robotics, Innovation, and Entrepreneurship (CRIE), the prototyping laboratory of the Federal Institute of Minas Gerais campus Governador Valadares (IFMG-GV), different models of face shields were tested. The model that provided the greatest comfort for users was selected, while also requiring less printing time and using less raw material. The production was carried out in accordance with Resolution 356/2020 of the National Health Surveillance Agency (ANVISA), which authorized and decentralized the production of large industries in an extraordinary and temporary manner.
Findings: Requirements for the manufacture, importation, and acquisition of medical devices were defined. In total, 223 face shields were produced and donated to the city's healthcare system, serving the Unimed Hospital, the Medical Association, and other local hospitals.
Research, practical & social implications: From the action, the IFMG-GV, as a public educational institution, played its role by providing support to local society, influenced by the consequences of the pandemic.
Keywords: Covid-19; Face shield printing; 3d printing.

RESUMO

Objetivo: O objetivo deste estudo é produzir protetores faciais, por meio da impressão 3D, colaborando na proteção individual de profissionais de saúde de instituições de saúde públicas e privadas, em meio à pandemia de coronavírus.
Referencial Teórico: No início da pandemia de Covid-19, tornou-se comum que profissionais de saúde relatassem a escassez de Equipamentos de Proteção Individual (EPIs) em seus trabalhos, o que resultou em um alto nível de contaminação daqueles envolvidos na linha de frente. O protetor facial destacou-se como um dos EPIs ausentes, sendo importante para a saúde e segurança dos trabalhadores, pois oferece uma barreira física contra a contaminação por secreções.
Metodologia/Abordagem: Para isso, por meio do Centro de Robótica, Inovação e Empreendedorismo (CRIE), laboratório de prototipagem do Instituto Federal de Minas Gerais campus Governador Valadares (IFMG-GV), foram testados diferentes modelos de protetores faciais. O modelo que ofereceu maior conforto de uso aos usuários foi selecionado, ao mesmo tempo em que exigia menos tempo de impressão e consumia menos matéria-prima. A produção ocorreu de acordo com a resolução 356/2020 da Agência Nacional de Vigilância Sanitária (ANVISA), que autorizou e descentralizou a produção de grandes indústrias, de maneira extraordinária e temporária.
Resultados: Foram definidos requisitos para a fabricação, importação e aquisição de dispositivos médicos. Ao todo, foram produzidos e doados 223 protetores faciais para o sistema de saúde da cidade, atendendo ao Hospital Unimed, à Associação Médica e outros hospitais locais.
Implicações da pesquisa, práticas e sociais: A partir da ação, o IFMG-GV, como instituição educacional pública, desempenhou seu papel ao fornecer suporte à sociedade local, influenciada pelas consequências da pandemia.
Palavras-chave: Covid-19; Impressão de protetor facial; Impressão 3D.

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1. INTRODUCTION

The COVID-19 pandemic has reached a global scale and has had widespread impacts due to its ease of transmission and high lethality among the infected (MEHTA et al., 2020). Brazil identified the first contamination by the new coronavirus in late February 2020, and community transmission began in March, the same month when the first death from the disease was recorded (OLIVEIRA, 2021). Covid-19 is characterized as a variant of Severe Acute Respiratory Syndrome (SARS) and is called SARS-CoV-2.

The viral load of Covid-19 is high, being found in the upper respiratory tract and fecal samples (ZOU et al., 2020). Virus transmission occurs through airborne droplets and contact, spreading through the mouth or nose of an infectious person when they cough, sneeze, sing, breathe heavily, or talk. Close contact with an infected person can result in inhalation or inoculation of the virus through the mouth, nose, or eyes (PAHO, 2020).

Precautions in patient care apply to waste management, environmental cleaning, sterilization of hospital equipment, and the use of personal protective equipment (PPE) (WHO, 2020a). Therefore, it is necessary to adopt precautions, especially through the use of protective masks and handwashing.

In Brazil, the Ministry of Health recommends the use of Personal Protective Equipment (PPE) whenever procedures involving aerosols are performed, which should be provided by the services and used by healthcare professionals responsible for attending suspected or confirmed cases of COVID-19. These PPEs include: 1) cap; 2) protective glasses or face shield; 3) mask; 4) long-sleeved waterproof gown; 5) procedural gloves (BRASIL, 2020).

As the use of PPE is crucial for protection against Covid-19 infection, the demand has increased significantly in a short period, leading to a shortage of PPE in the market. BOCCHINI (2020) states that all three levels of government (federal, state, and municipal), as well as private hospitals, initially faced difficulties in purchasing most of the personal protective equipment (PPE).

This fact motivated the exceptional release by ANVISA of Resolution No. 356, allowing for the production and distribution of face shields. In Brazil and other countries, the development of personal protective equipment through 3D printing was common, with the designs being freely shared with a network interested in the topic, as a way to strengthen the production of face shields that were in short supply at the time (Amin et al., 2023; Celik et al., 2020; Perencevich, Diekema, Edmond, 2020; Flanagan, Ballard, 2020; Novak, Loy, 2020; Jorge et al., 2020).

With the scarcity of face shields and the high demand for them, the Federal Institute of

Minas Gerais Campus Governador Valadares (IFMG-GV) undertook to produce face shields through 3D printing in response to the coronavirus pandemic, aiming to support both public and private health institutions. According to De Negri et al. (2020), effective coordination between the government, researchers, and scientists from public universities was necessary during the pandemic to generate meaningful contributions in addressing Covid-19, leading to socio-economic impacts.

