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3D Printing PPE: A Three-Minute Face Shield Solution

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Learning Objectives

- Learn about the global maker's response to the COVID-19 crisis.
- Learn how Warwick University responded and helped using 3D printing.
- Learn how to print a PPE face shield in under three minutes.
- Learn about large-scale additive manufacturing.

Description

When the COVID-19 outbreak began, makers across the globe came together to help fill the shortfall in supply chains and provide personal protective equipment (PPE) for frontline workers by harnessing the power of a localized collective factory of 3D printers. At Warwick University we also sprang into action to help fight the virus. Large-scale additive manufacturing (LSAM) is a technology similar to that used in hobbyist desktop 3D printers. However, it generally has much bigger build platforms, larger nozzle diameters, and higher volumetric flow rates. This means it can be used as a rapid-response bridge manufacturing from 3D printing to injection moulding. Using Fusion 360 software's parameter tables, the speaker was able to generate a design that could be easily changed based on the printer setup and be optimized for the faster printing times. In just three design iterations we went from 10 minutes to just 3.5 minutes.

Speaker

Elizabeth Bishop is a Postgraduate Researcher at the University of Warwick researching Large-Scale Additive Manufacturing (3D Printing). She has been interested in 3D printing for several years now, following a successful project surrounding designing and making a humanitarian rescue UAV. Elizabeth also volunteers as a Maker in Residence in the Engineering Build Space at Warwick University where she explores making, CAD and CAM alongside 3D printing.

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Introduction

In December of 2019, an outbreak of a novel form of coronavirus (now named SARS-Cov-2) was reported in China [1], initially focused in Wuhan in the Hubei province [2]. This outbreak is now commonly referred to as coronavirus or COVID-19. The infection has spread globally reaching the necessary level of spreading to be classified as a global pandemic by the World Health Organisation (WHO) [3]. It has been established that the contagiousness of the disease is higher than previous outbreaks such as SARS in 2002-2004 [4], and can be transmitted through airborne droplet and contact transmission [5]. It can also been established that many people are able to transmit the disease without showing symptoms (they are asymptomatic) [6]. This is why the WHO has recommended that Personal Protection Equipment (PPE) be used [7]. PPE has become critical to frontline workers including medics, carers, and pharmacy staff. The use of PPE later grew to include teachers, the hospitality industry, and shop workers. It is now widely recommended across the world that every individual wears some form of PPE to help prevent the spread.

With this increase in global demand for PPE, many countries have struggled to supply enough PPE for regular use cases, let alone the extra demand from those who now needed extra protection to return to their jobs. The supply chain issues have been not only been impacted by the increased demand, but also by the closure of workplaces, factories, and production lines, with added disruption shipping lanes and transportation.

In response to the shortage of PPE across the globe, many companies, academic institutions and individuals (hobbyists) have come together in a joint effort to use 3D Printers (generally Fused Filament Fabrication (FFF) systems) to manufacture PPE items at a highly localised level. Due to the widespread presence of desktop FFF 3D printers, most designs being manufactured by these hobbyist community are optimized for common 3D Printers. These designs typically take around 1 to 2 hours to print, which can limit production.

This is where Large-Scale Additive Manufacturing (LSAM) comes in. LSAM systems have build volumes with dimensions of 1 meter or greater and typically use nozzles with diameters of 1 mm or greater. This is compared to desktop machines with nozzles typically of 0.4 mm to 0.8 mm. The ability of deposit the thermoplastic material at rates of around 100 mm^3/s on Large-Scale machines, compared to desktop machines at the order of 10 mm^3/s means that PPE items can be manufactured considerably quicker. The faster production rates have allowed for production of a face shield design at around 3 minutes per piece.

