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BRIGHT

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BOOSTING THE SCIENTIFIC EXCELLENCE AND INNOVATION CAPACITY OF 3D PRINTING METHODS IN PANDEMIC PERIOD

O5 - BRIGHT e-case study 3

Project Title	**Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517**
Output	**O5 - BRIGHT e-case studies for project based learning method used in developing, testing and manufacturing of new medical products by 3D printing technologies in pandemic period BRIGHT e-case study 3 – face shield**
Date of Delivery	**February 2023**
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Version	**FINAL VERSION**

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1 Introduction

This is a documentation regarding the e-case study #3 of the BRIGHT project that was focused on 3D printable face shield for medical personnel – protection device that was used during the COVID pandemics. In this e-case study, all main four stages of work are presented – design using CAD models, simulations in CAE, manufacturing using FDM and SLA 3D printing technology and testing – both destructive and non-destructive methods.

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2 BRIGHT e-case study #3 – main ideas

2.1 Main concepts of the product

The product is a 3D printable face shield, used in times of COVID pandemic as a quick-resort disposable protection device for medical personnel dealing with the infected (Figure 1). The 3D printed part is the head section, to which a transparent shield is attached, along with a rubber band holding the whole shield at user's head. Originally, the product was designed by the Prusa company in Czech Republic and first recommended for use by Czech Ministry of Health.

Figure 1. 3D printed face shields, supplied to medical personnel
source: drukujdlalekarza.put.poznan.pl

The shield is 3D printable of any material – PLA and PET-G are recommended as being known for proper behavior in contact with user's skin. ABS and other materials could also be used, provided that there is no direct skin contact or sterilization is performed before and also after use. 3D printing of the head part takes approx. 20-40 minutes, depending on the material and printer used. The design has been thoroughly tested during beginnings of COVID pandemics – at Poznan University of Technology, hundreds of these shields were produced, assembled and given to various medical specialists (in the period of 03-06.2020), during the action "print for the doctor" (orig. "*drukuj dla lekarza*"). That is why in BRIGHT project this case study is used only in educational context, as an example of a medical product useful in times of pandemics.

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2.2 Requirements and recipients

To realize a 3D printing and manufacture the face shield, the following is needed:

1) parametric 3D model of the shield upper part (printable) + drawing of shield part
2) FDM printer (of any type – the cheapest ones are also able to perform) with PLA or other material, or other printer type (SLA, SLS, PolyJet are also possible to use)
3) shield part, cut out of PET-G or other rigid transparent foil
4) elastic band, for head mounting
5) foam for forehead rest
6) basic tools for post processing (file, sandpaper, knife, driller etc.)

The recipients of the face shield are as following:

- medical personnel working with infected patients in hospitals – doctors, nurses etc.
- personnel of drug stores (pharmacists), vaccination stations and testing stations,
- people working in places where risk of infection is higher, e.g. retail/customer service
- anyone wanting increased face protection

Also, for students and 3D printing specialists, this is a nice example of a product to work on iterative design improvements and optimization of 3D printing technology for faster manufacturing.

2.3 Plan of work and task distribution

The model was first designed and created independently, during the #drukujdlalekarza action coordinated at Poznan University of Technology in the beginning of the pandemics. Tt was manufactured and tested with numerous use cases in local hospitals and other medical facilities in Poland. On that basis, educational materials were developed (lectures, instructions for the students, movies etc.). In the BRIGHT project it was then used as an educational tool during the first summer school. It was manufactured by almost all partners, through means of additive manufacturing but also injection molding, by the BM Plast company. It has been also used as an AR model in building of the virtual platform in O3.

The scope of work is presented in the scheme given in Figure 2

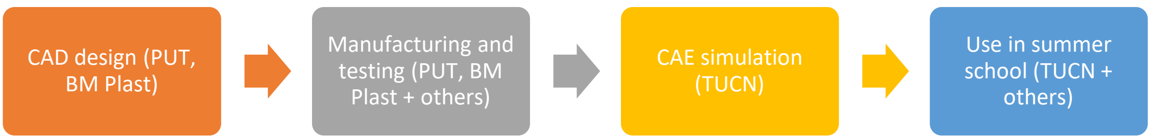

Figure 2. Scope of the project work related to case study 3

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3 BRIGHT e-case study #3 – realized work

3.1 Design

The face shield is an assembly, composed of several parts. Apart from the 3D printed main part, the product also contains the shield (cut out of rigid foil), protective foam and rubber band for head mounting (Figure 3).

