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SHORT ORIGINAL PAPER

3D printed devices to avoid hand contact with commonly shared surfaces

A. Pais[1] · C. Ferreira[1] · V. Pires[1] · V. Silva[1] · J. Lino Alves[1] · J. Bastos[2] · J. Belinha[2]

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Abstract

In the context of the COVID-19 pandemic, public spaces had to be quickly adapted to the new circumstances especially under the uncertainty of the pandemic development. Door handles are some of the most touched surfaces and so, this point of contagion was chosen to be tackled and two solutions were developed that would prevent direct touch with the handle: a portable and a fixed device. The portable device (HYHOOK + HYTIP) is a hook-like device holding a finger cover, which permits to open doors and push buttons safely. The fixed device (HANDGENIC) is meant to be assembled in door handles to equip buildings, such as universities or schools. With the fixed device, the user can open the door using their forearm which makes them less likely to transfer any particles to eyes, nose or mouth. The 3D printing Fused Filament Fabrication (FFF) process was selected as manufacturing technique, which allows the fast production of prototypes. This work portrays the development process and design iterations taking into consideration the concerns about the functioning of the devices and possible failures or alternative uses. To assure structural integrity of the parts, finite element (FE) analysis was used to verify its mechanical response. As conclusion, it was found that FE analysis indicate that the devices are structurally sound to be used in public spaces and that 3D printing is a useful way to rapidly develop devices while testing several design possibilities.

Keywords 3D-Printing · Fused Filament Fabrication · PLA · FE analysis · COVID-19

1 Introduction

Surfaces and objects in public places can become vehicles of transmission of disease and the pandemic has raised awareness to this fact. It has been studied that SARS-CoV-2 can persist in plastic or stainless steel surfaces for up to 72 hours [1]. Doorknobs, elevator buttons, handrails are some of the most touched surfaces. If these are adapted to avoid touch, contagion can be reduced, since it is not as common to touch the face with the forearm or elbow.

All over the world, additive manufacturing (AM) revealed to be a powerful tool in mitigating personal protective equipment (PPE) shortages and for producing other PPE for the general population [2–4]. In the review done by Irfan Ul Haq et al. [5] it is referred that AM technologies can also be employed in the manufacturing of medical grade equipment such as ventilators, which were at shortage all over the world due to the high number of severe disease cases. Face shields for medical professionals are one of the most investigated and improved designs [6–10], as well as 3D-printed masks [11,12]. Moreover, in open sources such as *thingiverse* (https://www.thingiverse.com/) and other platforms, many

✉ J. Belinha
job@isep.ipp.pt

A. Pais
ana.i.pais@gmail.com

C. Ferreira
up201609347@fe.up.pt

V. Pires
up201809222@fe.up.pt

V. Silva
up201706583@fe.up.pt

J. Lino Alves
falves@fe.up.pt

J. Bastos
jab@isep.ipp.pt

1 INEGI, Faculty of Engineering, University of Porto, Porto, PT, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal

2 School of Engineering, Polytechnic of Porto (ISEP), Porto, PT, R. Dr. António Bernardino de Almeida 431, 4200-072 Porto, Portugal

Table 1 Printing parameters for PLA and TPU

Material	Layer height	Bed temp.	Nozz.temp.	Perimeters	Layers	Speed (layers and perimeters)	Speed (infill)
PLA and clean PLA	0.2mm	60°C	215°C	2	5 top + 4 bottom	45mm/s	80mm/min
clean TPU	0.1 mm	60°C	240°C	2	9 top +7 bottom	25mm/s	-

examples of readily available devices can be replicated and printed. One of the main advantages of AM is that it allows the flexibility in the process to develop and iterate possible designs at a low cost and to obtain solutions which do not imply high costs with tools and therefore, in an emergency a high number of parts can be made to mitigate shortages [5]. The radical changes during the pandemic have caused a new conscience about hygiene where, even in an eradication scenario there is still possible demand for these devices. Even before the pandemic, literature described ways to avoid contamination and contagion in hospitals [13] as this has been, for a long time perceived as an important issue.

Three years prior to the pandemic, a paper by Muirhead et al. [13] detected the need to reduce contact with door knobs and suggested a novel design mostly based on the anti-bacterial properties of the material. François et al. [14] described the development of door-handle fixtures to avoid contact, using cable ties to assemble the fixture on the handle. The work by Chen et al. [15], presents a solution which significantly reduces hand contamination as well as it requires less parts to be assembled.

Several hook devices are available in open-sources. Usually, these consist of a hoop (where the user holds the device) and a hook which is used to open the door. Some solutions are equipped with a pointer to touch buttons. It was also found that finger cover solutions are less common.

As a response to existing solutions, the HANDGENIC proposes a door handle fixture to permit activation from the user's forearm instead of using the hand. This device would be assembled in a doorknob permanently.

