



The Numeric[All] STEM Module on 3D printing



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1. General Concepts

1.1. What are 3D Modelling, Photogrammetry and 3D Printing?

In recent years, replicating and creating objects in three-dimensional spaces has become increasingly popular and a highly desirable skill. However, most of the time, it is not exactly clear how digital objects become physical objects and how they are created. It appears to be a skill reserved for experts, but the basics of 3D modelling and printing can be learnt by anyone willing to try. Many simple items can be modelled and printed in 3D form.

The picture below shows that the 3D Modelling software was used to create the physical item that the person is holding.



Figure 1. Example of 3D Software and Item (Source: Canva)

3D Modelling is the process of creating an object in a three-dimensional space that contains faces, vertices and edges.



Figure 2. Example of 3D Model (Source: Canva)

Photogrammetry is the process of creating a realistic representation of a 3D model with the use of photographs from multiple angles. It essentially recreates a real-life object as a 3D model in software by reading the pictures taken (for more information, see Annex 1).

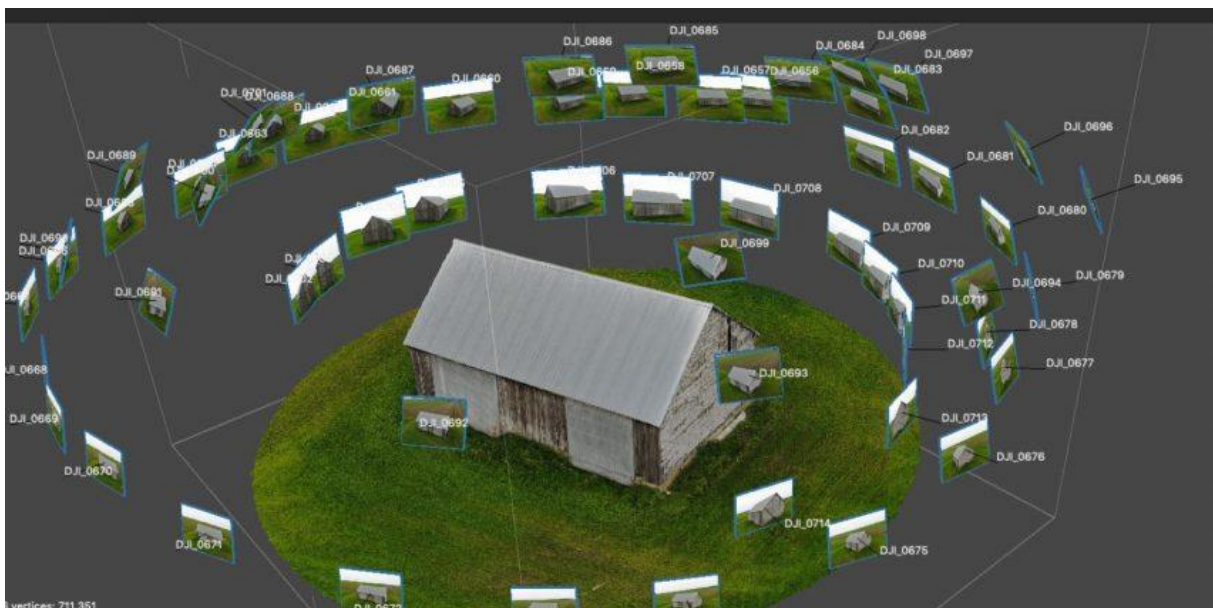


Figure 3. 3D model created from photographs – Photogrammetry (Source:

<https://bitfab.io/blog/photogrammetry/>)

3D printing is an additive manufacturing process that creates real three-dimensional objects from a digital model. It essentially takes the 3D model you created and prints it as a physical object.

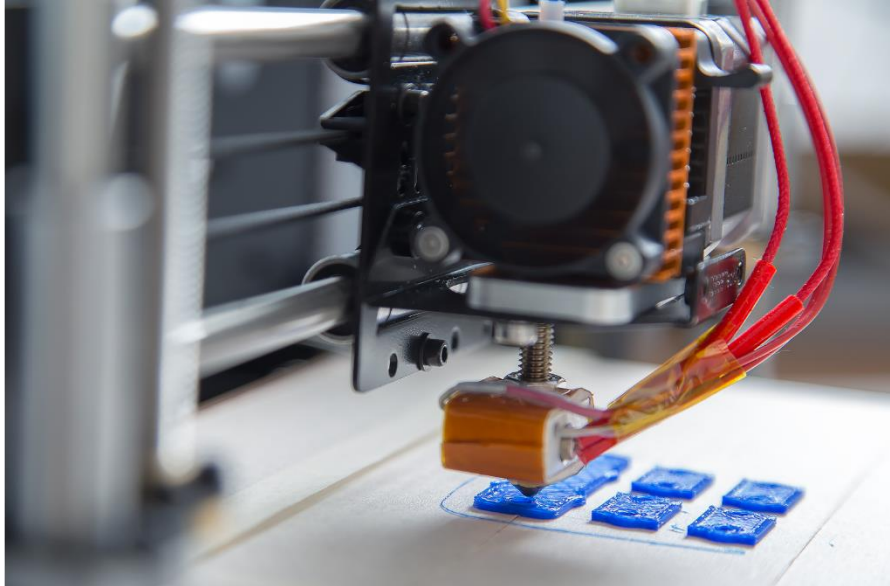


Figure 4. 3D printer in action (Source: Canva)

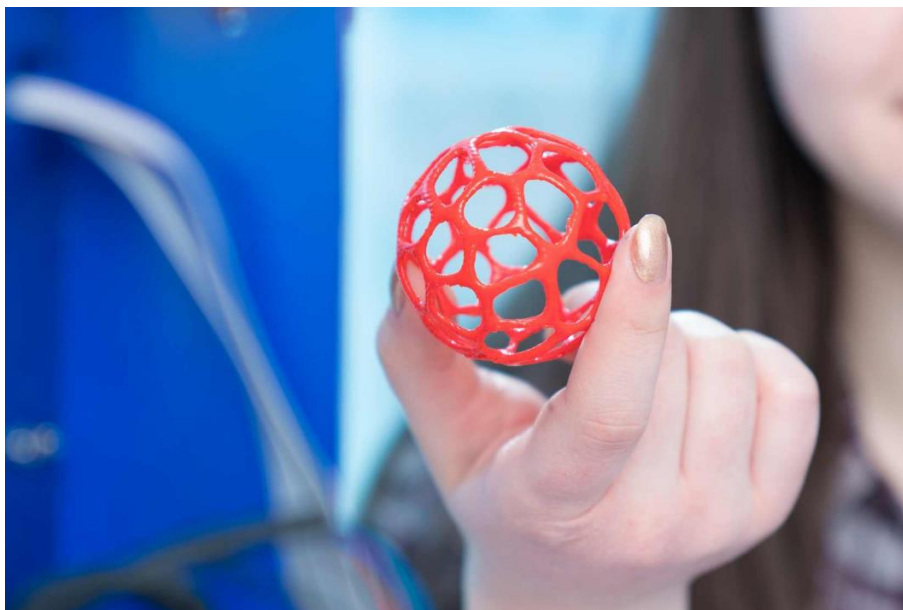


Figure 5. 3D printed item (Source: Canva)

1.2. Applications

Now you might be wondering, how can we use them?

3D Modelling is used in many industries as a pre-step to 3D printing or as a way to create animated characters and games. In this module, we will focus on the 3D printing aspect. There are many different 3D printing processes that are used in different industries such as stereolithography, fused deposition modelling (FDM), powder bed fusion and more.



Education



Prototyping and Manufacturing



Medicine



Jewellery



Art



Construction

Figure 6. Main industries employing 3D printing solutions

There is an infinite pool of resources available to describe the different 3D printing processes in each of those fields. However, for the purpose of this module, we will focus on Fused Deposition Modelling (FDM) due to its low-cost, high flexibility and ease. For a more detailed review of 3D printing processes, materials and applications, see Jandyal et al. (2022).

Depending on your needs, there are 5 things to consider before selecting a 3D printer:

- **Application:** How are you going to use the 3D item?
- **Material Compatibility:** Is it sustainable for the desired application?

- **Build Volume:** How big do I want the item to be?
- **Material Availability and Cost:** Is it easy to find the material required to print the 3D item? How much does it cost?
- **Resolution:** How detailed do I want my 3D item to be?

After considering these 5 points, it is easier to choose the right 3D printer for you.

1.3. 3D Printing in Education and Mathematics Museums

There is a significant number of studies focusing on the use of 3D printing and modelling in education, from early childhood to higher education, as well as, in informal learning spaces (e.g., Pearson & Dubé, 2021). Even though there is a vast amount of knowledge produced, it is quite sparse and addresses diverse aspects of 3D printing and modelling. Ford and Minshall (2016) identified where and how 3D printing is used within formal education settings and uncovered six distinct categories. These categories involved, amongst others, 3D printing as a tool used by learners in diverse educational levels and educators using 3D printed artefacts in mainly STEM-oriented disciplines to support the learning process without teaching it in the classroom (Ford & Minshall, 2016).

Within the formal education sphere, 3D printing revolves around geometry (Ford & Minshall, 2016), algebra and functions, and fractions (Stigberg, 2022). As Stigberg (2022) underlines, there is room for other mathematical concepts to be added, as well as, enhancing the resources available for designing and sharing mathematical 3D objects. However, formal education settings present certain restrictions that do not apply in informal spaces, such as museums and makerspaces, that can expand beyond that (Pearson & Dubé, 2021). This perception better aligns with our efforts through the Numeric[All] project to bring forward the pedagogical and methodological approaches of mathematics museums in Adult Education.

The use of 3D printed artefacts in museum spaces has grown exponentially, especially in archaeological, anthropological, natural history and science museums, as a way to allow visitors to interact with concepts presented (Coates, 2019; Cooper, 2019). 3D modelling is already used in mathematics museums such as IMAGINARY – Open Mathematics in Germany (Rainone et al., 2014) and MMACA Museum of

Mathematics in Cornellà (Spain) (<https://mmaca.cat/en/moduls/impressio-3d/>).

However, research focusing on mathematics museums does not address 3D printing and its potential in such spaces. 3D modelling and printing enable the creation of objects with a higher degree of precision and sometimes even complexity, as well as the ability to visualise the 3D object before printing it. Moreover, it adds to the production process followed in museums where the number of objects on display is limited to one or only a few.

This enhances the value of our attempts to connect the two since there is an inherent connection between 3D modelling and printing to mathematics (e.g., Ng et al., 2022). Studies have also demonstrated that multi-sensory approaches to learning are vital to understanding mathematical concepts (e.g., Cuturi et al., 2022; Manches & O'Malley, 2016), and can be beneficial to persons with visible and invisible disabilities (e.g., Bouck et al., 2021). A concept that is central to the philosophy of mathematics museums. Therefore, through this module, we are trying to demonstrate the usage of 3D modelling and printing in mathematics exhibits and provide concrete resources of diverse mathematical concepts to expand their applicability in Adult Education.

1.4. The Numeric[All] Context and Objectives of the Module

This project result encompasses a 20-hour STEM module with a comprehensive introduction to “3D modelling”. It aspires to endow lifelong learning organisations and other relevant institutions with the appropriate knowledge on how to employ computer-aided design software to ideate, design, and print out three-dimensional exhibits. These exhibits will be identical to those conceived, delineated and illustrated in the previous result (PR2) to satisfy the learning needs of adult learners with low proficiency in basic education competencies. The module will be accompanied by the Non-Formal Laboratory Manual, which will outline the target groups, learning objectives, required equipment and necessary software and relevant information on usage, preparation, methods and procedures.

We will also design a DIY creation kit with design maps, detailed instructions, indicated materials and appropriate measurements for all 16 interactive exhibits of the gamified mobile museum. This will consult users on designing, physically building and assembling interactive 3D constructions by embedding relevant photos, pictures,

comments, ideas and ready-made tutorials. It will also explain the independent assembly of the hands-on exhibits by indicating all preparatory steps the facilitator should follow to assemble/disassemble and store the 3D objects along with the required timeframes. All information will be provided in all partner languages and remain free and available for anyone aspiring to reproduce and build the exhibits.

The learning objectives of this module are the following:

- Understand the meaning, the potential as well as possible application fields of Fusion 360 and Cura software;
- Realise the importance of such software to the modern job market, for instance: the automotive and aircraft industry, architecture, interior and product design, computer games industry, film industry, virtual reality, etc.;
- Become able to create 3D objects of various levels of difficulty on their own, for instance, a cup (simple), a castle (medium), a suspension bridge (advanced);
- Become able to design a real object on 3D software, based on the proportions of other objects, e.g., a virtual application/copy.
- Understand how a 3D printer works by comprehending the basic settings of the slicer software;
- Become able to print 3D objects independently;
- Learn different types of mates to do various types of assembly (several 3D virtual objects (set of objects) can be used to do an assembly);
- Assemble several components on a Computer Aided Design Software;
- Understand the principles of photogrammetry, as well as the different application possibilities of photogrammetry;
- Become able to create 3D objects by processing photos through photogrammetry software.

2. Getting started with 3D Modelling

We will briefly describe the 3D Modelling process to understand how to 3D print a model you have created.

