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

O2 - BRIGHT e-toolkit manual REPORT

Project Title	**Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517**
Output	**O2 - BRIGHT e-toolkit manual**
Date of Delivery	**November 2021**
Authors	**Răzvan Păcurar**
Version	**FINAL**

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1 *Introduction, objectives and tasks of O2*

Aspects related to 3D printing technologies / working principles of these types of modern technologies are easy to be understood in theory, but very hard to be applied in practice. When it comes to practice, the way the parts are being designed and prepared to be printed differs from one product to another in accordance with the shape of the part to be printed out, the type of material, parameter settings, part orientation, type of method used for printing, etc. In this context, the BRIGHT toolkit manual which has been prepared by the BRIGHT consortium in relation with 3D printing technologies for producing specific parts (applications) made for the medical sector consisting in 6 laboratory toolkit modules have been related not just to the basics knowledge about 3D printing processes that could be used for certain application in close correlation to the CAD particularities of the parts and specific technology of 3D printing selected for the realizing of these applications, and also to the other preliminary steps that are required to be followed for pre-validation steps of the needed to be performed for the setup of the 3D printing equipment (pre-processing steps), setup of the 3D printing orienting and parameters specific that are used for 3D printing process itself and post-processing steps that are needed to be realized in the end.

The toolkit laboratory modules that have been comprising the e-toolkit manual that has been realized in the frame of O2 were shared and are available on the BRIGHT project website to be accessed in open access mode or to be downloaded as they can be found on the following link: https://bright-project.eu/?p=254 (see Figure 1).

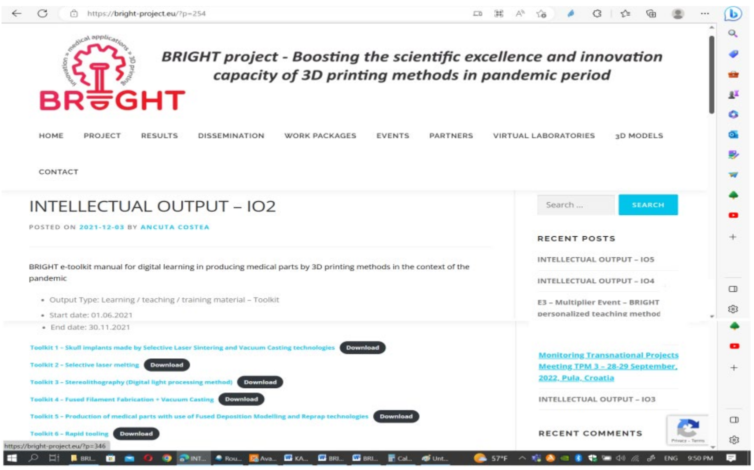

Figure 1. BRIGHT toolkit laboratory modules shared on the BRIGHT project website, available to be "freely" accessed in open access mode and to be downloaded

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Examples provided in the toolkit laboratory modules have been selected in concordance with the existing infrastructure, logistics and 3D printing equipment items (3D printing technological methods) that are available within different Higher institutions of BRIGHT consortium in close correlation to the type of applications (parts) on which the BRIGHT consortium partners have been working on for medical case studies / specific patients.

Therefore, first toolkit module has been related to the realizing of skull implants that were made at Technical University of Cluj-Napoca using the Selective Laser Sintering (SLS) 3D printing technology and Rapid Tooling (Vacuum Casting) technologies for producing real implants of the patients that were surgically operated on Medical Clinics in Cluj-Napoca.

2nd toolkit module is oriented on a second case study that has been realized at TUCN for manufacturing of a customized facial implant that was used to reconstruct the supraorbital margin and zygomatic bone, this part being produced by using the Selective Laser Melting (SLM) 3D printing technology.

3rd toolkit module has been realized by the University of Nis (Serbia) partner, being focused on the realizing of one medical fixator that has been produced using the Stereolitography (SLA) 3D printing process.

4th toolkit module has been realized by Poznan University Technology (PUT) partner in Poznan in collaboration with BM Plast company of Opatija (Croatia), being focused on the realizing of mid-surgery supplies in otolaryngology using Fused Filament Fabrication 3D printing technology and Rapid Tooling (Vacuum Casting)

The 5th toolkit module that has been related to the producing of an orthosis made by Fused Deposition Modelling 3D printing and Reprap technologies has been produced by PUT partner in collaboration with Juraj Dobrila University of Pula (Croatia).

Last, but not least the 6th toolkit module that was focused on the realizing of an orthosis reinforcement aimed to replace metallic components with resin ones has been realized jointly by STU Trnava and BIZZCOM partners, using casting of different types of resins into silicone rubber molds that have been produced by Rapid Tooling (Vacuum casting) technology.

Since TUCN has high experience and expertise in the field of 3D printing technologies used for testing new materials/developing of products in the medical sector in cooperation with scientists and doctors from the medical institutes (Oncological institute, Maxilla-Skull reconstruction clinic, University of Medicine and Pharmacy) from Cluj-Napoca in the last 25 years, the research contributing to the saving of lives of more than 200 patients using 3D printing technologies (professors from TUCN got the Romanian academy prize in 2017 - https://research.utcluj.ro/index.php/premii-ale-academiei-romane-2017-308.html) TUCN has been assigned as responsible leading partner in O2 in coordinating the activities related to the BRIGHT toolkit manual provided as teaching materials to professors & students.

