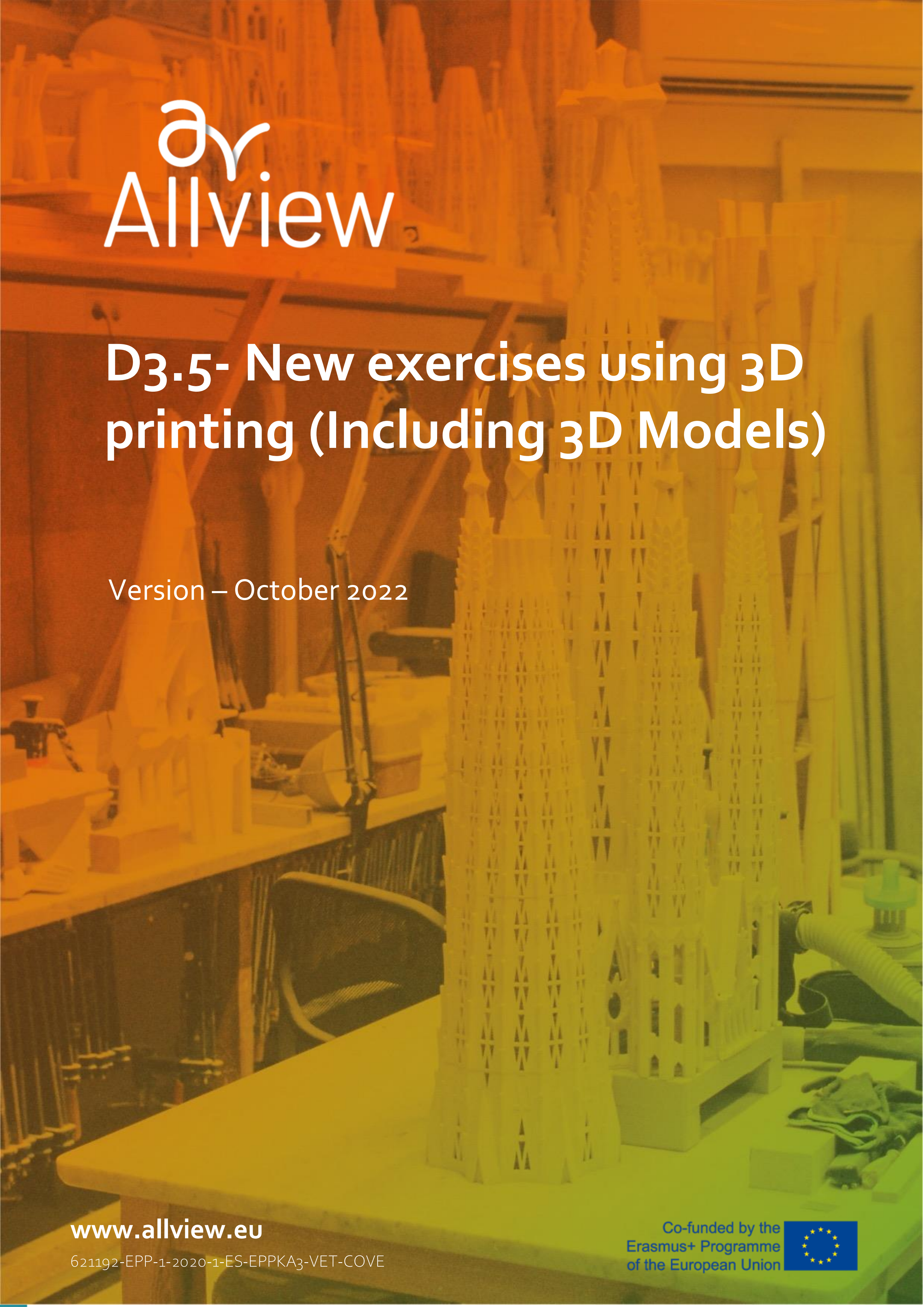

Allview

D3.5- New exercises using 3D printing (Including 3D Models)

Version – October 2022

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The ALLVIEW project is a new transnational cooperation platform that connects Centres of Vocational Excellence (CoVEs) within the wood and furniture sector. ALLVIEW has operational objectives on a regional, national, and European level which aim at an innovative approach to modernising vocational education and training.

1

Introduction

Introduction

This document reports the results performed in task **"T3.4: 3D printing set of exercises"** in the framework of the **WP3 "KET kit for training in the F&W sector"**.

One of the objectives of this work package was to research new teaching methods based on the project approach and in which students and teachers use Industry 4.0 technologies as enablers in the classroom. In the field of education, the use of technologies such as 3D printing improves performance, the learning process, the development of skills and a greater engagement of students and teachers with the subject matter. In addition, 3D printing stimulates creativity and collaborative problem solving.

As a result of this task, 14 exercises on 3D printing have been defined, designed, and printed. The set of 3D printing exercises will allow students to reinforce concepts related to wood and furniture but will also serve to introduce them to the world of 3D printing itself. This is very important, as additive manufacturing has proven to be a mainstay in the furniture and wood sector.

The procedure followed by the consortium in carrying out this task was as follows:

→ Creation of a template with which to define the exercise at three levels: description of the idea and model, graphic definition of the exercise, and specifications for its use in the classroom.

→ Identification of subjects or topics mainly related to the furniture and wood sector for which exercises would be created.

→ Identification and description of the exercises on a theoretical, graphic, and educational level following the template.

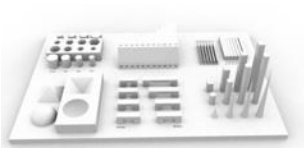
→ 3D design of each of the models that make up the 14 exercises.

→ 3D printing and testing of the exercises.

→ Compile all definitions and .STL files of the exercises for free dissemination through the e-Learning platform of the ALLVIEW project.

This document is the second deliverable of the task **T3.4. "Set of exercises with 3D printing".** In the first deliverable ***D3.4 "Definition of new exercises with 3D printing"*** a generic introduction to the identified exercises was made. In addition, the methodologies for their insertion in the classroom were identified, as well as the main learning outcomes and benefits that students will obtain through this technology and these exercises. With this second deliverable of task T3.4, taking the previous report as a starting point, the aim is to make a progressive immersion in additive manufacturing technology. The reader will acquire the necessary knowledge about what this technology is and how it works (section 2), the main applications within the furniture and wood sector (section 3), and the benefits of its use in education (section 4). In addition, the 3D printing exercises developed in this work package are included (section 5). We believe that this material will bring added value to those schools and teachers who want to get started in this field.

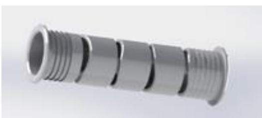
The definitions of the 14 exercises can be found at the end of this document and all models can be downloaded in .stl format via the following links. In addition, both documents will be available on the Allview e-Learning platform.



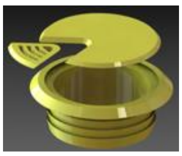
Setting up a 3D printer for printing dedicated to the furniture sector — Link

Materials and finishing dedicated to 3D printing (FDM) — *Link*

Eccentric Connector — *Link*

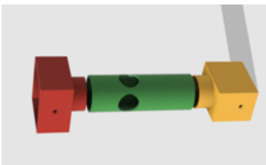
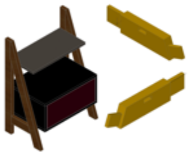
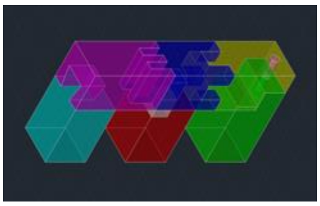


Cable Route — *Link*



Cable Groumet — *Link*

Prototyping in 3D printing — *Link*

	Design of furniture with complex geometry in 3D printing	*Link*
	Chair repair connectors	*Link*
	Furniture design with 3D printed connectors	*Link*
	Furniture design with 3D printed parts	*Link*
	Chair design with 3D printed connectors & simple wooden elements	*Link*
	Parametric design of 3D printed furniture-meeting ergonomics and standard requirements	*Link*
	Assembled Pieces for furniture design	*Link*
	Technical drawing and wood workshop for the disabled people	*Link*

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2

What is 3D Printing and How it works?

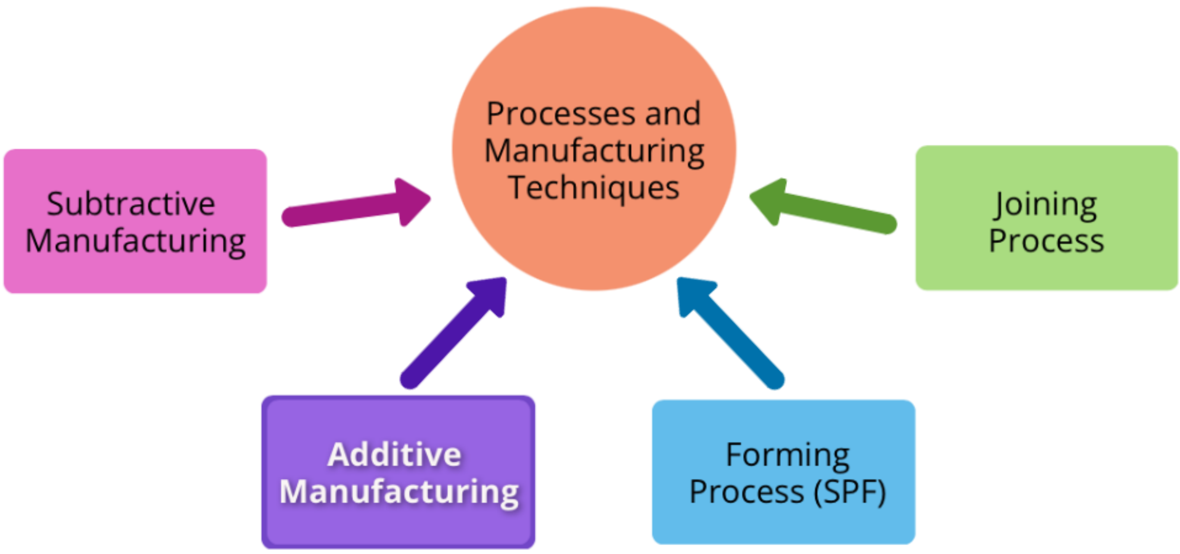
What is 3 Printing and How it works?

Additive Manufacturing or 3D printing (commonly called) is a process that creates a physical object from a digital design. There are different 3D printing technologies and materials you can print with, but all are based on the same principle: a digital model is turned into a solid three-dimensional physical object by adding material layer by layer [1].

It is important to point out from the beginning that Additive Manufacturing does not constitute a single technology but a set of manufacturing processes, very different from each other, that share three common characteristics:

- They are manufacturing processes by addition of material to construct a solid three-dimensional object.
- The object is constructed by superimposing successive layers of material.
- The object is made from a digital 3D model.

They are called ADITIVE Manufacturing processes to differentiate them from conventional processes. Together with these, they are part of the set of processes available to the industry.



Scheme 1: Processes and manufacturing techniques.

Some of the most used Additive Manufacturing technologies that best suits to the educational area will be described in the following point of this guide. These technologies are: Fused Deposition Modeling (FDM), Stereolithographic (SLA) and Selective Laser Sintering (SLS).

Figure 2: FDM Printer [34].

Figure 1: SLA Printer [36].

Figure 3: SLS Printer [35].

HOW DOES 3D PRINTING WORK?

It all starts with making or obtaining a virtual design of the object you want to create. This virtual design can be made in a CAD (Computer Aided Design) file using a 3D modeling software (for the creation of a totally new object) or with the use of a 3D scanner (to copy an existing object). A 3D scanner makes a 3D digital copy of an object. There are also lots of online file repositories where you can download existing 3D files that will help get you started.

The 3D printing process turns an object into many, tiny little slices, then builds it from the bottom up, slice by slice. The layers then build up to form a solid object [2].

Some advantages of Additive Manufacturing compared to conventional processes:

- Fewer steps between the CAD model and the production of the part.
- Generally, few human resource requirements due to a high level of automation.
- A large number of geometrical forms can be manufactured, enabling for instance the production of parts which are topologically optimised, with internal channels, etc.
- High-speed manufacturing for small, complex parts.
- Generally, less material wastage.
- Possibility to reconstruct damaged sections of existing objects, depending on the part material.
- No special tooling required.

The 3D printing technology that is most suitable for educational purposes due to its versatility, ease of use and price is FDM (Fused Deposition Modelling). Based on this technology, the following pages describe the production process for the 3D printing.

FUSED DEPOSITION MODELING (FDM)

Home printers typically work with plastic filaments. The technology behind this, is often referred to the Fused Deposition Modeling (FDM); a 3D printing technology that works by extruding a thermoplastic polymer through a heated nozzle which gets deposited on a building stage. FDM is also considered to be a form of additive manufacturing, which at the same time is a "process of joining materials to make objects from 3D model data, usually layer upon layer".

Creating a 3D printed object through FDM requires, in the first place, to work on a STL file (stereo lithography file format) which mathematically slices and orients the model for the next building process. Sometimes, the software is capable of generating support structures for the object automatically. In general, the machine requires materials for both the object and the support [3].

The mere process involves a plastic filament which is fed by a spool to the nozzle where the material is liquefied and "drawn" on the platform. As soon as it touches the build stage, the filament hardens while being gradually deposited, following a certain structure, to create the final 3D print. When a layer is drawn, the platform lowers by one-layer thickness so that the printer is able to start working on the next layer.

There are many different materials which can be used with FDM. In the first place, they are divided between the industrial and the consumer categories. The most commonly used are ABS (Acrylonitrile Butadiene Styrene), PLA (Polyactic Acid) and Nylon (Polyamide), but other exotic varieties of materials can also be used, like a material blend of plastic and wood or carbon [4].

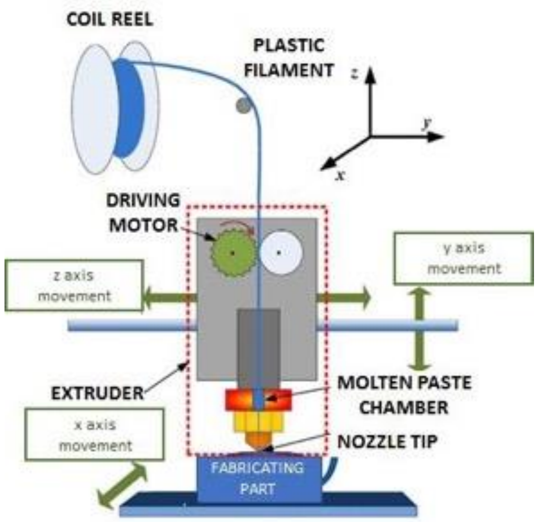


Figure 4: FDM Technology [5].

PROUCTION PROCESS IN 3D PRINTING

This section describes all the processes and steps necessary to obtain a real printed part from a digital design. It is important to mention that there is no single valid process for printing three-dimensional parts. What is explained here is a series of steps that must be adapted to the type of part, the selected technology, the type of machine, and even the software used. In addition, the process described below is primarily intended for fused deposition (FDM) 3D printers.

In the 3D printing production process, experience, the characteristics of the part, the machine used, etc. have a lot of weight. It is certain that someone with little or no experience will 3D print many faulty parts before finding the key. The production process, in general, is as follows:

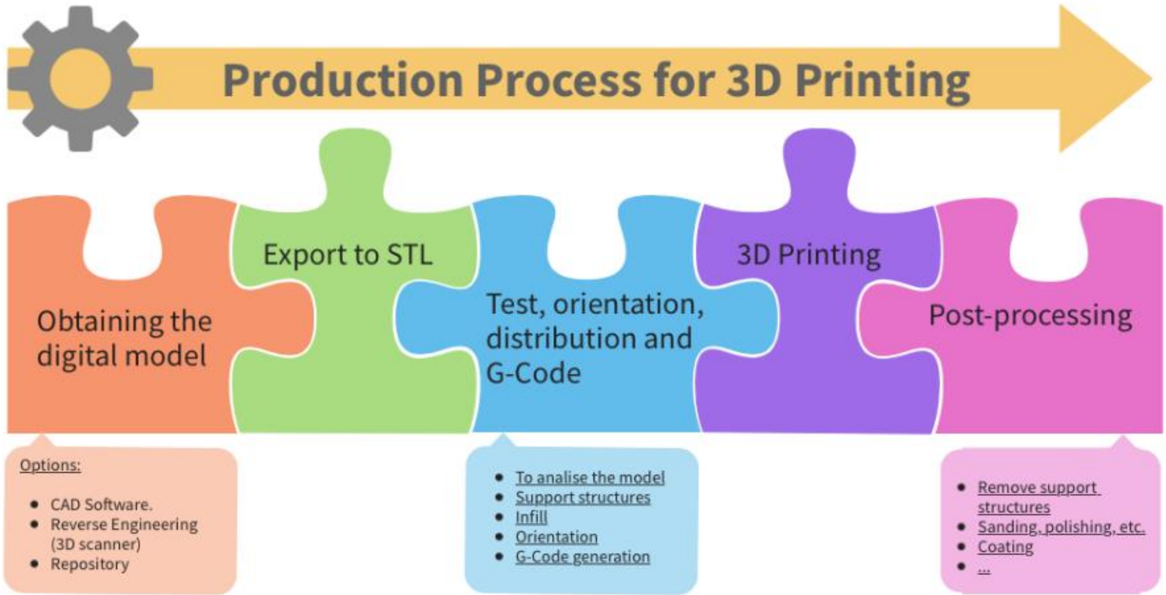


Figure 5: Production Process in 3D printing.

Obtaining the digital model.

There are several possibilities for obtaining the 3D model or digital model that is wanted to print. Specifically, there are three possibilities:

<u>To model the piece using a CAD software:</u> With this first option, in order to get the three-dimensional model, a computer aided design (CAD) software must be used. There are a lot of available CAD software for modelling, and there is not a best option; it will depend on the user and their abilities with the software.

<u>To obtain the geometry by Reverse Engineering and 3D scanners:</u> By this option a 3D scanner is used to digitally obtain the geometry of a real object. This is not a simple process, and some ability

and experience are required. In addition, there are several types of 3D scanners, and they are usually expensive.

The reverse engineering process usually is for copying, improving, or customizing real objects, or also for incorporating complex surfaces to a 3D modeled piece.

Downloading the model from repositories or asking someone to design it for you: If you do not have knowledge in computer-aided 3D design, or you do not have the necessary equipment (or software, or even knowledge) for applying a process of reverse engineering, to download the model from a repository or to ask somebody to design it for you is the best option. Depending on whether the repository is a 3D printing model repository (e.g.: Thingiverse) or a more general digital model repository (e.g.: GrabCAD), the downloaded model will be ready for 3D printing, or it will be not.

In the next tutorial it can be seen a range of CAD design tips for 3D printing, depending on the material selected: *https://www.sculpteo.com/en/materials/materials-design-guidelines/*

And in the next link it can be found more information and more tutorials about how modelling and preparing a piece for being 3D printed by different CAD software:
https://www.sculpteo.com/en/tutorial/

Exporting and repairing the STL file.

When you work designing and printing 3D models, a wide range of formats or types of files are available. Some of them are thought for designing or scanning, but others are associated to 3D printing, such as: STL, OBJ, PLY or FBX, among others. Depending on the modeled piece, on the software, on the 3D printer features, etc., one or another format must be used. In this guide, to unify criteria, it is explained how to export and use the STL file.

When the piece is designed and modeled, a format conversion to the ". stl" file is needed. If the piece has been downloaded from a repository, this conversion is frequently already done. However, if free or commercial CAD software has been used this conversion is needed.

Normally, exporting a CAD design to STL format is as simple as going to the used software menu and clicking on "Save as..." or in "Export" and choosing STL.

Sometimes, there are problems during conversion to STL, either because the model is not thought for 3D printing, either because the design in the CAD software has not been made correctly, or either other cause. So, the exported model may have some errors. These errors are of various kinds: holes or gaps, reversed triangles, duplicated faces or triangles, faces or triangles that intersect, singular points or faces (out of the model), etc.

The digital model reparation is explained in the next step of the production process in 3D printing because it is very linked to the implementation of analysis to the pieces.

Testing, orientation, distribution, and G-Code.

This stage of the production process in 3D printing is about the preparation of the pieces or digital models (previously exported to STL) for being 3D printed. It is about performing the next process, orderly:

Analysing the piece or model.

The analysis usually is necessary when pieces are relatively complex, or when the origin of the pieces is not known, or it can be done just if you want to be one hundred per cent that the piece is suitable for being 3D printing. In addition, a good analysis can detect errors in the triangle mesh arisen from the STL conversion.

Normally, this analysis is carried out with some software, which can also be useful for other purposes. Implemented analysis of:

Thickness: Recommended thickness depends on the 3D printing machine (and frequently on the used technology). Some machines allow to bigger thickness than others. To search the specific machine and to see the allowed thickness should be enough. Generally speaking, for fused deposition modelling (FDM) machines, thickness about 1 millimetre should be considered, approximately. This parameter must not be confused with layer thickness.

Holes or gaps: The model want to be printed must be perfectly closed, or best said: it must be watertight. This means that the triangular mesh must not have holes or gaps, or what is the same, it must not have vertex or triangle points not joined; every of them must be connected to other triangles.

Angles and overhang: By this analysis it can be found, depending on the selected technology and machine, if the model or piece will need of support structures for being printed. Generally, for FDM printers the minimum allowed inclination angle is 45 degrees.

Finally, it is noticeable that many of the used programs for analysing the piece allow, not just to detect errors or problems, but also allow to repair, or what is best, auto repair the model.

Support structures.

For some technologies, it is necessary that, in order to beat gravity and to print overhang parts (or with internal gaps), support structures are inserted on these zones. They are usually necessary from 45 degrees (for FDM printers).

Figure 6: Support structures [6].

Support structures are usually done by the same material as the piece, although there are 3D printers that print two materials: piece's one and support structures one. With these printers soluble support materials in certain liquids can be used.

As support structures are thought just for holding the first layers of the model that are cantilevered or "floating", support structures are built lightly and using less material than for the piece itself. In addition, they will not mark so much the piece when they are removed.

Most of the available software, either analysis software or either the own software of the printer machine, allow two options: making a design of the support structures, or automatically calculating and inserting these structures.

A good guide for designing, using and calculate how and when using supports can be found in the following link: https://www.3dhubs.com/knowledge-base/supports-3d-printing-technology-overview.

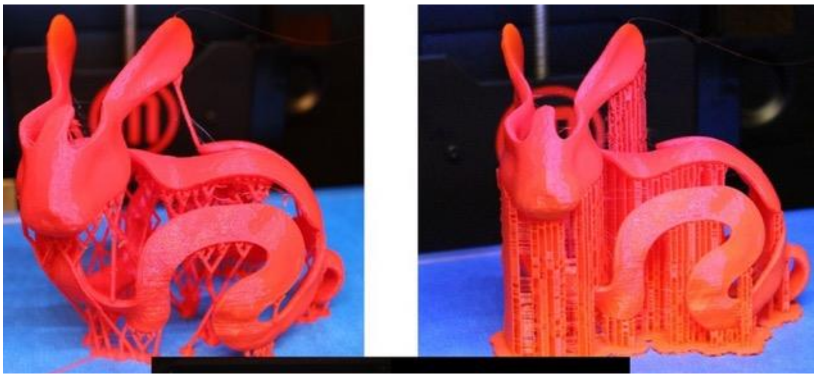


Figure 7: Differences between a piece with optimized support structures (left) and non-optimized (right). Differences between printing times can also be seen [37].

Model infill.

When we talk about the infill it is about the structure printed inside the object. It means, if we think in the example of a cube, the six external walls will be printed in a solid way, with a certain thickness, but the internal part of the cube will not be solid; you will have to choose the infill percentage, and even the geometrical shape of the infill.

The geometrical pattern of the infill can be also chosen. Some of them are more resistant than others, but generally, the default pattern of the software can be selected.

Percentage and pattern shape will be chosen according to several aspects: total weight of the piece, used material, resistance to be achieved, printing time and sometimes decorative features. In general, the greater the infill percentage, the stronger the printed piece will be, but the longer will take to be printed. A percentage about 15% usually is enough. Hereunder some examples can be seen (on software and on printed pieces):

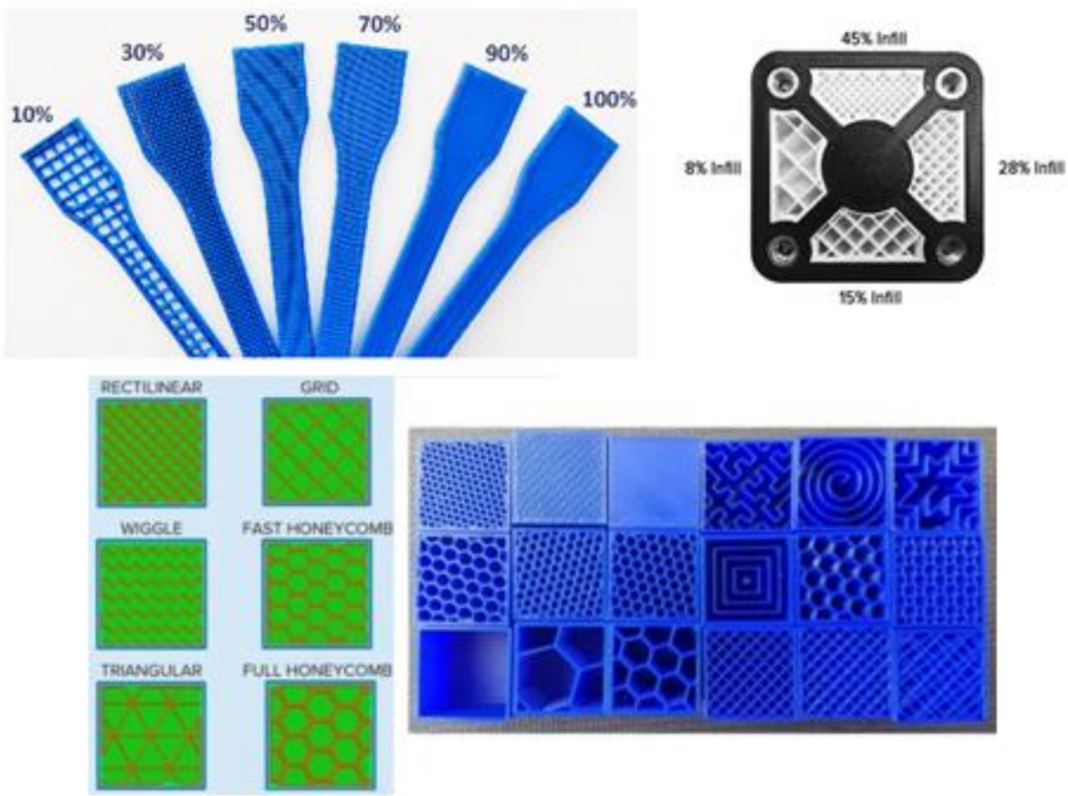


Figure 8: Different infill percentages and patterns [7] [8] [9].

Positioning and orientation.

To decide the position and orientation of the piece on the printing surface or printing bed is one of the most important parts of the whole process. It is a decision that will have a great impact on the piece quality and properties.

One of the most used criteria for choosing position and orientation is using the minimum amount of material (and spending less printing time). This is achieved by minimizing overhang parts. Consequently, less support structures will be printed, and the piece will be built in less time. However, sometimes quality to achieve is more important, so that orientations that are not optimal in terms of material and printing time, can be chosen.

Some tips, in a general way, are:

To center the pieces in the printing surface or bed surface. This will reduce the movements of the printing head (and, consequently, the printing time). Furthermore, it will increase the quality and precision of the piece because printing platforms are usually more levelled and calibrated in its central part, and because if they are heated, heat is greater in the central part.

If there are curved or sloped surfaces, and these parts of the piece are desired to be printed with quality, piece should be positioned so that these surfaces are positioned on XY plane (horizontal plane), or as parallel as possible to this plane. So "stair-stepping" effect will be avoided, in which curved or sloped surfaces are not smooth.

Watching the previous picture, if the piece has an inner hole, or a through hole, it would be adequate to put this hole with its axis perpendicular to the printing bed, if a great quality is required in the hole surface.

A very long and plane section printed on the horizontal plane or XY plane may suffer deformation, which means that its outer borders get cold and shrink very quick, causing the piece to warp upwards. Sometimes, to print these pieces so their longest section is perpendicular to the building plate is convenient.

In a general way, the top surface of a printed piece will have the best finishing.

If we are printing functional pieces, that have to withstand forces and loads, it is much more likely for them to de-laminate and to break when the forces or loads are perpendicular to the layer's direction.

Generating the G-Code.

Once all the previous steps have being developed, it is time to generate what is known as G-Code or machine code. This code is the translation of the piece (and all the parameters that have been previously set) into instructions that the machine can understand.

Before that, depending on the used software, it is necessary to choose the layer height or layer thickness. This parameter has also a lot of importance and it will have a great impact on the final quality of the surface of the piece. A higher layer height will result on a great resolution or quality, but also will result on a greater printing time.

It is quite important to understand what is more important: aesthetics or a quick and cheap printing. Sometimes, differences between two identical pieces, but with layers height of 100 microns and 200 microns are hard to distinguish. But the 100 microns piece will take the double to print and will cost more. Therefore, it is very important to know what the final use of a piece is. It is also crucial to know the amount of curves and angles of the piece, because the layers height is more visible on these parts than on straight walls.

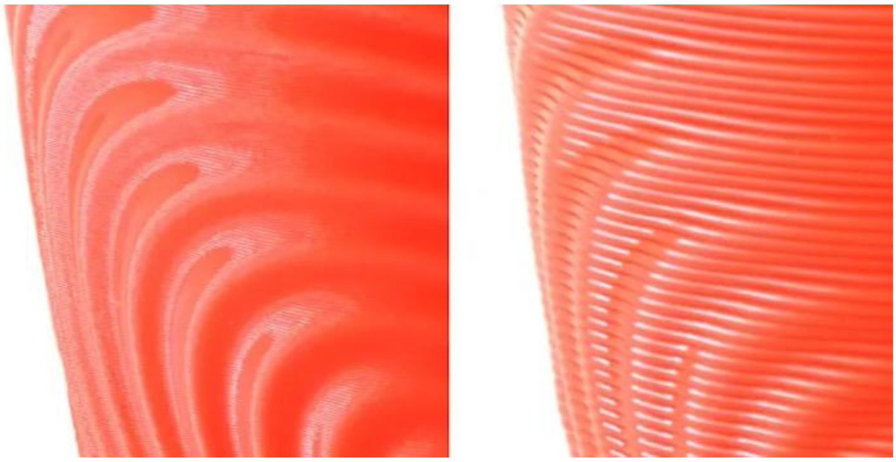


Figure 9: 0,2mm Layer Height (Left) vs 0,9mm Layer Height (Right) [10]

To sum up with the layer height matter, it is noticeable that for each machine and technology a certain range of layer height values is available to be chosen. For example, for FDM, a very common range is from 50 to 300 microns (0.05 to 0.3 millimetres).

So, at this point the G-Code must be generated, and this can be done by various software. Probably, some of the programs to be used may have already be used in a previous step. The software cuts the model into horizontal "slices" or layers, generating the path that the machine head will follow. It also calculates the amount of material (weight and metres) and the estimated printing time.

With the chosen program, the G-Code is exported and saved, in a SD card or in a pen drive. Or it can be also directly sent to the machine, depending on the software and machine.

To sum up this part, it should be taken into account that there are a lot of parameters that can be changed: wall thickness, printing speeds, printing temperatures and bed temperature, flow, etc. But these are parameters to edit by users with experience, and it is advisable to let them default.

3D printing.

Now the G-Code has being obtained the process of 3D printing can be implemented. There are a few things to consider and to check before printing. For FDM printers, the temperatures of the bed or printing platform and of the extruder must to be checked (the software or the printer do that automatically when you start to print). To use some kind of lacquer or varnish is also recommendable in order to extract the piece easly. It is advisable to read the instructions to also know how to load the filament on the printer for example, and for further information. Therefore, the G-Code is sent to the machine, and the machine starts to work.

Extracting pieces.

When the printer has already finished, it is the moment to implement the process of extracting the piece/s. Once again, depending on the machine and mainly, on the technology and used materials, the extraction processes will vary.

For fused deposition modelling machines (FDM), pieces often are removed by hand, or with some tool like a blade. It is also possible to have flexible platforms that ease a lot the extraction. There are even other methods such as using a solvent or applying cold or with dental floss.

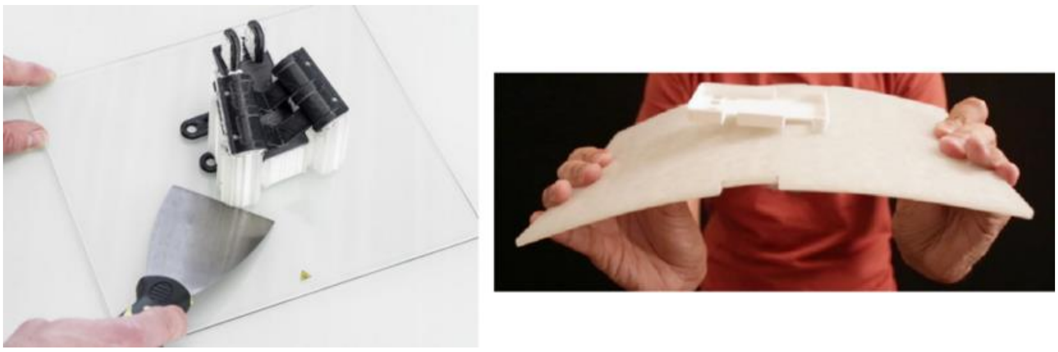


Figure 10: Extraction [11] [12].

Post-processing.

For a lot of pieces, a finishing process is needed, that once again varies along the kind of technology and kind of machine. For some technologies and machines this process is necessary.

First of all, it is important to note that some of the printed pieces may not need a post-processing step. Or maybe some of them will need just to remove mechanically the support structures.

There are a lot of finishing processes and post-processes:

- Remove support structures: this can be done mechanically, as it has been said, or using a solvent bath (even water), if the printing material is the adequate one.

Figure 11: Mechanical process and bath for removing the support structures [13] [14].

- Sanding: it is a process to apply when the support structures have been already removed. Several sanding grades can be chosen.
- Polishing: if the piece is wanted to have a "mirror-like" surface it is necessary to polish the piece. It is needed to sand the piece with a sandpaper of number 2000, previously. Then, the powder should be cleaned, and the piece will be polished with a microfiber cloth and a special enamel, which will produce a lasting shine. There are also rotary sanders and polishers.
- Coatings: all the pieces are capable of applying a coating. In the case of paints, it is advisable to apply first a coat layer and then to paint with aerosol, acrylics, or airbrushes. Epoxy gels, metal coatings, etc. are also available [15].

Figure 12: Different finishing [16].

There are more finishing processes: shot blasting, smoothing with acetone vapour… For knowing more post-processes for FDM technology the following link is provided: *https://www.3dhubs.com/knowledge-base/post-processing-fdm-printed-parts*

Allview

3

Application of AM in the furniture and wood sector

Application of AM in the furniture and wood sector.

This chapter presents a significant sample of uses and applications of additive manufacturing in the furniture and wood sector that refer to the most fundamental and revolutionary aspects of this method, such as energy efficiency and, respect for the environment, product tailoring and agility in the creation of new products.

In a first group we have those solutions that refer to ecology in all its aspects, such as energy efficiency and material efficiency - as it is an additive process by layers, only the necessary amount of material is used and little waste is generated, therefore generally recyclable. In this group we can find the reuse of waste as raw material for the creation of new objects; eco-design focused on the modularity of furniture and its connecting pieces to promote reuse and recycling and reduce the carbon footprint; the creation of spare parts to promote the reuse of furniture and reduce the volume of waste generated. All these actions are perfectly aligned with sustainable design of products and social economy.

This group includes the following sections:

1. Connecting parts to facilitate the assembly and transport of furniture
2. Fittings and replacement parts for furniture repairs
3. Reuse of waste in furniture manufacturing

The second group refers to the capacity for customization and adaptation to the user that additive manufacturing allows. This second group includes solutions that make it possible to reduce production batches without the need to create new molds or constantly adapt tools or installations; applications that make it possible to adapt and personalize products according to the preferences or needs of the end user while enriching the product itself by providing more functionality and improving its usability; solutions that allow a high degree of creativity and innovation in the design and materials used in the furniture itself.

