Life cycle assessment of accessories of personal protective equipment PPE of easy manufacture: Ear-saver and anti-contact key

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Abstract. The exponential growth of additive manufacturing techniques and their applications to accessory manufacturing for personal protective equipment (PPE) is becoming a reality. In the forthcoming years it will be able to supply local demands with more efficient and easier to use devices for medical protection. In this article we propose a method of customizing the design and manufacture of PPE accessories such as the Ear-Saver and Anti Contact Key. The proposal considers not only innovative aspects of the product design and rapid manufacturing issues, but also defines a framework considering the product lifecycle and outlines important indicators from economic, social and sustainable perspectives. A set of experimental case studies that are included to enrich the proposed framework and its metrics allows better assessment of the different activities and the environmental impact of the product.

Keywords: Additive manufacturing, Customized design, Life cycle assessment, Environmental impact.

1. Introduction

The new worldwide normality entails the care and use of personal protective equipment such as N95 Masks, which protect us from possible infection and diseases. The evaluation of accessories for personal protective equipment from the manufacturing design, such as anti-contact keys and ear savers, makes it possible to develop a product according to the users’ needs and environmental issues. Humankind throughout its history has suffered epidemics and pandemics of all kinds, however, unknown new disease has radically affected the life of society, including high mortality rates due to respiratory complications.

COVID-19 is commonly transmitted through contact with surfaces and aerial transmission with the potential presence of biological microorganisms. Subsequently, one of the preventive measures to minimize the risk of contagion is the manufacture of ergonomic PPE accessories to prevent hand contact with surfaces. When people touch surfaces, viruses, bacteria, fungi and other pathogenic agents can enter the body through the routes of entry (mouth, nose, eyes) causing highly contagious diseases such as COVID-19, which has generated a public health emergency worldwide [1].

The manufacture of these security accessories at the place of consumption is a current option that allows minimizing the contagion of infectious diseases such as COVID-19 and excessive import costs.
For example, one of the innovative uses in the medical field is in surgical sleeveless guides printed in 3D with biodegradable materials [2]. However, all these innovations must be designed and developed in a collaborative and dynamic environment.

The focus should be on healthcare workers, vulnerable elderly people and service personnel such as in transport and security as well as education professionals, who have a high risk of contagion of COVID-19 [3]. Accessories such as the so-called "ear saver" and "anti-contact keys", can be produced in a 3D printer with a general CAD/CAM application and will allow users in hospitals and schools such as medical personnel and teachers, and society in general, to extend the useful life of respirator fasteners (protection masks) such as the N95. It will also help to avoid unnecessary infections by manipulating directly access facilities such as doorknobs, window handles or elevators buttons. Accessories can be optimized, prioritizing the correct use and ergonomics by providing a personalized design.

There is now a significant interest in integrating additive manufacturing and topology optimization to product design [4] and manufacturing these elements in collaborative environments will allow the product life cycle stages to be carried out autonomously. Laser Additive Manufacturing (LAM) and other 3D printing techniques offer the possibility of saving time in spare part supply chains [5] and 3D printing enables easy and rapid production based on open-source data [6].

In the product manufacturing stage, 3D printers can be used to manufacture at the site where the product is used, thus allowing savings in transport and distribution.

Currently, most low-cost printers make objects primarily from Acrylonitrile Butadiene Styrene (ABS) or Polylactic Acid (PLA) [7] and it is important to determine the mechanical properties of the parts made with PLA to improve the manufacturing technology [8].

In figure 1 the PLA material Lifecycle assessment (LCA) is represented [9] showing the different stages. LCA is a standardized approach for assessing the environmental impact, from the acquisition of raw material until product disposal [10]. There are also analyzes of distributed manufacturing systems [11], as well as the impacts of additive manufacturing [12].

![Figure 1. Lifecycle PLA - PPE Accessories.](image)

PLA is very easy to work with in 3D printing, which is attractive for environmental reasons [13]. Hydrogen peroxide sterilization is an alternative to avoid the deformation of 3D-printed objects made from PLA during conventional steam sterilization (autoclave) [14]. On the other hand, research on the comparison of environmental impacts has also been carried out [15].

