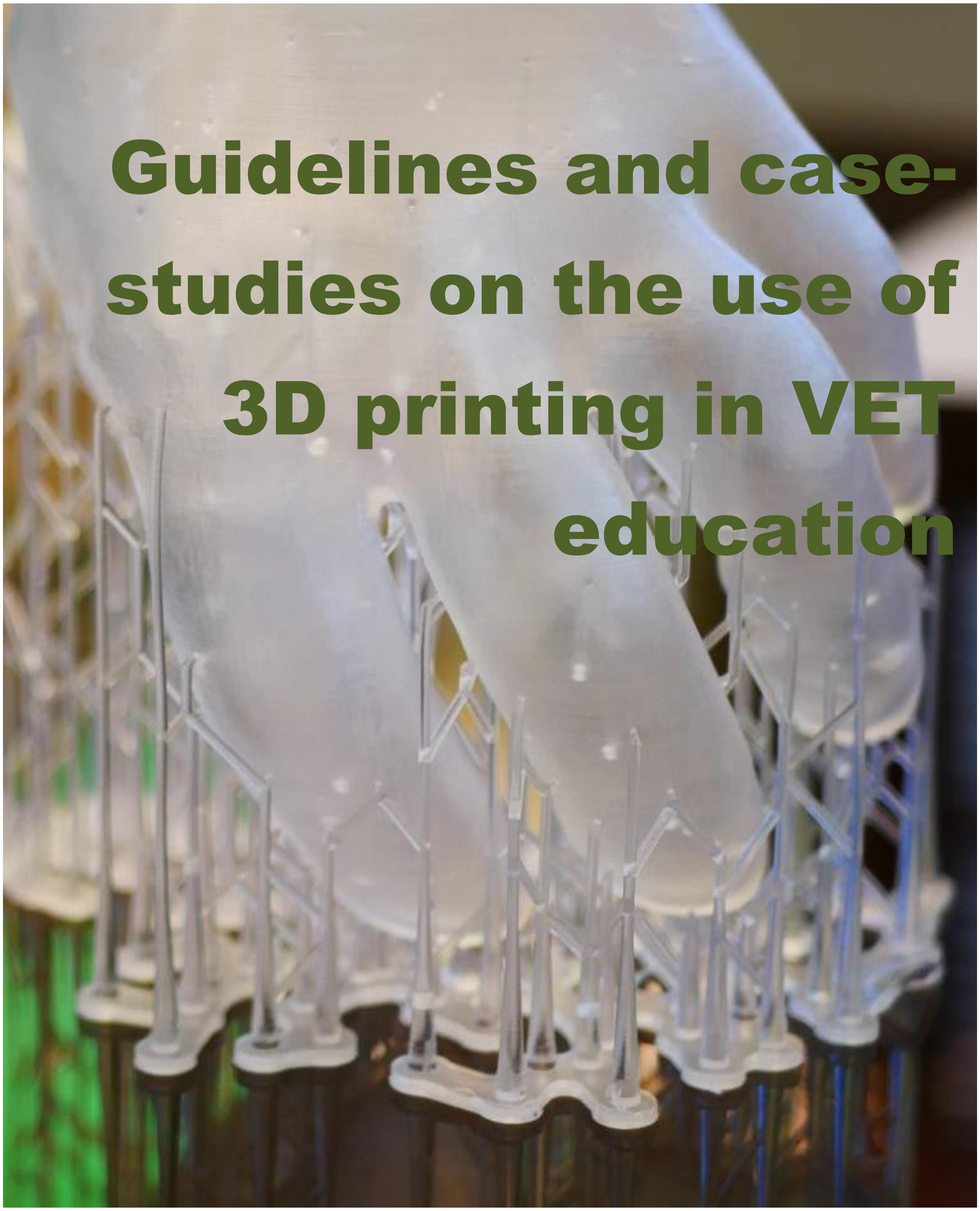
Guidelines and case-studies on the use of 3D printing in VET education



www.3d-p.eu/

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1.0 Background

The 3D printing (3DP) technology market is expanding rapidly. According to the new *Worldwide Semiannual 3D Printing Spending Guide from International Data Corporation* (IDC), the expenditure on 3D-P technology in Western Europe will grow from "nearly $2.6 billion in 2015 to $7.2 billion in 2019"[1]. Such development and investment brings along the creation of new jobs and requires specific knowledge and skills in various areas related to 3DP. Despite this, Vocational Education Training (VET) programs have some gaps in the provision of such specialized skills. Within this context, the overall goal of this project is to strengthen VET curricula with 3DP technology related learning material. More specifically this project is primarily concerned with:

- generating innovative curricula and;
- developing course content which is translated into e-learning material.

It is aimed that the resulting project deliverables will equip vocational students (aged 15 years and older) with specific skills related to ICT, engineering and technology which are free and accessible for everyone.

Before developing such resources, it is of paramount importance that the consortium understands well what the training needs are. To this end, this report aims at reviewing 3DP related training needs in VET. This shall help the consortium partners to streamline their common view on the subject matter.

Based upon this introduction, the rest of the report is organised as follows. Section 2 focuses on the expected innovative characteristics of the training programme. Section 3 identifies the critical implementation actions required by the consortium to develop an innovative training programme, whilst Section 4 lists a number of stakeholders who are required to be involved. Section 5 draws guidelines on the use of 3D Printing for VET education, based on the outcomes of the previous sections. Section 6 provides a number of case studies which will be used to educate vocational students. Finally, Section 7 draws key conclusions and suggests future work.

2.0 Expected Innovative Characteristics of the Training Programme

Based on the project proposal, when compiling the training programme, the consortium has to take into account a number of innovative characteristics, such that the programme distinguishes itself from similar programmes resulting from other projects. This can be accomplished by analysing existing training/curricula programs and proposing more efficient approaches focused on both theoretical and practical knowledge for the different categories which form the project target group. In particular, the programme should:

- be innovative in terms of curriculum content;

[1] https://www.idc.com/getdoc.jsp?containerId=prEMEA40991016

- develop skills for efficient use of 3D printers, by rational design and competent fabrication, allowing managers/entrepreneurs/leaders prepared thanks to *ERASMUS3D+*, to work with the designers/operators/ programmers trained through 3DP project;
- develop skills not only for manufacturing but, also, for design and engineering. Related to this, an important topic is *'Design for 3D Printing'*[2];
- be applicable not just to one sector (e.g. consumer products) but applicable to a wide spectrum;
- offer a structured learning frame and pan-European advanced certified skills, including both self-evaluation certification to be approved by ECDL;
- provide solid education on the 3D printing subjects and equip trainers with efficient and certified teaching tools;
- increase motivation for 3D-P technology learning and in addition prepare students for real jobs;
- have an impact in terms of creating a critical mass of students being trained in 3D printing technology, via the e-learning platform.

3.0 Critical Implementation Actions

To be able to compile an innovative training course as described above, a number of critical implementation actions are required by the consortium, including the following:

- identify a number of case studies related to the 3DP process steps and to the most important fields of applications;
- perform the pilot testing of 3DP course;
- facilitate the multiplier events (hands-on workshops in every partner country);
- train other colleagues from their organizations;
- teach 3DP course to students, youths and adults.