2. Requirements according to target groups

As stated in the previous chapter, the target groups to whom the toolkit laboratory manual comprising 6 toolkit laboratory modules is being addressed are comprised mainly to the following categories of target groups, represented by:

- the professors which have been requested to produce teaching materials and methods in relation with the course modules that have been realized within O1, through which theoretical knowledge that has been gained following the course modules can be actively applied in the case of concrete 3D printing technology methods that can be used for the realizing of specific medical applications that can be realized by 3D printing technologies to support patients in the time of pandemic.
- Students that are interested in getting a much better understanding on the tools and methods that can be used further on as good practice examples in getting the right skills on a very practical level in the field of 3D printing methods, so as they be able to be engaged in developing, testing and producing of medical parts by 3D printing technologies for supporting medical institutions (hospitals) in the context of the pandemic.
- SMEs that are using 3D printing technologies and Rapid Tooling methods (like Vacuum casting) for developing, testing new materials and producing of medical parts by 3D printing technologies for supporting medical institutions (hospitals) in the context of the pandemic. They have represented the main stakeholders that have been invited to take part on the Multiplier Event that has been organized in Poznan in February 2022, event through which the main results reached within O2 have been disseminated. Due to pandemic the event has been organized online as one may notice on the following link: https://bright-project.eu/?p=240. During the Multiplier event organized, new potential case studies that can be developed, produced &

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tested for medical sector within the BRIGHT project has been identified together with 29 participants that have attended to this event, many of these companies (like Omni 3D) providing support further on to professors and students who have been working on case studies made by 3D printing technologies to support hospitals in time of pandemic

- Medical institutions / patients (as potential end-users) represent the last category of targeted group in this case. During the Multiplier Event organized in Poznan one of the main aim was to disseminate the results reached in the frame of O2 with medical doctors to emphasize them / to familiarize them with the potential of using 3D printing technologies and Rapid Tooling methods (like Vacuum casting) in sorting out different medical case studies with real benefit for the patients, as well as to get them familiarized with the complexity of different types of 3D printing methods in terms of pre-setup, manufacturing and post-processing steps that are required to be followed in each case of presented methods.

3. BRIGHT toolkit laboratory modules

As it was mentioned before in the previous chapters, 6 toolkit laboratory modules that are constituting the e-laboratory toolkit manual have been prepared by the BRIGHT project consortium, presenting the pre-processing steps, manufacturing procedure with specific particularity of 3D printing method presented and post-processing steps for realizing specific medical case studies (applications) that have been used for supporting real patients in time of pandemic.

3.1. BRIGHT toolkit laboratory module 1 – Skull implants made by Selective laser sintering and Vacuum casting technologies

First toolkit laboratory module that has been produced by TUCN partner of BRIGHT consortium is related to the producing of skull implants made by Selective laser sintering and Vacuum casting technologies (see Figure 2) that is available to be accessed and downloaded for free on the next following address on the BRIGHT project website:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_1.pdf

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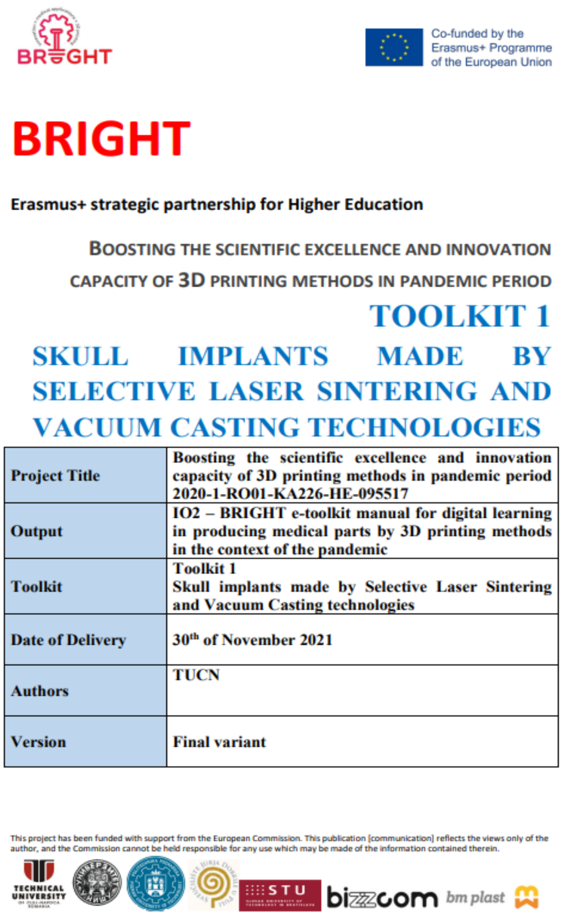
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TOOLKIT 1