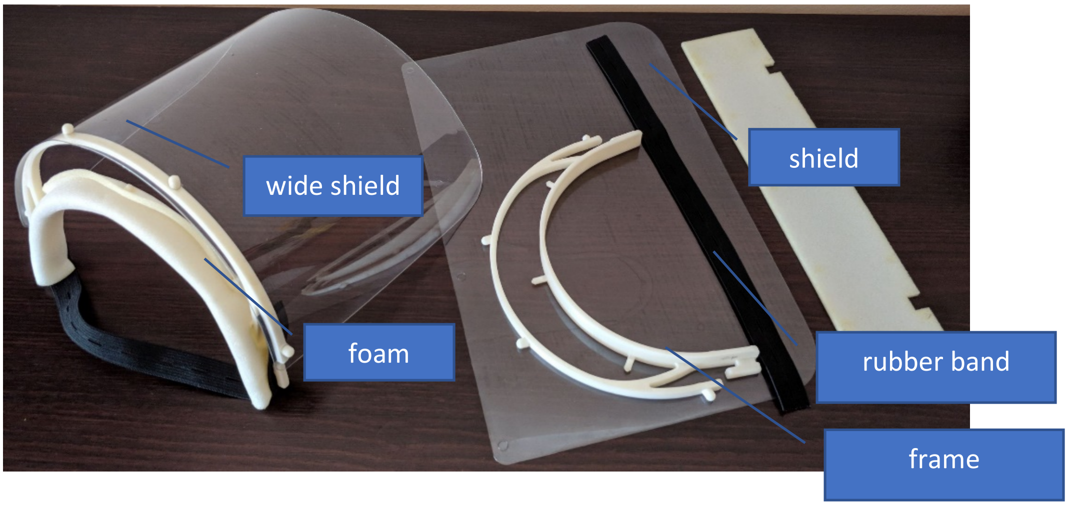

Figure 3. Structure of the shield.

The design of the shield can be prepared in any software – originally, it was Autodesk Inventor CAD system, where the models were prepared by PUT team (Figure 4). Figure 5 shows work realized in the Rhinoceros software by the BM Plast company, as done in the case of the webinar (O4).

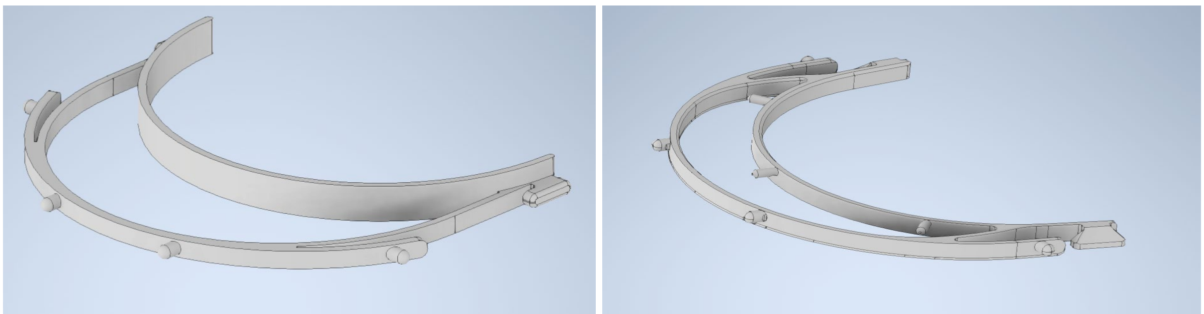

Figure 4. Face shield model, basic (Prusa) version (top) and final model (version 11 – bottom), designed in Autodesk Inventor

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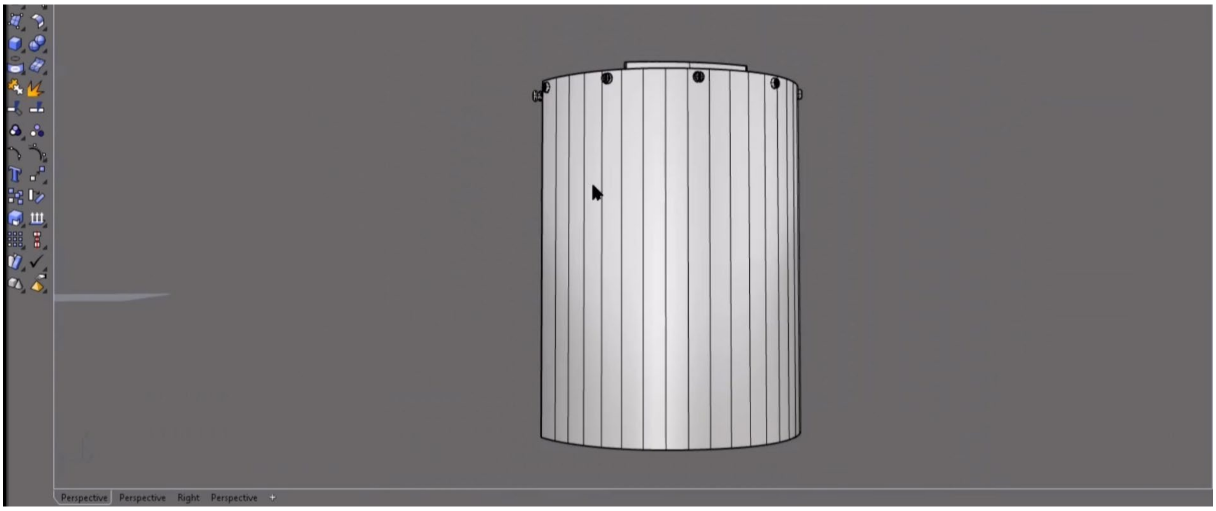

