

# Open Design and 3D Printing of Face Shields: The Case Study of a UK-China Initiative

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## ABSTRACT

At the start of the COVID-19 outbreak, many countries lacked personal protective equipment (PPE) to protect healthcare workers. To address this problem, open design and 3D printing technologies were adopted to provide much-in-need PPEs for key workers. This paper reports an initiative by designers and engineers in the UK and China. The case study approach and content analysis method were used to study the stakeholders, the design process, and other relevant issues such as regulation. Good practice and lessons were summarised, and suggestions for using distributed 3D printing to supply PPEs were made. It concludes that 3D printing has played an important role in producing PPEs when there was a shortage of supply, and distributed manufacturing has the potential to quickly respond to local small-bench production needs. In the future, clearer specification, better match of demands and supply, and quicker evaluation against relevant regulations will provide efficiency and quality assurance for 3D printed PPE supplies

**Keywords:** 3D Printing, Distributed Manufacturing, Face Shields, Healthcare, Open Design, Optimisation.

## INTRODUCTION

The World Health Organization (WHO) designated “coronavirus disease 2019” (Covid-19) a global pandemic on the 11th March 2020. In March and April 2020, many countries were experiencing rapid increase of confirmed COVID-19 cases, but doctors, nurses and other frontline workers were dangerously ill-equipped to care for COVID-19 patients. WHO called on industry and government to increase manufacturing of personal protective equipment (PPE) by 40 per cent to meet the rising global demand (WHO, 2020). In some countries, the situation has become so dire that some providers are using social media and have even set up websites to obtain PPE directly (Ranney et al, 2020).

Many distributed 3D printing teams hoped to contribute to combating the pandemic. A number of initiatives of different scales have been quickly set up. Around the world, 3D printing teams in the United States first shared their design files of 3D printing masks. Therefore, the mask design of the American teams provided us with a reference. The U.S. Food & Drug Administration (FDA) teamed up with the Department of Veterans Affairs

Innovation Ecosystem and the National Institutes of Health 3D Print Exchange, to share data and coordinate on open-source medical products for the COVID-19 response (FDA, 2020). These agencies also work with America Makes that help connect health care providers and 3D printing organisations (Fig 1, screenshot of <https://www.americamakes.us/statement-on-covid-19/>).



Figure 1. America Makes' connecting healthcare providers, manufacturers and designers

The European Association for Additive Manufacturing (CECIMO) have set up networks to respond the increasing PPE demands. To optimise the time to market of PPE production, HP Digital Manufacturing Network and HP Production Partners are partnering in delivering medical supplies and devices to healthcare providers. Face shields are a major type of PPE being 3D printed. By mid-May 2020, HP has published four designs of face shields (Fig 2. Screenshot of enable.hp.com)

For example, the Avid Face Shield was developed for 3D Printing with HP Multi Jet Fusion technology. The Design for Additive Manufacturing (DfAM) face shield frame prints in a compact geometry and parts assembles into the 3D shape by placing the face shield (sheet) on the pins. The design files can be freely downloaded, modified, and improved for 3D printing, which is typical open design.

### COVID-19 applications and designs

We are coordinating with government, health, and industry agencies and experts in numerous countries to identify the parts most in need, validate designs, and begin production.









	Face Shields	4 designs -
	AIDIMME 3D Printable Face Shield	▼
	3D Printable Face Shield	▼
	Avid Face Shield	▼
	Budman Face Shield	▼
	Masks	3 designs +
	CPAP Components	2 designs +
	Personal Accessories	4 designs +
	Ventilator Components	1 design +

Figure 2. HP COVID-19 applications and designs (HP, 2020)

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Thanks for the efforts made by organisations like Hewlett-Packard, which also provided additional references to our team's design work