The HYTIP (Hygienic Finger Tip) is an object designed for the fingers, aiming at reducing the risk of contagion of COVID-19 in situations where it is necessary to touch surfaces repeatedly, such as elevator panel buttons and ATM terminals. It is shaped like a thimble and carried in a case, where it fits tightly so there is no contact of the finger or hands with the area of the HYTIP exposed to the surfaces on which it is used. The HYHOOK (Hygienic Hook) is an object designed to reduce the risk of contagion of COVID-19 in situations of opening doors and/or as support for hanging on public transport handrails. Both have a common goal and complement each other, so a new object emerged from their combination: the HYHOOK with the HYTIP case integrated in its structure.

It is important that these devices are ergonomic, visually pleasant, and intuitive, as well as durable and effective in their purpose. Moreover, these devices are not aimed at requiring medical certification, but simply, to make public spaces safer and to make the user feel safer.

2 Materials and Methods

All devices were designed to be 3D printed using Fused Filament Fabrication (FFF), which is a material extrusion process where the extrusion head (moving in the xy plane) deposits material layer by layer in the z direction. The 3D printer used to print the parts was an Mk3s printer by Prusa.

The chosen material for most parts was PLA except for the finger cover, which is designed to be built with anti-bacterial TPU filament. PLA was selected because it is one of the most used materials with FFF, presenting adequate mechanical properties. Moreover, its processing conditions are easier to tackle than other FFF materials. The printing parameters depend on the material and part characteristics. For that reason, already existing printing configurations from PrusaSlicer v2.3.0 were used for most parts, for a layer height of 0.2mm. The printing parameters can be consulted in Table 1. Parts considered structural were analysed with the finite element (FE) method and were printed with 100% infill. Regarding the PLA, it was assumed the following mechanical properties: Young's modulus $E = 3500MPa$ and Poisson's coefficient $\nu = 0.3$ [16].

2.1 HANDGENIC

Following a thorough study of already available solutions, some main problems were detected and thus, some main requirements must be followed:

1. The part must be fully 3D printed, preferably in one single component, avoiding cable ties or threaded connections;
2. It must be possible to open the door using only one's forearm, thus not contaminating the user's hand;
3. The part must support the mechanical loads of assembling and from the opening door movement;
4. The part must be as accessible as possible for disabled users.

As opposed to solutions found in the literature, in order to fix the part on the door, it was thought of a tweezer mechanism, (Fig. 1 a).

The tweezer mechanism took several iterations (Fig. 1b, 1c, 1d) until the grip to the door handle was adequate. The initial design (Fig. 1 b) did not present enough gripping area and as such, this was corrected for the following iteration (Fig. 1 c), as well as some minor changes to the tweezer shape. The final iteration (Fig. 1 d) presents smaller dimensions in relation to the previous design.

In addition to the tweezer mechanism, it was necessary to decide how the movement was activated. The first idea was a lever-like activation (Fig. 1 b, 1 c). Under prototyping this proved not to be effective in materializing the downwards movement of the door handle, as well as increasing the bending moment in the part making it more fragile. Thus, this was re-designed to a more ergonomic shape to the forearm (Fig. 1 e), easing the downwards movement.

