Co-funded by the
Erasmus+ Programme
of the European Union

BRIGHT

Erasmus+ strategic partnership for Higher Education

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

O4 - BRIGHT e-learning webinars on the use of 3D printing technologies REPORT

Project Title	**Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517**
Output	**O4 - BRIGHT e-learning webinars on the use of 3D printing technologies in development, testing and producing of medical parts in pandemic period**
Date of Delivery	**November 2022**
Authors	**Filip Gorski, Remigiusz Labudzki, Magdalena Żukowska, Mate Babic, Dan-Sorin Comșa, Răzvan Păcurar, Eugen Guțiu, Sven Maričić, Peter Koštál, Nikola Korunović, Nikola Vitković, Michal Gallia, Martin Zelenay, Branislav Rabara**
Version	**FINAL VERSION**

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table of content

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

1 Introduction

In the context of the pandemic and how it redefined notions of both theoretical and practical teaching, it is very important to be able to provide knowledge in visual form, but not necessarily through direct, on-site contact with the student. That is why educational videos have become immensely popular in time of pandemic and regular seminars, lectures and even laboratory exercises were changed into online courses. In that context, webinars are digital, remote forms of teaching, applicable everywhere it is possible to replace or supplement direct contact between teacher and student.

The intellectual output 4 is BRIGHT e-learning webinars on the use of 3D printing technologies in development, testing and producing of medical parts in pandemic period. The webinars integrate knowledge and skills of all the consortium partners, to create a synergic educational effect. They holistically approach almost the whole life cycle of various medical products, focusing on design, manufacturing and testing stages. Their form is of recorded videos – that can be watched anywhere, anytime, by everyone who's concerned – to increase their level of knowledge of cutting-edge technologies used in modern medical engineering.

The main concept of the webinars is their division into four main thematic areas related to product lifecycle – that is design (CAD), simulation (CAE and AR), manufacturing (3D Printing) and use (testing). Three (of total five) of BRIGHT case studies were selected and each of four main webinars covers topics related specifically to these cases, with great technical details.

The webinars are very important part of the BRIGHT project, condensing interdisciplinary knowledge of consortium partners into easily digestible videos, of high educational value. They are freely available through the project YouTube channel, that can be found on YouTube itself (BRIGHT Erasmus Project) or accessed directly by this link:

https://www.youtube.com/@brightprojecterasmus

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

2 *Requirements, according to target groups*

The e-learning webinars are educational, pre-recorded videos, containing high amount of interactive educational content, addressed to everyone who is involved in teaching process of 3D printing of medical parts, taking into account the whole process – starting from design, through various simulations, manufacturing and finally quality control and putting to use.

The main beneficiaries of this platform are:

- students, as they can gain lots of knowledge in short time – especially at Biomedical Engineering or any Medical Engineering degree; but also students of purely industrial or purely medical study majors could be interested,
- professors who perform the didactic process – as they can easily supplement their lecture or laboratory materials with the selected webinar content, aiding the students in gathering more up-to-date knowledge,
- the medical environment – as the videos mostly work using the "show, don't tell" principle – they are perfect demonstrators of modern 3D printing technology use in medicine and doctors can get familiarized with what could be achieved in their own work environment.

The webinars were also thought as an useful tool during the COVID-19 pandemics, or anywhere and anytime the teaching has to be realized remotely and/or at a distance (also, e.g. in war conditions) – they contain lots of practical knowledge that can be easily applied if the viewer has similar setup. Three very distinct medical products were selected, with very different design processes and requirements, to demonstrate a very wide range of possible techniques used in their development.

After ending of the BRIGHT project, the webinars will continue to be used in the didactic process, both at partners' institutions and in new institutions, interested in their content.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

3 BRIGHT e-learning webinars

3.1 Main concepts and scheme of work

The BRIGHT e-learning webinars are series of freely available educational videos, in which lecturers, scientists and practitioners from BRIGHT consortium present various aspects related to 3D printed medical parts, based on selected practical cases. Originally, it was planned to realize 4 webinars, focused on various stages of development of medical products manufactured by 3D printing technologies. These stages are:

1) Design (CAD), with all the stages also related to medical image acquiring and processing
2) Analysis (CAE), mostly focusing on strength analysis using Finite Element Method,
3) 3D printing – rapid, usually additive manufacturing using various technologies and materials, along with post processing techniques,
4) Testing – after-manufacturing check, both destructive and non-destructive methods – accuracy measurement, fitting with patient, tensile tests etc.

Each of these activities had to be planned, recorded and accordingly assembled into educational videos. The main idea is presented in Figure 1.

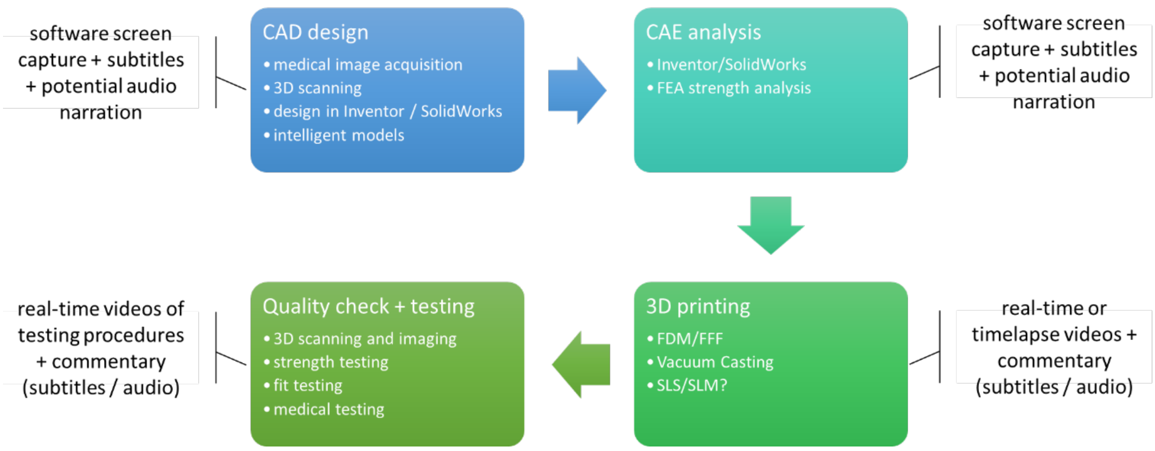

Figure 1. Main concept of BRIGHT e-learning webinars

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Later, on the basis of successful implementation of Augmented Reality technology at the stage of developing the e-learning platform (IO3) it was decided to prepare another, extra webinar regarding that technology. Planning and realization of the webinars was done in four basic stages. First, case studies were selected for realization (out of 5 cases realized in the BRIGHT project, 3 different ones were chosen). Then, basic scenarios were written and tasks were distributed among the partners. Partial videos were recorded at all partners, using different equipment and approaches. Then, the complete webinars were assembled by assigned partners and internally checked by other partners. After that process, all the webinars were published on the YouTube channel of BRIGHT project, first in private mode, than, after feedback, videos were corrected and uploaded again, this time in public mode. This scheme is presented in Figure 2.

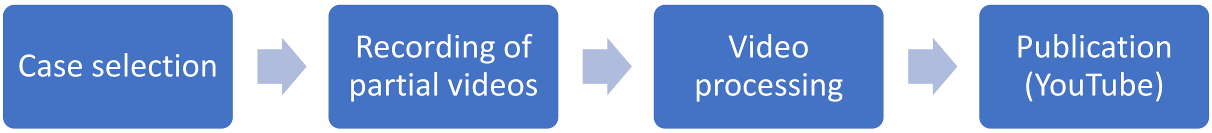

Figure 2. Scheme of work during the webinar preparation

As the first step of preparing the webinars, the case studies were selected, as a result of brainstorming during project meetings. Three different cases were selected, distinct from each other:

1) Wrist hand orthosis – a fully 3D printed product, anatomically individualized on the basis of 3D scanning, designed in a CAD system
2) Tongue with tumor – a product realized by 3D printing, but also Vacuum Casting technology, out of various soft and hard resin materials; individualized anatomically on the basis of Magnetic Resonance Imaging (MRI) of a specific patient, designed partially in mesh processing software and partially in CAD
3) Face shield – a product prototyped using 3D printing and finally manufactured using injection molding, not individualized anatomically, consisting of several parts made in different ways, designed in CAD

As such, the three cases were very distinct from each other, regarding all the process stages. They were designed using entirely different tools and software, 3D printed and produced of various materials in differing processes and made for entirely different purposes. That helped maximizing the educational value of prepared webinars. The selected cases are presented in Figure 3.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Furthermore, main structure of webinars was devised, creating a matrix of what parts of each case study should be realized in a specific webinar. This matrix, without details, is presented in Table 1.

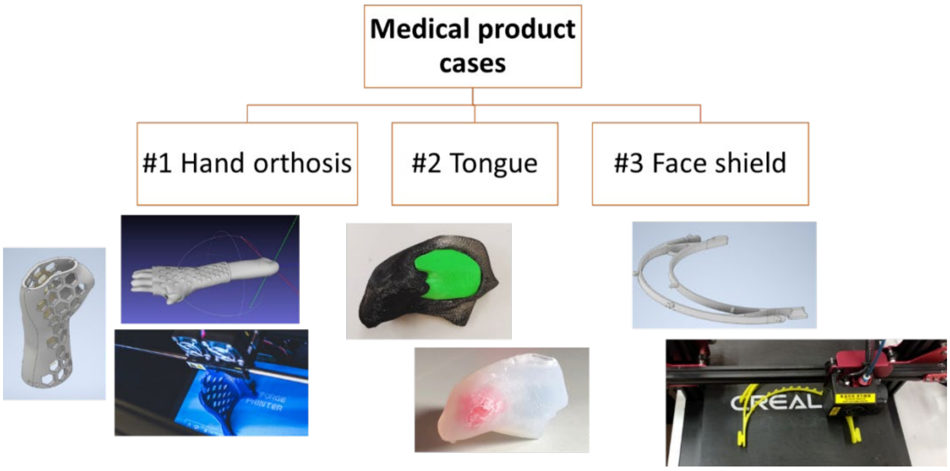

Figure 3. Selected medical product cases for the webinars

Table 1. Matrix of connections between cases and webinars

	CAD webinar	CAE webinar	3D Printing webinar	Testing webinar
Case #1 Hand orthosis	• 3D scanning of limb • automated design – MeshLab, Inventor	• FEA analysis – 3-point bending	• FDM 3D printing and post processing	• fit with patient • 3-point bending • 3D scanning
Case #2 Tongue with tumor	• DICOM processing • mesh processing • mold design	• FEA analysis - shear	• FDM 3D printing • Vacuum Casting • SLA/DLP	• visual assessment • simulated surgery
Case #3 Protective equipment	• Inventor / SolidWorks design process	• FEA analysis – tensile + other	• FDM 3D printing • DLP 3D printing • injection molding	• strength testing • accuracy testing • fit testing

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

In further activities, the work was divided. Detailed division is presented in chapter describing each of the webinars, so it will not be described here. However, the main responsibilities were as below:

1. CAD webinar – managed & assembled by Poznan University of Technology (PUT).
2. CAE webinar – managed & assembled by Technical University of Cluj-Napoca (TUCN).
3. 3D printing webinar – managed & assembled by Slovak University of Technology (STU).
4. Testing webinar – managed and assembled by two partners together – University of Nis (UNI) and Juraj Dobrila University of Pula (UNIPU).
5. Augmented Reality webinar – managed by Bizzcom company.