Thus, the study aimed to answer the following research question: "How did the production of face shields through 3D printing contribute to the individual protection of healthcare professionals from both public and private health institutions amid the coronavirus pandemic?”. Through the Robotics, Innovation, and Entrepreneurship Center, IFMG-GV’s prototyping laboratory, it was consolidated the production of face shields, which were donated to meet the need and ensure the protection provided by this PPE for healthcare professionals in the region of Governador Valadares – Minas Gerais. It's worth noting that amid the pandemic, given the shortage of medical supplies, the collaboration of local researchers in developing face shields that met the requirements of ANVISA Resolution 356/2020 was crucial in supporting both public and private healthcare networks, in order to provide comfort and safety for use by professionals and cost-effectiveness and manufacturing productivity.

2. LITERATURE REVIEW

The theoretical foundation of this work consists of the reflections on the impact of Covid-19 in Brazil, the role of public universities in this context and how to develop prototypes and products through 3D printing.

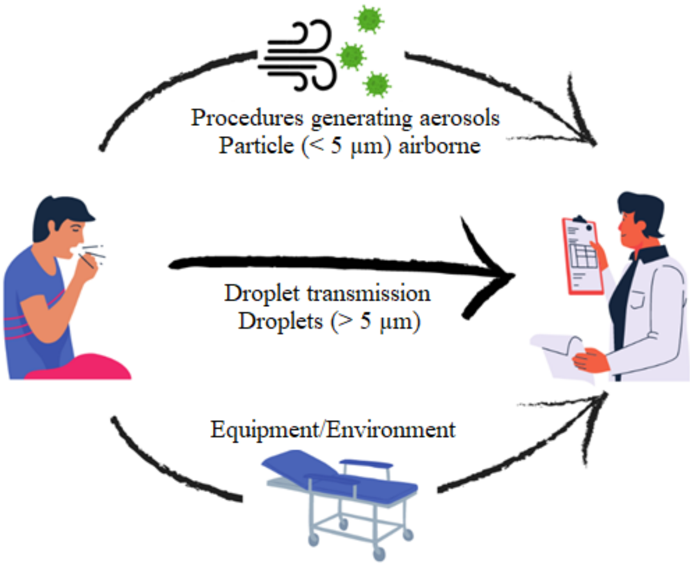
2.1 Reflections of Covid-19 in Brazil

Covid-19 is characterized as a variant of Severe Acute Respiratory Syndrome (SARS) and is called SARS-CoV-2. By the end of March 2020, there were records of Covid-19 in all 26 states and the Federal District; by the end of June 2020, there were 1,448,753 infected individuals and 60,632 deaths (Brazil, 2020). With this brief history of Covid-19 in Brazil, the rapid transmission of the virus in the early pandemic can be observed.

Its transmission (Figure 1), as warned by PAHO (2020), occurs through airborne droplets and contact in any healthcare assistance, spreading through the mouth or nose of an infectious person when they cough, sneeze, sing, breathe heavily, or talk. Close contact with an infected person can result in the inhalation of the virus through the mouth, nose, or contact with the eyes.

Figure 1

Possible transmission routes.



Source: Peres, Boléo-Timé, Santos, 2020.

Infection has a wide range of etiological agents, transmitters such as bacteria, viruses, parasitic fungi, or prions. There are also various transmission routes, including bloodborne, droplets, or aerosols, with more than one transmission route possible (Peres, Boléo-Timé, Santos, 2020).

Weber et al. (2016), reviewing past pandemic cases, emphasize the need for healthcare facilities to develop contingency plans to deal with these pathogens, including early identification and isolation of cases and the provision of personal protective equipment. The recommended personal protective equipment (PPE) for use during the care of suspected or confirmed COVID-19 cases includes: 1) cap; 2) protective glasses or face shield; 3) mask; 4) long-sleeved waterproof gown; 5) procedural gloves (Brasil, 2020). For the greater efficiency of collective protective measures, the use of PPE is essential to minimize the risks of healthcare workers coming into contact with Covid-19.

The assurance of access to Personal Protective Equipment (PPE) for all workers in quantity and quality is the responsibility of the employer, whether public or private. It's important to note that this is a finite resource; therefore, there is a need for rational and appropriate use (BRAZIL, 2020). Whenever aerosol-generating procedures are performed, such as intubation or tracheal suction, non-invasive ventilation, cardiopulmonary resuscitation, manual ventilation before intubation, induction of sputum, nasotracheal sample collection, and bronchoscopies, the use of a respirator with a minimum filtration efficiency of 95% for particles up to 0.3μ (such as N95, N99, N100, PFF2, or PFF3) is recommended. These are typical situations when attending to Covid-19 patients (Peres, 2020).

In the first months of the Covid-19 pandemic, due to the high level of contagion and the global scale of the disease, the demand for Personal Protective Equipment (PPE) increased not only for professionals involved in combating Covid-19 but also for the general population. An estimated 89 million masks were being required monthly, representing a 40% increase in demand, leading to a supply crisis for these items (WHO, 2020b). This explains the supply crisis, given the quantity and short delivery time required, emphasizing the need for rational use of equipment. In a survey conducted by the São Paulo Medical Association (2020), among various doctors and healthcare professionals, this shortage becomes evident on the front lines of combating Covid-19.

Due to the shortage of supplies and the need to meet demand during the COVID-19 epidemic, the National Health Surveillance Agency (ANVISA) exceptionally and temporarily authorized the use of respiratory protective masks (N95/PFF2 or equivalent) for a longer period or a greater number of times than specified by the manufacturer (ANVISA, 2020a). For this, the professional should follow a series of precautions, such as: a) protecting the mask from exposure to droplets expelled by the patient by using a face shield; b) healthcare services must define a protocol to guide healthcare professionals on the use, removal, storage, integrity assessment, duration of use, and criteria for mask disposal.