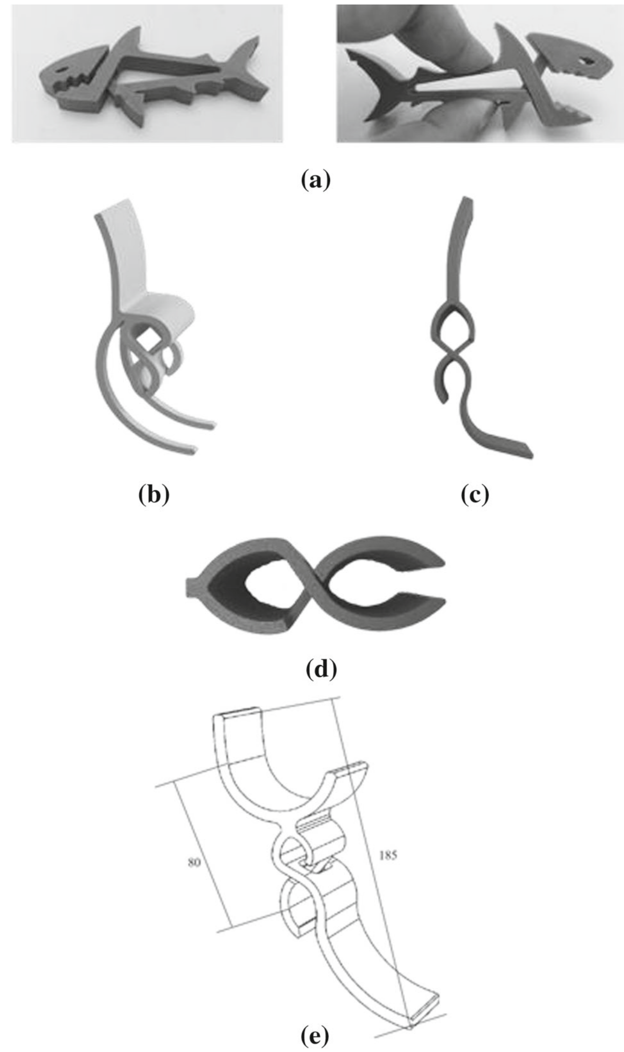


Fig. 1 Development of the tweezer mechanism **a)** tweezer idea; **b)** initial design iteration, **c)** second design iteration, **d)** final tweezer design, **e)** final design iteration with an improved forearm support

2.1.1 FE analysis

The software used to run the FE analysis was ABAQUS. There are two main phases in the functioning: the assembly, being that the part is permanently loaded while assembled and the pressing for opening the door. It is relevant to model the first moment (preliminary action) to obtain the accurate deformation of the PLA part when on the door, only this way it is possible to evaluate the maximum admissible load. The HANDGENIC was discretized into 9585 nodes and 6573 hexahedral elements (Fig. 2 a). The door handle was discretized into 1189 nodes and 896 hexahedral elements. For both parts, C3D8 elements with reduced integration were used.

The first step simulates the mounting of the fixture on the door with the objective of obtaining the stress state that the part is constantly subject to. It is important that there is a high safety coefficient to minimize damage due to deformation. Thus, as Fig. 2 b) shows, to simulate this part, the door handle has fixed (all degrees of freedom were constrained - shown with orange and blue cones in the doorhandle surface) and to the top of the HANDGENIC it was applied a vertical displacement along Oy axis of 30mm - shown with verical orange arrows which are pointing down. The interaction between the HANDGENIC and the handle was defined as surface-to-surface contact with frictionless properties. Finally, self-contact was defined in the tweezer intersection area to avoid intersection of the elements, with a no-slippage contact condition. This self-contact property is also propagated for step 2.

Step 2 is a load case which occurs when the door is opened. Thus, it is allowed that the maximum stress here is closer to the yield stress. The boundary conditions for this step, Fig. 2 c), consists of allowing rotation at the axis of the door handle and fixing along Ox axis the base of the HANDGENIC (where the door is blocking the displacement in the direction orthogonal to the door's plane) to prevent rotation in relation to the door handle surface. Finally, the contact boundary condition was altered to stop slippage between the HANDGENIC and door handle nodes, and this way, avoid excessive opening of the bottom part. Also, this condition is more accurate of the actual contact between the two parts due to an auxiliary part made of TPE which was not included in the FE analysis. The opening movement was materialized though a vertical force applied along the Oy axis perpendicular to the rotation axis at the top of the HANDGENIC, and a displacement of the Ox axis applied at the top of the part, which is equivalent to the force the user would apply when the door is being pulled. This displacement component is important since the door might be stuck or locked and it