Figure 5. Face shield drawn in Rhinoceros

Some improvements to the design include creation of forehead rest part covered in foam, widening the shield and flattening the whole part to allow stacked manufacturing (several pieces in one process, one on top of another). Process of introducing of these changes is partially shown in Figure 6. It was one of the tasks of students taking part in 2021 BRIGHT summer school.

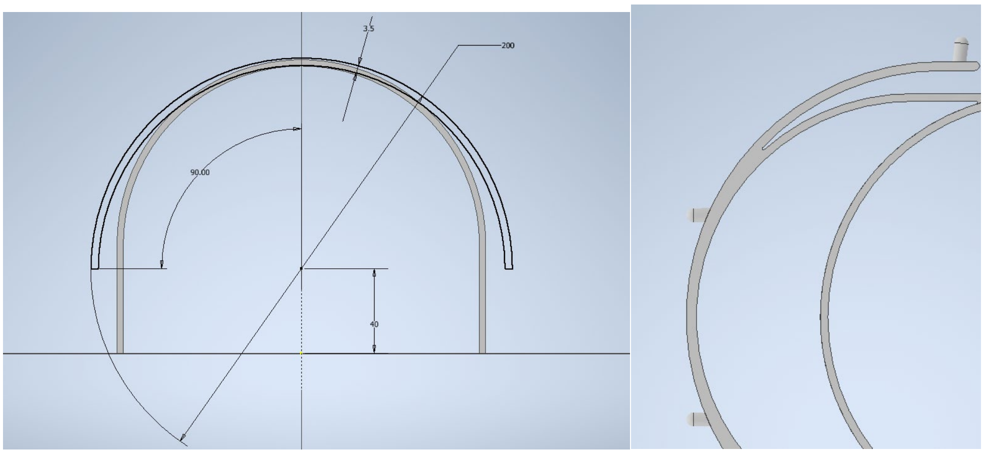

Figure 6. Face shield improvements – tasked to the summer school students

In the summer school, the students in some groups also realized interesting modifications to the original concept. Some of them are presented in Figure 7.

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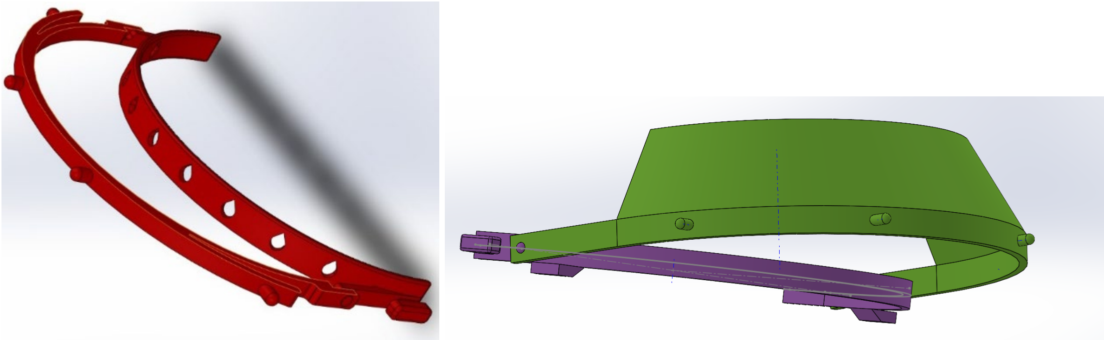

Figure 7. Some modifications to face shield design introduced by summer school students

3.2 CAE simulations

The main objective of the finite element analysis (performed by scientific team but also by the students in the summer school) has been to evaluate the strength characteristics of the face shield base (Figure 8) by simulating a dimensional adjustment procedure (Figure 9). As one may notice in Figure 9, the bilateral symmetry of the shield base allows to perform the finite element analysis on half of its geometric model. Of course, appropriate boundary conditions must be defined on the surfaces generated by the intersection with the symmetry plane. The dimensional adjustment procedure consists in enforcing the rear ends of the shield base to approach the symmetry plane. Only the displacement along the normal to this plane is constrained, its value being gradually increased from 0 (zero) to 7.5 mm.