Given the need for the development of quick and cost-effective solutions to prevent the virus's spread (Erickson et al., 2020), both public and private entities started contributing to society by manufacturing Personal Protective Equipment (PPE), enabling initiatives through 3D printing (Livingston, Desai, Berktis, 2020; Ishak, Lipner, 2020).

Simultaneously, ANVISA also authorized, on an exceptional and temporary basis, Resolution 356, the production and distribution (including donations) of face shields. For this, it established requirements for the manufacture, import, and acquisition of priority medical devices in healthcare services, given the international public health emergency related to SARS-CoV-2 (ANVISA, 2020b). As a result, there was collaborative effort from both public and private initiatives, including individual manufacturers, producers, and makers, to produce and supply PPE to healthcare institutions (Jorge et al., 2020; Andrade et al., 2020).

2.2 Role of Higher Education Institutions (HEIs) in combating the pandemic

Due to the high contagion rate, the new coronavirus spread rapidly, leaving no time for healthcare institutions to prepare. There was a widespread global search for Personal Protective

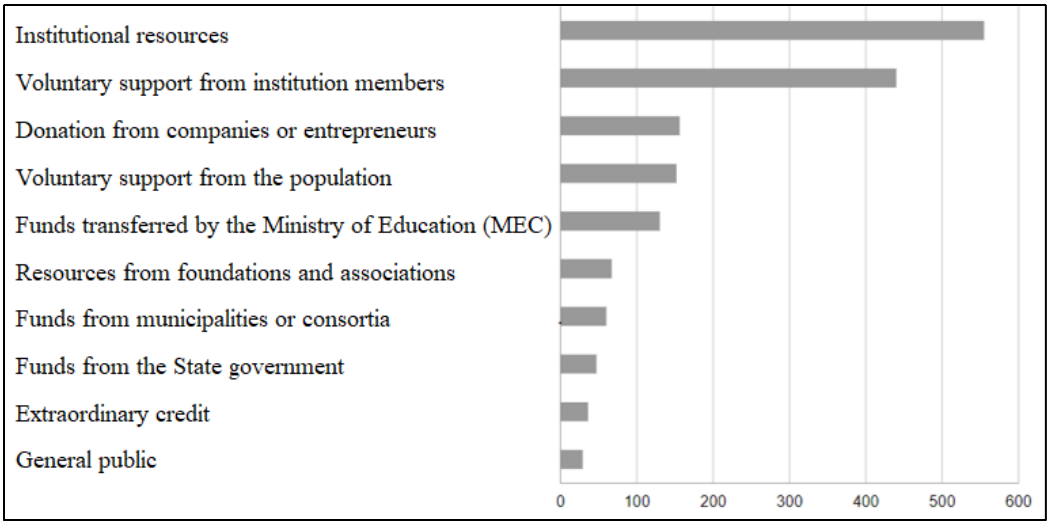
Equipment (PPE), 70% alcohol, masks, and respirators (Monteiro et al., 2020).

In this context, some national Higher Education Institutions (HEIs) mobilized their infrastructures, employees from different areas, students, and researchers. Numerous initiatives were conducted to minimize and overcome the negative effects of the disease (Gimenez, Souza, Feltrin, 2020). A survey by the Ministry of Education (MEC) indicated that, only in the federal education network, there are 3,480 actions impacting 43 million people (MEC, 2020).

Most of the actions had their projects funded by institutional resources (Figure 2), with broad support from internal volunteers, such as students, faculty, and administrative staff (Almeida et al., 2020). There was also some collaboration, albeit to a lesser extent, from federative entities and the participation of civil society.

Figure 2

Covid-19 combat actions, by supporting resources.



Source: Almeida et al. (2020).

Partnerships between universities and the community provided mutually beneficial relationships, where both higher education institutions and the population could express their desires and needs (Delaine, 2014). Arrais, Corcioli, and Medina (2021), based on analyses conducted with the institutional materials of the universities themselves, demonstrated their involvement in three directions: solidarity actions, support for crisis management, and research.

The Covid-19 response actions of Higher Education Institutions (HEIs), especially federal ones, aimed at producing alcohol (gel, glycerinated, and/or 70%), manufacturing Personal Protective Equipment (PPE) through 3D printing, creating educational materials, providing psychological support services, developing disinfection mechanisms, and vaccine development (Almeida et al., 2020). According to Boothroyd (2010), universities are responsible for knowledge production, stimulating problem-solving, and collaborating with governmental institutions.

2.3 Development of prototypes and products through 3D printing

3D printing is a process in which a three-dimensional model is created in a Computer-Aided Design (CAD) system, generating a file that is then sent to a Computer-Aided Manufacturing (CAM) system to be "sliced" into layers. After this process, a thermoplastic filament is unwound from a coil to the extruder of the 3D printer. The extruder nozzle is heated to melt the thermoplastic, and a mechanical system allows the material to flow onto the printer bed, which may be heated or not, for layer-by-layer deposition, from bottom to top, until the completion of the designed piece.

The most commonly used process among low-cost 3D printers is called Fused Deposition Modeling (FDM), used to produce conceptual models, functional prototypes, and final-use parts in standard, engineering, and high-performance thermoplastics. It is the only professional 3D printing technology that uses production-grade thermoplastics.

For a successful print, the configuration must align with the function and material the printed object is intended for. Starting the configuration with the material's melting temperature, nozzle temperature, temperature at which the material becomes malleable for extrusion, print bed temperature parameter, not all printers have a heated print bed, this parameter aids in fixing the piece to the bed, first layer height parameter, the height of the first layer that will fix the piece to the bed, first layer temperature parameter, you can set the temperature at which the first layer will be subjected to help fix the piece, layer height parameter, a configuration that changes the layer height, this configuration directly affects the finish of the piece and print time, the smaller the layer, the better the finish of the piece, and the longer the print time, infill percentage parameter, this configuration defines the percentage of infill of the piece, making it more hollow or solid, shell thickness parameter, a configuration that defines the thickness of the outer layer, support for printing parameter, a configuration that defines whether the print will have supports or not, support density parameter, a configuration that defines the density of the support; print head speed configuration, a configuration that defines the speed at which the print head will move.