SKULL IMPLANTS MADE BY SELECTIVE LASER SINTERING AND VACUUM CASTING TECHNOLOGIES

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 1 Skull implants made by Selective Laser Sintering and Vacuum Casting technologies
Date of Delivery	30th of November 2021
Authors	TUCN
Version	Final variant

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Figure 2. Selective laser sintering and Vacuum casting technologies toolkit laboratory module realized by the TUCN partner

As images presented in Figure 3 suggests within the provided toolkit laboratory manual there are presented the main steps that are required in the case when a skull implant needs to be realized for a patient that has been suffering from a car accident, starting from the CT images, that are being imported in specific design programs for CAD realizing of the model (skull reconstruction) and continuing with the realizing of the master model (model of the skull and necessary for the reconstruction) and continuing with the use of this master model for realizing of a pair of silicone rubber molds made by Rapid Tooling technology (e.g. Vacuum Casting), the pair of realized molds being further on used for producing of real implant made of PMMA material by Vacuum Casting.

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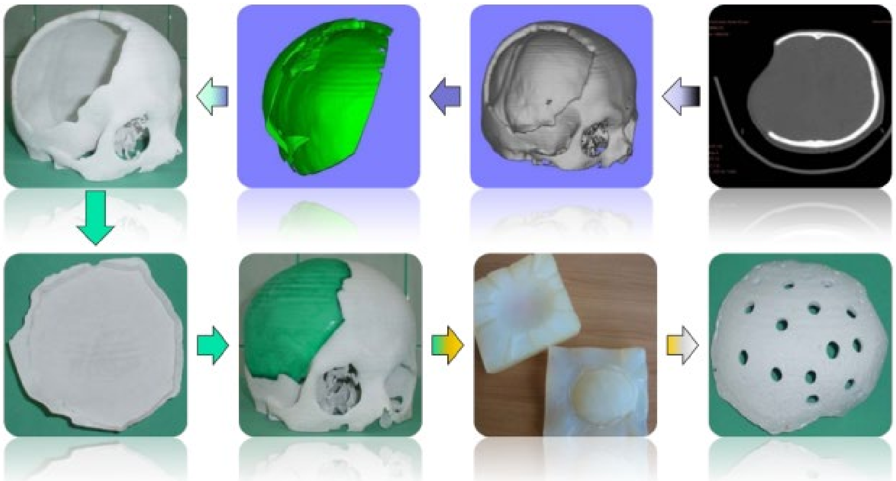

Figure. 3. Required steps for obtaining a customized implant by Selective Laser Sintering and Vacuum Casting technologies

3.2. BRIGHT toolkit laboratory module 2 – Designing and manufacturing of customized facial implant used to reconstruct the supraorbital margin and zygomatic bone by SLM

The 2nd toolkit laboratory module has been produced in the same manner by TUCN partner of BRIGHT consortium like the first one, but being focused in this case to the producing of customized facial implant used to reconstruct the supraorbital margin and zygomatic bone by using the Selective Laser Melting technology that is available at TUCN (see Figure 4), this toolkit laboratory module being available to be accessed and downloaded for free on the next following address on the BRIGHT project website:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_2.pdf

Within the realized toolkit laboratory module there are presented in very detailed way for one specific implants the pre-processing steps that were required to be followed in the preamble before the part has been designed and prepared for being realized by Selective Laser Melting 3D printing technology. Important aspects that have been considered regarding the CT reconstruction of the implant, as well as the CAD important steps and particularities that were necessary to be considered in close correlation with the type of 3D printing to be used and specific constraints imposed by this type of technology have been presented in detail within the realized toolkit laboratory module (see Figure 5).

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TOOLKIT 2

DESIGN AND SLM MANUFACTURING OF CUSTOM FACIAL IMPLANT USED TO RECONSTRUCT THE SUPRAORBITAL MARGIN AND ZYGOMATIC BONE.

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 2 Selective laser melting
Date of Delivery	November 2021
Authors	Cosmin COSMA, Petru BERCE, Nicolae Balc
Version	Final variant

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Figure 4. Producing of customized facial implant used to reconstruct the supraorbital margin and zygomatic bone by using the Selective Laser Melting technology by TUCN partner