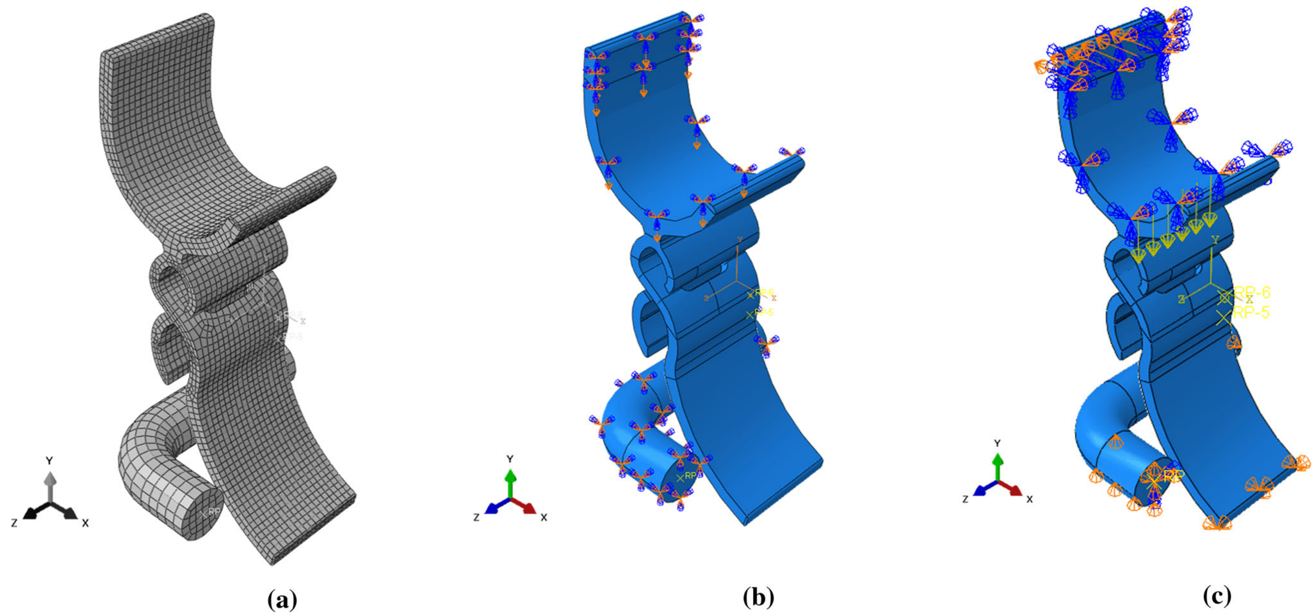


Fig. 2 Simulated model showing: **a)** the mesh discretization; **b)** boundary conditions for step 1 when the HANDGENIC is being assembled and; **c)** boundary conditions for step 2 when the door is being opened

is important that the part withstands these times of excessive force. The modulus of the vertical force was consulted from the literature where it is mentioned that 15N [17] is enough to activate the door handle, and for that reason, the component is projected for a much more higher force: 50N. The applied force is indicated in Fig. 2 c) as the downwards yellow arrows.

2.2 HYHOOK + HYTIP

A hook solution (Fig. 3), improved from already existing solutions was created. It aims at being able to open the same door handle type as the HANDGENIC as well as including the case with the finger cover for button pressing. The main goal of this device was to present a compact solution that the user could carry in their pockets. The casing design includes a clean PLA cover which fits in the casing. The initial diameter of the clean PLA cover is slightly larger than the diameter of the casing so this part will stay in place. The objective of this part is to prevent the dirty part from touching any non-antibacterial PLA. This cover has a slot, which is also present in the casing to keep the finger cover in place using the flaps in it. In order to keep the clean PLA cover in place, it is recommended that this part is glued to the rotating casing. The modifications in the hook design aim to reduce and compact its design. The final assembly images show the casing in its retracted position for storage, the casing in the position to access the finger cover and the full assembly with the finger cover kept in the casing.

3 Results

The FE analysis has validated the HANDGENIC (Table 2) for both load cases. The obtained safety coefficients calculated from (1), approximating the yield strength of the material to 50 MPa, are sufficient to predict that the device can withstand the necessary loading.

$$N = \frac{\sigma^{yield}}{\sigma^{max}} \tag{1}$$

At step 1, the maximum stress does not occur at the final position, but when the opening is maximum. Still, the maximum stress occurs at the tweezer intersection zone (Fig. 3), where the cross section is minimum. The results of Step 2 have validated the part for functioning.

Regarding the HYHOOK, the model was discretized into 2673 nodes and 1769 hexahedral C3D8 elements with reduced integration (Fig. 5). The aim of this analysis is to obtain the maximum admissible load which leads to a maximum von-mises stress of 40MPa in the part, which means a safety coefficient of N = 1.25. The analysis concluded a maximum possible loading of 720 N (Fig. 4), which is considerably higher than the force magnitude described in the literature as the necessary force to open a door, around 15N [17]. The maximum allowable load in this device also makes it suitable to use as a bag carrier, for example.

It is possible to print this part using a lower infill percentage, which leads to lower maximum load but allows reduced printing times and less printing material (lowing the printing cost). Thus, the initial model was altered to present 1mm

