Data Article

Design and manufacturability data on additively manufactured solutions for COVID-19

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\textbf{A B S T R A C T}

Designers around the world have leveraged the rapid prototyping and manufacturing capabilities of additive manufacturing (AM), commonly known as 3D printing, to develop numerous engineering design solutions for the COVID-19 pandemic. This dataset consists of the design and manufacturability data for twenty-six such engineering design solutions spanning three categories: (1) face masks (N = 12), (2) face shields (N = 6), and (3) hands-free door openers (N = 8). The designs were collected from open-source websites such as Thingiverse, GrabCAD, and the NIH 3D Print Exchange. The manufacturability of these designs was simulated using Ultimaker Cura software and three measures were obtained: (1) build time, (2) build cost, and (3) build material. Furthermore, these simulations were performed for multiple materials and infill densities for comparison. Additionally, the manufacturing cost using injection molding was simulated using the Cost Estimation Tool in Solidworks. This dataset comprises (1) the STL files for the designs, (2) the simulated manufacturability data (for additive manufacturing and injection molding), and (3) images that depict the build orientation used in these manufacturability simulations. This

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dataset can facilitate the development of future innovations that leverage the capabilities of AM processes. Furthermore, this dataset can be used by designers and manufacturers to compare solutions and choose appropriate ones for manufacturing.

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### Specifications Table

| Subject                  | Mechanical Engineering |
|--------------------------|------------------------|
| Specific subject area    | Additive Manufacturing, 3D Printing, Engineering Design. |
| Type of data             | STL Computer-aided Designs (CAD) |
|                          | JPEG Images |
|                          | Excel Worksheets |
| How data were acquired   | Manual search of open-source digital design repositories such as GrabCAD, Thingiverse, and the NIH 3D Print Exchange. Designs were assessed using Ultimaker Cura and Solidworks 2019-2020 for obtaining manufacturability data. All manufacturability data was consolidated and organized using Microsoft Excel. |
| Data format              | Raw (STL CAD Files) |
|                          | Simulated (excel worksheet and images for manufacturability data) |
| Parameters for data collection | Sources: |
|                          | 1. GrabCAD (grabcad.com) |
|                          | 2. Thingiverse (https://www.thingiverse.com/) |
|                          | 3. NIH 3D Print Exchange (https://3dprint.nih.gov/) |
| Keywords                 | 1. “face mask” |
|                          | 2. “respirator” |
|                          | 3. “hands free door opener” |
|                          | 4. “face shield” |
| Description of data collection | The designs were manually collected through open-source databases. The collected designs were then simulated for their manufacturability using Ultimaker Cura Software V4.6.1. The designs were also simulated for manufacturing cost with injection molding using Solidworks 2019-2020. |
| Data source location     | Institution: The Pennsylvania State University |
|                          | City/Town/Region: University Park, PA |
|                          | Country: USA |
| Data accessibility       | Primary data sources: See Table 1 |
|                          | Repository name: Mendeley Data |
|                          | Data identification number: http://dx.doi.org/10.17632/j3hj76y3kr.3 |
|                          | Direct URL to data: http://dx.doi.org/10.17632/j3hj76y3kr.3 |

### Value of the Data

- These data can be used to compare and evaluate designs based on their suitability for additive manufacturing.
- Designers, engineers, researchers, and manufacturers can use these data to inform their engineering design and manufacturing decision-making.
- These data may be used by designers or engineers as a starting point to develop innovative solutions in the future. Furthermore, designers and manufacturers may use these data to seed comprehensive solution repositories to respond to future medical crises or supply chain shortages.

1. **Data Description**

The data comprises three components:
1. **CAD files in .STL file format:** The computer-aided design files for each design have been included. For designs with multiple components, a CAD file for each component has been included.

2. **Build orientation screenshot in JPEG file format:** A screenshot image depicting the build orientation used to simulate the manufacturability data has been included for each design.

3. **Manufacturability data for the design in .xlsx file format:** The manufacturability data consists of build time (in minutes), cost ($), and material (grams). The data is simulated for three infill densities and three materials determined most appropriate for the design. For designs with multiple components, the manufacturability data for each component has been included. Additionally, the data also consists of manufacturing cost estimates for each design using injection molding.

The CAD files and build orientation snapshots for each design are consolidated in a corresponding subfolder, and these subfolders are organized according to the solution category (i.e., face masks, face shields, and door openers). A master spreadsheet consolidating the manufacturability data for all designs within each solution type is provided, with links to sheets comprising the data for each design. In the sheet for each design, we report the source from where the design was retrieved and the corresponding creator(s). In Table 1, we provide a summary of all the designs, the sources from which they were retrieved, and attribution to the creator(s).

2. **Experimental Design, Materials and Methods**

This dataset comprises three components that were generated as discussed next.

1. **CAD data:** The CAD data was manually collected from open-source 3D printing websites and online repositories. Specifically, we searched through websites such as GrabCAD, the NIH 3D Print Exchange, and Thingiverse. We used the following keywords in our search: (1) ‘face mask,’ (2) ‘respirator,’ (3) ‘hands free door opener,’ and (4) ‘face shield.’ A summary of the designs gathered, and the corresponding sources and attributions are presented in Table 1. Additionally, we referenced each source throughout our research to keep up to date with the latest versions of each design. It should be noted that consent could not be obtained from the creators of two designs, and therefore, the STL files for these designs were not included in the dataset. The files for these designs can be obtained from the corresponding GrabCAD links presented in Table 1.