The sections that are included in this group are:

4. Furniture accessories
5. Ergonomic adaptation of furniture
6. Introduction of new materials in furniture manufacturing
7. Customization of furniture and reduction of production batches

The third group, finally, shows a series of applications related to the new limits that additive manufacturing brings to the production of furniture, allowing professionals and users to create in a more agile, fast, and comfortable way products that until now were not possible to manufacture or required high constructive requirements. This group includes solutions related to the creation of prototypes with a low cost and execution time but with high fidelity to the final piece of furniture; the production of efficient assembly solutions but without the need of complex machining in the different parts of the furniture; the application of complex geometry for the production of furniture that allows to reduce the number of components and can also provide a high structural rigidity to them without the need to invest a lot of raw material in the product.

The following sections are included in this group:
8. Furniture design and prototyping
9. Assemblies with complex shapes (grooves, dovetails, dowels, ...)
10. Furniture with complex geometry
11. Lightweight but strong structures for furniture

Additive manufacturing applications in the furniture and wood industry.

1. Connecting parts for easy assembly and transport of furniture.

Additive manufacturing allows the application of a unique connectors design that can be adapted to the geometry of the pieces to be joined, simplifying the rest of the materials used for the production of the furniture, which can be printed by the manufacturer or even by the customer himself/herself. They provide a great ease of assembly and transport due to the simplicity of the rest of the pieces to be assembled, which can be simple boards or straight beams.

Figure 13: Table by Studio Minale-Maeda made of wooden tabletop and beams and printed connectors [17].

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Figure 14: Detail of the connectors obtained by additive manufacturing by Studio Minale-Maeda in 2014 [17].

This application also allows the composition of modular furniture, using the 3D printed connectors to combine the modules of a product in multiple ways and providing great versatility to the minimum number of pieces required.

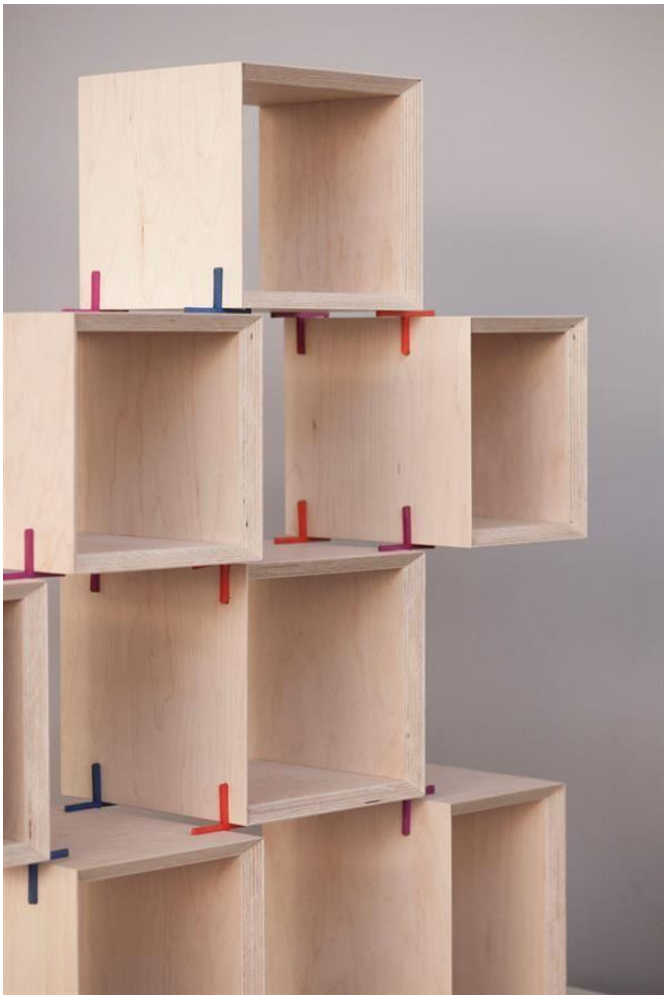


Figure 15:Modular shelving + Shelf created by Vera Shur [18].

2. Fittings and replacement parts for furniture repairs.

Additive manufacturing is very useful for the creation of fittings or specific parts for the reparation of furniture or parts of them. The breakage of an element can be remedied with the use of an ad-hoc printed part to maintain the stability of the furniture, but it can also be the only possible solution in the case of the need to replace an entire part that is out of stock due to its age.

Figure 16: Hanging rail bracket for Ikea wardrobes by the Dutch designer Peter Uithoven [19].

3. Reuse of waste in furniture manufacturing.

Another notable application is 3D printing of street furniture using a printing filament made from the plastic waste of city inhabitants. This practice highlights the key role that 3D technologies can play in preserving the environment and creating value in the sector.

Figure 17: Urban bench in Amsterdam, created by The New Raw studio from recycled plastic [20].

Figure 18: Urban bench in Thessaloniki, Greece, created by The New Raw studio from recycled plastic [21].

4. Furniture accessories.

Additive manufacturing is also a good solution for the creation of furniture accessories, especially for office furniture, such as cable holders, hooks for personal items or discreet cable grommets. The use of additive manufacturing allows accessories to be fully adapted to the existing furniture, improving its usability without the need to modify it too much or at all.

Figure 19. Parameterized hanger design for all types of furniture by the French designer and artist Serge Payen [22].

5. Ergonomic adaptation of furniture.

One of the solutions provided by additive manufacturing in relation to personalization is the customization of furniture but according to the particular ergonomics of each user. The user scans and sends the company the data for the production of each particular piece of furniture.

Figure 20: Ubik, IKEA's 3D printed gamer chair customized for each gamer [23].

6. Introduction of new materials in furniture manufacturing.

The use of this new production method also allows the introduction of new materials with different properties and innovative aesthetics in the field of furniture.

Figure 21: Printed concrete benches with a complex weave pattern, by the startup XtreeE in collaboration with the design studio Studio 7.5 [24].

7. Customisation of furniture and reduction of production batches.

Nowadays, production batches have been drastically reduced to unit batches in order to satisfy end-user demand for customized products. Additive manufacturing has the ability to offer such customization without the cost implications of other manufacturing methods used to date. Through additive manufacturing, unique and customized products can be achieved without adding hours and production costs to the final product.

Figure 22: Di-lamp lamps created by Pierre-Yves Jacques, founder of the LPJacques design studio, customisable in design and colour by customers [25].

8. Furniture design and prototyping.

This manufacturing technique can be used to achieve the unitary production of furniture, on a scale or real size, for the stages prior to production. This stage of prototyping using 3D printing reduces the time and costs of product development due to its versatility and capacity to reproduce new and complex shapes, as well as speeding up product marketing times, since the customer can evaluate the product on a physical and reliable replica of the future piece of furniture. Furthermore, with this prototyping system, products can be tested under real conditions of use in order to foresee future behaviour of the components or materials.

Figure 23: HOSU office solutions prototype of a 7 cm highchair [26].

9. Assemblies with complex shapes (grooves, dovetails, dowels...).

Joints are the most complex and sensitive part of any object and by means of additive manufacturing it is possible to achieve angles and assembly shapes that perfectly fit the constructive needs of each piece of furniture. Without the need to screw, drill holes or add glue to the joints, entire pieces of furniture can be produced by printing joints for the assembly of larger elements.

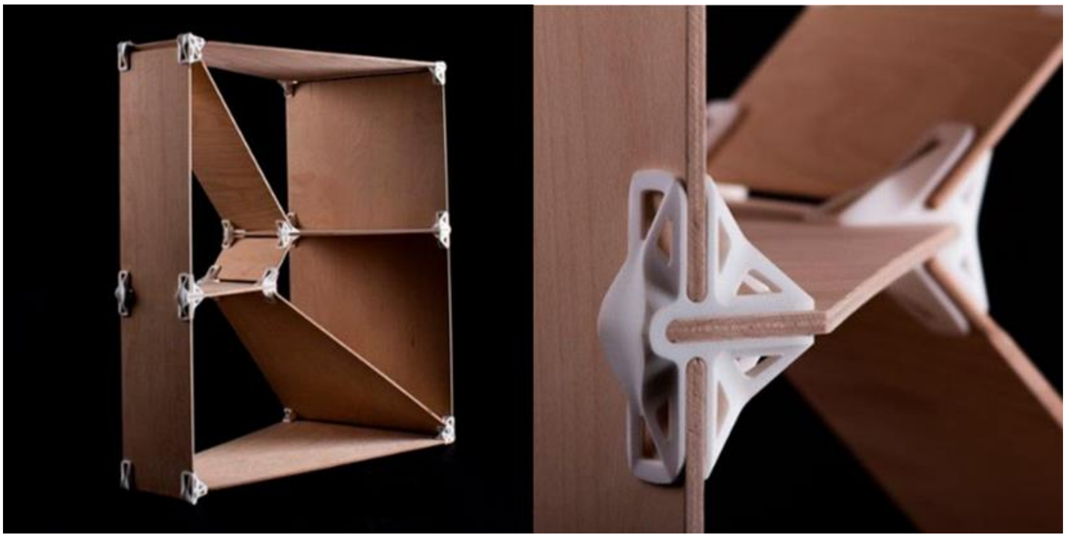


Figure 24: Collection of joints for the assembly of different materials by Hungarian industrial designer Ollé Gellért [27].

Figure 25: Connecting parts for three-dimensional assemblies created by Jean-Charles Rodinger's Alternative Design Lab [28].

10. Furniture with complex geometry.

Additive manufacturing enables one-piece printed furniture that allows a higher degree of complexity in terms of geometry and at the same time sets no limits in terms of creativity for designers. Using various techniques, such as FDM (Fused Deposition Modeling), and printers of the right size, all kinds of geometries can be created in a cost-effective and resource-efficient way.

Figure 26: Ocke Series Collection with complex geometries by designer Beatrice Müller [29].

Figure 27: Table that imitates fabric produced by a FDM (Fused Deposition Modeling) process, from Berlin-based start-up BigRep [30].

11. Lightweight but strong structures for furniture.

Another application of additive manufacturing in relation to complex geometries is the production of strong structures that can support the weight of dense woods or other materials but are also lighter and less bulky than traditional support structures due to their geometrical optimization and the properties of the printing material.

Figure 28: Table designed by the London studio Aleska, with a light structure and walnut top [31].

4

3D Printing in Education

3D Printing in Education.

3D printing has already found applications in many fields, for example in design and applied arts, where it allows the creation of 3D models at an early stage of product development, without the need for expensive moulds. In mechanical and electrical engineering, 3D prototyping is the most cost-effective option [32]. It allows architects to create detailed models that have the strength and durability needed. In medicine, 3D printing allows the creation of anatomically accurate models and replicas specific to the patient and their medical condition [33]. It is a more practical, flexible, and cost-effective option for producing almost any product in small batches.

3D printing is a technology that is becoming more and more widespread, with practical applications in many sectors. Besides technical uses, the use of 3D printing as a support tool in education is also widespread. Benefits include increased student engagement, the ability to visualize and better understand theoretical concepts, and the integration of practices and theoretical skills.

In education, 3D printers can be used in many fields. What 3D printing allows is the visualization of one's concept ideas as well as the plastic transformation of real material objects into new, original tactile forms and the visualization and translation of complex objects into a three-dimensional experience.

Advantages and opportunities of 3D printing usage for students.

3D printing is about creativity and innovation, allowing every student to express their ideas or concepts in a physical, realistic space. Thus, 3D printing allows and encourages different approaches to learning: visual because it implies sketching, designing, and modelling of selected 3D objects; kinaesthetic because it implies a concrete manipulation; logical (mathematical) because it implies the creation and solving of problems; social because it implies the differentiation of ideas, approaches, and solutions; constructivist because it implies the planning and design of new ideas and concepts through critical thinking [34].

This type of technology in education helps to develop skills and increase the engagement of both students and teachers in the subject. 3D printing is the process of creating three-dimensional parts of virtually any shape from a digital model, which must, of course, be created in 3D software beforehand. 3D modelling stimulates young people's imaginations and further enhances their creativity and practical skills. It is an interplay between fine arts, physics, mathematics, chemistry, and other subjects, as each of them requires certain knowledge about design, structure, materials, etc.

Advanced schools that have started using 3D printers in their teaching have found that students who print objects with 3D printers are much better at using the tools to make 3D models. This is because they can see the benefits of this skill set when they can get real and tangible objects. Additionally, children discover for themselves how many products may be manufactured and constructed, as opposed to merely being consumers of finished goods [35].

Students with access to a 3D printer are considerably more comfortable with 3D modelling software, as 3D models are no longer merely virtual items on a computer screen, but are eventually transformed into real, substantial objects.

The applications of 3D printers in schools are numerous; for example, 3D representations of molecules and complex proteins can be utilized in chemistry lectures. For mathematics, a variety of geometric shapes can be printed. Planet models in the appropriate size range can also be printed. Many instruments can be manufactured after the models are completed, and a school assembly using just 3D printed instruments is also possible.

Students that are exposed to 3D printing technology study and use cutting-edge technologies utilized in sectors such as the automotive, aerospace, fashion, military, and medical domains. This indicates that the use of 3D printing technology in the classroom is essentially equivalent to what industry professionals are already doing, therefore the skills acquired are highly relevant to professions that are in high demand now and will continue to expand in the future (ibid).

Through open-source 3D printing communities, children and young people should be able to engage with other young people from all around the country and the world. Working with each other's peers can have a range of positive outcomes, including the formation of new friendships.

Other classification of student benefits of using 3D printing includes additional categories. According to Dario Assante, Gerardo Maria Cennamo and Luca Placidi (2020) [36]. Various recent studies have found several possible benefits of using 3D printing in education:

⇒ Creates anticipation and active participation: the student may be involved in the research and design process of the models all the way through to the stage of object realisation.

⇒ Prevents students from taking a passive position in the learning process: instead of being a passive consumer of knowledge, students can actively participate in the creation of things related to the lesson topic.

⇒ Expands learning opportunities: the ability to "visualise" in 3D the items presented in lessons enhances learning by increasing the quantity of information that can be gained in a context without visualisation.

⇒ Promotes problem-solving skills: in order to print objects accurately, students must learn to confront and solve real issues, as well as enhance their manual skills, perseverance, and endurance. Students will also become less afraid of tackling more difficult projects and ideas as a result of making mistakes and repeating the methods until success is achieved, improving their awareness.

⇒ Supporting tool: 3D printing may also be a helpful supporting tool for visually impaired or blind pupils. The Tactile Picture Books initiative, which developed tactile books for visually impaired children, is a notable example. Not only does this project provide vital support for children with impairments, but it also allows middle and high school students to explore with 3D printing technology.

Advantages and opportunities of 3D printing usage for teachers.

The advantages of using 3D models in education are multiple, they are a powerful tool and an aid to the teacher in the plastic presentation of complex models and their three-dimensional representation. In addition, the 3D printer allows to increase the motivation, focus, concentration of students, teamwork and is an element of the integration of different techniques which enables the development of new knowledge skills and competences.

Students and instructors alike are motivated by the ability to educate using 3D technology. 3D is a fascinating and dynamic experience, and students are encouraged to learn more as long as they are engaged. Teachers are inspired to offer their best when they see their pupils engaged and delighted with a session [37].

Pedagogical barriers

From the pedagogy and didactic perspective there are few Challenges that should be considered [38]. The first is related to students' background knowledge and need for support. Which is focused on the:

- Different backgrounds of the students.
- Different students' opinions on teaching support.

Second Challenges is related to the new student role:

- Students must be responsible for their learning.
- Students must be open to creativity.

The third Challenges is related to knowledge content:

- Different subjects combined to be learnt.
- More technical information needed.
- Understanding the affordances of the technology.

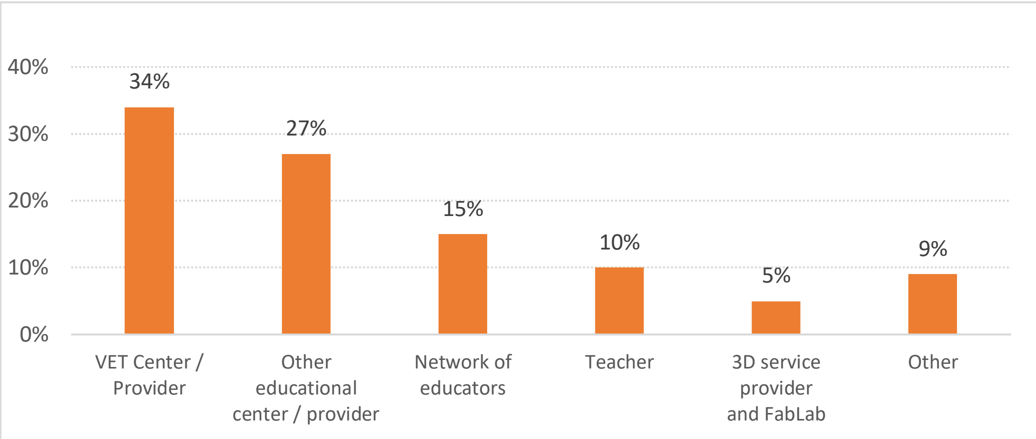
Presentation of a research on 3D printing usage in education.

In order to present a broader perspective on the implementation of 3D printing in schools, education we will present the findings of the research 3D Printing in Education: A European perspective [36].

In the next part of this report, we would like to present a research study involving vocational and general education teachers, representatives of various education centres and other stakeholders and their opinions regarding opportunities, advantages and skills/competences development possibilities concerning 3D printer and modern teaching approaches as part of integration into education.

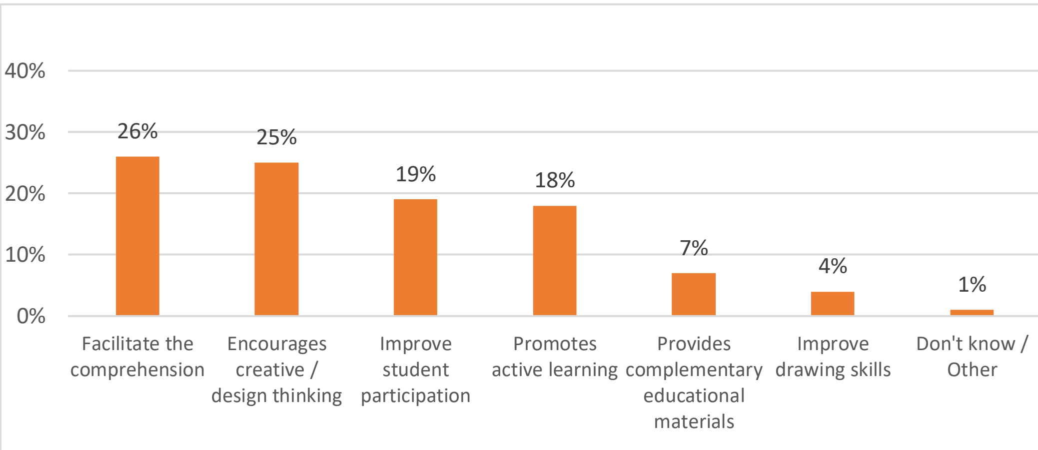
As the authors said: "The main aim of the questionnaire has been to understand the potentials of the use of 3D printing in education, the actual limiting aspects and the skills needed to successfully adopt the technology" (ibid). As the survey was limited to a reduced number of experts, the target groups were suitably selected from the different categories dealing with 3D printers. Most of the questions have been designed as multiple choice, leaving a couple of them as open. To facilitate the diffusion of the questionnaire at European level, it has been translated in seven languages, before disseminating it through the web.

A survey has been designed, and submitted online, spread at European level. More than 160 replies have been collected from experts coming from VET centres, network of educators, 3D printer suppliers, FabLab and manufacturing centres. The distribution of the experts (sample) by working activity is shown in Graphic 1.



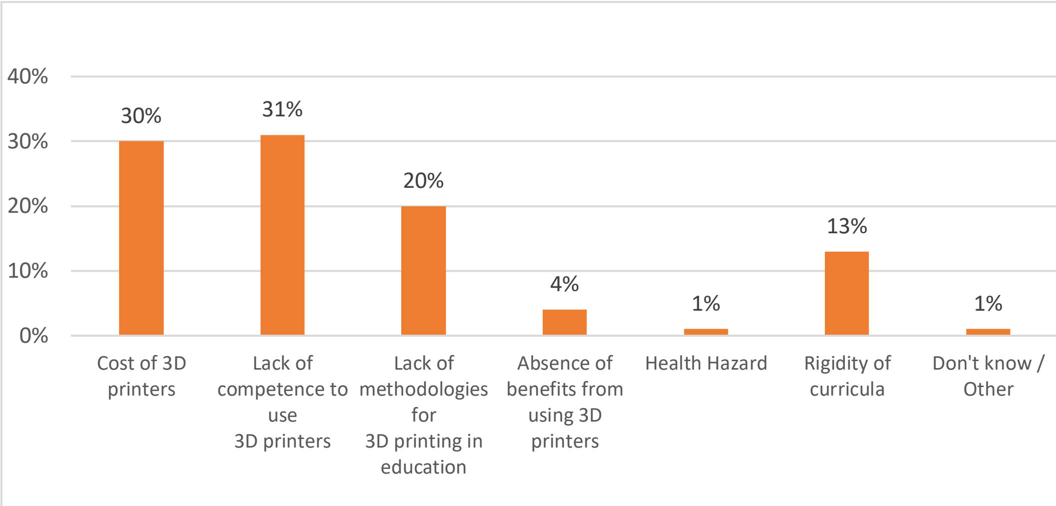
Graphic 1: Distribution of experts

The second question was to determine the primary benefits of implementing 3D printing in education. Over a quarter of respondents agreed with "Facilitating understanding through visualization of real objects". Another more common response was "*Improves student participation/engagement*", "*Promotes active learning*" and "*Encourages creative/design thinking*". The findings are presented in Graphic 2.



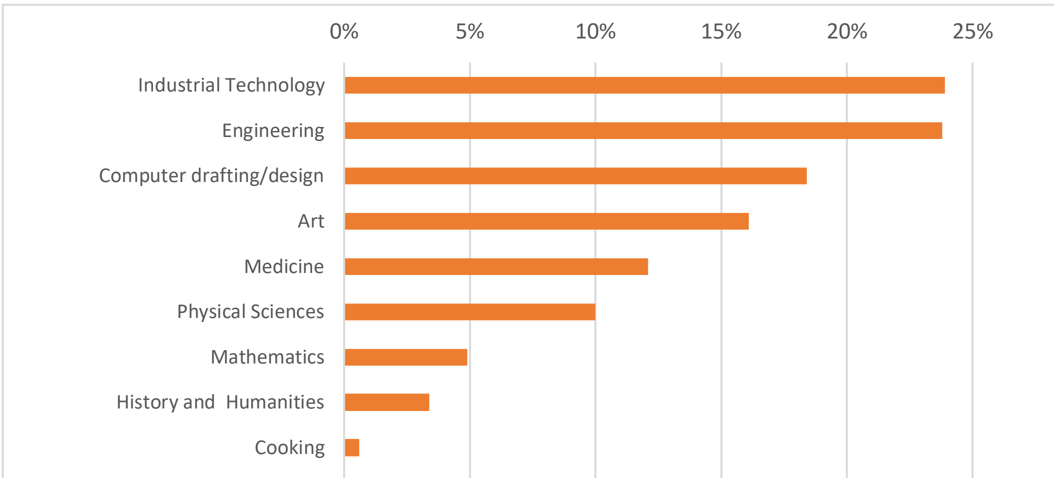
Graphic 2: The main advantages of 3D printing in education.

The following supplementary question was focused on the factors that are preventing widespread use of 3D printers in educational institutions. Strikingly, the cost of 3D printers is still the most important limiting aspect, due to the continuous drop in prices and the availability of affordable printers. The other two main limiting aspects are the lack of competences and methodologies to use 3D printing in education. In contrast, health risks are not considered as a limiting aspect. Results are shown in Graphic 3.



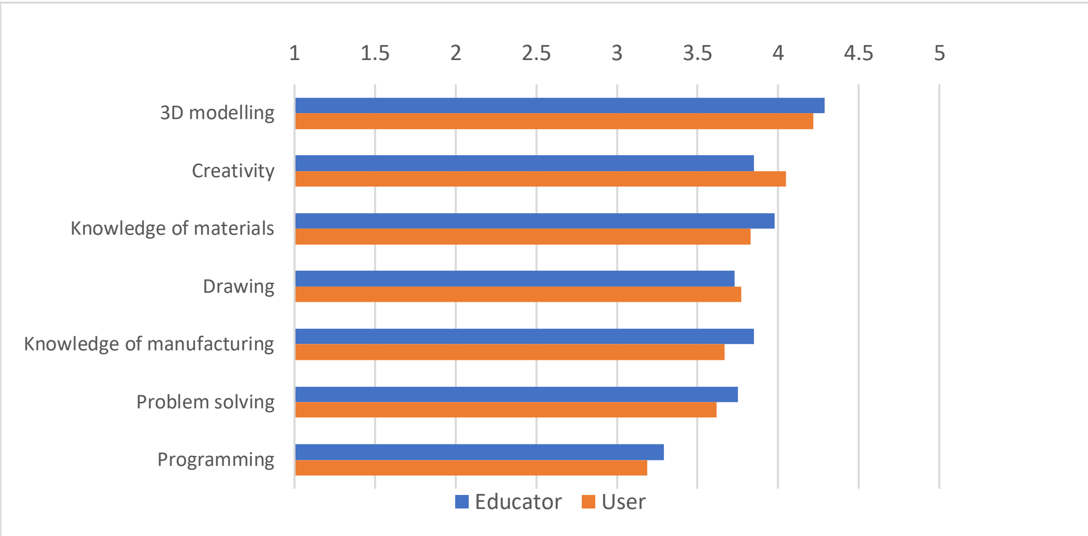
Graphic 3: The main limitations of the diffusion of 3D printing in education.

The next question was: what sectors are more likely to benefit from the use of 3D printing in education. The most selected sectors were "Mechanics/Industrial Technology", "Engineering" and "Computer Design", just followed by "Arts". The first two answers probably reflect the view that 3D printing is highly related to manufacturing processes. So maybe the idea of linking 3D printing to other disciplines isn't as popular yet. Results are shown in Graphic 4.



Graphic 4: Which sectors can benefit most from the use of 3D printing in education?

In the next step, the Survey focused on skills. Different skills were listed and ranked in order of importance (1 not important to 5 very important). The question was: Please rate the importance of the following skills for: introducing 3D printers in education (the perspective of educators -blue and from the perspective of the user -orange). Graphic 5 shows the averages for the educators and users of 3D printers. It should be noted that the most significant skill would be "3D modelling". This is important because these are the skills that most educators do not possess, except in some sectors. "Creativity" is also considered important, which is relevant because it is much more difficult to teach than the purely technical elements.



Graphic 5: Skills importance ranking.

Presentation of good practices using 3D printing and CNC technologies in wooden construction of organic shapes organic.

In the context of a broader approach to the topic of 3D printer implementation in the learning process, we presented some cases of good practice and the operational part of the integration of 3D printers in education through examples of the design and production of individual products made by students. These examples of good practices in a field of 3D printing technologies which follows the principles of disassembly, adaptability, and reuse in a context of wood design and manufacturing are well presented in Kitek Kuzman, Kariž article on "Teaching timber design interdisciplinary: Design and manufacturing of organic shape constructions" [39].

The authors present specific case studies (examples) in which they advocate the benefits of operability in repeatability and larger quantity production and modelling any kind of shape by combining 3D print and CNC technologies. Examples of good practices are focused on wooden construction of organic shapes.

EXAMPLE 1: RIVER STONE SEATING ELEMENT

Idea: designing wooden sitting element following organic shape.

Aim: making 3D printing prototypes before CNC production by using 3D modelling software.

Steps:

1. Taking photos on river stone (top front, left view).
2. Importing photos to SolidWorks and getting basic silhouettes.

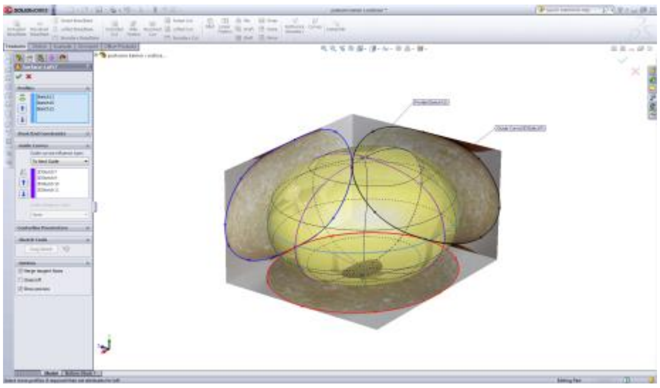


Figure 29: Silhouette of the stone (modelling with SolidWorks).

3. Creating model of the stone with Surface loft.
4. Adjusting the model by flattening the bottom part and creating the seat on upper part.

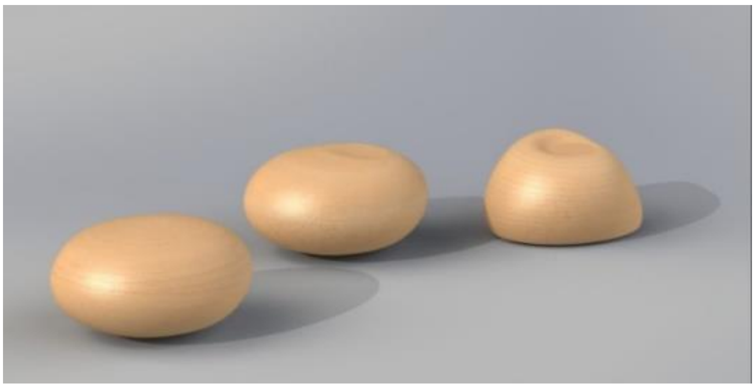


Figure 30: Different model designs.

5. 3D printing of models and optimizing material consumption (frames from plywood panels).

6. Exporting 3D models from SolidWorks to AlphaCAM, making program for CNC router, carving the product (several options were available: creation from larger block of wood, half stone, slicing the model to several slices and assembling them together).

Figure 31: Finished product.

EXAMPLE 2: 3D PRINTING WITH MIXTURE OF WOOD POWDER AND ADSIVE

Idea: Using wood as a material for 3D printing

Aim: Experimenting different mixture ratio between wood powder and adhesive

Steps:

1. Creating different ratios of wood powder, together with polyvinyl acetate (PVAc) and urea-formaldehyde (UF) adhesives to form a mixture for 3D printing.
2. Printing the simple blocks.

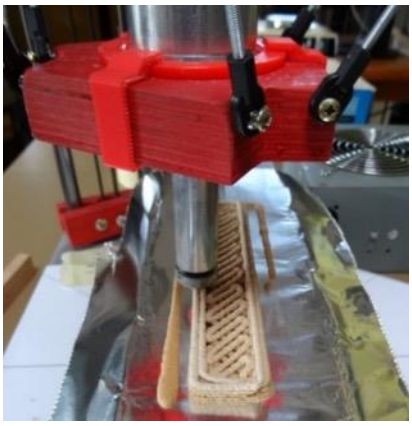


Figure 32: 3D printing of simple blocks for bending test.

3. Defining the bending properties by testing and evaluating the effect of wood ratio and type of adhesive.

Figure 33: Testing of joint on universal testing machine.

4. Identifying different combinations of mixture of thermoplastics, recycled plastics and natural fibres as suitable materials for 3D printing.

Through the presented examples, we can highlight the effective link between the integration of new technologies in education, the development of new pedagogical principles [40] the development of new and useful recyclable materials and the production of new products by actively involved students throughout all production phases.

Allview

5

Conclusions

CONCLUSION

Rapid technical developments and global competition in all European countries are creating an increasing demand for highly skilled workers. Industries and companies are looking for workers who are highly specialised in modern technologies and ready to take on digital challenges as soon as they graduate. To meet the demands of the labour market, VET institutions need to keep pace with modern technologies and educate their students in a way that enables them to meet the requirements of employers. This includes adapting school curricula to the requirements of labour markets. Teachers and trainers should be enabled to transfer knowledge and skills of new ICT technologies using innovative methods and pedagogical approaches.

In this report, we wanted to show the obvious need to implement new technologies in the learning process and the advantages of using a 3D printer as a meaningful tool which enables the development of the necessary competences for new, future professions.

We have tried to highlight the benefits, advantages, and opportunities of 3D printing usage for students and teachers, but we have also tried to raise awareness of the potential problems and challenges that are present in the technology itself (the aspect of adaptation, learning to the exercise new technology and the limitations both at the level of the technology and the pedagogical didactic process).

In the context of a broader approach to the topic of the implementation of a 3D printer in the education process, we have tried to present the research on scholar's opinions regarding opportunities, advantages and skills/competences development possibilities concerning 3D printer and modern teaching approaches as part of integration into education.

Finally, a panoramic view of the issues raised earlier, namely, how to respond to the future challenges of integrating new technologies in education, has been updated with specific examples of 3D product printing practices performed by students, demonstrating that technological implementation is necessary and achievable considering the upcoming challenges of economic growth and labour market competitiveness.

Scan the following code to get access to the 14 exercises (descriptions and .stl files).

Scan me!

Allview

6

3D Printing set of exercises

Defined Exercises

1. Exercise "Setting up a 3D printer for printing dedicated to the furniture sector"

INFORMATION

Exercise Name	"Setting up a 3D printer for printing dedicated to the furniture sector"
Specific Subject	Product Design, Sustainability, 3D printing
Number of pieces of which the model is composed	7 pieces

3D MODEL DESCRIPTION

Written description.

The goal is to design parts separately. It will allow the student to learn how to use and test the knowledge on each of the parameters of the 3D printer deposit of wire (FDM).
Depending on the parameters, we will have:

- Bridge/bridging tests
- Tests of angles and tips/hollows
- Precision tests (scale/diameter)
- Rope/rod tests
- Tolerance tests (wall/interwall)
- Cantilever angle tests
- Curve and rounding tests

The idea is to design different test modules allowing for each of them to test and validate the printer settings (depending on the material used).
There are different "test board" dedicated to 3D printing.
The idea is to make them independent of each other, in order to work on a precise setting and parameterization of the machine.

Graphic Definition of the 3D Model.

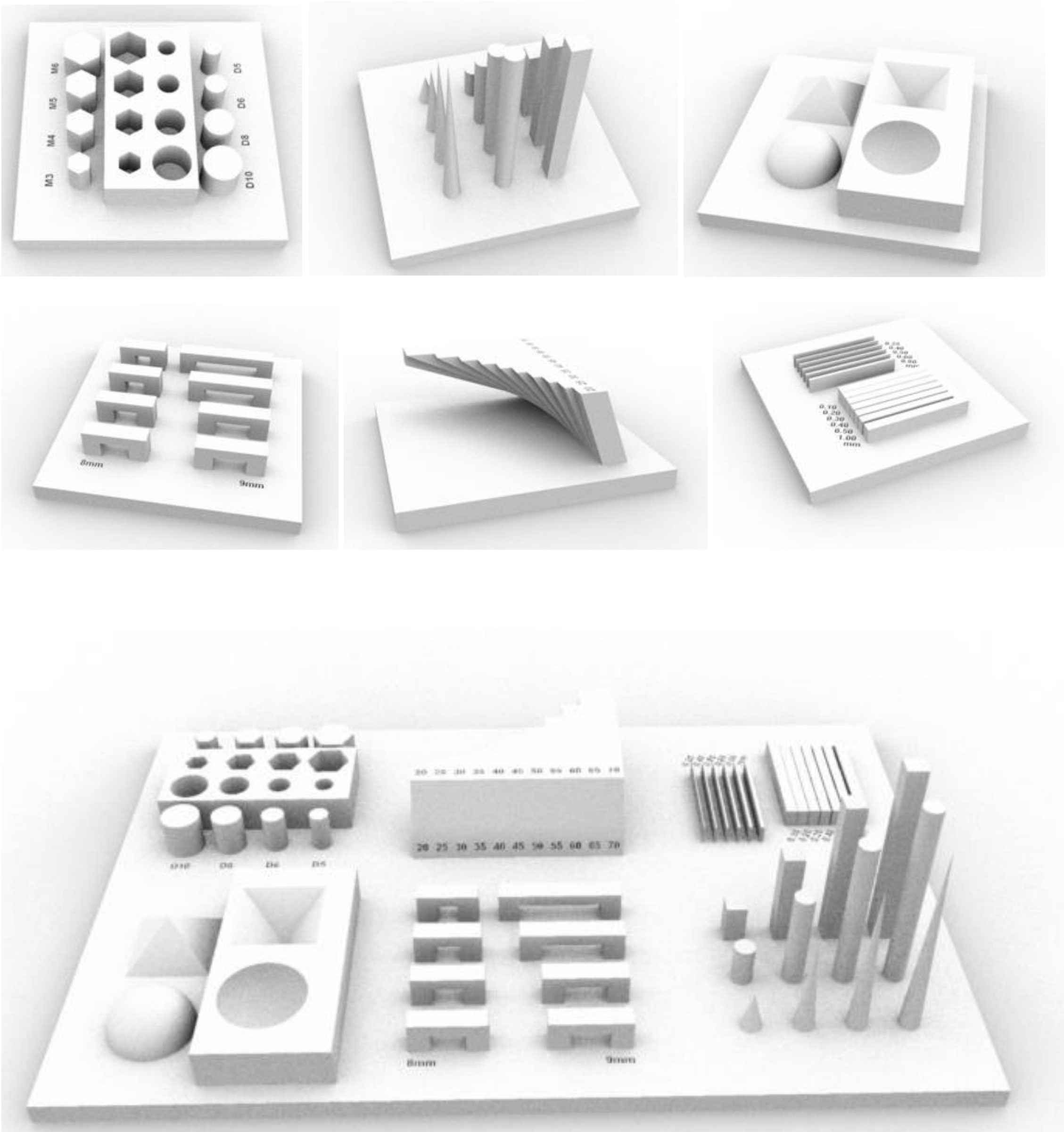


Figure 34: Model kits for testing.