## 1. OPEN DESIGN AND 3D PRINTING OF FACE SHIELDS

Open design (Van Abel et al., 2014) is a form of co-creation, which generally refers to the design, exploitation, and distribution of products, machines, or systems by sharing information resources. Michel Bauwens distinguishes three different dimensions of open design (Bauwens, 2009): Input side, Process side and Output side. On the input side, we have voluntary contributors and free raw materials that can be freely modified and improved (e.g., the downloadable Avid face shield design file). The process side is based on design for inclusion, with low barriers to participation, modular tasks, and communal validation of the quality and excellence of alternative solutions, equivalent to peer governance (e.g., the Sino-British multinational 3D printing design alliance to be introduced in the case study). On the output side, it creates a common, ensuring that everyone can use the final result (e.g., the 3D printed face shields and the improved design files). The common output in turn become new open free materials that can be used for the next iteration (van Abel et al., 2011).

Open design has potential value for both professional and non-professional manufacturers because it is a means of producing better products (Green and Kirk, 2018). 'Openness' means sharing solutions, processes and assets, and collecting feedback from other designers, design communities and non-designers. The entire process of open design is usually promoted by the Internet. Open design provides designers (both professionals and amateurs) with unprecedented possibilities. It challenges the definition of certain characteristics of professional design and blurs the boundary between professional and non-professional designers (Cruickshank, 2014).

Distributed 3D printing can be understood as the establishment of partnerships between 3D printing manufacturers or makers in different regions. They have different production scales and capabilities to provide products or services that can quickly respond to emerging market demand. In the post-industrial digital era, through open design and distributed 3D printing, more and more stakeholders will get the opportunity to participate in the design, manufacture and distribution of products.

Information and communication technologies and social media have facilitated open design of PPEs during the COVID-19 pandemic. Architects, designers and engineers have joined the force to help produce the much-needed face shields. In the USA, studios including BIG, KPF and Handel Architects have joined an open source project to print face shields; in Spain, Nagami Design has switched its machines from making furniture to shields; British architecture studio Foster + Partners has designed an alternative face shield that can be laser cut; Researchers at the Massachusetts Institute of Technology have developed a disposable face shield made from a single piece of plastic, which can be mass-produced and shipped flat (Shepherd and Parry, 2020).

On the 7th April 2020, Apple unveiled its design for a face shield to protect health workers fighting coronavirus (Dezeen, 2020). Its CEO Tim Cook stated, "We've launched a company-wide effort, bringing together product designers, engineering, operations, and packaging teams, and our suppliers, to design, produce, and ship face shields for health workers."

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On the same day, Nike also announced its full-face shield development in collaboration with Oregon Health & Science University, which utilised Nike-owned materials and manufacturing facilities and transformed elements of the Nike’s footwear and apparel into the much-needed PPE (Nike, 2020).

These design responses to COVID-19 only reveal one part of open design, i.e., the input side, and lacks process information. The case study we are going to introduce in this paper will focus on the process side. It had delivered face shields to the UK front line workers before Apple and Nick’s launch of their face shields.

## 2. METHODS

Content analysis was used in this case study. Content analysis is defined as the systematic, objective, quantitative analysis of message characteristics (Neuendorf 2016). The interpretational content analysis (Zou, 2006) has been chosen for this study as it is the most appropriate means of examining, understanding, and interpreting the interactive content (text, images, videos) exchanged through the social media forums created for the project.

Wechat was the host of the forum because all our participants already use this social media, and it accommodates multiple languages (in text or audio format), images, and video input. Between 24th March and 7th April 2020, 648 pieces of data were exchanged (514 text messages, 97 images, 12 videos, and 25 links). The data exchange took place naturally among a dozen core participants. The interaction covered the following key themes (Table 1) which were counted and analysed by the first author and checked by the last author.