Also, general framework structure of each webinar was proposed. In general, the structure of each main webinar is similar and looks as below:

1) Intro, review of cases / basics
2) Case 1-3 activities
3) Outro / summary

Guidelines for the intro and outro were also prepared, as below.

Intro structural guidelines:

- Intro credits (1. BRIGHT logo and title + WWW of the project, 2. Logos of all partners, 3. IO4 title + some background music)
- Short review of cases with subtitles, audio narration or live talk
- Review of main ideas around the topic of the given webinar (e.g. for 3D printing: what is 3D printing? how and why we use it for medicine?) – audio narration or live talk

Outro structural guidelines:

- Summary of obtained results (most important achievements for all the cases, underlining importance on a given technology etc.)
- Links, references to institution webpages, other projects, papers, movies etc.
- Outro credits – containing names of all presenters and technical persons involved, as well as institutions and other important information

The intro credits were prepared in advance, before all movies were recorded.

The next stage of development was recording the partial movies and assembling them into full webinars. This is described in the following chapters.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

3.2 Selected case studies

3.2.1. Case 1 – Wrist Hand Orthosis

The product is an orthosis used for wrist joint stabilization in time after an injury (e.g. Colles fracture) or for patients with conditions that require stabilization (rheumatoid arthritis, muscle atrophy and many others). The orthosis is openwork, to enable skin access in both comfort and hygienic reasons (Figure 4).

Figure 4. Wrist hand orthosis example

The orthosis is customized on the basis of a 3D scan geometry of patient's hand and forearm (or mirror image of the other limb, when the actual limb is damaged and e.g. wrapped in plaster cast). It is 3D printed using one of the basic FDM technology materials: PLA, ABS, PET-G and PA-12 (nylon), of which PLA and PA-12 are recommended due to proper combination of mechanical and processing properties, as well as no known issues with skin irritation. The 3D printing takes approx. 3-4 hours for one part of the orthosis, for an adult patient.

The product is originally created in Autodesk Inventor CAD system (Figure 5), as an intelligent model – its design can be changed freely by supplying it with various data from 3D scanning, leading to automated re-design. The model and its know-how is a part of AutoMedPrint system developed at Poznan University of Technology (automedprint.put.poznan.pl), which was awarded as the Polish Product of the Future of year 2022.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

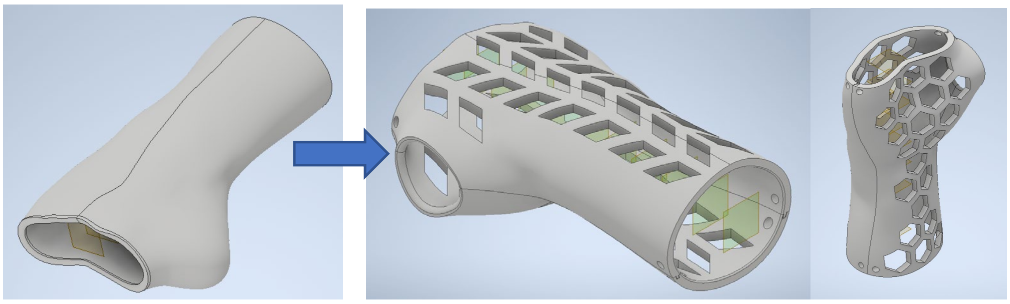

Figure 5. Design of orthosis in Inventor

For the webinar, an actual case has been selected – a patient with current wrist injury was invited specially for realization of the webinars. The patient was a 26-year old man, with an injury to his right wrist, caused by bite of a dog resulting in some bone crush. A full process was undergone and recorded for him, finished with obtaining a complete functional orthosis.

3.2.2. Case 2 – Tongue with cancer tumor

The second case study is an anatomical model of a tongue with cancer tumor. This type of model has a number of applications – first and foremost it is used as a pre-operative aid – for simulated surgery procedure. It is also used for mid-surgery support, to help with tissue reconstruction process (after sterilization, the model can be taken into the operating room). It can also be used for educational purposes (by students of medical universities) and for showing to the patient prior to the operation itself. The anatomical models of soft tissues can be produced either as hard models (for mid-surgery) or as soft ones (for simulated surgery before the operation), as shown in Figure 6.

Figure 6. Model of a tongue with cancer – hard 3D print (left) and soft casting in a 3D printed mold (right)

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The product is customized basing on medical imaging – in the case of soft models, MRI is the most popular technique. Basic DICOM images require proper segmentation (Figure 7), then a 3D mesh is generated in STL format. It can be further processed – for hard 3D prints (using FDM, SLA, DLP or PolyJet) it can be used right away, but for soft resin castings (using Vacuum Casting technology), molds need to be created first and then they are printed (using FDM or PolyJet). A number of different software tools are used in the design process, starting from medical image processing software (Invesalius), through mesh processing software (GOM Inspect, MeshMixer etc.) and CAD software (Inventor).

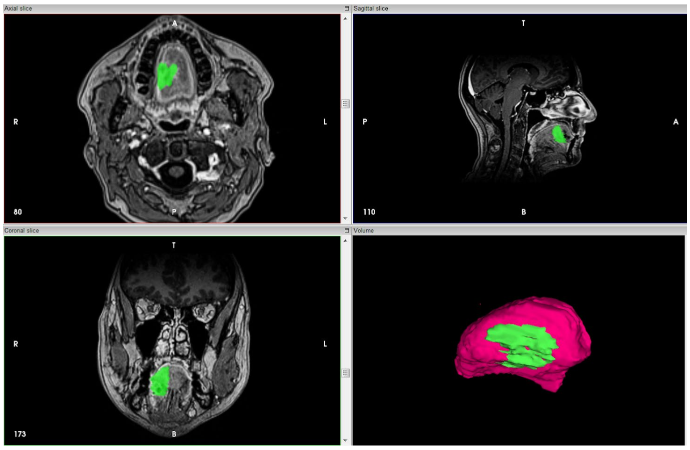

Figure 7. Basic design process – DICOM segmentation

For the webinar, a clinical case of a cancer was selected in cooperation with Poznan University of Medical Sciences – it was a 53-year old woman with tongue cancer, diagnosed with use of Magnetic Resonance Imaging (MRI). By the time of webinars realization, the patient was already recovering after surgery, so it was not a current clinical case – however still relevant.

3.2.3. Case 3 – Face shield

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. 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

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Health. It was printed with success in Poland in beginning of 2020's pandemics, during the action "print for the doctor" (orig. "*drukuj dla lekarza*"), where hundreds of shields were supplied to hospitals and other medical facilities off charge (Figure 8).

Figure 8. 3D Printed assembled face shields for a hospital

The shield is 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. 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 9).

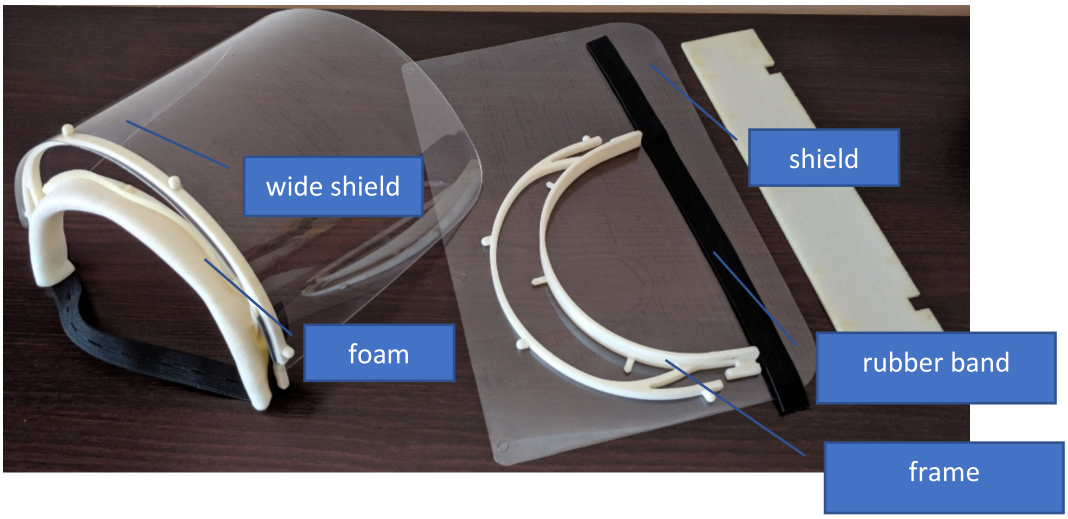

Figure 9. Structure of the shield.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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 10).

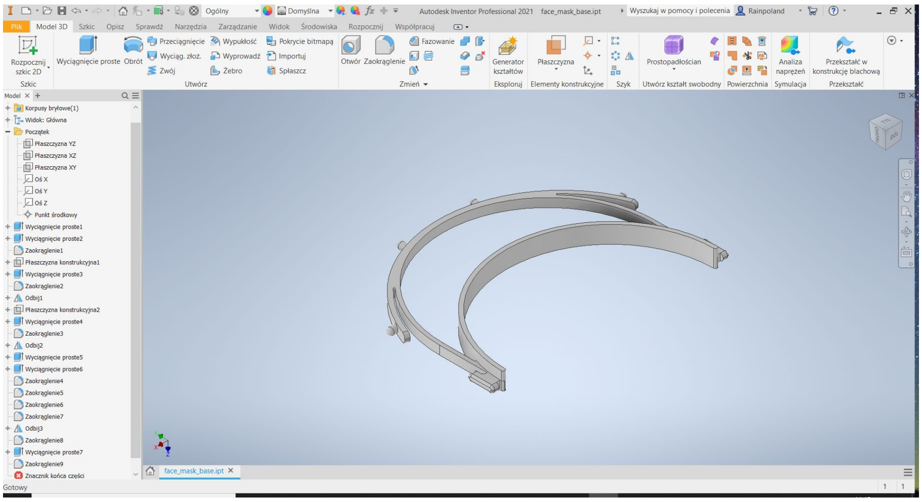

Figure 10. Face shield model, basic (Prusa) version, designed in Autodesk Inventor

3.3 *Webinars description*

3.3.1. Webinar 1 - Computer Aided Design (CAD)

The first webinar is focused on the design part. Its main purpose is to introduce the viewers to the cases – different medical products manufactured with use of 3D printing – and to present detailed, various ways of designing various types of products. It should be viewed as a first webinar in the series, as it introduces the cases – but can be also skipped if viewers are not interested in the design part itself. The presented techniques are cutting edge and innovative – some automation techniques are used, as well as clever ways of data processing. The whole webinar takes approx. 1 hour and 10 minutes, but it is noteworthy that many processes have been sped up several times, in order to make it more interesting to the viewer. The webinar is available here: https://www.youtube.com/watch?v=FHLqj7sNMiM

The webinar was taken for preparation by the team of Poznan University of Technology, generally most experienced in design of medical products of all partners in the consortium. Every part of the webinar, except modelling in case 3, was realized by team of PUT, in PUT laboratories. The general scenario is presented in table 2.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table 2. General scenario and responsibilities for the webinar #1 – CAD

No.	Step (partial video)	Who?
1	Intro, review of cases	PUT
2	Case 1 – 3D scanning of patient	PUT
3	Case 1 – CAD design	PUT
4	Case 2 – DICOM processing	PUT
5	Case 2 – mesh processing	PUT
6	Case 2 – mold CAD design	PUT
7	Case 3 – CAD modelling	BM Plast
8	Outro	PUT

The webinar starts with the intro credits and then the introduction is realized. It is done by representatives of PUT team, who are also engaged in the other activities in this and subsequent webinars. The cases are also introduced and shortly described (Figure 11).