Additional materials for a better description.

Example of a test board:

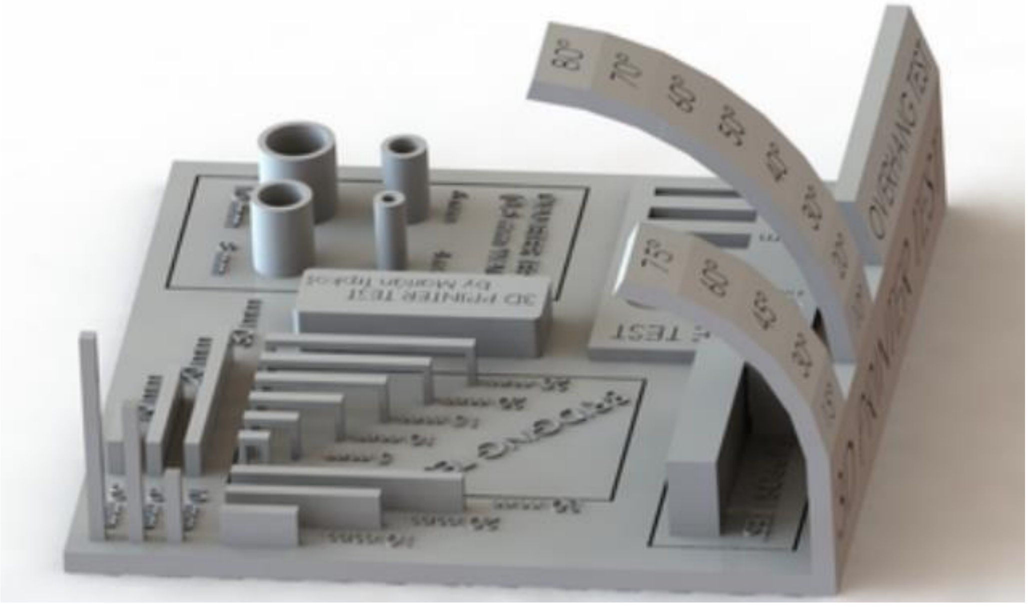


Figure 35: Example [41].

These modules can be printed according to the choice of settings we wish to validate/test.

The design of these parts will be done in such a way as to have each of the above-mentioned parameters associated with a part and a printout (this saves time during validation, if we intervene only on one aspect), so it will not be necessary to print a board including all the tests.

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to make the student work on a limited number of settings depending on the part he will have to print.

The student's objective is to print one of the modules without encountering any printing problems (dripping, oozing, lack of material ...), it must leave the printer without any error.

Thanks to this exercise, the student will be able to determine the source of the problem during his future printing. Moreover, he will also be able to correct the parameters in order to ensure the good realization of his part by the machine.

What methodology can be used for its integration into the classroom/curriculum?

To ensure integration within a class/curriculum, the principle would be to provide to different students (or groups of students) a module on which work with.

This exercise can be worked on in class as a multi-step exercise:

- Prepare and run a printout of the module, having in mind when designing the G-code, that this part must come out identical to the 3D model.
- Identify the possible problems that we encounter/could encounter with this type of printing.
- List the parameters to influence to anticipate/correct the problems that could be linked to these different prints.
- Re-print the part with the appropriate corrections for a good printing execution.

Module-based learning is meaningful for students because they acquire the necessary skills to anticipate and correct printing errors that they might find in all their 3D printing projects.

What benefits can be obtained with its use?

The purpose of using this exercise is to provide to each student, through the realization of a successful print, with the necessary knowledge to understand the problems commonly encountered in the field of 3D printing with molten wire.

By pushing the exercise further, the students could also experiment by changing the parameters to see how the prints react according to the modifications.

In addition, these exercises determine the printing results, and by interacting with the associated parameters, they can discover and exploit aspects, usually avoided, to diversify the printing possibilities.

In terms of learning outcomes, the learner will be able to:

- Identify printing problems
- Correct these errors by changing the printing parameters
- Anticipate possible errors before printing
- Exploit additional features of the printer

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	Fused Deposition Modeling (FDM)
Material	PLA/ABS/PETG
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They can be printed on a 200*200 tray without any problem.
Should the piece be resistant or be subjected to stress?	No
Number of pieces of which the exercise is composed:	6 pieces
Ensemble type if necessary (slot, clip, screwed ...)	
Accuracy and definition required. (Quality) Low, mid or High.	Medium or high (maximum nozzle diameter 0.4mm)
Support material or post-processing.	For a good realization of the exercise, it is not necessary to use supports and it is not necessary to carry out post-processing either.

2. Exercise "Materials and finishing dedicated to 3D printing (FDM)"

INFORMATION

Exercise Name	"Materials and finishing dedicated to 3D printing (FDM)"
Specific Subject	Product Design, Sustainability, 3D printing
Number of pieces of which the model is composed	1 piece

3D MODEL DESCRIPTION

Written description.

This 3D model aims to represent the different types of surfaces, structures, and shapes that could be met on prints. It will be composed in different ways to be able to work on the post-processing of the materials after printing.

It incorporates several aspects that can vary greatly depending on the materials used:

- The details in relief or inlays.
- Connections between two surfaces that are not on the same plane.
- Fillets and chamfers.
- Vertical and horizontal cylinders.
- Hollow and curved surfaces.
- Protruding edges.
- A temperature printing scale.

Graphic Definition of the 3D Model.

Figure 36: Model diagram of different surfaces.

Additional materials for a better description.

This "model" allows us to observe and work on the different types of surfaces that might be found on 3D prints.

Figure 37: Model example [42].

Here it is displayed an example of a model allowing to see the results of printing (it is useful as a basis to check the good settings of the printing parameters). The model of figure 4 doesn´t offer the possibility to work on the post-processing of the material, as it incorporates very fine details which do not allow an easy "test post-processing" as opposite of the model of figure 3.

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise will be presented in the form of a "practical work" during which the students will have to develop a good printing of the part in a first step (exercise similar to "Setting up a 3D printer for prints dedicated to the furniture sector").

In a second step, they will have to choose to apply one or several post-processing on the part after printing:

- Painting
- Varnishing
- Sanding
- Removal of clinging points/marks related to the supports
- Evidencing/sculpting
- Smoothing (with a hot iron)
- Texture work

What methodology can be used for its integration into the classroom/curriculum?

To ensure integration within a class/curriculum, the idea would be to pass the 3D model to the students to print and post-process in several steps:

- Preparation of the file in the form of G-Code (knowledge of the settings of a print, see exercise: "Setting up a 3D printer for prints dedicated to the furniture sector").
- Consider the temperature tower in the configuration.
- Set up of supports adapted to the printing/exercise.
- Printing correctly to obtain a compliant part.
- Application of the various forms of post-processing (quoted in the higher paragraph, number of post-processing with the goodwill of the professor) on the printed part.
- This exercise can be repeated as many times as the user aims to work with a different material.

This exercise will allow the students to apprehend, according to the geometry of the part, the various problems which we can meet in post-processing according to the printed materials

Moreover, it also allows to perceive on which aspects to intervene upstream during the preparation of the G-code, in order to avoid certain steps of post-processing (detail depending on the materials used).

What benefits can be obtained with its use?

The purpose of this exercise is to make the student to experience the range of printing possibilities thanks to the printing of different materials and the various post-processing operations that can be applied. Moreover, the learner will experience the effects that will have on the final part. It will allow the students to experiment with surface treatments (sanding, milling, etc.) on the part to exploit the characteristics of the materials to the fullest extent possible in terms of their printing.

In terms of learning outcomes, the learner will be able to:

- To make a print with a loaded material (with particles of material (wood, rock, fibers ...) incorporated in PLA and ABS).
- To treat the points of hangs of the support.
- To define the parameters according to the expectations of the result (ex: high temperature = changes of colours and/or roughness of the material more pronounced).
- Application of different finishes, and the different results that we can obtain depending on the techniques/products they that use.
- Anticipate and apply certain parameters upstream (during the creation of the G-code) to avoid certain phases of post-processing, and/or to provide particular aspects to the different materials.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	Fused Deposition Modeling (FDM)
Material	PLA ABS composits
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They can be printed on a 200*200 tray without any problem.
Should the piece be resistant or be subjected to stress?	Yes/No (depending on the post-processing applied)
Number of pieces of which the exercise is composed:	1 piece
Ensemble type if necessary (slot, clip, screwed ...)	
Accuracy and definition required. (Quality) Low, mid or High.	Low, medium or high (minimum nozzle diameter 0.6mm because on smaller sizes, the particles present in the material may clog the nozzle).
Support material or post-processing.	Setting up supports is MANDATORY in order to approach the post-processing of the hanging places of the supports in a print.

3. Exercise "Eccentric connector"

INFORMATION

Exercise Name	Eccentric connector
Specific Subject	Design and print functional replacement of broken eccentric connector
Number of pieces of which the model is composed	1 piece

3D MODEL DESCRIPTION

Written description.

Eccentric connectors are probably the most popular joints in particleboard and medium-density fibreboard (MDF) flatpack furniture. Variety of these screws with plastic sockets are offered by many manufacturers for these kinds of joints. They are usually made of plastic or low strength metal, like ZAMAC, with a base metal of zinc and alloying elements of aluminium, magnesium, and copper. These connectors are usually not meant to be used multiple times and break easily when excessive force is applied. Due to the variety of products and manufacturers, it is usually problematic to find and replace model used several years ago, especially when dimensional standards change. This exercise aims to design and print replacements for broken flange of the eccentric joint.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

There is a variety of available eccentric joints, they are also made of various materials, with similar function – join two panels together, usually at 90% angle.

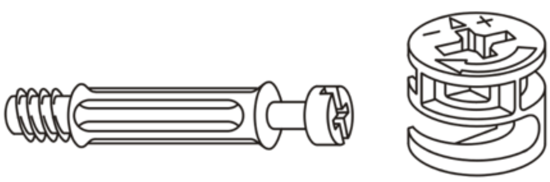


Figure 38. Typical eccentric joint.

The connector will be a simplified version of original ZAMAC connector, which happened to break. Geometry of the original connector is relatively complex. To save up on material, our version will be simplified, because it is going to be made of plastic (preferably ABS) and some strength will be needed. Original connector flange, while you still have it:

Figure 39. Sample eccentric connector.

Unfortunately, these flanges tend to break:

Figure 40. Connector flange with broken off (almost) piece.

Crucial for understanding how to model one, is to have the dimensions of the original one. In our case it is 13mm high with 15mm diameter. We start with a simple block:

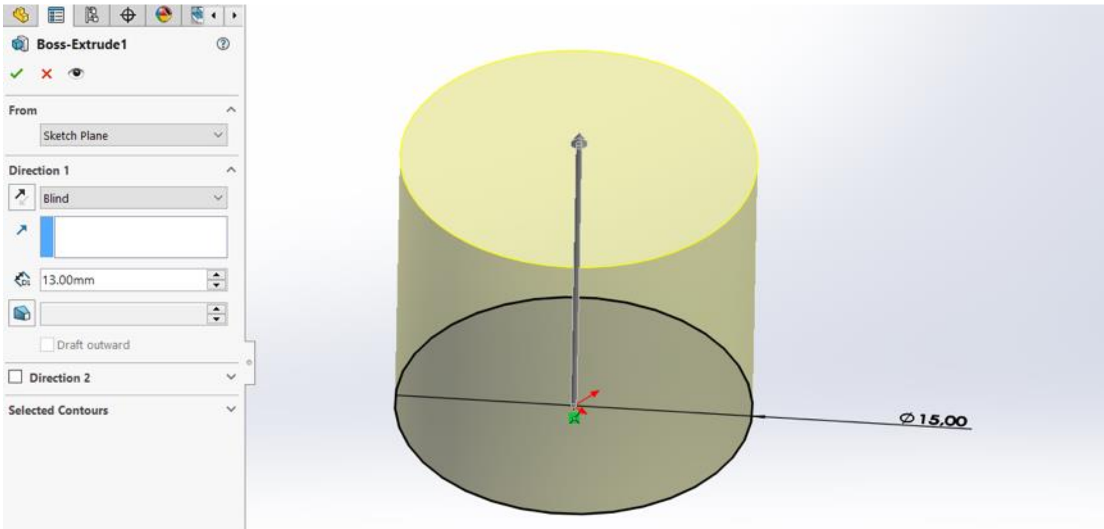


Figure 41. Flange block.

It is needed to create two sketches, one with measured opening, and the second with eccentric path:

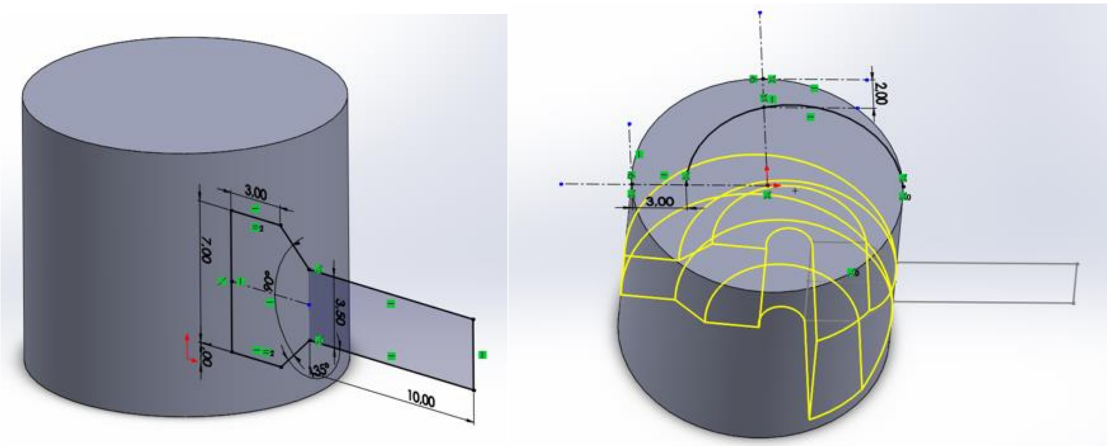


Figure 42. Opening and eccentric path sketches.

And combine into eccentric opening of a given profile:

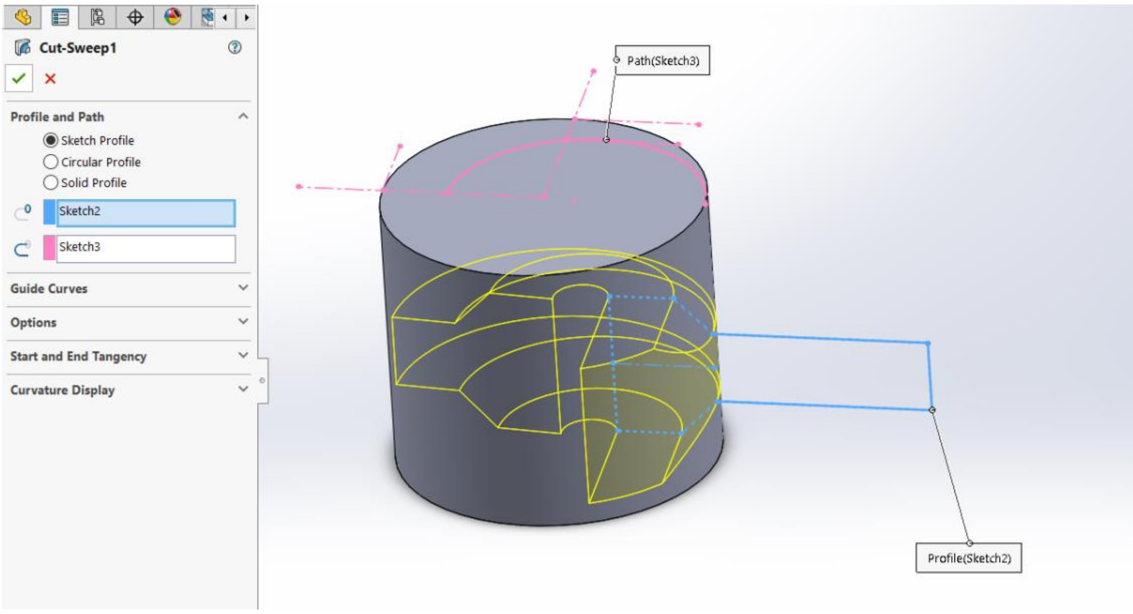


Figure 43. Opening cut.

Obviously, dimensions of both are dependent on the one flange you have.

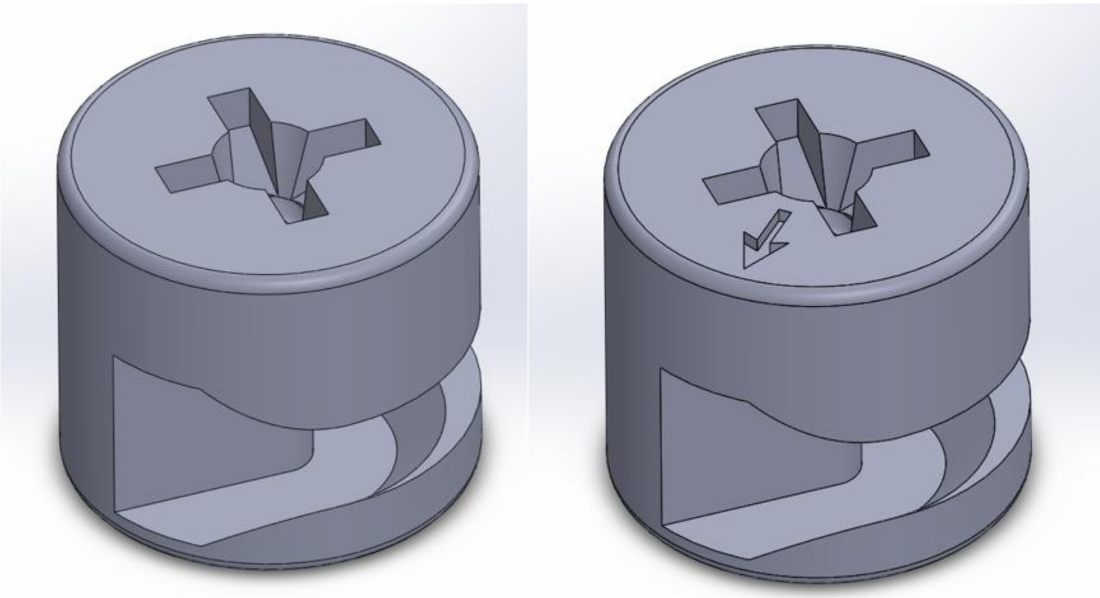


Figure 44. Connector model.

It is necessary to cut Philips or hex socket for the screwdriver that you have, as well as point direction in which flange is going to be positioned during assembly.

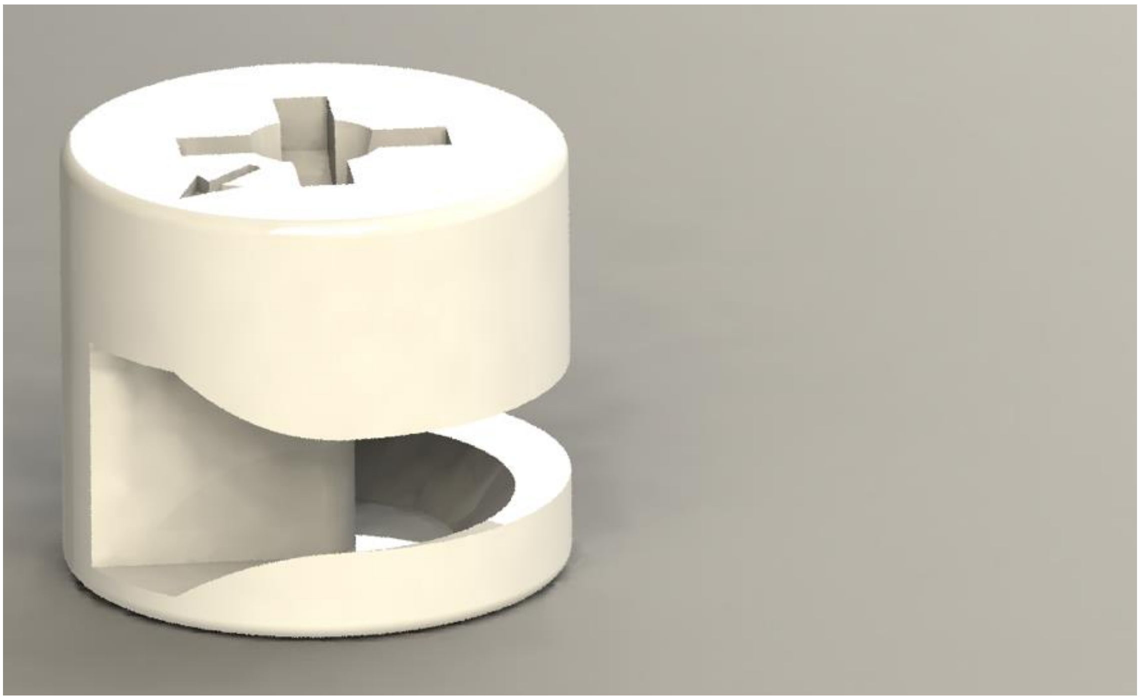


Figure 45. Finished connector.

Figure 46. Printed connector

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge on how to creatively model working mechanical part and scale it to required dimensions.

What methodology can be used for its integration into the classroom/curriculum?

The connector will be fully modeled / printed by each student, to a given standard or non-standard existing dimensions or real example of the flange, to be measured by student. Model after printing should be cleaned and checked against functionality. Will it pull the connector?

What benefits can be obtained with its use?

The students will learn about:

- Self-sufficiency in dimensioning.
- Modeling of precise shapes.
- Details on printing of a model, to provide sufficient loose fit.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM, due to quality-price ratio of materials and machine.
Material	ABS recommended due to higher strength. PLA possible, not recommended due to lower strength, can be used in the exercise however
Suitable dimensions for its use in the classroom (mm)	Here, it must be specified the necessary size of the object or model. You can just provide connector to duplicate, or indicate general dimensions, printing will be done 1:1
Should the piece be resistant or be subjected to stress?	Practical model – due to mechanical nature and necessary squeezing with assembly it needs to be printed with 100% infill
Number of pieces of which the exercise is composed:	Single piece matching to given connector
Ensemble type if necessary (slot, clip, screwed ...)	Screw-on assembly, some areas may need to be manually cleaned and sanded to fit
Accuracy and definition required. (Quality) Low, mid or High.	Medium to high quality, visual appearance and precise dimensions of the functional model is a key
Support material or post-processing.	Support material can be the same as printing material, removal and cleaning up model necessary

4.Exercise "Cable route"

INFORMATION

Exercise Name	Cable route
Specific Subject	Design of cable route prototype for furniture with moving and matching parts
Number of pieces of which the model is composed	3+ piece – dependent on length required

3D MODEL DESCRIPTION

Written description.

Cable routes are the structures used to protect the cable from mechanical stress and harsh situation such as abrasion which might degrade the insulation, while improving visual appeal and tidying up overall looks of the workplace. We will be designing simple desk cable route, for pass-thru of some wires, usually for computer or phone use, with limited bending radius.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

There is a variety of available cable routes, made of various materials, with similar function – prevent damage of the cables against regular usage and external dangers like vacuum cleaner. Other not so obvious problem that can be addressed with these, is the lack of cable bend-radius control, especially important in fibreoptics, and furniture-reconfiguration limitations.

Figure 47. Traditional cable routing.

Figure 48. Flexible wiring duct [20].

Figure 49. Flexible cable snake [21].

Our cable snake will be based on two grommet cases, aimed at pushing into existing predrilled hole in the desk, with modules required to join the grommets making elastic route. In our case, bending will be limited to 15 degrees, so they can be applied to fibreoptics also. This is a sample design only and you may decide on details, diameter, and length on your own.

Figure 50. Sample exploded assembly of cable snake.

Figure 51. Connector should be printed out in required number as this part providing length of the unit.

Assembly of the product should be made by simple pushing parts into place, add as many connectors as you wish.

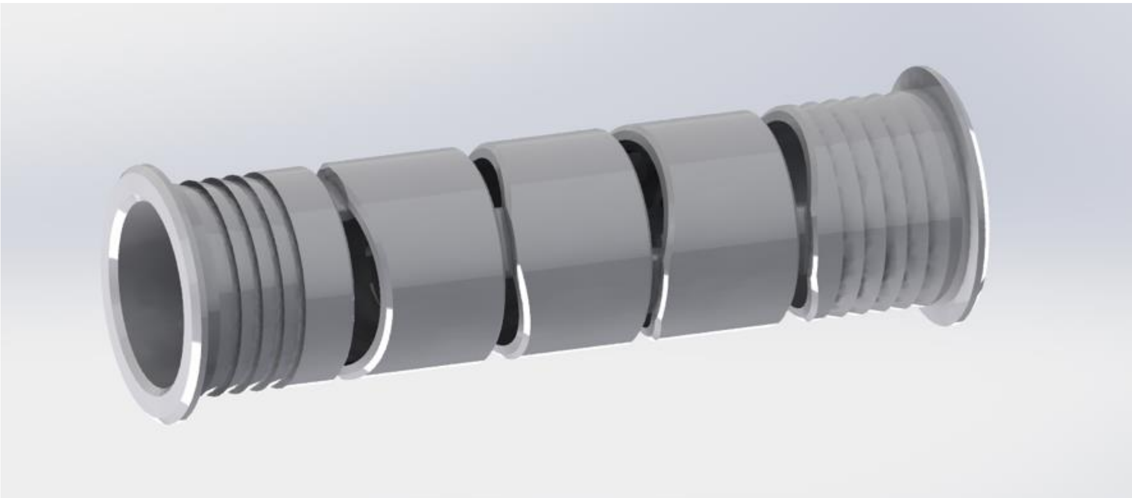


Figure 52. Assembled cable snake.

It is easy to see, that each connector can be rotated independently, in any direction set by rotating part around its own axis.

To understand how to model one, it is crucial to have the dimensions of the desk opening, and thickness of the board – in this case opening of 30mm and board thickness of 19mm were assumed – this can obviously be adjusted as needed.

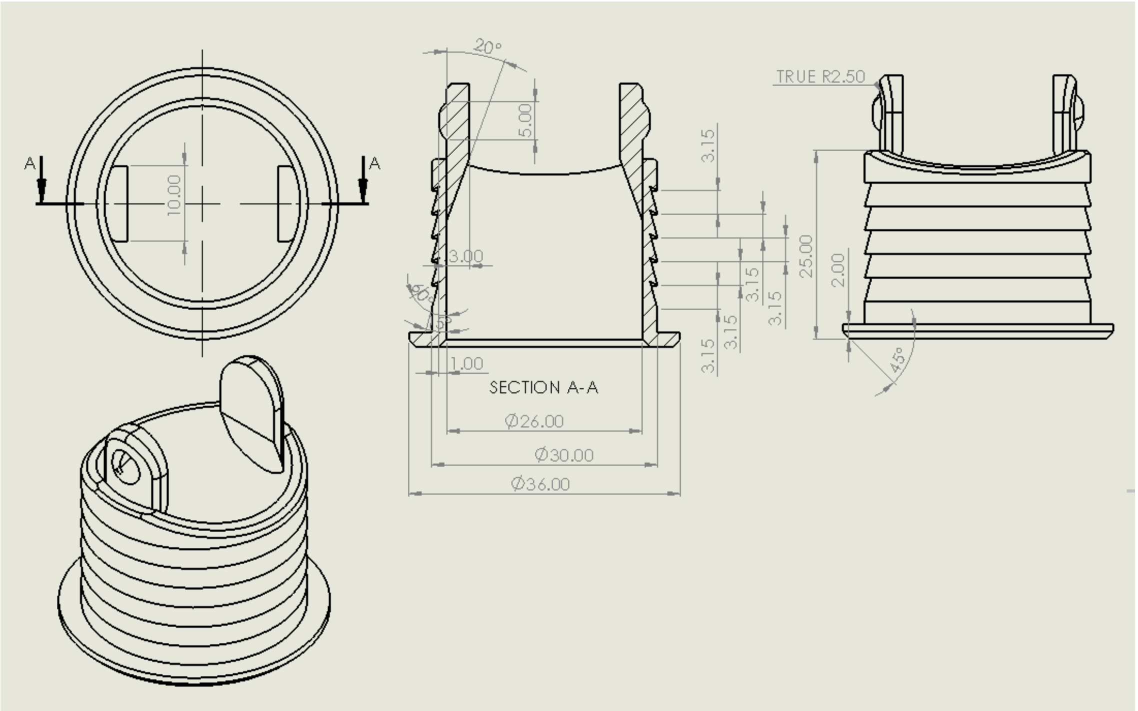


Figure 53. Bottom grommet case dimensions.

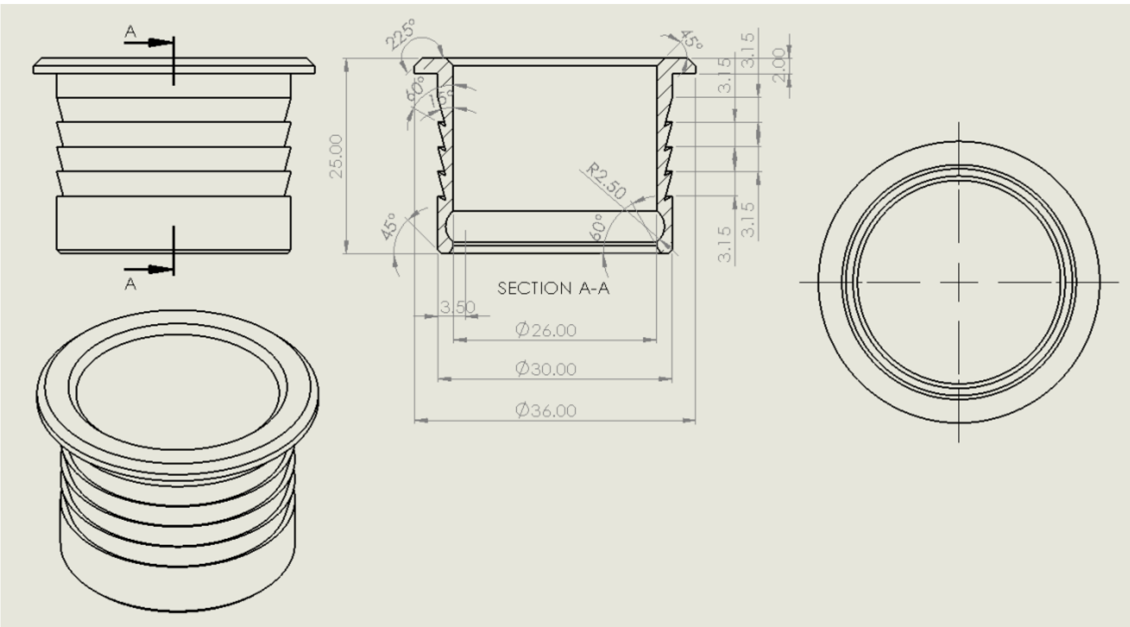


Figure 54. Top grommet case dimensions.

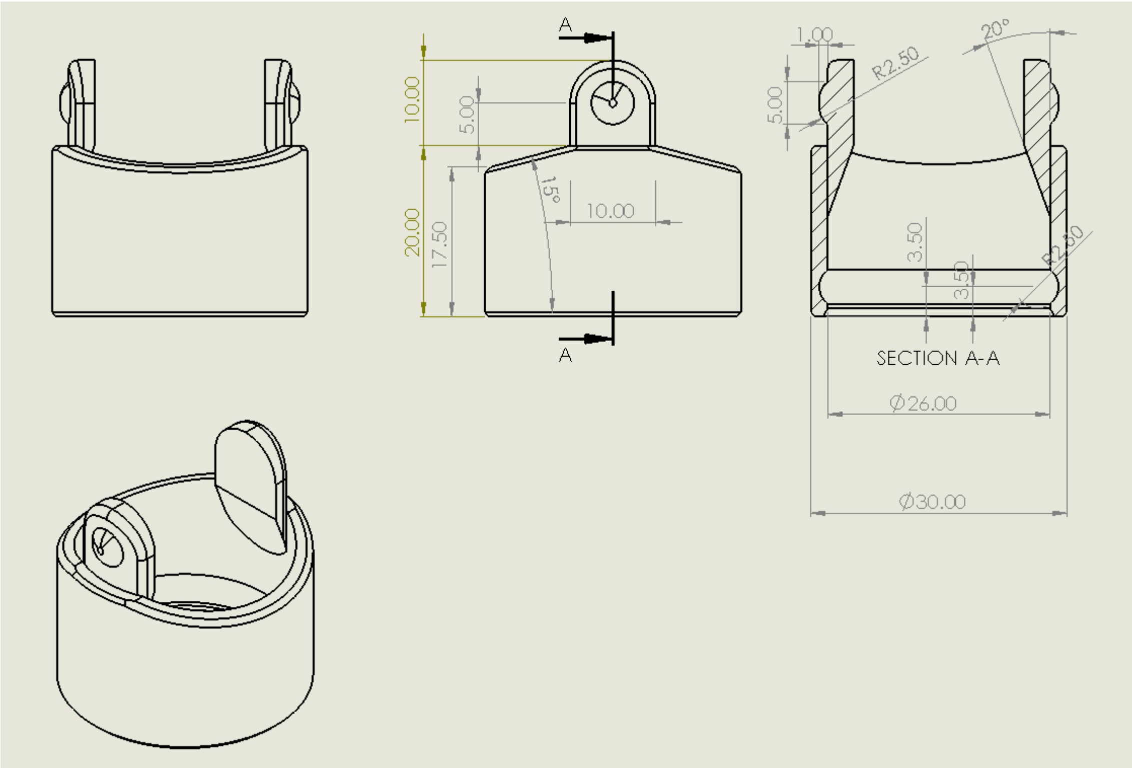


Figure 55. Connector dimensions.

Despite of the set dimensions of original model, it is relatively easy to scale model down or up to custom bore, length, and panel thickness.