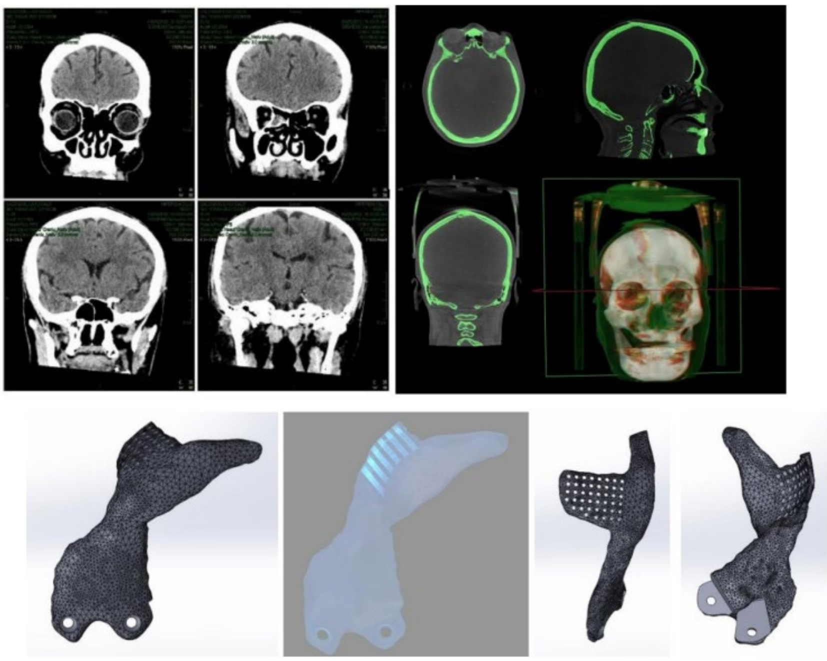

Figure 5. CT reconstruction and 3D model of the realized implant

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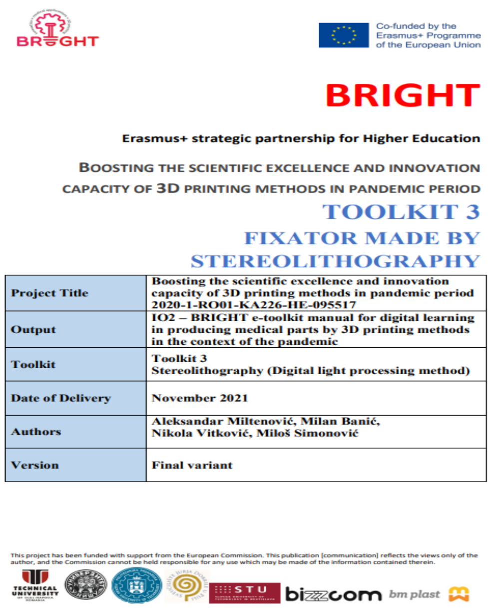
In continuing of the toolkit laboratory module are provided in a very detailed way all the pre-processing steps that have been considering for producing the implant shown in Figure 5 made of titanium material by Selective Laser Melting using MCP Realizer 250 equipment that is available at the Technical University of Cluj-Napoca (TUCN, Romania). Last, but not least are provided important details regarding the setup of the SLM machine for 3D printing of the part in close correlation with the necessary technological parameters, important details about simulating of the SLM process and real process of SLM in producing the customized implant, ending with post-processing steps for removing supports and finishing of the implant.

3.3. BRIGHT toolkit laboratory module 3 – Medical fixator realized by Stereolitography (SLA) process

The 3rd toolkit laboratory module was focused on the producing of a medical fixator (See Figure 6) by Stereolitography process (Digital Light Processing 3D printing method) in particular, part that was realized for one patient at University of Nis (Serbia), the realized toolkit laboratory module being available to be accessed and downloaded for free like the previous one on the next following address on the BRIGHT project website:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_3.pdf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TOOLKIT 3

FIXATOR MADE BY STEREOLITHOGRAPHY

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 3 Stereolithography (Digital light processing method)
Date of Delivery	November 2021
Authors	Aleksandar Miltenović, Milan Banić, Nikola Vitković, Miloš Simonović
Version	Final variant

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Figure 6. Medical fixator made by Stereolitography (SLA) by Univ. of Nis (Serbia) partner

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Within the realized toolkit laboratory module, there are provided in the beginning important details on how 3D model realized using Autodesk Inventor program must be prepared in particularized and specific way considering the type of 3D printing technological method that has been selected and consider as being proper for producing of such type of medical model. In continuing there are presented the important technological aspects and parameters that have to be considered taking into account the type of 3D printing equipment that has been used for printing the medical model, including important hints for the pre-processing step in selecting the proper types of supports for sustaining the part during the 3D printing process. Last, but not least are provided details about the 3D printing process itself and post-processing steps that are needed for removing the supports and finishing operations of the medical model during post-processing stage (see Figure 7).