Figure 11. Webinar #1 – intro by PUT team

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The next two stages of webinar present different phases of designing the first case – wrist hand orthosis. First phase is 3D scanning of patient's limb and data processing. For that part, AutoMedPrint system was used (see more at https://automedprint.put.poznan.pl). Complete set of actions is presented (Figure 12). Then, Autodesk Inventor model of the orthosis is shown. In general, the design is automated and the user rarely has to interact with the CAD system (in the AutoMedPrint system the model re-creates itself when obtaining dataset of another patient, extracted from a 3D scan). Here, for increased educational value, all the stages of design were shown by manual interaction with the CAD system (Figure 13).

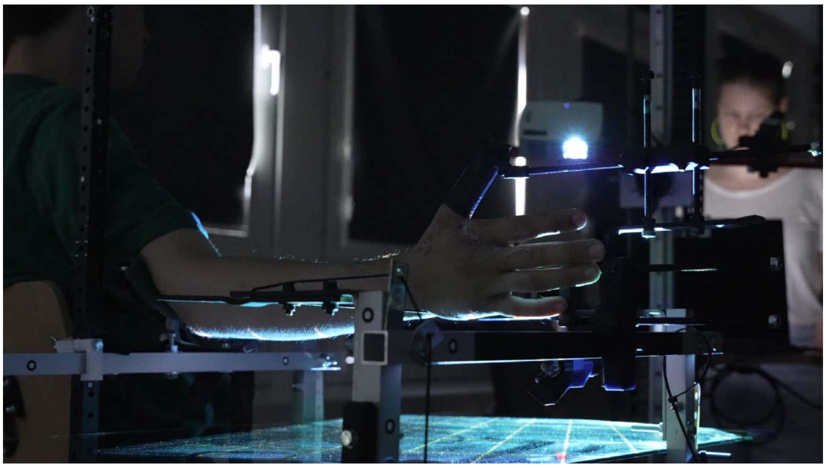

Figure 12. Webinar #1, case study 1 – patient scanning

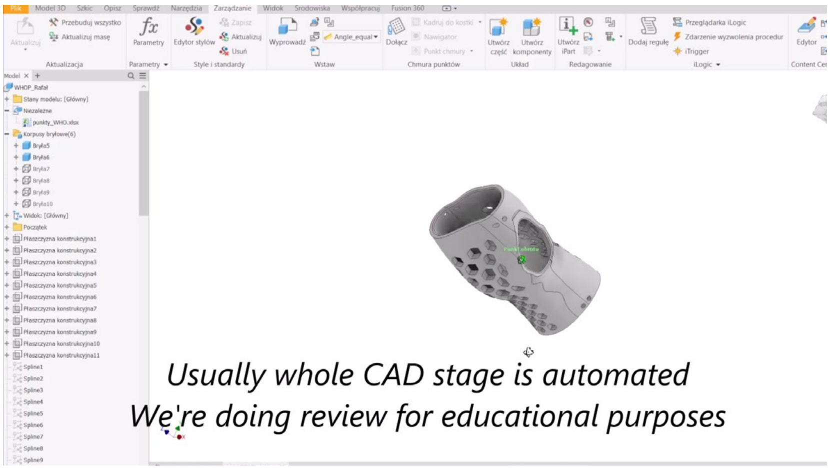

Figure 13. Webinar #1, case study 1 – product design

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The 4-6 sections of the webinar are various stages of design of anatomical model of tongue with tumor. Here, mostly freeware / open source software was used. The DICOM processing and segmentation in InVesalius software is shown in Figure 7. Result of this process – performed on raw set of medical images straight from the MRI system, with aid of professional radiologist – is a triangular mesh in the STL format. The next stage is realized in GOM Inspect software – it is repairing and smoothing of the mesh (Figure 14). After the mesh is ready, it can be used for direct printing using hard materials (for pre-operative purposes). For soft resin casting in vacuum, mold must be prepared. This is done using a combination of free software – Blender and MeshMixer (Figure 15). Full procedure is shown in the webinar.

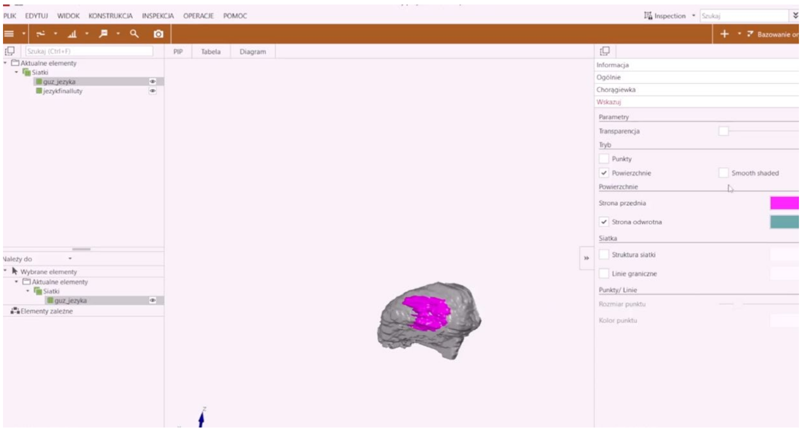

Figure 14. Webinar #1, case study 2 – mesh processing

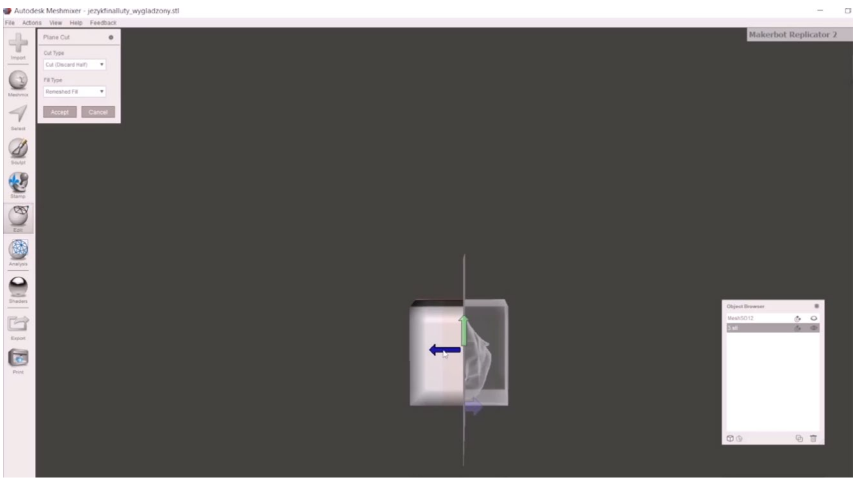

Figure 15. Webinar #1, case study 2 – mold design

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Design of the third product is realized in a different manner. To diversify the used software and increase the educational effect, regular CAD software and solid modelling (such as Inventor or SolidWorks) was not used in this case. Here, Rhinoceros software was used with features of surface modelling. Full process was covered, starting from the scratch. The modelling is presented in Figure 16, while final effect – in Figure 17. This process concludes this webinar.

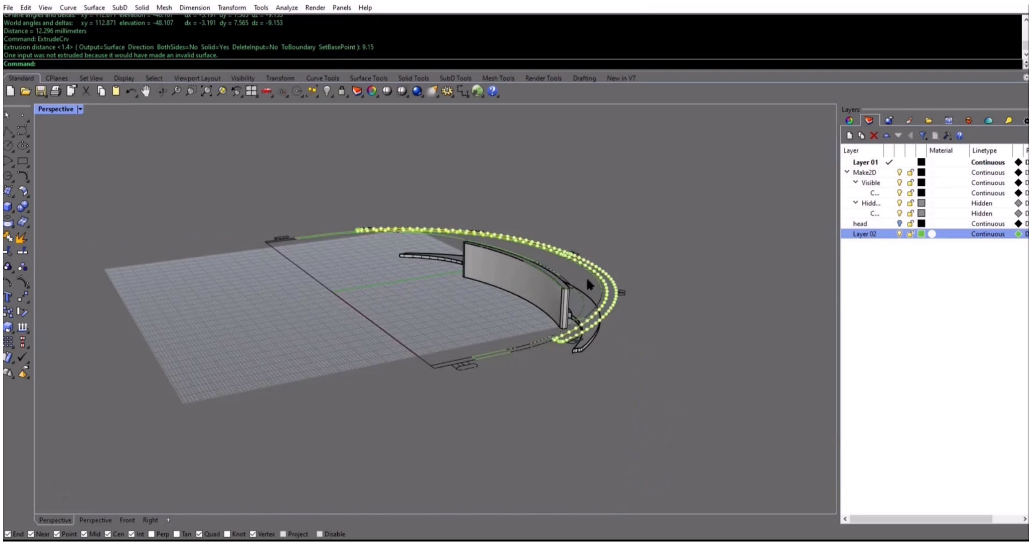

Figure 16. Webinar #1, case study 3 – 3D design

Figure 17. Webinar #1, case study 3 – final result

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

3.3.2. *Webinar 2 - Computer Aided Engineering (CAE)*

The CAE webinar has focused on providing the students with the basic knowledge of applying the finite element method in the design of medical devices. Three case studies have been considered. They have consisted in the computer simulation of different tests meant to evaluate the strength characteristics of a wrist hand orthosis, a tongue casting mould, and a face shield base. The finite element analysis module SOLIDWORKS Simulation (component of the SOLIDWORKS computer-aided design software package) has been used to perform the tests. A recording of the CAE webinar has been uploaded on YouTube and is directly available here: https://www.youtube.com/watch?v=HvELM896GPc. The whole webinar is 1 hour and approx. 8 minutes long. It contains full audio narration of the realized processes.

The webinar was taken for preparation by the team of Technical University of Cluj-Napoca (with guidelines from the PUT team), generally most experienced in terms of engineering simulation of all partners in the consortium. Every part of the webinar was realized by team of TUCN. The general scenario is presented in table 3.