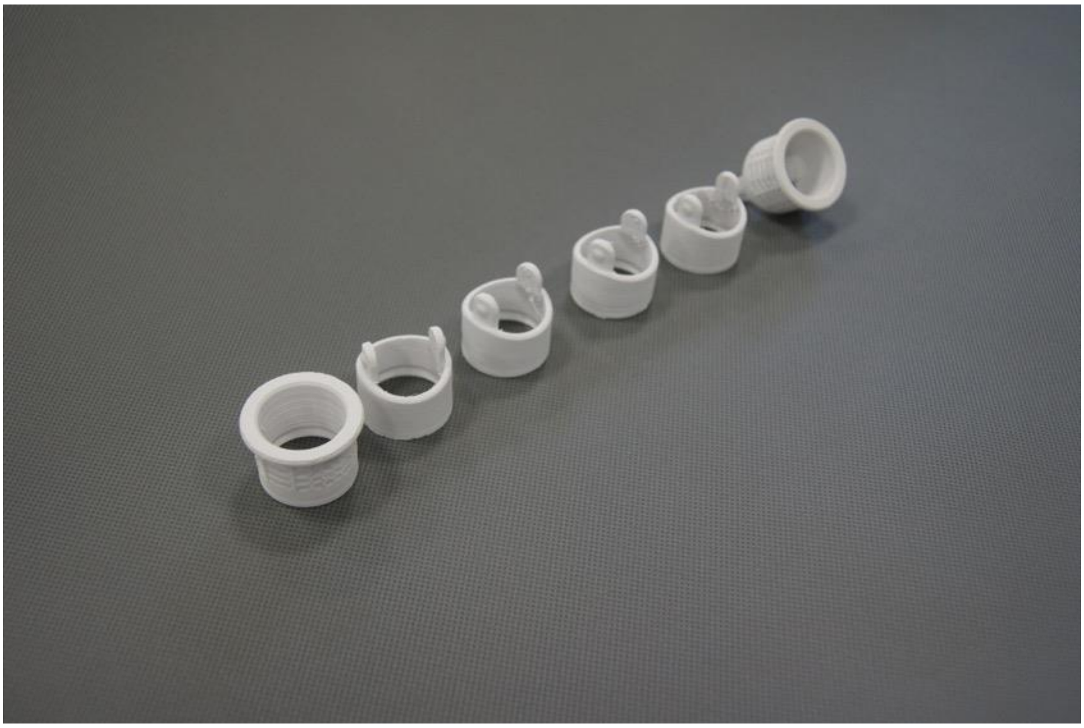


Figure 56. Printed connector parts

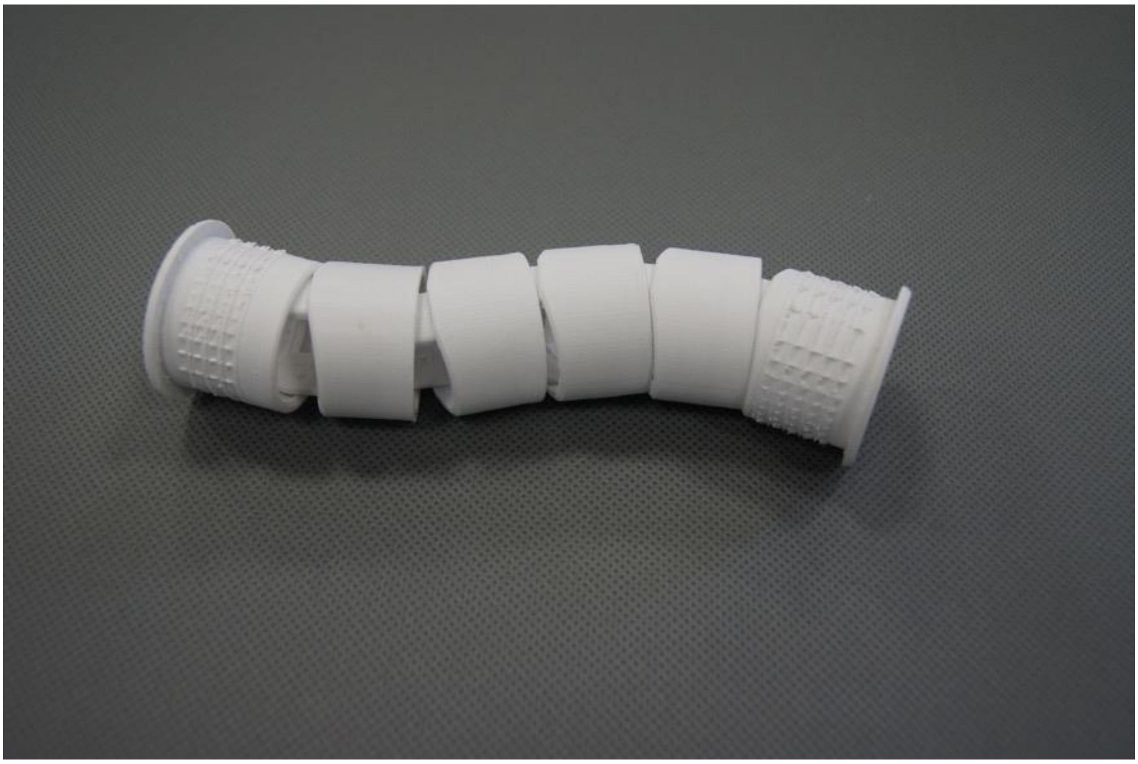


Figure 57. Assembled connector

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge on how to creatively model complex part and scale it to required dimensions.

What methodology can be used for its integration into the classroom/curriculum?

The cable snake will be fully modeled / printed by each student, to a given standard or non-standard dimensions, basing on the suggestions. Student will also have to determine best printing orientation of a model – to minimize waste material

What benefits can be obtained with its use?

The students will learn about:

- Self-sufficiency in finding out the necessary documentation.
- Modeling of complex shapes.
- Modeling of movable parts.
- Details on positioning of a model, to save on support material.
-

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM, due to quality-price ratio of materials and machine.
Material	PLA recommended due to hygienic measures. ABS possible, not recommended due to thermal shrinking and deformation of a thin structure
Suitable dimensions for its use in the classroom (mm)	Here, it must be specified the necessary size of the object or model. You can indicate very general dimensions, like bore and panel thickness, so printing will be done 1:1
Should the piece be resistant or be subjected to stress?	Practical model – due to thin walls and necessary squeezing with assembly it needs to be printed with 100% infill
Number of pieces of which the exercise is composed:	3+ matching pieces, depending on length
Ensemble type if necessary (slot, clip, screwed ...)	Push-on assembly, some areas may need to be manually sanded to fit
Accuracy and definition required. (Quality) Low, mid, or High.	Medium to high quality, visual appearance and precise dimensions of the functional model is a key
Support material or post-processing.	Support material can be the same as printing material, removal and cleaning up model necessary

5. Exercise "Cable grommet"

INFORMATION

Exercise Name	Cable grommet
Specific Subject	Design of cable grommet prototype for furniture with moving and matching parts
Number of pieces of which the model is composed	3 pieces

3D MODEL DESCRIPTION

Written description.

Cable grommets are a sort of cable accessory designed for use with electrical cables. They are usually made of, plastic, rubber or metal and are commonly used when wires need to pass through a panel. Cable grommets are produces as wire grommets, panel grommets, desk grommets, cable entry grommets and more. In our case, we will be designing simple desk grommet, for pass-thru of some wires, usually for computer or phone use.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

There is a variety of available desk grommets, made of various materials, with similar function to prevent damage of the cables against sharp edge of cable opening in the laminated chipboard, usual material used for work desks.

Figure 58. Cable grommets.

Our cable grommet will be based on grommet case, aimed at pushing into existing predrilled hole in the desk, with removable top and cable inlet, with adjustable opening. This is a sample design only; you may decide on details on your own.

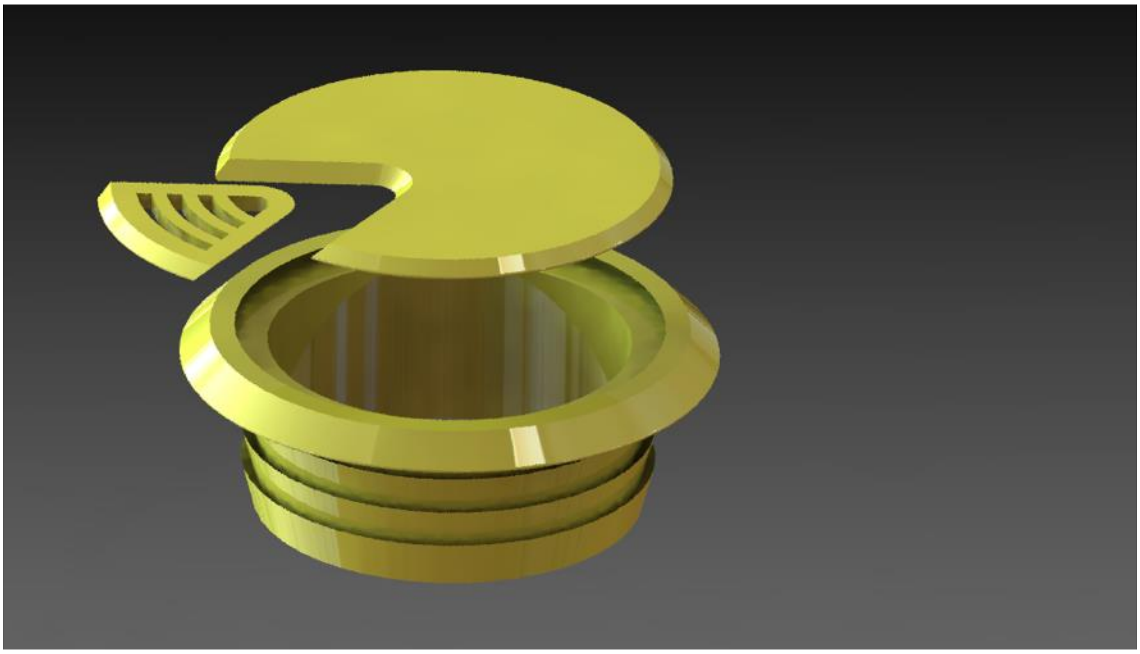


Figure 59. Sample exploded assembly of grommet case, removable top, and adjustable cable plug.

Assembly of the product should be made just by simple pushing parts into place:

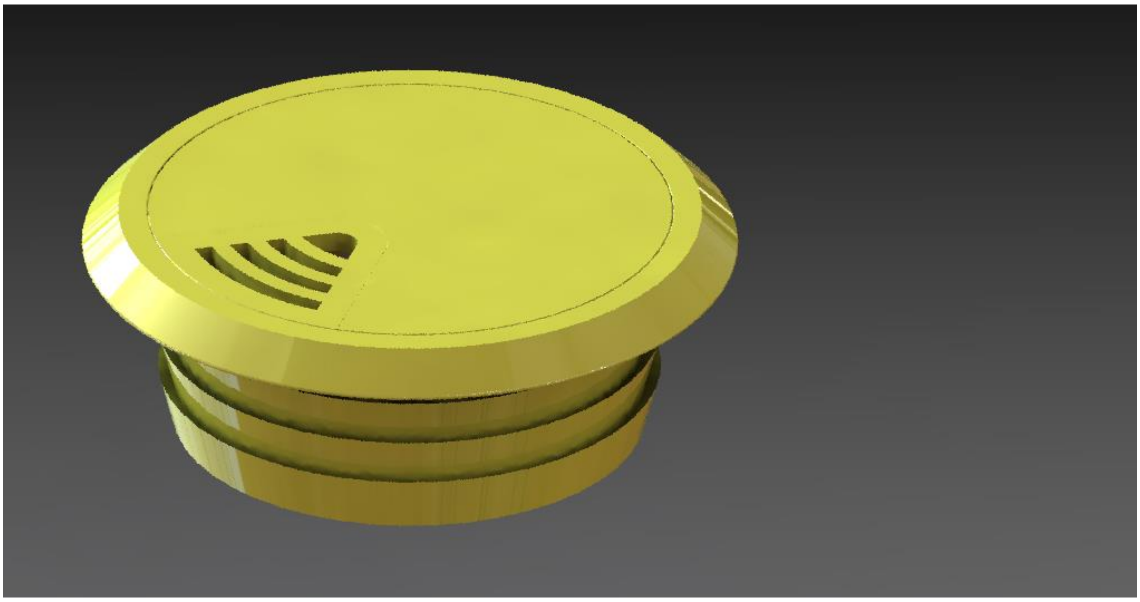


Figure 60. Assembled grommet.

It is crucial to have the dimensions of the desk opening, and thickness of the board to understand how to model one. In this case opening of 50mm and board thickness of 19mm were assumed – this can be adjusted as needed.

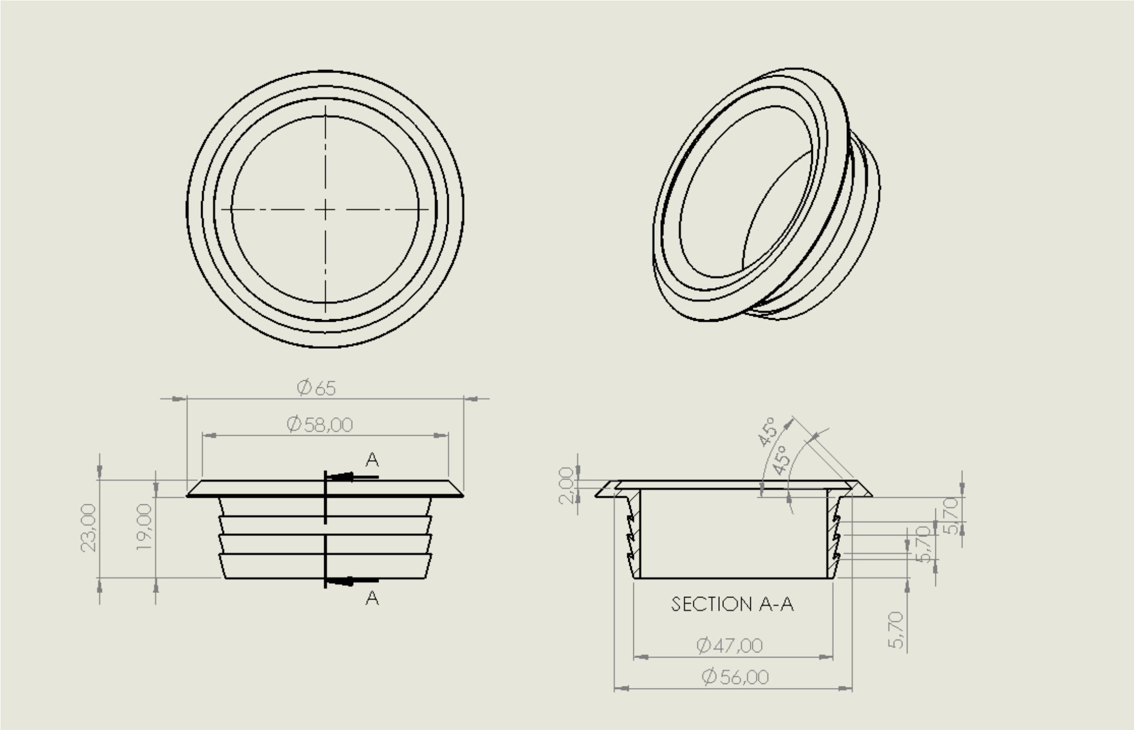


Figure 61. Grommet case dimensions.

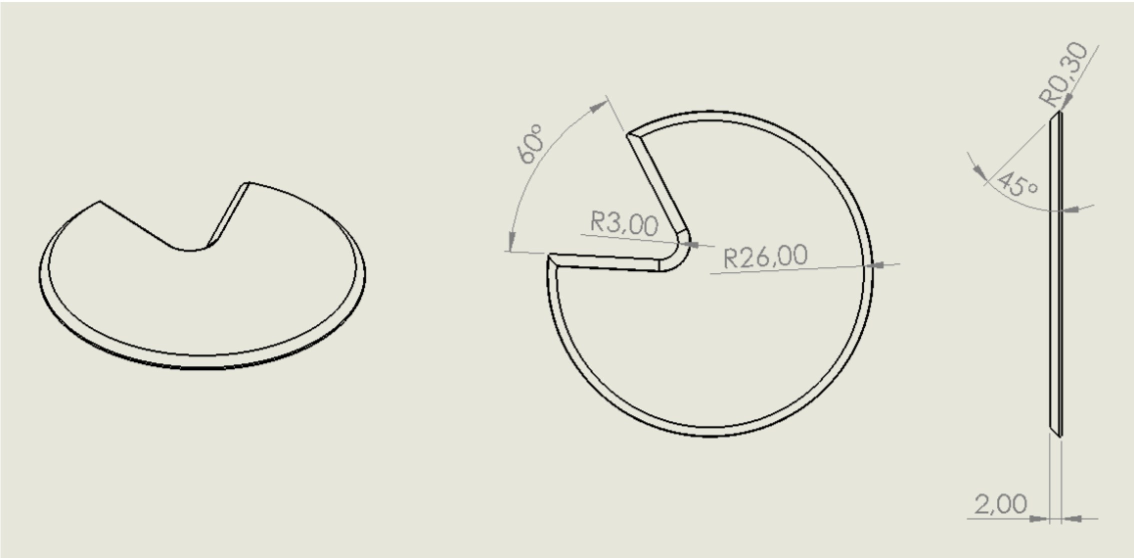


Figure 62. Top cover dimensions.

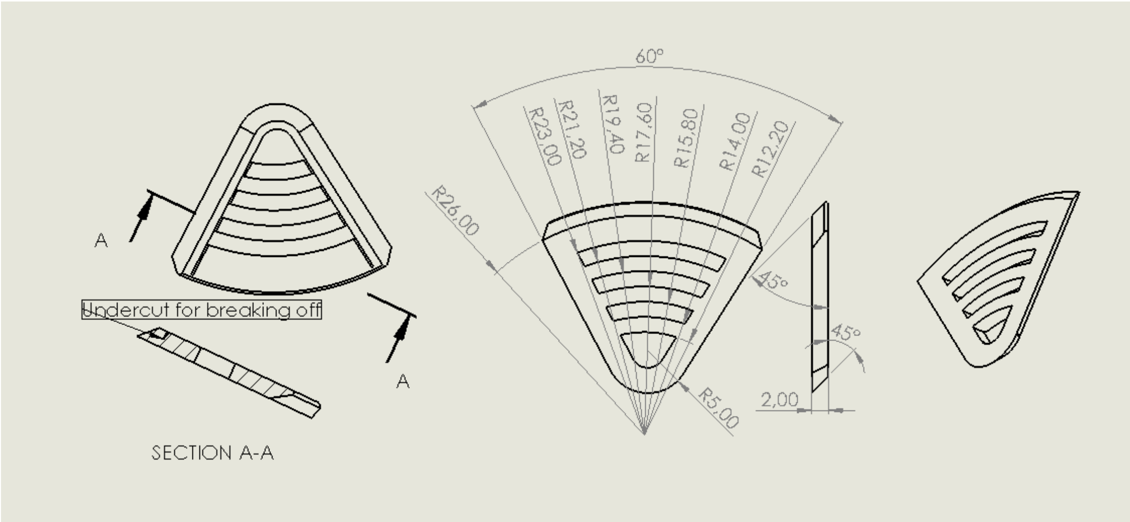


Figure 63. Plug dimensions.

Despite the fixed dimensions of the original model, it is relatively easy to scale the model down or up to fit the orifice and panel size.

Figure 64. Printed grommet parts

Figure 65. Assembled grommet

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge on how to creatively model complex part and scale it to required dimensions.

What methodology can be used for its integration into the classroom/curriculum?

The grommet will be fully modeled / printed by each student, to a given standard or non-standard dimensions, basing on the suggestions. Student will also have to determine the best printing orientation of a model – to minimize the waste of material.

What benefits can be obtained with its use?

The students will learn about:

- Self-sufficiency in finding out the necessary documentation.
- Modeling of complex shapes.
- Modeling of movable parts.
- Details on positioning of a model, to save on support material.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM, due to quality-price ratio of materials and machine.
Material	PLA recommended due to hygienic measures. ABS possible, not recommended due to thermal shrinking and deformation of a thin structure
Suitable dimensions for its use in the classroom (mm)	The necessary size of the object or model must be specified. Very general dimensions can be indicated, e.g.: bore and panel thickness, so printing will be done 1:1
Should the piece be resistant or be subjected to stress?	Practical model – due to thin walls and necessary squeezing with assembly it needs to be printed with 100% infill
Number of pieces of which the exercise is composed:	3 matching pieces
Ensemble type if necessary (slot, clip, screwed ...)	Push-on assembly, some areas may need to be manually sanded to fit
Accuracy and definition required. (Quality) Low, mid or High.	Medium to high quality, visual appearance and precise dimensions of the functional model is a key
Support material or post-processing.	Support material can be the same as printing material, removal and cleaning up model necessary

6. Exercise "Prototyping in 3D printing"

INFORMATION

Exercise Name	Prototyping in 3D printing
Specific Subject	Design of furniture which could be hard to prototype with other technology
Number of pieces of which the model is composed	Multiple pieces

3D MODEL DESCRIPTION

Written description.

The cornered coffee table is an example of contemporary furniture, designed by Dylan Gold (*https://www.dylangold.com/custom-furniture*)

It doesn´t differ too much from average coffee table, but one of the legs is replaced with an angled cubic form for holding newspapers and magazines.

from Dylan Gold:

'cornered', as we call it, means to be simple. It values clean surface area yet holds a place for your favourite few books or magazines. It's just your average coffee table with one leg constructed as a cross-section of a rotated cube that embodies the inherent function of all coffee tables. Nice and easy" (https://karmatrendz.wordpress.com/2010/01/11/cornered-table-by-dylan-gold/)

Cornered coffee table is relatively simple in construction, however, it is complex to prototype, due to the multiple angles of the designed parts - common machinery is not designed for these tasks, so 3D printing could be useful in this case, to allow its visualisation.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

Cornered coffee table is based on regular coffee table, with thick standard legs and cubic box made of four angularly cut parts:

Figure 66. Cornered coffee table [45].

Crucial to understanding how to model one, is to recognize cubic structure which is perfectly rectangular, but angled in two directions:

Figure 67. Cornered coffee table box front view [45].

Whole box is cut at an angle, so all the parts would be angle-cut in two directions.

Figure 68. Cornered coffee table box view [45].

Despite set dimensions of original model, it is relatively easy to scale model down or up to custom size, like for kids or population which doesn’t fit standard dimensions.

Additional materials for a better description.

First start assembly with just worktable part, of 1000x1000x50 dimensions

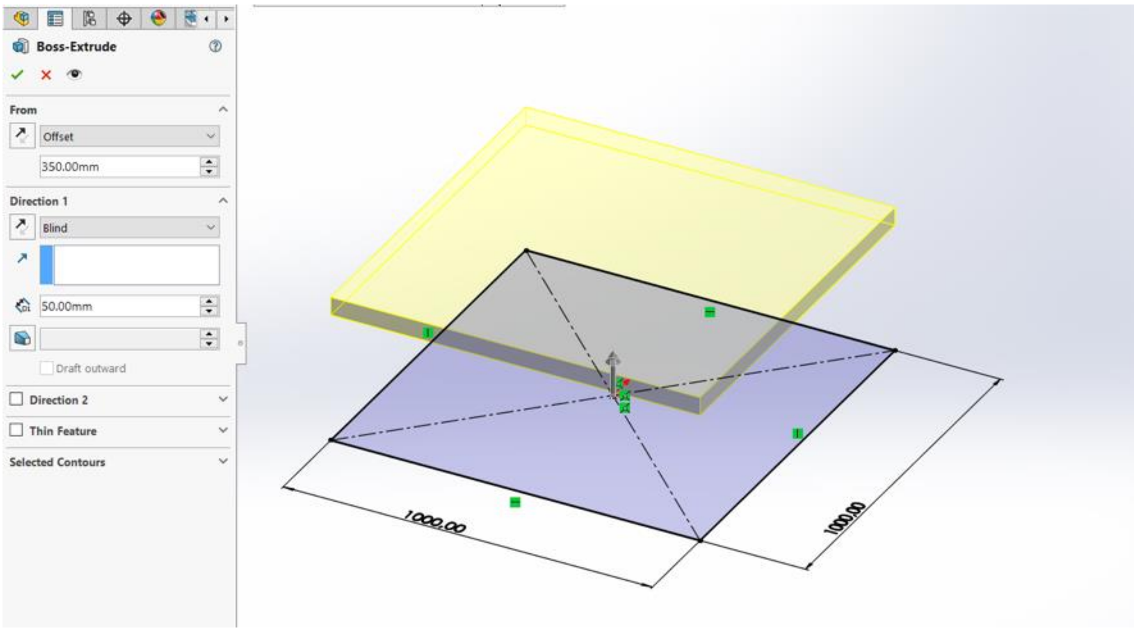


Figure 69. Worktable sketch and extruded part.

Then, lets sketch and taper-extrude a leg on the bottom of the table.

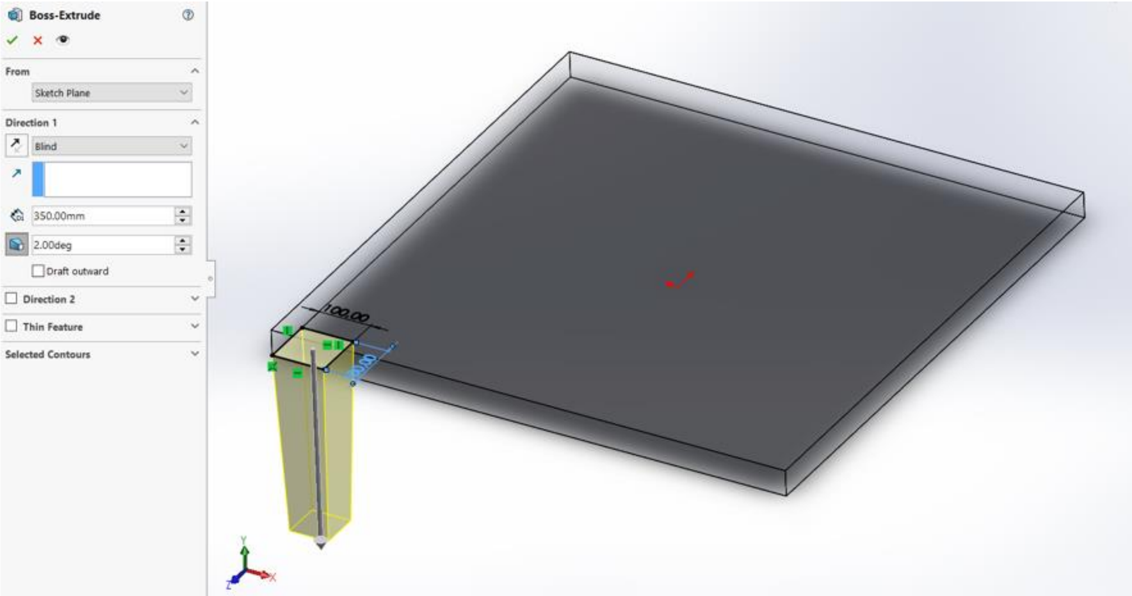


Figure 70. Tapered leg.

Possibly, at this stage, some joints could be needed:

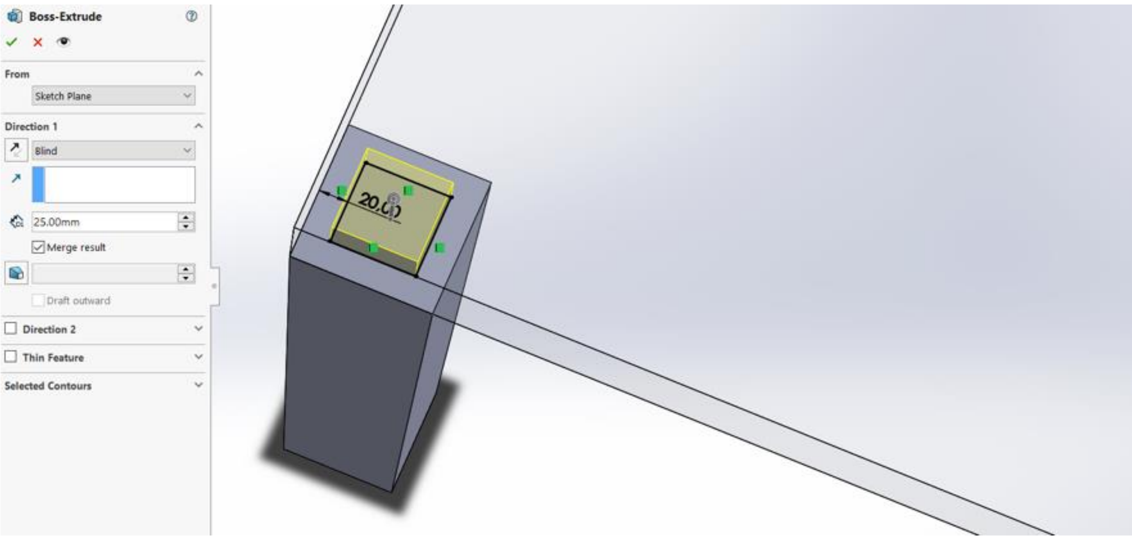


Figure 71. Leg joint.

After that – we can copy or mirror parts into table corners:

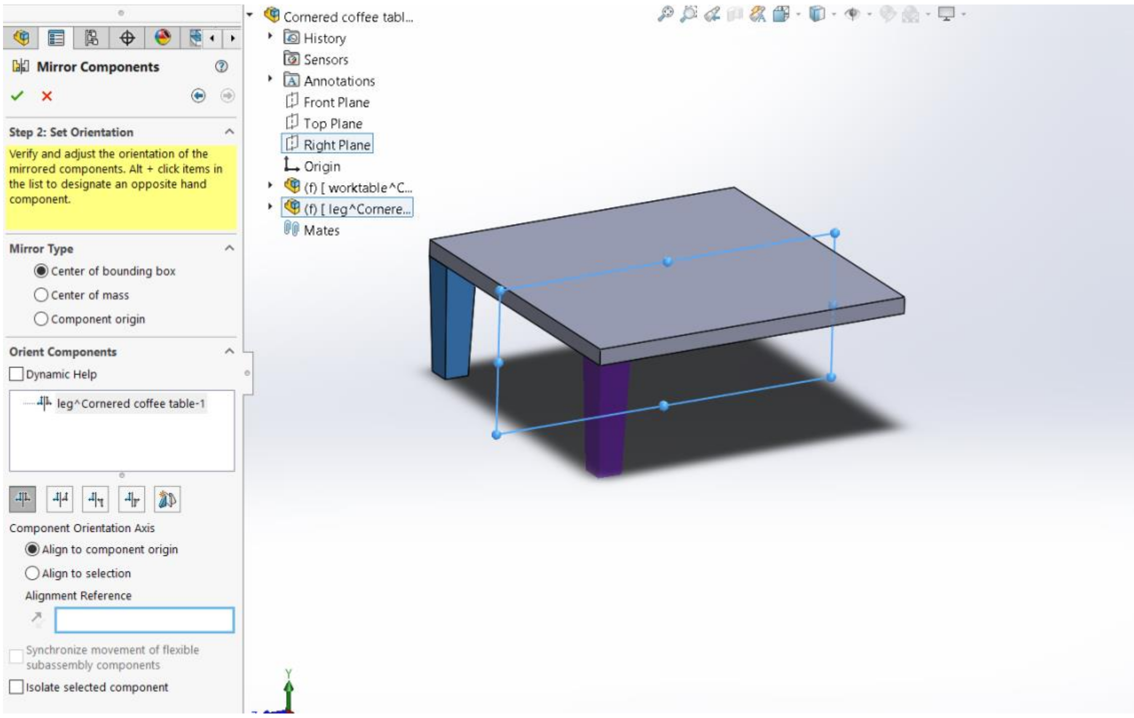


Figure 72. Mirror leg.

Obviously, we need to do it twice:

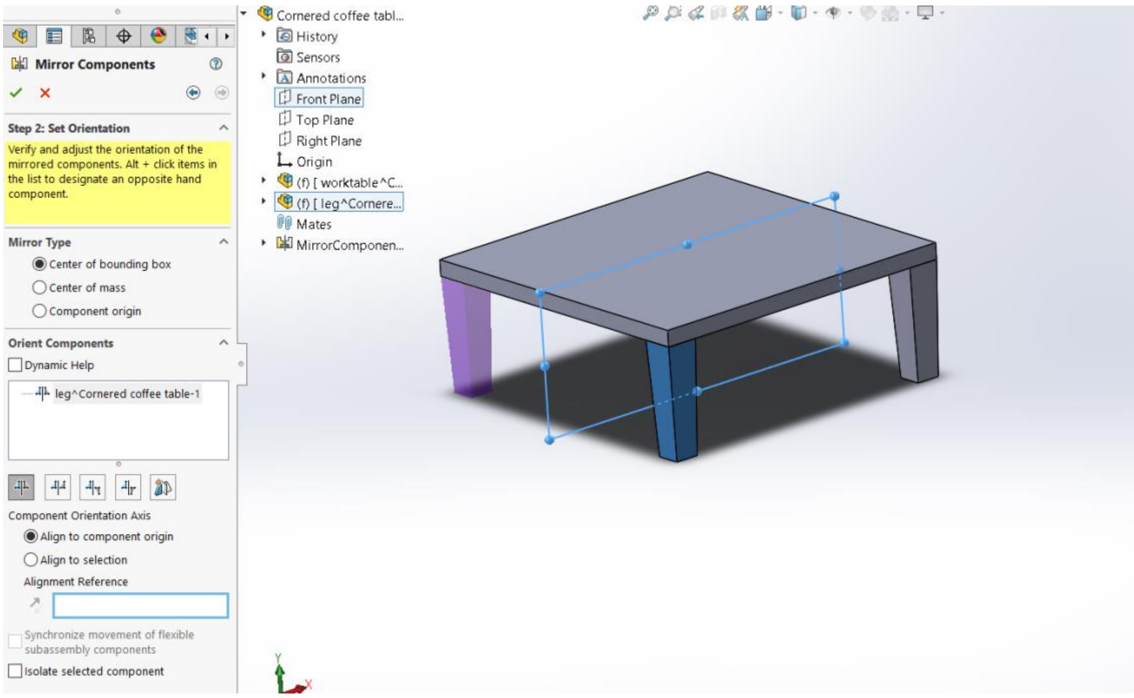


Figure 73. Second leg mirror.

Now let's sketch and cut opening – no dimensions are crucial, except parallel distance of 50 mm to the corner – we need to align side boards later:

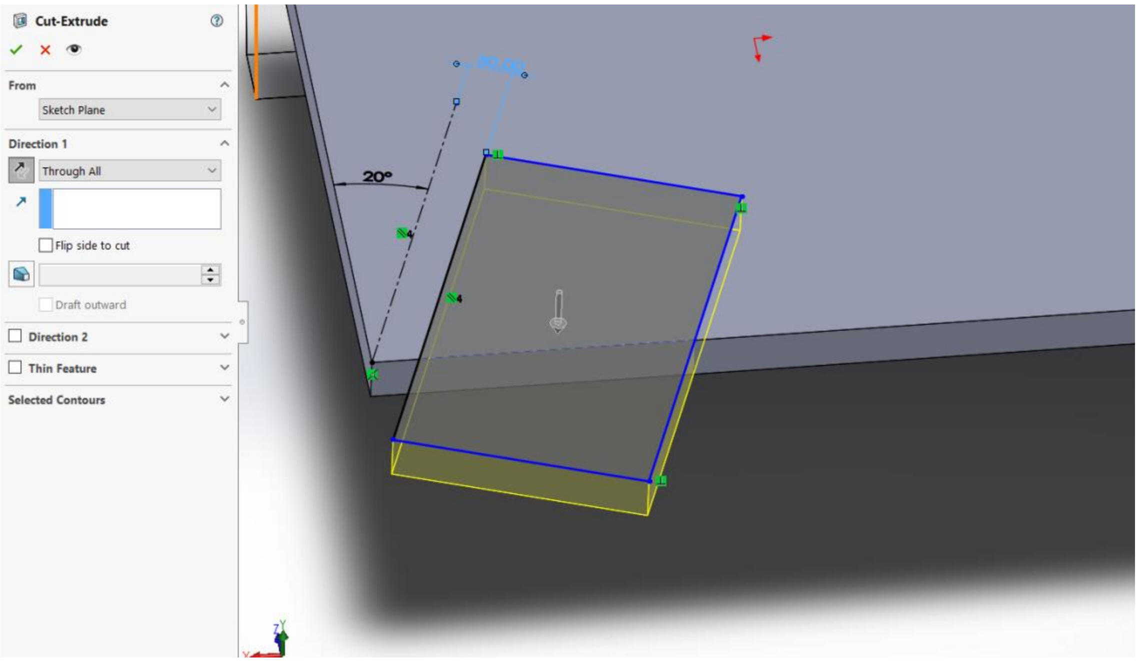


Figure 74. Cut of table opening.