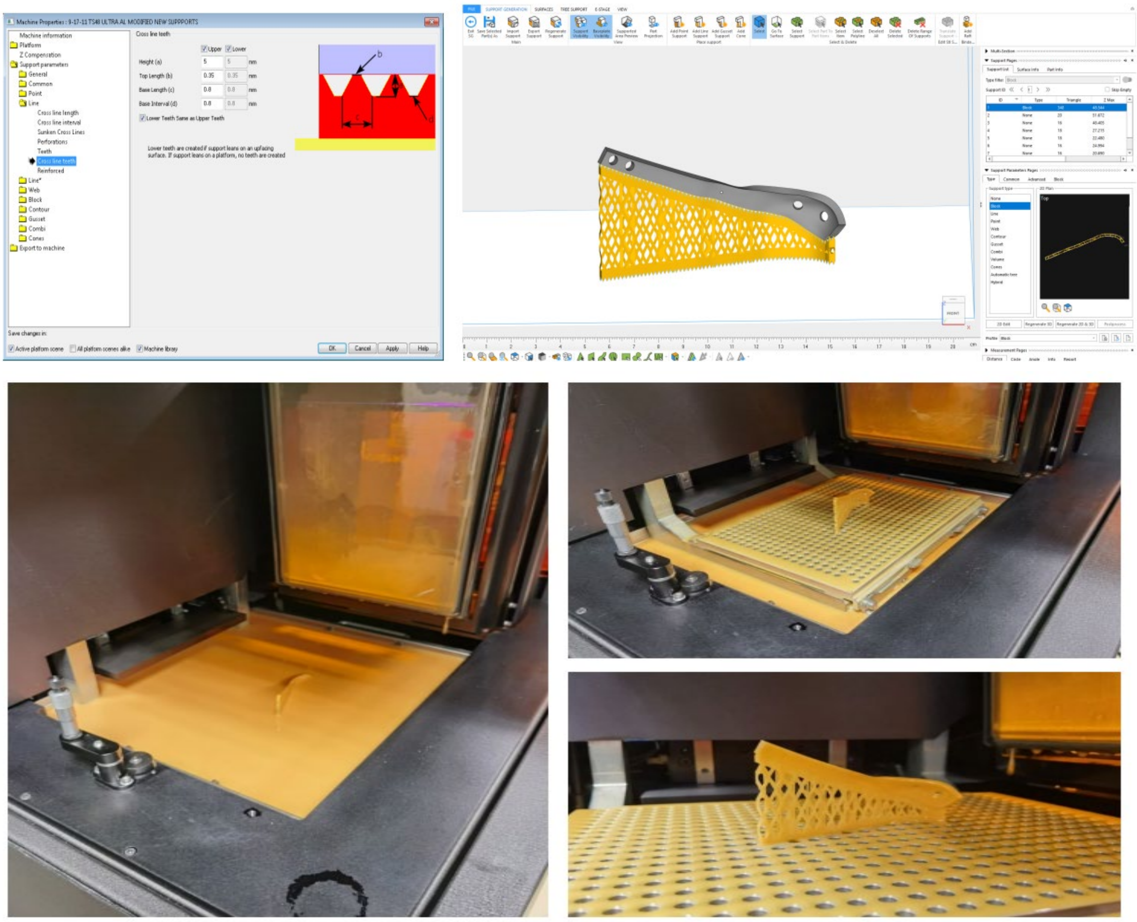

Figure 7. Selecting of proper supports and 3D printing process of medical model

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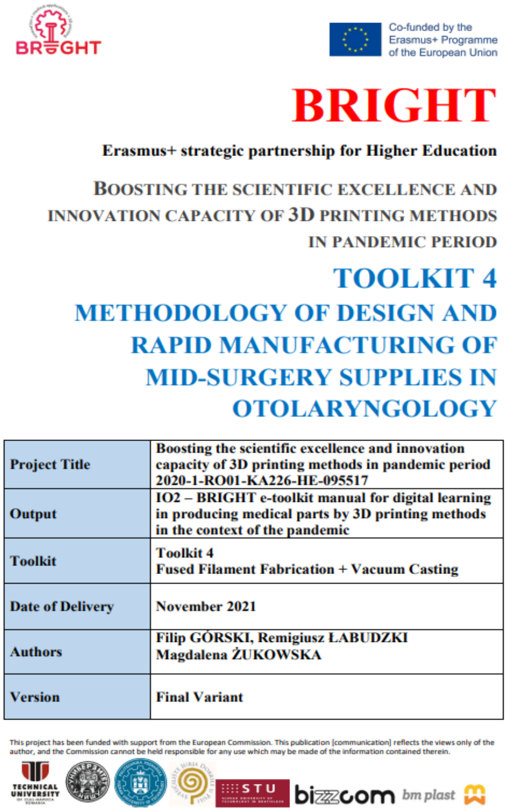
3.4. BRIGHT toolkit laboratory module 4 – realizing of mid-surgery supplies in otolaryngology using Fused Filament Fabrication and Vacuum Casting

The 4th toolkit laboratory module has been realized by PUT partner in collaboration with BM Plast company of Opatija (Croatia). The toolkit module has been oriented on realizing of mid-surgery supplies in otolaryngology (Figure 8) using Fused Filament Fabrication and Vacuum Casting technologies that have been used by PUT (Poland) in producing this part by 3D printing, while BM Plast (Croatia) has provided perspectives, particularities and hints in using injection moulding process for producing this type of parts by conventional technologies. Details about toolkit laboratory module number 4 are available and can be downloaded for free on the next following address on the BRIGHT project website:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_4.pdf



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TOOLKIT 4

METHODOLOGY OF DESIGN AND RAPID MANUFACTURING OF MID-SURGERY SUPPLIES IN OTOLARYNGOLOGY

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 4 Fused Filament Fabrication + Vacuum Casting
Date of Delivery	November 2021
Authors	Filip GÓRSKI, Remigiusz ŁABUDZKI Magdalena ŻUKOWSKA
Version	Final Variant