4.0 Stakeholders Involvement

Based on the project proposal, the beneficiaries of the training programme include a number of target groups:

At a local/regional level:

- VET organisations, educational organizations with VET activities;
- VET students willing to enhance their creativity, innovation and entrepreneurial spirit;
- Companies, in particular SMEs, engaging in design and/or related industries and relevant key staff in those industries (industrial design, architecture, home and office design, etc.) to boost their entrepreneurial spirit and their innovation and creativity;
- Post-tertiary graduates in the fields of design, engineering, architecture, who are willing to enhance their knowledge and skills base before and after starting their career in

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[2] As a starting point for vocational training, this can be implemented by focusing on one type of commonly used 3D-P technologies, such as fused deposition modelling (FDM)

industry;
- Intermediaries and intermediary organisations, Industrial Liaison Offices of universities, research and technology centres (RTC), as well as their key staff.

At a national and EU level:

- VET providers, regional development agencies, political decision makers, chambers of commerce and industry, industrial associations, foundations relating to design and 3D printing, capital investors, patent attorneys etc.;
- Stakeholders working in education, business and public organisations from countries with different and complementary experiences.

5.0 Guidelines on the use of 3D Printing for VET education

Based on partners' experience, the innovative characteristics referred to in Section 2, the implementation actions identified in Section 3, the target audience in section 4, and preliminary discussions on a number of case studies, a number of guidelines for vocational students and trainers on the use of 3D Printing have been drawn up.

Key terms used in the context of the guidelines are defined in the glossary provided in Table 1. It is advisable that reference is made to Table 1, before going through the guidelines in order to avoid confusion in the terms used.

Table 1 – Glossary of <u>core</u> terms used in the <u>context</u> of the guidelines

Term	Definition
3D CAD	Computer-Aided Design makes use of computer-technology to create three-dimensional (3D) virtual models which are then converted to physical models using a 3D printer. There is a wide range of CAD software packages available on the market, which appeal for beginners, intermediate and advanced users of 3D printing.
3D model orientation	The alignment of a 3D virtual model with respect to the z-direction of a 3D-printer. The orientation has a drastic effect on the quality of the 3D physical model produced and the amount of support material required – thus building time and cost, where relevant.
3D printer	The equipment used in 3D printing. 3D printers can be classified into two three main classes – industrial 3D printers, desktop printers and home/hobbyists 3D printers. Examples of manufacturers of the former first two types are *Stratasys* and *3D Systems,* whilst those of the latter type are *Reprap* and *Makerbot*.
3D printing	The layer-by-layer fabrication of physical models/prototypes directly from Computer-Aided Design (CAD) virtual models. The layer-by-layer fabrication is also commonly referred to as Additive Manufacturing.
3D printing technology	The type of technology used in 3D printing. This greatly depends on the state of raw material employed. The most common types of 3D printing technology include SLS (Selective Laser Sintering), FDM (Fused Deposition Modelling) and SL

	(Stereolithography). Powder, softened polymer based material and liquid photosensitive polymers are used respectively in SLS, FDM and SL.
3D-P Beginner user	A vocational student/trainer who is not knowledgeable on how to generate simple 3D virtual and physical models using CAD and 3D printing respectively, and whose intention is primarily to gain basic familiarisation with 3D CAD and 3D printing technology.
3D-P Intermediate user	A vocational student/trainer who is typically aware on how to create 3D virtual models in CAD using common basic commands (e.g. extrude), has an idea of 3D printing and whose intention is primarily to create 3D CAD models for 3D printing purposes, to use 3D printed physical models for visualising the 3D form geometry and for communicating the form ideas.
3D-P Advanced user	A vocational student/trainer who is typically aware on how to create 3D virtual models in CAD using advanced 3D modelling commands, knows the basic steps of 3D printing and whose intention is primarily to create 3D CAD models using advanced features for 3D printing purposes, to use 3D printed physical models for visualising the 3D form geometry, for communicating form ideas and and/or for testing functional aspects. Such a student/trainer is considered as an independent 3D-P user.
Accuracy of 3D-Printed models	It is a measure of the quality of 3D printed models. The accuracy and how it is measured, depends on the type of 3D printing technology. For instance, in FDM, the quality of the 3D printed models depends on the nozzle size and the precision of the movement of the nozzle head in the X, Y and Z axis direction. In SL, besides the precision of the movement of the head in the X, Y and Z directions, the resolution depends on the optical spot size either of the laser or the projector[3].
Build envelope	The largest size of the 3D physical model that a 3D printer can produce. The size of the build envelope is specified in the X, Y and Z axis.
EBM	*Electron Beam Melting* is similar to SLS, except that an electron beam, rather than a laser, is employed to bind together the powdered material.
FDM	*Fused Deposition Modelling* is one type of 3D printing technology in which a 3D physical model is created layer by layer by depositing a filament of material extruded through a nozzle.
Layer thickness	Also known as the layer height is the minimal thickness of a layer that the 3D printer produces in one pass. The layer thickness is depends on the type of 3D printing technology used. For instance, typically SL process provides a finer layer thickness compared to FDM process.
Mesh model	A 3D virtual model which is hollow and which is characterized characterised by a skin of polygons which contain data on the structure and vertices of the 3D virtual model.
Post-processing	The phase following the layer-by-layer fabrication of a 3D model. The steps required during this phase depends on the 3D Printing technology employed. Typical steps

[3] https://all3dp.com/3d-printer-resolution/

	include removal of support structures and removal of loose powder from internal features.
SL	*Stereo Lithography Apparatus* is one type of 3D printing technology in which a 3D physical model is created layer by layer by polymerising a photosensitive liquid polymer, typically using a laser as the power source.
SLS	*Selective Laser Sintering* is one type of 3D printing technology in which a 3D physical model is created layer by layer by binding powdered material, using a laser as the power source.
Solid model	A 3D virtual model whose volume characterises the geometry of the model.
STL	STereoLithography is a type of file format widely used in 3D printing technology. An STL file format segments a 3D CAD model into adjacent triangles and *typically* describe only the surface geometry of 3D CAD model, without any representation of colour, texture or other common CAD model attributes [4]. In some cases, an STL file possesses information on colour. Such files are employed when it is required to 3D print colour parts, such as is the case with Z Corp printers[5] currently rebranded by *3D Systems Inc*. as *Color Jet*)
STL file repair	It is the process of repairing errors (such as missing triangles) which result when converting 3D CAD models, typically having complex geometries, into an STL file format. There are a number of software packages on the market which assist 3D printer users to repair STL files, such as *Materialise Magics*[6].
STL file resolution	Refers to the resolution of the tessellated (or triangulated) 3D model. The higher the resolution is, the smaller are the triangles in the STL file and the higher will be file size.
STL file viewer	A software package which allows users to view a 3D CAD model exported in STL format. Examples of an STL file viewers are *Materialise Mini Magics* [7] and *Netfabb Basic*[8].
Support structures	Required when the 3D virtual model to be 3D-printed has overhanging features requiring support during the layer-by-layer fabrication. In general, support structures are required when the raw material used for 3D printing is softened polymer (used in FDM) or liquid (used in SL).