Table 1. Key themes of the interactive content

Themes	Example	Number
Identifying needs	“Zhang : There is no unified medical standard for protective face shields. “	63 pieces
Design iteration	“Shu: It takes less time to print without the need for elastic band.”	308 pieces
Examples	“Zhang: A team is also designing 3D printing protective face shields. Here is its website: <a href="https://www.thingiverse.com/thing:4236924">https://www.thingiverse.com/thing:4236924</a> ”	79 pieces
3D printing optimisation	“Pete: This morning, I conducted a bending installation simulation on the drawing of the visor and adjusted the assembly column according to the position of the hole.”	136 pieces
Distribution	“Hao: We hope to call on more 3D printing teams to use idle 3D printers to produce face shields.”	21 pieces
Other (evaluation etc)	“Dong : Preliminary evaluation: easy to pack and post ... “	41 pieces (evaluation 16, Likes 10, contacts 9, and other)

## 3. CASE STUDY

The UK-China initiative was launched by three professors (One from the UK, and two from China). Inspired by the success of the 3D printing of the Venturi ventilator valves created by the Italian 3D printing company Isinnova, on 24th March 2020 they issued a call for designers to propose PPE designs for combating COVID-19, and established a Wechat forum with participants from design, engineering, and enterprising backgrounds. They were piloting a 3D printing intelligent manufacturing and distribution alliance, with the purpose to make better use of idle 3D printing resources in response to healthcare emergencies. As the

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project continues to expand, an increasing number of process-related practitioners have responded to the call and joined the team (totaling 48 by the end of April).

### 3.1. Identifying the PPE

At the beginning, it was not clear what PPE should be produced. There were 63 pieces of text and voice data on the topic of identifying needs. Ventilators and its parts were discussed but soon the focus turned to face shields. Mrs Zhang said: "There is no unified medical standard for protective face shields." It means that the official medical institution will not ban our design work.

The threshold for satisfactory ventilator equipment production standards is relatively high which requires team members' professional medical knowledge, and it has to meet the regulations of medical devices. For this reason, it is not possible to develop new PPE equipment meeting industry standards within in a short period of time. In addition, different clinical settings may use different types of ventilators.

The team soon reached a consensus that they should apply 3D printing technology to the production of protective face shields to alleviate the urgent self-protection needs of frontline workers. Usually face shields are subject to FDA enforcement guidelines, but the FDA have relaxed their guidelines, stating that they do not intend to object to the distribution of improvised face shields as long as they create no 'undue risk' to help foster greater availability of PPE for the duration of the public health emergency. (Sarah, Flanagan, David, Ballard, 2020)

### 3.2. Design Process

Once focusing on face shields, the team searched for existing designs, examples and open files, and shared them (e.g., Prusa protective face shield -RC3; face shields designed by University of Bath) in the Wechat forum to allow team members to evaluate different designs and make necessary modifications. Most of the discussion also took place at this stage, with a total of 306 messages appearing on Wechat. Team members found and shared more design examples (in addition to the American design team and Hewlett-Packard mentioned in the introduction) and started their own mask design. Figure 3 shows a primitive design which was mounted on the wearer's glasses.



Figure 3. Face shield design – the first version

This design was for people who wear glasses/goggles: a half open square metal bracket was used as the head support, and two screws were used to attach the face shield to the metal bracket. Users' glasses/goggle frames were to support the metal bracket above (as shown in (a) in Figure 3). The connection part was further refined, which utilised a hollow T-shaped foam to replace the metal bracket so that the face shield can be directly supported by the frame of the user's glasses (as shown in (b) in Figure 3). The advantage of this design is that the assembly is very convenient and efficient. However, the disadvantages are also obvious. Firstly, the user has to wear a pair of glasses. Secondly, the stability of the face shields is questionable because of its thin structure. Thirdly, the design does not cover the user's forehead, and the eyes are not properly protected. Therefore, this design has not been taken forward.

After comparing several open designs online, the FAB619 face shield design (files available from <https://github.com/FAB619/protection-Mask--COVID-19>) was deemed as most appropriate. Its design has combined the advantages of two face shield prototypes (i.e., Prusa and ENISO) and has been adjusted for easier and faster 3D printing. In addition, very detailed design, printing and assembly instructions have been provided online, what is more, the design has gone through verifications with doctors and experts. However, there were further issues to be solved for production.