As for filaments used as inputs in 3D printers, the most commonly used materials are PLA, ABS, and PETG (Table 1). The choice of printing material depends on strength, durability, costs, environmental characteristics (such as toxicity), energy consumption, and recyclability.

Table 1

Most commonly used materials for 3D printing.

PLA	Polylactic Acid (PLA) is the main filament used in 3D printers; it has a lower printing temperature than Acrylonitrile Butadiene Styrene (ABS), so it does not require a heated print bed. Additionally, PLA is a biodegradable material.
ABS	ABS is a copolymer obtained from reactions involving three different monomers (acrylonitrile, butadiene, and styrene), and its printing requires more technical knowledge and a heated print bed. It has superior mechanical properties compared to PLA, being more durable, strong, and lightweight, while also being more cost-effective. ABS can withstand higher temperatures and has a slight flexibility.
PETG	Polyethylene Terephthalate (PET) is a polyester, transparent, glossy, lightweight with good design performance, and ease of molding, providing high mechanical strength (impact resistance) and chemical resistance, as well as barriers for gases and odors. In general, PET, PETG, and PETT are stable and harmless polymers, recyclable, and do not produce smoke or odors during the printing process. Their printing temperature is typically around 220°C to 250°C, and they require a heated print bed.

Source: Simplify 3D (2024).

PLA has high surface hardness and is highly resistant to abrasion. Parts that will undergo wear through contact are perfect for being printed with PLA. It is possible to produce amazing pieces with a lot of shine and detail levels using PLA (3DFILA, 2024). Its applications stand out in decoration, architecture, and prosthetics.

ABS has higher mechanical strength than PLA; however, it is more challenging to print, requiring a heated bed, and for larger parts, a closed printer must be used. ABS solidifies faster than PLA, leading to printing defects in an open printer. Its applications are similar to PLA but with a bit more heat resistance; PLA softens around 70°C, while ABS does so at 105°C (BITFAB, 2024).

PETG enables the printing of more translucent objects and reduces their melting point, making it ideal for creating durable and easy-to-extrude parts. Due to its ease of extrusion and thermal stability, PETG is increasingly used in the 3D printing world. PLA is primarily used for producing parts that require some flexibility, good impact resistance (even at low temperatures), such as pressure-exposed parts, protective parts, or food containers, which can be fully recyclable (FILAMENTE2PRINT, 2024).

3. METHODOLOGY

This study is characterized, methodologically, by its applied nature. According to OECD (2018), this is a step that involves the practical use of science, a modality that requires scientific knowledge to be applied in technology, solutions, or inventions. Thus, this study seeks a solution by applying scientific knowledge.

Regarding the approach, it is classified as qualitative. Araújo et al. (2019) emphasize that this type of research aims to interpret the phenomenon that occurs, i.e., observe, describe, understand, and give meaning to the problem. This type of research presents a process that seeks process improvement, derived from the results found and the meanings attributed by the researcher. Therefore, this study observed, understood, and improved the face shield manufacturing method.

The study's objective is exploratory. Araújo et al. (2019) explain that exploratory research aims to develop, clarify, and modify concepts and ideas for the formulation of subsequent approaches. This study observed and modified parameters to improve the production process and developed ideas for better practices in future projects.

This work employs a case study as a methodology. According to Andrade et al. (2017), the case study as a research method requires the researcher to carefully design the protocol, explaining formal procedures while recognizing the study's strengths and limitations, as demonstrated in this study by listing the stages of development and production.

Data collection was conducted through experimental surveys in the laboratory. Araújo et al. (2019) state that in this type of research, a study object is determined, variables that can influence it are selected, ways of controlling and observing the effects the variable can produce on the study object are defined, and bibliographic research, explaining a problem based on theoretical references published in documents, such as books, journals, articles, and material available on the Internet, among other sources.

Data analysis followed the content analysis method, a continuous process seeking to identify dimensions, categories, trends, patterns, relationships, unveiling their meaning. This complex, non-linear process involves the reduction, organization, and interpretation of data starting in the exploratory phase and throughout the research cycle (Texeira, 2011). This study analyzes data simultaneously with their acquisition.

In summary, the development of this work went through four stages:

Stage 0: Selection of the 3D model for the face shield from searches on collaborative community websites and definitions with researchers from the IFMG network.

Stage 1: Creation of head support models through 3D printers, according to project specifications. The materials and equipment needed in this stage are:

- 3D printers;
- PETG, PLA, or ABS filament of 1.75mm, from any brand or color;
- Computers for print configuration.

Stage 2: Laser cutting of transparent sheets. The materials and equipment needed in this stage are:

- Rolls or sheets of acetate with thickness greater than 0.5mm.
- Laser cutting machines.

Stage 3: Development of the assembly manual for the face shields, based on the separately delivered parts.

Stage 4: Delivery of assembly manuals and face shields to healthcare institutions.

The production of face shields took place at the Robotics, Innovation, and Entrepreneurship Center, the prototyping laboratory of the Federal Institute of Minas Gerais Governador Valadares campus (IFMG-GV). The work involves the production of face shields using 3D printing.

Before production, the need for this type of PPE was assessed with the representative of the Local Medical Association, where the difficulty of acquiring face shields and the quantity required for local hospitals' demand were identified.

The project developed was based on the e-Nable Brasil model, a community composed of volunteer members from fablabs and maker spaces who design, print, and distribute prostheses manufactured with 3D printers to support healthcare institutions (E-NABLE, 2020).