Table 3. General scenario and responsibilities for the webinar #2 – CAE

No.	Step (partial video)	Who?
1	Intro, review of cases	TUCN
2	Case 1 – hand orthosis – 3-point bending	TUCN
3	Case 2 – tongue – shear test	TUCN
4	Case 3 – face shield – tensile test	TUCN
5	Outro	TUCN

The webinar has been divided into three parts, each of them being devoted to the presentation of a case study in the following steps:

- Emphasizing the objectives of the case study
- Describing the medical device to be analysed
- Describing the test to be simulated with the aim of evaluating the strength characteristics of the medical device

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

- Detailing the preparation of the finite element model of the test with SOLIDWORKS Simulation
- Analysing the numerical results provided by SOLIDWORKS Simulation
- Formulating some conclusions.

The most significant aspects of the finite element analysis of medical devices have been approached during the presentation of the case studies.

- Defining material properties
- Specifying contact interactions
- Enforcing various types of boundary conditions (kinematic constraints and external loads)
- Controlling the size of finite elements
- Generating the finite element mesh
- Postprocessing the numerical results.

The first case study has focused on evaluating the strength characteristics of a wrist hand orthosis by simulating a three-point bending test. The principle of the test and main setup is shown in Figure 18. As one may notice, the lower and upper parts of the orthosis are assembled and placed on a support block. The upper part of the orthosis is then loaded by a downward vertical force acting on the red surface patch. This load gradually increases from 0 (zero) to 125 N.

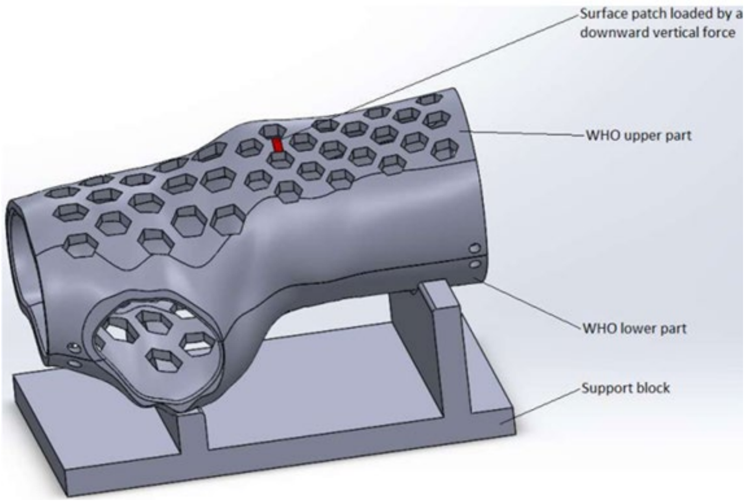

Figure 18. Webinar #2, principle of the three-point bending test of case study 1

In the further stages, material properties were assigned to the parts of the model (ABS material model was used). Then, mesh was defined, along with constraints (supports and loads – selected to match requirements of three-point bending). Results are visible in Figure 19.

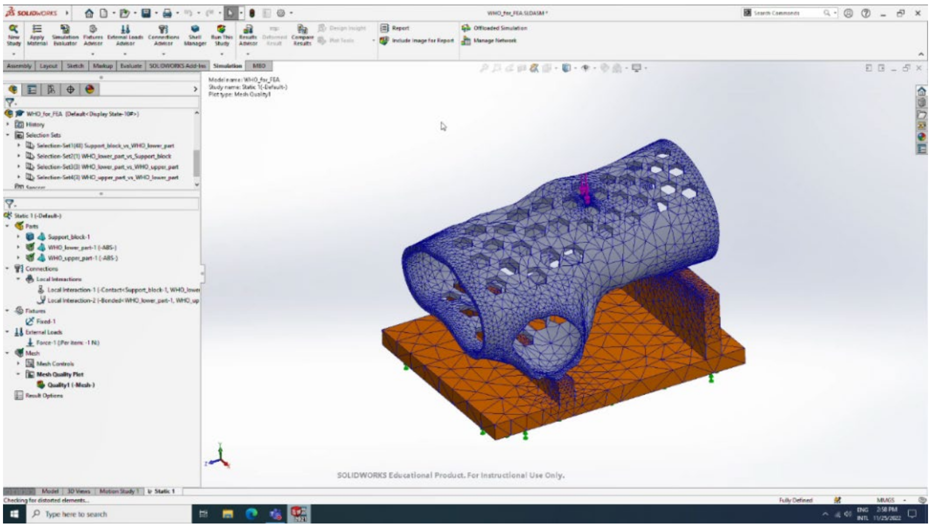

Figure 19. Webinar #2, finite element model of the three-point bending test of case study 1

Finally, the model was solved – deformations and stresses were obtained as a result, identifying weaker spots in the orthosis model. These results are presented in Figure 20.

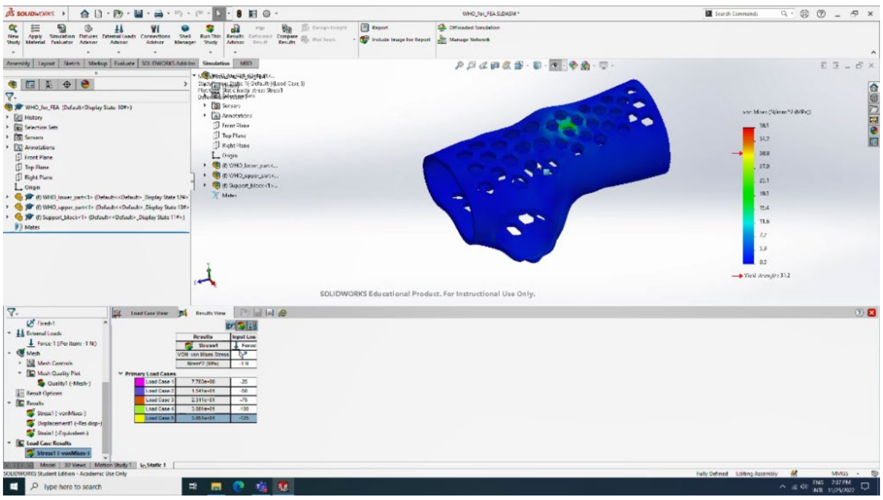

Figure 20. Webinar #2, colour map showing the von Mises equivalent stress distribution of case study 1

The second case study has focused on evaluating the strength characteristics of a tongue casting mold by simulating a pressurization test. The principle of the test is shown in Figure 21. As one may notice, the inner surfaces of the mould parts are loaded by pressure after being clamped between two rigid plates in their assembled configuration. The inner pressure gradually increases from 0 (zero) to 8 MPa.

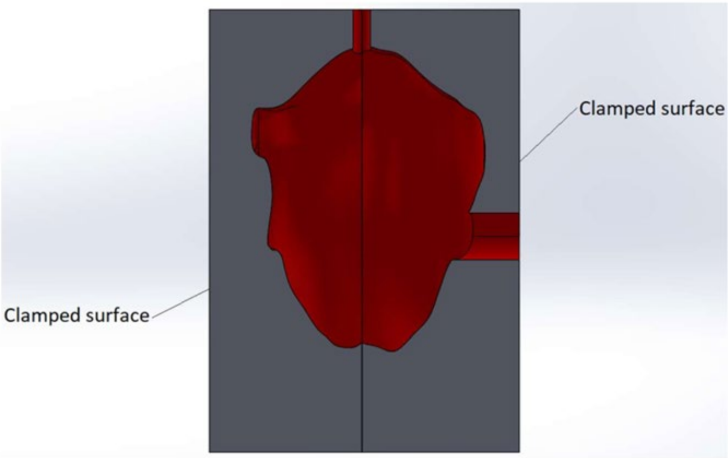

Figure 21. Webinar #2, principle of the pressurization test of case study 2 (tongue mold)

In this case, PLA material model was used. Appropriate constraints were applied, as well as loads (simulating pressure while realizing the casting process of resin material). The final model, after mesh creation, is presented in Figure 22.

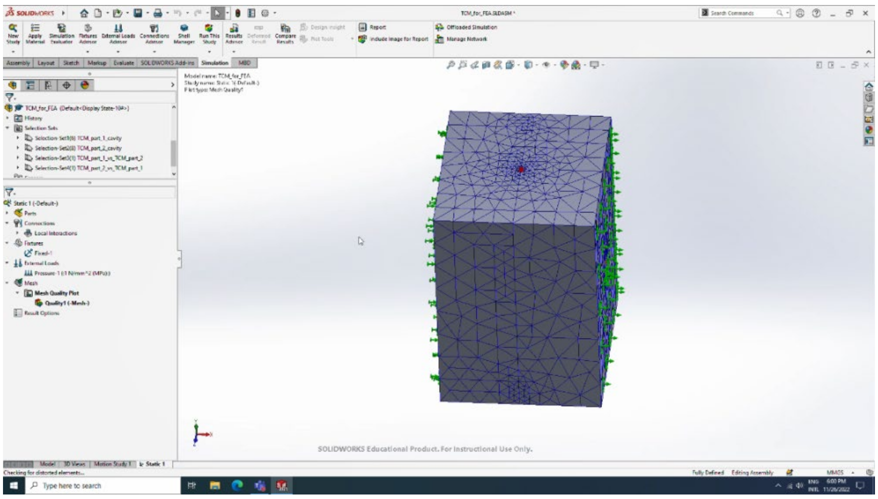

Figure 22. Webinar #2, finite element model of the pressurization test of case study 2

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

Figure 23 shows the most significant results provided by the finite element analysis module SOLIDWORKS Simulation: distributions of the von Mises equivalent stress in the mold parts for the fourth load case (testing pressure of 8 MPa). Similar distributions associated to other load cases have also been analyzed.

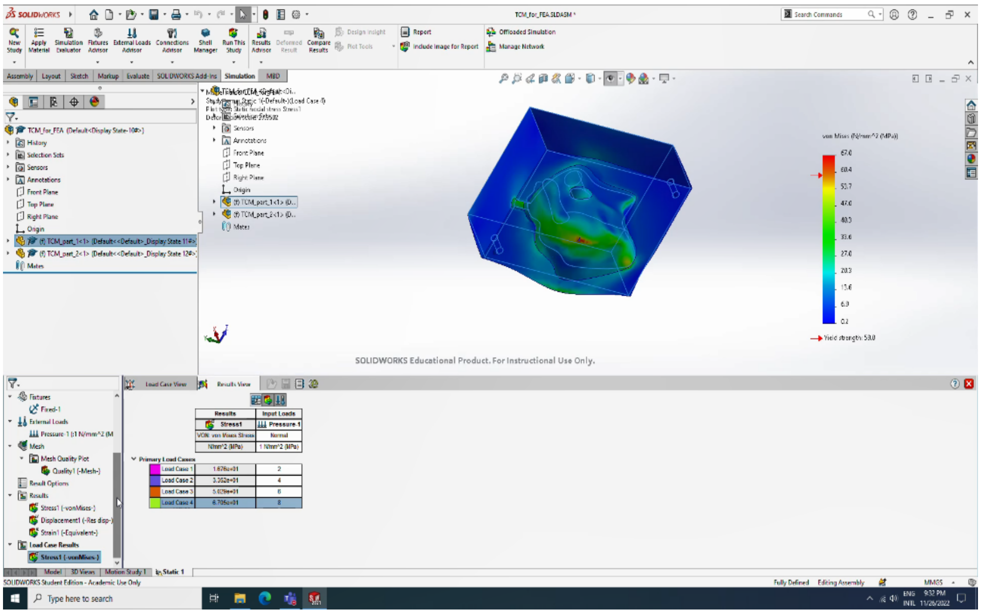

Figure 23. Webinar #3, color map showing the von Mises equivalent stress distribution in the upper part of the mold for the fourth load case – testing pressure of 8 MPa

The third case study in the second webinar has focused on evaluating the strength characteristics of a face shield base by simulating a dimensional adjustment procedure (Figure 24). As one may notice in Figure 24, 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.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

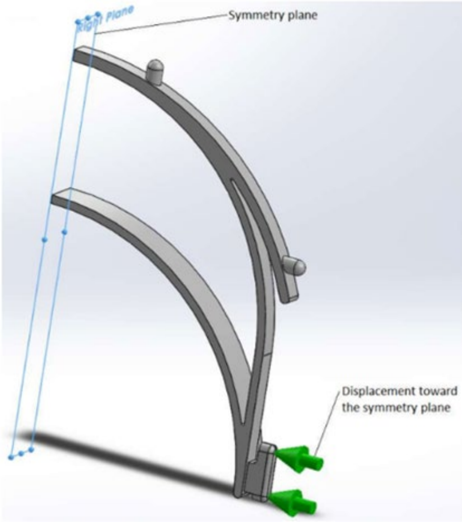

Figure 24. Webinar #2, dimensional adjustment simulated for evaluating the strength characteristics of the face shield base – case study 3

The finite element model of the dimensional adjustment procedure has been prepared assuming that the face shield base is made from PETG characterised by an isotropic linear elastic behaviour. The model after adding all the constraints and loads, after meshing, is shown in Figure 25.