And add some angle to the opening:

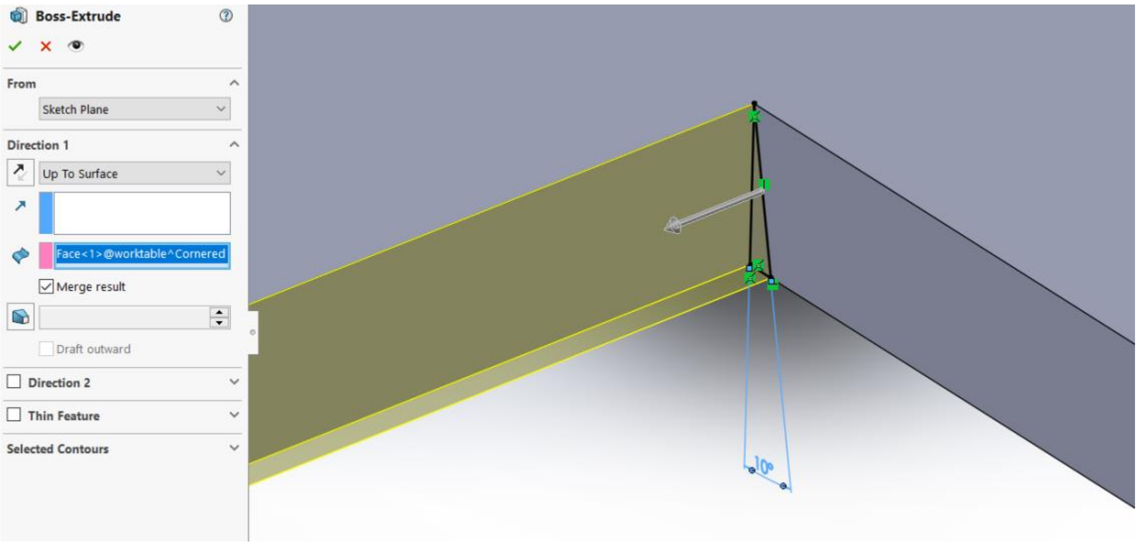


Figure 75. Table cut angle.

Now we can model box parts:

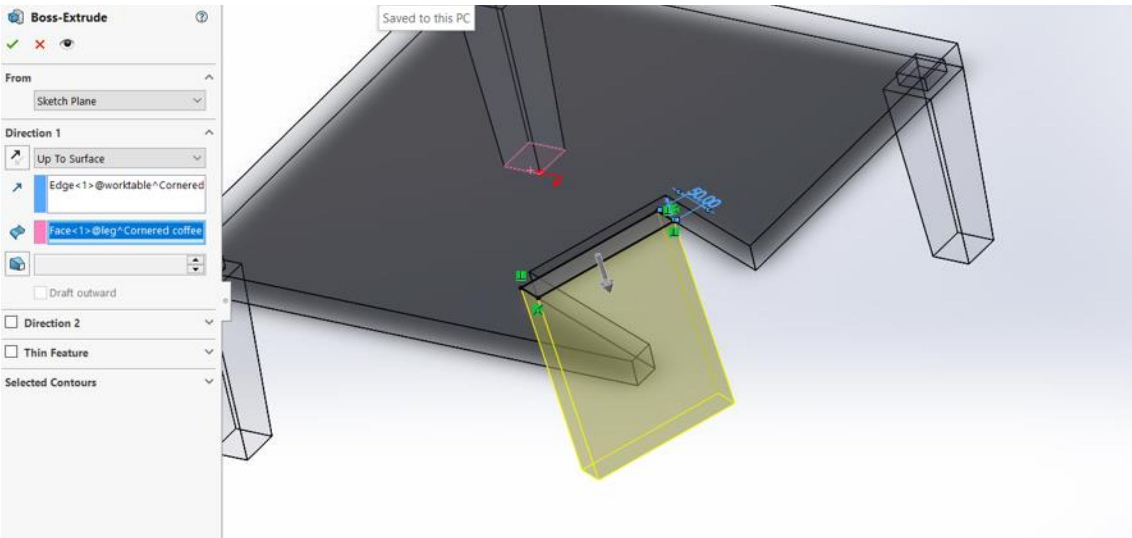


Figure 76. Box rear panel.

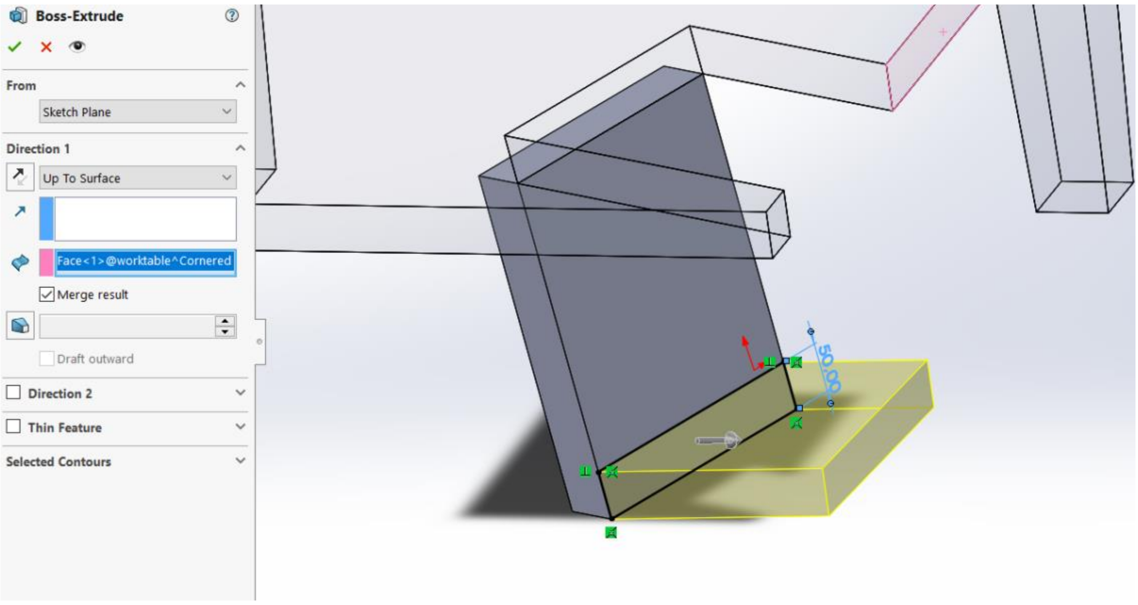


Figure 77. Box bottom panel.

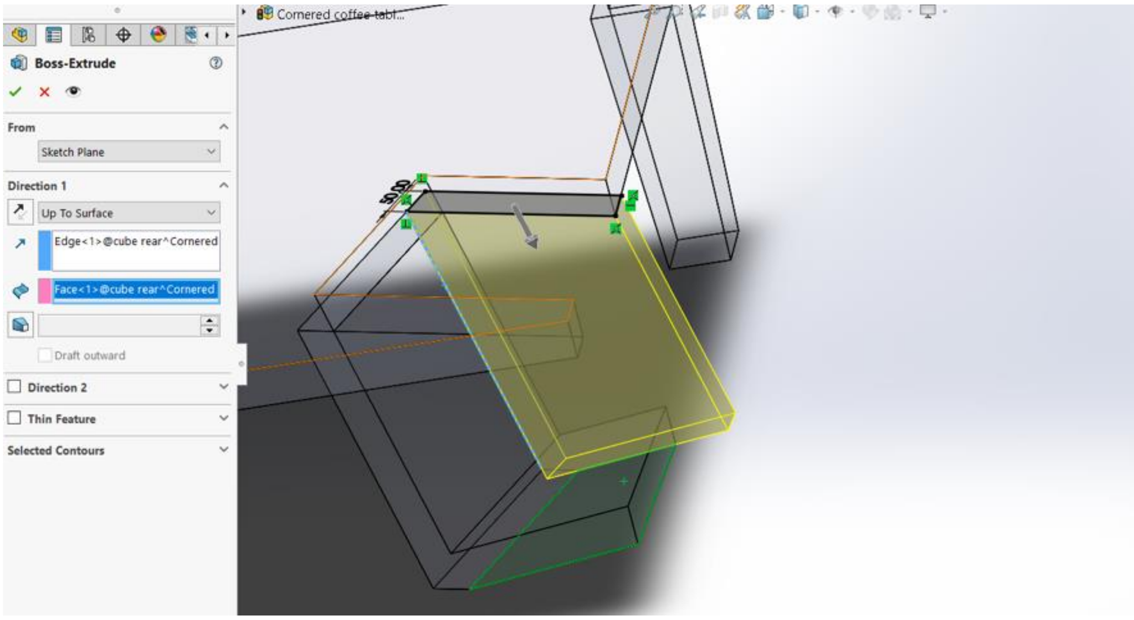


Figure 78. Right and left side modeled the same way.

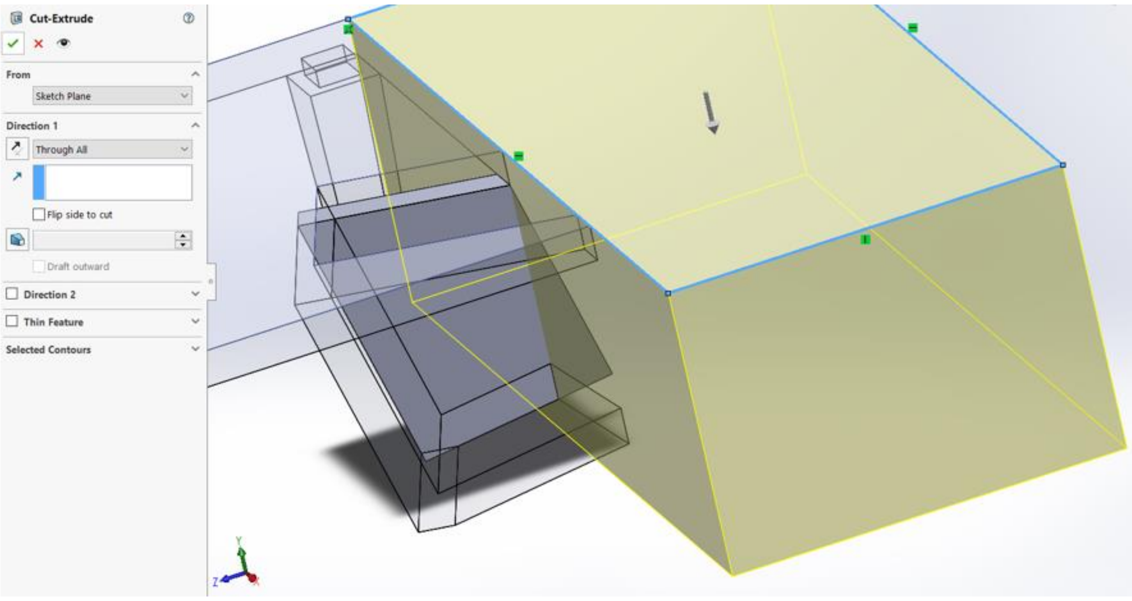


Figure 79. Excess parts need to be cut off.

Last step would be adding come connection bores with pins for pieces to match together, with necessary clearance, joints are oversized, because model will be printed in scale:

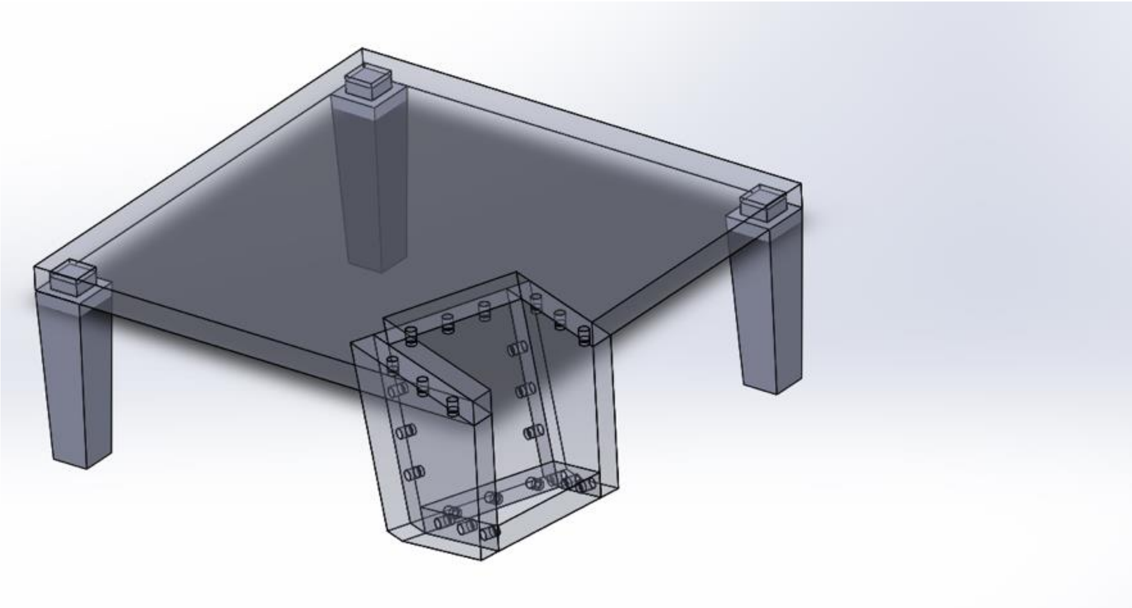


Figure 80. Connections added.

After that we have complete assembly, ready for printing the consequent parts.

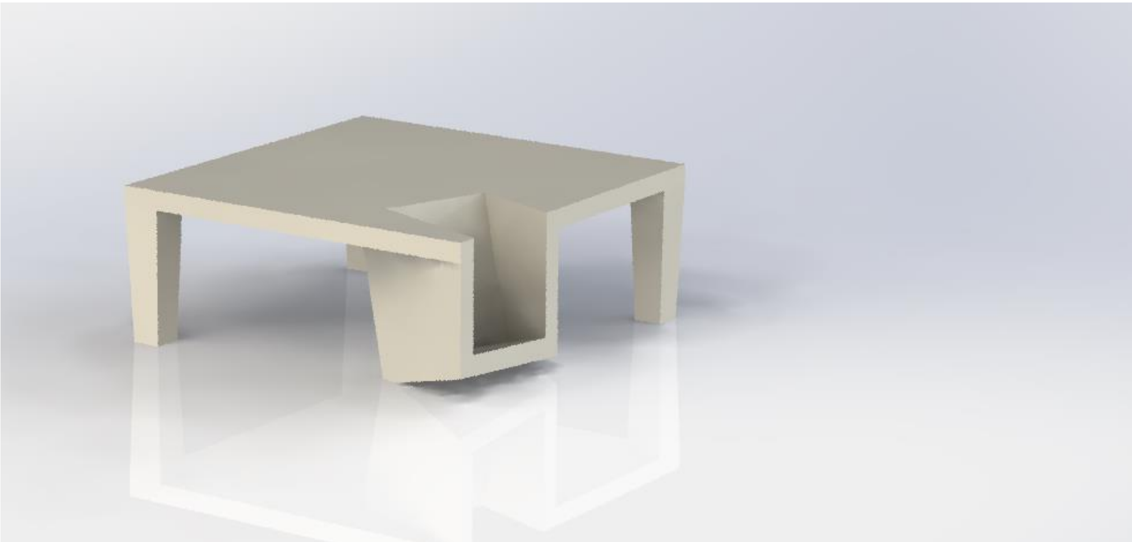


Figure 81. Final model.

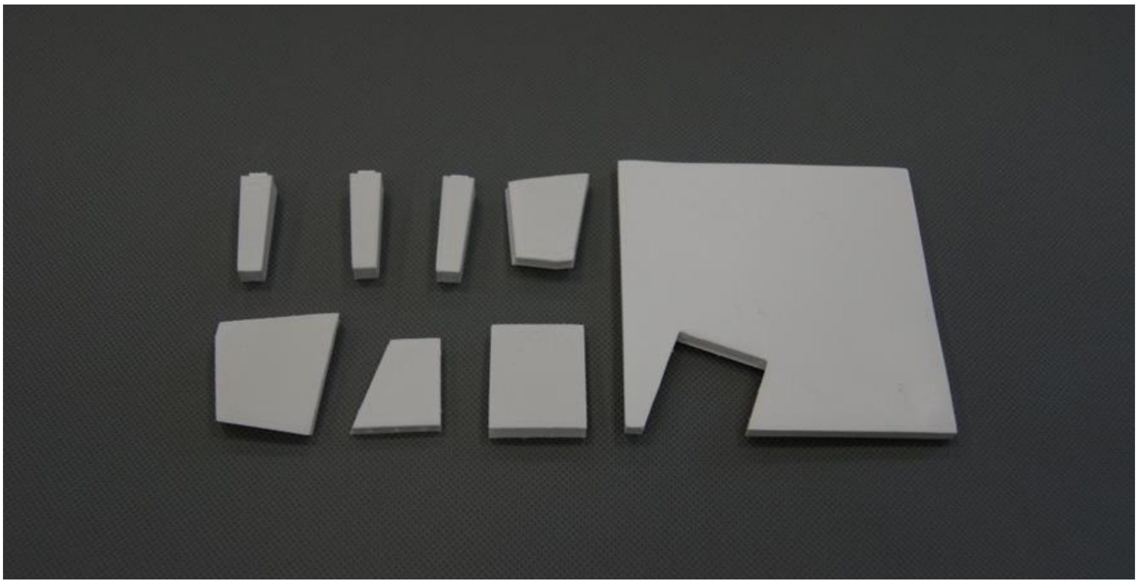


Figure 82. Printed table parts

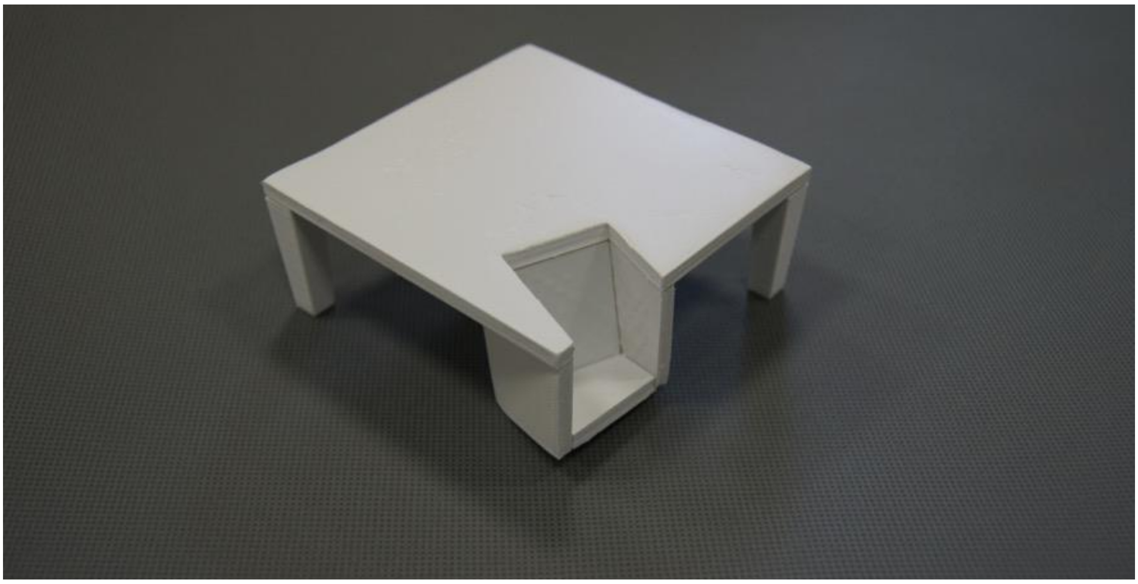


Figure 83. Assembled table

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge on how to creatively model furniture for assembly – students need to rethink the assembly order while modelling parts.

What methodology can be used for its integration into the classroom/curriculum?

The table parts will be fully modeled / printed by each student, to a given standard or non-standard dimensions. The student will also have to determine the best printing orientation of parts – to minimize the waste of material. After printing and cleaning, the table should be cleaned and assembled

What benefits can be obtained with its use?

The students will learn about:

- Modeling of self-dependent shapes.
- Modelling of fitting joint.
- Details on positioning of a model, to save on support material.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM, due to quality-price ratio of materials and machine.
Material	PLA recommended due to hygienic measures. ABS possible, not recommended due to thermal shrinking and deformation of a thin structure
Suitable dimensions for its use in the classroom (mm)	Here, it must be specified the necessary size of the object or model. You can indicate very general dimensions, such as length, height, width (x, y, z). Or it is also possible to give more specific dimensions, like diameters, thickness, or the size of more specific parts of the object. It is recommended to indicate the measures in millimetres. On this part it is also convenient to consider the printing bed size. This will restrict the size of the object to print.

Should the piece be resistant or be subjected to stress?	Show model – no specific requirements, can be up to 2 mm walls with 20-30% infill.
Number of pieces of which the exercise is composed:	Multiple pieces.
Ensemble type if necessary (slot, clip, screwed ...)	Push-on assembly, some areas may need to be manually sanded to fit.
Accuracy and definition required. (Quality) Low, mid or High.	Medium to high quality, visual appearance of the model is a key.
Support material or post-processing.	Support material can be the same as printing material, removal and cleaning up models necessary.

7. Exercise "Design of furniture with complex geometry in 3D printing"

INFORMATION

Exercise Name	Design of furniture with complex geometry in 3D printing.
Specific Subject	Design of furniture with complex geometry which could be hard to prototype with other technology.
Number of pieces of which the model is composed	Single piece.

3D MODEL DESCRIPTION

Written description.

The Panton Chair is a classic in the history of furniture – designed by Verner Panton in 1960, the chair was developed for serial production in collaboration with Vitra (1967).

It was the first chair made completely out of plastic in one single piece. Since its introduction to the market, it has advanced through several production phases. The first rather heavy model, which required substantial finishing work, was subsequently improved and adapted to industrial production using thermoplastic polystyrene which led to a marked reduction in cost. In 1968, Vitra initiated serial production of the final version which was sold by the Herman Miller Furniture Company. The material used was Baydur, a high-resilience polyurethane foam produced by Bayer in Leverkusen, Germany. It was offered in several colors.

In 1979, however, production was halted as it became apparent that polystyrene was not sufficiently durable and began to look shabby over time. Four years later, the model was again produced as the Panton Chair Classic, This time in the rather more expensive polyurethane structural foam. Finally, in 1999, Vitra used polypropylene for manufacturing the Panton Plastic Chair in a variety of colours. Panton was a contributor to the development of sleek new styles reflecting the "Space Age" of the 1960s which became known as Pop Art. It is regarded as one of the masterpieces of the Danish design. The chair was included in the 2006 Danish Culture Canon.

Panton chair as it was total breakthrough in the 1960's, still has futuristic look, and is relatively complex to model and produce in traditional technologies. 3D modelling and 3D printing takes this structure from incredibly complex to moderately hard to model and easy to prototype.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

Panton chair is based only on lightly specified curves, no single straight line is present in the model.

Figure 84. Panton chair.

Crucial to understanding how to model it, is to use at least one photo sideview. We can apply also more views, like front or top view to match designed curvature.

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Figure 85. Panton chair sideview.

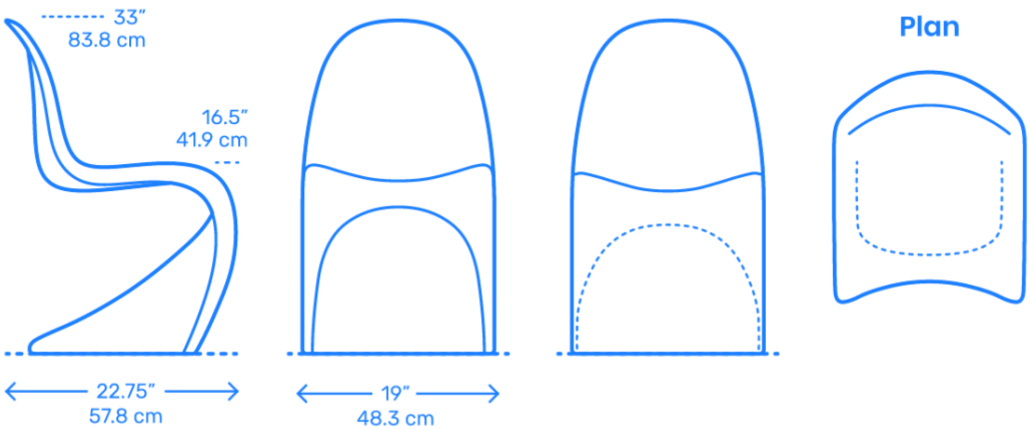

Figure 86. Panton chair dimensions [23].

Despite of the set dimensions of original model, it is relatively easy to scale model down or up to custom size, like for kids or population which doesn't fit standard dimensions.

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Figure 87. Panton chair scaled down for kids.

Additional materials for a better description.

Model is based on the bottom line and edge line curves sketched on a picture, with edge curves and front view projected into 3d curve:

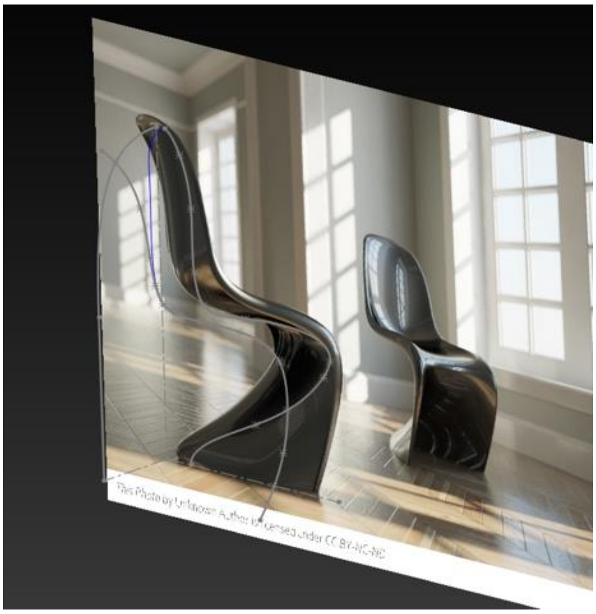


Figure 88. Bottom line and edge line curves, with projected blue curve of outer chair edge.

Then, you need to loft surface from projected curve into bottom curve, using 3d guides forming chair's seat:

Figure 89. Chair seat formed from projected and bottom curves.

Procedure can be repeat with outer bent strengthening edge – next projected curve:

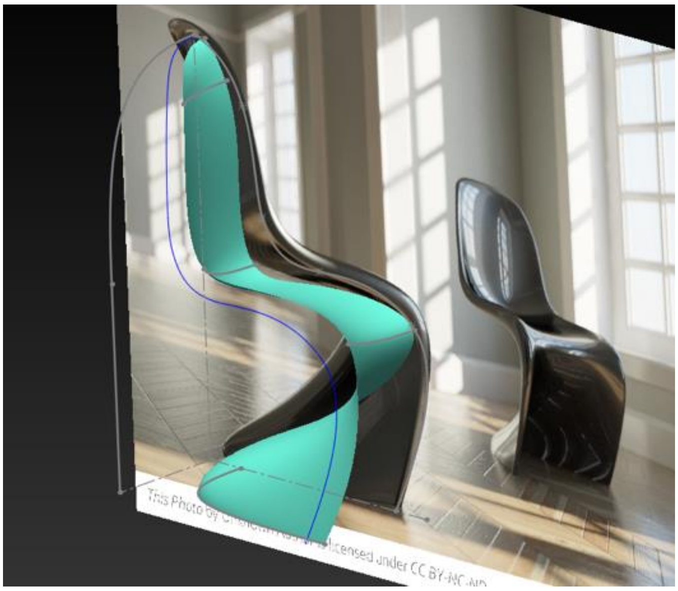


Figure 90. Projected curve of outer strengthening edge.

After creating of the curve – another lofted surface for edge:

Figure 91. Both surfaces created.

These faces need to be filleted, mirrored, and knit together:

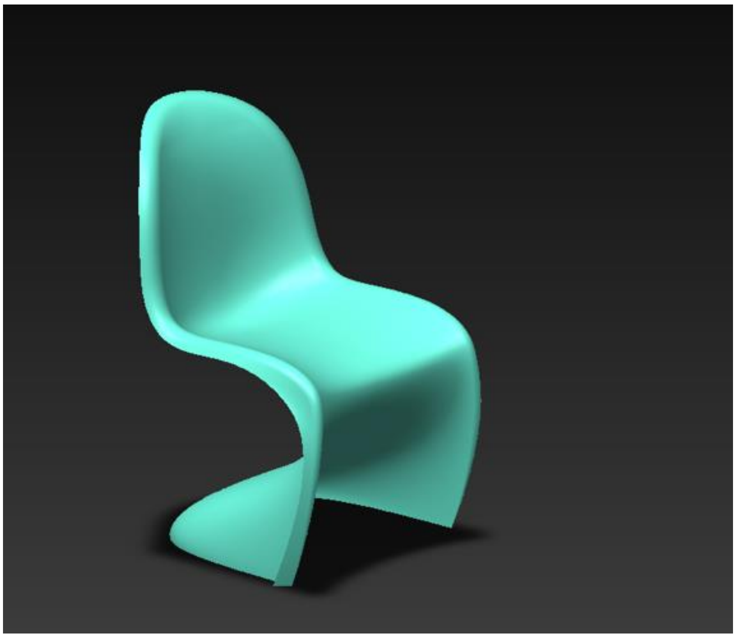


Figure 92. Joined, filleted, and mirrored faces into one final surface.

This final face needs to be thickened and sliced again, at least from the outer edge. Remember that depending on the final printing scale, you need to have a reasonable thickness, so final model has at least 1-2 mm to stay on one piece. If printing will be done in 1:5, this means thickening at least 10 mm.

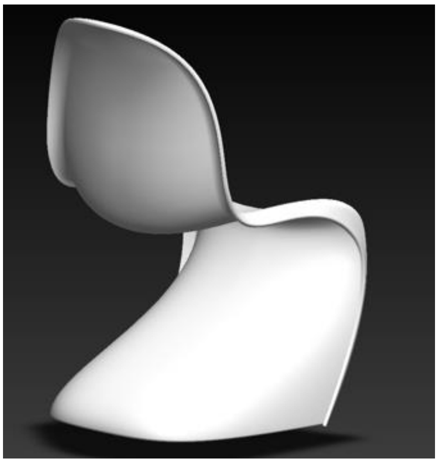


Figure 93. Thickened and filleted model.

Have a look to the final creation:

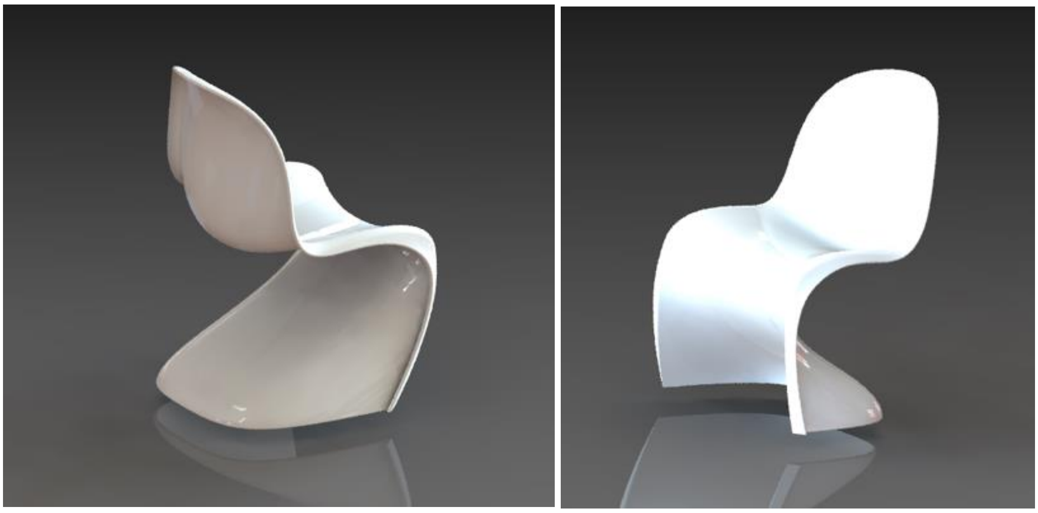


Figure 94. Final Panton chair model.

Figure 95. Printed Panton chair

TEACHING SPECIFICATION

How can this model be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge on how to creatively model complex furniture and scale it to required dimensions.

What methodology can be used for its integration into the classroom/curriculum?

The chair will be fully modeled / printed by each student, to a given standard or non-standard dimensions, basing on the pictures found on the internet. Student will also have to determine best printing orientation of a model – to minimize the waste of material.

What benefits can be obtained with its use?

The students will learn about:

- Self-sufficiency in finding out documentation necessary
- Modeling of complex shapes
- Surface modeling techniques
- Details on positioning of a model, to save on support material.

TECHNICAL SPECIFICATION OF THE EXERCISE

TECHNICAL SPECIFICATIONS

Technology	FDM, due to quality-price ratio of materials and machine.
Material	PLA recommended due to hygienic measures. ABS possible, not recommended due to thermal shrinking and deformation of a thin structure
Suitable dimensions for its use in the classroom (mm)	Here, it must be specified the necessary size of the object or model. You can indicate very general dimensions, such as length, height, width (x, y, z). Or it is also possible to give more specific dimensions, like diameters, thickness, or the size of more specific parts of the object. It is recommended to indicate the measures in millimeters. On this part it is also convenient to consider the printing bed size. This will restrict the size of the object to print.
Should the piece be resistant or be subjected to stress?	Show model – due to thin walls it needs to be printed with 100% infill
Number of pieces of which the exercise is composed:	Single piece
Ensemble type if necessary (slot, clip, screwed ...)	Not for assembly, single piece
Accuracy and definition required. (Quality) Low, mid or High.	Medium to high quality, visual appearance of the model is a key
Support material or post-processing.	Support material can be the same as printing material, removal and cleaning up model necessary

8. Exercise "Chair repair connectors"

INFORMATION

Exercise Name	Chair repair connectors
Specific Subject	Product Design, Sustainability
Number of pieces of which the model is composed	5 pieces

3D MODEL DESCRIPTION

Written description.

The exercise proposal is a joint that allows the reparation of chairs and stools that can no longer be used because they have cracks in the legs and support.

The joint has been designed to be easily inserted and adapted to any section, whether rounded, quadrangular, or rectangular. It can also be adjusted by means of a screw system so that it adapts to the size of the furniture in question.

The piece is composed of a main tubular part and various parts that fit into the main joint and modify the attachment according to the section of the chair leg. It is also possible to assemble pieces of chairs with different sections in such a way as to recover as much material as possible.

The whole piece is made up of 5 pieces and in particular a tubular joint and four reducers, 2 rectangular and two quadrangular.

The piece can be printed in various colours according to the object that needs to be repaired.
The general measures are 200 x 50 x 50 mm.

The main piece will be connected with the reducers using of an interlocking while the reducers according to the dimension of the leg of the chair and the stool will be assembled by means of an interlocking and edged utilizing screws that will be positioned in the holes.
The exercise in question has been designed to allow students of furniture and wood courses to focus on elements that can in a certain sense limit the waste of material and repair objects that would end up in landfills. In addition to the technical components that need to be developed, the design and adaptability to any chair and stool also provide elements of sustainability and recycling of materials and products.

The performance of the exercise will enhance and put into practice awareness on the use of different materials, recycling but also how to bring innovation to existing objects.
Statics lessons can also be combined to understand if the piece is resistant to the forces or forces on the joint.
The material that can be used for printing the piece is ABS or PLA. The use of ABS is recommended for the finished piece as it must be resistant to various forces.

Graphic Definition of the 3D Model. (Technical draws, hand free sketches and renders).