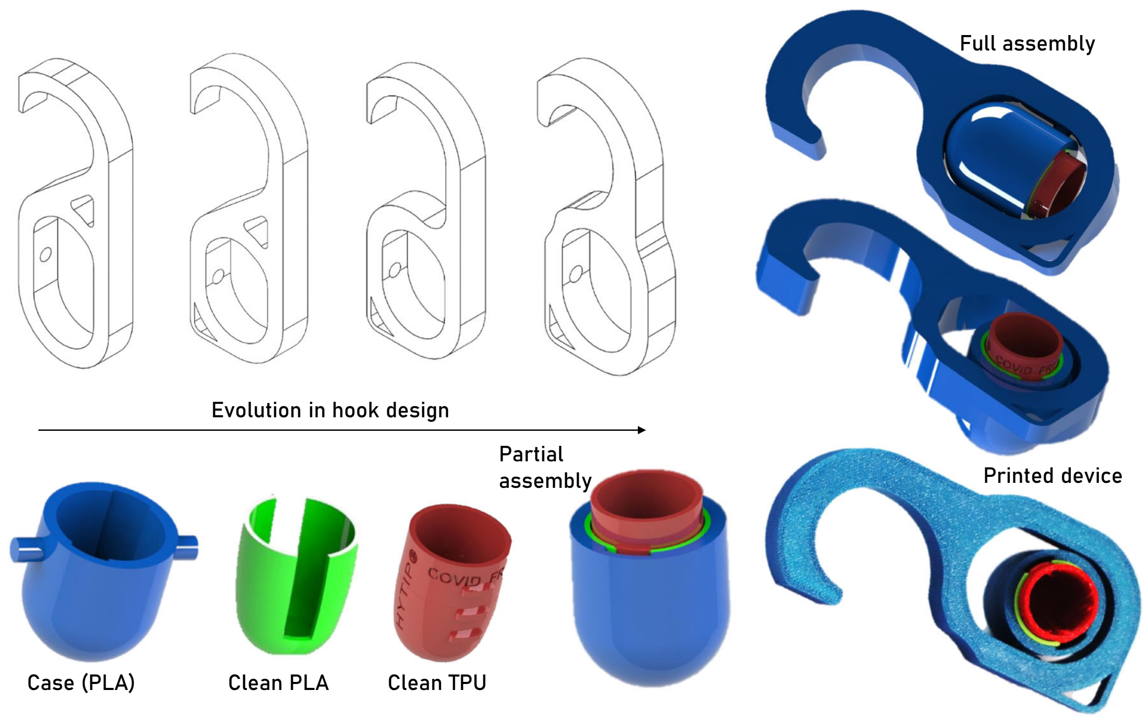


Fig. 3 Design iterations in the HYHOOK, HYTIP and assembly

Table 2 Maximum Von Mises stress summary

Step	Maximum stress [MPa]	Safety coefficient	Description
1 (at maximum opening)	31.96	1.56	One-time occurrence
1	22.24	2.25	Constant stress
2 (load = 5kgf + 10mm hor. disp.)	37.15	1.35	When the door is being opened
2 (load = 5kgf + 14mm hor. disp.)	44.56	1.12	When the door is being opened

thickness and then was discretized into 18110 nodes and 9071 tetrahedral C3D10 elements. The loading is equivalent to the loading in the first case. It was obtained a maximum load of 126N, still much higher than the 15N necessary to activate a door. This shows that having 1mm of thickness (5 top and bottom layers and 3 perimeters for 0.2mm layer height and 0.4mm nozzle diameter) the part can be infilled and still withstanding the necessary loads with a reasonable safety coefficient (Fig. 5).

3.1 Improvements on the HANDGENIC

In order to improve the usability of the HANDGENIC, three parts were developed (Fig. 6):

1. Clean PLA cover for improved safety
2. Soft PLA grip to improve contact with the door
3. TPE grips to improve friction with the door handle

Regarding the clean PLA component (1), this filament can be printed using the same printing parameters as non-antibacterial PLA. This component is secured to the HANDGENIC via a pressure fit as the flap presents an angle to press against the top part of the HANDGENIC. The thickness of this part is 2mm. Moreover, this part should be glued to the main part. The soft PLA grip (2) is assembled at the bottom of the HANDGENIC. Similarly to the clean PLA top cover, this part is secured to the base of the HANDGENIC with a pressure fit, as well as being glued. The flexibility of soft PLA helps achieving this effect more easily than with the clean PLA. The shape of this part helps increase surface contact area with the door and the material texture increases friction. When printing this material, the behaviour is similar to other flexible materials, such as TPU or TPE, and some cautions must be taken such as having to retraction length and using preferably a textured bed surface to print the parts. These parts are printed vertically to avoid the need for support material. Without the TPE grip (3) the HANDGENIC would rotate in the doorknob and correct functioning would