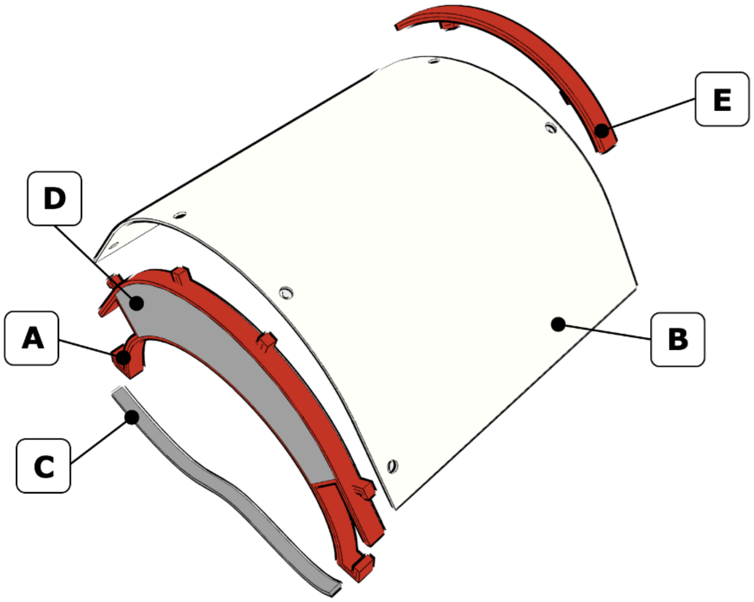
This handout will discuss the approach form the Engineering Build Space Team at the University of Warwick, UK in producing PPE for frontline staff, medics, and the community.

What is PPE?

PPE stands for Personal Protective Equipment and in the context of this paper and talk, encompasses protective equipment used to help reduce the spread of droplet infections. Particularly for protection of the face, mouth, and nose, against coughs and sneezes.

What is a Face Shield?

A face shield is a form of PPE that can be worn by the user to help protect against aerosol or droplet infection. They come in many forms, but a typical face shield might be made up of the components shown in Figure 1. The key components are the headband (A); a visor or lens (B) and a strap to hold it on the head (C). There might also be additional components depending on the design. The plastic parts of a typical face shield can be produced using 3D Printing technology.



A – Headband

B – Visor/Lens

C – Strap

D – Optional foam insert

E – Optional bottom reinforcement piece

Figure 1: Typical components which make up a face shield.

Community Response

Across the globe the 3D printing community really sprung into action to help provide this PPE where it was needed at a very high localised level, including where individuals in their homes were able to contribute to these disrupted supply chains and help those in need. Figure 2 shows some on the most widely used designs. The main contributors included Prusa Research in the Czech Republic, who have printed and donated almost 200,000 Face Shields. Other consortiums and distribution points have been established in various countries including, for the UK, the National 3D Printing Society (N3DPS) who have their own design and 3DVerkstan in Sweden. Another key contributor in the UK was Photocentric who are supplying the National Health Service (NHS) with over 7.6 million face shields.

Prusa Research | N3DPS | 3DVerkstan | Photocentric

Figure 2: Most widely used designs of 3D printed face shields used in the UK.

Large-Scale Additive Manufacturing

Additive Manufacturing is the process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies [8]. The terms Additive Manufacturing and 3D Printing are often used interchangeably, with the term most widely being used to describe the specific process of material extrusion, called Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF). Figure 3 shows the difference in terminology when referring to the scale of 3D printers.

Desktop Scale	Large-Format	Large-Scale	Very Large-Scale
Ultimaker 3 Extended	*3DP WorkBench + E3D Extruder*	*3DP WorkBench + HFE (High Flow Extruder) 300*	*Thermwood LSAM 1020*

Figure 3: Differences in terminology describing scale of 3D Printers.

Large-Scale Additive Manufacturing (LSAM) has high material flow rates of the order 100 mm^3/s, which can lead to faster print times. They typically have a build volume of at least 1 m^3 with parts typically having dimensions of around 1 m. The high flow rates, large nozzle sizes, and large layer heights can also lead to superior mechanical properties. The disadvantages are that material extrusion, including oozing, can be difficult to control. Additionally, if a print fails, the waste is usually much larger and the time lost can be greater.

Warwick University Face Shield Design

Initial Design

The proof of concept for a face shield for LSAM was designed in Fusion 360 using a parameter driven design based on the nozzle size. The only available equipment at the time was a research piece of equipment to test high flow rate extrusion, fitted with a 2.5 mm nozzle. The initial design can be seen in Figure 4 alongside the first print. The design was intended to minimise travel moves and retractions. This initial design printed in under 10 minutes.