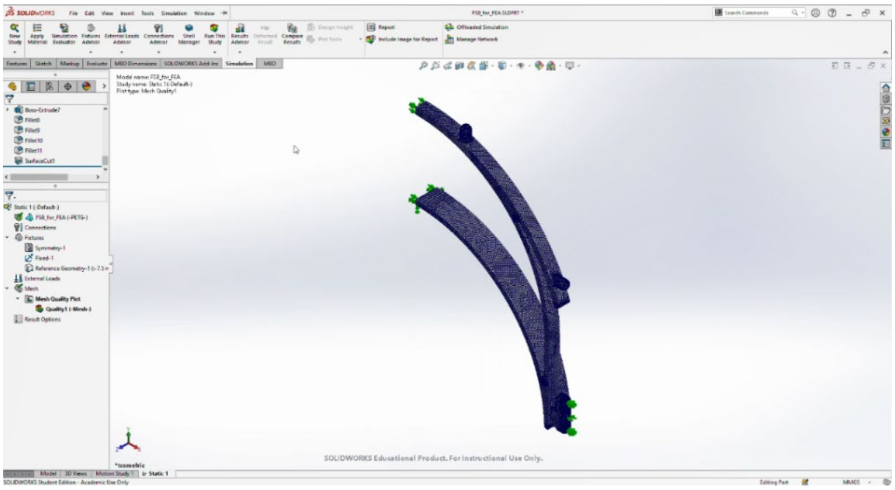

Figure 25. Webinar #2, finite element model of the case study 3

Figure 26 shows the most significant result provided by the finite element analysis module 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.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

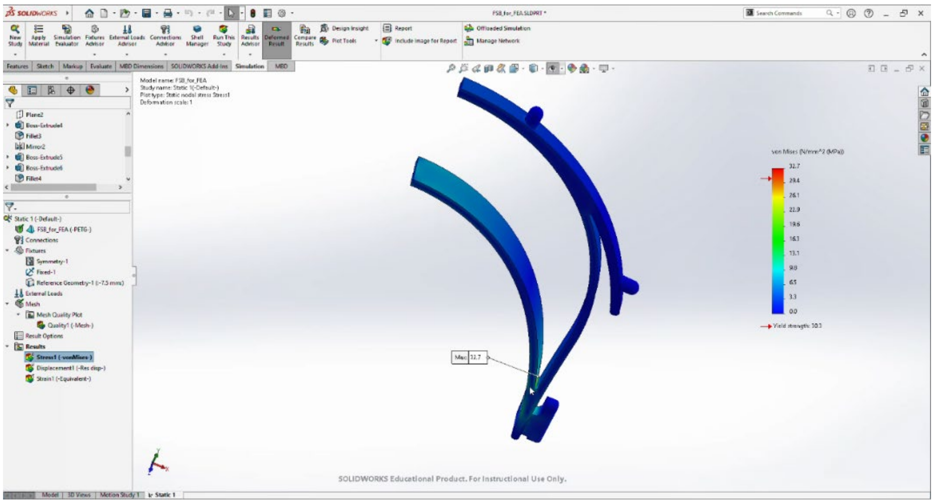

Figure 26. Webinar #2, color map showing the von Mises equivalent stress distribution of case study 3

The case studies presented in the second BRIGHT webinar demonstrate the capability of finite element analysis programs to assist the designers of medical devices in assessing and improving the quality of their projects, as well as in ensuring the conformity of their projects with the strength requirements.

3.3.3. Webinar 3 - 3D Printing

The 3D printing webinar presents the actual manufacturing of the case studies designed in the first webinar and analyzed in the second webinar. However, as in the other cases, it can be viewed as a standalone movie. It shows preparation of the processes and materials, realization of the various processes (3D printing and also casting), as well as post processing of obtained parts. This webinar is the longest of all, approximately 90 minutes in length, with many parts of the material sped up (timelapse recordings were made for some longer 3D printing processes). It is available directly on YouTube under the following link: https://www.youtube.com/watch?v=qjtj8nDT0LU

The webinar was taken for preparation by the team of Slovakian University of Technology. However, as all teams are experienced with the 3D printing and manufacturing processes, this webinar is the most diversified in terms of task distribution – all universities in BRIGHT consortium were engaged here. The general scenario is presented in Table 4.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table 4. General scenario and responsibilities for the webinar #3 – 3D Printing

No.	Step (partial video)	Who?
1	Intro	STU
2	Review of 3D printing methods	UNIPU
3	Case 1 – FDM + post processing	PUT
4	Case 2 – FDM tongue	PUT
5	Case 2 – Vacuum Casting, PolyJet + post processing	PUT
6	Case 2 – SLA + post processing	TUCN
7	Case 3 – FDM	UNIPU
8	Case 3 – SLA + post processing	TUCN
9	Outro	STU

The webinar starts with the intro credits and then the introduction is realized. It is done by representatives of UNIPU team. The 3D printing technology is introduced and shortly described (Figure 27).

Figure 27. Webinar #3 – introduction

Then, it's all focused on manufacturing of specific case studies. Case 1 is 3D printed using a FlashForge Creator Pro 3D Printing machine. The preparation of the machine, as well as the printing itself is presented in Figure 28. Figure 29 shows how the post processing stage was recorded – the orthosis needs a number of specific manual operations and they are fully covered in the webinar.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

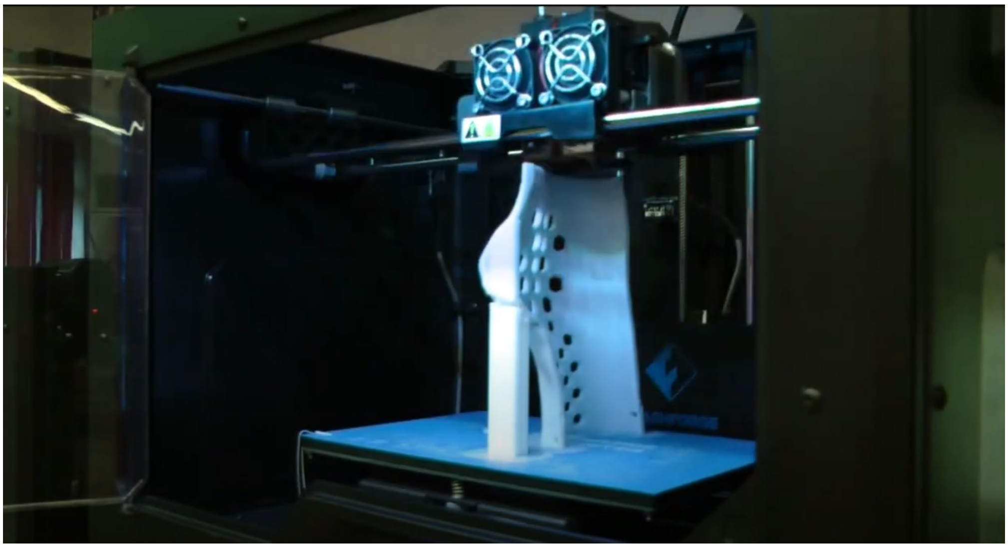

Figure 28. Webinar #3, 3D printing, case 1

Figure 29. Webinar #3, 3D printing – post processing, case 1

Then, the second case study is presented. First, very short timelapse of FDM printing of tongue is presented (Figure 30). Then, casting process is presented in full, using 3D printed mold (Figure 31).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

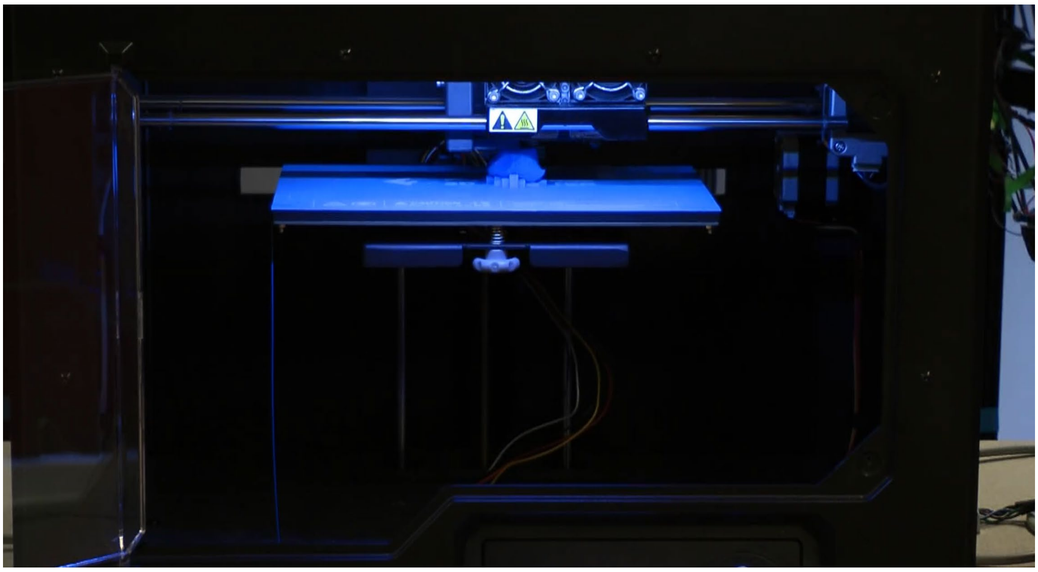

Figure 30. Webinar #3, FDM 3D printing – case 2

Figure 31. Webinar #3, resin casting – case 2

Then, the 3D printing of second case is shown using the PolyJet technique. Software part is shown (as opposed to FDM, this is not trivial), then timelapse of the layer deposition is presented (sped up x250, Figure 32). Finally, post processing (support removal by use of water jet) is presented (Figure 33).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