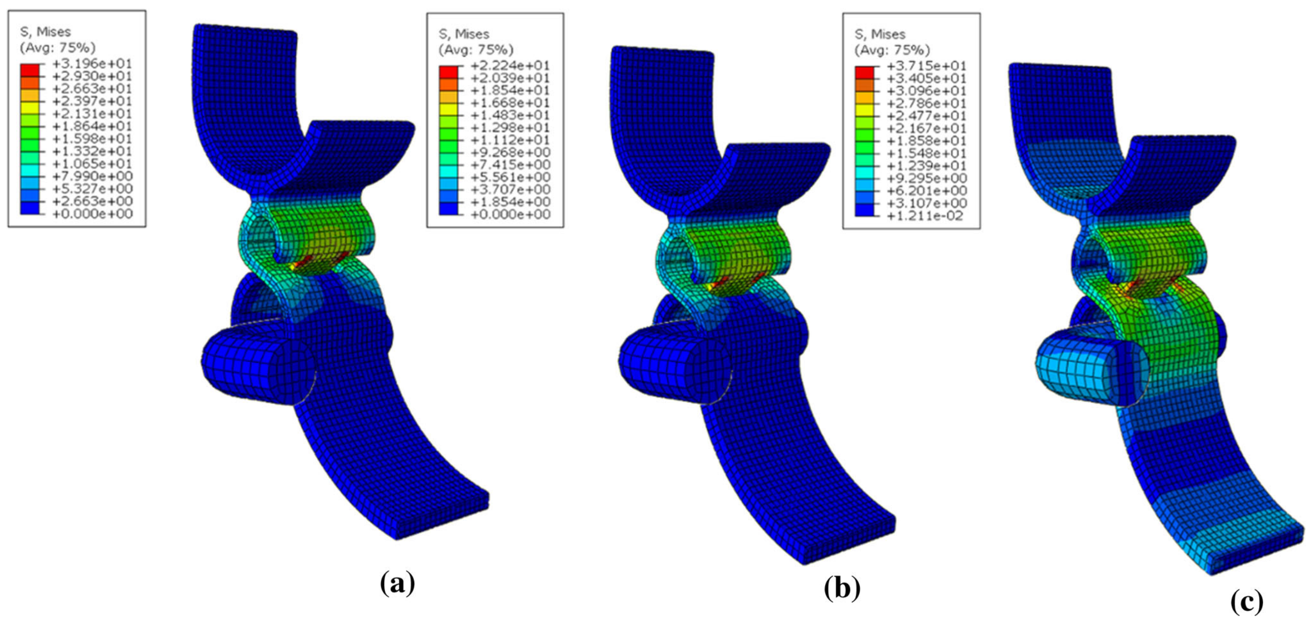


Fig. 4 Von Mises stress field for **a)** when the part is at its maximum opening (step 1), **b)** when the part is assembled (end of step 1), and **c)** at the end of step 2 when a force is being applied to open the door as well as 10mm horizontal displacement

not be possible. Finally, it is possible to see the part being used.

In Fig. 7, it is possible to see each component individually with further detail.

4 Discussion

4.1 HANDGENIC

Even though the HANDGENIC has been tested for door handles with a diameter of 20mm, the HANDGENIC can easily be altered to other diameter door handles. Thus, the HANDGENIC size tested in this paper is good for door handle diameters up to 20mm, depending mainly on the inner diameter of the TPE grips. By scaling the part, the device can be mounted on other diameter door handles. An adaptation of the TPE grips can also help adjust to smaller diameter doorknobs. For other section shapes of door handle, the tweezer shape can be changed according to need, as well as altering the shape of the TPE grip. However, this device is only valid for circular section doorhandles which is a limitation, as it cannot be used in spherical or other shape doorhandles.

Regarding the FE results, the permanent stress obtained in Step 1 is more important since it is the load that the part is constantly subject to. It is also important that this load presents a high safety coefficient due to the deformation behaviour of thermoplastics. In step 2, the safety coefficient can be much lower as this situation only verifies for a short period of time and only as frequently as the door is opened. In terms of necessary load to activate the doorhandle, the part can withstand a much higher load than the 15N. It was verified that the most critical area of the part is the thin section of the tweezer. This area cannot be filleted or both sides of the tweezer would touch. For the worst case where the door is locked or stuck and the device is pulled the maximum possible displacement is around 14mm. This situation should be avoided as much as possible as it would constitute misuse of the part. It can be observed, comparing the results with 10mm displacement and 14mm displacement, applying 14mm displacement leads to higher stress levels (because it also generates higher bending moments in the tweezer). Just for comparison purposes, notice that a cantilever beam under a concentrated load P at the free end, made of a material with a Young modulus E, possessing a length L and a transverse constant inertia moment $I = \frac{bh^3}{12}$, shows a transverse displacement at the free end of $\delta = \frac{PL^3}{3EI}$. Thus, if one considers a cross-section area equal to that of the part $b = 45mm$ and $h = 6mm$ (so that I is equal $810mm^4$) and length L equal to the distance between the center of the door handle and the point where the force is being applied (so that $L = 80mm$), the necessary force P to obtain a 10mm displacement δ would be approximately 164N and the necessary force P to obtain a 14mm displacement δ would be 232N. Most solutions in the literature and open-sources require the use of external fixtures which can be as simple as a cable tie or require other components such as bolts. It is not ideal to have a plastic 3D printed part connected with a bolt since, when the door is being opened the movement can damage the part in the threaded connection area.