Fusion 360 Design First Print

Figure 4: Proof of concept design for a face shield printed using large-scale 3D Printing.

Lack of access to lab equipment due to the UK national lockdown led to some very basic home experimentation as shown in Figure 5. However, this initial testing and pictures initiated talks to allow the Engineering Build Space Team access back into the University of Warwick Campus to begin production to help the National effort to produce PPE.

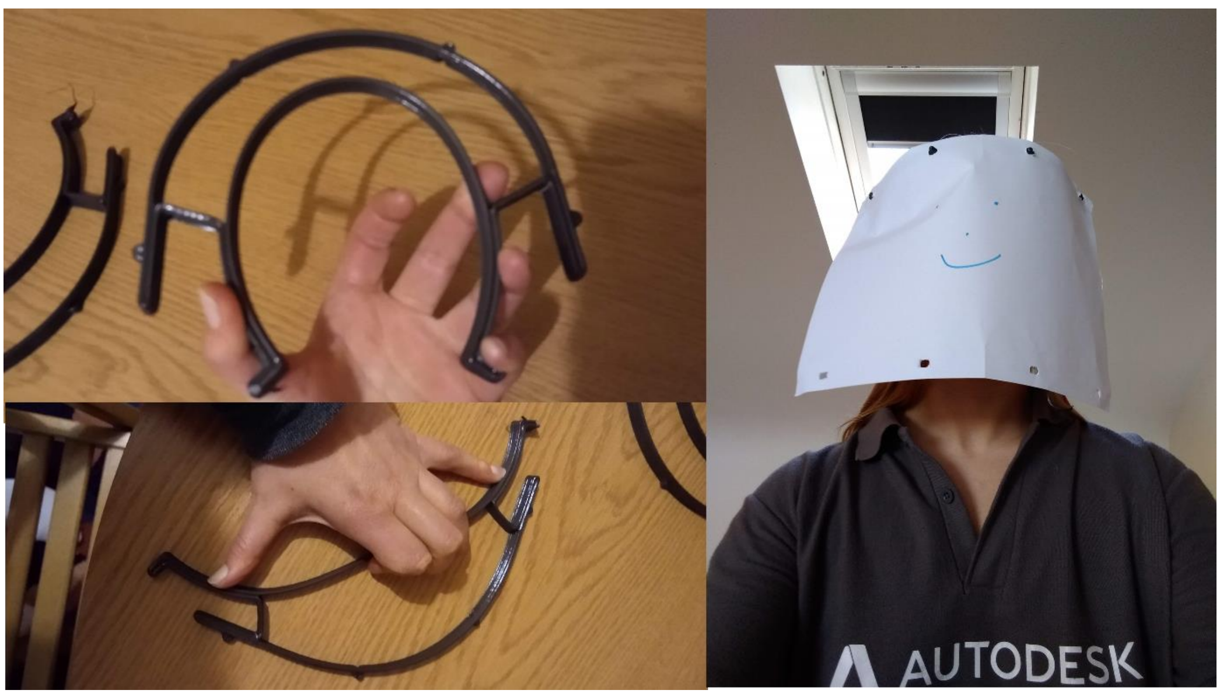
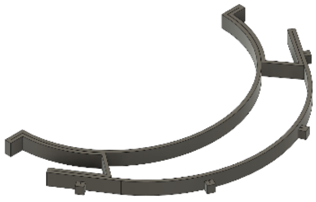
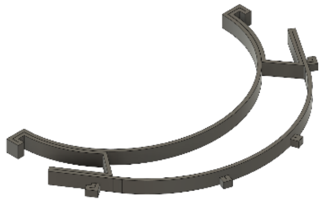
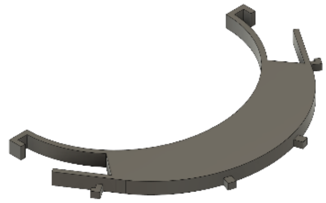


Figure 5: Initial ‘home’ testing of the proof of concept face shield design.