Subsequently, a group of teachers and students at IFMG identified the characteristics that a face shield should have, according to ANVISA, complying with resolution 356/2020, as well as the models already developed and available on the internet. The chosen model was the PRUSA Headband Brasil V3, an open-source model, considering factors such as surface print quality, adjustable or fixed elastic fastening, and the size of the printer's print bed, which would allow multiple prints at once through stacking (Figure 3) (PRUSA PRINTERS, 2020).

Figure 3

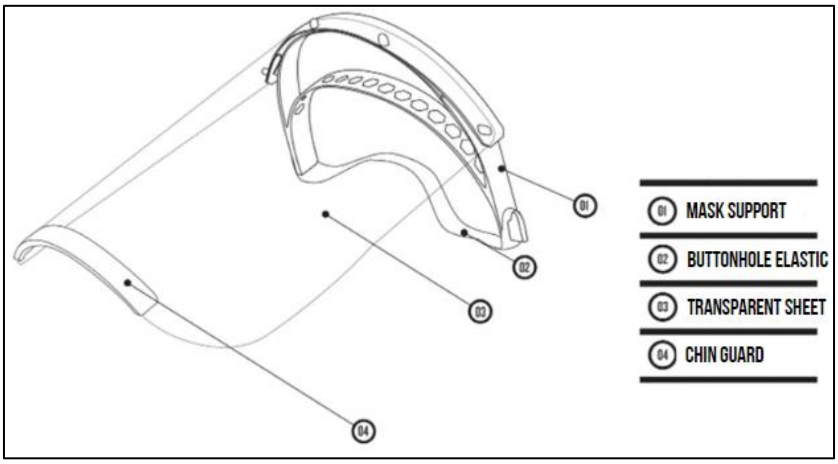
PRUSA Face Shield Model - Headband Brasil V3.

Source: Prusa Printers (2020).

With the chosen model, some modifications were made to expedite production for timely donation. The manufactured PPE (Figure 4) consisted of two pieces of PLA, ABS, or PETG plastic produced by a 3D printer (items 1 and 4, respectively), a 0.5 mm thick, 24x24 cm acetate sheet (item 3), and a sewn elastic band for head fixation (item 2).

Figure 4

Produced Face Shield.



Source: Own elaboration.

4. RESULTS AND DISCUSSION

The production of face shields took place at the Robotics, Innovation, and Entrepreneurship Center (CRIE), a prototyping laboratory at the Federal Institute of Minas Gerais, Governador Valadares campus (IFMG-GV). The 3D printer model used at CRIE is a da Vinci 1.0 Pro 3-in-1, developed by the company XYZprinting. It is an FFF - Fused Filament Fabrication technology printer with a print area of 200 x 200 x 190 mm, layer resolution of 20 – 40 microns, and precision of 0.0004 mm. It operates with extrusion nozzle temperatures of up to 240º C and a print bed that can be cold or at temperatures from 40 ~ 90º C. The printer uses 1.75mm diameter filaments such as PLA, ABS, PETG, and HIPS (XYZPrinting, 2020).

To define production, a survey of the need for face shields was conducted with the local Medical Association, along with the exchange of information from different research professors in the IFMG network, given the difficulty in acquiring them at the time. There was also the need to select a model that would meet the operational constraints of the campus printer, the comfort conditions for professional use, the cost-effectiveness and speed of production, and the aspects defined by ANVISA's Resolution 356/2020, which include:

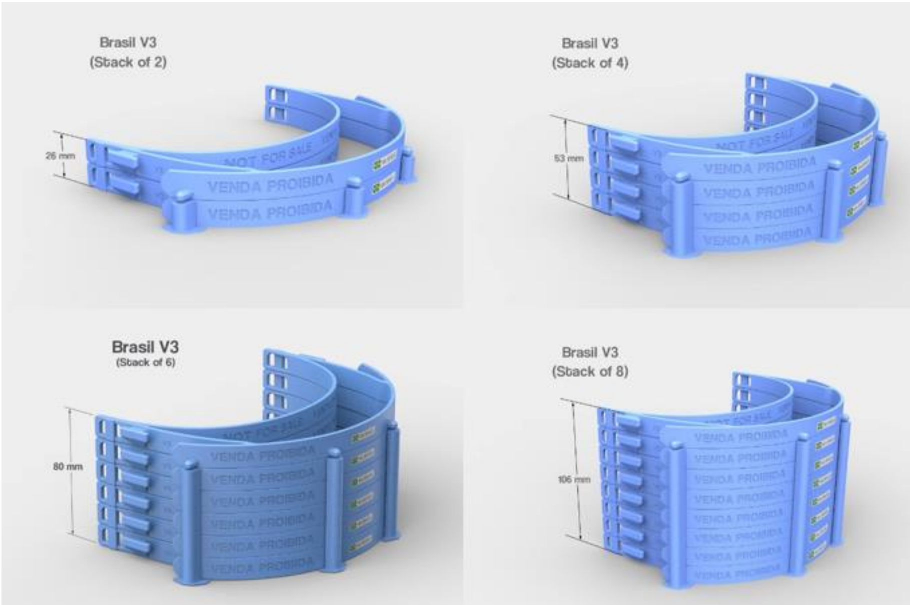
> Art. 6° Full-face shields must comply with the requirements established in the following technical standard:
> I - ABNT NBR ISO 13688:2017 - Personal eye protection - Eye and face shield - Requirements.
>
> § 1° Full-face shields must not have protrusions, sharp edges, or any defects that may cause discomfort or accidents to the user during use.
> § 2° User adaptation must be facilitated so that the face shield remains stable during the expected period of use.
> § 3° Straps used as the main means of attachment must be adjustable or self-adjusting and have a minimum width of 10 mm over any part that may come into contact with the user.
> § 4° The front visor must be made of transparent material and have minimum dimensions of 0.5mm thickness, 240mm width, and 240mm height. (ANVISA, 2020b).