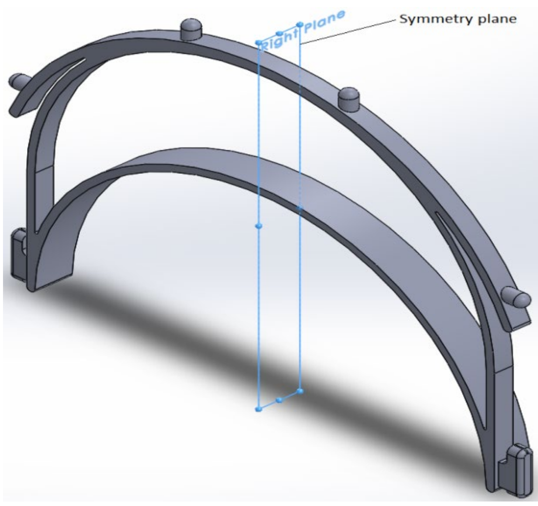

Figure 8. 3D model of the face shield base

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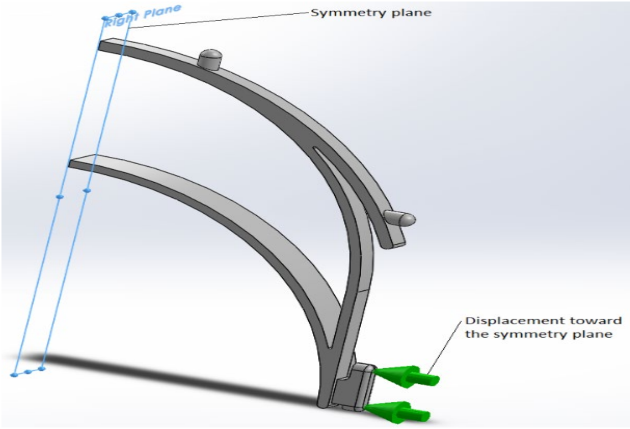

Figure 9. Dimensional adjustment simulated for evaluating the strength characteristics of the face shield base

The finite element model has been prepared assuming that the face shield base is made from PETG characterised by an isotropic linear elastic behaviour defined by the following parameters: elastic modulus *E* = 1660 MPa, Poisson's ratio *ν* = 0.419, and yield strength *Y* = 30.3 MPa. The finite element model has been elaborated and solved with SOLIDWORKS Simulation in the following sequence of steps (Figure 10):

a) Associating the PETG material to the face shield base
b) Enforcing symmetry-type kinematic constraints on the surfaces generated by the intersection with the symmetry plane of the face shield base
c) Enforcing a full locking kinematic constraint on the inner edge of the face shield base generated by the intersection with the symmetry plane
d) Enforcing the rear end of the shield base to approach the symmetry plane along a distance of 7.5 mm

   Note: This boundary condition induces significant distortions of the face shield base. Because finite element models affected by significant distortions cannot be analysed for different load cases, the mechanical response of the face shield base has been investigated by repeating the simulation of the dimensional adjustment procedure for displacements of the rear end having the following values: 1.5 mm, 3 mm, 4.5 mm, and 6 mm.
e) Activating the "Large displacement" option of the finite element analysis module SOLIDWORKS Simulation

   Note: This option must be activated whenever the finite element model is affected by significant distortions.
f) Controlling the local and global dimensions of finite elements and generating the mesh.

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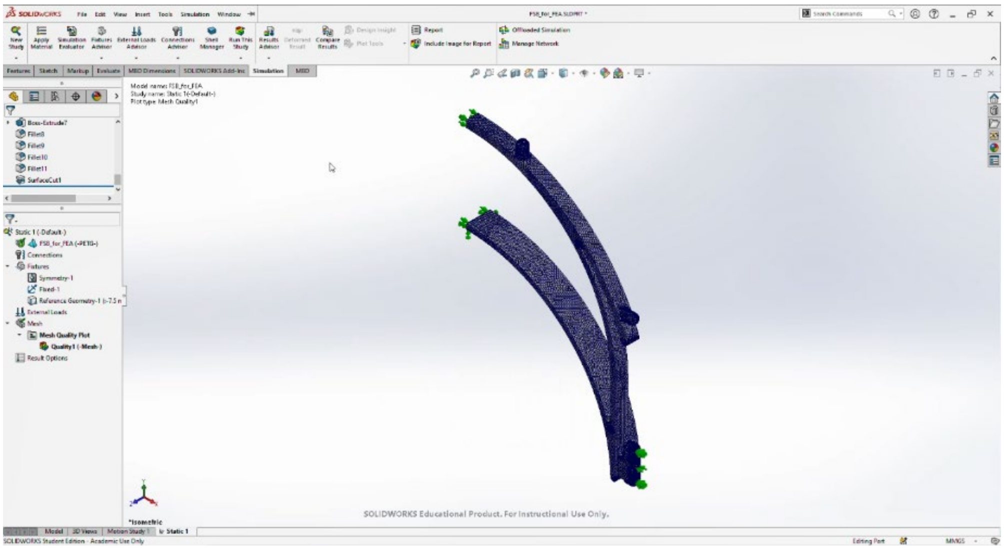