**Material:** the first task was to identify appropriate face shield/sheet material. A4 Acetate sheets (available on Amazon) were tried but they were found too thin. PETG, PET and Acrylic (PMMA) sheets were considered and A4 acrylic (200 -250 micron) proved ideal. Initially the holes were designed to fit a Swedish hole punch (with a two-hole footprint), and later the design was modified to accommodate single hole punches as well: a universal bracket was added that fits any 6mm-diameter hole. This way the design could fit different head sizes.

**Printing modification:** 3D printing optimisation became necessary. The team members tried to improve printing efficiency and save printing time. The content analysis suggested that 136 pieces of interactive contents were about this theme. Some team members asked to convert the original STL file to dwg or dxf files. Some asked to modify the design to suit smaller 3D printers (e.g., diameter 100mm, and height 170mm). Vertical stacked models were designed for printing two, four or eight frames in one go (Figure 4) to improve efficiency. These modifications had reduced printing time from around 120 minutes/set to around 15-20 minutes/set.

The team also explored alternative designs, as shown in Table 2. Some have tried to combine the chosen FAB619 design and the Design C (in Table 2), i.e. plugging in the gap between the outer and the inner frames (Figure 4) to provide better protection of the eyes.

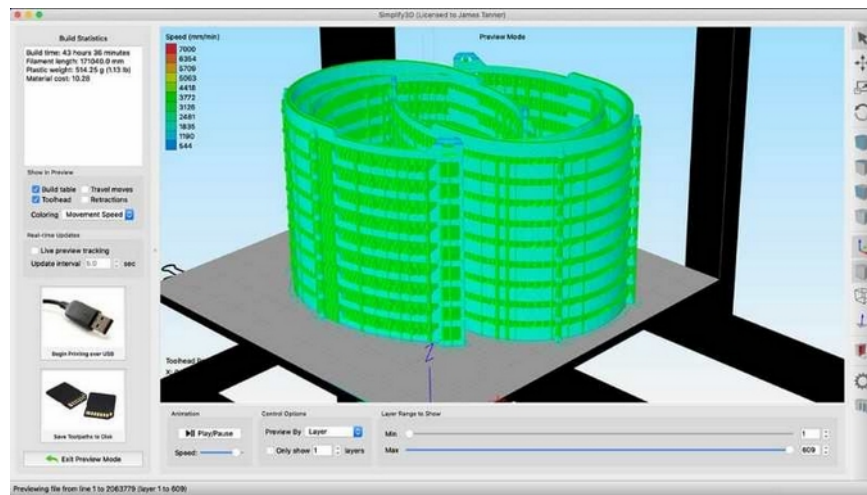


Figure 4. Multi-layer printing and layout to increase efficiency and reduce material use

Table 2. Summary of alternative designs

Designs	Source files and advantages	Images
Design A	<p>Files available from <a href="https://www.youmagine.com/designs/zipvisor-faceshield*.XoZFG1KyMMk.twitter">https://www.youmagine.com/designs/zipvisor-faceshield*.XoZFG1KyMMk.twitter</a></p> <p>The parts to hold the sheet are very small, and they can be printed using small 3D printers. Zip ties can be used to adjust the size.</p>	
Design B	<p>Files available from <a href="https://www.thingiverse.com/AnyubicEurope/designs">https://www.thingiverse.com/AnyubicEurope/designs</a></p> <p>The design is stackable, and many can be printed in one go, increasing the efficiency of printing</p>	
Design C	<p>Files available from <a href="https://3dverkstan.se/protective-visor/">https://3dverkstan.se/protective-visor/</a></p> <p>Simple structure, quick to print and easy to assemble. With print setting guide <a href="https://3dverkstan.se/protective-visor/protective-visor-print-guide/">https://3dverkstan.se/protective-visor/protective-visor-print-guide/</a></p>	

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Figure 5. Combined new design

The original FAB619 design uses elastic materials (shown in Figure 6) to adjust the size. These have been changed to PLA plastic bands which can be produced by 3D printing as well. Therefore, all the parts except the face protection sheet can be produced directly by 3D printers. The face protection sheets can be bought in bulk from stationary shops.