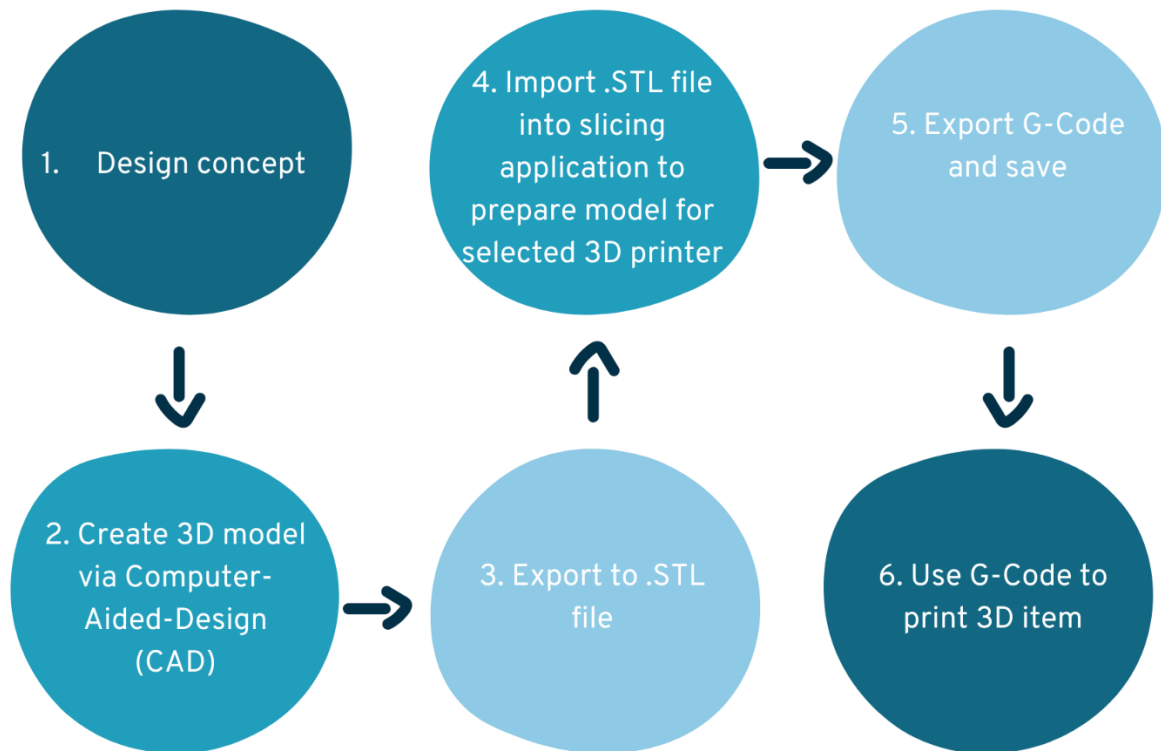


Figure 7. Comprehensive Process of 3D printing

Step 1: Design concept (The idea)

The first step is all about the conceptualisation of the 3D item that you want to create. It can start by taking the dimensions of actual items and drawing your item on a piece of paper.

Step 2: Create 3D model via Computer-Aided-Design (CAD)

In the second step, you recreate the item through 3D Modelling software. Depending on the object and if it comprises several parts, you might need to break it down into separate files to make printing easier later on. Another important thing to consider is if the items need to be connected to one another, which will require matching points to be assembled.

Step 3: Export the 3D model to a .STL file

After you have completed your 3D Model and want to see it printed, you simply export your 3D design into a .STL file to pass it through the slicing software.

Step 4: Importing .STL file into slicing application to prepare the model for selected 3D printer

In the fourth step, you import the .STL file into your chosen slicing software (e.g., Cura) and prepare your model to be printed on a 3D printer. The slicing software goes through your model layer by layer to inform the printer how to create it with more customisation available, which we will go through in Chapter 4.

Step 5: Export G-code and save

After you have finalised your model through the slicing software, you export the G-code and save it into a USB or an SD card, depending on the ports available on your 3D printer.

Step 6: Use G-code to print the item

The sixth and final step entails providing the 3D printer with the G-code you have saved to know what to print and how to print it.

The G-code essential contains a set of instructions that a 3D printer understands to print the item that we modelled.

2.1. Perspective Projections

In order to understand how 3D modelling works, let's take a look at perspective projections. Perspective projections are essentially the angle at which you see an item. There are three-point perspectives, which indicate how many sides of an item you can see.

The first-point perspective is essentially the way an item looks from one angle. You can only see one side of the item.



Figure 8. One-point perspective

The second-point perspective allows you to see the item from two angles.

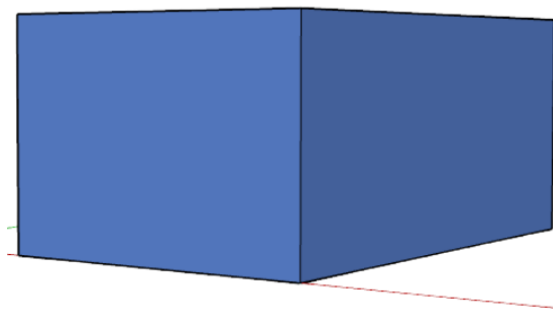


Figure 9. Two-point perspective

The three-point perspective shows you all three angles of an item, as it will be an item in a three-dimensional space.

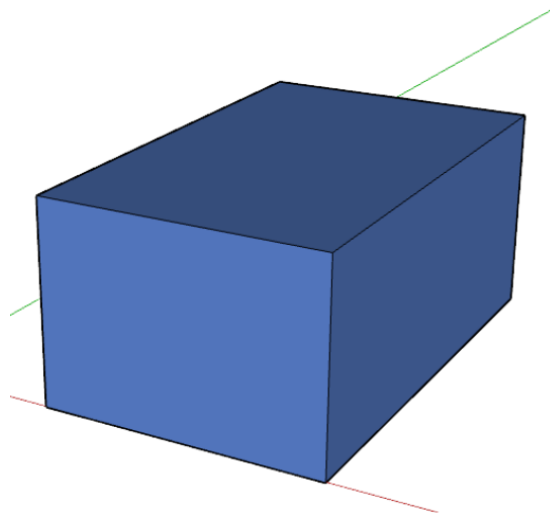


Figure 10. Three-point perspective

Through 3D Modelling, you create items in a three-dimensional space with three axes, x, y and z. To understand this a bit better, let's try to visualise it. Figure 11 below demonstrates the three axes in 3D software. At first, this might seem a bit confusing, but it is easier than you imagine. It just takes some practice and familiarisation.

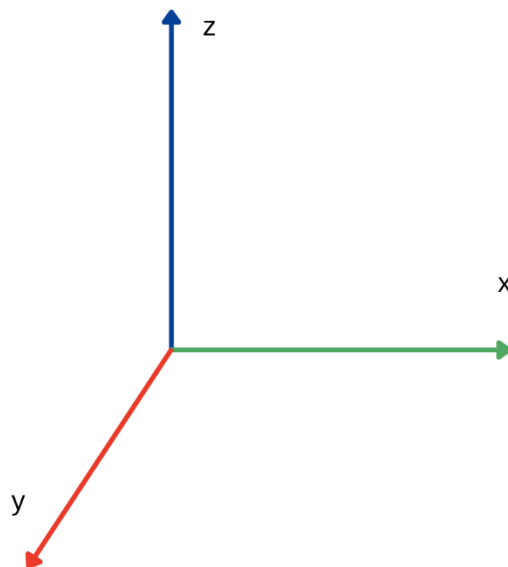


Figure 11. Three-dimensional space (x, y, z axis)

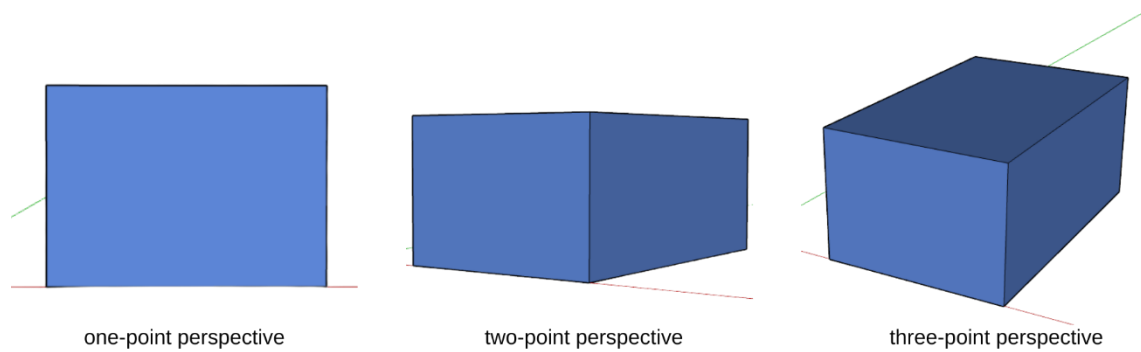


Figure 12. Perspective projections (made in SketchUp)

2.2. Options for 3D Models

There are two options to create your own 3D model and print it.

You can:

- either use a 3D Modelling software to create your model from scratch with the specifics you would like
- or you can create it using photogrammetry.

Apart from creating your own 3D model to print it, you can use ready-made 3D printing blueprints that are free to use.

You can find hundreds of 3D printing blueprints at websites like [Thingiverse](https://www.thingiverse.com/) and [MyMiniFactory](https://www.myminifactory.com/). All you have to do is download the .STL file, and you are ready to print the item.

2.3. 3D Modelling software

Many 3D Modelling software available require different levels of expertise and learning difficulty. Depending on the industry, professionals might choose specific software programmes for 3D Modelling.

Tinkercad

Autodesk's Tinkercad (<https://www.tinkercad.com/>) is a free web application and one of the most popular programmes in education that are used to introduce 3D design,

electronics, and coding. It is pretty easy to use and has many ready-made 3D printer blueprints available to download.

SketchUp

SketchUp (<https://www.sketchup.com/>) is a 3D modelling programme available on the web and desktop and has many different extensions depending on the subscription and needs of the user. This programme is used in many industries, such as architecture, interior design, civil and mechanical engineering, and industrial and product design, amongst others. The free version, we will learn in this module, is available online.

Fusion 360

Autodesk's Fusion 360 (<https://www.autodesk.com/products/fusion-360/overview>) offers a 3D cloud-based platform that integrates¹ diverse design and manufacturing aspects from the initial design stage to its engineering and circuit functionality.

Onshape

Onshape (<https://www.onshape.com/en/>) is a cloud-based product design platform which focuses on 3D computer-aided design (CAD), and product data management (PDM) and offers analytics insights and collaboration opportunities. It essentially creates a centralised system available within an organisation or company to manage diverse aspects of product design and production.

OpenSCAD

OpenSCAD (<https://openscad.org/>) is a free parametric 3D CAD programme that allows users to create solid models with the use of scripting. It can be useful to set a number of fixed parameters on your model. It is specifically used in mechanical engineering.


¹ More specifically, it includes the following: Computer-aided design (CAD), Computer-aided manufacturing (CAM), Computer-aided engineering (CAE), and Printed Circuit Board (PCB) applications.

3. Setting up with SketchUp

In this section, we will go through the functionality and ready-made tools of 3D Modelling software: SketchUp, as an introduction to start making our own 3D models. We have also dedicated a section to recreating five models in 3D software from the exhibits that we have created in the gamified mobile museum of the Numeric[All] project.

Now, let's get started with SketchUp!

Steps:

1. Go to: <https://www.sketchup.com/plans-and-pricing/sketchup-free>
2. Select the button 
3. Sign-up to save your designs, and you are all set.

3.1. Interface

Once you have completed the steps above, you will see the interface below.

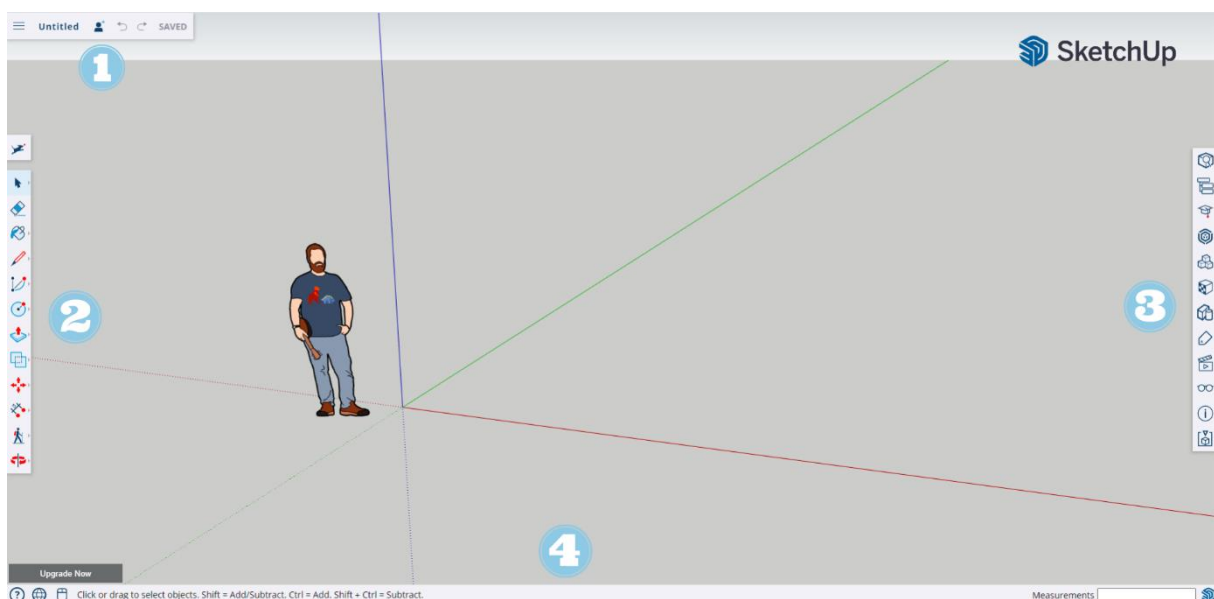


Figure 13. SketchUp Interface - Web version

The SketchUp interface is quite simple to use. The following paragraphs will explain the numbers shown in Figure 13 above.

1. Model/Preferences menu

This is located on the upper left side of our page.