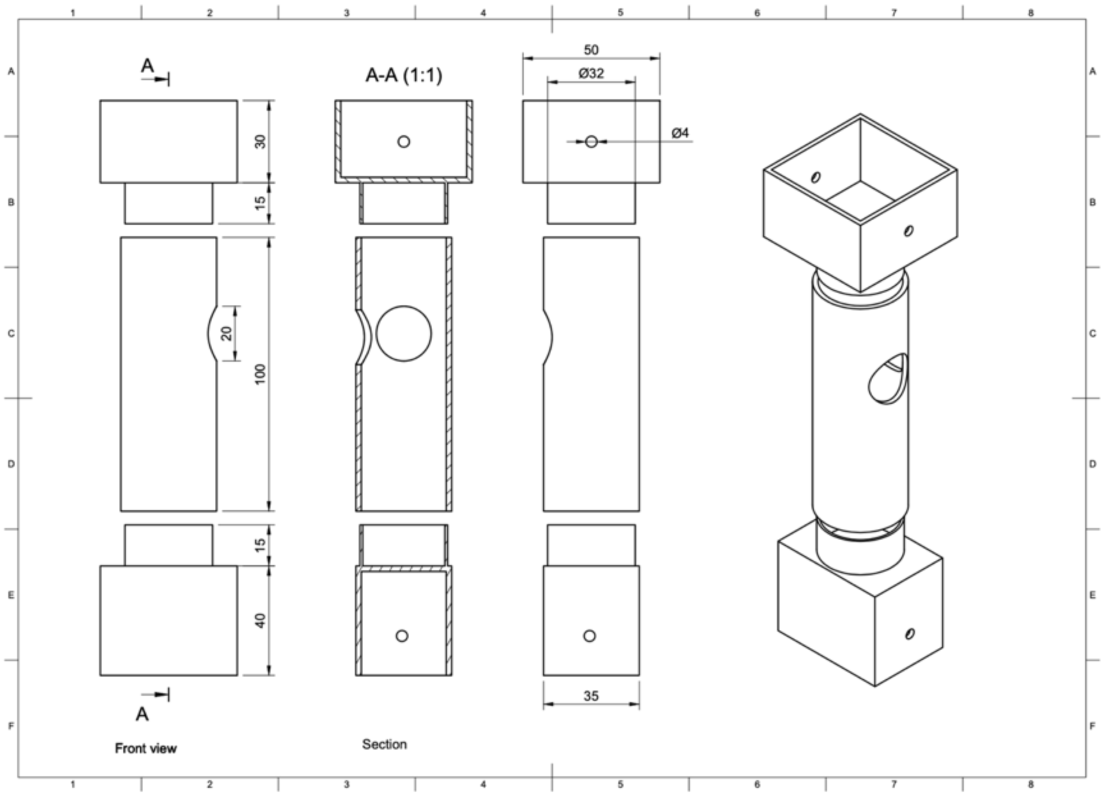


Figure 96: Schematic drawing of the model "Chair repair connectors".

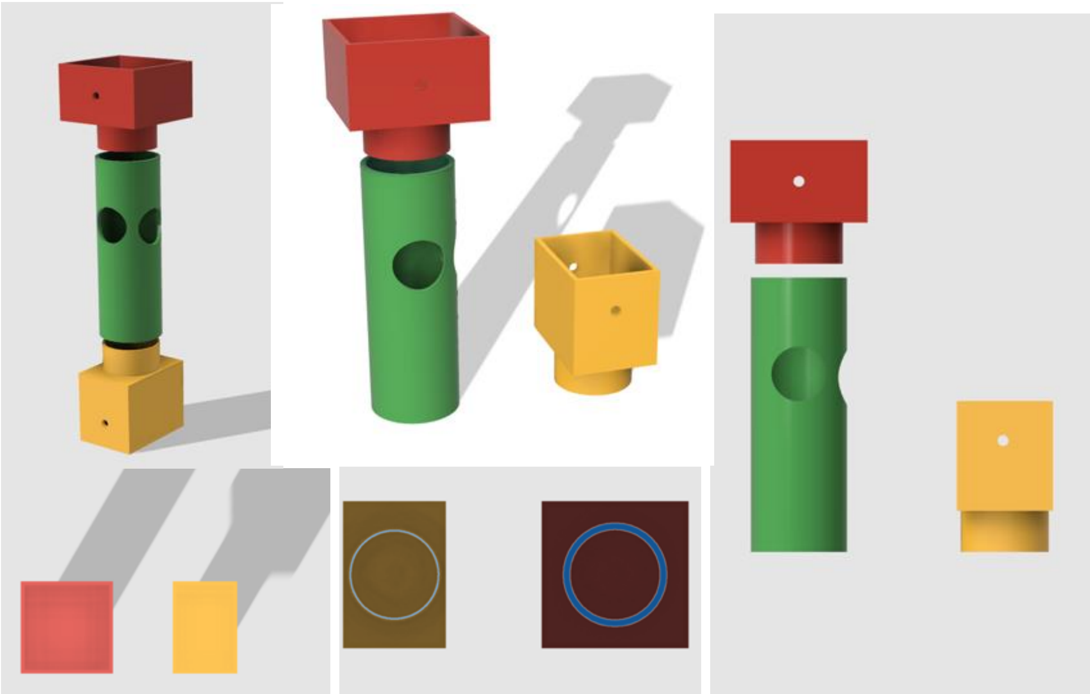


Figure 97: Renderings of the model "Chair repair connectors".

Additional materials for a better description.

Figure 98: Examples of similar products.

TEACHING SPECIFICATION

How can this model be used in the classroom?

The teacher in the classroom can both use the exercise to create eco-design workshops, focusing on how it is possible to reuse dismissed chairs and stools to give them a new life.

All this can be accompanied by technical drawing lessons, Life cycle assessment of the product but at the same time to create new joints with new sections for other types of furniture.

The main purpose is to make students understand the reuse process and how with modern technologies it is possible to repair products that are now destined to be dismissed.

The lesson may focus on new ways of producing, using, and reusing industrial products, but also to record the new frontiers of conscious innovation on the issues of duration, circularity, sharing and services. The aim is precisely to investigate what has been done and is still being done around this issue.

It is also possible to focus the lesson on which products are simple and therefore more accessible, in what direction the repairability technologies are proceeding, how the strategies on spare parts, materials, projects of new aesthetics, etc. are studied. Without neglecting the programs that involve social issues and the territory, in view of the reconstruction of an economy that includes new logics of duration and repairability.

What methodology can be used for its integration into the classroom/curriculum?

To develop the exercise, the teacher will be able to use different teaching techniques. We suggest one, namely that of design thinking.

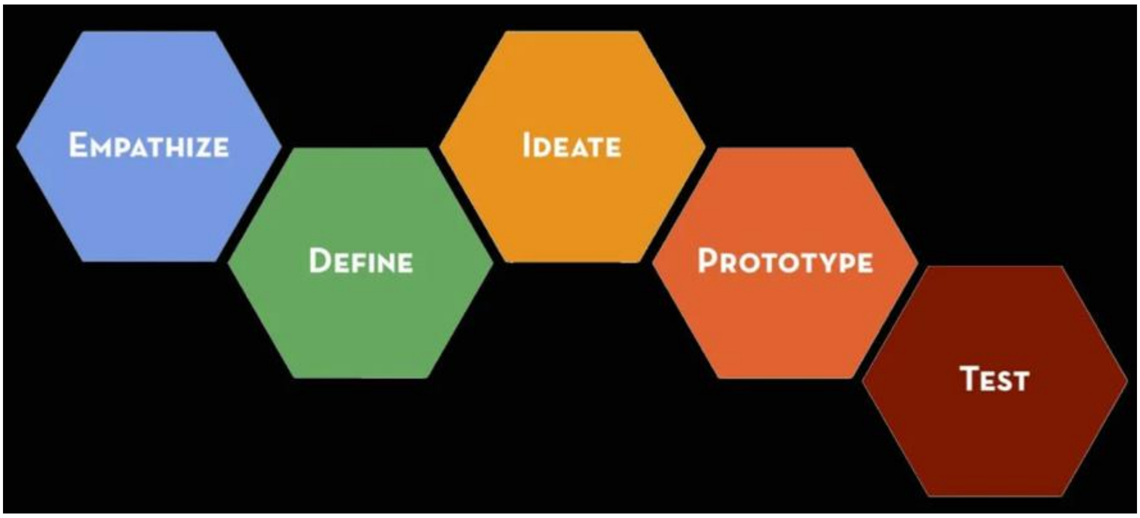


Figure 99: Design Thinking Methodology [24].

Through this process it is a matter of defining (the possible opportunity), developing the "prototype", comparing, improving, reaching, and finally achieving the project idea.
By adopting this approach in the classroom, students will be much more motivated and involved in carrying out the exercise itself and will develop infinite ideas for using the joint.

What benefits can be obtained with its use?

As evidenced many times, this exercise is multidisciplinary as by developing it various subjects can be taken into consideration and at the same time the student will be able to benefit in various fields.

For example, thanks to the technical reproduction of the artefact, he will be able to learn how to draw a complex and geometric shape from life or technically on the PC.

Th student will also be able to understand how to build the joints and at the same time how to assemble pieces of different materials.

Furthermore, he will be able to learn the laws of statistics as he will have to test if the piece is resistant at the junction and load points of the object.

Then, there are all the aspects related to the recyclability and circularity of the subjects and the environmental protection that represent important notions to know and from which students can benefit.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	ABS, PLA
Suitable dimensions for its use in the classroom (mm)	200 x 50 x 50 mm
Should the piece be resistant or be subjected to stress?	Yes
Number of pieces of which the exercise is composed:	5
Ensemble type if necessary (slot, clip, screwed ...)	Screw and pressure adjustments
Accuracy and definition required. (Quality) Low, mid or High.	Mid
Support material or post-processing.	It is necessary removing the different supports.

9. Exercise "Furniture design with 3D printed connectors"

INFORMATION

Exercise Name	Furniture design with 3D printed connectors
Specific Subject	Furniture design, Carpentry, Prototypes.
Number of pieces of which the model is composed	7 pieces

3D MODEL DESCRIPTION

Written description.

The idea is to design 3D connectors for the manufacture of a three-legged low table, using them as an assembly system for the different parts that make up the piece of furniture.
There are as many different types of designs as the imagination of the designer, as an example for the definition of the exercise the following is proposed:

Design of 7 connectors to be printed in 3D and used as a table assembly system:

⇒ 3 pieces to assemble the legs to the central reinforcement.

⇒ 1 piece for the central reinforcement to which the legs will be assembled.

⇒ 3 pieces to assemble the three legs to the seat.

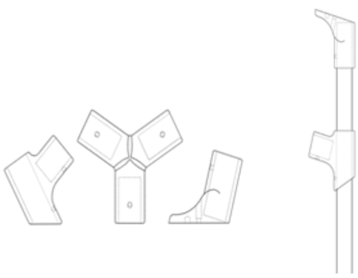


Figure 100: Chair connectors.

The colour and shape may vary depending on the designer's taste and skills.

This exercise aims to teach students how to integrate 3D printing into the furniture design and manufacturing process, showing them various options so that they can develop their creative thinking and knowledge of this technology while applying it to real and fully functional items.

The freedom of design and customisation in this type of exercise will provide the student with skills for future work.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

In addition to the 3D printed parts, we need 15 screws, three pieces of wood for the legs of the height we want the table to be, three short pieces of wood for the central assembly that gives stability and rigidity to the table, and the tabletop.

The length of the wooden pieces required for the legs of the side table should be 515 mm and the diameter 30 mm. 3 wooden legs are needed for this procedure.

The length of the wooden pieces required to connect the middle connection piece and the plastic fittings on the legs should be 105 mm and the diameter 30 mm. 3 wooden sticks are needed.

Two models have been designed for this exercise to show that the teacher or student can develop their own version. The images of these are shown below:

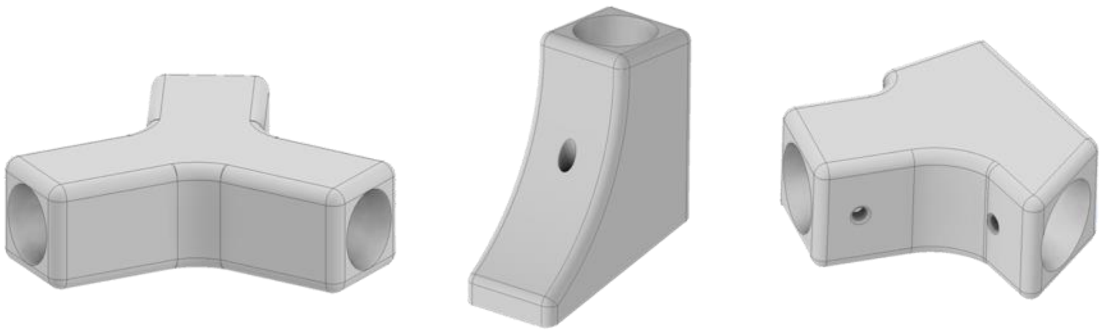


Figure 101: First proposal. Design of connectors.

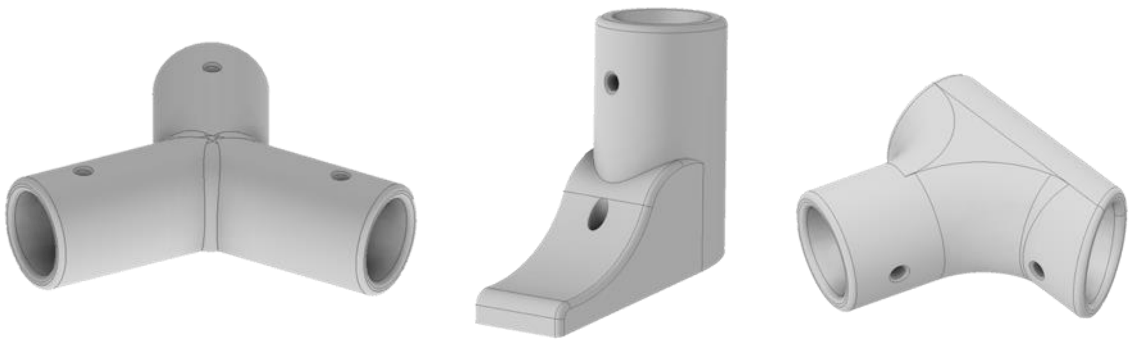


Figure 102: Second proposal. Design of connectors.

Additional materials for a better description.

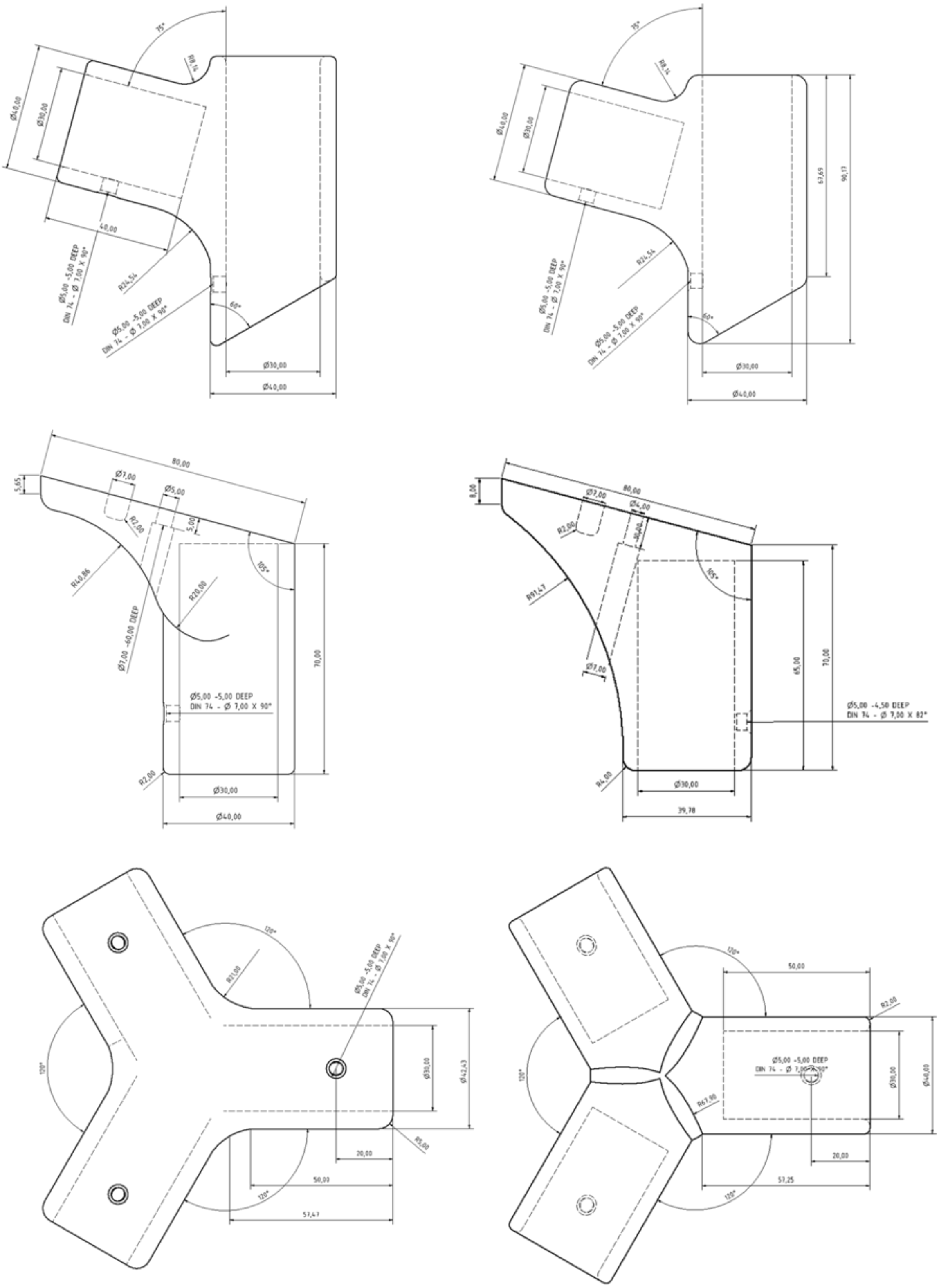


Figure 103: Measurements of the two connector designs.

TEACHING SPECIFICATION

How can this exercise be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge to integrate 3D printing into the design and production of furniture. Through "hybrid technology" where traditional manufacturing and additive manufacturing merge, the student will explore the advantages and possibilities of integrating this technology into furniture production by learning by doing.

The aim is for the student to be able to use their knowledge of furniture design and manufacture to design connectors that will be 3D printed, and which will act as an assembly system in their furniture designs.

With this exercise the student will analyse and will be able to redesign if desired the assembly system to be 3D printed. With the printing of the connectors, the student will gain and expand knowledge about 3D technology: use and possibilities within the furniture and wood sector.

What methodology can be used for its integration into the classroom/curriculum?

An appropriate way to integrate this exercise into the classroom/curriculum would be to use a project-based methodology for the integration of 3D printing technology as a tool for the development of innovation and creativity in furniture design. This exercise can be performed in class as a multi-stage exercise:

- Design of a piece of furniture by designing and integrating 3D printed connectors as an assembly system.
- 3D printing of connectors and post-processing of parts where necessary.
- Preparation of the rest of the components (cutting and treatment of the different pieces of wood necessary for the manufacture of the table).
- Manufacturing process by means of assembly.
- Final analysis of the furniture and verification of its functionality.

Project-based learning is meaningful to students because they develop the skills necessary to develop their abilities in designing and integrating technology into their work. Within the framework of the technology project, students can pursue their own interests and work on customising their designs/prototypes/furniture.

What benefits can be obtained with its use?

To internalise the concept of a customised product. By modifying the design of the connectors, the student can create a multitude of table designs. The exercise will provide the student with more design opportunities and the possibility of making more complex structures.

This technique can be used both for final products such as the one in the exercise and for the manufacture of prototypes at a lower cost and production time.

Students could explore the differences and potential of traditional manufacturing techniques and additive manufacturing technologies, using the examples in class to facilitate an open-minded approach in design.

In terms of learning outputs, the learner will be able to:

- Analyse and optimize the design for 3D printing.
- Know the Influence of additive manufacturing on the design and prototyping of a product.
- Know how 3D printing is being used in the furniture market.
- Acquires knowledge about competitiveness of the additive manufacturing in the production sector.
- Work with hybrid technology (Pieces of wood assembled with 3D printing parts).

Generally speaking, the students tend to work with subtractive manufacturing, i.e. an object is created by removing material and waste is generated. This factor disappears with additive manufacturing. As the final object is created layer by layer and only the material required for the desired volume is consumed. The result is zero waste or a considerable reduction of waste. This new way of production will open the student's mind and help to reconcile with the environment.

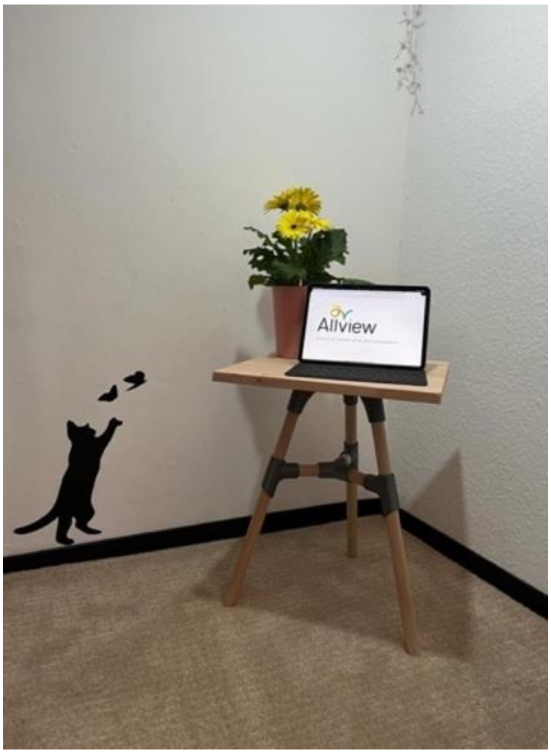


Figure 104: Result Table made with connectors.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They will be able to be printed without problems on the printing bed.
Should the piece be resistant or be subjected to stress?	Yes
Number of pieces of which the exercise is composed:	The number of parts will depend on the final design, 7 are specified in the example.
Ensemble type if necessary (slot, clip, screwed ...)	These printed parts act as connectors for the assembly of a wooden table, so some tolerances may be needed when printing them.
Accuracy and definition required. (Quality) Low, mid or High.	Mid or High
Support material or post-processing.	If the angles do not exceed 45° no support material is required. Sanding will be applied as post-processing to remove possible imperfections.

10. Exercise "Furniture design with 3D printed parts"

INFORMATION

Exercise Name	Furniture design with 3D printed parts
Specific Subject	Bring more colour and different materials to your design.
Number of pieces of which the model is composed	2 pieces or more

3D MODEL DESCRIPTION

Written description.

The idea is to integrate 3D printed parts in the design of a cabin. To bring more colour and different materials into the design.

Design two parts to connect the legs of the cabin.

The colour and shape may vary depending on the designer's taste and skills.

With this exercise we aim to raise awareness in our students about new materials.
In this way, they discover that 3D printing will give them even more design freedom. In some cases, the use of wood as a raw material can come together with some limitations that can be also reduced or removed by using 3D printing.
This also ensures that new materials get to know.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

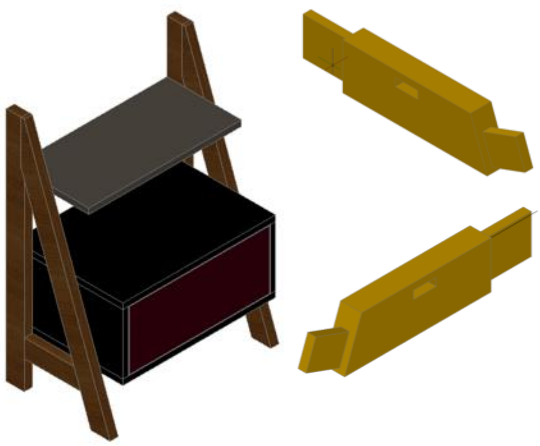


Figure 105: Rendering of the exercise "Furniture design with 3D printed parts".

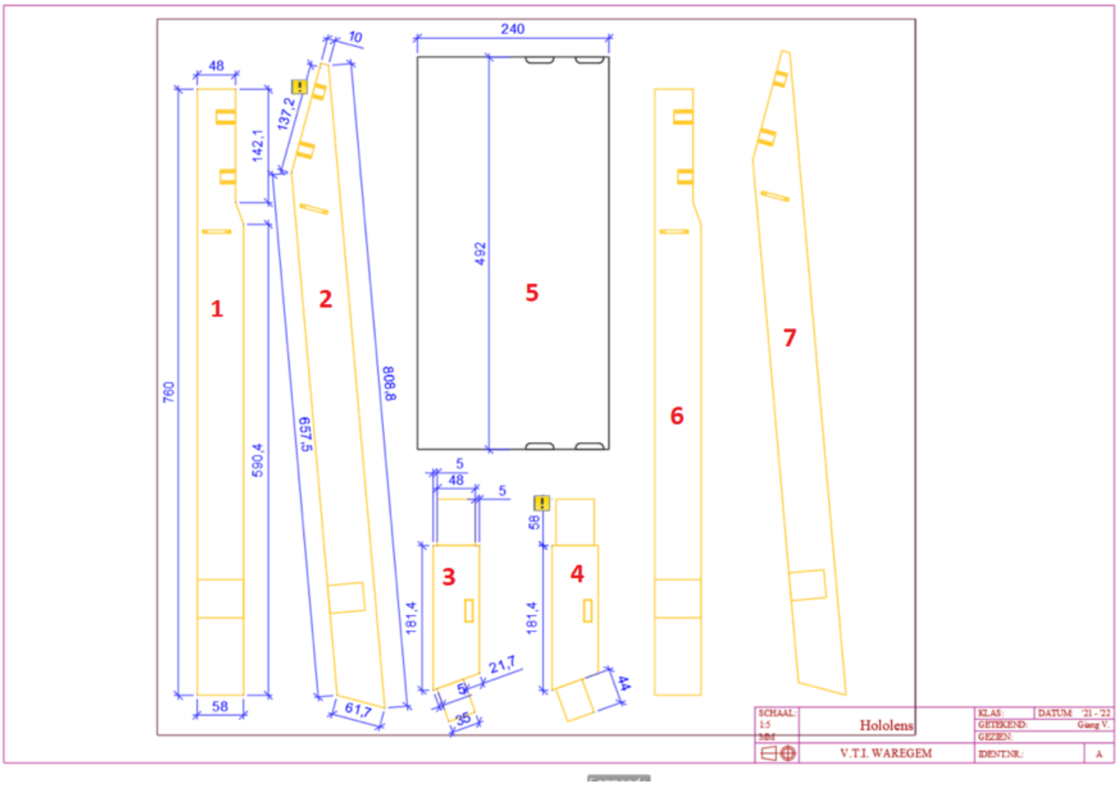


Figure 106: Numbering and measurements of parts.

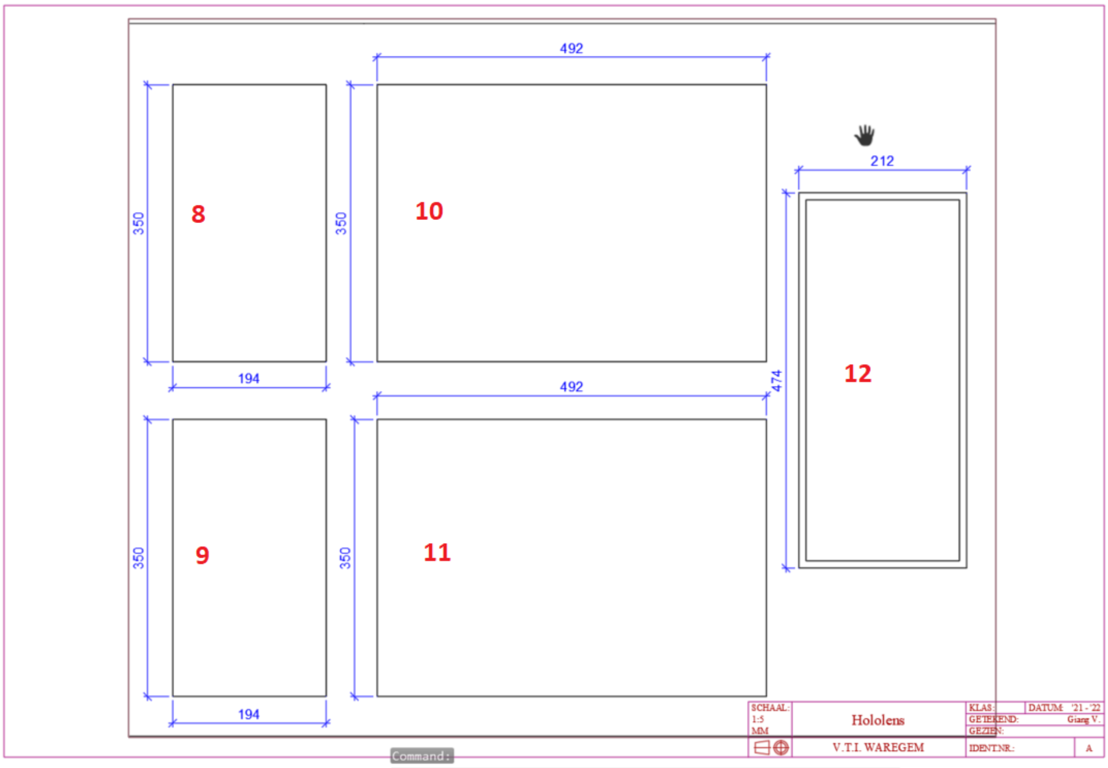


Figure 107: Numbering and measurements of parts.

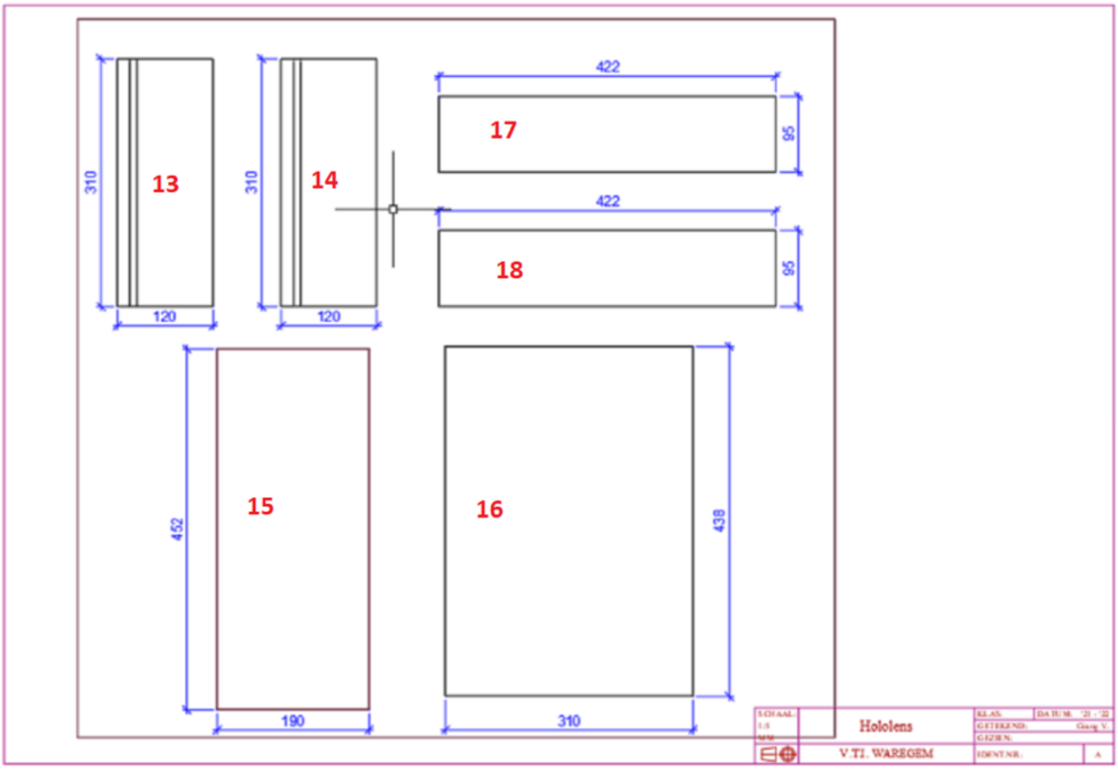


Figure 108: Numbering and measurements of parts.

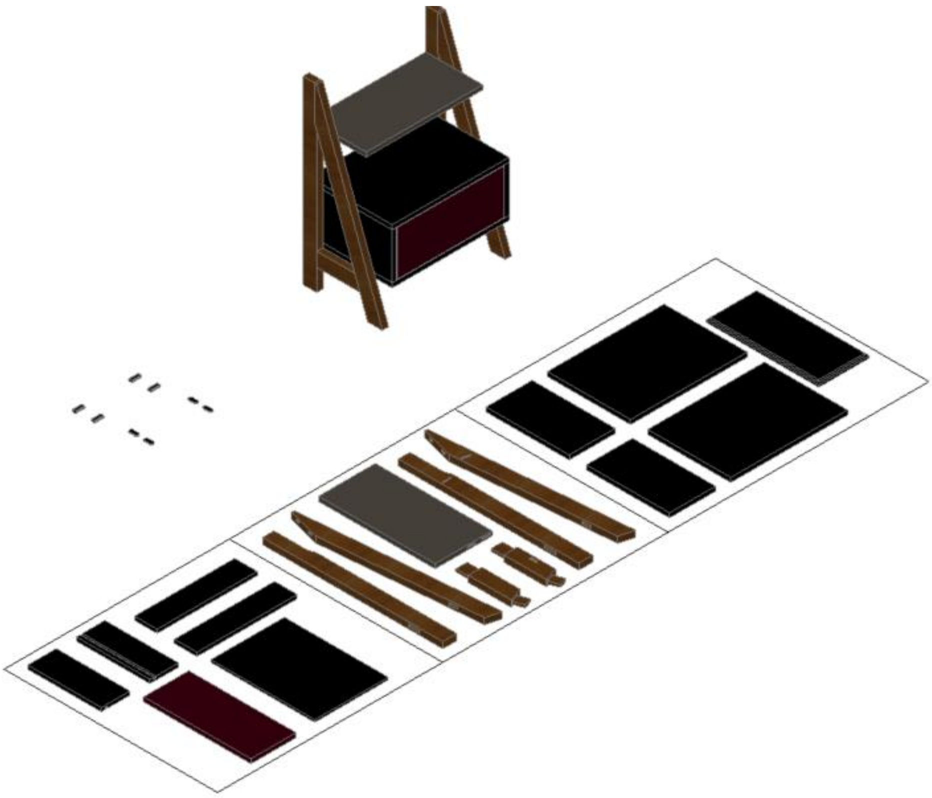


Figure 109: Breakdown of the cabin.

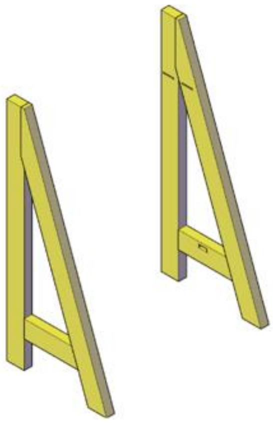


Figure 110: Cabin legs.

NR	NAME
1	Left style
2	Slanted left style
3	Under rule left
4	Under rule right
5	Shelf
6	Right style
7	Slanted right style
8	Corpus left
9	Corpus right
10	Corpus bottom
11	Corpus top
12	Corpus back
13	Drawer left
14	Drawer right
15	Drawer front
16	Drawer back
17	Drawer front cover
18	Drawer bottom

Additional materials for a better description.

In addition to the 3D printed parts, we also need the other parts which will be made of wood. And will be manufactured in the different lessons.

There are other parts that also can be 3D printed. Depending on the size of the 3D printer but also on the design of the student.

TEACHING SPECIFICATION

How can this model be used in the classroom?

The exercise is intended to be put into practice in wood training at EQF level 4 of vocational training. Every student will manufacture this cabinet. The students must first draw each part themselves before they can start making. These also ensures that each student can design the connectors to his own preference. And then later can have it printed in color in material of your choice. To then, during the assembly of all parts, add these pieces to all parts that were manufactured in wood.

What methodology can be used for its integration into the classroom/curriculum?