5.1 Guidelines for Vocational Students

5.1.1 Guideline no. 1 (GS1)

IF you are a 3D-P beginner user **AND** you intend to *quickly* generate a 3D physical model from an existing 3D virtual model ***THEN***

[4] Adopted from the definition available at: https://en.wikipedia.org/wiki/STL_%28file_format%29
[5] https://www.3dhubs.com/3d-printers/zcorp
[6] http://software.materialise.com/magics
[7] http://software.materialise.com/minimagics-stl-viewer
[8] https://www.netfabb.com/

- Find a readily available free 3D virtual model from an on-line repository such as *Pinshape*[9], *Thingiverse*[10] and *Grabcad*[11].
- Download the STL file.
- Check the 3D-P facility at your institution/service bureau or an on-line network of 3D printing bureau such as 3*DHubs*[12].
- Provide the STL file to the personnel responsible at the 3D-P facility at your institution/service bureau or upload the STL file yourself on the aforementioned on-line 3D printing bureau, in order to get a quote for the printing costs incurred.
- Select a low cost FDM printer.
- Choose Polylactic Acid (PLA) filament as material.

RECOMMENDATIONS:

- Use objects which have simple geometry if you want to quickly obtain the 3D model.
- Check that the STL file is error free using free dedicated software (*Netfabb Basic*, *MiniMagics*, etc.). If it has errors, consult a technical competent person so that the STL file is repaired.
- Consult a technical competent person for an advice on the process parameters, in particular the diameter of extruded filament and the 3D model orientation. This is required in order to reduce material consumption, costs and to obtain the required quality of the printed object.
- Typical student's background/interest: art and design.

5.1.2 Guideline no. 2 (GS2)

IF you are a 3D-P beginner user **AND** you intend to change an attribute (e.g. colour) of an existing 3D virtual for learning purposes **OR** to exploit the resulting 3D printed model in practice ***THEN***

- Find a readily available free 3D virtual model from an on-line repository such as *Thingiverse* and *Grabcad*.
- Change the colour of the default model, if required, following the instructions provided in the on-line repository.
- Look at other relevant instructions provided in guideline no. *GS1*.

RECOMMENDATIONS:

- Use objects which have simple geometry if you want to reduce the costs.
- Look how the product properties (e.g. matte vs. varnished colour) and material type change when you switch colour.

[9] https://pinshape.com
[10] https://www.thingiverse.com/
[11] https://grabcad.com/
[12] https://www.3dhubs.com/

- Look at other recommendations listed in guideline no. *GS1*.
- Typical student's background/interest: art and design.

5.1.3 Guideline no. 3 (GS3)

IF you are a 3D-P beginner user **AND** you intend to convert your aesthetic form idea by 3D printing a physical model ***THEN***

- Obtain a 3D virtual model of your design. In the case you wish to learn on how a simple 3D model can be generated, you can find free CAD packages aimed for beginner CAD users. Example of such CAD packages is *3Dtin*[13] which allows users to draw directly in the internet browser or *123D Design*[14], *TinkerCAD*[15] and *A360 Fusion*[16].
- Export the CAD model which you generated in STL file format.
- Print model as indicated in guideline no. *GS1.*

RECOMMENDATIONS:

- If the design you wish to print has organic form (i.e. with no geometric flat surfaces), it is recommended that you seek advice from technical personnel at your institution/service bureau on how such forms are created in a CAD package and how the resulting STL files are correctly generated, i.e. error-free.
- To reduce the building time and reduce costs, be aware that the layer thickness must be increased. On the other hand, be aware that if you want to obtain a fine resolution, the layer thickness must be reduced as much as possible, however at the expense of time and costs.
- Refer to other relevant instructions provided in guideline no. *3GS1*.
- Typical student's background/interest: art and design.

5.1.4 Guideline no. 4 (GS4)

IF you are a 3D-P intermediate user **AND** you intend to convert your idea by 3D printing for a *preliminary* visual evaluation **AND/OR** to publicize the creativity behind your idea on-line ***THEN***

- Refer to relevant steps suggested in guideline no. *GS1* to obtain a 3D print of your idea economically.
- Look for an on-line 3D printing service provider which allows you to upload a 3D virtual model of your design and make it public.
- Upload your 3D model in STL file format or in any other format (e.g. **.obj*) accepted by the on-line service provider.

[13] http://www.3dtin.com/
[14] http://www.123dapp.com/design
[15] https://www.tinkercad.com/
[16] https://a360.autodesk.com/

- Make sure that you choose the correct dimensions (mm vs. inch) and domain (private vs. public) when uploading the model.
- Choose a proper building orientation.
- Select a low-cost FDM printer.
- Materials: PLA and ABS (acrylonitrile butadiene styrene).

RECOMMENDATIONS:

- Since you want to 3D print your idea <u>economically</u>, make sure that you choose a suitable filament thickness; the thinner it is, the higher will be the accuracy and surface quality of the printed object, however at the expense of building time.
- Be aware that the 3D model orientation plays a crucial role of the quality of the object and its mechanical properties. If your model has a large surface area (e.g. a trendy case for a smartphone), ensure that the largest surface is placed horizontal and not vertical.
- Ensure that the STL file is free of errors <u>before</u> sending it for printing. There are on-line software packages which allow you to analyse and repair *STL* files, such as *Netfabb Basic*.
- Typical student's background/interest: art and design, architecture, product design.

5.1.5 Guideline no. 5 (GS5)

IF you are a 3D-P intermediate user **AND** you intend to produce a *high quality* physical model of your design ***THEN***

- Export the 3D CAD model which you generated in STL file format and pay attention to the STL accuracy parameter settings and to any errors in the STL file.
- Check that the model which you intend to print fits in the build envelope of the 3D printer.
- Provide the STL file to get a quote for the printing costs incurred.
- Choose a proper building orientation.
- Select either a desktop SL printer or an FDM printer, which can give you high quality parts, available at your institution/printing bureau or an on-line network of 3D printing bureau.
- Material: Photopolymer resin (in case of SL process) or ABS or Polycarbonate (PC) (in case of FDM process).

RECOMMENDATIONS:

- Be aware that the finer STL mesh is the longer will the layer-by layer fabrication, hence increasing the quality of the parts fabricated, however at the expense of costs. Consult technical personnel for an advice, if you encounter any problems on STL resolution setting and/or STL file repair in the corresponding software.
- Refer to other relevant instructions provided in guideline no. *GS4*, in particular those related to 3D model orientation.

- Typical student’s background/interests: art and design, architecture, product design.

5.1.6 Guideline no. 6 (GS6)

IF you are a 3D-P advanced user **AND** you intend to produce a *high quality* **AND/OR** functional physical model of your design ***THEN***

- When modelling in 3D CAD, ensure that there is a suitable clearance between mating parts, if your model is constituted of more than one component.
- Export the 3D CAD model which you generated in STL file format. When exporting in the STL format, improve the resolution of the STL file in the CAD package.
- Open the STL model in an STL file viewer for a preliminary visual check of triangles and check any errors in the STL file by using the appropriate software package.
- When you open the STL file in the specialized software accompanying the machine (e.g. *CatalystEX* software comes with the FDM printer *DIMENSION 1200es model*[17]) orient the STL model such that it consumes less support structures material, whilst at the same time, maintain the structural integrity of the part.
- Set the smallest filament thickness possible.
- Ensure a good quality on important surfaces (surfaces in contact with support structures have poorer quality).
- Check that the model which you intend to print fits in the build envelope of the 3D printer. If not, set the scale and ensure dimensions are the same used when 3D modelling your design in CAD.
- Provide the STL file to get a quote for the printing costs incurred.
- Select a high-resolution industrial FDM printer available at your institution/ printing bureau.
- Material: PC, Carbon Fibre Filament, Nylon, ABS and Polyethylene Terephthalateco (PETG).