Figure 10. Finite element model of the dimensional adjustment procedure simulated for evaluating the strength characteristics of the face shield base

Figure 11 shows the most important result provided by SOLIDWORKS Simulation: distribution of the von Mises equivalent stress in the face shield base corresponding to the 7.5 mm displacement of its rear end. The maximum values of the von Mises equivalent stress $\sigma_{eq,max}$ corresponding to dimensional adjustments (displacements of the rear end) d = 1.5 mm, d = 3 mm, d = 4.5 mm, d = 6 mm, and d = 7.5 mm have been displayed on the diagram in Figure 12.

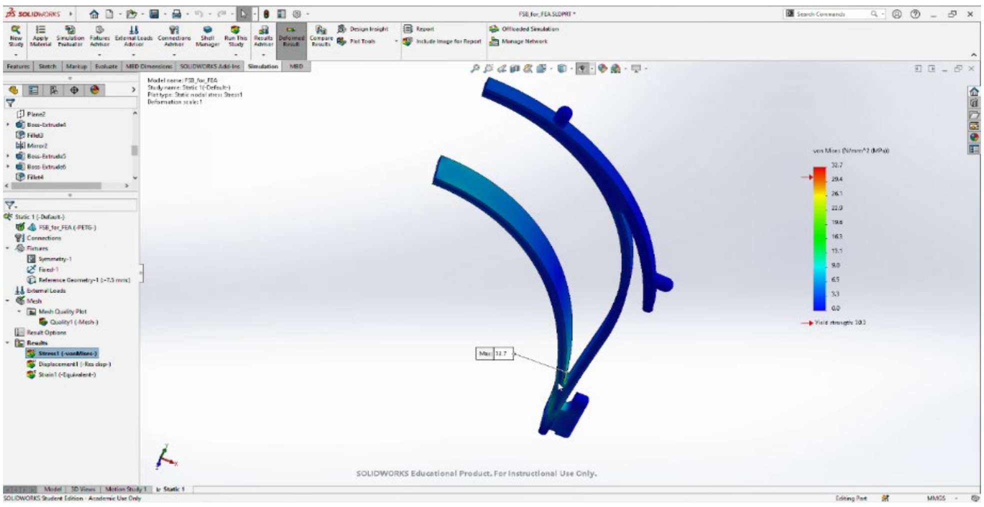

Figure 11. Distribution of the von Mises equivalent stress in the face shield base corresponding to the 7.5 mm displacement of its rear end

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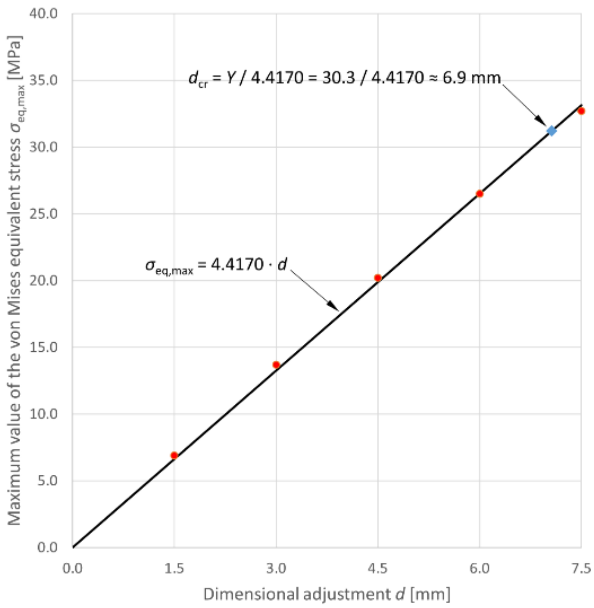

Figure 12. Maximum values of the von Mises equivalent stress associated to different dimensional adjustments of the face shield base: red dots – numerical results; black path – linear regression; blue diamond – dimensional adjustment at which the maximum value of the equivalent stress equals the yield strength

The following conclusions have been formulated after examining the diagram:

a) The mechanical response of the face shield base is well approximated by means of the linear regression $\sigma_{eq,max} = 4.4170 \cdot d$ (see the black path displayed on the diagram in Figure 12).
b) This regression can be used to determine the displacement adjustment at which the maximum value of the equivalent stress equals the yield strength of the PETG material: 6.9 mm (see the blue diamond displayed on the diagram in Figure 11).

3.3 Manufacturing

3.3.1. Additive manufacturing

The shield was generally manufactured using the FDM technology. However, for educational purposes, SLA technology was also included at the stage of O4 (webinars).