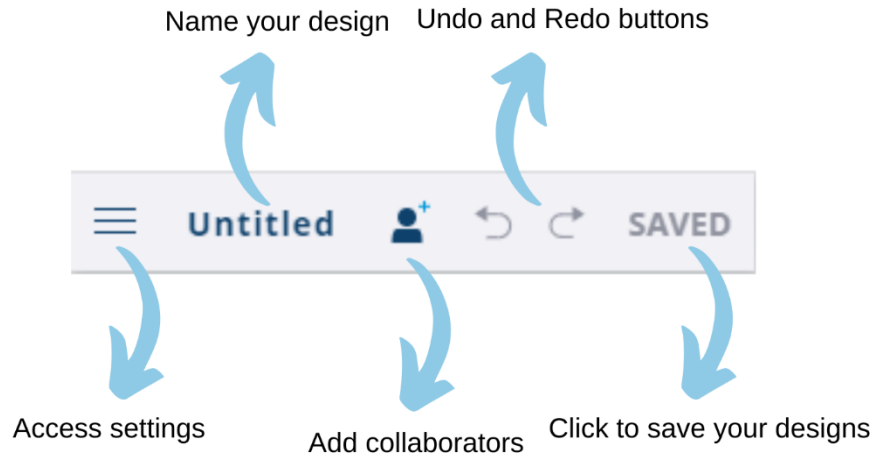


Figure 14. Bar options (upper left side)

If you click on the three bars, the following menu drops down:

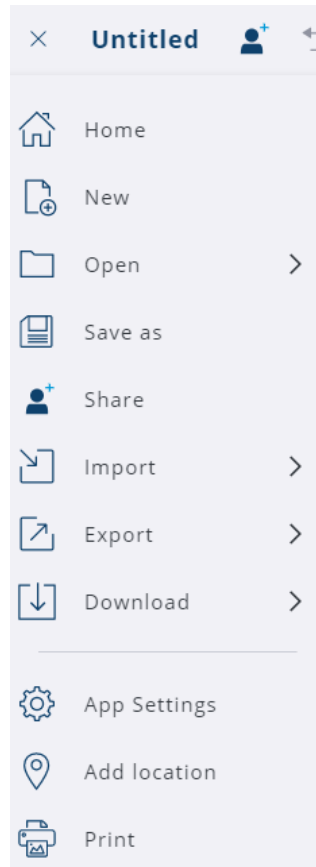


Figure 15. Settings drop-down menu

Here you have the option to create a new design, save your design, share your design with other people, import from your device or Trimble connect, export in various file formats and download your design in .skp, .png, and .stl formats. You can also customise the interface through app settings, add your location and print your design in 2D.

2. Toolbar

Here, you can find various tools to build your 3D models. We will go through each one in the next section (3.2. Uses of ready-made tools).

3. Panels

On the right side of the interface, you can access the following:

- Entity info: contains information about the selected object, such as type, instance, definition, layer, shadow and visibility settings.
- the Instructor: gives you information on what a tool does and how to use it
- Components: these are useful when you need to reuse an object (e.g., a window for a 3D house model) by creating it, uploading it from your device or searching the Trimble 3D warehouse. For more information, visit: <https://help.sketchup.com/en/working-components-sketchup#introduction>
- Materials: makes your 3D models more realistic by adding colour and texture (optional) to surfaces.
- Styles: contains a series of predefined styles that show the edges, faces and background in a specific style (e.g., sketchy rough edges).
- Layers: adjusts the visibility of objects in your 3D environment when multiple objects are present
- Scenes: changes the background and perspective projection of your 3D model.
- Display: allows you to edit what you see in your display, such as lines, objects, components, shadows and fog.

4. Status bar

Here, you can access the Help Centre, the language menu, input device options, tips and options for selected tools, and the measurement box for more accurate modelling.

3.2. Uses of ready-made tools

In this section, we will go through the ready-made tools available on the SketchUp web version and their uses.



Search tool

You can use this to search for anything related to SketchUp.



Selection tool

You can select lines, faces or objects.

- To select one side of a surface (face), click twice.
- To select an edge and its connecting face, click on it twice.
- To select an object, click three times.



Lasso tool

You can draw your own selection area.



Eraser tool

You can erase lines, faces or other objects.



Paint Bucket tool

You can add active material to surfaces (faces).




Sample tool

You can use this tool to make any material you click the active material.




Line tool

You can create straight lines that, if connected, will create a surface (face).

 Freehand tool


You can create freehand lines that, if connected, create a surface (face).

 Arc tool

You can create arcs or circles with the help of a protractor. You start by selecting your centre point after choosing your desired angle as the endpoint and finish the arc.

 2-point arc tool

You can create an arc by setting the two arc points with the pencil and the bulge of the arc.

 3-point arc tool


You start by setting a centre point, then a pivot point and your endpoint to create an arc.

 Pie tool

This tool works the same way as the arc tool, but instead of creating an arc, it creates a pie shape.

 Rectangle tool

You can create a basic rectangle or square shaped item.

 Rotated rectangle tool

This tool allows you to create a rectangle at any angle instead of an axis.

 Circle tool


You can create a circle using this tool.

 Polygon tool

You can create a polygon with any number of sides.

 3D Text tool

You can add a text in 3D on your model and select whether it will be extruded or filled.

 Push/pull tool


This tool pushes an object into the three-dimensional space or makes it flat.

 Follow-me tool


With this tool, you can create complex 3D shapes by leading a face along a path.

 Offset tool

This tool creates an object that is an offset distance from another object.

 Outer shell tool

It is used to remove the inner faces of overlapping solids and leave only the outer faces.

 Move tool


This tool is used to reposition, copy, or stretch objects.

 Rotate tool

With this tool, you can rotate objects at a specified angle.

 Scale tool

With this tool, you can resize and reshape objects.

 Tape measure tool

This tool helps you measure your objects.

 Dimensions tool


You can mark the length or angle of an object.

 Text tool

This tool allows you to add text on your screen and specify certain points on your model (e.g., the material that is made of).

 Section tool

With this tool, you can cut through a model to see inside the object.

 Protractor tool

You can measure the angles of your 3D objects.

 Axes tool


This tool allows you to set a model's or component's axes.

 Tag tool


You can organise your objects and change their visibility.

 Walk tool

This tool allows you to walk around your model (e.g., buildings)

 Position camera tool

You can position the viewpoint at a specific height according to your model.

 Look around tool

After you use the position camera, it automatically changes to this tool, which allows you to look from side to side.

 Orbit tool


This tool allows you to rotate around your 3D object.

 Pan tool


With this tool, you can view your scene up, down, left and right.

 Zoom tool

You can zoom in or out on specific surfaces of your object,

 Zoom window tool

This tool allows to select a specific rectangular window of your object.

 Zoom extents tool

This tool puts in your view the whole model you have created.

3.3. Numeric[All]'s exhibits to try out

In this section, we will try to recreate 5 of Numeric[All]'s exhibits from the gamified mobile museum (PR2) in their simplified versions. More detailed versions of these and other exhibits will be found on the project's website (<https://numericall.eu/>) ready to be printed in .STL files. The following exhibits were selected so they can give you the opportunity to practice your 3D modelling skills with different shapes and progressive levels of difficulty. Let's try to create your first 3D object on SketchUp!

Fill the Box

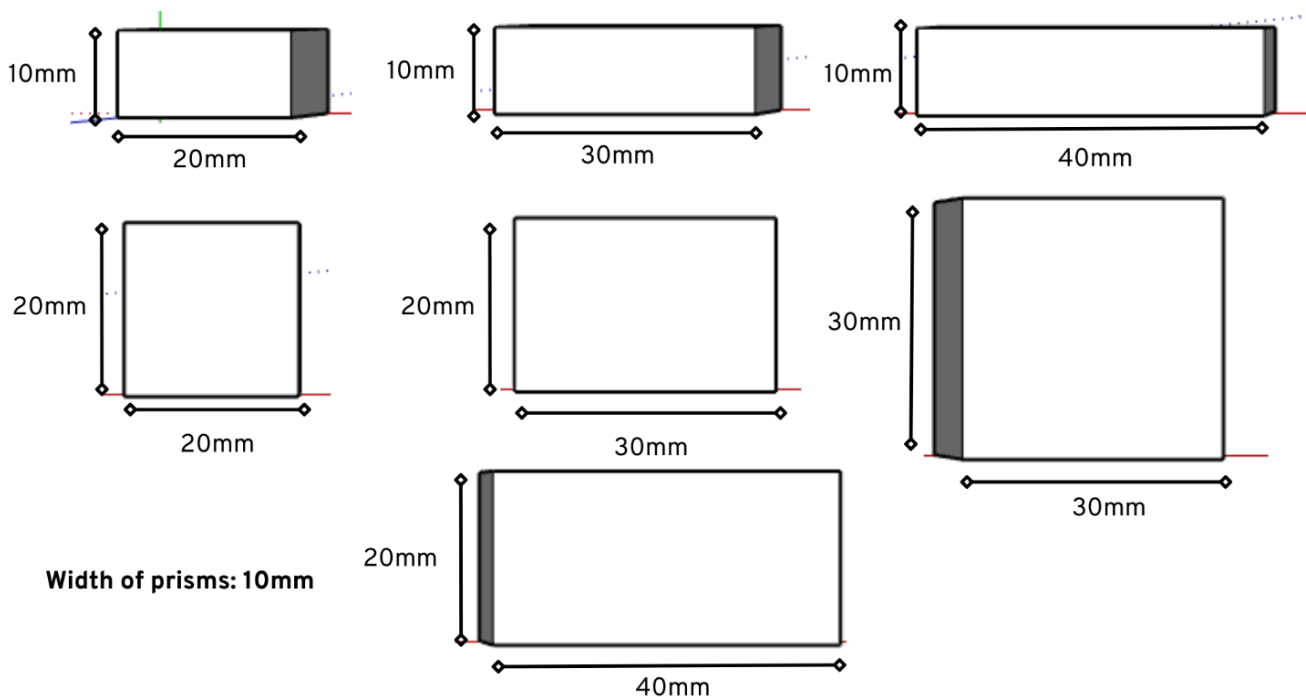
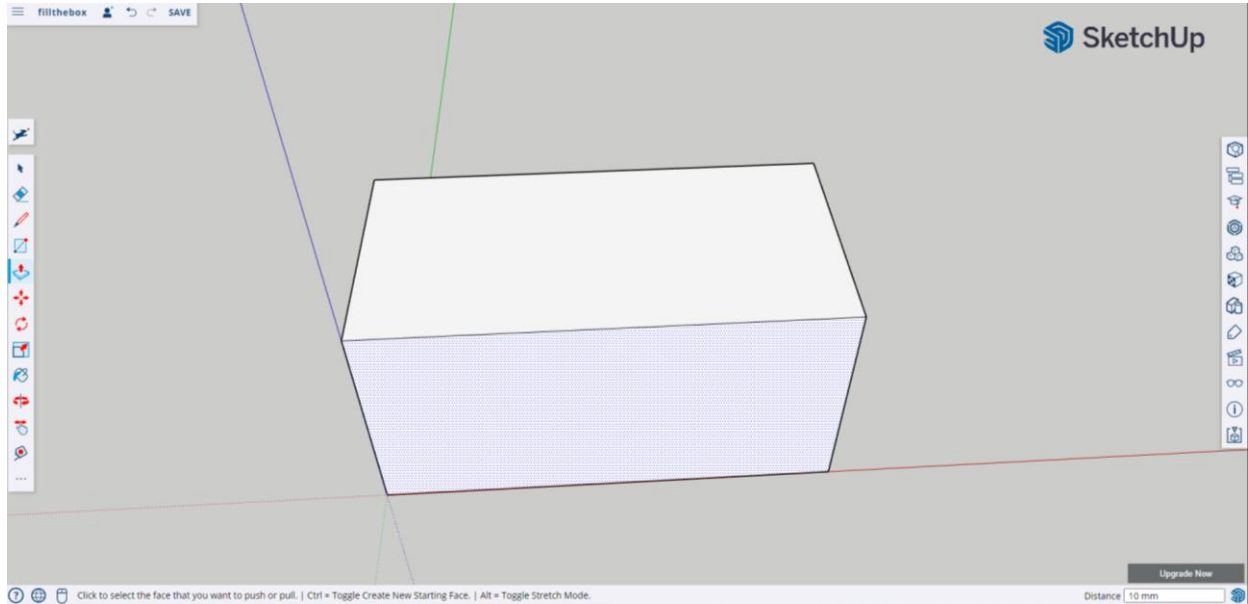


Figure 16. Prisms dimensions

Step 1: Select the rectangle tool, put it on the corner of the axes and press enter to specify the dimensions 20mm, 10mm (2cm, 1cm) and press enter again to create the rectangle.



Step 2: Use the push/pull tool to raise the width of the prism to 10mm (1cm).

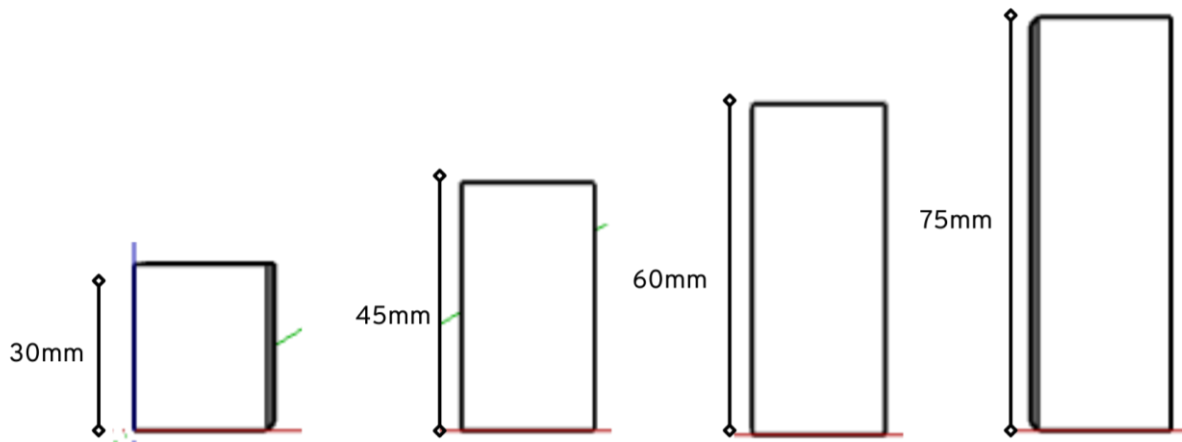


And you have made the first prism of the fill the box exhibit! The rest can be made following the same steps and their corresponding dimensions.

Recommendation: Create two prisms together in a file to save time when printing them.