This contribution shows the proposed method within the framework of two cases studies described below. The results are analyzed and a series of conclusions on the design and manufacture of the product are also given.
2. Experimental Procedure

The evaluation of Personal Protective Equipment (PPE) accessories (ear savers and anti-contact keys) was carried out in the design, manufacturing, use and end-of-life-cycle stages, so that a reengineering of the process could be carried out. It should be remembered that the manufacturing parameters, such as material, thickness, and process time, influence the sustainable indicators of the manufacturing process [16]. One of the advantages of CAD/CAM design for manufacturing is to include manufacturing constraints in the design step to allow optimizing the part through the advantages offered by the process [17]. Figure 2 shows the 3D Production Process for PPE accessories.

![Figure 2. PPE Accessory 3D Printing Process.](image)

The experimental data, which was evaluated and improved, was collected on commercial products designed for that aim. Table 1 shows the evaluation of the life cycle carried out, where the Objective of Sustainable Development (OSD) considered in this analysis. For the 3D printing of the EPP accessories, the CREALITY printer model ENDER 3D PRO® (200 x 220 x 250 mm) and PLA material with a filament diameter of 1.75 mm were used.

| Stage       | OSD Objective of sustainable development                        |
|-------------|-----------------------------------------------------------------|
| Design      | Simulate the manufacturing process parametrically.             |
| Production  | Select according to the procedure                                |
| Use         | Adapt to infrastructure were used                                |
| End of Life | Ecological Disposal                                              |

The evaluation of the product life cycle of various PPE accessories was carried out and improvements were proposed to adapt them to the customer's needs.
2.1. Case Study: Ear saver

The ear caver is a PPE accessory that allows the ergonomic use of protective masks. There are a wide variety of models on the market that can be manufactured by means of 3D printing.

2.1.1. Design. CAD modeling was performed on open-source models available on the web: Figure 3 shows an image of the CAD modeling.

![Figure 3. Proposed CAD Design: Ear Saver.](image)

2.1.2. Production. The manufacturing process was carried out (figure 4) in accordance with the data shown in Table 2. The manufacturing process data was obtained after making a batch and the data shown are the average values. The 3D Printer parameters were set up with Layer Height of 0.2mm and a Infill of 20%. The cost of the 3D printing was represented by a 60% raw material, 20% machining, 10% distribution, 6% energy and 4% supplies.

![Figure 4. Production the Ear Saver.](image)

### Table 2. Ear Saver Fabrication Data.

|                  | 3D Print without supports | No scaling |
|------------------|---------------------------|------------|
| Type of process  | 3D Print without supports | PLA        |
| Material         | PLA or ABS                | PLA        |
| Process Time     | ( min:s )                 | 40:38      |
| CAD Measurements | L x W x T (mm)            | 163 x 33.9 x 3 |
| Real Measurements| L x W x T (mm)            | 163.36 x 33.98 x 2.2 |
| Weight           | (gr)                      | 5.3        |
| Hardness         | SHORE D                   | 69         |
| Color            | Blue or White             |            |
| Cost of production| (USD)                    | 2.4        |

2.1.3. Use. This element is used in conjunction with facial masks such as the Type N95. Figure 5 shows how it is used. It is easy to use and cleaning recommendations are given, they as explained in the graphs to allow its correct use and storage.

![Figure 5. Use the Ear Saver.](image)
2.1.4. **End of Life.** The following are the general characteristics in the use of PLA, from an environmental point of view [9].

- Eco-friendly – It is renewably-sourced, biodegradable, recyclable and compostable
- Biocompatible – It is non-toxic
- Processability – It has better thermal processability than poly (hydroxyl alkanoate) (PHA), poly (ethylene glycol) (PEG) and poly(γ-caprolactone) (PCL)

2.2. **Case Study: Anti contact Key**
The anti-contact key can be used to prevent direct contact with surfaces that could contain germs or bacteria. It is used as an element of personal protection. There are open-source versions on the web which can be used, and their applicability will depend on their performance, since there are a great variety of models in different materials. The analyzed design is a model that is available for manufacturing on the internet.

2.2.1. **Design:** The anti-contact key can be produced in various materials and designs. The model A evaluated here shown in figure 6 [18] and model B figure 7 [19]. The two models were modified according to the requirements of the place where they are to be used, since the commercial models had measures that did not allow the opening of security doors. We proposed two models to be evaluated: Model A and Model B (figure 6 and figure 7).