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In the case of FDM, the following machines were used:

- Prusa i3 MK2 (Figure 13)
- FlashForge Creator Pro (Figure 13)
- Anycubic Chiron (Figure 14)
- Creality CR-10

In most cases, standard settings were used, with ABS, PLA or PET-G material used.

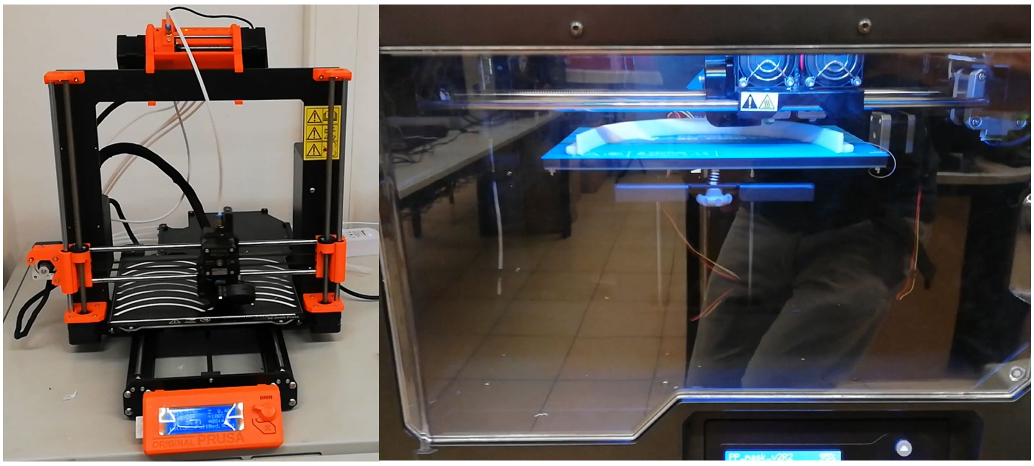

Figure 13. FDM 3D printing of face shield – Prusa (left) and FlashForge Creator Pro (right)

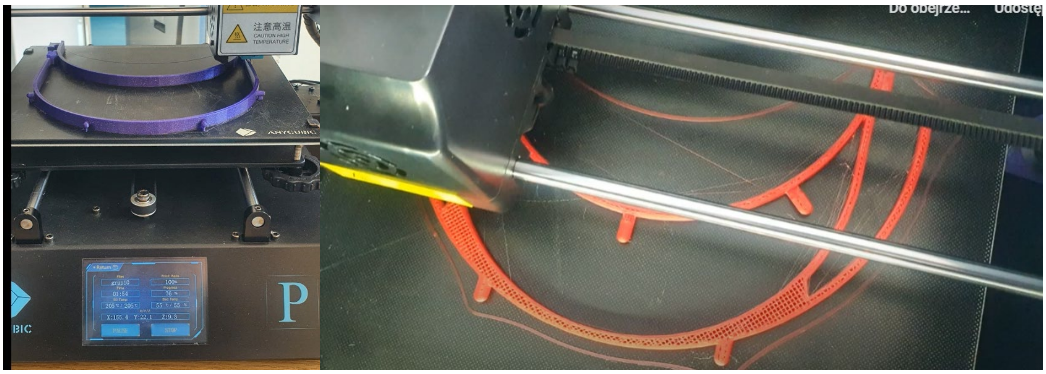

Figure 14. Face shield printing using Anycubic Chiron machine

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In the case of SLA technology, Anycubic Photon Mono X 4k was used (Figure 15). The machine operates in the LCD-based SLA technology. Anycubic Standard Resin+ material was used. The 0.5 mm layer thickness was used, The manufactured parts were post-cured using Anycubic Cure Plus Machine (Figure 16), in time of 5 minutes, after previous cleaning in isopropyl alcohol.

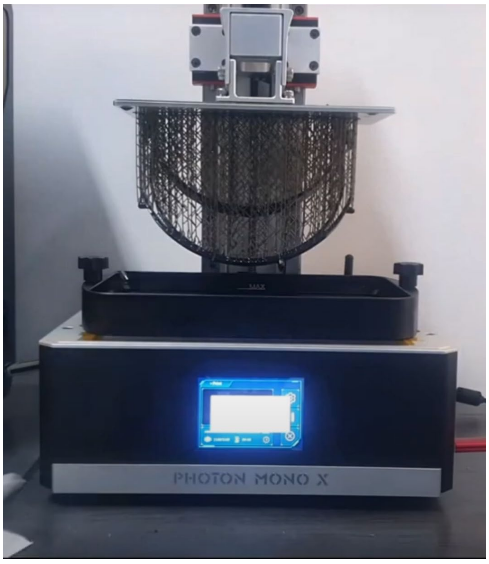

Figure 15 SLA printing of the shield using Anycubic machine

Figure 16. Anycubic SLA post-curing machine – post-curing of the shield base

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3.3.2. Injection molding

The injection molding process was planned and realized in the facilities of the industrial partner of the BRIGHT project – the BM Plast company. During the process planning and manufacturing following steps were realized:

STEP 1:

Making of 3D drawing

STEP 2:

Printing a sample in 3D printer (rapid prototyping)

STEP 3:

Adapting the sample to the injection moulding technology (avoiding negative angles)

STEP 4:

Making an injection mould (machine processing – milling, turning, erosion, drilling, grinding) – presented in Figure 17

Figure 17. Productive moulds preparation/ quality inspection

STEP 5:

Mould testing with planned material (PP COPO) – Figure 18.