Skyscrapers

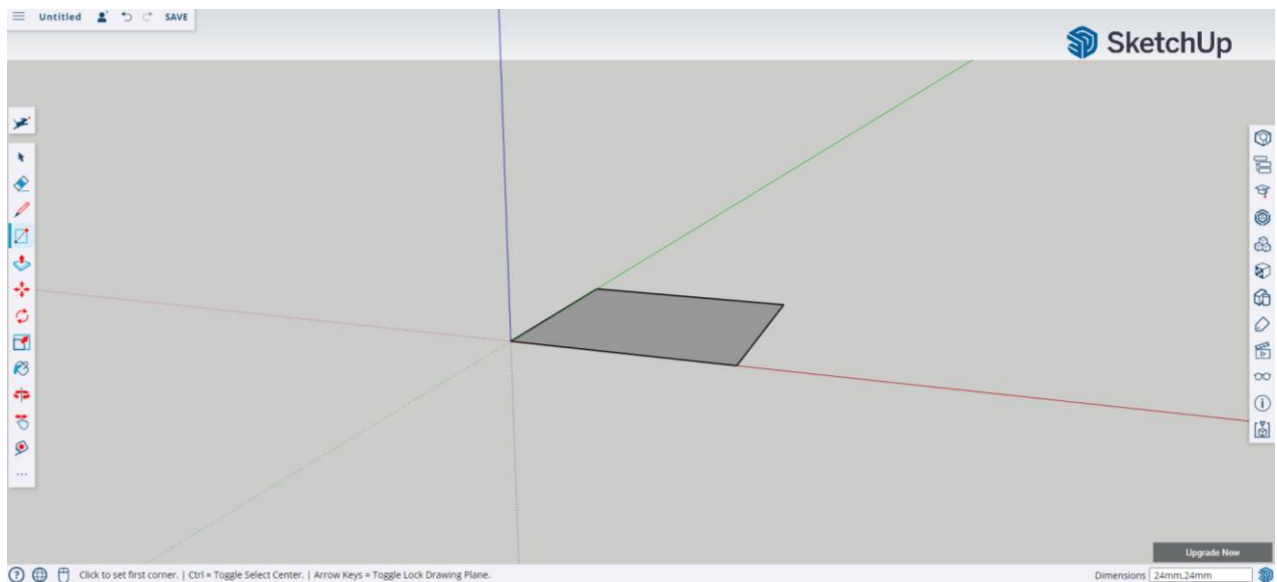
This exhibit uses rectangular prisms as skyscrapers of different heights. The dimensions of the skyscrapers are shown in the figure below.



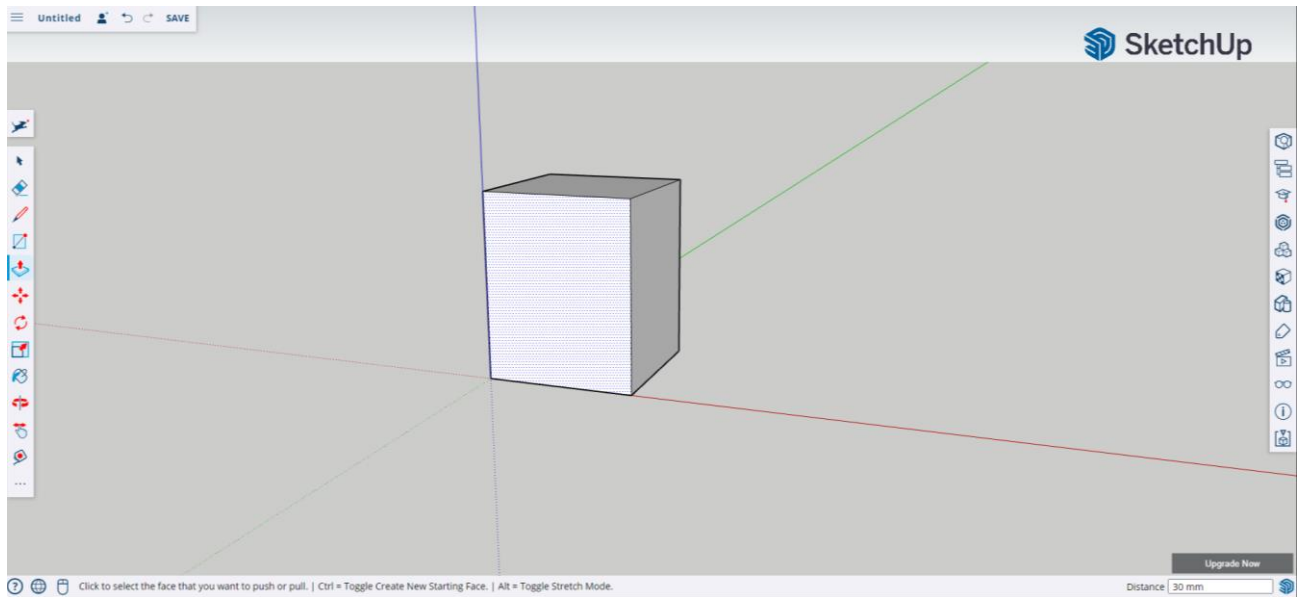
Base of skyscrapers: 24mm x 24mm

Figure 17. Dimensions of Skyscrapers

Step 1: Use the rectangle tool and set the dimensions to 24mm x 24mm (2.4cm x 2.4cm) to make the base of the skyscrapers.



Step 2: Use the push/pull tool to set the height to 30mm (3cm).



Step 3: You follow the same process for the other skyscrapers with different heights.

Hint: Copy (Ctrl+C) and paste (Ctrl+V) each skyscraper in the same file 4 times in order to print them all in one go.

Cubes

Our exhibit with the cubes is based on L-shaped pieced with 3 and 4 units. So, we will start off with the measurements to be able to draw it in 3D.

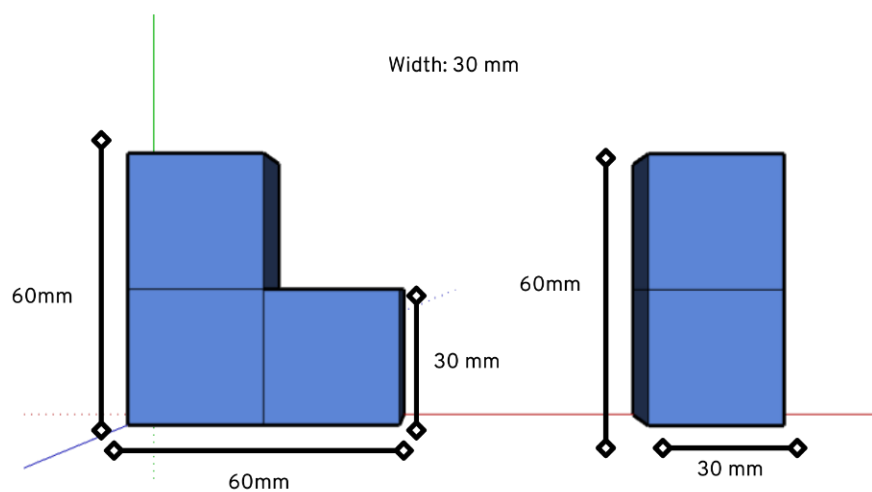
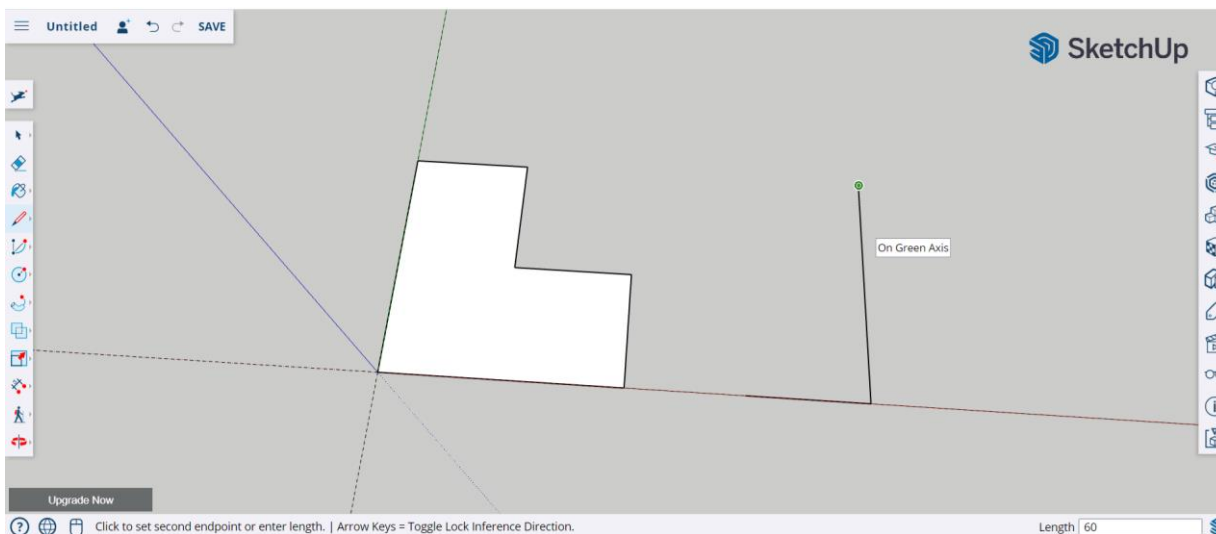
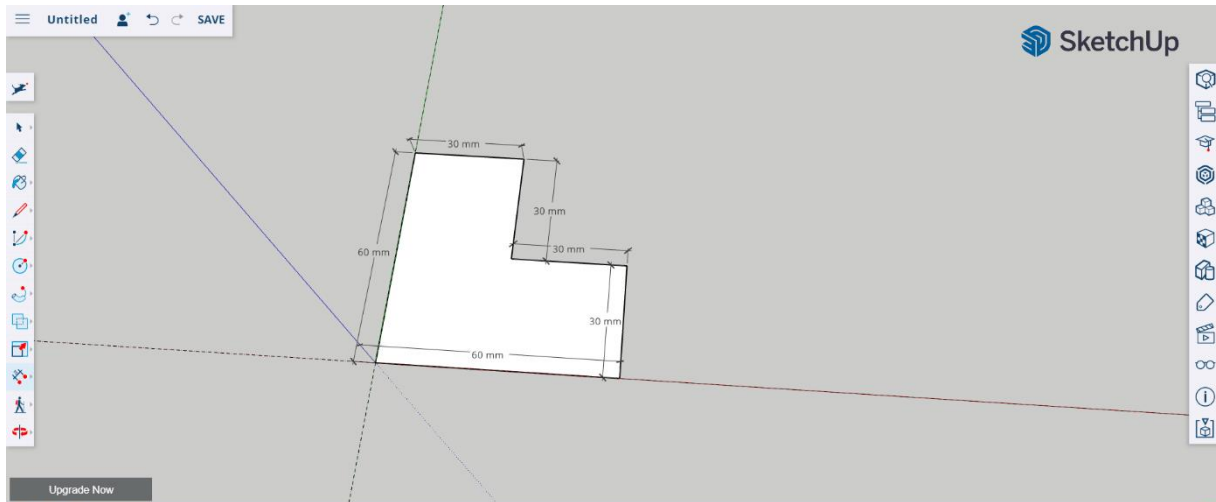


Figure 18. Dimensions 2x2x2 cube

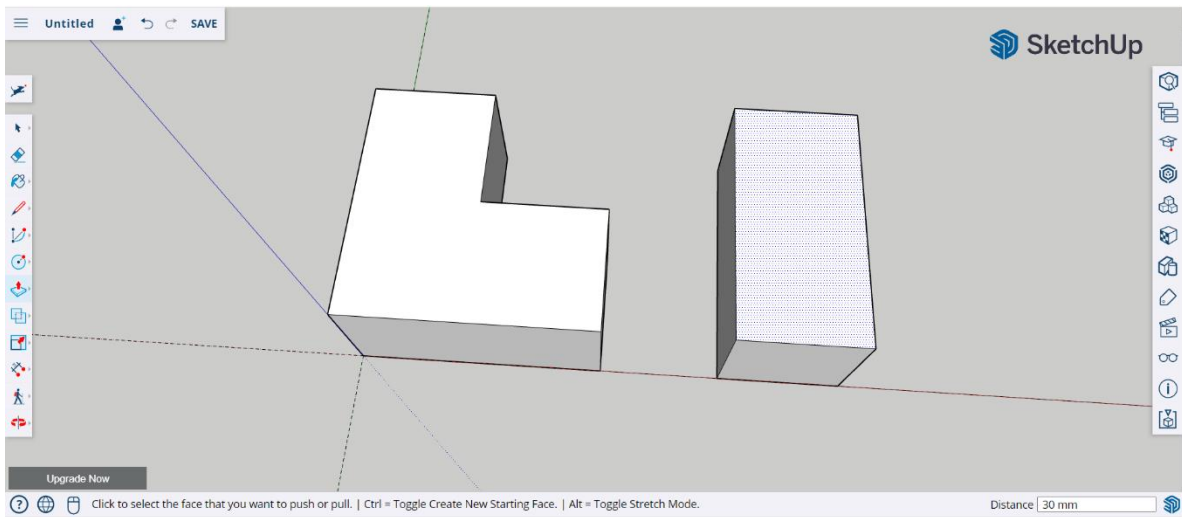
Step 1: Use the line tool to make each cube based on the dimensions shown in the figure above.

When you make a line, you can see if you are drawing on the right axis. To create the shape of the cubes, we are moving along the green and red axis.