RECOMMENDATIONS:

- Consult technical personnel and/or guidelines provided by the 3D printer supplier regarding the clearance between mating components, as this depends on various factors, such as material, 3D printer and building orientation. Typically, 3D-P machine suppliers provide guidelines on clearances, such as *Stratasys*[18]. On-line forums are also available in which the clearance aspect is discussed, such as that available at *3Dhubs*[19].
- Look for on-line available charts which compare the properties of different types of FDM material filaments. An example of such as a chart is available at *All3DP*[20].

[17] http://www.stratasys.com/3d-printers/design-series/dimension-1200es
[18] https://www.stratasysdirect.com/resources/fused-deposition-modeling/
[19] https://www.3dhubs.com/talk/thread/functional-parts-fdm-single-material
[20] https://all3dp.com/best-3d-printer-filament-types-pla-abs-pet-exotic-wood-metal/

- If the model to be printed has complex geometry (e.g. a model of a human skull), it is recommended that instead of a virtual solid model, a surface model is used.
- To reduce the time of the build, it is recommended that the model is placed close to the home position of the printing head.
- Typical student's background/interests: product design engineering, applied and health sciences.

5.2 Guidelines for Vocational Trainers

5.2.1 Guideline no. 1 (GT1)

IF the student is a 3D-P Beginner user ***THEN***

- Distinguish between subtractive, formative and additive manufacturing processes for prototyping purposes.
- Cover the basic 3D printing process steps.
- Explain the X-Y-Z coordinate system.
- Mention what standard file format is required.
- Provide examples where 3D-P can be employed.
- Cover the working principle of the common desktop 3D printers available on the market.
- Mention materials which are typically used.
- Cover basic principles of 3D CAD modelling.

RECOMMENDATIONS:

- Use schematic diagrams and a simple example (such as a block with a slot) to explain the above relevant topics.
- Mention and discuss one file format, namely STL.
- Cover just SL and FDM.
- Complement theory on various topics related to 3D-P technology with hands-on exercises covering STL file processing on at least one desktop 3D printer.
- Use case studies in the architecture and product design domain.
- Typical target vocational course: art and design.
- Involve a number of stakeholders to customize and assess the curriculum in terms of the needs of SMEs in design and/or related creative industries

5.2.2 Guideline no. 2 (GT2)

IF the student is a 3D-P intermediate user ***THEN***

- Cover the basic 3D printing process steps.
- Explain how a 3D virtual model can be generated (e.g. CAD package, reverse engineering).

- Mention what standard file format is required.
- Explain how the original 3D CAD model is triangulated when converted to the standard file format.
- Explain how the triangles and normal of each triangular facet in an STL file can be viewed.
- Distinguish between build and support material and why the latter is required.
- Provide examples where 3D-P can be employed.
- Cover the working principle of main 3D printers available on the market (home, desktop and industrial printers).
- Explain some basic capabilities of the 3D printers (e.g. build envelop, accuracy etc.) and other process parameters (e.g. layer thickness, machine accuracy and laser spot power).
- Mention different types of materials grades which can be typically used.
- Cover basic principles of 3D CAD modelling.

RECOMMENDATIONS:

- Use schematic diagrams and number of examples (such as a block with a slot, models with internal features) to explain the above relevant topics.
- Mention and discuss one file format, namely STL.
- Show students how they can download and use a free STL file viewer[21].
- Include SL, FDM and SLS processes.
- Complement theory on various topics related to 3D-P technology with hands-on exercises covering STL file generation, viewing and processing on at least two different 3D-P technologies.
- Use case studies in the architecture, medical and product design domains.
- Typical target vocational courses: product design, furniture design and manufacturing, interior design, applied sciences and cultural heritage.
- Involve a number of stakeholders to customize and assess the curriculum in terms of the needs of SMEs in design and/or related industries.

5.2.3 Guideline no. 3 (GT3)

IF the student is a 3D-P advanced user ***THEN***

- Cover the basic 3D printing process steps.
- Explain how a 3D virtual model can be generated (e.g. CAD package, reverse engineering).
- Explain how the resolution of an STL file can be modified within a CAD package (such as by adjusting chord height).
- Mention what standard file format(s) can be used.
- Explain how the original 3D CAD model is triangulated when converted to the standard file format.

[21] https://all3dp.com/best-free-stl-file-viewer-online-mac-pc-linux-download-android-ios-app/

- Explain how the triangles and normal of each triangular facet in an STL file can be viewed.
- Explain why and how errors during the pre-processing stage can be corrected before sending the model for 3D printing.
- Provide examples where 3D-P can be employed.
- Cover the working principle of main 3D printers available on the market.
- Explain some basic capabilities of the 3D printers (e.g. build envelope, accuracy etc.) and other process parameters.
- Cover the sources of inaccuracies at different stages including data preparation, building process and post-processing and measures one can take to mitigate them. Highlight that such inaccuracies surface in applications where 3D CAD data is acquired via Computed Tomography (CT) scanning technology.
- Mention different types of materials grades which can be typically used.
- Cover material related to 'design for 3D-printing' expressed as general design rules.
- Cover basic and advanced principles of 3D CAD modelling.

RECOMMENDATIONS:

- Use schematic diagrams and number of examples (such as a block with a slot, models with internal features, 3D models in STL file format with different chord heights) to explain the above relevant topics.
- Mention standard file formats which are currently being used including STL and AMF.
- Show students how they can download and use a free STL file viewer.
- Show students how they can repair errors in STL files using specialized commercial software packages such as *Materialise Magics*[22].
- Include SL, FDM, SLS and EBM.
- Complement theory on various topics related to 3D-P technology with hands-on exercises covering STL file generation, viewing, editing and processing on at least three different 3D-P technologies (including a metal 3D printer).
- Use case studies in the architecture, medical, manufacturing and product design domain.
- Typical target vocational courses: applied and health sciences, product design, interior design, marine engineering, tooling, polymer processing and cultural heritage.
- Involve a number of stakeholders to customize and assess the curriculum in terms of the needs of SMEs in design and/or related industries.

[22] http://software.materialise.com/magics

6.0 Case Studies on the use of 3D Printing for VET education

This section provides a number of case studies which will be employed to teach vocational students how 3D printing technology can be applied across a number of application sectors. The criteria which were employed to select the case studies are the following:

- **Accessibility of the 3D-P technology** – it might be an issue for vocational students to access advanced industrial 3D printers (e.g. Electron Beam Melting, Selective Laser Sintering) compared to desktop printers and home/hobbyists 3D printers. For this reason, preference would be given to the latter two classes of printers;
- **Promotes Creativity** – This aspect was considered important as the aim of the project is to foster EU innovation and creativity amongst vocational students through 3D-P. Therefore, whenever possible original case studies which give the opportunity for students to unleash their creativity were sought;
- **Contribution to vocational education training –** selection of case studies was made such that there is a mix of examples in a range of sectors which were deemed appealing for beginners, intermediate and advanced users. In addition, the extent to which the case study covers related 3D-P topics, in particular hands-on 3D CAD modelling, was considered as an asset.