Design Iterations

The design iterations are summarised in Table 1 below. These were printed on a 3DPlatform 300 with a HFE extruder and 1.8 mm nozzle. Version 1 was around 6 minutes, Version 2 around 5 minutes and Version 3 around 5 minutes.

Table 1: Design Iterations and the major changes between designs.

		
VERISON 1	VERSION 2	VERSION 3
Attachment points for visor were too small Nowhere for a strap to attach to.	Added hooked outer attachment points for the visor. Strap attachment designed.	Redesigned to be printed in vase/spiral mode to reduce production time and remove travel moves and retractions.

This led to the design shown in Figure 6 below. This design took inspiration from the Prusa design and could be used with the visor they recommended. However, the Engineering Build Space Team had no way of producing visors that large, so an alternative was found in the form of A4 clear report covers. The Design was modified slightly to allow these report covers to be hole-punched using a standard hole punch – allowing for production of the entire face shield to be completed in-house.

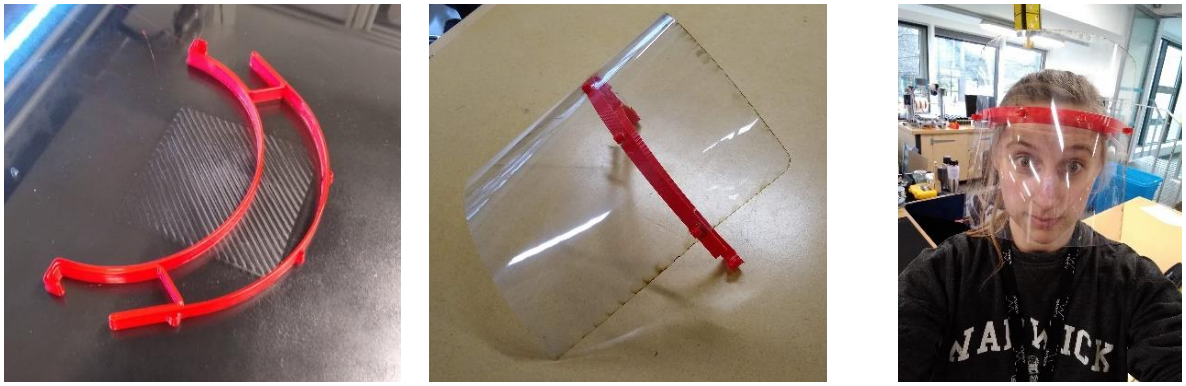


Figure 6: Design iterations and initial concepts.

Scaling Up Production

In order to utilise resources and increase production capacity, the operation was scaled up to print multiple headbands at the same time on a single print bed, as shown in Figure 7. This started off at 18 headbands per bed, with the number increasing to 27 per bed as confidence grew.