The development of face shields did not involve design and efficacy testing phases in the process with the public of Governador Valadares since the Prusa Printers model, designed by e-NABLE Brazil, had been officially tested and approved for printing and use in hospitals in Brazil, one of the reasons it was chosen.

It is worth noting that the produced PPE was not intended to replace those manufactured by authorized companies but to assist the general public in the face of a shortage of personal protective equipment. In order to optimize production in terms of time and printing speed, stacking was tested. Stacking is the assembly of multiple parts in a single print to produce more items with less interference, tested with stacking of 2, 4, 6, 8, and 10 units (Figure 5), also observing print quality and the smooth operation of the printer without interruptions or failures. Production capacity varies based on machine settings and operating conditions.

Figure 5

Stacking 2, 4, 6, and 8 pieces.



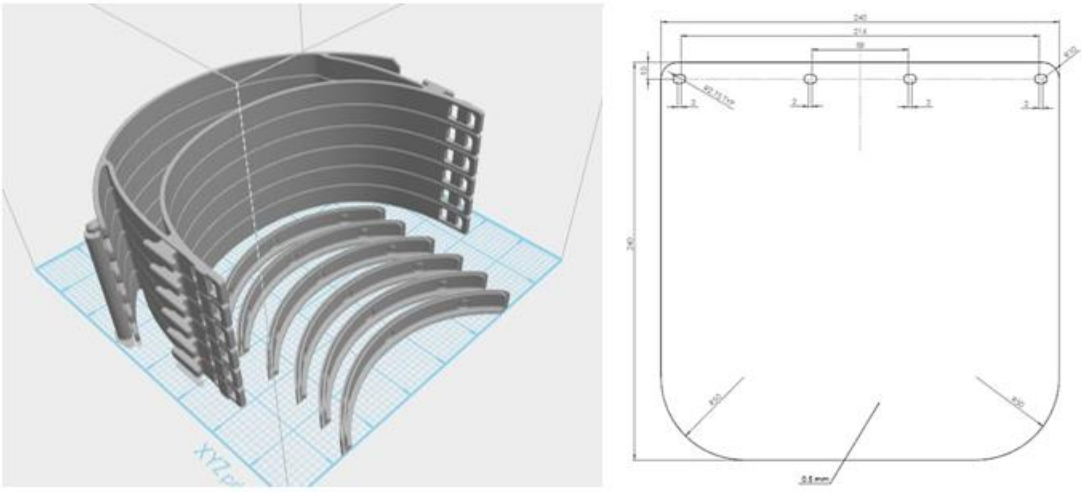
Source: Prusa Printers (2020).

The adopted modifications considered the need to expedite printing and make the model stackable for printing, as well as to provide additional methods of attaching the elastic strap. For this purpose, a plastic clip was added to the end of the model, and an extra layer was created to facilitate detachment from one model to another when stacking.

The stacking process was facilitated by the chosen Prusa model being flatter and without protruding edges. This made it possible to stack several pieces for production with less interference. The dimensions are smaller than the printer's print bed, allowing for the accommodation of the pieces (Figure 6).

Figure 6

Model printed at CRIE.



Source: Own elaboration.

As for the methods of attaching the elastic strap, the chosen model has two types of fastening. It can be used with a looped elastic, which is secured to the side flaps at the end of the piece, or with latex surgical tube strips on the plastic buckle (Figure 7). The chosen material for production was PLA, based on filament availability for manufacturing.

Figure 7

The correct attachment of the looped elastic.

Source: Own elaboration.

As PLA is a biodegradable material, it was suggested that disinfection be done with 70% alcohol or another disinfectant suitable for this purpose, for at least 5 minutes. This recommendation was made to ensure that the technical specifications of the material were not altered. It was also suggested not to use abrasive substances on the transparent sheet.

Once the model was chosen, changes were made to configure the model for the 3D printer control software. In it, material parameters were defined as follows:

General:

- Fill density: Medium (30%)
- Fill type: Rectilinear
- Shells: Normal
- Layer height: 0.3 mm
- First layer height: 0.3 mm
- Speed: Standard
- Retraction length: 5.00
- Retraction speed: 25mm/s
- Detail threshold: 0.040 mm

Supports:

- Supports enabled
- Support type: Rectilinear
- Support density: Low
- Overhang threshold: 45
- Support spacing: 1 layer(s)
- Extend supports: 0 mm
- Raft enabled
- Raft type: Rectilinear
- Raft spacing: 0.30 mm
- Brim disabled
- Brim width: 10

A filling density of 30% was used, as it is sufficient to ensure the necessary strength for the piece to bend without breaking and optimized the use of material. The layer heights were set at 0.3mm to expedite the printing speed without making it rough. Printing with supports was chosen; supports are structures designed to support the parts of your project that do not have anything underneath. This way, supports provide crucial support, preventing material from being deposited in the air. They are used when a piece requires a lot of detail or has a slope less than 45° in relation to the table, making the piece parallel to the table. The temperature used was 210ºC at the print head and 60ºC on the print bed.

When the printing file is generated, the software slices the 3D model into several layers with the configured layer height. A G-Code is also obtained, which is a coordinate code that instructs the printer on the paths it should follow, when to extrude the melted filament, and when to move to the next layer.

After completing the procedure, the printer provides information on the average amount of material used and the average completion time. With this information, a work routine was developed to obtain the maximum number of protectors without exceeding the printer's limits. From 8:00 am to 12:30 pm, a stack of 2 protectors was printed, from 12:30 pm to 8:00 pm, a stack of 4 protectors, and from 8:00 pm to 8:00 am, a stack of 4 protectors. In this way, 10 protectors were produced per day.