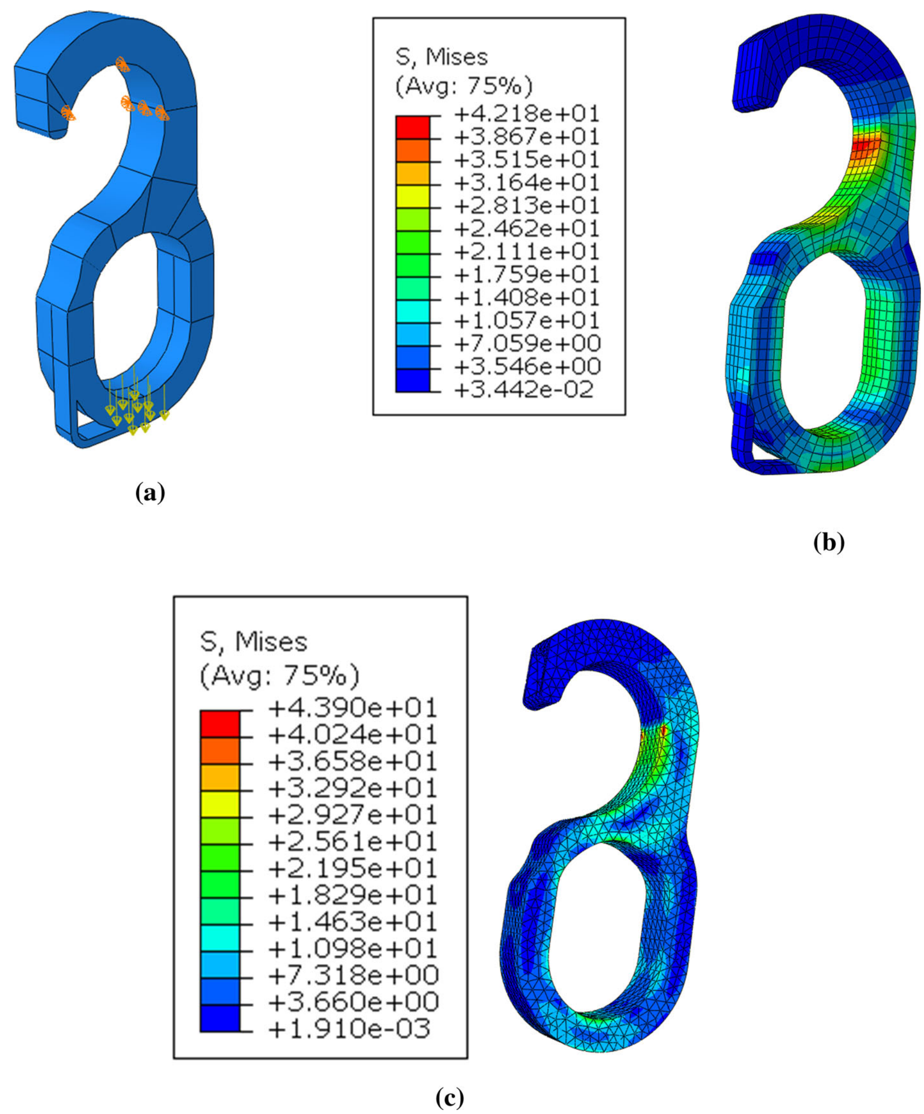


Fig. 5 **a)** Model and boundary conditions in the HYHOOK study, **b)** equivalent von Mises stress considering a solid part and **c)** equivalent von Mises stress considering 1mm thickness

Finally, it must be mentioned that since the parts are made through FFF, it is possible to very quickly replace a defective or damaged part, which proves again the advantage of AM.

4.2 HYHOOK + HYTIP

With regards to the HYHOOK in comparison to open-source developments, it presents the advantage of serving the double purpose of a hook device and holding a finger cover in a way that is safe and hygienic. The FE analysis allow to observe that the parts can be printed with an infill and still present the necessary safety coefficient. It is also relevant to point out how 3D printing can build moving parts such as the hook-casing connection. Finally, the HYTIP, also with the inclusion of the cover in anti-bacterial polymer, presents a safe solution to touch buttons in public spaces.

5 Conclusion

The functionality of the devices in preventing virus spread is still to be tested in the field. It is possible to argue that surface transmission might not be as hazardous as initially thought. Nonetheless, hand hygiene is always important [18] and thus, this device presents a simple, inexpensive solution which does not require any permanent alterations to the door. The inclusion of clean filament helps stopping the transmission as it can deactivate the virus.