Following are the case studies proposed by the partners. As illustrated in the following pages, for conformity purposes, a case-study template was created. It must be mentioned that an additional field was incorporated in the original template which gives an indication of the *European Qualifications Framework (EQF)*[23] reference level(s), which a particular case study is the most appealing for vocational students.

[23] https://ec.europa.eu/ploteus/en/content/descriptors-page

Case study no.:	*1*
Case Study Title:	**Prototyping a Full Scale Human Skull with Customised Titanium Cranial Implant**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science x Medical □ Other. Please specify: ____________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	FDM and EBM
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	ABS and Ti6AlV4 ELI
Description:	In this case study, a physical full scale prototype of a human skull with titanium cranial implant is produced. The actual skull is produced from ABS directly from the CAD model, acquired from CT scan data and the cranial titanium implant is fabricated layer by layer using EBM.
Target EQF Level:	5
Contribution to VET:	Through the chosen case study, vocational students can learn and appreciate how 3D-P can contribute to plan a surgery in advance and how an implant can be customised, depending on various factors, e.g. the shape of the skull and the cranial areas inflicted by the tumour. In addition, given its complex geometry, students will be exposed to new ways of how one can generate a 3D virtual model beyond CAD technology.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package x Has to be generated from scratch using other means (CT scan data).
Insert photo and/or URL:	 **Figure 1** – Full scale human skull with Titanium implant (Courtesy: University of Malta

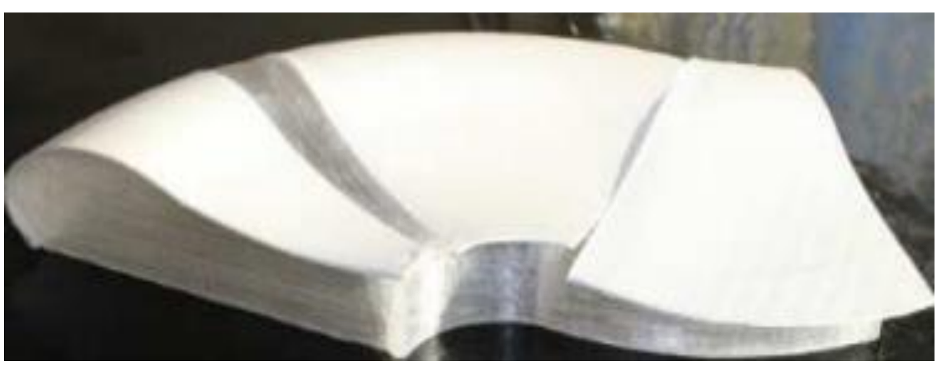
Case study no.:	*2*
Case Study Title:	**3D Printing of a multi-material architectural model**
Sector (tick where relevant):	x Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ______________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	FDM
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	PLA and PETT (t-glase)
Description:	In this case study, an architectural model assembly is fabricated using PLA and transparent PETT filament. The two materials are 3D printed with very different parameters (temperatures, speed, layer thickness) and then joined together.
Target EQF Level:	4
Contribution to VET:	This case study shows the ability of 3D printing to make use of different materials to obtain complex assemblies. The vocational students can learn how to make a good decomposition of assemblies in parts, how to position the parts for optimal 3D printing and how to select the right printing parameters for a given material.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) x In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 2 – Multi-material architectural model (Source: Ludor Engineering portfolio)

Case study no.:	*3*
Case Study Title:	**Replicating singular monuments of complex 3D printing geometries**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: Mechanical manufacturing design, culture.
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	FDM
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) *x* High (typically >0.2mm)
Material used:	PLA
Description:	In this case study, a miniature (mockup) of a popular monument in a city is created, more specifically, taking the "*Karola*" Crane - a vestige of former shipyard Euskalduna in Bilbao, as an exemplar.
Target EQF Level:	3
Contribution to VET:	Activity undertaken by first year students of DFM3 (Mechanical Manufacture Design) in the third semester. Skills acquired in 3D printing of complex parts and geometries.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 3 – Prototype of a shipyard crane (Source: Centro Formación Somorrostro)

Case study no.:	*4*
Case Study Title:	**Direct 3D printing of assembly models**
Sector (tick where relevant):	□ Architecture x Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ______________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	FDM
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	ABS, PLA
Description:	In this case study, several 3D printed assemblies are manufactured on Zortrax M200 machine using ABS material and a layer thickness of 0.19mm. These assemblies show the ability of 3D printing processes to directly manufactured assemblies (i.e. there is no need to separately print the assembly's components and then to assemble them) and mechanisms.
Target EQF Level:	4
Contribution to VET:	The chosen products can be downloaded from open-source repositories or created by vocational students using a CAD package. The skills required for designing and manufacturing such assemblies refer to a correct prescription of clearances values between components, as well as a correct choice of the building orientation. *Design for Additive Manufacturing* (or 3D Printing) rules should be learned and applied by vocational students.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 4 – Prototype of a gear mechanism produced by 3D-P (Source: thingiverse.com)

Case study no.:	*5*
Case Study Title:	**Exploiting SL for Accurate 3D Printing of mobile phone support**
Sector (tick where relevant):	□ Architecture x Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ______________________
Purpose (tick as relevant):	x To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	SL
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	Photosensitive polymer
Description:	In this case study, a physical prototype of a single piece mobile support will be 3D printed on a *Formlabs2* Printer.
Target EQF Level:	3, 4
Contribution to VET:	The chosen product is used in office spaces, at home, it is a single piece and is portable. For these reasons, it will lead to appreciation by students of the potential of 3D printing to foster innovation and creativity in product design.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 5 – Prototype of a mobile phone support (Source: https://pinshape.com/3d-marketplace.)

Case study no.:	6
Case Study Title:	**Application of 3D printers in Orthopaedics**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science x Medical □ Other. Please specify: ______________________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	SL (PolyJet)
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	Vero family of opaque materials, including various neutral shades and vibrant colors, medical: MED610, high temperature RGD525 white, transparent: VeroClear and RGD720.
Description:	The most known cases of application of 3D printing in medical concern orthopaedics for the study of preoperative and fractures of the most delicate operations, the realization of prosthesis, or for the construction of custom orthotic, able to adapt perfectly to the patient's anatomical conformation. Two excellent Italian examples of application of 3D printers in orthopaedics are coming from the *Rizzoli Orthopaedic Institute of Bologna* and from the *University of Verona*. CT scanning with 3D reconstructed images are currently used to study articular fractures in orthopaedic and trauma surgery.
Target EQF Level:	5
Contribution to VET:	Design with 3D software and prototyping. Testing and improvement. Students can acquire 3D knowledge and can create prosthesis useful also in teaching.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package x Has to be generated from scratch using other means (CT scans).
Insert photo and/or URL:	 **Figure 6** – Model of a foot fabricated by 3D PolyJet in multi-material (Source: http://www.stampanti3d.it/2016/09/stampa-3d-e-medicina-vantaggi/)