Every 30 hours of production, there was a cleaning routine for the print head, as indicated in the equipment's operating manuals. After that, a new printing routine was started. During the first printing batch of the day, the printed parts were treated, and the support material was removed. The surface of the piece was given a better finish by sanding the printing imperfections with iron sandpaper No. 100.

Maintenance, following the printer's parameters, proved to be essential. In addition to cleaning the print head, the table was recalibrated to ensure that it remained perpendicular to the print head. This maintained the distance between the nozzle and the table so that the material was properly deposited during printing. The produced batches were donated to the Municipal Hospital, Unimed Hospital in Governador Valadares, and the Medical Association of Governador Valadares, the latter being partners of the Institute in this project, providing input donations for production. In total, 223 units of face shields were produced and distributed (Table 2).

Table 2

Quantities distributed among public and private health units in Governador Valadares.

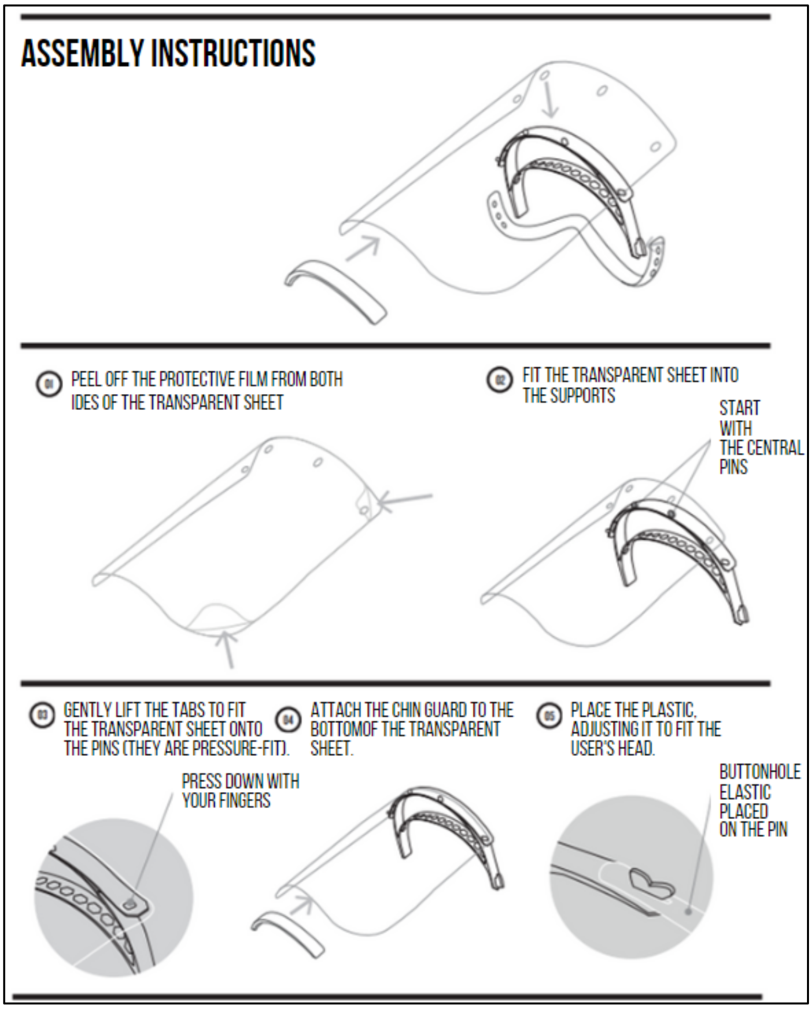
Institutions served	Quantities
Unimed Hospital in Governador Valadares	45
Municipal Hospital in Governador Valadares	20
Medical Association of Governador Valadares	158

Source: Own elaboration.

The produced kits were delivered disassembled, and to assist in the assembly, a manual was provided to users (Figure 8).

Figure 8

Assembly manual for the face shield.



Source: Own elaboration.

The delivery of disassembled kits facilitated the production process for project collaborators as well as the distribution routine among the served institutions.

Throughout the production process, a record of the adopted parameters and achieved productivity was maintained. At the beginning of the prints, an issue was noticed where the print bed did not adhere to the piece; after the first layer, the piece started to detach from the bed, starting from the sides. To address this, the room temperature was controlled, maintained around 25ºC using air conditioning. The use of glue on the print bed was implemented to create a more adhesive surface. The glue recommended by the printer manufacturer was utilized; however, other fixation methods, such as glue sticks, masking tape, special papers placed on the print bed, and lacquer spray, were considered. The solution recommended by the manufacturer was chosen.

Another issue identified was the correct temperature for printing each material. Although there are tables with ideal temperatures, they may not account for distinct environmental conditions. After tests, it was observed that the optimal printing temperature for PLA ranged from 205 to 215ºC. This variation was considered due to the different filament quality throughout the roll. This circumstance led the team to monitor the beginning of the print to ensure it occurred as expected.

Another challenge encountered was nozzle clogging. This occurred because the filament had absorbed moisture, and with the equipment's operating heat, it expanded, leading to nozzle clogging. For maintenance, it was necessary to contact the technical representatives of the equipment, who supervised the maintenance procedure. In this case, the procedure used deviated from the one suggested in the printer's manual, which involved a nozzle cleaning routine for nozzle obstruction. Instead, the disassembly of the print head was required, removing the electrical control and heat dissipation parts and applying heat with a heat gun only to the print head to unblock it by introducing a metal rod to remove the stuck material. This situation highlighted the need to check the quality and characteristics of the filament before printing.