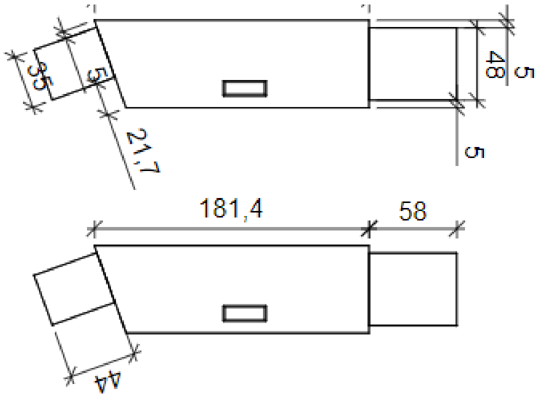
The workpiece will be made by each student. The students will learn new connection techniques and will be able to print the parts in 3D.

Before all parts are made, the workpiece must first be fully drawn.

What benefits can be obtained with its use?

The students do not only learn to work with wood but can combine different materials. Get to know new techniques.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA is very easy to print, very accurate and rigid, so it is one of the options more frequent for printing models. ABS is a bit more complicated to print because it tends to deform.
Suitable dimensions for its use in the classroom (mm)	
Should the piece be resistant or be subjected to stress?	Yes, the part will experience forces. The part should hold the ben of the cabinet together. And will be glued with the legs.
Number of pieces of which the exercise is composed:	There's a minimum of 2 pieces
Ensemble type if necessary (slot, clip, screwed ...)	Pin hole connection. By designing the piece, the drawing has to be perfect. So the connecting can be made.
Accuracy and definition required. (Quality) Low, mid or High.	Low quality can work for this part. The higher the quality, the more attractive the workpiece will be. The part is also clearly visible in the whole.
Support material or post-processing.	No supporting material will be required.

11. Exercise "Chair design with 3D printed connectors and simple wooden elements"

INFORMATION

Exercise Name	Chair design with 3D printed connectors and simple wooden elements
Specific Subject	Chair design, Carpentry, 3D printing, bonding wood to PLA, Prototypes.
Number of pieces of which the model is composed	Six 3d printed pieces

3D MODEL DESCRIPTION

Written description.

The idea is to design a chair with use of 3D printed connectors and simple wooden elements (which could be bought/prepared in ordinary DIY shop), bonded together with selected adhesive.

Simple wooden elements (square, rectangular, shapes and panels) are proposed, since not all schools have additional woodworking machinery to machine more complex parts. There are different options of design of connectors, depend on the level of modelling skills and available machinery for wood preparation. The basic limitations for chair design should be basic chair dimensions:

- Seat height 450-470 mm
- Seat slope angle 0-5°
- Seat width min 380 mm
- Backrest height 100 mm
- Backrest angle (from horizontal plane) 95-110 °
- Seat depth 400-440 mm
- Distance between seat and lower edge of backrest 210 mm

Figure 111: Schematic drawing of the chair.

Several types of designs are possible. The simplest consist of:

⇒ 6 different 3d printed connectors,
⇒ 4 wooden legs,
⇒ 4 wooden stretchers,
⇒ 2 wooden backrest parts and
⇒ panels for seat and backrest.

The colour and shape of chair and connectors may vary depending on the designer's taste and skills.

This exercise aims to teach students how to integrate 3D printing into the furniture design and manufacturing process, showing them various options so that they can develop their creative thinking and knowledge of this technology while applying it to real and fully functional items. Also, by including wooden elements, we could use smaller connectors and thus could chair be printed on smaller 3D printers.

The freedom of design and customisation in this type of exercise will provide the student with skills for future work.

The example below can be used as a basis. The diagrams are shown in the following section.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

In addition to the 3D printed and wooden parts we need 4 screws (connecting the seat to stretchers) and adhesive for bonding connectors and wooden parts.

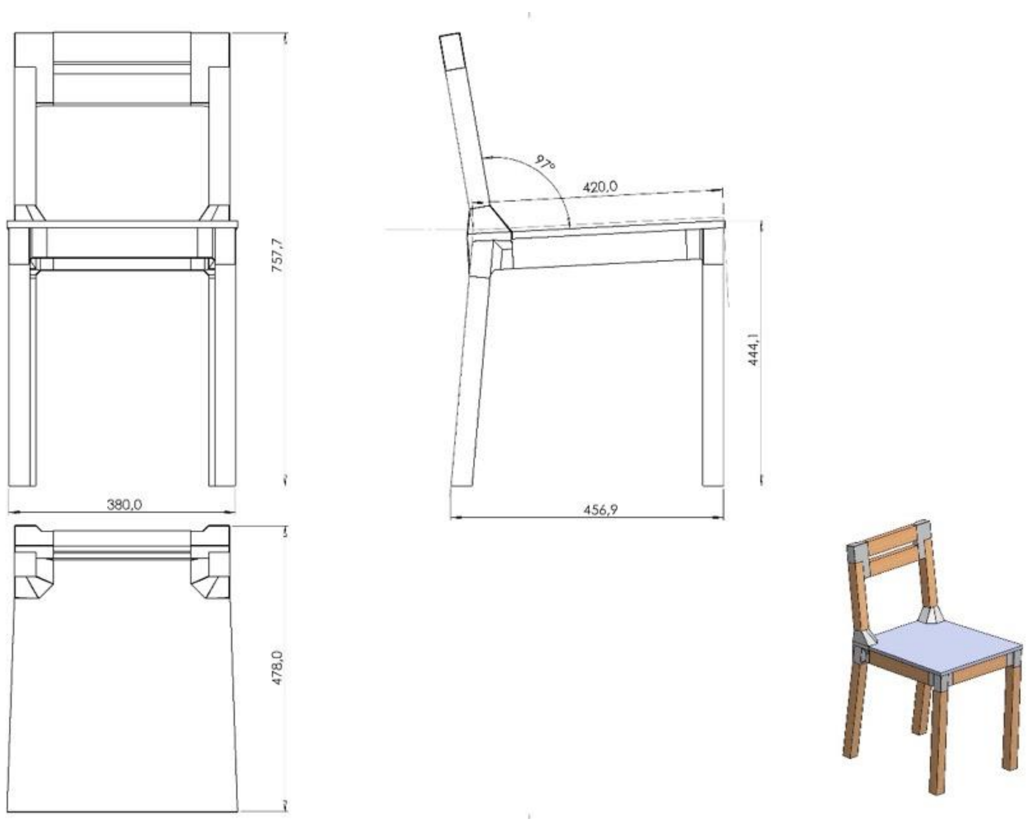
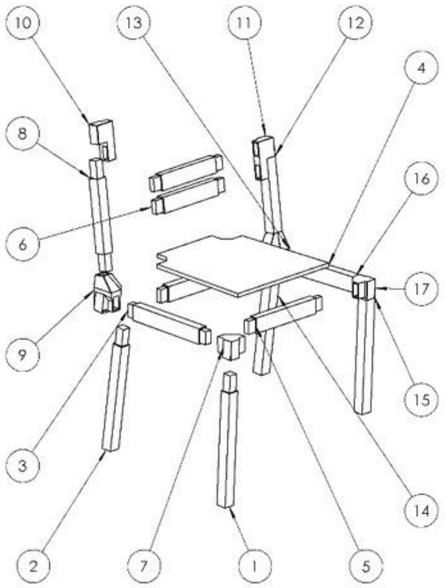


Figure 112: Chair with 3d printed connectors-basic dimensions.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Front leg		1
2	Back leg		1
3	Rail side		1
4	Seat panel		1
5	Rail front		1
6	Rail back		3
7	Front right connector		1
8	Backrest post		1
9	Back right connector		1
10	Backrest top right connector		1
11	Backrest top left connector		1
12	Backrest post		1
13	Back left connector		1
14	Back leg		1
15	Front leg		1
16	Rail side		1
17	Front left connector		1

Figure 113: Breakdown of the parts.

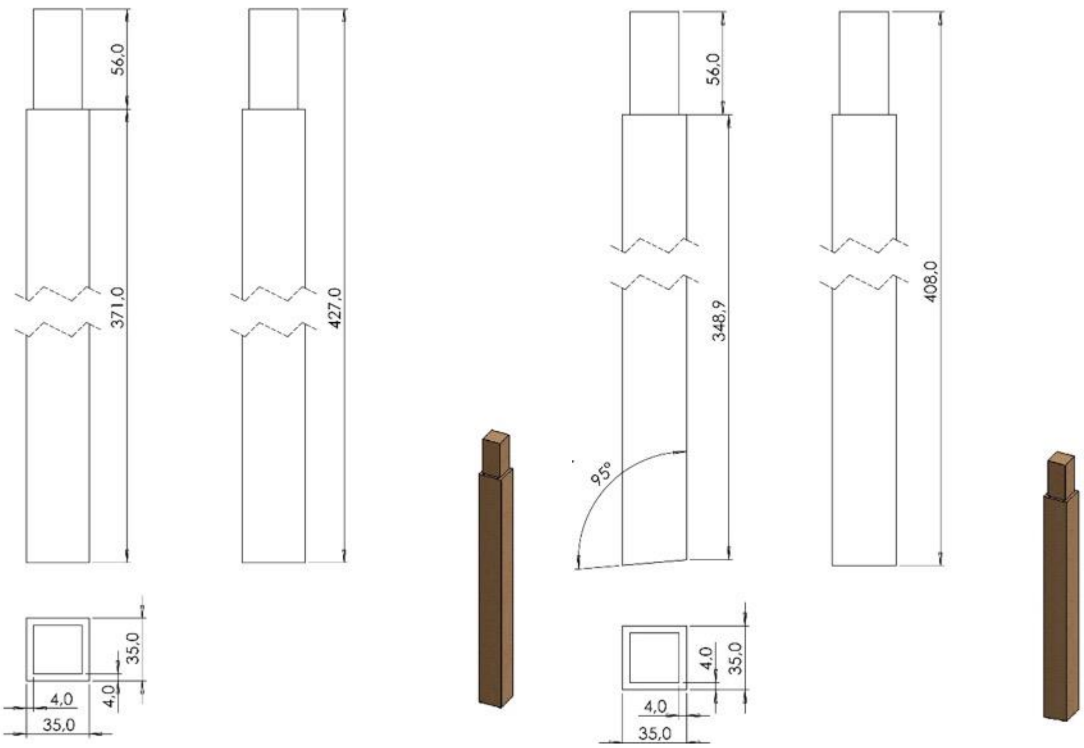


Figure 114: Front leg- left, back leg- right

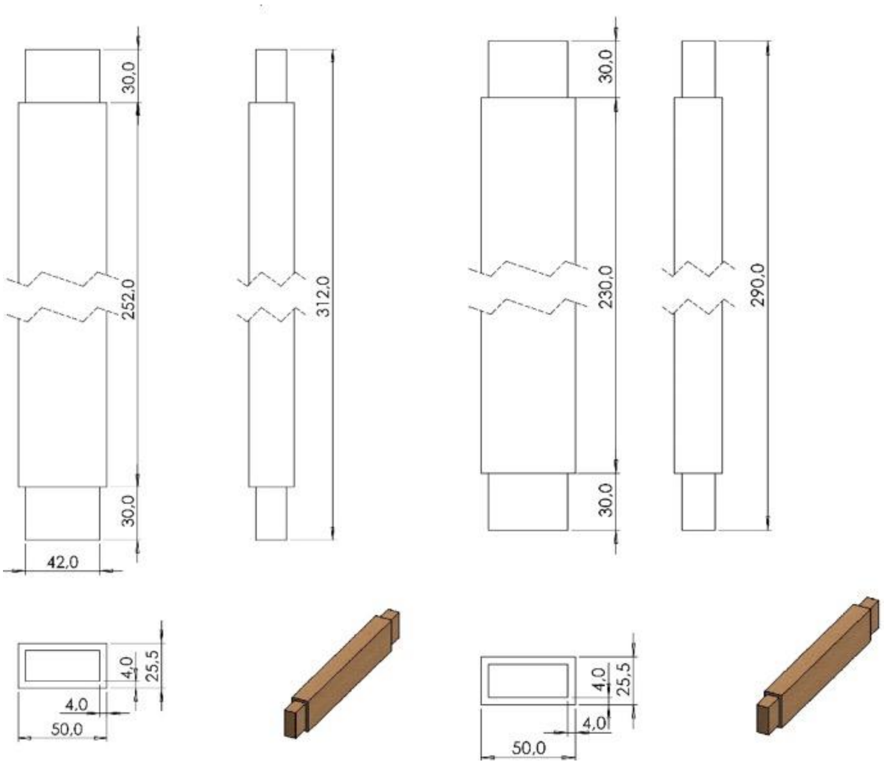


Figure 115: Front rail- left, back rail- right

Figure 117: Exploded view of chair with 3d printed connectors

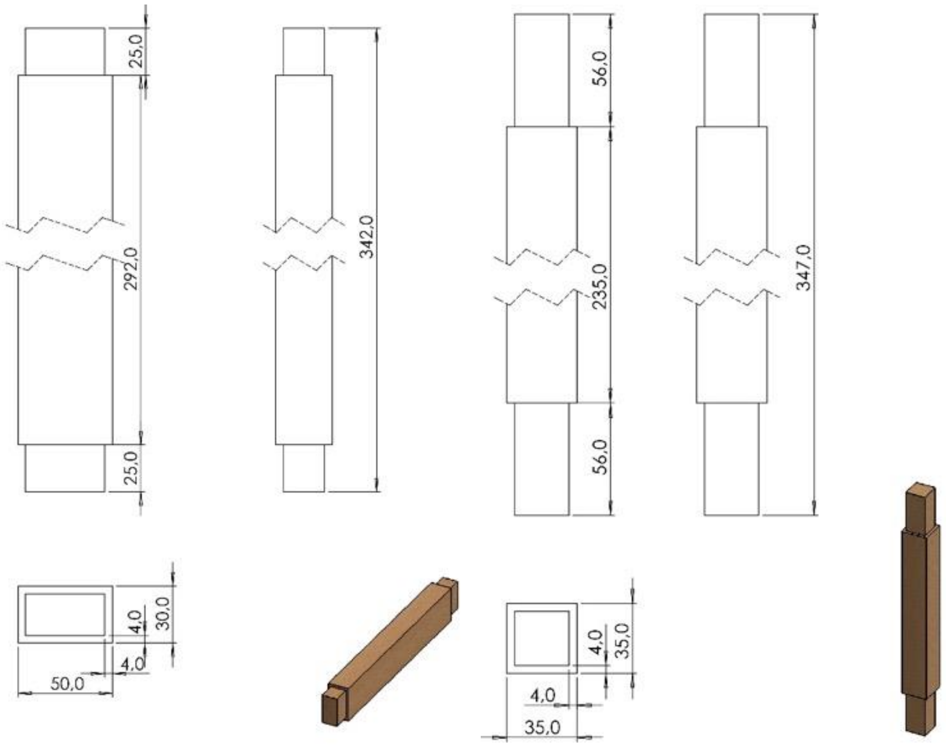


Figure 116: Side rail- left, backrest post- right

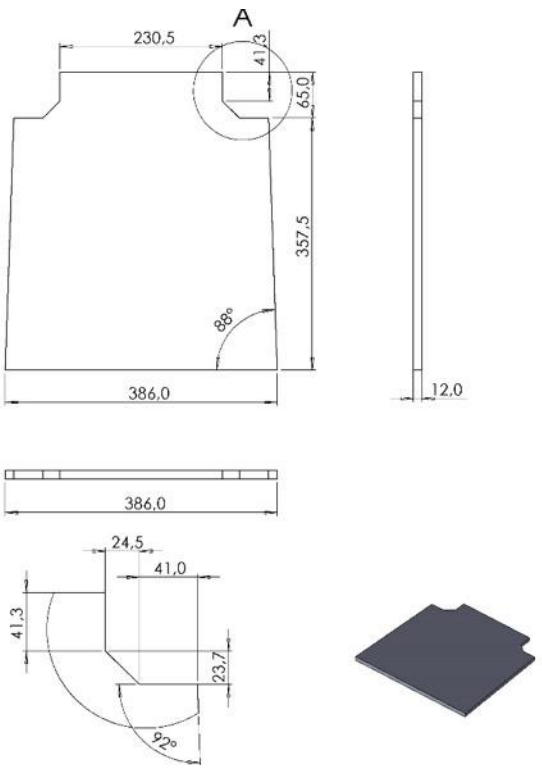


Figure 118: Seat panel

Figure 119: Chair render

Figure 120: Chair wooden parts preparation.

Figure 121: Chair wooden parts preparation.

Additional materials for a better description.

If additional woodworking machines are available, the design could be more complex, for example:

Figure 122: chair with 3d printed connectors [31].

Figure 123: chair with 3d printed connectors [32].

TEACHING SPECIFICATION

How can this exercise be used in the classroom?

This exercise is designed to provide the student with the necessary knowledge to integrate 3D printing into the design and production of furniture.

The aim is for the student to be able to use their knowledge of furniture design and manufacture to design connectors that will be 3D. These 3D printed elements, together with wooden elements will act as an assembly system in their furniture designs.

During the design phase, the student needs to take into consideration chair dimensions, the limitation of use of simple wooden elements, provide sufficiently strong connectors (selection of materials, wall thickness, infill, enough area for bonding), optimize construction (mid/bottom additional stretchers, additional diagonal connectors) and select appropriate adhesive for bonding.

What methodology can be used for its integration into the classroom/curriculum?

This exercise can be performed in class as a multi-stage exercise:

- Study of the existing chairs and their version with 3d printed connectors.
- Design of a piece of furniture by designing and integrating 3D printed connectors as an assembly system.
- 3D printing of connectors and post-processing of parts where necessary.
- Selecting appropriate adhesive- option testing different adhesives for bond strength wood-3d printed parts.

- Selecting appropriate connections- adhesive/screws, snap fit.
- Preparation of the rest of the components (cutting and treatment of the different pieces of wood necessary for the manufacture of the table).
- Manufacturing process by means of assembly.
- Final analysis of the furniture and verification of its functionality.

The students will develop designing skills of furniture with 3d printed elements and awareness of different technologies (woodworking and 3D printing) and how to combine them to get both to design functional product.

What benefits can be obtained with its use?

Thinking about design from different materials and their properties. How to incorporate different materials to functional product. Understanding customer wishes and limitations in the design phase. Understanding 3d printing technology- effect of material selection, printing orientation, connections to form bigger objects.

In terms of learning outputs, the learner will be able to:

- Analyse and optimise the design for 3D printing.
- Knows the Influence of additive manufacturing on the design and prototyping of a product.
- Knows how 3D printing is being used in the furniture market.
- Acquires knowledge about competitiveness of the additive manufacturing in the production sector.
- Work with hybrid technology (Pieces of wood assembled with 3D printing parts).
- Understanding material selection, printing orientation to achieve full strength of connectors.

- Understand loading on seating chair and how to design connectors to withstand these forces -exercise could be extended to testing phase: chair could be tested according to standard EN 1729-2 Furniture - Chairs and tables for educational institutions - Part 2: Safety requirements and test methods. Or just a part of the chair, front connector could be tested on universal testing machine to compare different connector designs:

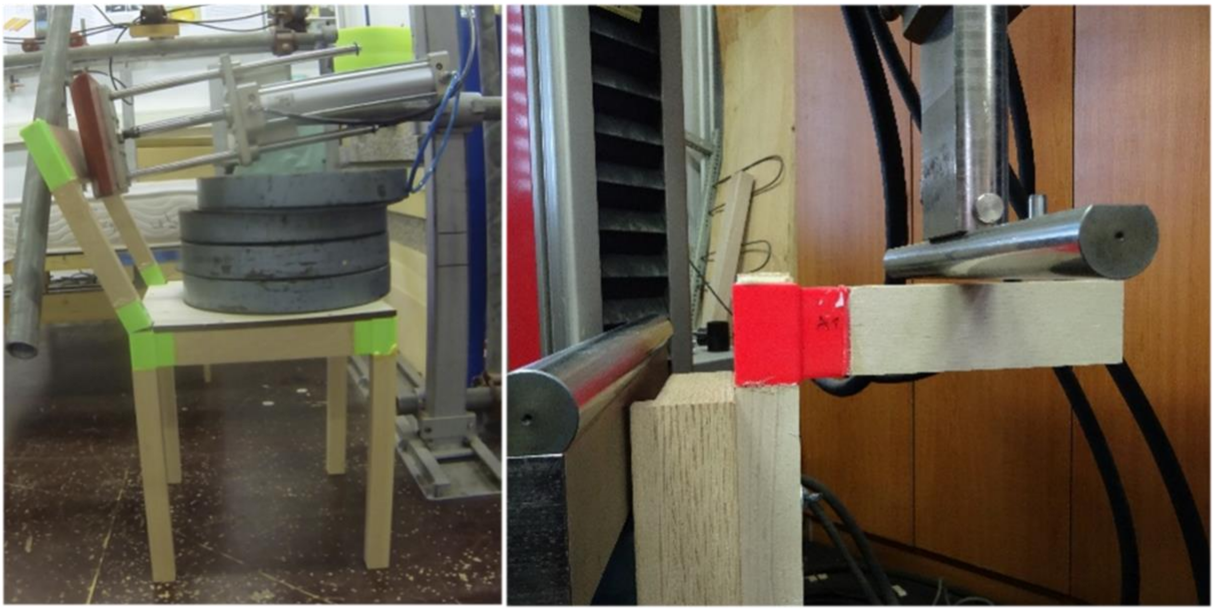


Figure 124: chair testing according to standard EN 1729- left; connector testing – right.

Advanced option 1: loading simulations, numerical simulations, FEA analysis.

→ https://youtu.be/lG_oSSo9vak

Advanced option 2: Topology study.

→ https://youtu.be/KjbnzZ6D4dc

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA, PETG, ABS (if appropriate printer is available)
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They will be able to be printed without problems on the printing bed.
Should the piece be resistant or be subjected to stress?	Yes
Number of pieces of which the exercise is composed:	The number of parts will depend on the final design, 6 are specified in the example.
Ensemble type if necessary (slot, clip, screwed ...)	These printed parts act as connectors for the assembly of a wooden table, so some tolerances may be needed when printing them. Also, bonding is required with selected adhesive or selection of right screws.
Accuracy and definition required. (Quality) Low, mid or High.	Mid or High
Support material or post-processing.	If the angles do not exceed 45° no support material is required. Sanding will be applied as post-processing to remove possible imperfections.

12. Exercise "Parametric design of 3D printed furniture-meeting ergonomics and standard requirements"

INFORMATION

Exercise Name	School chair design for different age of kids
Specific Subject	Chair design, Carpentry, 3D printing, Prototypes, standards, ergonomy.
Number of pieces of which the model is composed	6 3d printed pieces

3D MODEL DESCRIPTION

Written description.

With 3d printing and digital models its even easier to manufacture products tailored to each customer or standard requirements. The goal is to prepare a parametric model of school chair with 3d printed connectors, which could serve as a base for all chair sizes, proposed in standard EN 1729: Furniture - Chairs and tables for educational institutions - Part 1: Functional dimensions.
For a basic model could serve the model design in previous lesson: "Chair design with 3D printed connectors and simple wooden elements".

When tailoring the product to different standard or customer requirements, not just the product dimensions need to be changed. It is also necessary to think about 3d printing- setting the dimensions of connectors, wall thickness, printing parameters, and dimensions of all components- depending on its mechanical properties and expected loading.

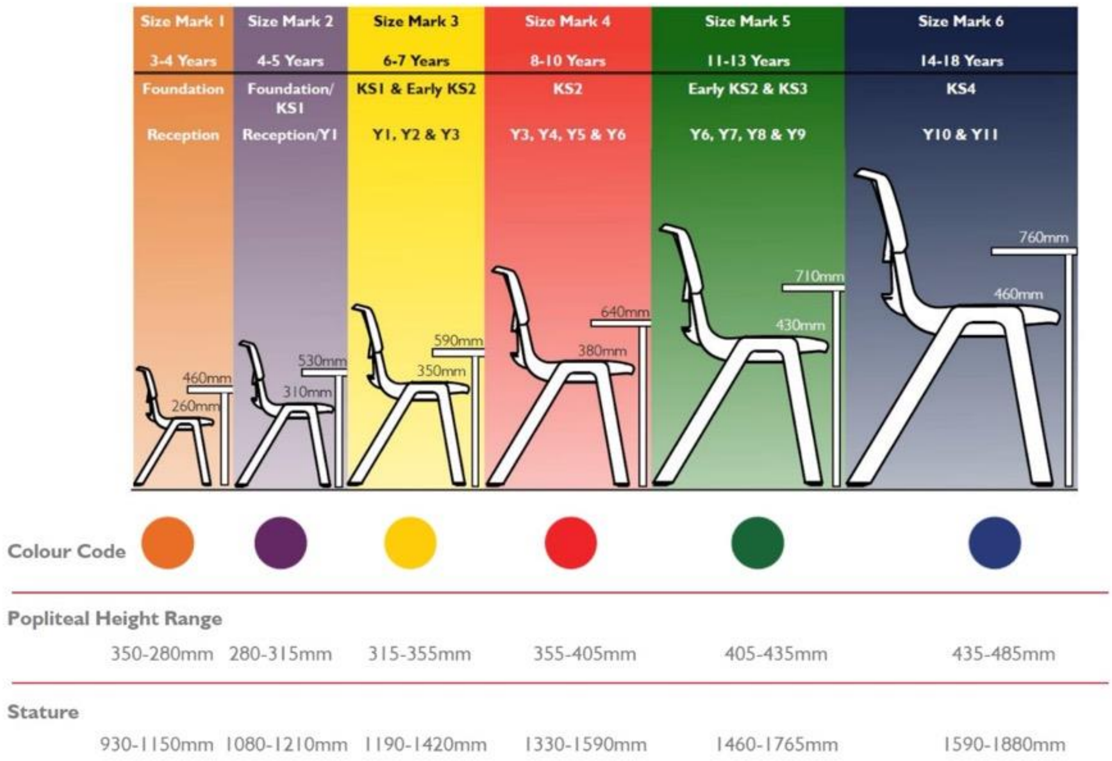


Figure 125: School/kindergarten chair dimensions according to standard EN 1729 [25].

Basic design of chair could be obtained from previous exercise-design of chair with 3d printed connectors. The dimensions of the connectors from previous lesson "Chair design with 3D printed connectors and simple wooden elements" were modified according to chair dimensions. For smaller chairs the wall thickness was decreased and also the cross sections of the wooden parts were reduced. According to 3d modelling software used and user modelling knowledge, the parametric modelling/design tables/configurations/rules could be used in modelling process.

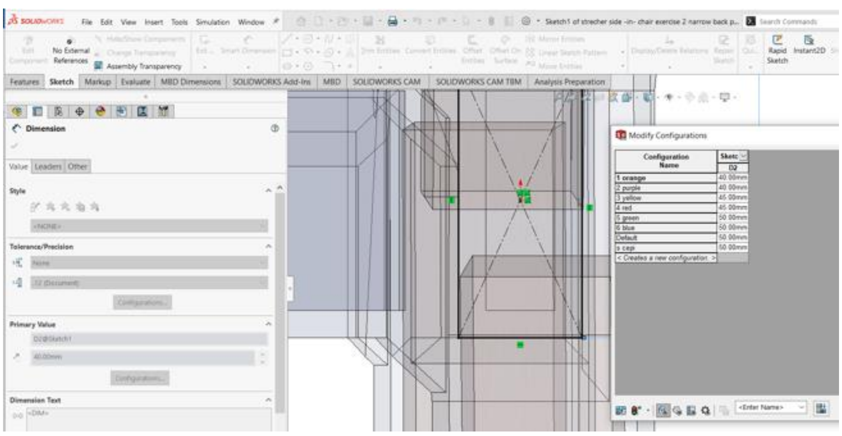


Figure 126: Configuration of different wood elements cross sections, according to chair size (example of modelling in SolidWorks)

The basic limitations should be basic chair dimensions for each age class:

Table 1: dimensions for each age class

Chair size mark	0	1	2	3	4	5	6
Colour code	white	orange	purple	yellow	red	green	blue
K Popliteal range (without shoes)	200-250	250-280	280-315	315- -355	355- -405	405- -435	435- -485
V Stature range (without shoes)	800--950	930- -1160	1080- --1210	1190-1420	1330- -1590	1460- -1765	1590- -1880
h8 height of seat ±10 mm	210	260	310	350	380	430	460
t4 depth of seat ±10 mm (0-2) ±20 mm (3-7)	225	250	270	300	340	380	420
b3 min. seat width	210	240	280	320	340	360	380
t7 depth seat surface (min)	actual t4 minus 20 mm						
h6 height of point S -10 to +20 mm	140	150	160	180	190	200	210
h7 backrest height min.							
b4 min. width of backrest	-	210	250	270	270	300	330
r min. horizontal radius of backrest	-	300	300	300	300	300	300
β inclination of backrest	-						
α inclination of the seat max							
h1 height, top ± 10	400	460	530	590	640	710	765
t1 min. depth of top		500	500	500	500	500	500

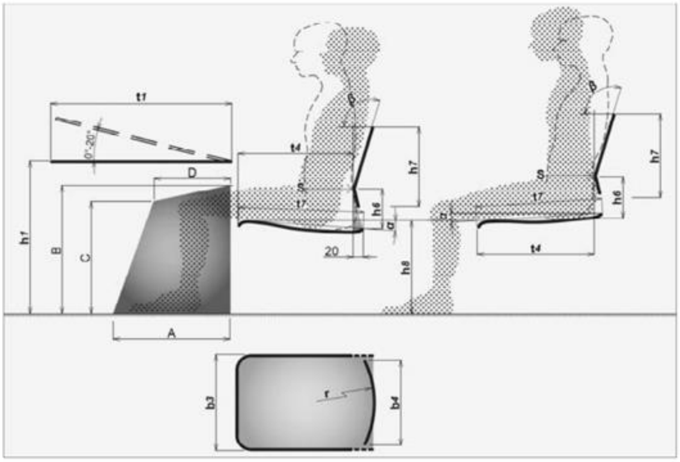


Figure 127: Dimensions of tables and chairs. School (Source: School and Health 21, 2011, Health Literacy through Education Requirements for chairs and tables for educational institutions).

Recommendations to 3D print the connectors:

- Wall thickness: for smaller chairs (like for mark 0-2), 3 mm, for bigger chairs at least 4mm of solid walls
- Infill: at least 40%
- Material: PLA, PETG
- Dimensions of wooden parts: for smaller chairs (like for mark 0-2), cross section at least 25x25 mm, for bigger chairs at least 35x35 mm.

The colour and shape of the chair and the connectors may vary depending on the designer's taste and skills. If the standard is strictly following - chairs need to be marked with colour code for each age size-colours in the top row of the table.

This exercise aims to teach students how to integrate 3D printing and parametric design into the furniture design and manufacturing process and emphasizing the need for considering 3d printing limitations.

The exercise could be then extended to study the standard requirements for strength and durability and testing the chairs. Tests could be done either in real laboratory or by simulations in CAD programs. For more information about strength loading test look for standard EN 1729-2 Furniture - Chairs and tables for educational institutions - Part 2: Safety requirements and test methods.

The example below can be used as a basis. The diagrams are shown in the following section.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

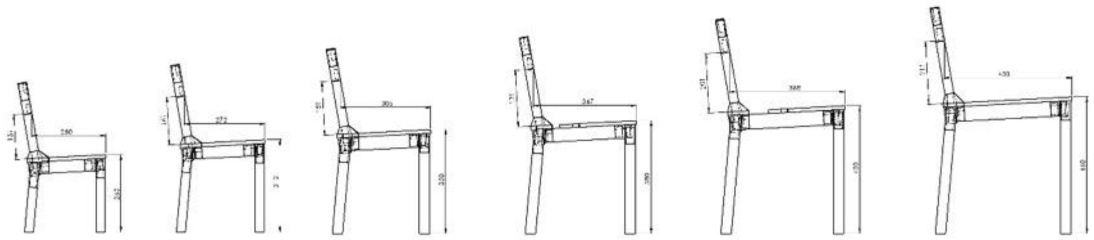


Figure 128: Different basic dimensions of the adaptable chair.

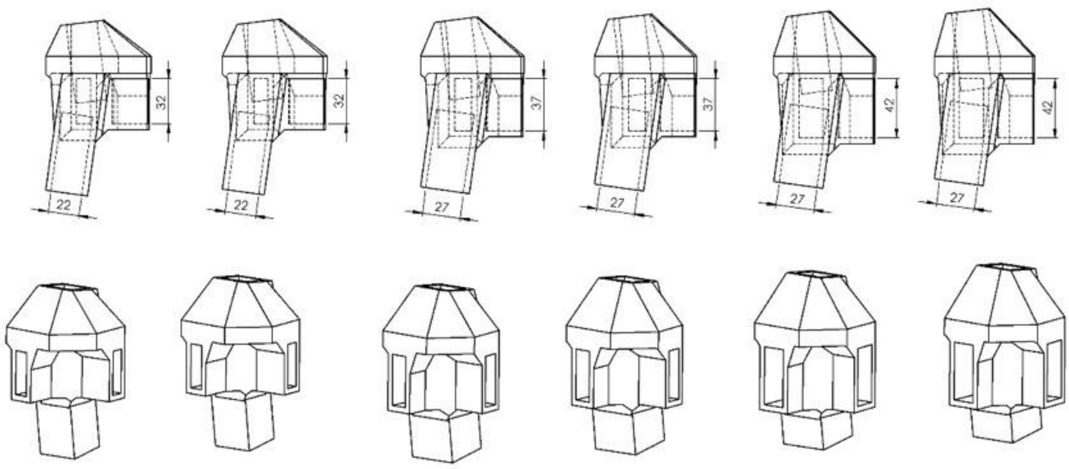


Figure 129: Different sizes of wooden elements and connectors for different size chairs.

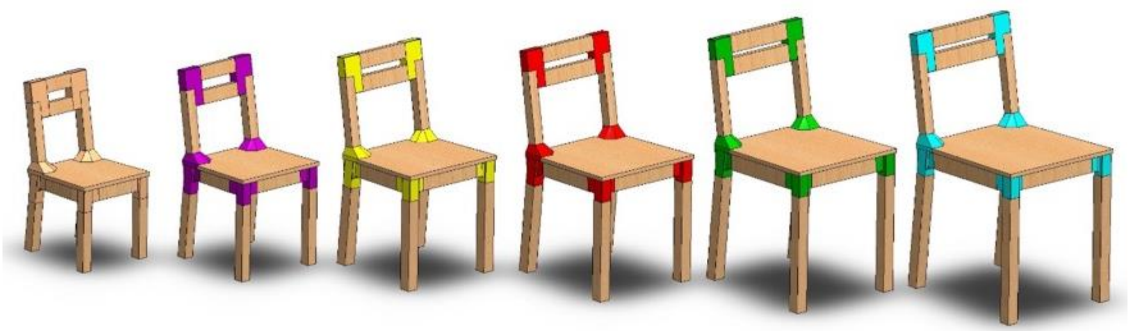


Figure 130: Different sizes of the adaptable chairs.

Additional materials for a better description.

Example of different sizes of school chairs (not necessarily 3d printed)

Figure 131: Different sizes of school chairs [33].

TEACHING SPECIFICATION

How can this exercise be used in the classroom?

This exercise is designed to encourage the student to think about tailoring product to different customers or to follow the standard requirements connected with ergonomic, dimensions, safety requirements.

The aim is for the student to be able to use their knowledge of furniture design and manufacture for designing connectors that could be parametrically adjusted to different customers, with regard also to 3D printing requirements and properties.

During the design phase, the student needs to take into consideration the dimensions, the limitation of use of simple wooden elements, provide sufficiently strong connectors (selection of materials, wall thickness, infill, enough area for bonding), optimize construction (mid/bottom additional stretchers, additional diagonal connectors) and select appropriate connection technique.

What methodology can be used for its integration into the classroom/curriculum?

This exercise can be worked on in class as a multi-stage exercise:

- Study of the existing chairs and their version with 3d printed connectors.
- Design of a piece of furniture by designing and integrating 3D printed connectors as an assembly system.
- Optimising connectors for parametric design.
- 3D printing of connectors and post-processing of parts where necessary.
- Selecting appropriate adhesive- option testing different adhesives for bond strength wood-3d printed parts.
- Preparation of the rest of the components (cutting and treatment of the different pieces of wood necessary for the manufacture of the table).
- Manufacturing process by means of assembly.