2. **Manufacturability and Build Orientation:** The manufacturability of the data was simulated using Ultimaker Cura software V4.6.1. The build parameters used in these simulations are summarized in Table 2. Unless explicitly provided by the designer, the build orientation was optimized to minimize build time. We have included screenshots depicting the build orientation used for simulating the manufacturability data for each design. The manufacturability was simulated with three materials which we considered best suited for the component. Additionally, we simulated the manufacturability for three infill densities: 20%, 50%, and 100% for comparison.

3. **Manufacturing Cost Estimate with Injection Molding:** The manufacturing cost estimate for the designs when manufactured with injection molding was simulated using the Solidworks 2020 Cost Estimation Tool. The mold cost was taken to be zero since the machine cost was not considered in the cost estimate with AM. The manufacturing cost was simulated for 102 to 108 parts and it was observed that the manufacturing cost converged to $3.33/part when

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1. grabcad.com.
2. https://3dprint.nih.gov/.
3. https://www.thingiverse.com/.
4. https://ultimaker.com/software/ultimaker-cura.
5. https://www.solidworks.com/.
| Solution Type     | Design ID         | Sources                                                                 | Attribution (License)                           |
|------------------|-------------------|--------------------------------------------------------------------------|-----------------------------------------------|
| Face Masks       | JPL Comfort Single Port | [https://github.com/nasa-jpl/COVID-19-respirators/wiki/JPL-Comfort-Respirator](https://github.com/nasa-jpl/COVID-19-respirators/wiki/JPL-Comfort-Respirator) | NASA JPL (Apache License 2.0)                  |
|                  | Montana Mask      | [https://www.makethemasks.com/3d-printing](https://www.makethemasks.com/3d-printing) | Make the Masks (GNU General Public License v3) |
|                  | 1T Mask           | [https://3dprint.nih.gov/discover/3dpx-013925](https://3dprint.nih.gov/discover/3dpx-013925) | STEAM (CC BY-NC-SA 4.0)                       |
|                  | 3DPX-0.13429      | [https://3dprint.nih.gov/discover/3dpx-013429](https://3dprint.nih.gov/discover/3dpx-013429) | Chris Richburg (CC BY)                        |
|                  | BE Mask           | [https://3dprint.nih.gov/discover/3DPX-014408](https://3dprint.nih.gov/discover/3DPX-014408) | BE Team (CC BY 4.0)                           |
|                  | *Respirator Model 1 | [https://grabcad.com/library/face-mask-respirator-corvid-19-1](https://grabcad.com/library/face-mask-respirator-corvid-19-1) | Xgentec Jason (GrabCAD License)               |
|                  | Flatpack – A22    | [https://3dprint.nih.gov/discover/3dpx-013318](https://3dprint.nih.gov/discover/3dpx-013318) | Blake Teipel (CC BY-NC-SA 4.0)                |
|                  | Mascara 20        | [https://3dprint.nih.gov/discover/3DPX-013334](https://3dprint.nih.gov/discover/3DPX-013334) | Rodrigosanchez (CC BY 2.0)                    |
|                  | Modular Interchangeable Filter Mask | [https://3dprint.nih.gov/discover/3dpx-014338](https://3dprint.nih.gov/discover/3dpx-014338) | Christopher Player (CC BY-NC)                 |
|                  | Nanohack          | [https://copper3d.com/hackthepandemic](https://copper3d.com/hackthepandemic) | Copper3D (CC BY-NC 4.0)                       |
|                  | F2 HEPA Filter Respirator | [https://3dprint.nih.gov/discover/3DPX-013439](https://3dprint.nih.gov/discover/3DPX-013439) | joshHughes.Studio (CC BY 2.0)                 |
|                  | Valvy Flexible Mask | [https://www.thingiverse.com/thing:4177128](https://www.thingiverse.com/thing:4177128) | iczfirz (CC BY 4.0)                          |
| Face Shields     | HP Face Shield V4 | [https://enable.hp.com/us-en-3dprint-COVID-19-containment-applications](https://enable.hp.com/us-en-3dprint-COVID-19-containment-applications) | HP (Non-commercial reuse)                    |
|                  | Avid (A3 3 Post)  | [https://avidpd.com/knowledge-base/](https://avidpd.com/knowledge-base/) | Avid (Non-commercial reuse)                  |
|                  | Avid (A3 4 Post)  | [https://avidpd.com/knowledge-base/](https://avidpd.com/knowledge-base/) | Avid (Non-commercial reuse)                  |
|                  | Makerbot Design   | [https://www.makerbot.com/stories/professional-3d-printing-resources/makerbot-3d-printing-initiative-to-combat-covid-19](https://www.makerbot.com/stories/professional-3d-printing-resources/makerbot-3d-printing-initiative-to-combat-covid-19) | Madiha Choksi, based on design by Budmen Industries |
|                  | Prusa (RC2 Headband) | [https://www.prusaprinters.org/prints/25857-prusa-protective-face-shield-rc2](https://www.prusaprinters.org/prints/25857-prusa-protective-face-shield-rc2) | Prusa 3D (Non-commercial reuse)               |
|                  | Prusa (RC3 Headband) | [https://www.prusaprinters.org/prints/25857-prusa-protective-face-shield-rc2](https://www.prusaprinters.org/prints/25857-prusa-protective-face-shield-rc2) | Prusa 3D (Non-commercial reuse)               |
| Door Openers      | Apriporta         | [https://grabcad.com/library/hands-free-door-handle-opener-2](https://grabcad.com/library/hands-free-door-handle-opener-2) | Federico Valente (GrabCAD License)            |
|                  | NHO-3.0           | [https://grabcad.com/library/hands-free-door-opener-1](https://grabcad.com/library/hands-free-door-opener-1) | http://www.itacec.com/                        |
|                  | V3-Cylindrical    | [https://www.materialise.com/en/hands-free-door-opener/technical-information](https://www.materialise.com/en/hands-free-door-opener/technical-information) | Alejandro Montes (GrabCAD License)            |
|                  | Circular Knob Design | [https://grabcad.com/library/hands-free-door-opener-push-pull-1](https://grabcad.com/library/hands-free-door-opener-push-pull-1) | Materialise (Non-commercial reuse)            |
|                  | *Provij (Four Variants) | [https://grabcad.com/library/hands-free-door-openers-cylindrical-1](https://grabcad.com/library/hands-free-door-openers-cylindrical-1) | Studio OREZ (GrabCAD License)                 |