Case study no.:	*7*
Case Study Title:	**Map of Lithuania –puzzle created designed and printed**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: General knowledge - geography
Purpose (tick as relevant):	x To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process □ To show the capabilities of 3D printing technology and its applications □ Other. Please specify:____
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	PLA
Description:	During a number of workshops school students designed own objects using *Sketchup Make* and printed with *MakerBot Replicator 2*. In this particular case study of a map of Lithuania composed of its different regions is fabricated in the form of a puzzle. It can be used for entertainment and educational purposes as every piece of puzzle is particular region of Lithuania. Pieces of puzzle are big enough to use for toddlers to develop motor skills.
Target EQF Level:	3
Contribution to VET:	Even though product is not difficult technically, it is very practical. A lot of creative and useful ideas are made simple; as this product example. Contribution to idea made it great. In addition, it can be extended to other consortium member countries.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	 **Figure 7** – Model of the regions in Lithuania (Source: Northern Lithuania College)

Case study no.:	*8*
Case Study Title:	**The bottle cork**
Sector (tick where relevant):	□ Architecture x Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ____________________________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications x Other. Please specify: To help students appreciate how 3D-P can be used with other processes, such as casting.
3D-P technology	*SLS*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	PA plastic
Description:	The bottle cork consisting of two threaded connected parts from polyamide (PA) plastic. According to the client's cork drawings a design concept was modelled in CAD and prepared for 3D printing. High quality products were printed using the SLS (Selective Laser Sintering) 3D printing technology. The polyamide-printed bottle cork details will be used in the production of silicone mould, and then for the casting of metal corks.
Target EQF Level:	4, 5
Contribution to VET:	To show how 3D modelling and printing services allows the customer to plug the casting model in just a couple of weeks, when the production of the traditional way it would have lasted much longer, as well as costly. In this way, the final product will be placed on the market earlier, thereby enabling higher revenue assurance.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) x In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 8 – CAD model of the cork (Source: http://3dcreative.lt/blog/)

Case study no.:	*9*
Case Study Title:	**Exploiting SL for Accurate 3D Printing of a One Handed Bottle Opener**
Sector (tick where relevant):	□ Architecture x Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ____________________________________
Purpose (tick as relevant):	x To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*SL*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	Photosensitive resin
Description:	In this case study, a physical prototype of a single piece one handed bottle opener will be 3D printed on a *Formlabs2* printer.
Target EQF Level:	4
Contribution to VET:	The chosen product is commonly used, it is a single piece and is portable. For these reasons, it will lead to appreciation by students of the potential of 3D printing to foster innovation and creativity in product design. In addition, given its simple geometry, it can be easily generated in a CAD package, hence it will lead to educating vocational students in how they can exploit CAD technology to produce simple yet innovative products.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

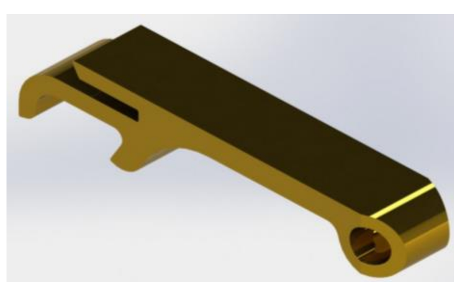


Figure 9 – CAD model of the single component bottle opener (Source: https://grabcad.com/library/bottle-opener-32)

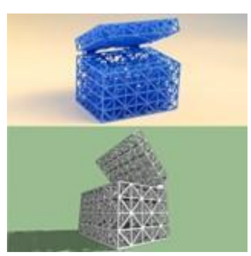
Case study no.:	*10*
Case Study Title:	**Two-piece custom-made box - designed and 3D Printed**
Sector (tick where relevant):	□ Architecture x Consumer Product □ Interior Design □ Applied Science □ Medical □ Other. Please specify: ___________________________________
Purpose (tick as relevant):	x To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	PLA
Description:	During a number of workshops school students designed own objects using *Sketchup Make* and printed with *MakerBot Replicator 2*. For this case study we had created and designed two pieces box from scratch. Even this box is consumer product, but created very accurately with many automated function to avoid any inaccurate measurements. Printed in two pieces and joined together.
Target EQF Level:	4
Contribution to VET:	Product was created by school students (14 years old). Product itself encouraged to work accurately and use various functions to print it well. As a result of great work, youngsters were motivated to strive for more and make more complicated objects. Making more difficult objects encourages students to have a wide view. Geometry, mechanics, and creativity – all combined together makes best 3D modelling and printing experience.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 10 – Model of boxes having complex geometries (Source: Northern Lithuania College)

Case study no.:	*11*
Case Study Title:	**Engine Copy Of The Single Motor Airplane LITUANICA**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: Mechanical Engineering
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*SLS, Direct Metal Laser Sintering (DMLS), SL (Polyjet)*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) (Varies, depending on 3D-P technology used) □ High (typically >0.2mm)
Material used:	PA2200, Titanium Ti6Al4V, Coloured plaster
Description:	Engine of the legendary single motor airplane LITUANICA which was flown from the United States across the Atlantic Ocean by Lithuanian-American pilots Steponas Darius and Stasys Girėnas in 1933. After successfully flying 6,411 km (4,043 miles), it crashed, due to undetermined circumstances, 650 km (404 miles) from its destination, Kaunas, Lithuania. The scale of engine copy 1: 2.
Target EQF Level:	4,5
Contribution to VET:	Visual educational model that delivers not only the latest 3D printing technologies, including and opportunities of combination of different printing technologies, including plastic SLS printer *EOS P396*, metal printer *EOSINT M280* and colour printing *Projet* 660Pro. In addition, students are exposed to invaluable Lithuanian aviation history.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

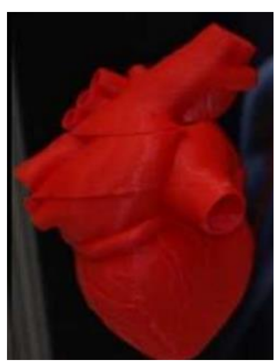
Figure 11 – Model of the airplane engine (Source: http://smartfactory.lt/galerija/pramone/)

Case study no.:	*12*
Case Study Title:	**Exploiting 3D-Printing For Fabricating Industrial Pumps For Water Extraction**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: industrial pumps for water extraction
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*SL (Polyjet)*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) x High (range of 650 x 650 x 6800 DPI)
Layer thickness:	x Low (typically <0.02mm) □ High (typically >0.2mm)
Material used:	VisiJet SL, VisiJet SL Flex e Jewel
Description:	This exemplar revolved round a practical case study at a company called *Pedrollo*, one of the world leaders in the design and manufacture of industrial pumps for water extraction. The times for the realisation of prototypes in the beginning, were very long: from the moment of the design to the one in which the models were ready, realised in outsourcing, normally it was necessary to have 4/5 months. So *Pedrollo* decided to increase the production of prototypes within the company, creating a department for this purpose. What may seem at an uneconomic choice in reality was very careful: the realisation of the models were reduced to a month and the company also gained total confidentiality about its own projects.
Target EQF Level:	4,5
Contribution to VET:	Students could learn how to create pieces for an industrial machine reducing the cost of producing prototypes.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) x In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 12 – Components of a water extraction pump produced by 3D printing (Source: https://www.3dz.it/news/stampa-3d-nella-meccanica-il-caso-pedrollo/)