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Figure 8. Mid-surgery supplies in otolaryngology made using Fused Filament Fabrication and Vacuum Casting by PUT (Poland) and B.M. Plast (Croatia) partners

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Medical case study that is considered for the analysis was oriented on otolaryngology. Otolaryngology is one of the branches of medicine dealing with the diagnosis and treatment of disease problems arising within the head and neck. This range also includes ailments related to the tongue and salivary glands. Medical case study presented in this laboratory toolkit module has been related to a specific case of one patient with cancer of the tongue, this being one of the most common malignancies in the oral cavity. Therefore for this specific medical case, there were provided for the beginning most important pre-processing steps that have been considered in terms of CT / MRI / 3D printing in pre-operative planning for the surgery, in the rest of the toolkit laboratory module being provided very important steps that have been taken into consideration / that have been particularized in relation with the patient needs / design methodology that has been considered in close correlation with the type of manufacturing technologies that have been considered for this case, namely Fused Filament Fabrication 3D printing technology and Rapid Tooling (Vacuum Casting) method (see Figure 9).

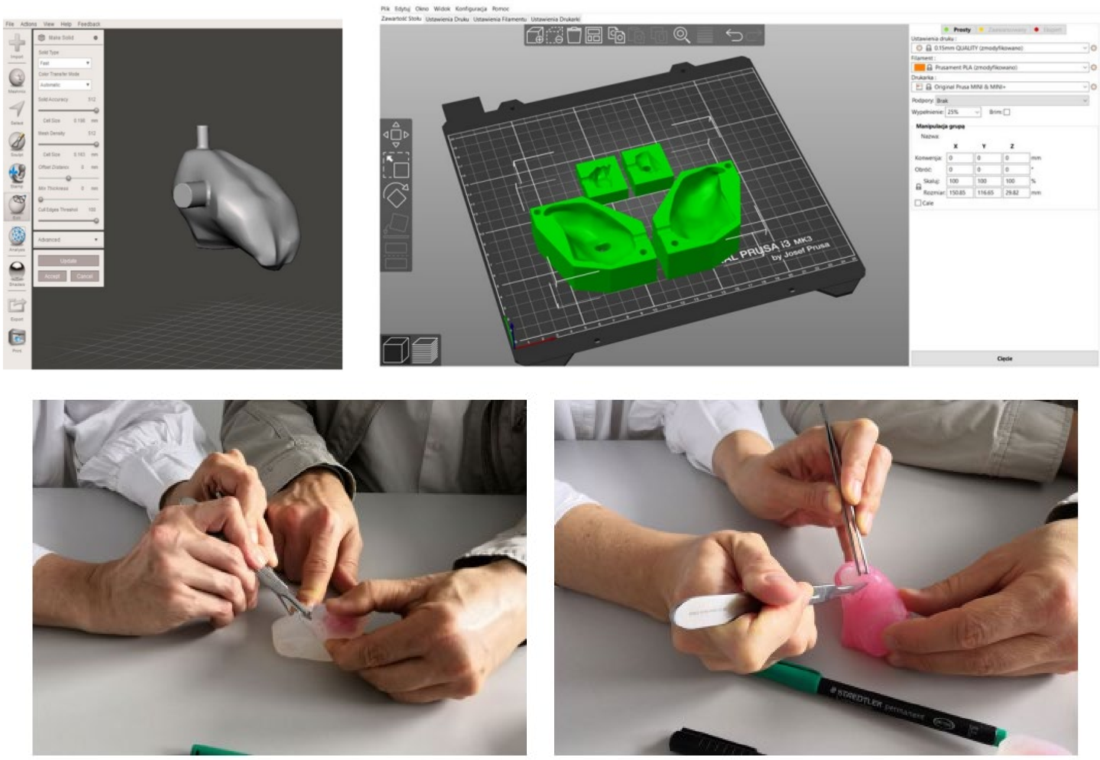

Figure 9. Designing steps of the part and the mold realized at PUT for producing the tongue model together with its colored tumor using Fused Filament Fabrication and Vacuum Casting

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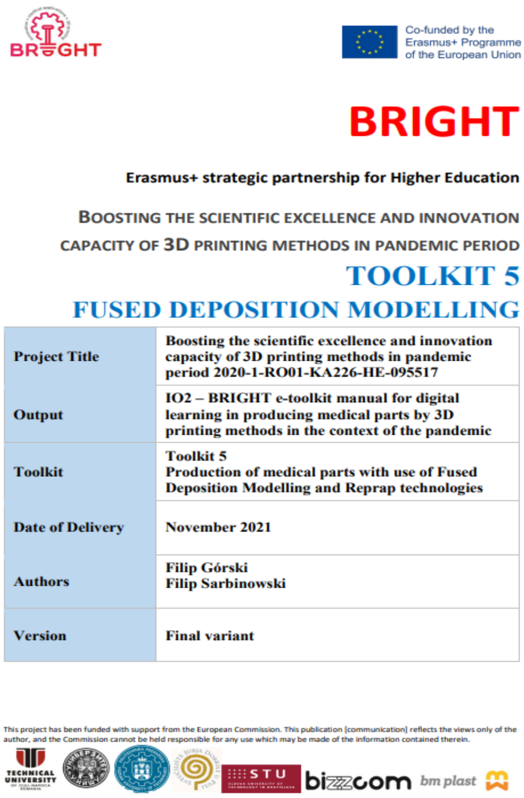
3.5. BRIGHT toolkit laboratory module 5 – orthosis made by Fused Deposition Modelling and Reprap technologies