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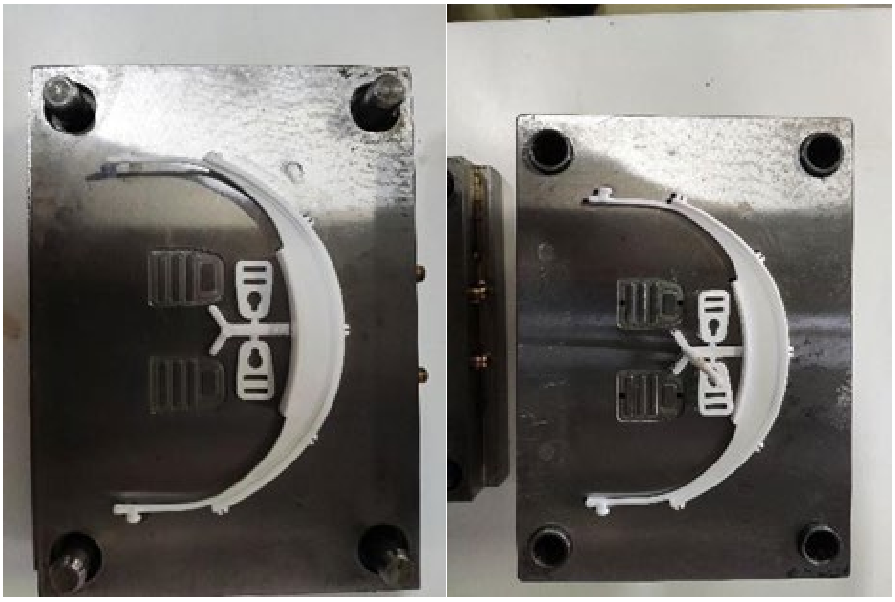

Figure 18. Testing phase results

STEP 6:

Subsequent mould correction - surface finishing, ejector correction, post-processing of the manufactured model (Figure 19)

Figure 19. Post – processing of the manufactured model

STEP 7:

Mass production (Figure 20).

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Figure 20. Manufacturing equipment for production in batch series

In the preparation phase, additive manufacturing technologies has been used. A Ultimaker Cura slicer was used in order to slice 3D CAD model for FFF producing.

In the parallel, also PUT team was able to create an injection mold and realize the final batch of the face shields with this technology (Figure 21).

Figure 21. Professors of PUT with injection mold for the face shield and examples of face shields manufactured with this technology

3.4 Testing

The following activities were realized in terms of testing of the face shield models:

- non-destructive testing – 3D scanning (realized at University of Nis) – Figure 22, quality check measurement (TUCN) – Figure 23, fit tests – all partners (Figure 24)
- destructive testing – tensile test (Univ. Nis) – Figure 25
- tests with medical personnel (Poznan University of Technology with befriended hospitals) – Figure 26

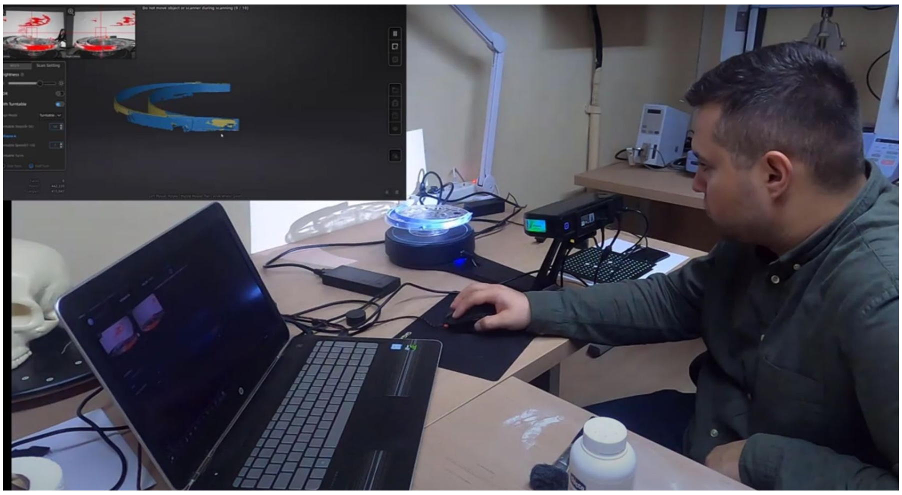

Figure 22. 3D scanning for accuracy measurement

Figure 23. Caliper measurement for quality check

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Figure 24. Fit and functionality testing