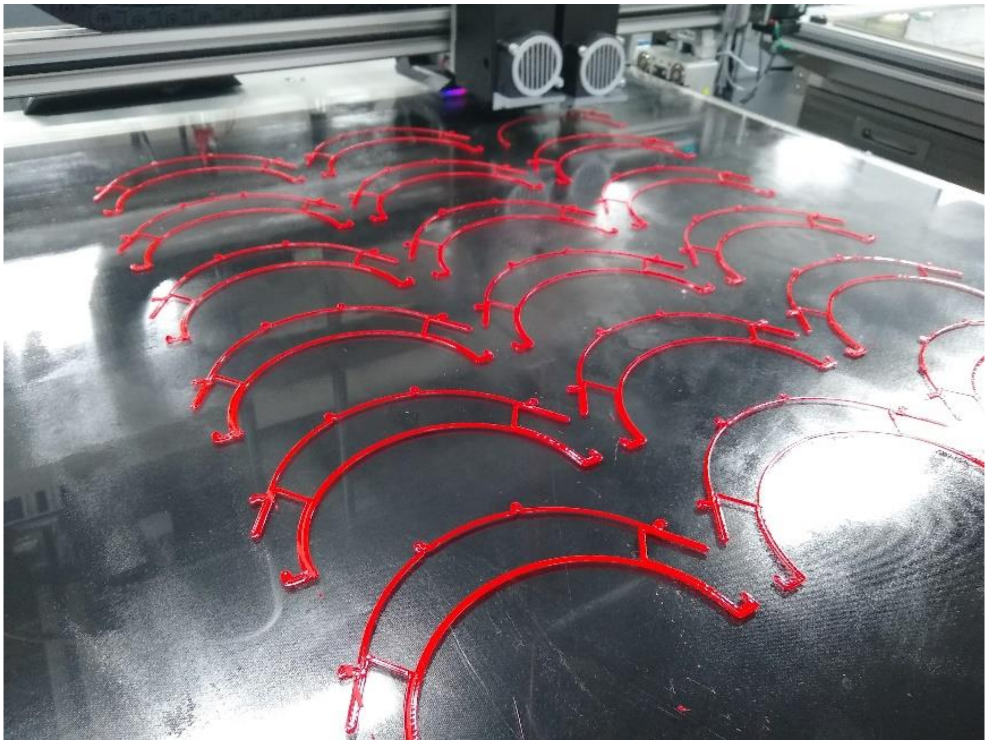
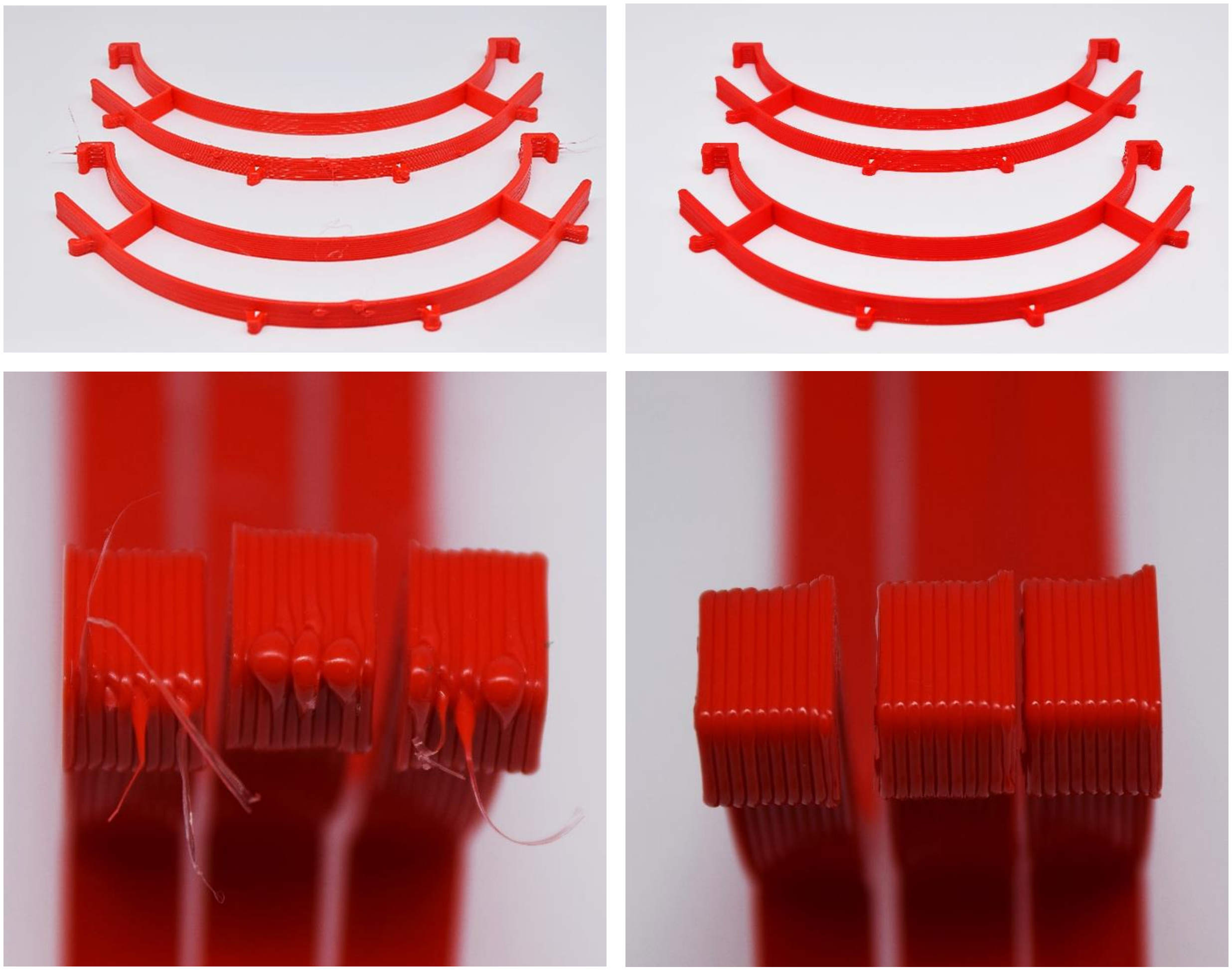