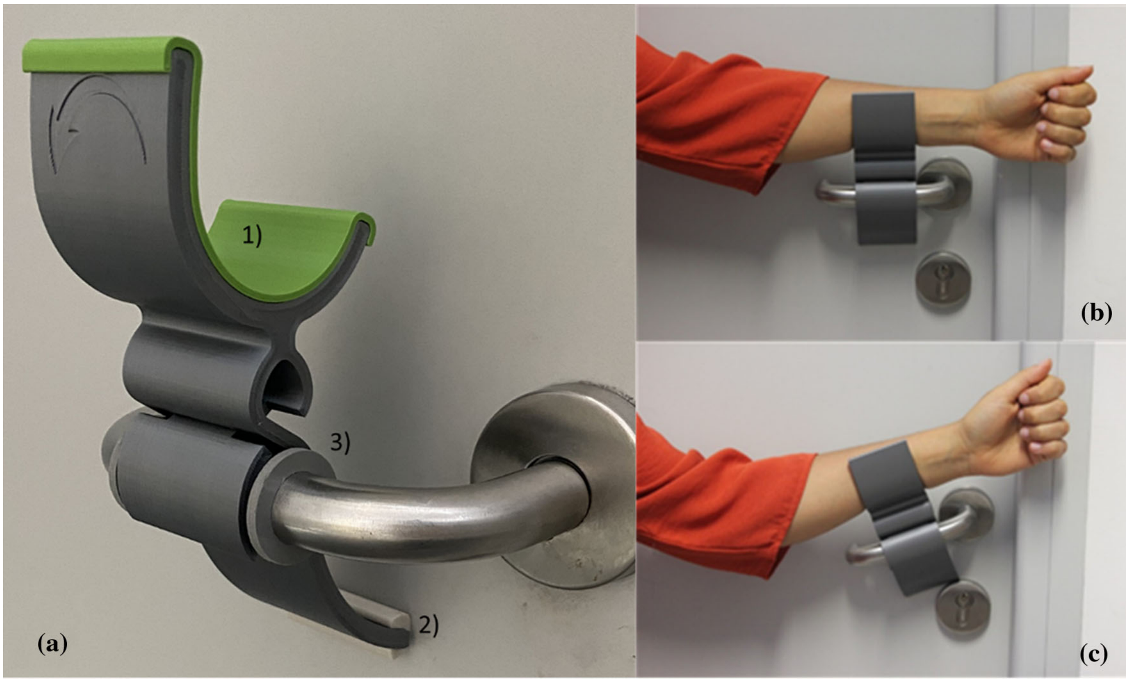
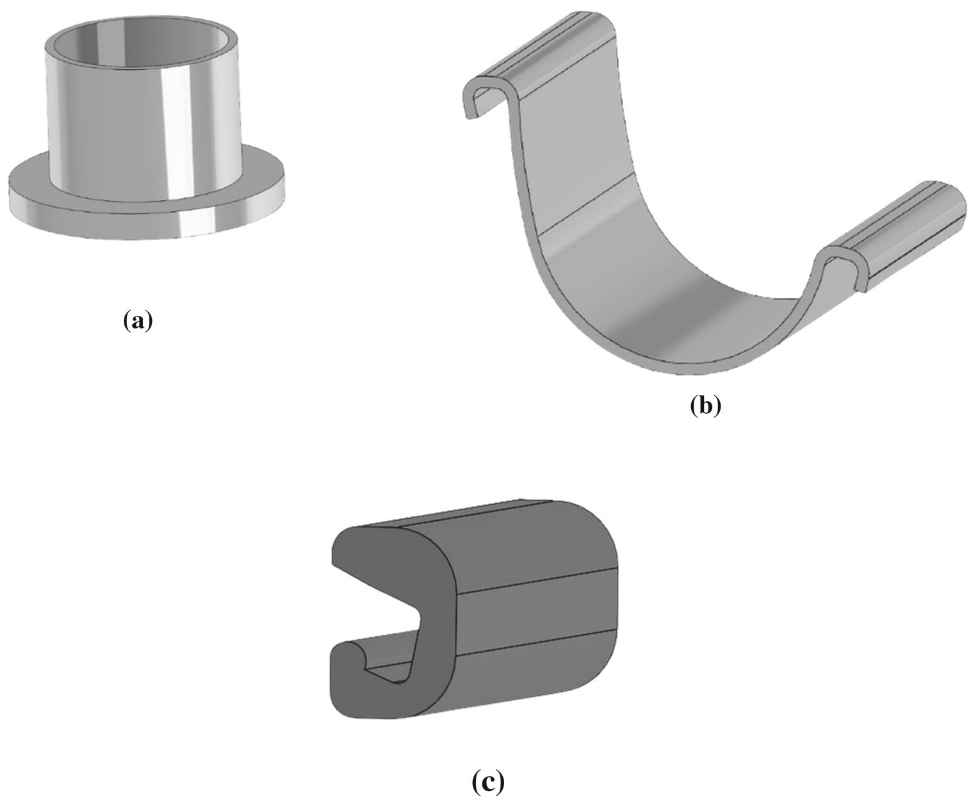


Fig. 6 HANDGENIC improvements: **a)**Accessory parts of the HANDGENIC to improve functioning: 1) a clean PLA top cover, 2) a soft PLA grip to improve contact with the door; and 3) a TPE grip; **b)** arm placement c) and the HANDGENIC being used to open a door

Fig. 7 Accessory parts of the handgenic to improve functioning: **a)** a TPE grip, **b)** a clean PLA top cover and **c)** a soft PLA grip to improve contact with the door



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