- Final analysis of the furniture and verification of its functionality/ possible strength testing

Project-based learning is meaningful to students because they develop the necessary skills to develop their abilities in designing and integrating technology into their work. Within the framework of the technology project, students can pursue their own interests and work on customising their designs/prototypes/furniture.

- Understand possibilities of tailoring the product to each user
- Know how 3D printing is being used in the furniture market.
- Acquire knowledge about competitiveness of the additive manufacturing in the production sector.
- Work with hybrid technology (Pieces of wood assembled with 3D printing parts).

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA, PETG, ABS (if appropriate printer is available)
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They will be able to be printed without problems on the printing bed.
Should the piece be resistant or be subjected to stress?	Yes
Number of pieces of which the exercise is composed:	The number of parts will depend on the final design, 6 are specified in the example.
Ensemble type if necessary (slot, clip, screwed ...)	The printed parts act as connectors for the assembly of a wooden table, so some tolerances may be needed when printing them. Also, bonding is required with the selected adhesive.
Accuracy and definition required. (Quality) Low, mid or High.	Mid or High
Support material or post-processing.	If the angles do not exceed 45° no support material is required. Sanding will be applied as post-processing to remove possible imperfections.

13. Exercise "Assembled Pieces for furniture design"

INFORMATION

Exercise Name	Assembled Pieces for furniture design
Specific Subject	Furniture design, Carpentry, Prototypes.
Number of pieces of which the model is composed	14 pieces

3D MODEL DESCRIPTION

Written description.

The main aim of this exercise is to facilitate in the classroom an open approach for furniture design and prototyping using 3D printing as a manufacturing tool.

The assembled parts exercise is composed of several parts showing the most common types of assemblies in wood furniture making. Four models are presented. All types show a repeating pattern that, when assembled, appears to create an inseparable joint.

The models are as follows:

1. Dovetail: The basic geometry of this model is a cube, divided in two halves. One half has two protrusions that are formed like the classic dovetail in carpentry (but distorted). The other half has two cavities that are also formed like the dovetail. These two halves create a connection, which can only be loosened by pushing the two parts in the right directions. There is only one possible axis that allows movement (forwards and backwards, thus two directions). This axis is parallel to the axis along which the cavities and protrusions are oriented and constructed.

2. Pentagon: This model is a variation of the dovetail. Here the two halves show a pentagonal shape, and apart from that it follows the same construction principles as the Dovetail.

3. Triangular dovetail: The two halves form an equilateral triangle which can only be loosened by rotating the triangle and then separating the parts. Here the pattern is rotated around the z-axis and intersects with the triangular body.

4. E-shaped pattern with various types of assemblies. It is intended to show five different assemblies that together form a single element. These assemblies are:

- Dovetail.
- Double tongue and groove.

- Cross-shaped mortise and tenon assembly.
- Mortise and tenon assembly.
- Half-Lap assembly with through bolt.

This exercise aims to teach students how to integrate 3D printing into the furniture design and manufacturing process, showing them various options, which will allow them to develop their creative thinking and knowledge of this technology while applying it to real and fully functional items.

The freedom of design and customisation in this type of exercise will provide students with skills for their future work, where they can integrate additive manufacturing as a method for making customised furniture and prototypes.

Graphic Definition of the 3D Model. (Technical draws, hand free sketch and renders).

The models can be printed in different scales and layer thicknesses according to the needs (printing time, finishing quality, final use...).
The following images show the pieces designed for this exercise:

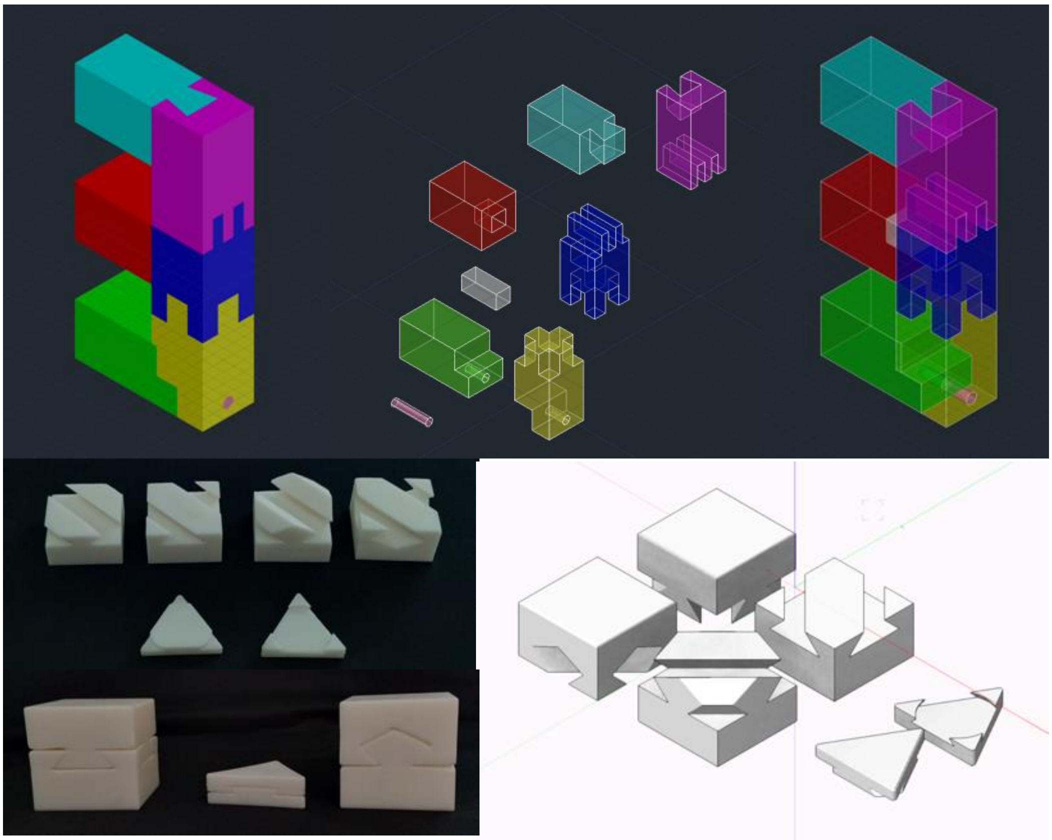


Figure 132: Models of the "Assembled Pieces for furniture design" exercise.

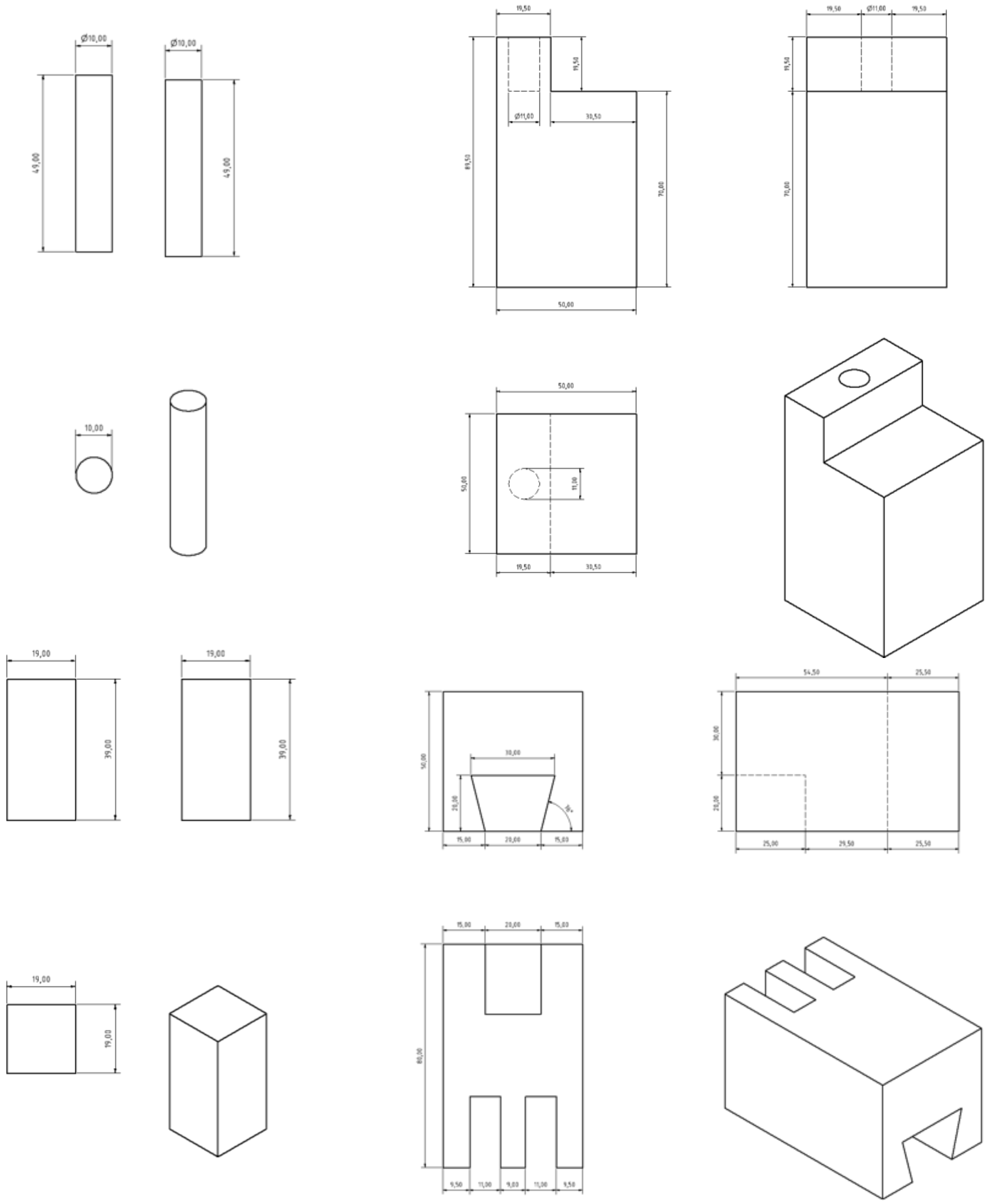


Figure 133: Measurements of the parts of the E-assembly.

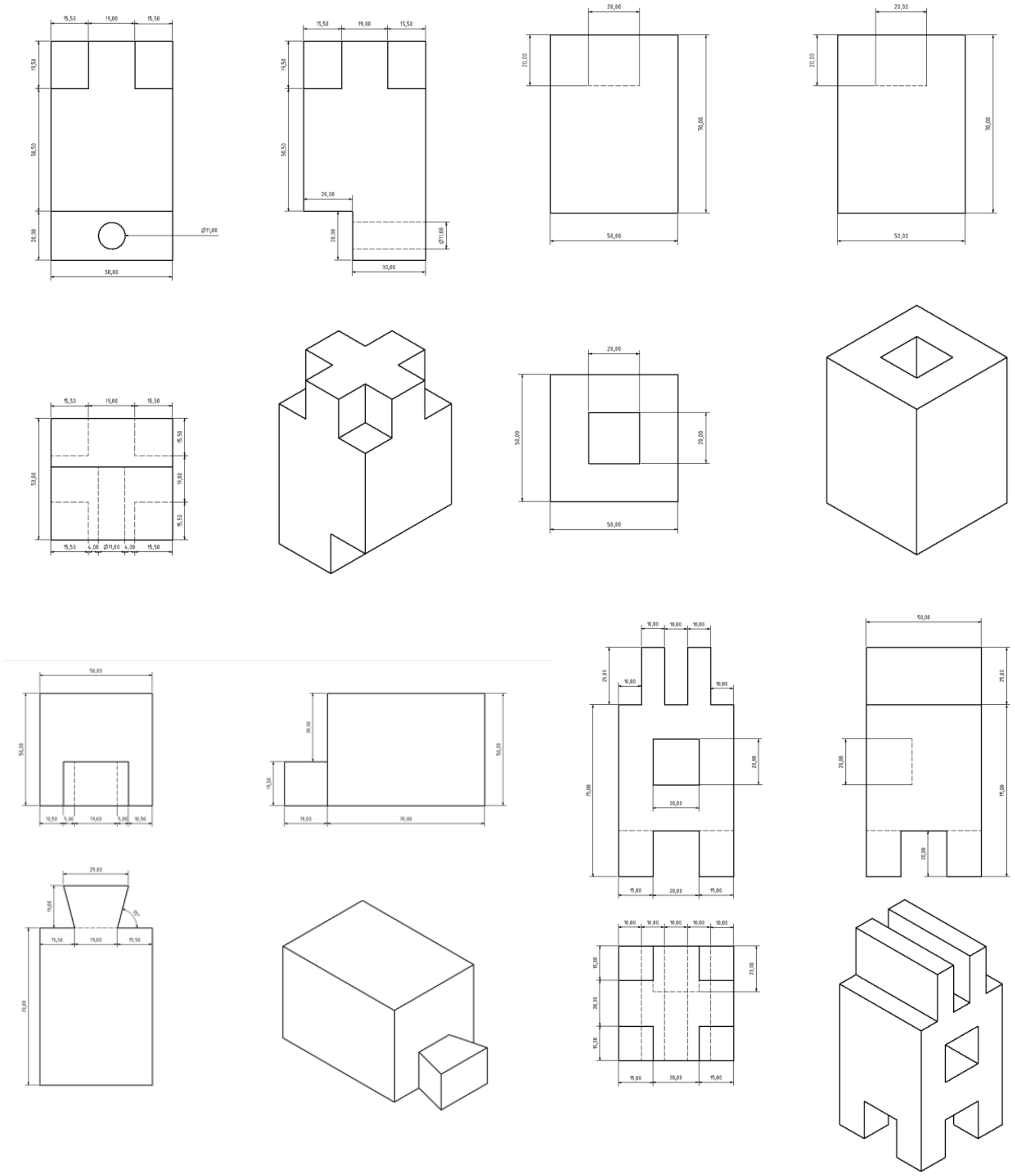


Figure 134: Measurements of the parts of the E-assembly.

Additional materials for a better description.

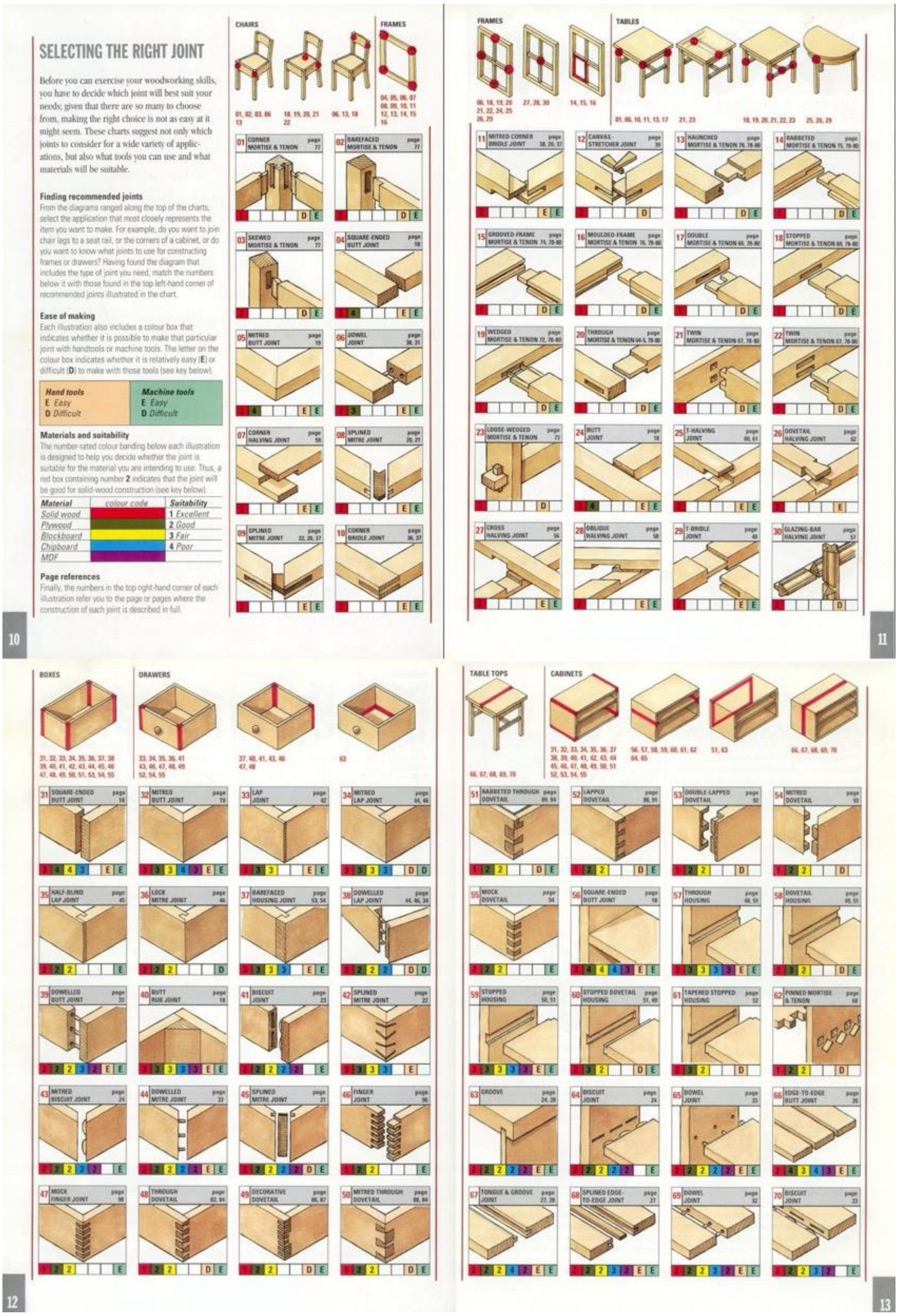


Figure 135: Joint for wood manufacturing *[26]*.

TEACHING SPECIFICATION

How can this exercise be used in the classroom?

This exercise is designed to provide the student with the necessary skills to integrate 3D printing into furniture design and production.

With the knowledge of the different types of joints that can be used to assemble the different parts that make up a piece of furniture, the student can create their designs to be fully 3D printed. These joints make possible to create larger pieces by assembling several parts, or even to put hybrid technology (traditional manufacturing with 3D printed parts) into practice.

The aim is to allow students to use their knowledge in furniture design and manufacturing to design furniture for 3D printing. With this exercise the student will analyse and be able to redesign if desired the assembly system to be 3D printed. With the printing and use of this type of assemblies, the student will acquire and expand knowledge about 3D technology: use and possibilities within the furniture and wood sector.

Students will be able to understand the geometrical principles that make this connection possible. An open approach to design should be facilitated. In time, they should be able to design their own models, customised and adapted to the needs of each design. In addition, the students can use the principle of the connection to test their design on a smaller scale by designing their prototypes using this kind of easy assembly. In this case, students could explore the differences and potentials of both traditional manufacturing techniques and additive manufacturing technologies.

What methodology can be used for its integration into the classroom/curriculum?

An appropriate way to integrate this exercise into the classroom/curriculum would be the project-based methodology for the integration of 3D printing technology as a tool for the development of innovation and creativity in furniture design. This exercise can be deployed in class as a multi-stage exercise:

- Observation of the models designed in this exercise.
- Analysis of the different types of assemblies: resistance, functionality, applications...

- Integrate these assemblies into your personal design.
- Create new assemblies and apply them to furniture prototypes. Final analysis of the furniture and verification of its functionality.

Project-based learning is meaningful to students because they develop the necessary skills to develop their abilities in designing and integrating technology into their work. Within the framework of the technology project, students can pursue their own interests and work on customising their designs/prototypes/furniture.

What benefits can be obtained with its use?

To internalise the concept of a personalised product. By modifying the design of the assemblies or integrating those proposed in this exercise, the student can create a multitude of furniture designs. This technique can be used for both final products and prototyping with reduced cost and production time.

Students could explore the differences and potential of traditional manufacturing techniques and additive manufacturing technologies, using the examples in class to facilitate an open approach to design.

In terms of learning outcomes, the student will be able to

- Analyse and optimise design for 3D printing.
- Know the influence of additive manufacturing on the design and prototyping of a product.
- Know the use of 3D printing in the furniture market.
- Acquire knowledge about the competitiveness of additive manufacturing in the production sector.
- Work with hybrid technology (wooden parts assembled with 3D printing parts).

The students of the woodworking and furniture sector tend to work with subtractive manufacturing, i.e., an object is created by removing material and waste is generated. This factor disappears with additive manufacturing, as the final object is created layer by layer and only the material required for the desired volume is consumed. The result is zero waste or a considerable reduction of waste. This new way of production will open the student's mind and help to reconcile with the environment.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA
Suitable dimensions for its use in the classroom (mm)	They will depend on the final design. They will be able to be printed without problems on the printing bed.
Should the piece be resistant or be subjected to stress?	Yes
Number of pieces of which the exercise is composed:	The number of pieces to show all the models in this exercise is 14.
Ensemble type if necessary (slot, clip, screwed ...)	These printed parts act as connectors for the assembly of a wooden table, so some tolerances may be needed when printing them.
Accuracy and definition required. (Quality) Low, mid or High.	Mid or High
Support material or post-processing.	If the angles do not exceed 45° no support material is required. Sanding will be applied as post-processing to remove possible imperfections.

14. Exercise "SHAPES4U".

INFORMATION

Exercise Name	SHAPES4U
Specific Subject	Technical drawing and wood workshop for the disabled people
Number of pieces of which the model is composed	15 pieces

3D MODEL DESCRIPTION

Written description.

The exercise has been designed to facilitate people with cognitive disabilities in the creation of geometric shapes with wood.

This exercise will allow the disabled person to not only be able to draw flat geometric shapes on a piece of wood such as: the triangle, the rectangle, the rhombus, etc., but also more complex ones: circle, ellipse, etc. On the other hand, it will also allow them to carve these shapes in wood. The shapes will allow the disabled person to easily manipulate them and to recognize shapes, perimeters, and areas much more easily than before.
Thanks to the shapes, students with cognitive disabilities can glue the geometric shape onto the piece of wood with double-sided adhesive tape. This can be cut both with normal tools such as the saw but also with the electric or column saw.

All the printed geometric figures will be of 3 different sizes: small, medium, and large.

- Overall: 50x50x70mm
- Overall: 80x80x70mm
- Overall: 150x150x70mm

Graphic Definition of the 3D Model. (Technical draws, hand free sketches and renders).

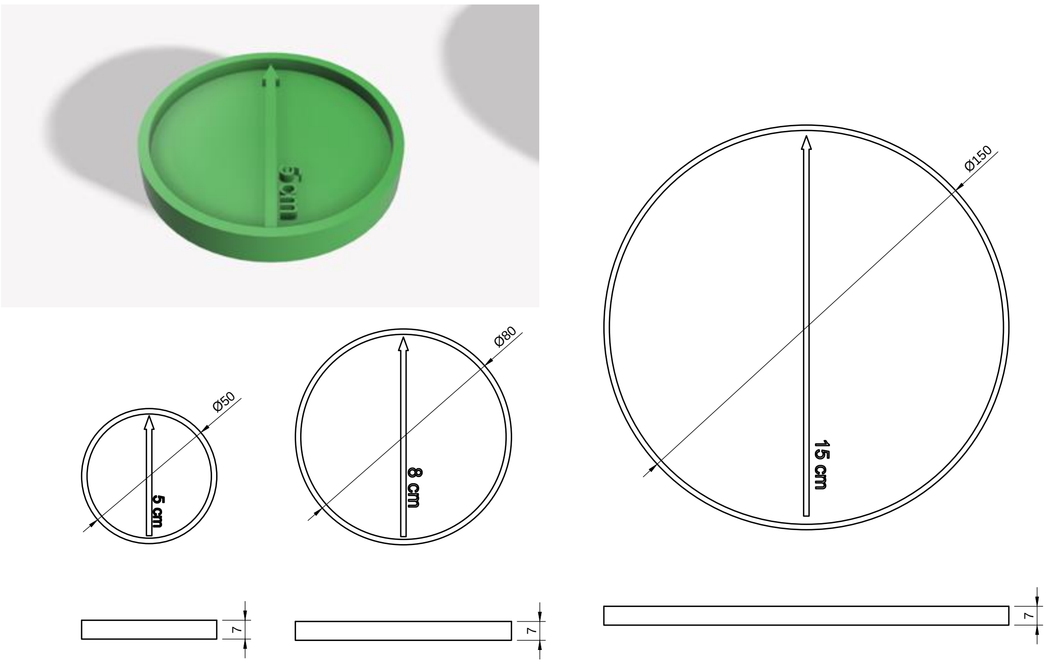


Figure 136: Circle model.

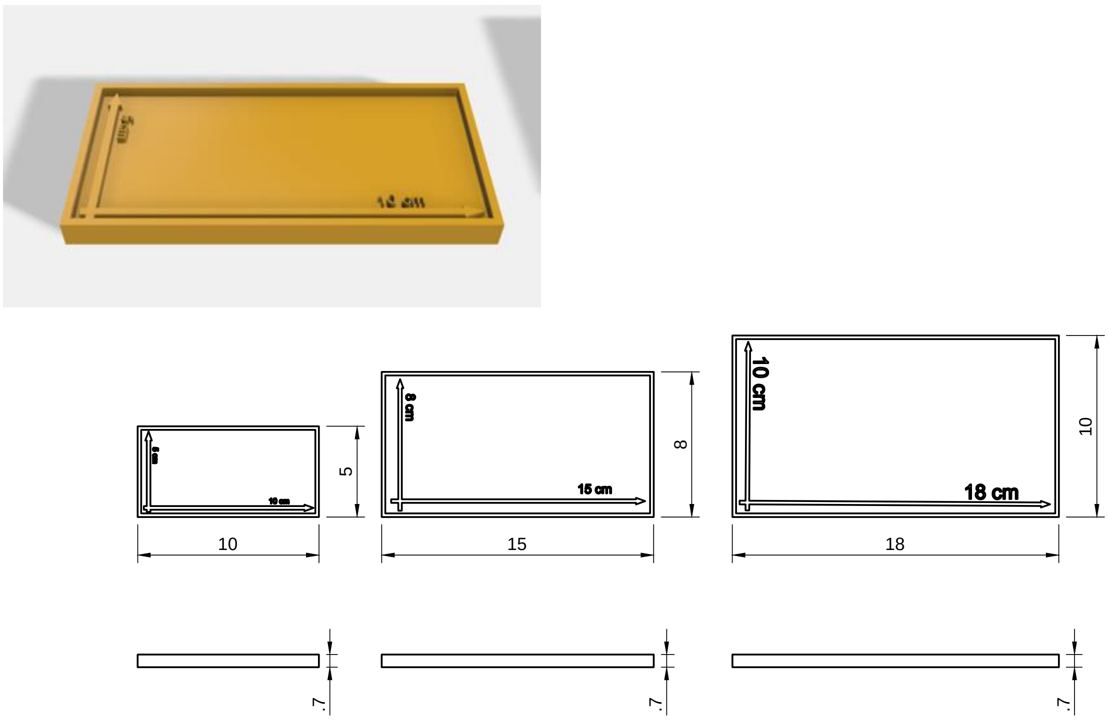


Figure 137: Rectangle model.

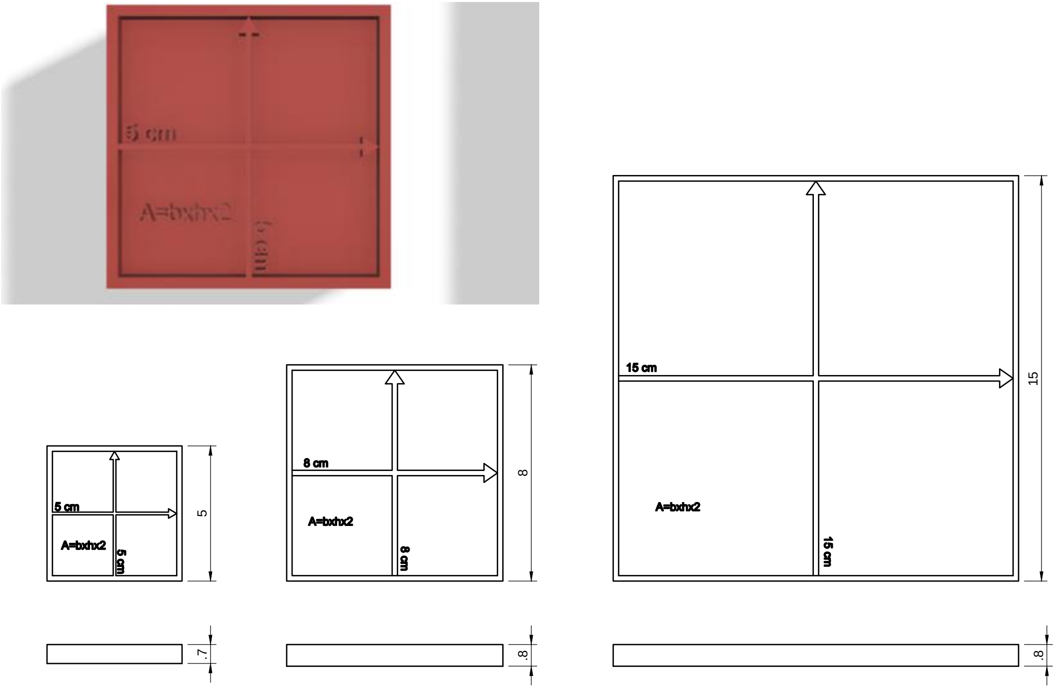


Figure 138: Square model.

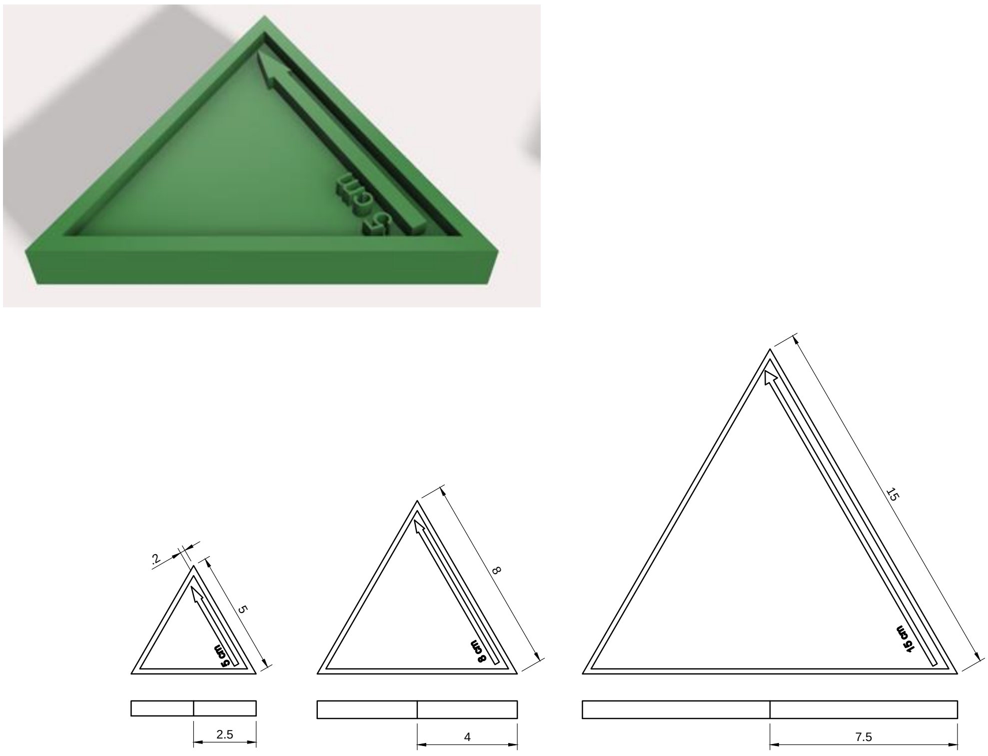


Figure 139: Triangle model.

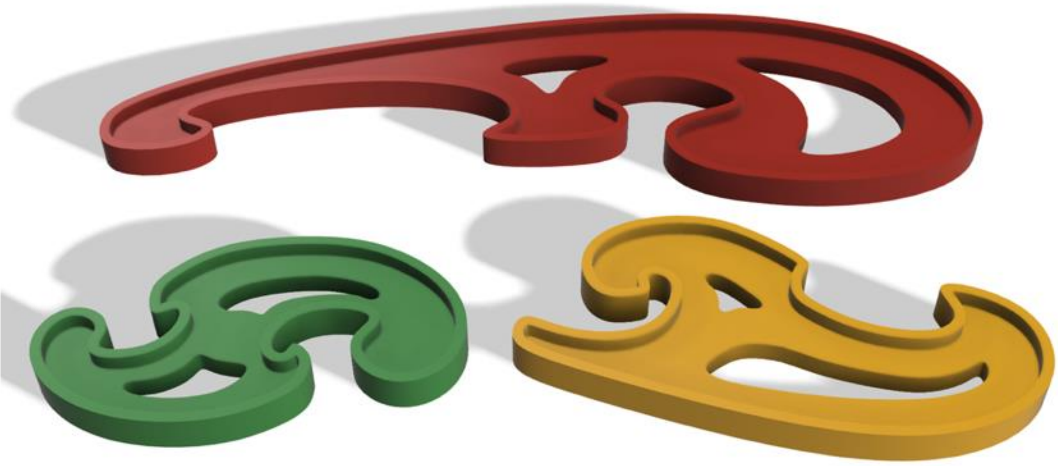


Figure 140: Shapes model.

Additional materials for a better description.

Figure 141: Examples of the use of this exercise.

TEACHING SPECIFICATION

How can this model be used in the classroom?

The exercise will be used during the geometry lesson, technical drawing, but also in the workshops for making wooden objects and furnishings (carpentry). This exercise will help the students to understand the dimensionality of an object at the visual spatial level of what they imagine.

Having a fixed figure for students with cognitive disabilities will help them understand the concept of perimeter, area, side, angle, vertex and so on ...
It will also be useful for improving visual memory, motor memory, dimensionality, and image memory.

Thanks to the various figures, a student with cognitive disabilities will be able to reproduce the same figure in other types of materials. He will be able to make the carvings following the perimeter of the figure itself and reproduce the various figures, from the simplest to the elliptical ones, correctly and easily.

What methodology can be used for its integration into the classroom/curriculum?

All the exercises developed for disabled people have to follow two different methodologies. The technical one respecting the piece that they are developing and the one related to the kind of disability.
For the disability one, the methodology that should be applied is the ABA (Applied Behaviour Analysis) one. ABA is the most used science in the intervention with people who have autism spectrum disorders, cognitive, behavioural, and emotional disabilities.

ABA is based on direct observations of behaviour as a primary measurement tool. The promoted skills must be objectively quantifiable and directly observable: the functional relationships between the individual and the environment are identified, objectively establishing causal relationships between environmental events, and observed behaviours. This process takes place through the systematic manipulation of the environment and the detection of behaviours exhibited under varying environmental conditions.

In ABA, the teaching procedures are described in detail, to facilitate their replication. The ABA procedures refer directly to the principles of behaviourism, excluding the forms of intervention lacking systematicity, or identified by the scientific community as "of reduced effectiveness" or "of not proven effectiveness".

The goal of the ABA is to promote the generalization of skills across different environments, people, and behaviours.

What benefits can be obtained with its use?

Students with the exercise will be able to improve:

- Visual memory.
- Motor memory.
- Image memory.

- Pre-syntactic skills (association of a quantity of objects to a number).
- It will help build images mental, static, or dynamic, related to concepts, that allow the
- re-enactment of the related content. Image memory.
- Pre-syntactic skills (association of a quantity of objects to a number).
- Lexical skills (visual recognition of colours, dimensions and shapes).
- Counting strategies (backward enumeration, ordering from largest to smallest).

It will help build images mental, static, or dynamic, related to concepts from store, that allow the re-enactment of the related content.

TECHNICAL SPECIFICATIONS OF THE EXERCISE

Technology	FDM
Material	PLA
Suitable dimensions for its use in the classroom (mm)	3 different ones: Overall: 50x50x70mm Overall: 80x80x70mm Overall: 150x150x70mm
Should the piece be resistant or be subjected to stress?	No
Number of pieces of which the exercise is composed:	15
Ensemble type if necessary (slot, clip, screwed ...)	No
Accuracy and definition required. (Quality) Low, mid or High.	Low
Support material or post-processing.	No

7

References

References:

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