Figure 7: Multiple face shield headbands being printed on a single bed of a 3DPlatform 3D printer.

The increase in number of headbands on the bed, however, led to issues surrounding retraction, oozing, and stringing. The headbands were being printed in a parallel way with a single form each part at a time, building all 27 up to the full height at the same time. The travel moves between the parts caused dangerous artefacts on the surface of the headband, as shown in Figure 8a. IT was therefore decided to regenerate the toolpaths and move a sequential printing method. This is where each part is fully printed before moving onto the next, this also allowed for a return to using vase/spiral mode, which was not possible when printing in parallel. The move to sequential printing removed the artefacts on the surface, as shown in Figure 8b, and actually reduced the overall time for the whole bed to print as there were no unnecessary travel moves.



(a) (b)

Figure 8: 3D Printed headbands using (a) a parallel printing toolpath, creating surface artefacts and (b) a sequential printing toolpath, with no surface artefacts.

By the 6th April 2020, the production line was working flat out with the new established printing workflow. A bottom reinforcement piece had been designed and was being printed on the second 3DPlatform 3D Printer, and distribution to the community, free of charge, was underway. The visors were being hole punched from A4 report covers and the whole face shield was undergoing testing with BSI. The headbands were also tensile tested alongside some of the other widely available deigns with the results shown in Figure 9 below. The headbands printed using LSAM were far superior in strength.

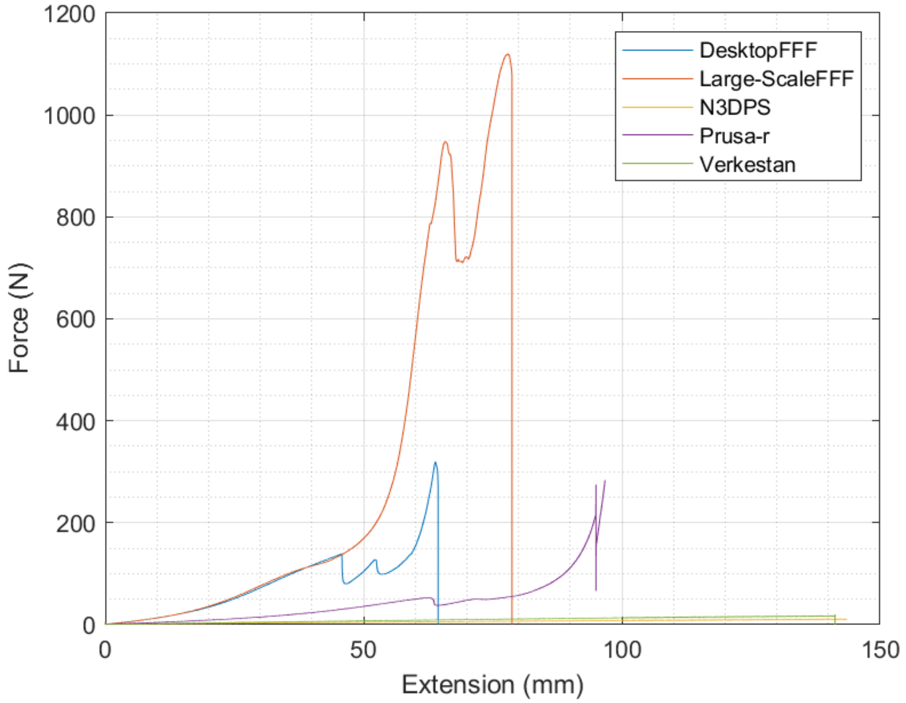


Figure 9: Results from Tensile tests of 3D Printed headbands.