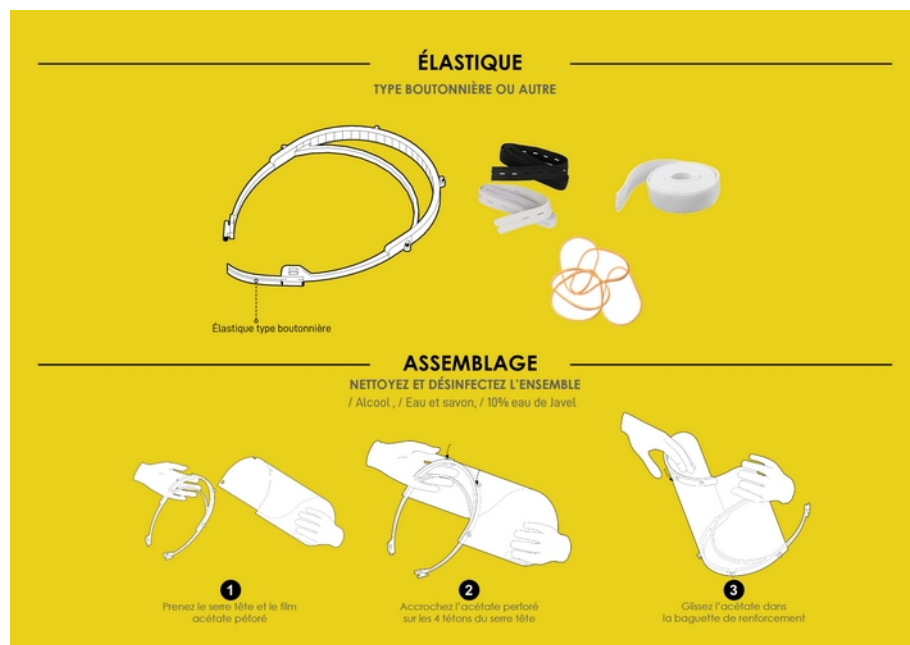


Figure 6. The FAB619 face shield design  
(available from <https://github.com/FAB619/Protection-Mask--COVID-19>)

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Further improvements include 1) adding a 3D-printed bottom reinforcement bar (simply slot in) for maintaining the overall shape and radians of the face shield. 2) Extending the length of the inner frame so as to keep a wider space between the face shield and the user's face to avoid fog. In many cases, the frame can fit the head well without the need for size adjustment, eliminating the need for the PLA plastic band. The whole set can be posted in a A4 envelope for the users to assemble by themselves (with an instruction) (Figure 7)





Figure 7. 'Compact' packaging easy for delivery and self-assembly

### 3.3. Issues

Several issues needed to be resolved during the process.

**Printing issues:** In order to print as many face shields as possible, and as quickly as possible, the team had to make use of idle 3D printing resources. The Sino-British 3D printing design alliance shared their refined design as an open-source file to allow more makers with available 3D printers to join in the production initiative. The team optimised the design by adapting it to meet the varying specifications of different printers. For example, the original size of the face shield frame design is 154mmX183mm, with the thickest part being 13mm. This frame was divided into two parts from the middle, and a node was designed to connect the two symmetric parts, using a M3 screw nut. The advantage of this modification is that small 3D printers can also print the parts, leading to increased production capacity. In the meanwhile, the Alliance contacted factories with large amount of 3D printing equipment to join the force, including the Dartford NHS Logistics Center which has 200 machines that can print 24 hours a day, seven days a week. On the other hand, printing speed is critical, and it is related to the movement speed of the 3D print head, the extrusion speed, the layout of the supporting material, and the scanning path (Wang Suyu et al., 2020). Therefore, it is necessary to optimise the layout of printing materials and supporting materials, and to design an optimal scanning path to improve the efficiency of printing. The design of the face shield printing scheme has undergone a change from single-layer, single-chip printing to multi-layer, double-chip printing (as shown in Figure 4). To print 20 frames in one go (10 layers, double chip layout) will take about 43 hours, with the advantage of working continuously. However, not all the printers can meet the requirements of accuracy on top of printing 20 frames in 43 hours, thus there is a risk of failure. To solve this problem, the number of printing layers can be easily reduced for printers with less precision.