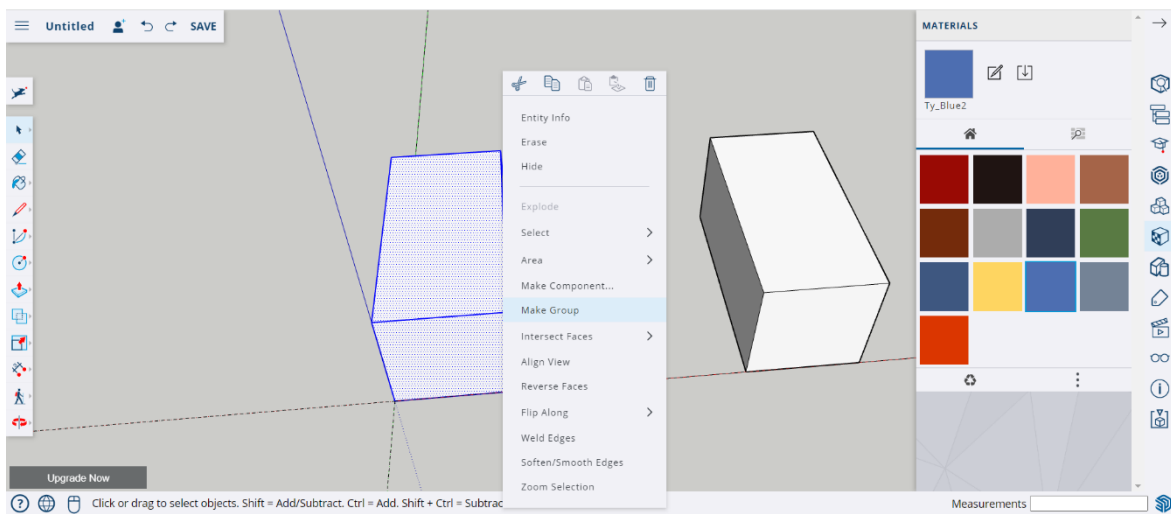




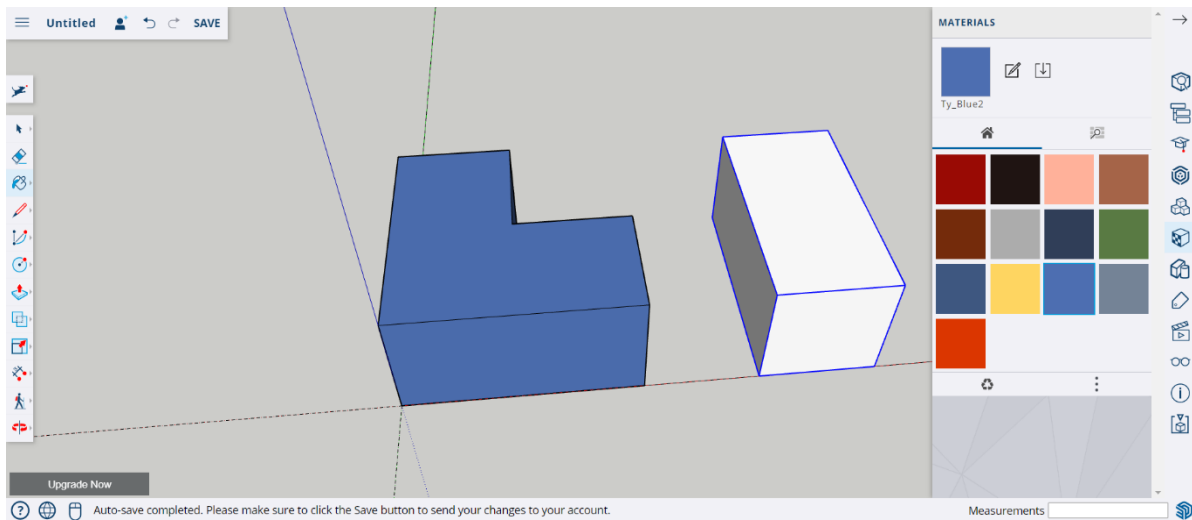
Step 2: Use the push/pull tool to make the cubes width 30mm.



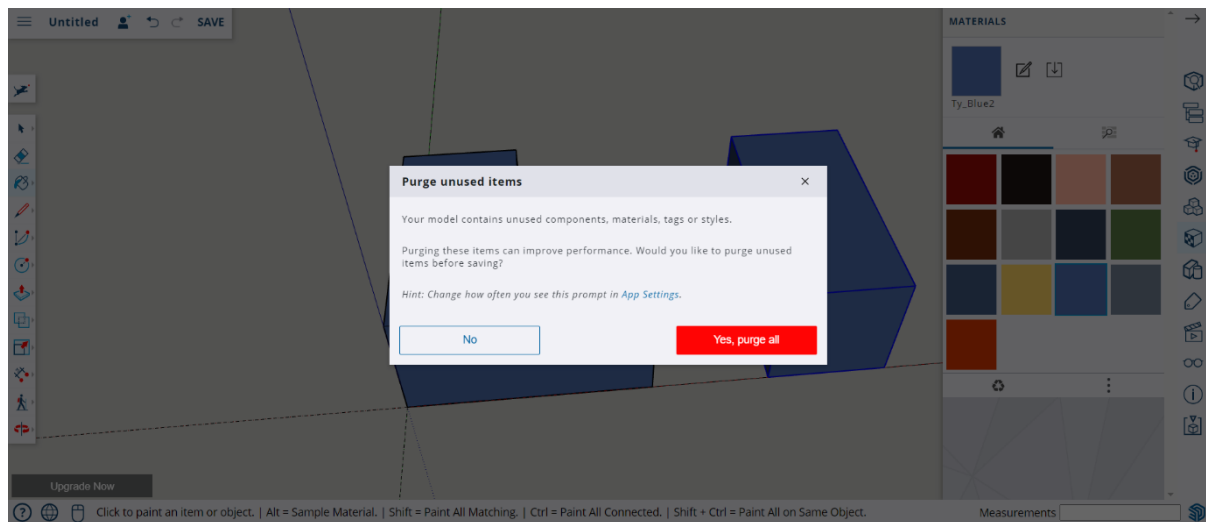
Step 3: Select each cube and make them into a group.



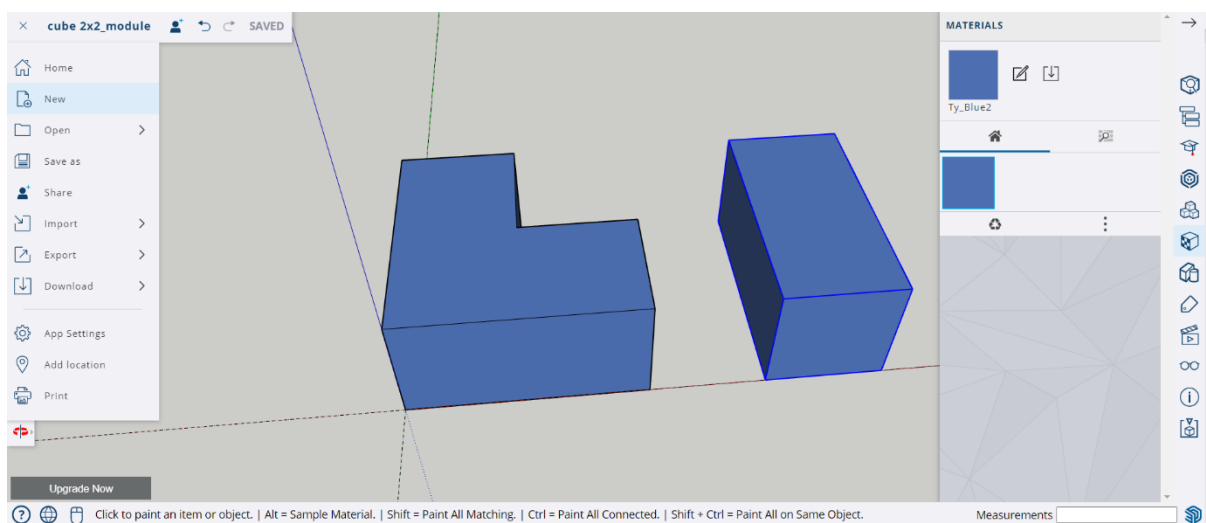
Step 4 (optional): Use the paint tool and choose the colour to make the paint.



Step 5: Save your file and purge all items.



Step 6: After saving the 2x2x2 cube, go ahead and create a file for the 3x3x3 cube.



Step 7: The same process is followed to recreate the 3x3x3 cube pieces. Use the dimensions given in the figure below and you are all set.

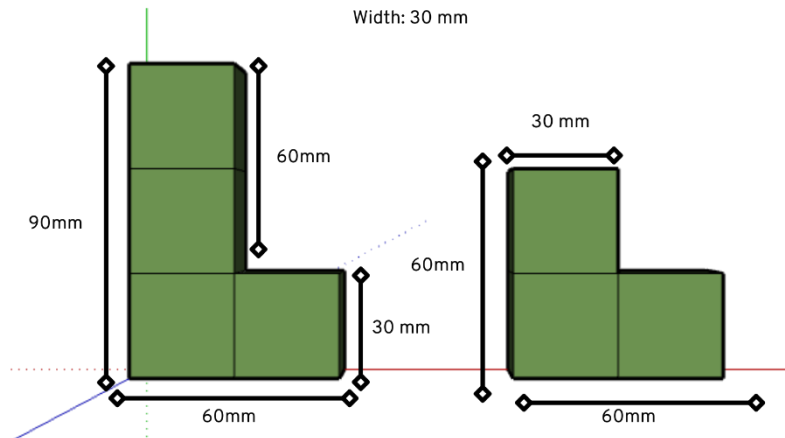


Figure 19. Dimensions of 3x3x3 cube

Dominoes

This exhibit uses domino pieces to practice numeracy skills in pairs. The measurements below indicate how to recreate the pieces on SketchUp.

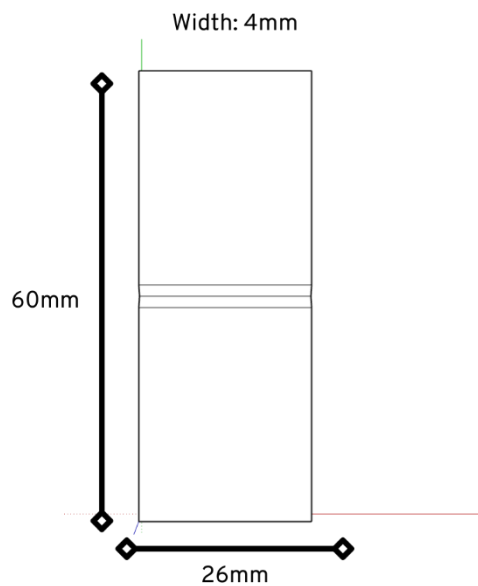
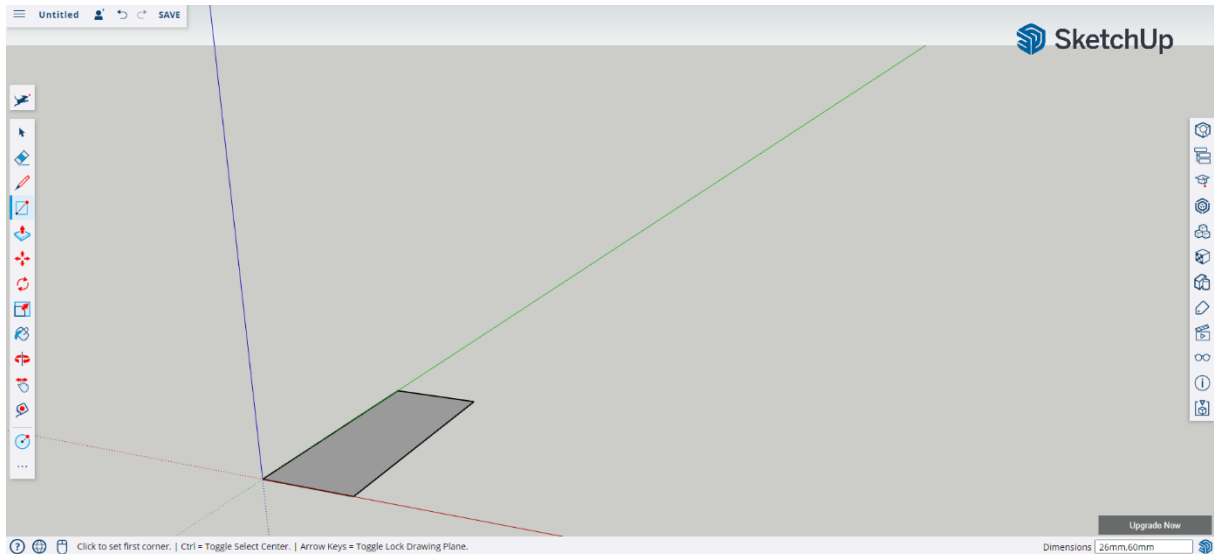
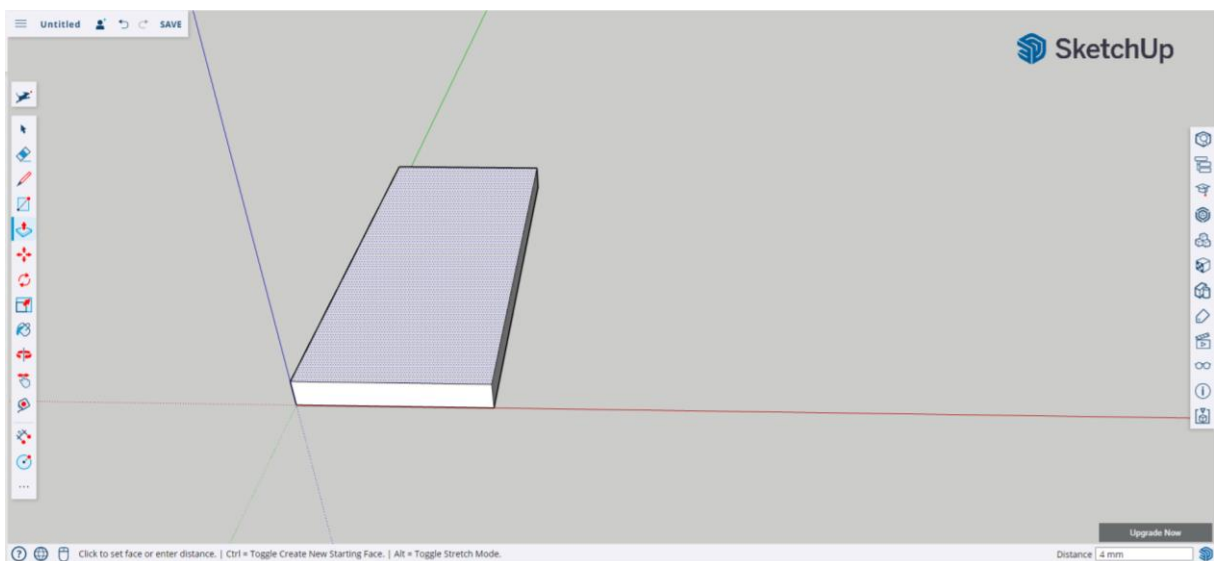