Producing of an orthosis (Figure 10) made by using Fused Deposition Modelling and Reprap 3D printing technologies have been jointly realized and presented by PUT (Poland) and Juraj Dobrila University of Pula (Croatia) partners within the 5th toolkit laboratory module that has been conceived and shared "freely" and with "open access" mode on the BRIGHT project website on the following address:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_5.pdf



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TOOLKIT 5

FUSED DEPOSITION MODELLING

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 5 Production of medical parts with use of Fused Deposition Modelling and Reprap technologies
Date of Delivery	November 2021
Authors	Filip Górski Filip Sarbinowski
Version	Final variant

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Figure 10. Orthosis made using Fused Deposition Modelling and Reprap 3D printing technologies by PUT (Poland) and Juraj Dobrila of Pula (Croatia) partners

Within this laboratory toolkit module there are presented pre-processing steps that have been considered in this case when one type of orthosis has been necessary to be realized for a patient in time of pandemic, starting from the 3D scanning process of the broken arm of the patient and continuing with the mesh cleaning process that has been realized in the CAD stage, as well as the continuing with all the other steps that have been done in CAD for realizing the orthosis shell in the end. Rest of the designing process which was focused on openwork parametric and designing steps needed for the manifold connections of the orthosis are also being provided along with the realized setup for the 3D printing process that has been realized using Fused Deposition Modelling and Reprap 3D printing technologies from two types of plastic materials, such as Nylon and PLA (see Figure 11)

Figure 11. Designing and 3D printing process of orthosis made by FDM and Reprap 3D printing technologies from Nylon and ABS material

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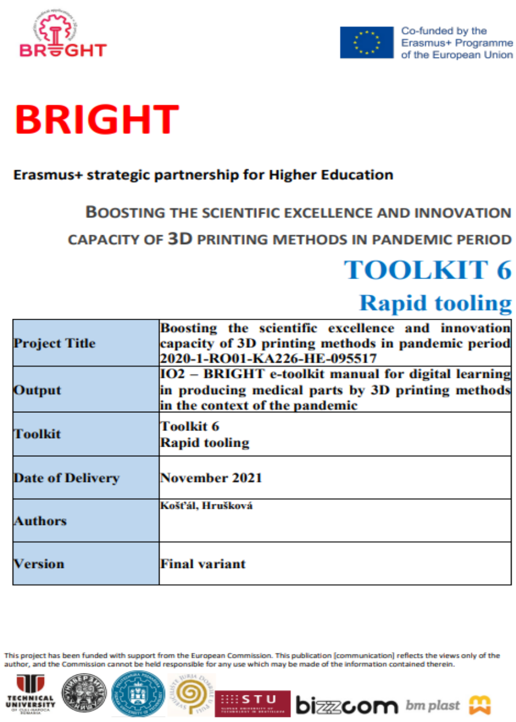
3.6. BRIGHT toolkit laboratory module 6 – orthosis reinforcement realized by Rapid Tooling

Last toolkit laboratory manual which was related to the producing of an orthosis reinforcement (Figure 12) (initially produced by metallic material) to be replaced with the one produced from resin materials using silicone rubber moulds produced by Rapid Tooling (Vacuum Casting) method has been realized jointly by STU Trnava and Bizzcom partners of Slovakia.

The realized toolkit laboratory manual has been shared and distributed “freely” and with “open access” on the website of the BRIGHT project, being available to be downloaded on he next following address:

https://bright-project.eu/wp-content/uploads/2022/04/BRIGHT_Toolkit-manual_6.pdf



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

TOOLKIT 6

Rapid tooling

Project Title	Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517
Output	IO2 – BRIGHT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic
Toolkit	Toolkit 6 Rapid tooling
Date of Delivery	November 2021
Authors	Košťál, Hrušková
Version	Final variant

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Figure 12. Orthosis reinforcement made using Rapid Tooling method by STU Trnava and Bizzcom (Slovakia) partners

In this sense, the main focus of the toolkit laboratory module has been oriented on the necessary steps that have been considered in the CAD / designing process for preparing of

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the silicone molding, the second part of the toolkit laboratory module being oriented on the practical experiments that were realized using a pair of molds that have been produced by vacuum casting and were finally used for producing of orthosis reinforcement made of two types of resins which have been finally tested. The NX software from Siemens has been used for designing the 3D models of the orthosis reinforcement, plexiglass plates being used for the producing of the silicone rubber molds that were made by Vacuum casting technology, these molds being finally used for producing of real parts made of two types of resins by Vacuum casting, one of these resins proving to be proper to be used in this process, without defective air bubbles that have remained trapped within the structure of the part in the first case of resin that has been tested (Figure 13).