**Matching supply and demand:** It is important to deliver the PPEs produced to people who need them; the supply and demand match was done by collecting PPE requests from a variety of public media (e.g., Government website, health sectors' website) and private channels (e.g., social media, email). The initial list was published at <http://www.inclusivedesign.org.cn/en/covid-19/>

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In March there arose a severe shortage of PPE across the UK as the surge in COVID-19 cases resulted in a rapidly growing imbalance between supply and demand. Some doctors question the legitimacy of the PPE guide, arguing that medical workers have the right to refuse to work in the event of insufficient supply (Clare Dyer, 2020). The alliance gave priority to the supply of 3D printed face shields to nursing homes and hospitals, ensuring that healthcare workers get the necessary protection. In early April, 3D printed face shields were sent to care homes and hospitals in Cambridge, Birmingham, and Glasgow. Positive feedback has been received from frontline workers (Figure 8) , with some saying that the equipment is easy to wear and had no foam concerns (some face shield design has a foam seal on the forehead and healthcare workers were concerned about the cleanliness of the foam).



Figure 8. UK Healthcare workers' wearing the 3D printed face fields

**Transportation:** The Alliance also aimed to print face shields in China and send them to the UK, and appropriate transportation needed to be identified. At first, for small quantities, the team tried to send through Shunfeng Express and DHL Express. For large quantities, they tried to contact international logistics companies, expecting to find a balance between timeliness and economy. In addition, the departure place has an impact on the logistics cycle. For example, the express delivery from Shenzhen and Sichuan would arrive in about 5 days, while from Wuhan, it took more than two weeks.

**Evaluation:** PPEs must satisfy the requirements under the EU's PPE Regulation 2016/425 however; this EU regulation does not prescribe specific requirements for 3D-printed PPE. The team performed a heuristic evaluation of its 3D printed face shield and has prescribed recommendations for reducing potential risks (material selection, safe form, easy assembly), simplifying user instructions, and for safe usage of the product (e.g. using the face shield together with a mask, along with recommendations for hours of use: i.e. 6-8 hours for medical treatment personnel, 48-72 hours for retail personnel, and 72 hours or longer for people who are in other low-risk public environments.) On the 4th June 2020, UK Government published the guidance "3D printing (additive manufacturing) of medical devices or component parts during the coronavirus (COVID-19) pandemic" (Gov.UK, 2020),

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which can be used as a benchmark for future evaluation reference. It is worth noting that where facemasks are not available, healthcare personnels might use homemade masks when caring for patients with COVID-19 and might use facemasks beyond the manufacturer-designated shield life during patient care activities.

#### 4. DISCUSSION AND CONCLUSIONS

Numerous factors have contributed to the success of the 3D printing face shield case study. At the beginning of this project, the COVID-19 outbreak in the UK was in its early stage and the National Healthcare Service was overwhelmed, while China had already passed the peak and medical supply was gradually resuming or even increasing; this had made it possible to offer help to the UK. The Alliance had brought together designers, engineers and makers from the UK and China to quickly share information and resources, thanks to the social media and the open design files online. There were ill-matched demand and supply, a lack of relevant standards and codes of conduct, and unknown legal implications. This project has provided a unique case study of open design in response to the emergent pandemic. While the process was open and collaborative, there were a lot of 'trial and error' iterations. The limitations of the case studies are summarised below:

**There was a lack of medical input in the process.** Healthcare professionals were overwhelmed, and the Alliance was created ad hoc and did not get input from healthcare sectors regarding the demands of PPE, recommendations or evaluation of designs in the early stage. Prototypes could not be quickly tested and validated by healthcare professionals and the match of demand and supply was largely on a 'first come, first served' basis. Due to the urgency, the face shields had to be put into use without rigorous testing. 3D-printed face shields may provide a physical barrier, but they are unlikely to provide the same fluid barrier and air filtration protection as FDA-cleared surgical masks and N95 respirators.