Therefore, before each print, a material test was conducted, involving bending the filament at a 45º to 90º angle. If the filament did not break, its quality was confirmed. Breakage indicated that the filament was brittle and could break at any time during the print routine—leading to nozzle clogging or even bursting, not feeding the print head. After use, the filaments were stored in their original packaging along with silica gel. This was done to reduce material moisture and the risk of becoming brittle.

Printing difficulties were faced, especially when the air conditioning was turned off, deviating from the ideal temperature. This empirically verified statement resulted in the printed piece becoming twisted, deviating from the desired specifications. The correction of the piece's twist was achieved using a heat gun, reshaping it. Maintaining a controlled temperature is crucial to keep the piece malleable without melting it.

There were also cases of warped pieces; when colder, the filament hardened more quickly, and when hotter, it took longer to harden. This demonstrates the importance of maintaining controlled ambient temperature through the use of air conditioning.

Additionally, it was noted that the printer's feeder (the component that pushes the filament to the print head) is external to the equipment, unlike other models from different brands. Due to this, there is a duct that connects the feeder to the print head, which needs to be fixed to ensure proper filament feeding. There was a moment when the connection of the duct broke, preventing filament feeding to the print head. This situation led to the need to purchase a new connector, and the replacement procedure was also supervised by the technical support of the equipment supplier. All these situations were duly documented as lessons learned. Therefore, the knowledge gained in the process can be replicated in future uses of the equipment.

The culture of "do it yourself" (DIY) has promoted the creation and appreciation of collective construction, empowering development through accessible tools (Hatch, 2014; Duarte, Sanches, Dedini, 2017; Pinto et al., 2016; Costa; Agustini, 2014; Lindtner; Hertz; Dourish, 2014). Since its inception, the maker culture has been based on technical knowledge, establishing a direct connection with the educational field, where pedagogical approaches have begun to integrate creative learning methodologies.

One of the first steps in creating a new product is prototyping, which involves developing a simplified version of the product with the main objective of demonstrating its usability and purpose, as well as allowing functionality tests within an incremental cycle. This enables the validation of user experience, helping to identify problems and obstacles that may arise, with the intent to enhance the efficiency and effectiveness of the product, eliminating potential flaws.

With the diffusion of new manufacturing technologies and the creation of productive and collaborative spaces, the development of innovative and low-cost solutions has been facilitated (Niaros, Kostakis, Drechsler, 2017). These environments allow for independent use of equipment and promote active learning practices, enabling experimentation, research, and dynamic production (Kohtala, 2016; Fressoli, Smith, 2015).

To achieve this, educational institutions must keep up with technological changes and adopt innovation platforms, making these pathways increasingly accessible (Aldrich, 2014). Innovation is no longer limited to the industrial sector; innovation environments, as demonstrated in the study, are essential for establishing this new order, promoting open, democratic, and shared innovation (Browder; Aldrich; Bradley, 2016; Chesbrough, 2006; Von Hippel, 2005). In this context, the maker movement empowers a decentralized collective, where anyone can develop solutions to everyday problems through collaborative and shared practices (Flowers; Henwood, 2010; Dougherty, 2013). The simplification and democratization of innovation practices create a new technological dynamic (Peppler; Bender, 2013).

The hybridization of science and technology drives technological development, transforming the way the innovation process is handled (Koulopoulos, 2011). The participation of educational institutions in this movement has become inevitable, fostering the growth of the creative industry by enabling the creation of functional solutions in an inclusive and empowering culture. The pandemic context highlighted the decisive role of educational institutions in developing solutions in a short period, given the unavailability of resources in the global production chain.

In educational institutions, innovation environments reinforce the importance of individual training, promoting knowledge exchange focused on developing solutions (Monfredini, Frosch, 2019). Interactions and research-extension actions enrich professional training, allowing individuals and collectives to engage in diverse ways and meet regional needs (Pretto, 2010).

Such initiatives articulate and strengthen the relationship between the agents of the triple helix of innovation, which consists of partnerships between universities, companies, and government. Educational institutions play a fundamental role in fostering relationships with companies and government, stimulating both production and political and financial regulation. As a result, new knowledge is generated from science and research, promoting economic development in response to the technological demands of society (Etkowitz, 2009).

5. CONCLUSION

At the onset of the COVID-19 pandemic, reports from healthcare professionals about the shortage of Personal Protective Equipment (PPE) during their duties became common, leading to the contamination of those on the front lines. In response, the CRIE, addressing this demand, began producing face shields through 3D printing. The model to be printed was decided after exchanging information with various research professors from the IFMG network, considering the challenges in acquiring them at the time. Additionally, it was necessary to select a model that would accommodate the operational constraints of the campus printer, meet the comfort needs of professionals, ensure cost-effectiveness and quick production, and comply with the stipulations of ANVISA's Resolution 356/2020.

The achieved results included the production and distribution of 223 units of face shields, which assisted in protecting and extending the lifespan of PFF2 masks for healthcare professionals. Additionally, a set of lessons learned has been documented as knowledge to be shared with the CRIE team for future actions and developments.

Due to the pandemic, the project faced challenges such as delays in raw material delivery and limited available workforce. Maintenance issues with the printer were addressed by the prototyping laboratory personnel with remote technical support. The pandemic situation restricted the movement of the CRIE team due to limited hours and public transportation availability.

For future projects, it is suggested to maintain essential spare parts for the printer, such as print nozzles and connection adapters. Having a controlled temperature and humidity environment, a set of tools for finishing the prints specific to 3D printing, and a dedicated area for the procedure are also important recommendations.

This study underscores the impactful role of public higher education institutions in responding to the challenges posed by the novel coronavirus. The quick adaptation to increasing demands, the development of new routines, and the exploration of new scientific research areas have significantly contributed to society amid the ongoing epidemiological, economic, and social crisis.

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