Figure 20. Dimensions of domino pieces

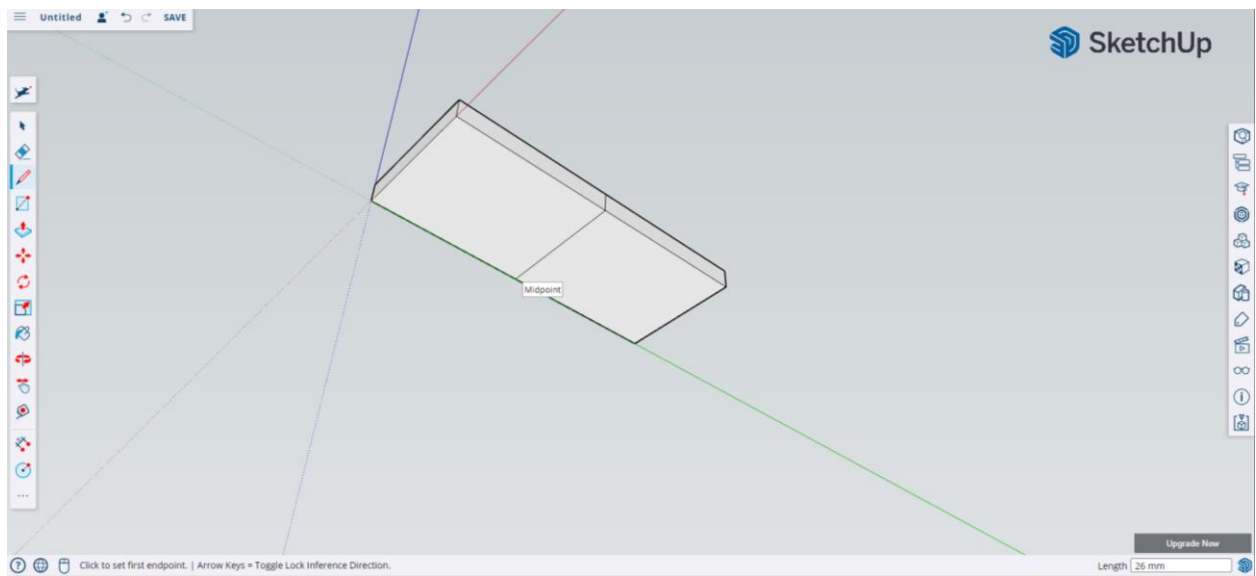
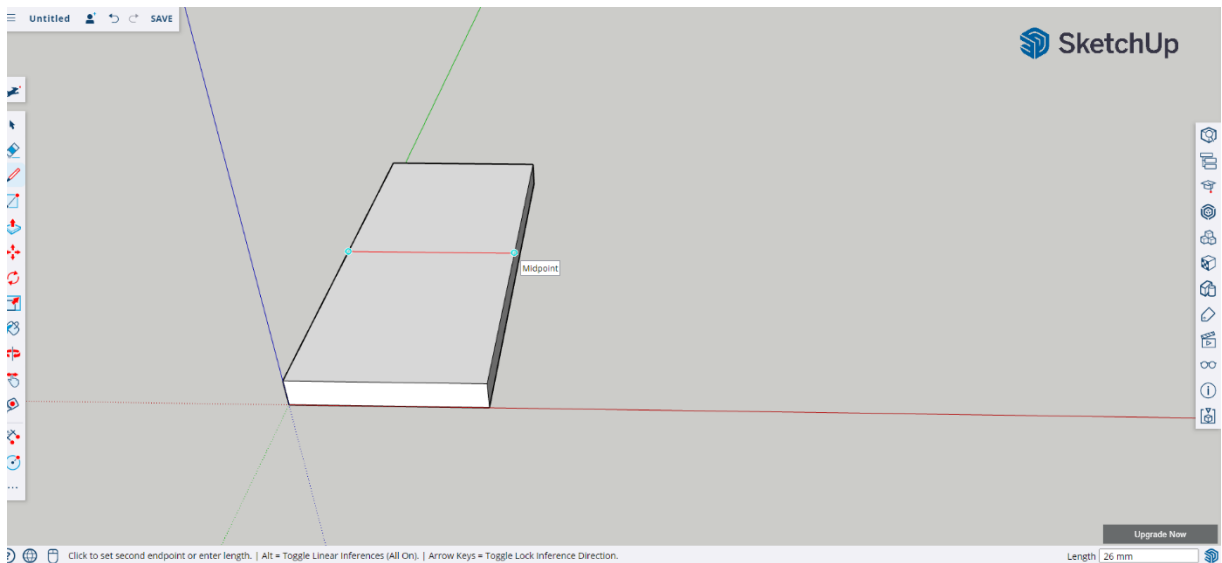
Step 1: Draw the rectangle using the rectangle tool (26 mm x 60 mm)



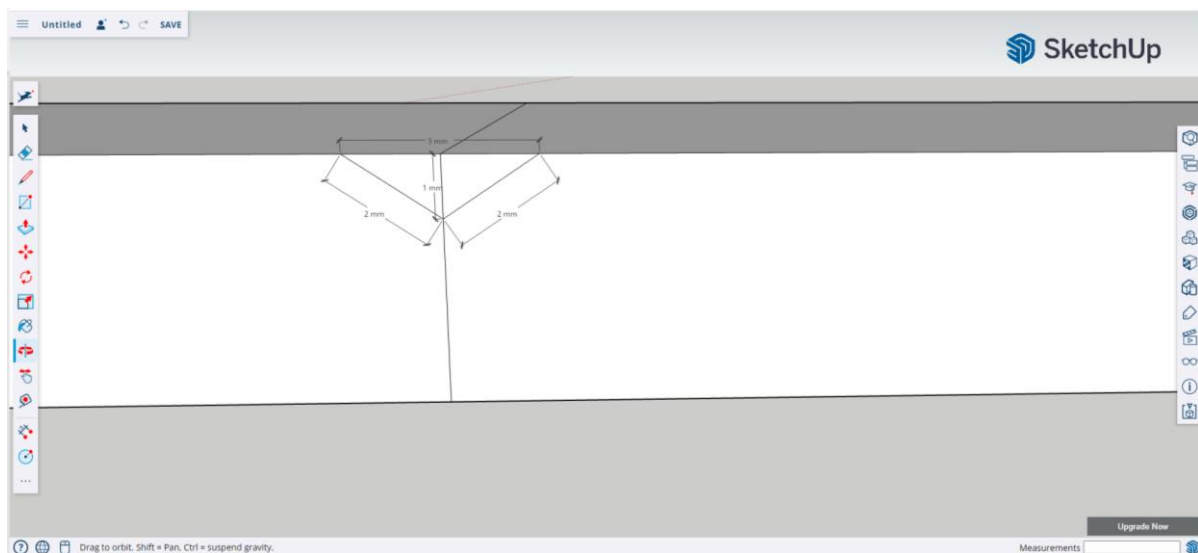
Step 2: Use the push/pull tool to set the height to 4mm.



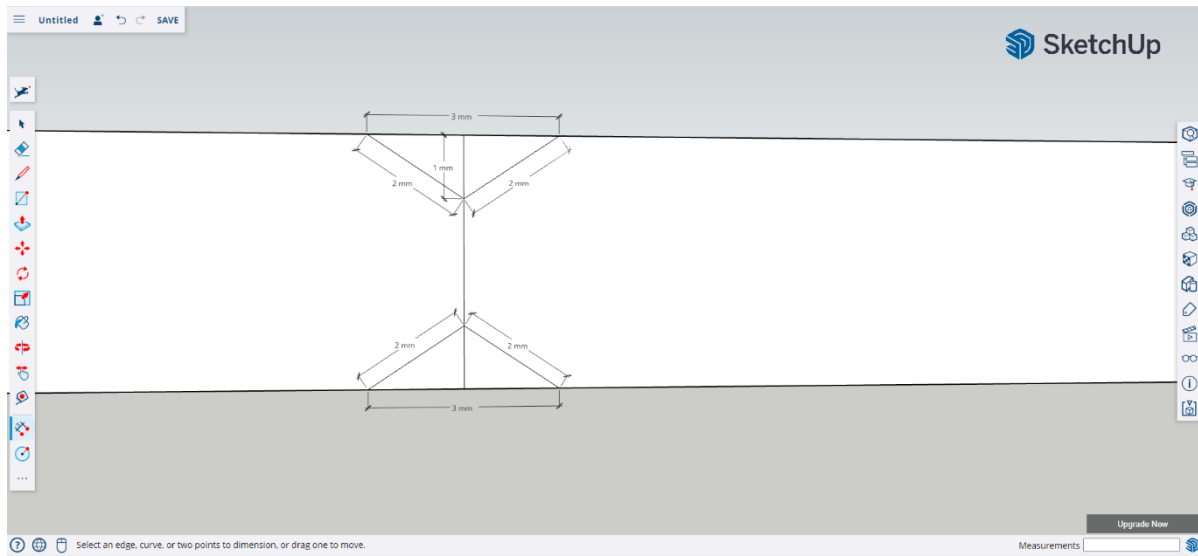
Step 3: Use the line tool to find the midpoint of the domino piece. Make sure to make the line in all sides of the domino.



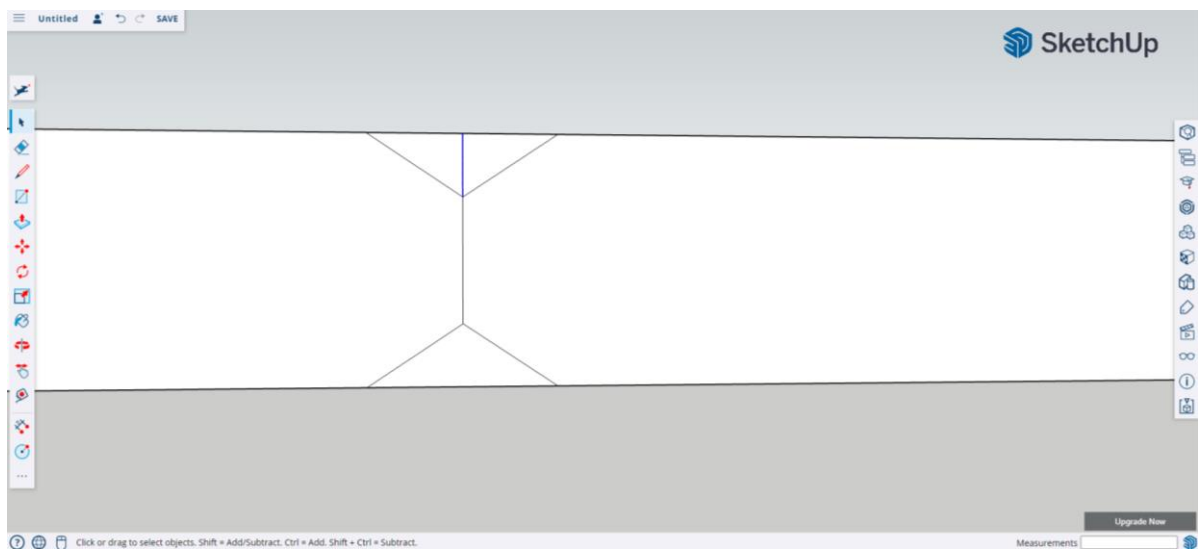
Step 4: Rotate the camera to the side and use the line tool to mark 1.5mm from the line on sides and 1mm down to make a triangle.



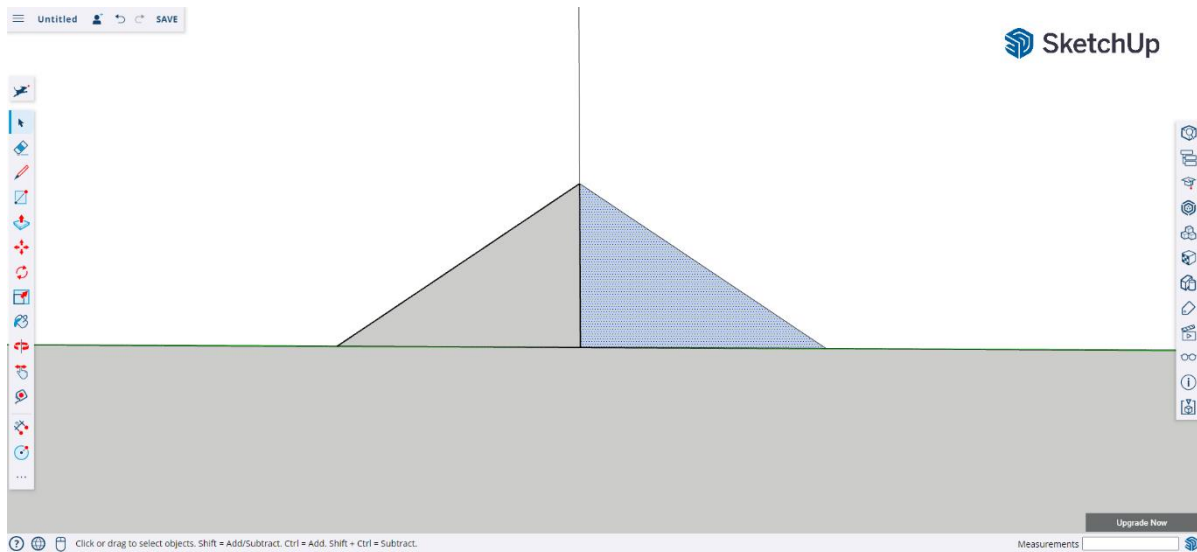
Do the same, on the bottom side of the domino piece.