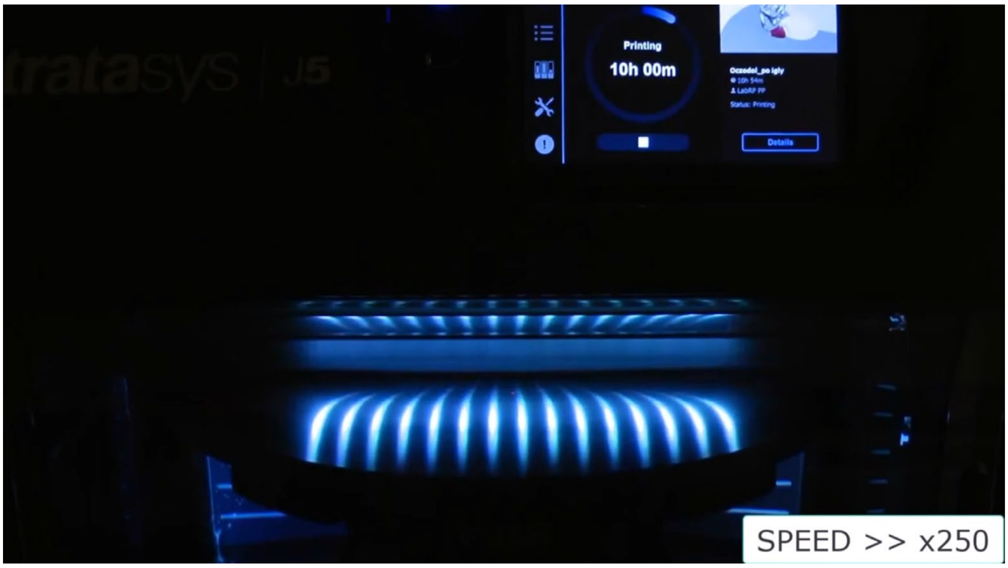

Figure 32. Webinar #3, PolyJet 3D printing – case 2

Figure 33. Webinar #3, PolyJet 3D printing – post processing – case 2

Another, last 3D printing technology for that case is SLA – resin printing. Here again everything is shown – machine preparation, software part, 3D printing (Figure 34) and post processing (cleaning and post curing – Figure 35).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

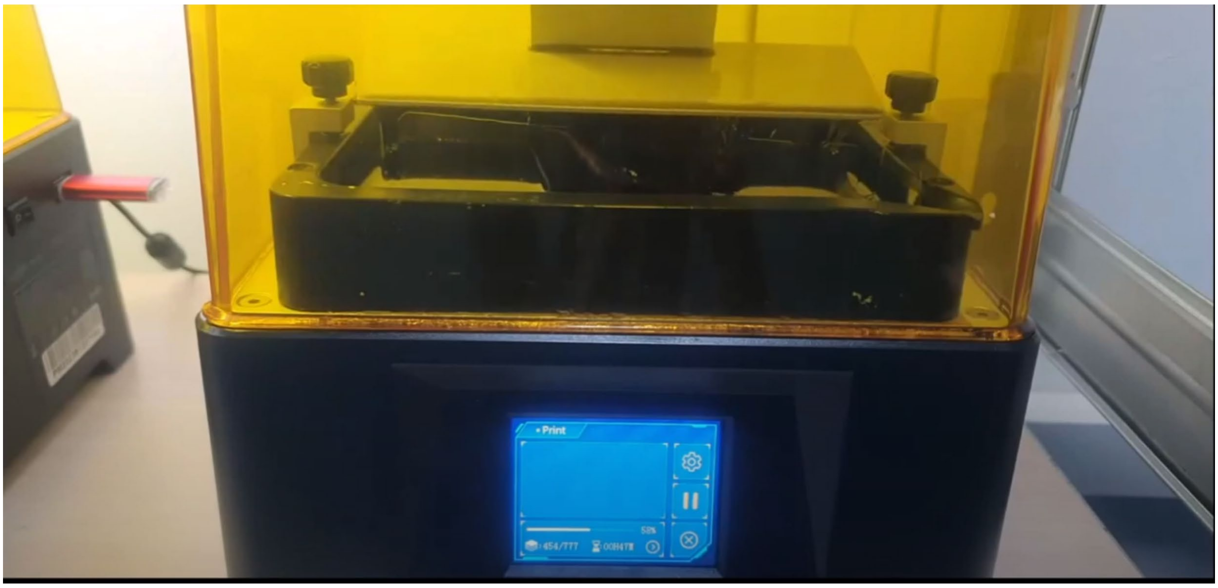

Figure 34. Webinar #3, SLA 3D printing – case 2

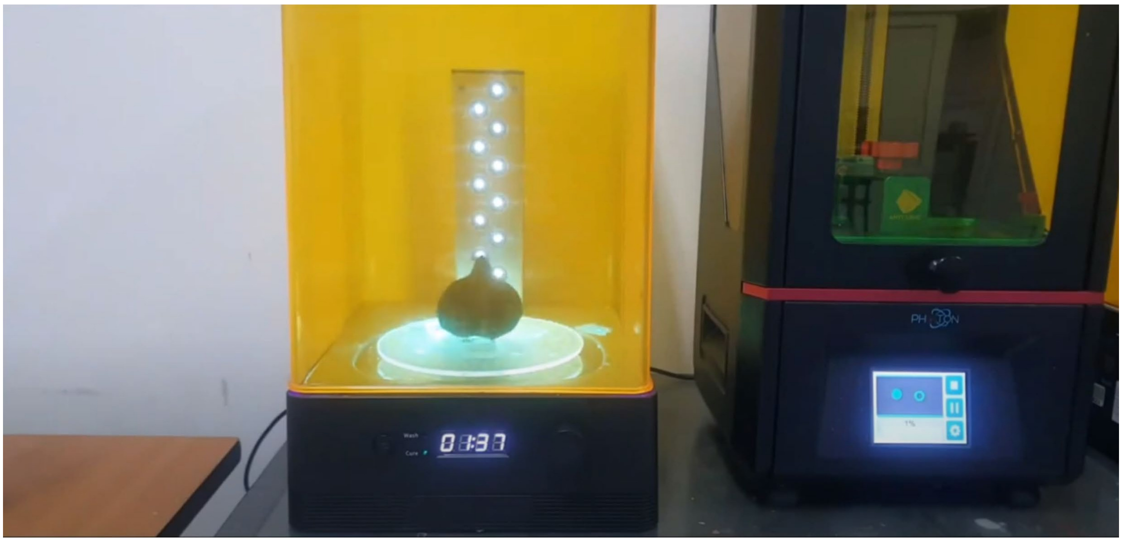

Figure 35. Webinar #3, SLA 3D printing – post processing – case 2

For the final case, two processes are shown: FDM and SLA 3D printing. The product is relatively simple, so for the FDM it was done really shortly. For the SLA, to show capabilities of supporting structures in SLA, it was printed at an angle, also – a different machine was used for the process. Again, whole process is demonstrated (Figure 36).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

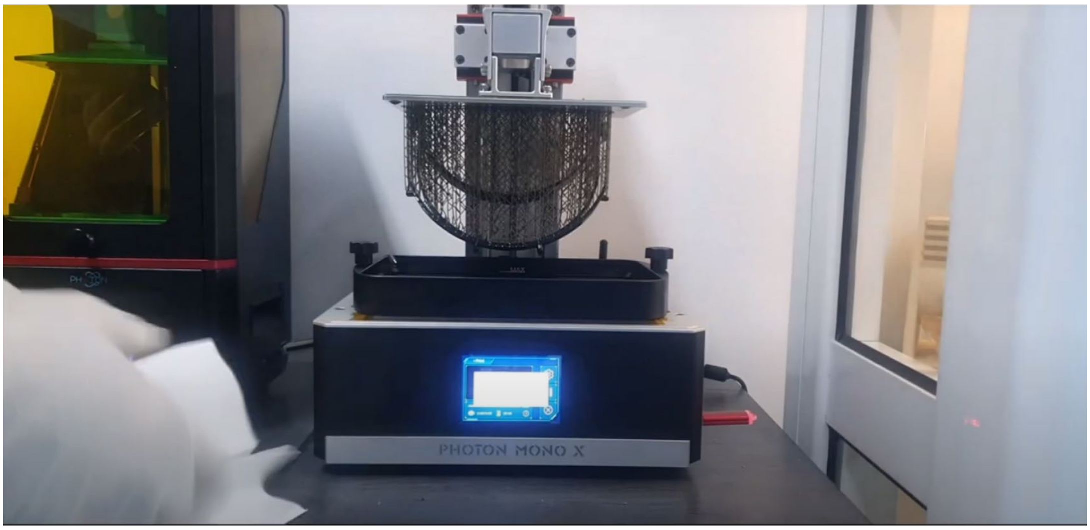

Figure 36. Webinar #3, SLA 3D printing – case 3

The case studies and technologies presented in the third webinar show great diversity and capabilities of current 3D printing technology. It was shown how a single product can be manufactured directly using various technologies – FDM, SLA, PolyJet – and also how 3D printing and casting can be combined to get products of controllable properties (notably, of soft materials), by using a technique of resin casting in FDM 3D printed molds, with aid of vacuum. The viewer can learn how this should be done using different types of technologies, also including the preparation of programs, as well as post processing, which makes for a full picture, very important from educational point of view.

3.3.4. Webinar 4 – Testing

The testing webinar finalizes the main part of the four originally planned webinars. It presents ready medical parts, subjected to various tests, using both destructive and non-destructive testing methods. This webinar can be viewed as a standalone movie, although it helps if the viewer knows what are the cases and what's the purpose of their manufacturing. This webinar is approximately 60 minutes in length. It is available directly on YouTube under the following link: https://www.youtube.com/watch?v=zzux7x11sjE

The webinar was assembled and managed by Universities of Nis and Pula, with many partial videos supported by Poznan University of Technology. General scenario with responsibilities is shown in Table 5.

Table 5. General scenario and responsibilities for the webinar #4 – testing

No.	Step (partial video)	Who?
1	Intro	UNI
2	Review of medical quality control standards	UNIPU
3	Review of testing methods	UNI
4	Case 1 – bending test	PUT
5	Case 1 – fitting with patient	PUT
6	Case 1 – 3D scanning	PUT
7	Case 2 – visual assessment & simulated surgery	PUT
8	Case 3 – various tests (tensile, accuracy, fitting)	UNI
9	Outro	UNI

The webinar starts with introduction done by team of University of Nis (Figure 37). Then, two topics are covered in form of a lecture. First, medical standards and quality control of medical parts is described (Figure 38) and then basic methods of mechanical testing are presented (Figure 39).