Case study no.:	*13*
Case Study Title:	**Exploiting FDM For Accurate 3D Printing Of Simplified Human Skull**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: Education/Biology classroom
Purpose (tick as relevant):	□ To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	PLA
Description:	In this case study, a physical prototype of a single piece of human skull will be 3D printed on an FDM Printer.
Target EQF Level:	3
Contribution to VET:	The chosen product is used in Biology classroom/laboratory and it is a single piece and is portable. For these reasons, it will lead to appreciation by students of the potential of 3D printing to foster innovation and creativity in product design.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	

Figure 13 – Simplified human skull produced by 3D Printing (Source: https://www.cgtrader.com/free-3d-print-models/science/biology/simplified-human-skull)

Case study no.:	*14*
Case Study Title:	**3D Printing of a Realistic Human Heart for Educational Purposes**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science X Medical x Other. Please specify: Education
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: ____
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	PLA
Description:	In this case study, physical replica of a human heart is reconstructed from data obtained by Computer Tomography (CT) and 3D printed on a FDM 3D printer, using PLA and 0.2 mm layer thickness.
Target EQF Level:	3, 4
Contribution to VET:	Through the chosen case study, vocational students can learn and appreciate how 3D-P can be used to produce complex shape objects, like the human organs replicas. In addition, students will learn about a new way of generating 3D models for 3D printing, through CT scanning.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means.
Insert photo and/or URL:	 **Figure 14** – STL file is available at: http://www.thingiverse.com/thing:632569. Picture source: Ludor Engineering portfolio

Case study no.:	*15*
Case Study Title:	**Assembly Mechanisms**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science □ Medical x Other. Please specify: Mechanical manufacturing/Machining
Purpose (tick as relevant):	□ To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications x Other. Please specify: To understand mechanisms
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	PLA
Description:	Design or scanning a part of crank rod system and prototyping through 3Dprinting.
Target EQF Level:	4
Contribution to VET:	Improve the capacity to visualize movements of the mechanisms and understand the kinematics of the mechanisms. Handling 3D printers and scanner.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) x Has to be generated from scratch in a CAD package x Has to be generated from scratch using other means (scan/reverse engineering).
Insert photo and/or URL:	

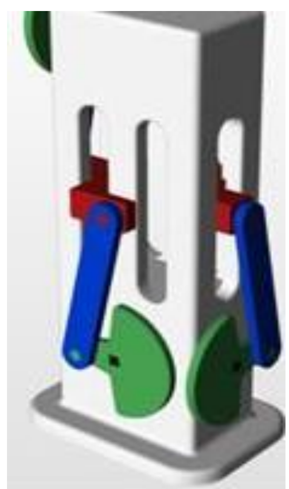
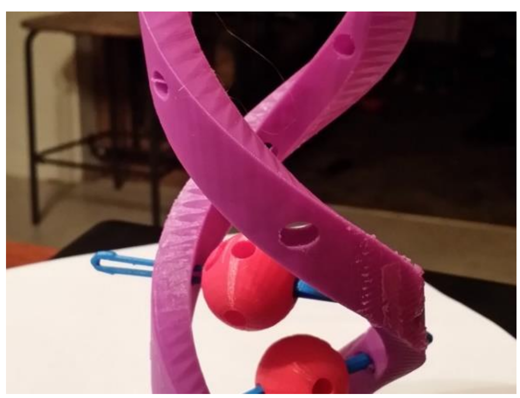


Figure 16 – Exemplar assembly mechanism consisting of a crank-rod system (Source: https://grabcad.com/library/mechanical-crank-rod-system-1)

Case study no.:	16
Case Study Title:	**Manufacturing physical replicas of medical models based on patient Computer Tomography (CT) scanning data**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design □ Applied Science x Medical □ Other. Please specify: ______________________________________
Purpose (tick as relevant):	□ To give an overview of the 3D printing process □ To give a detailed description of the 3D printing process x To show the capabilities of 3D printing technology and its applications □ Other. Please specify: _______________________________________
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	ABS
Description:	In this case study, physical replicas of anatomical bone structures are reconstructed from patient specific medical scanning data (CT) and manufactured using Mojo 3D printer from ABS using a 0.178mm layer thickness. The virtual medical models are reconstructed using dedicated medical modelling software.
Target EQF Level:	5
Contribution to VET:	The chosen products are very useful for visualization purposes, for training medicine students, for doctor-doctor or doctor-patient communication, as well as for surgery preplanning. The medical reconstruction from CT data requires dedicated skills and expertise from vocational students. This valuable interdisciplinary knowledge can provide students a very important competitive advantage on the labour market.
Availability of CAD model (tick where relevant):	□ Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package x Has to be generated from scratch using other means (scan/reverse engineering).
Insert photo and/or URL:	

Figure 17 – Exemplar physical replicas of medical models (Source: University Politehnica of Bucharest)

Case study no.:	*17*
Case Study Title:	**Exploiting SLA for Accurate 3D Printing of a DNA model**
Sector (tick where relevant):	□ Architecture □ Consumer Product □ Interior Design x Applied Science □ Medical □ Other. Please specify: Science classes
Purpose (tick as relevant):	□ To give an overview of the 3D printing process x To give a detailed description of the 3D printing process □ To show the capabilities of 3D printing technology and its applications □ Other. Please specify: To help students visualize DNA arrangements
3D-P technology	*FDM*
Resolution (if relevant):	□ Low (range of 300 x 300 x 600 DPI) □ High (range of 650 x 650 x 6800 DPI)
Layer thickness:	□ Low (typically <0.02mm) x High (typically >0.2mm)
Material used:	ABS
Description:	In this case study, a structure of DNA molecule will be printed.
Target EQF Level:	3
Contribution to VET:	The chosen model requires printing several parts and combining them together. The model can be used at science classes to show students the structure of DNA molecule and how specific features, such as the sequence of chemical bases allow the molecule to carry and pass on the information related to the inheritance of traits.
Availability of CAD model (tick where relevant):	x Available on-line (free) □ Available on-line (at a cost) □ In our possession (but it has copyright) □ In our possession (but with no copyright) □ Has to be generated from scratch in a CAD package □ Has to be generated from scratch using other means (scan/reverse engineering).
Insert photo and/or URL:	 **Figure 17** – Exemplar DNA model (Source: http://www.thingiverse.com/thing:1699972)

6.1 Analysis of Case Studies

As stated in the proposal, the consortium has to identify the most relevant 6 case-studies relative to the uses of 3D Printing in education and the selected case-studies are analysed in order to find out best practices and other useful ideas for the 3DP course. This section is aimed in this direction. As a first step, a summary of the case studies described previously is provided in Table 2. A comparison with respect to the criteria together with the type of 3D-P process/processes employed, is also provided.