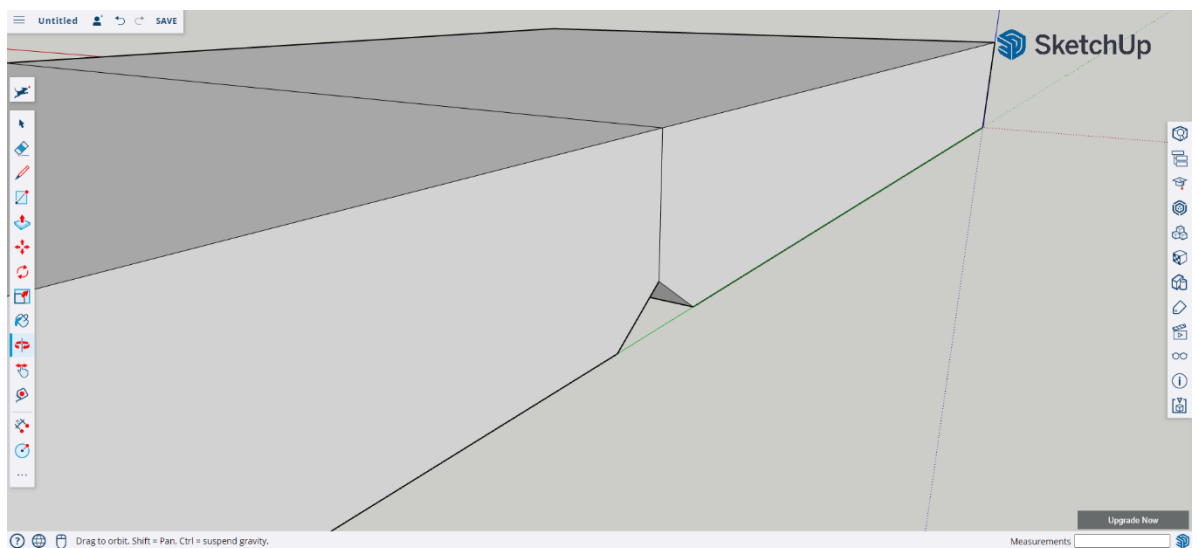
Step 5: Select the middle line and delete it from both triangles.



Step 6: Use the push/pull tool to make the triangle cut on both sides.



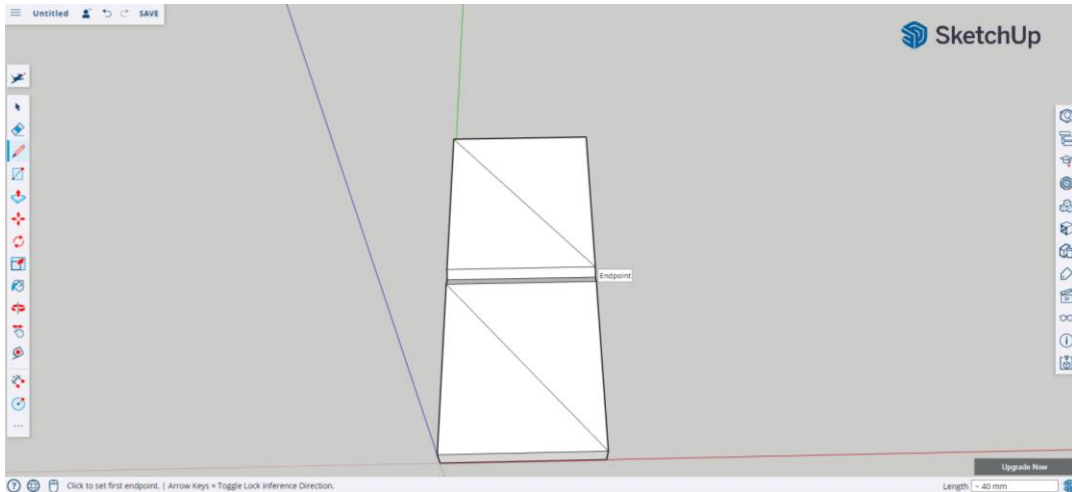
Remember to check on both sides that there is no material or lines left of the triangle.



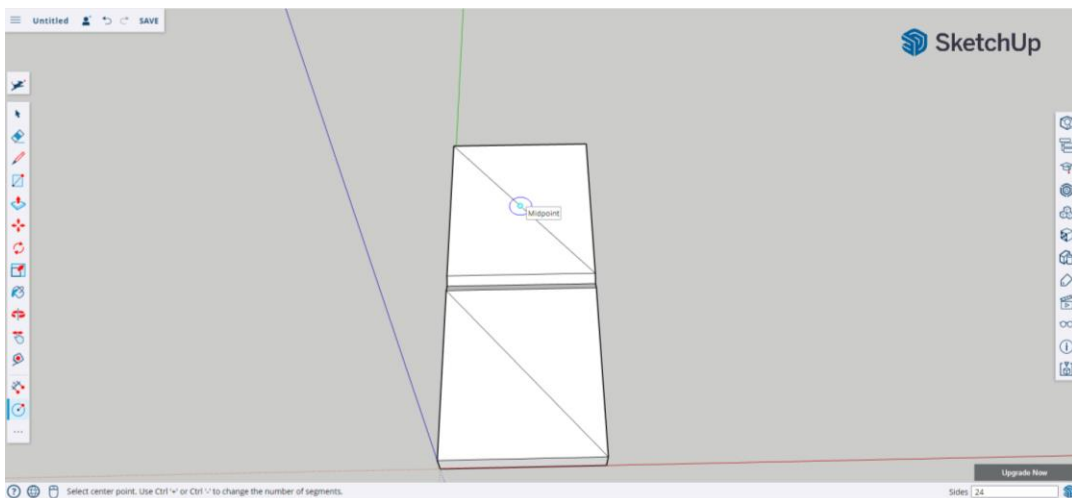
Step 7: Use the circle tool to make the numbers on the domino pieces. Leave one without any to represent zero.

To make the domino piece with one dot:

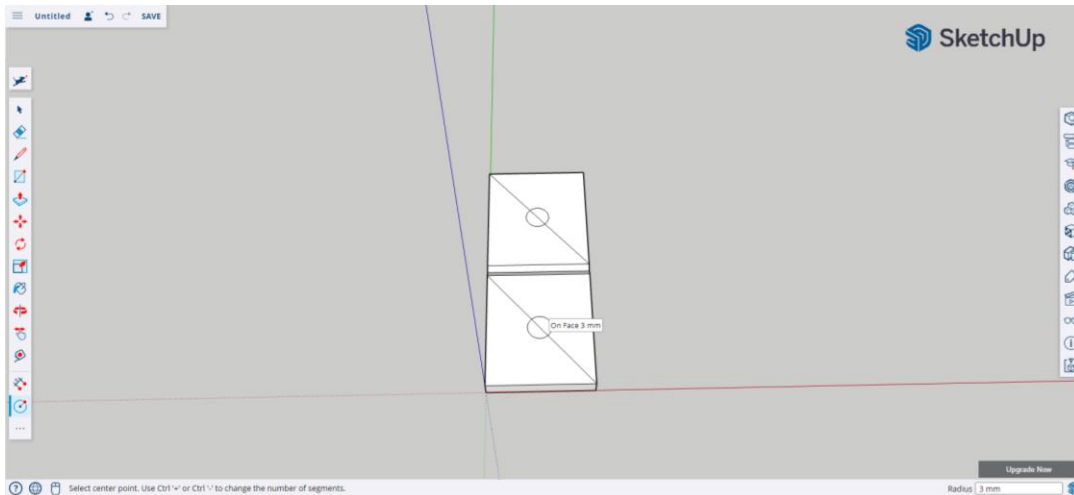
- a) Use the line tool to draw a diagonal line on the domino.



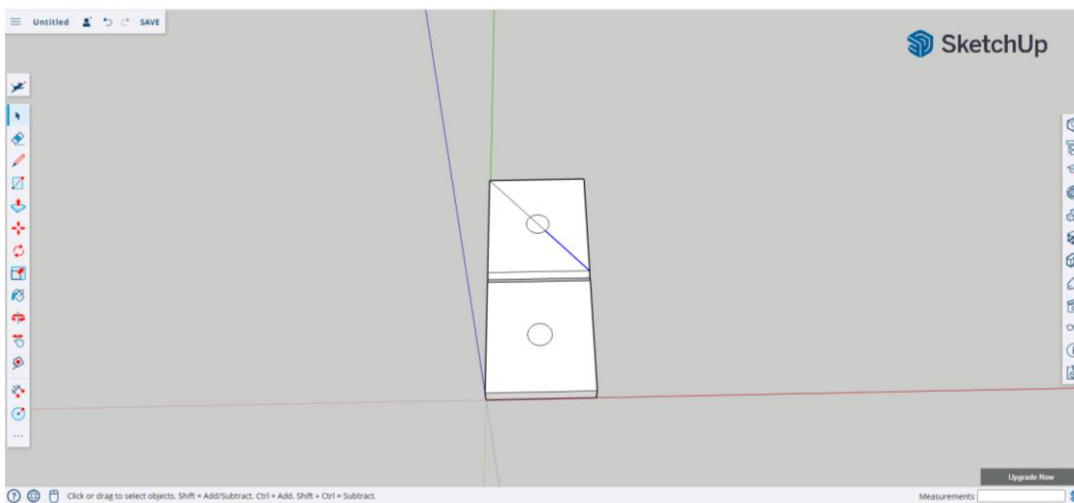
- b) Select the circle tool and move diagonally on the line until you find the midpoint.



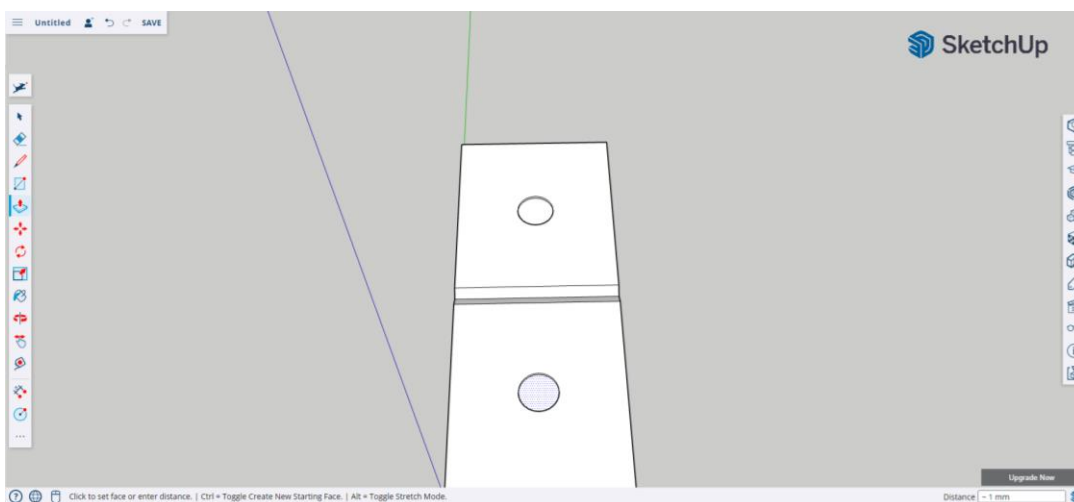
c) Set the circle radius to 3mm.



d) Select the diagonal lines and delete them.



e) Use the push/pull tool to push down the circle by 0.5mm.



Step 8: Repeat this process for the other domino pieces.

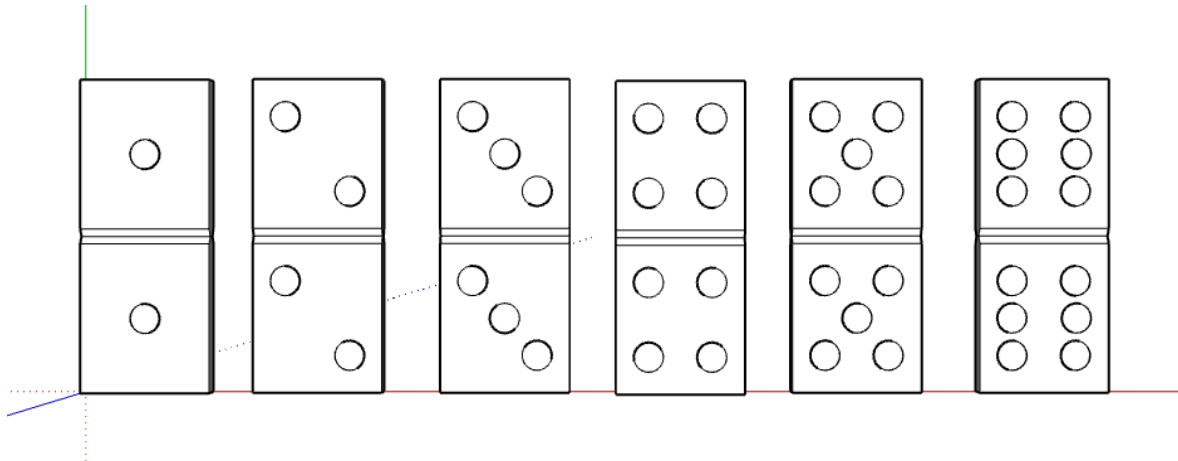


Figure 21. All domino pieces (made in SketchUp)

*** Make sure that you select each domino piece and group it before downloading it to an .STL file.**

Alternative option: Create the shape of the domino based on the dimensions that we specified (i.e., 60 mm x 26 mm x 4 mm) and print it 6 times. Once printed, use a permanent marker to make the circles or use circle stickers.

Hidden Coin Box

The Hidden Coin Box exhibit practices probability by engaging learners to count how many coins of 1 and 2 are in the box with simply shaking it each time. There are two parts to this exhibit, the box and the coins. First, we will explain how we can model the box and then the coins.