![Figure 6. Anti-contact Key sample Model A.](image)

![Figure 7. Anti-contact Key sample Model B.](image)

2.2.2. **Production.** Table 3 and table 4 show the manufacturing data for this model A (figure 8) and model B accessory (figure 9). It should be noted that the data shown are averages of a production batch. For measurements, L x W x T means length x width x thickness.
### Table 3. Anti-Contact Key / Fabrication Data Model A.

| Type of process | 3D Print without supports | No scaling |
|-----------------|----------------------------|------------|
| Material        | PLA or ABS                 | PLA        |
| Process Time    | (min:s)                    | 60:57      |
| CAD Measurements| L x W x T (mm)             | 115.67 x 30 x 10 |
| Real Measurements| L x W x T (mm)             | 115.65 x 30 x 9.65 |
| Weight          | (gr)                       | 8.3        |
| Hardness        | SHORE D                    | 64         |
| Color           | Blue / White / Red         | Blue or White |
| Cost of production | (USD)                     | 3          |

### Table 4. Anti-Contact Key / Fabrication Data Model B.

| Type of process | 3D Print without supports | No scaling |
|-----------------|----------------------------|------------|
| Material        | PLA or ABS                 | PLA        |
| Process Time    | (min:s)                    | 60:57      |
| CAD Measurements| L x W x T (mm)             | 105.1 x 50.09 x 10 |
| Real Measurements| L x W x T (mm)             | 105.1 x 50.06 x 9.84 |
| Weight          | (gr)                       | 10.1       |
| Hardness        | SHORE D                    | 62         |
| Color           | Blue / White / Red         | Blue or White |
| Cost of production | (USD)                     | 3.6        |

#### Figure 8. Anti-Contact Key Model A.

#### Figure 9. Anti-Contact Key Model B.

2.2.3. **Use.** This accessory is very versatile since it can be used as a keychain or as a complementary part of PPE to avoid contagion from doors, entrances, and elevators. Figure 10 and figure 11 show some examples. A supplementary cleaning procedure is recommended.

#### Figure 10. Use Anti Contact Key Model A.

#### Figure 11. Use Anti Contact Key Model B.
2.2.4. End of life. The same recommendations apply as for the previous accessory. Cleaning is important for its care and use. Section 2.1.4 describes the characteristics of the material.

3. Results and Discussion
Various manufacturing alternatives for these accessories and various models were evaluated. For both technologies, the CAD CAM design of the product was carried out to obtain a parametric model that satisfies the specific requirements and enables mechanical simulation and evaluation of different production processes. Parametric models seek to meet customers’ ergonomic criteria.

The product life cycle was also carried out, mainly for the manufacturing phase, to complement the study by defining the characteristics and requirements that adapt the product to the customer's needs.

Other results of this study are as follows: a) an ergonomic element was designed and adapted to the conditions of use, and b) these elements can be manufactured in the place where they are to be used.

The indicators analyzed were:

- Production time: time used to manufacture the accessory.
- Weight: amount of mass of material that is used.
- Production cost: the amount of material, cost of use of machinery and equipment, personnel and use of inputs for its manufacture. To determine the sales price, marketing expenses and taxes must be considered.

Table 5 shows the values of the indicators of the alternatives analyzed. The model A of the anti-contact key has better indicators. The ear guard model considered adapts to the requirements of the infrastructure where it will be used.

| Metric          | Unit | Ear Saver | Anti-Contact |
|-----------------|------|-----------|--------------|
| Material        | PLA  | Biodegradable polymer |
| Production Time | [min: s] | 40.38     | 60:57        | 60.57        |
| Weight          | [gr] | 5.3       | 8.3          | 10.1         |
| Production Cost | [USD]| 2.4       | 3            | 3.6          |

4. Conclusions
We considered that it is possible to make improvements in different stages of the life cycle:

- For de Design phase, the model was generated and tested to obtain parametric models. Parametric designs can be selected according to ergonomic criteria and user requirements. The use of biodegradable materials allows better care of the environment.

- For the manufacturing phase, the process that can perform small-scale production on 3D printers was selected. The plastic injection manufacturing process will be analyzed in complementary studies. 3D printing process is available at the site where the element is going to be manufactured, which makes it available at the site where it will be used. PLA offers great facilities for its manufacture.

- For the use phase, the evaluation is carried out according to the characteristics of the users and the facilities where it will be used. The PPE accessory is easy to use, but the complementary cleaning and disinfection processes, which allow their correct use, must not be neglected.

- For the end-of-life phase, recommendations for final disposal or recycling. Establish recycling points.

In Future Jobs we consider other indicators such as energy consumption, Carbon footprint in different materials and in different manufacturing processes.

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