Figure 37. Webinar #4, introduction by team of UNI

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

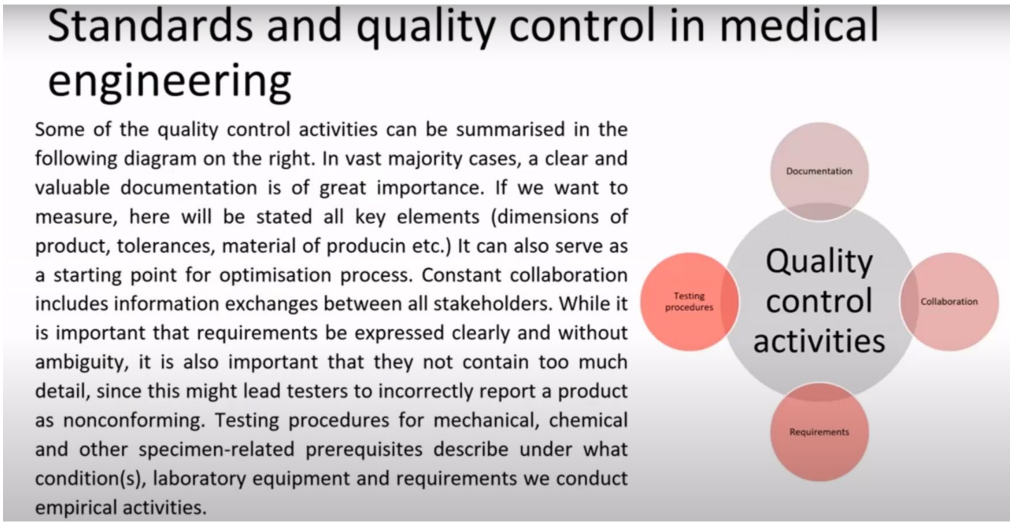

Figure 38. Webinar #4, review of medical standards

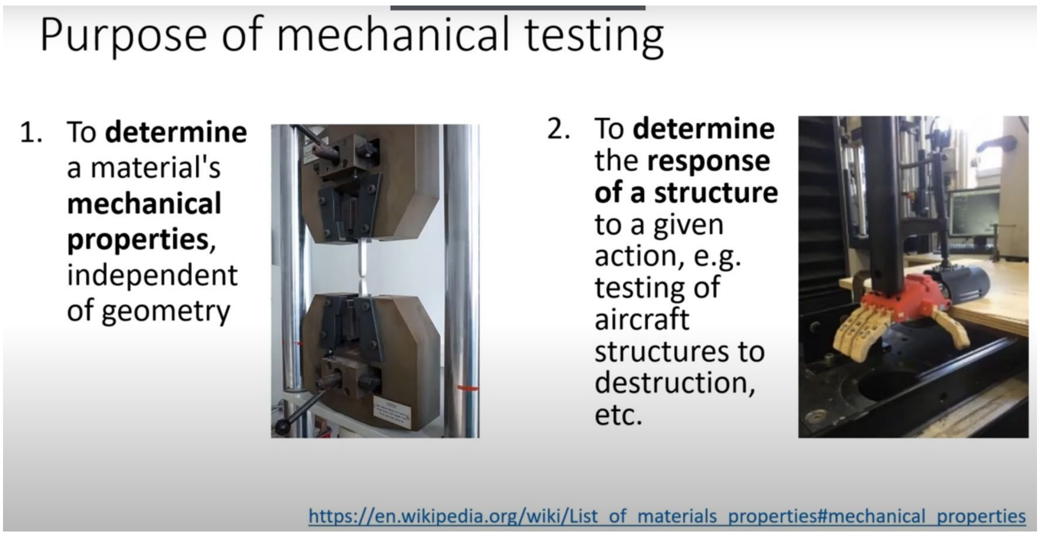

Figure 39. Webinar #4, review of testing methods

After the introductory part, specific tests are shown. For the case 1 (orthosis), the non-destructive part involves accuracy testing done with use of 3D scanning (Figure 40). In that part, both the 3D scanning process and the software part of quality control is presented. Also, fitting with patient is shown (Figure 41). In the destructive testing part, three-point bending test is shown (as simulated in CAE webinar) – Figure 42.

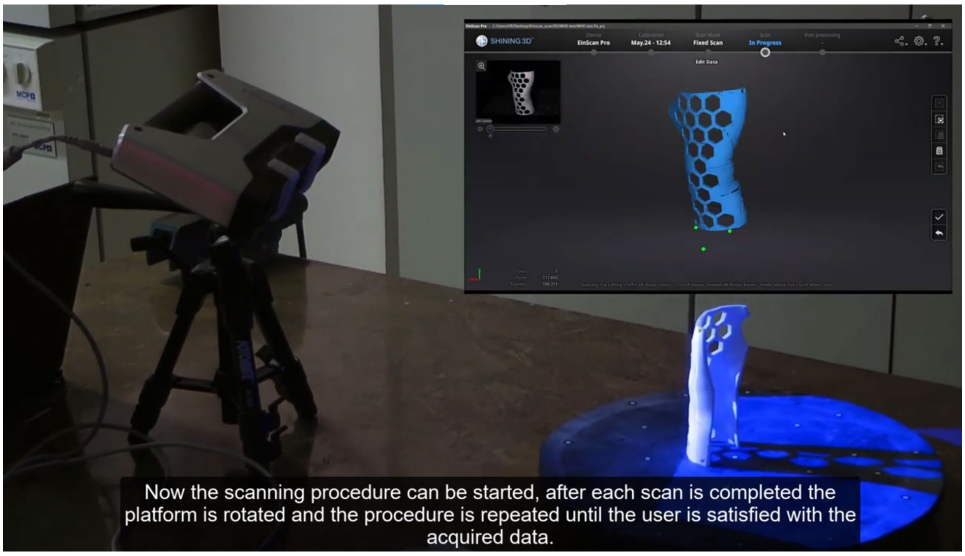

Figure 40. Webinar #4, case 1, 3D scanning for accuracy

Figure 41. Webinar #4, case 1, fitting with patient

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

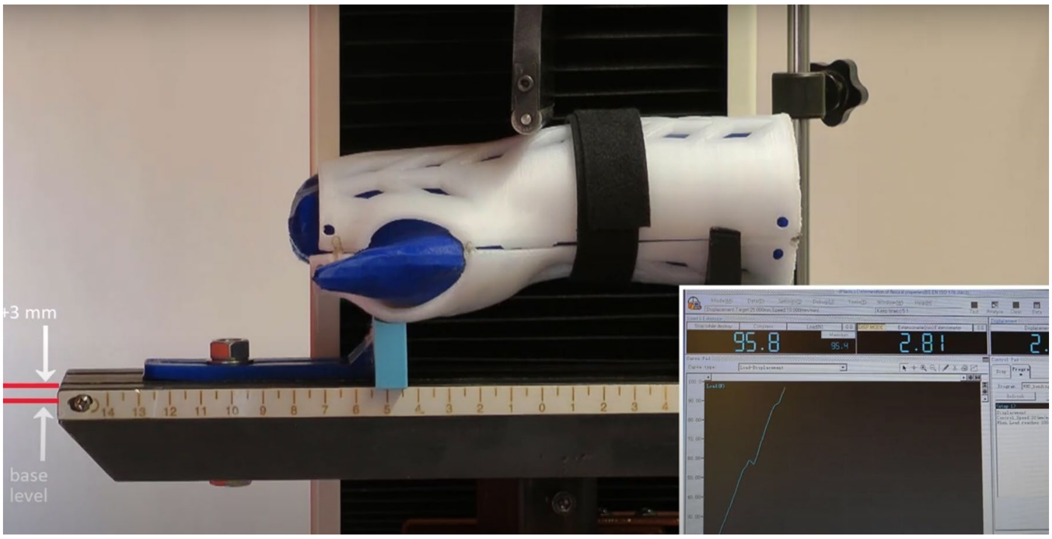

Figure 42. Webinar #4, case 1, three-point bending test

For the case study 2, the testing procedure is the shortest one. The tongue model is mostly a visual aid and also a simulated surgery model. As such, no strength tests are required, similarly no accuracy testing is needed – just a visual assessment. The simulated surgery process is shown in detail in the webinar (Figure 43).

Figure 43. Webinar #4, case 2, simulated surgery

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

In the last case study – face shield – a similar set of tests is performed as in the first case study. The destructive testing is presented (tensile test) in full detail (Figure 44). The non-destructive part comprises the 3D scanning (Figure 45) and fitting test (Figure 46).

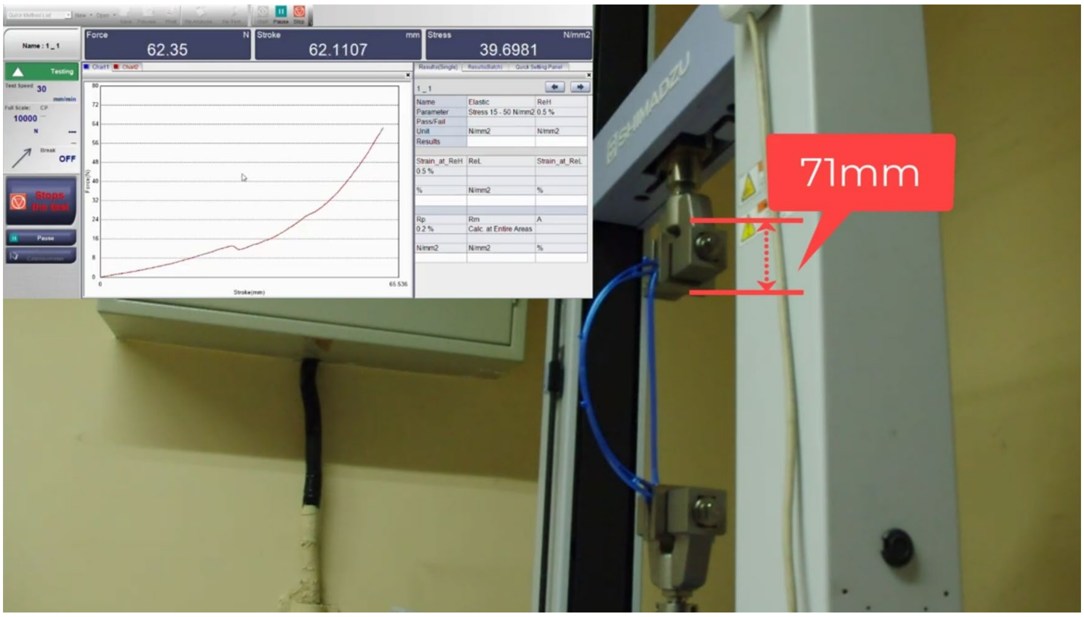

Figure 44. Webinar #4, case 3, tensile test

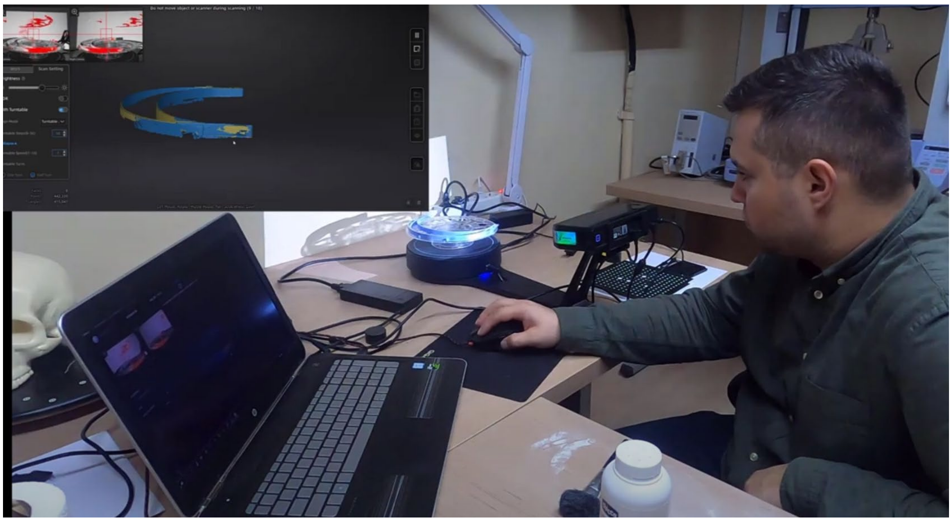

Figure 45. Webinar #4, case 3, 3D scanning for accuracy measurement

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Figure 46. Webinar #4, case 3, fit and functionality testing

The webinar is concluded by an outro done by team of University of Nis, summarizing all the cases. The selected range of destructive and non-destructive methods is diverse enough for the students to learn in great detail how the 3D printed medical parts should be subjected to testing prior to putting them for medical use. As such, educational value of this webinar is definitely very high, as the cases and their treatment are unique to the BRIGHT project.