Improving Production

The production was now being limited by the making of elastic straps for the kits. This was being done by hand and limited by the world shortage of elastic. To improve the production line a 3D printable strap was designed for LSAM, which could be printed on the 3DPlatform (Figure 10). These straps could be printed in batches of 64 taking around an hour per batch. The straps were removed from the print bed whilst warm and formed to a curve shape before cleaning and cooling.

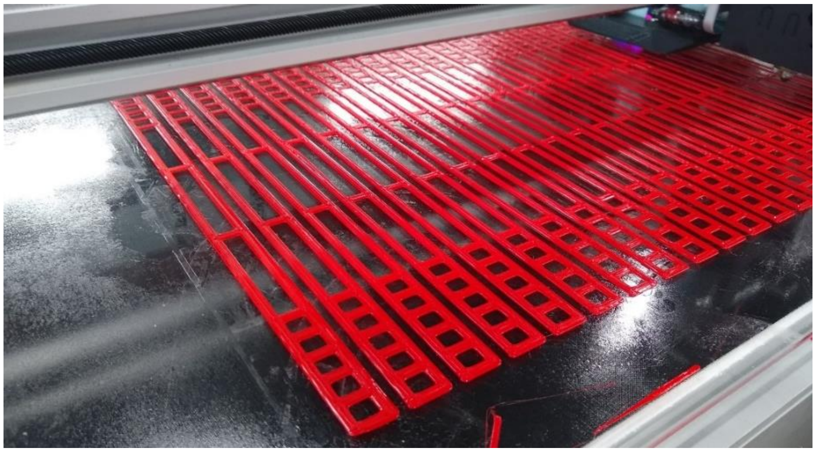


Figure 10: Straps for the face shields being 3D Printed.

Entire Re-Design

The initial design (Version 3) unfortunately failed to pass the BSI testing as the visor did not provide enough coverage. The whole face shield was redesigned, sourcing new, larger, visors from an external manufacturer. The new design can be seen in Figure 11 and consists of a visor, 3D printed headband and 3D printed strap. The printed headband can be printed in under 3 minutes. These shields have been designed and tested to conform to BS EN 166 2002 and EU Commission Recommendation (EU) 2020/403 for PPE.

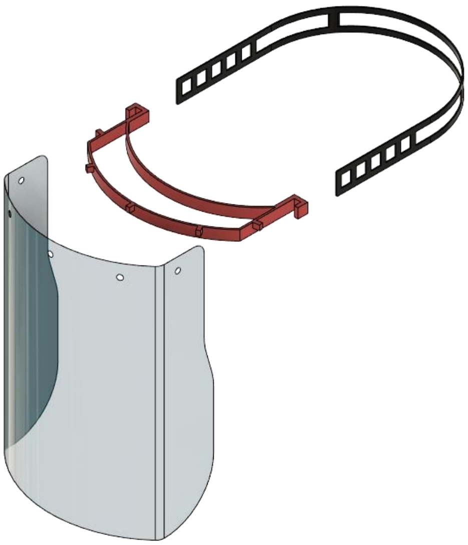


Figure 11: New design of face shield.

Conclusions

LSAM has been shown to be a technology capable of producing components of PPE devices in significantly less time than with traditional 3D printing systems such as desktop FFF devices. Through the thorough understanding of the interplay between design and process parameters it is feasible to parametrically optimising a design using Fusion 360. The resulting design has been printed in under 3 minutes and passed necessary BSI requirements to be distributed in the UK. The Engineering Build Space team at the University of Warwick, UK have so far managed to produce 7667 face shield kits for the community and distributed them where required across the UK, free of charge.

References

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