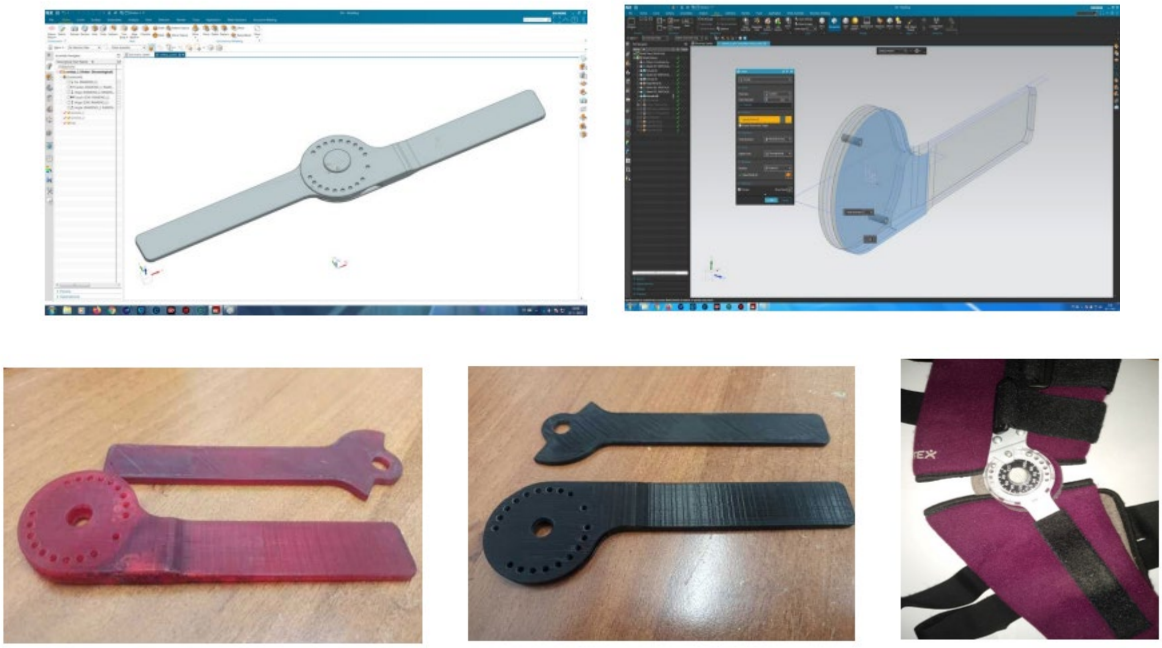

Figure 13. CAD and manufacturing process of the orthosis reinforcement made using Rapid Tooling method

4. Conclusions

As it was mentioned in the introductive chapter, the BRIGHT toolkit manual which has been prepared by the BRIGHT consortium in relation with 3D printing technologies for producing specific parts (applications) made for the medical sector consisting in 6 laboratory toolkit modules have been related not just to the basics knowledge about 3D printing

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processes that could be used for certain application in close correlation to the CAD particularities of the parts and specific technology of 3D printing selected for the realizing of these applications, and also to the other preliminary steps that are required to be followed for pre-validation steps of the needed to be performed for the setup of the 3D printing equipment (pre-processing steps), setup of the 3D printing orienting and parameters specific that are used for 3D printing process itself and post-processing steps that are needed to be realized in the end. Results that were reached within O2 about toolkit manual have been disseminated at the Multiplier Event that has been organized Poznan University of Technology (Poland) in February 2022, the realized toolkit laboratory modules being used in continuing by the professors which have been requested to produce teaching materials and methods in relation with the course modules that have been realized within O1, through which theoretical knowledge that has been gained following the course modules have been actively applied in the case of concrete 3D printing technology methods that can be used for the realizing of specific medical applications that can be realized by 3D printing technologies to support patients in the time of pandemic and also by the students that were interested in getting a much better understanding on the tools and methods that can be used further on as good practice examples in getting the right skills on a very practical level in the field of 3D printing methods, so as they be able to be engaged in developing, testing and producing of medical parts by 3D printing technologies for supporting medical institutions (hospitals) in the context of the pandemic. During the organized Multiplier Event in Poznan, important stakeholders (SMEs) have been attracted to sustain further on the activities that have been developed within the BRIGHT project, by identifying important case studies that were able to be developed and realized by 3D printing technologies to support hospitals in time of pandemic. Medical institutions have been also attracted through the organized Multiplier Event that was organized with the main aim of disseminating the results reached by the BRIGHT consortium within O2, medical representatives being able to comprise much better in this way the real benefit that 3D printing and Rapid Tooling technologies can bring for their patients in different specific issues related to the medical case studies that can be realized using these types of manufacturing methods. Results reached in terms of laboratory toolkit modules realized for the toolkit manual within O2 have been further on used and integrated within the virtual laboratory platform that has been realized by the BRIGHT consortium in the frame of O3 in the end.

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