3.3.5. Extra webinar 5 – Augmented Reality models

The fifth webinar was done extra – during the work on IO3 platform, methodology of creation of 3D models for viewing in browser or using Augmented Reality technology was created by one of the partners – the Bizzcom company. As such, Bizzcom developed a webinar presenting this methodology.

This webinar uses Blender software for body part object modelling and AR model animation. In this webinar, its viewers can learn how to use Blender's powerful features to create detailed and realistic models of body parts, including bones, organs, and tissues. They can also discover how to use Blender's object rotation feature to create stunning AR model animations that can be used for medical training, patient education, and more.

This webinar is shorter – approx.. 15 minutes. It is available through YouTube, via the following link: https://www.youtube.com/watch?v=4lR5oSyzMKY

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The webinar starts with very short company introduction (Figure 47) and review of the topic by company representatives. Then, methodology of preparation of 3D models is presented (Figure 48). The next stage is showing the work done in Blender, with preparing models, animating them and exporting for further use (Figure 49). Many different models are used of case studies in the BRIGHT project.

Figure 47. Webinar #5, company introduction

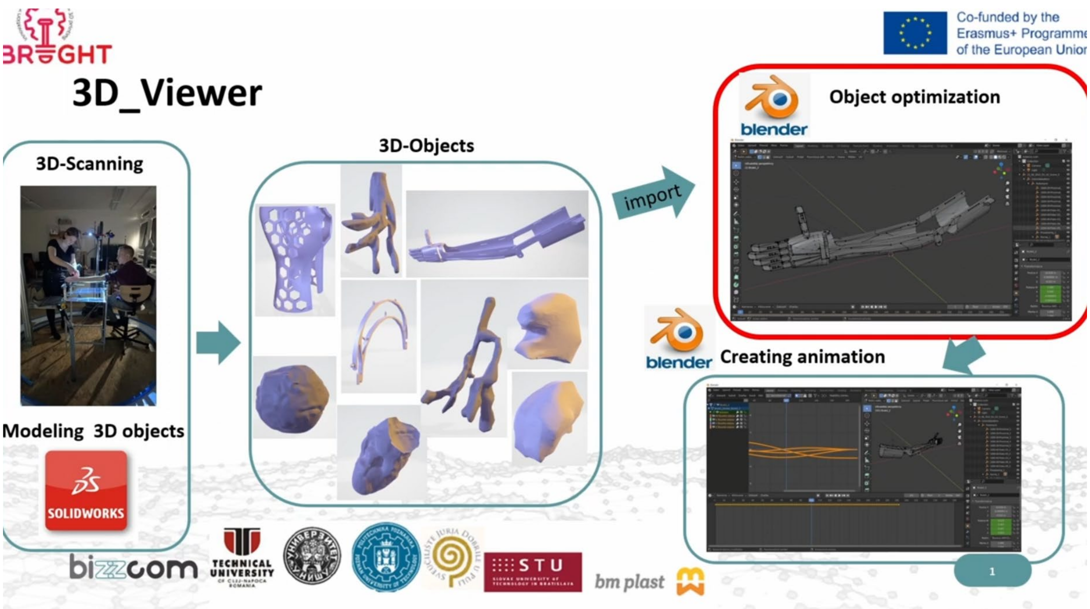

Figure 48. Webinar #5, methodology overview

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

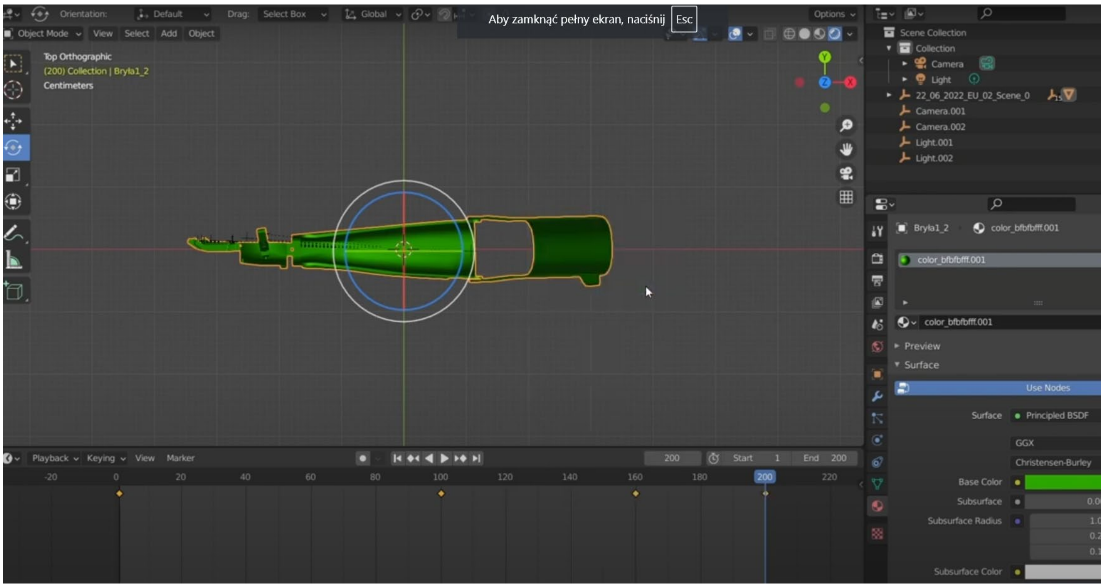

Figure 49. Webinar #5, model creation methodology

The next part of the webinar is the programming part – used tools and developer kits are presented and the code making is shown (Figure 50). In the final parts, the results of the work are shown, in form of models accessed from website and also viewed in Augmented Reality (Figure 51 and 52).

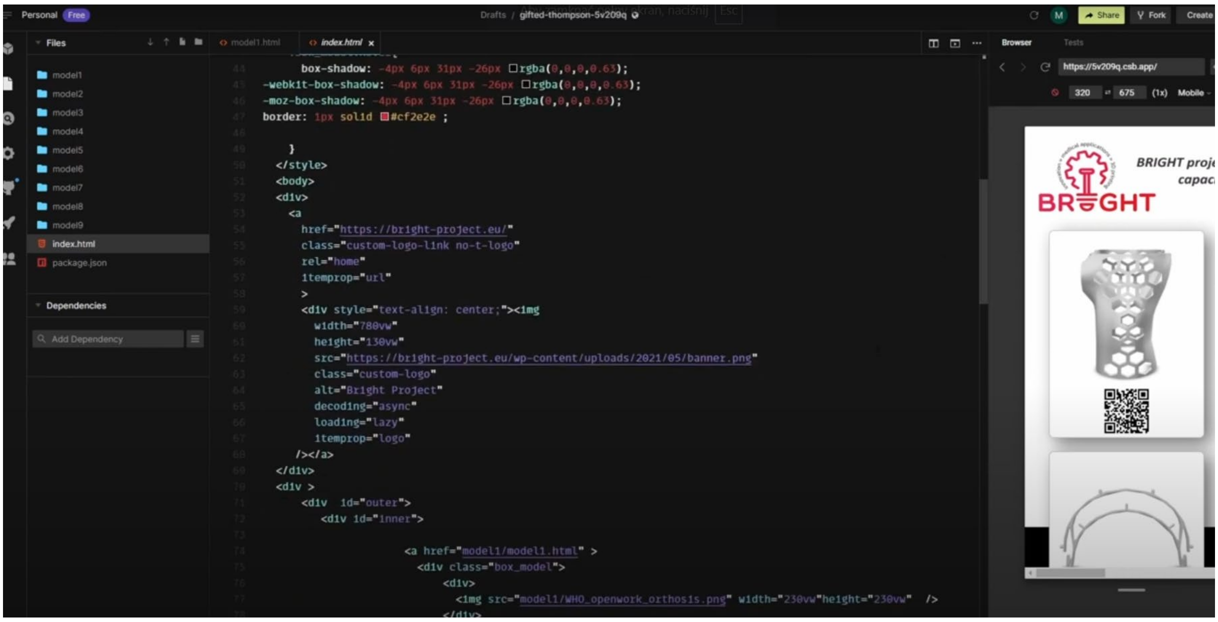

Figure 50. Webinar #5, coding the 3D viewer for web model view

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Figure 51. Webinar #5, Augmented Reality model view

Figure 52. Webinar #5, web interface for accessing the models

The extra webinar is a valuable addendum to the main track of webinars, presenting knowledge of how 3D models of printable medical parts should be prepared for visualization and animation, using widely available tools and also Augmented Reality technology.

4 Conclusions

The webinars prepared in the IO4 contain high amount of modern, innovative, practical knowledge regarding 3D printing of medical parts. The cases and methodologies are not standard and widely known, but rather very new and still largely in the development stages. As such, educational value of these webinars is extremely high. Its recipients can be students, but also professors, lecturers and practitioners who wish to implement 3D printing in their daily work with medical products. They are also very useful for any form of remote, distant learning and can be supplementing standard forms of teaching in relevant courses or subjects.

The webinars, as opposed to other forms of educational materials developed in the project, are of highly visual value. They would also be a very good tool in demonstration and communication of modern engineering capabilities to medical practitioners, showing specific examples and ways of their clinical use. The BRIGHT consortium partners hope that they will be used as a tool to convince more medical specialists to implement modern, digital technologies in healthcare.

The webinars were partially treated as a summary of practical effects developed in the project with all its partners. Three of total five case studies of the BRIGHT project are shown there in great detail. The webinars are currently being used as an educational tool in consortium partners' classes, especially for novice students to get familiarized with the techniques, before being involved in more advanced cases for their diploma projects or other work. The authors hope that these results could be also spread and beneficial for higher education institutions outside the consortium in the future.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.