Table 2 – Summary of case studies

No	Title	Accessibility of 3D-P tech.	Promotes Creativity	VET Contribution	Type of 3D-P technology(ies) (Make, if specified)
1	*Prototyping a Full Scale Human Skull with Customised Titanium Cranial Implant*	✓	✓	✓✓✓	FDM (*Stratasys Dimension 1200es*) and EBM (*Arcam EBM S12*)
2	*3D Printing of a multi-material architectural model*	✓✓✓	✓✓✓	✓✓✓	FDM (Not specified)
3	*Replicating singular monuments of complex 3D printing geometries*	✓✓✓	✓	✓✓	FDM (Not specified)
4	*Direct 3D printing of assembly models*	✓✓✓	✓✓✓	✓✓✓	FDM (*Zortrax M200*)
5	*Exploiting SL for Accurate 3D Printing of mobile phone support*	✓✓✓	✓✓✓	✓✓	SL (*Formlabs2*)
6	*Application of 3D printers in Orthopaedics*	✓✓	✓	✓✓✓	SL (*PolyJet*)
7	*Map of Lithuania –puzzle created, designed and printed*	✓✓✓	✓✓✓	✓✓✓	FDM (*MakerBot Replicator 2*)
8	*The bottle cork*	✓	✓✓✓	✓✓✓	SLS (Not specified)
9	*Exploiting SL for Accurate 3D Printing of a One Handed Bottle Opener*	✓✓✓	✓✓✓	✓✓	SL (*Formlabs2*)
10	*Two-piece custom-made box - designed and 3D printed*	✓✓✓	✓	✓✓	FDM (*MakerBot Replicator 2*)
11	*Engine Copy Of The Single Motor Airplane LITUANICA*	✓	✓✓	✓✓✓	SLS (*EOS P396*), DMLS (*EOSINT M280*) and SL (*Projet 660Pro*)

12	*Exploiting 3D-Printing For Fabricating Industrial Pumps For Water Extraction*	✓✓	✓	✓✓✓	SL (*PolyJet*)
13	*Exploiting FDM For Accurate 3D Printing Of Simplified Human Skull*	✓✓✓	✓	✓✓	FDM (Not specified)
14	*3D Printing of a Realistic Human Heart for Educational Purposes*	✓✓✓	✓✓	✓✓	FDM (Not specified)
15	*Assembly mechanisms*	✓✓✓	✓	✓✓	FDM (Not specified)
16	*Manufacturing physical replicas of medical models based on patient Computer Tomography (CT) scanning data*	✓✓	✓	✓✓	FDM (*Mojo 3D Printer, Stratasys*)
17	*Exploiting SLA for Accurate 3D Printing of a DNA model*	✓✓✓	✓	✓✓✓	FDM (*MakerBot Replicator 2*)

Legend: ✓✓✓ **:** Greatly satisfied ✓✓ **:** Satisfied ✓ **:** Somewhat Satisfied

As a general observation, the best-practices for VET education which emerged across different case studies were the following:

1) rather than finding an (on-line) readily available 3D model, give the opportunity to vocational students to create the 3D virtual model preferably from scratch using 3D CAD modelling;
2) allow students appreciate the potential of 3D printing by first resorting to a wide spectrum of application areas (e.g. medical, mechanical and consumer products), secondly by utilising different materials aimed at training students the different process parameters required and thirdly using 3D models of varying complexity levels, ranging from a simple puzzles to a model of a human heart.

With reference to Table 2, it can be observed that FDM was the dominant 3D-P technology suggested – it resulted in eleven out of seventeen case studies (65%). This was followed by SL (24%). In terms of the application areas one can observe overlaps and hence sub-groups. For instance, in six case studies, a medical-related theme was proposed. Since this resulted to be the dominant area, it is recommended that at least one of the candidate case studies comes from this sub-group. Another sub-group emerged, constituted of the case studies no. 4, 10 and 15, in which assembly models coupled with the use of FDM, were recommended.

There were a number of case studies which either make use of readily available on-line models (e.g. in case studies no. 5, 9, 13, 14 and 17) or models which have been developed at universities (e.g. in case studies no. 1, 2, 6) or even industry (e.g. in case study 12). Copyright might be a big hurdle in the latter two cases. In the case of on-line models, whilst in some cases it does not make sense to alter the original model (e.g. in the case of the human heart or skull), in certain examples (e.g. one-handed bottle opener and assembly mechanisms), students can alter or even come up with their own designs. This is advantageous for various reasons – firstly it avoids any copyright issues, secondly creativity is promoted. In addition, if all the case studies selected use readily

available on-line 3D models for 3D printing, the wrong message might be conveyed at the end of the project, particularly when disseminating the project results.

Another observation made was that two case studies (no. 1 and 11) proposed the use of multiple 3D-P technologies. Whilst it can be argued that this will be advantageous as students will be exposed to a wider spectrum of technologies, accessibility can be an issue in view of the advanced industrial printers proposed (EBM and metal SLS). Interestingly, case study no. 8 promoted the use of 3D-P technology as a complementary process to another manufacturing process – metal casting.

7.0 Conclusions

The report provides a formal set of guidelines for vocational students and trainers, together with a set of case-studies which can be exploited to educate and make students aware of the potential of 3D-P technology in a range of application sectors. The training needs presented in this report can be summarized as follows:

1) it is mandatory for the project's target groups to gain an understanding of the terminology used for the 3D printing technology;
2) the 3D-P course shall equip vocational students with 3D printing specific skills related to ICT, engineering and technology;
3) take into account the intention of the trainee (i.e. to generate a 3D physical from an existing file, to create a functional model etc.)
4) provide practical knowledge and understanding of the 3D printing technology: process steps, file types used, 3D printers, materials, software, printing services, printing recommendations, applications etc.;
5) tailor the programme to beginners, intermediate and advanced users;
6) give the opportunity to students to unleash their creativity, not just by using a 3D printer, but rather by going through conceptualising – CAD modelling – prototyping cycle;
7) 3D printing technology employed should be easily accessible by students, in particular home/desktop FDM printers;
8) course graduates should have the possibility to have their skills certified at European level;
9) specific skills for manufacturing, design and engineering are required by the 3D printing market, this it is mandatory to involve 3DP producers, large service bureaus or networks, 3DP services providers etc., who need to hire vocational students, adults etc.

Based on the analysis in Section 6.1, including the best practices identified and the three review criteria, it is concluded that if six case studies are shortlisted they will be as follows:

- Case Study nº7 - map of Lithuania (or any of the partner countries) - puzzle created, designed and printed;
- Case Study nº4 - direct 3D printing of assembly models;
- Case Study nº2 - 3D Printing of a multi-material architectural model (but using typical students' projects as exemplars);
- Case Study nº9 - exploiting SL for accurate 3D printing of a one handed bottle opener/mobile phone support;
- Case Study nº14 - 3D Printing of a realistic human heart for educational purposes;

- Case Study nº8 - the bottle cork.

As a final remark, it can be concluded that this report contributes a step for the consortium to identify the training needs for 3D printing in vocational education training. Nevertheless, to assess the validity of the training needs, as next action, the guidelines will be assessed by interviewing relevant stakeholders. In addition, the case studies are subject to further objective scrutiny by the consortium. Finally, to gain more accessibility and visibility of potential stakeholders who can provide feedback in this project, it is suggested to submit proposals to employers' associations to include 3D printing operator and 3D printing specialists in the national lists of occupations.

- End -