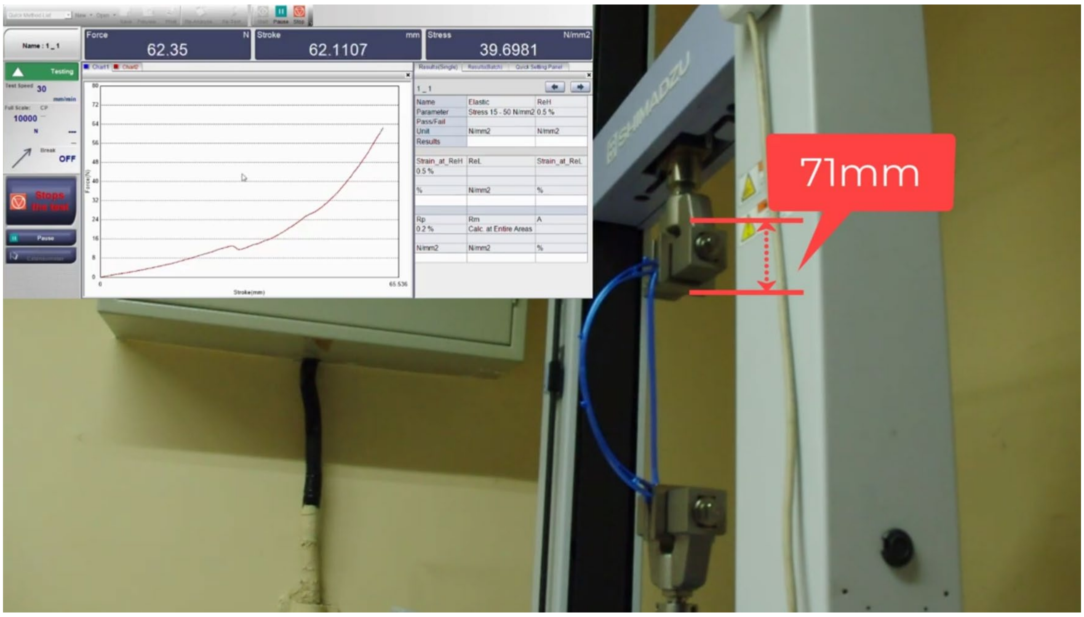

Figure 25. Tensile test of the face shield base

Figure 26. Testing in clinical conditions – 3D printed version (left) and injection mold version (right)

Most tests were realized with participation of students, or recorded for their use in the educational process, to maximize reach and possible teaching effect.

3.5 Dissemination results

The orthosis has been used during the BRIGHT summer school in 2021. Some groups have selected it as their main product of choice and implemented several interesting improvements, as noted in the chapter 3.1. The face shield models were printed at almost each partner institution, as a simple example of 3D printed product needed in times of pandemics, with many possible design iterations in a short time. The shields are widely acclaimed in the medical environment, and positive feedback was gathered from the cooperating hospitals and other medical facilities regarding their use. However, nowadays they are not as used as before, as the pandemics is no longer in the intense stage.

The face shield example has been taken and implemented in the study program of selected partners (including PUT and TUCN), as easily printable medical device, with plenty of design customization possibilities even for novice engineers. This is also an example that allowed integration with the industrial partner (BM Plast) and demonstrate the full path of using 3D printing as a prototyping technique before implementing mass production with use of conventional technologies, such as injection molding.

Presentations to several workshops, seminars, conferences and other events (like summer schools) were delivered by the project participants were also concerning this specific case study, to demonstrate unique capabilities of 3D printing in rapid design iteration, as it was presented in the Final dissemination report of the BRIGHT project.

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4 Conclusions

The presented case study pertains to personal protection device that can be printed using any technology (FDM, SLA or other), as well as manufactured on mass scale using injection molding. It was designed and prepared on the basis of available sources by representatives of Poznan University of Technology (PUT), also in cooperation with the BM Plast company. The model was used in educational activities in BRIGHT project, first and foremost as a case study in the BRIGHT summer school realized in 2021. It is a versatile device, and a perfect educational example for students to work with design of simple, 3D printable medical device. For educational effect, all the stages were realized in product development, starting from design for specific patients, through CAE simulation, manufacturing (with use of many technologies) and fitting and strength testing. Positive feedback was obtained from the medical environment. The case was also used to integrate partners from PUT, TUCN, BM Plast and all others, during the summer school and other activities that have been linked to the BRIGHT project.