**3D printing facilities were not readily available.** Many places in the UK, for example universities, were closed because of the pandemic. Therefore, it was not easy to access 3D printing facilities. Through some 3D printing network, it was possible to identify available 3D printers, but they differ in type and size, making it impossible to use one file for all. Whilst it is possible to access a large amount of 3D printing equipment in China, timely delivery became an issue. This has made the team think about future manufacturing.

Traditionally design happens before commercial production and distribution. However, open design has enabled many stakeholders to be engaged in designing, manufacturing and distribution. Open design has made a positive impact on the production of small-scale emergency supplies, which is due to its 'distributed manufacturing' value proposition. Open design implies reconfigurable and scalable design: anyone can access the open digital blueprints and modify them to suit their specific needs. The resulting blueprint is not only user-centric, but user-led (Avital and Van Abel, 2014).

Despite the 'trial and error' approach, the project has inspired a new mode for future manufacturing. The traditional vertical value chain consists of designer - manufacturer - redistributor - consumer. Mass production took place in different regions, and then shipped to warehouses and distributed to various retail stores. There are many intermediate links in the entire process, and they are indispensable (Gebler et al. 2014; Gershenfeld 2008; Raasch et al. 2009). Open design reduces the number of links and provides designers and consumers with an open network and a direct chain (Avital and Van Abel, 2014). 3D printing is a rapid

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prototyping technology for constructing objects based on digital model files. This technology has the potential to revolutionise our existing traditional supply chain. It crosses the regional limitations of technology and space: whether the user is a novice or an expert, wherever they are, they can design locally and then customise and make what they want (Balka et al., 2009, Kuk and Kirilova, 2013). Open design avoids inefficiency and friction between product ideas and delivery to users, changing the way products find consumers, thus improving efficiency. Through 3D printing, users can continue to innovate based on the reuse of previously created designs (Fischer and Giaccardi, 2006). While rapid prototyping manufacturing technologies are developing and maturing, the cost of materials and time for manufacturing will continue to reduce. When utility and inexpensive manufacturing methods are combined with social media, this also means more and more objects can be produced without the help of professional designers (Cruickshank, 2014). In the future, a 3D printing distributed intelligent manufacturing model can be established to utilise Internet of Things (IoT), cloud computing, big data and other emerging information technology and public service platforms, together with 3D printing manufacturing enterprises with different production scales and capabilities in different regions, so as to provide a new mode of flexible, low cost and high-quality manufacturing system, as an alternative to mass manufacturing.

To conclude, this project has been a spontaneous response to the COVID-19 pandemic. Open design and 3D printing have been used to quickly produce face shields for healthcare workers. The collaboration between the UK and China was organised timely and proved useful. There were some good practice and some lessons learned. Specifically, open design files need to be assessed, compared, and adapted for local printers; material, layout and design need to be optimised to achieve maximum efficiency; distributed manufacturing is promising for the future and clear specification, rapid demand and resource matching are needed, together with regulation to ensure quick evaluation. These will help improve the efficiency, quality and sustainability of using open design and 3D printing for manufacturing.

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## APPENDIX

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### Video screenshot

### Title and link

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Prusa Face Shield

URL: <https://www.prusaprinters.org/prints/25857-prusa-protective-face-shield-rc2>

(This design is mentioned but not discussed in this study; the website has useful links to 3D-printed face shields and video links to assembly)

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