* Only manufacturability data included in the dataset. STL files can be obtained from the link provided.
Table 2
Print parameters used for simulating manufacturability data.

| Parameter                  | Value                                                                 |
|----------------------------|------------------------------------------------------------------------|
| Filament Material          | Nylon (cost: 0.35 $/m)                                                |
|                            | Polylactic Acid (PLA) (cost: 0.20 $/m)                                |
|                            | Tough Polylactic Acid (Tough PLA) (cost: 0.44 $/m)                    |
|                            | Co-polyesters (CPE) (cost: 0.64 $/m)                                  |
|                            | Thermoplastic Polyurethane (TPU-95A) (cost: 0.73 $/m)                 |
|                            | Acrylonitrile Butadiene Styrene (ABS) (cost: 0.24 $/m)                |
|                            | Polycarbonate (cost: 0.71 $/m)                                        |
|                            | Polypropylene (cost: 0.35 $/m)                                        |
| Infill Range               | 20%, 50%, and 100%                                                   |
| Layer Height               | 0.2mm                                                                  |
| Wall Thickness             | 0.8mm                                                                  |
| Wall Line Count            | 2                                                                     |
| Infill Pattern             | Triangles                                                             |
| Printing Temperature       | 250°C                                                                 |
| Build Plate Temperature    | 85°C                                                                  |
| Print Speed                | 60mm/s                                                                 |
| Retraction                | Enabled                                                               |
| Z Hop When Retracted       | Enabled                                                               |
| Cooling Fan Speed          | 2%                                                                    |
| Support Overhang Angle     | 60°                                                                   |
| Build Plate Adhesion Type  | Brim                                                                  |

Table 3
Parameters used for estimating manufacturing cost with injection molding

| Parameter                     | Value                                                                 |
|-------------------------------|------------------------------------------------------------------------|
| Plastic Material              | ABS                                                                    |
| Material Cost                 | 2.54 USD/kg                                                            |
| Template                      | machiningtemplate_default(englishstandard)                            |
| Runner System                 | Hot Runner Mold                                                        |
| Maximum Wall Thickness        | 2.50 in                                                                |
| Mold Cost                     | 0 USD                                                                  |
| Waste Material                | 0.00%                                                                 |
| Number of Parts (and Cavities)| 10,000                                                                 |

the number of parts was greater than 10,000. Therefore, the manufacturing cost for each part was assumed to be $3.33 and the material cost was added to obtain the total cost estimate. The material cost was calculated by multiplying the volume of the part, the density of the material (ABS), and the cost of the material (ABS). The specific parameters are presented in Table 3.

Ethics Statement

The designs in this repository were developed by the creators listed in Table 1 and were available under the open-source licenses listed in Table 1 for non-commercial reuse. For designs retrieved from GrabCAD, consent was obtained from the creators to reuse the designs unless otherwise noted in Table 1. Any findings or opinions in this paper reflect those of the authors and not necessarily those of any designer/creator.

CRediT Author Statement

Rohan Prabhu: Conceptualization, Methodology, Writing – Original Draft, Writing – Review & Editing; Joseph T. Berthel: Methodology, Software, Data Curation, Writing – Review & Editing;
Jordan S. Masia: Methodology, Software, Data Curation, Writing – Review & Editing; Nicholas A. Meisel: Writing – Reviewing & Editing, Funding Acquisition; Timothy W. Simpson: Conceptualization, Writing – Review & Editing, Supervision, Funding Acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

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