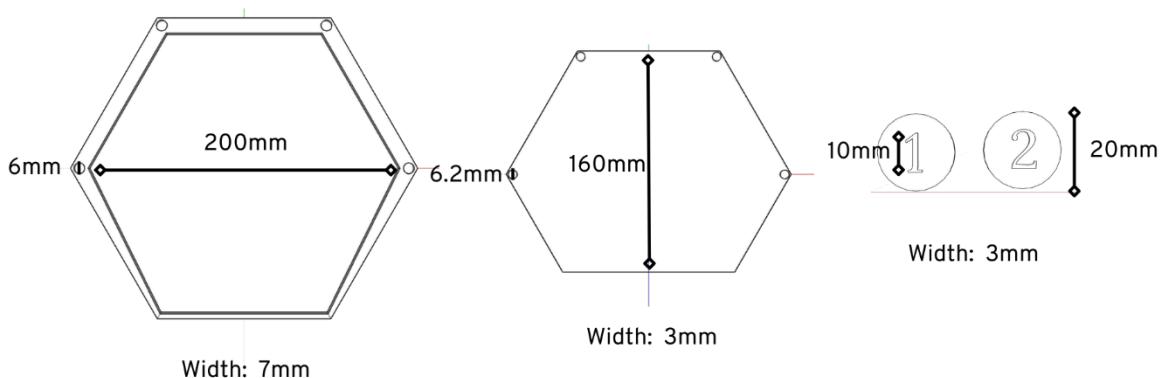


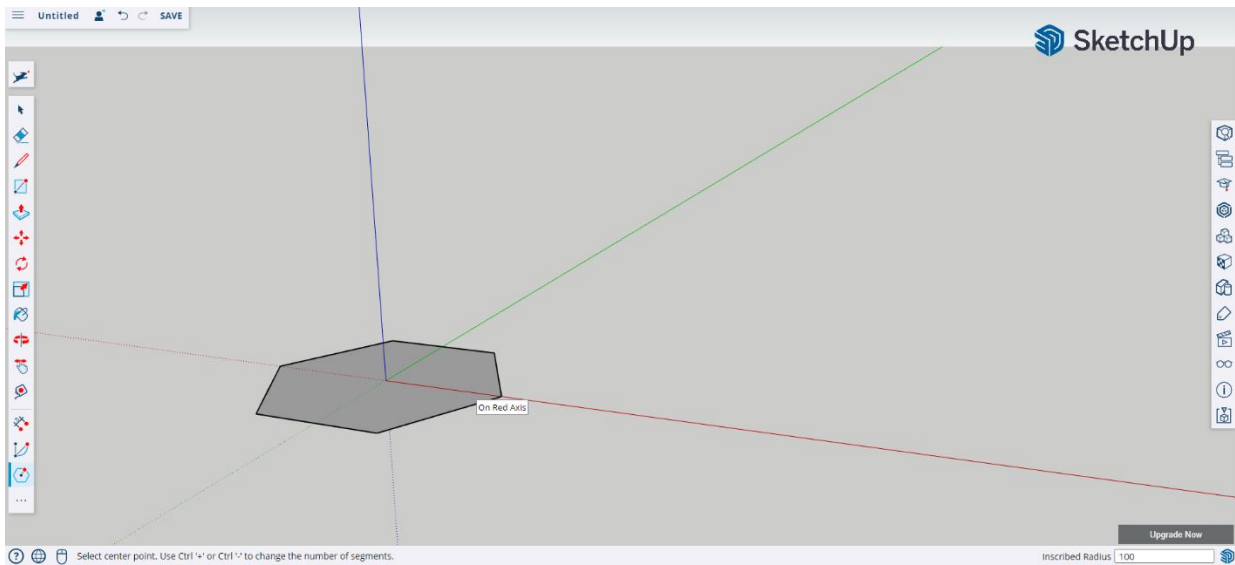
Figure 22. Dimensions of Hidden Coin Box parts

Box

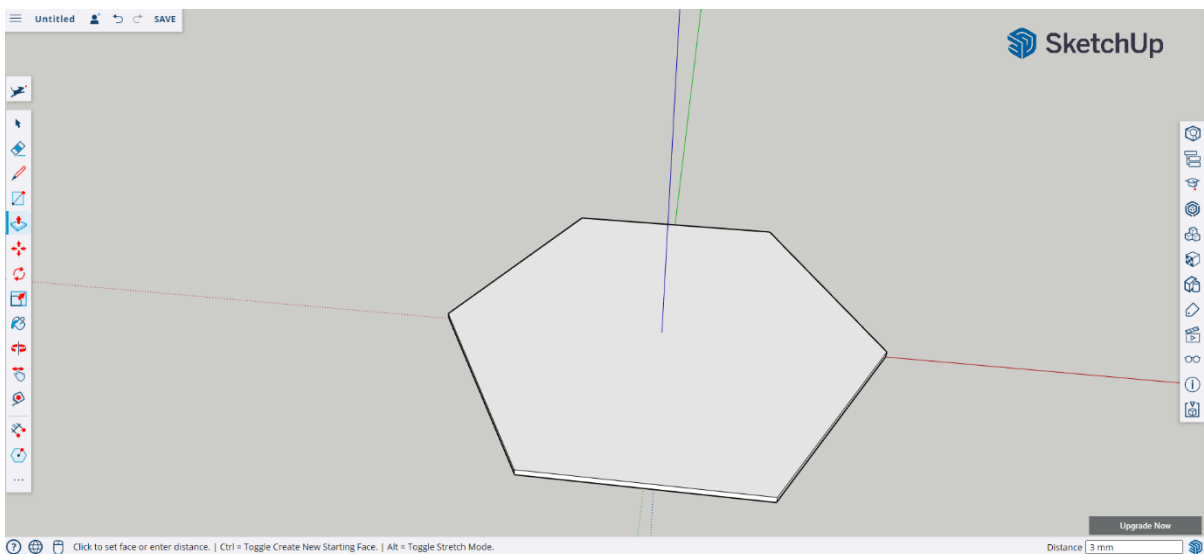
Before, we go through the steps. It is important to mention that the box will be split in two pieces that can be assembled once printed to allow us to insert the coins.

Top part of box

Step 1: Use the polygon tool to draw a hexagon with an inscribed radius of 100mm. Use the axes to help you center the hexagon.

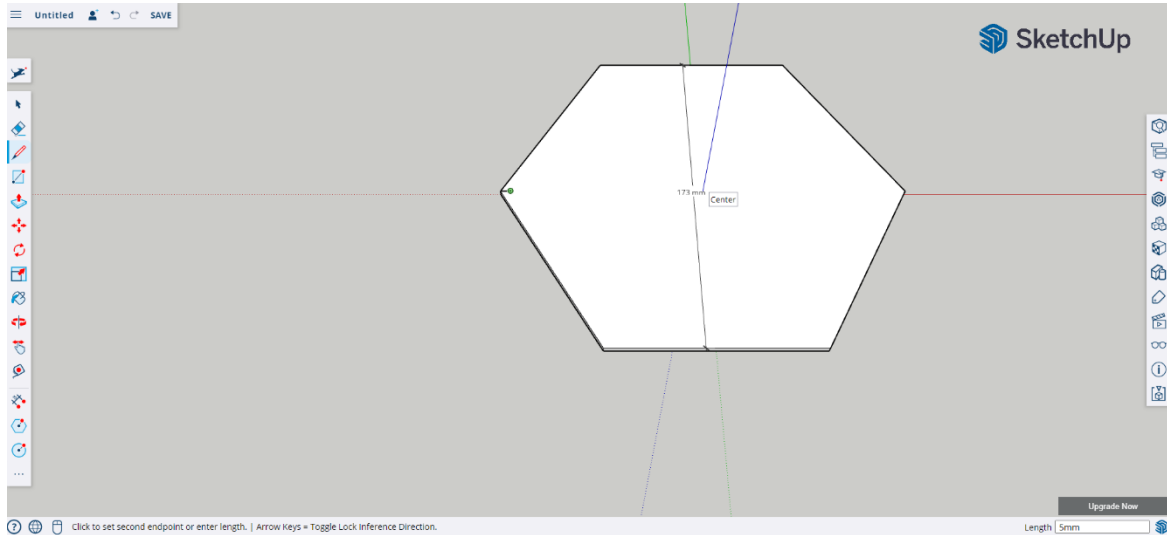


Step 2: Use the push/pull tool to set the height to 3mm.

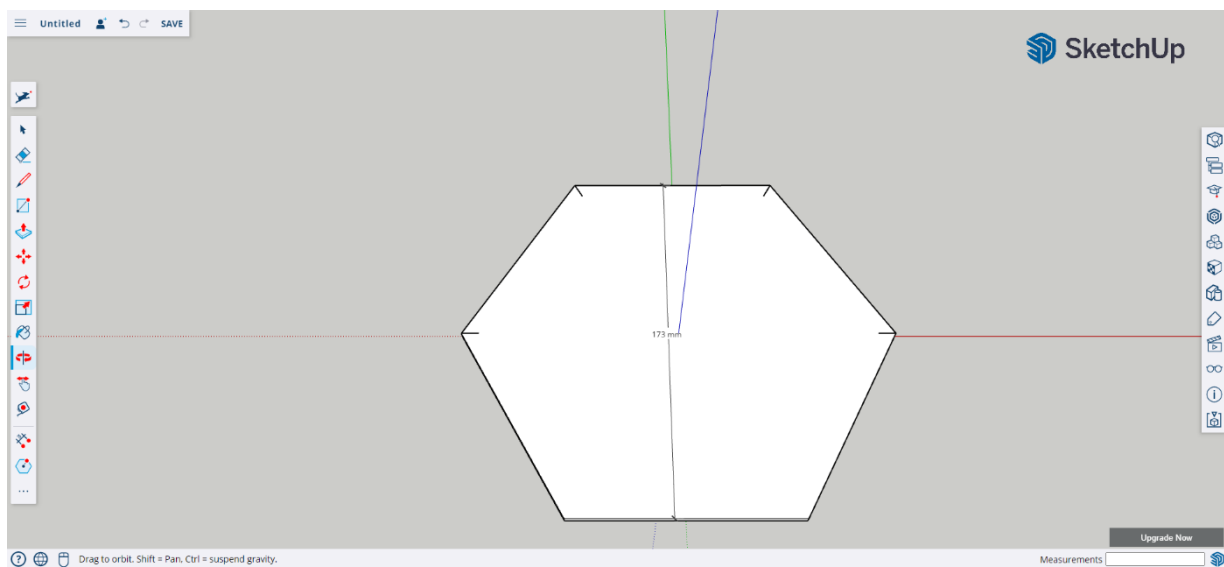


Step 3: Now it's time to create 4 circles that will serve as assembly parts later on.

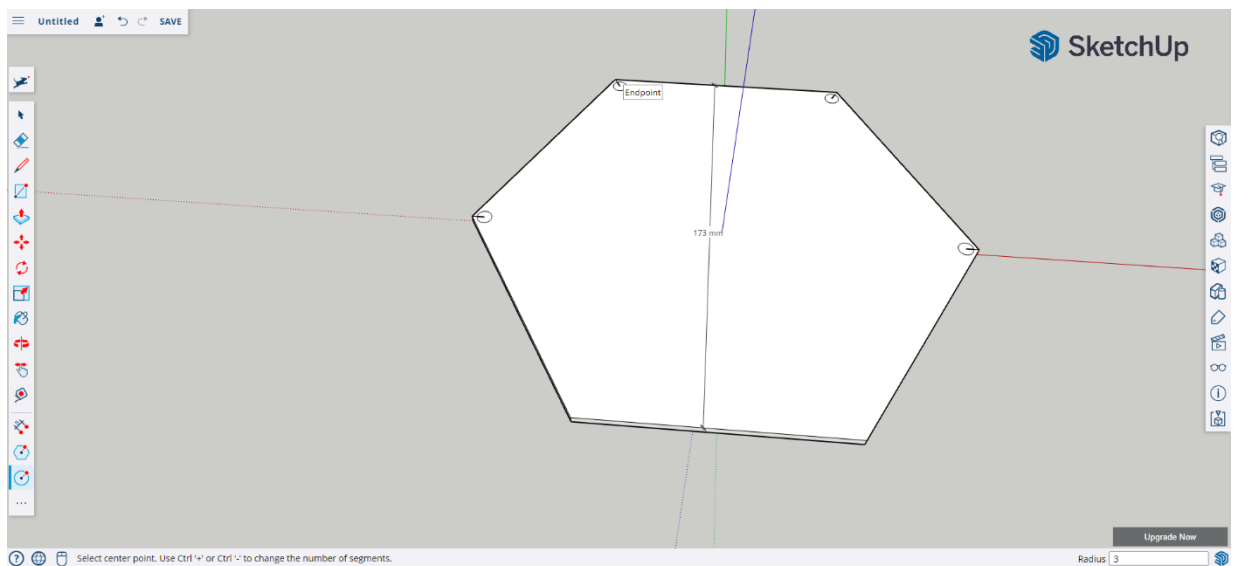
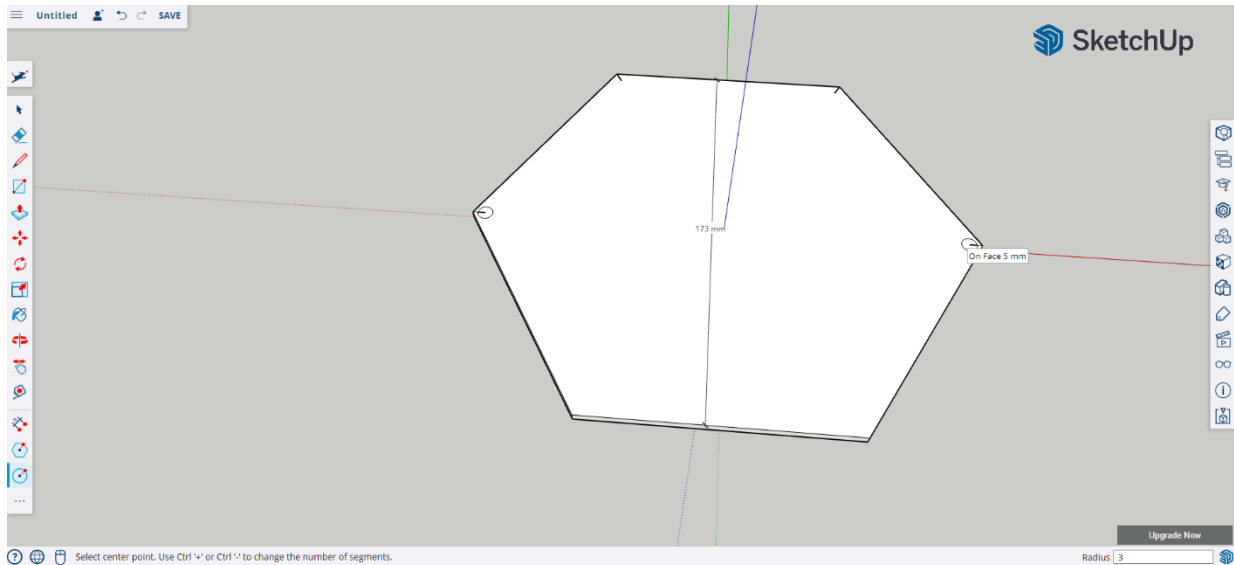
1. Use the line tool to mark the distance of the circle. We will delete the line after we make the circles. Set the distance to 5mm.



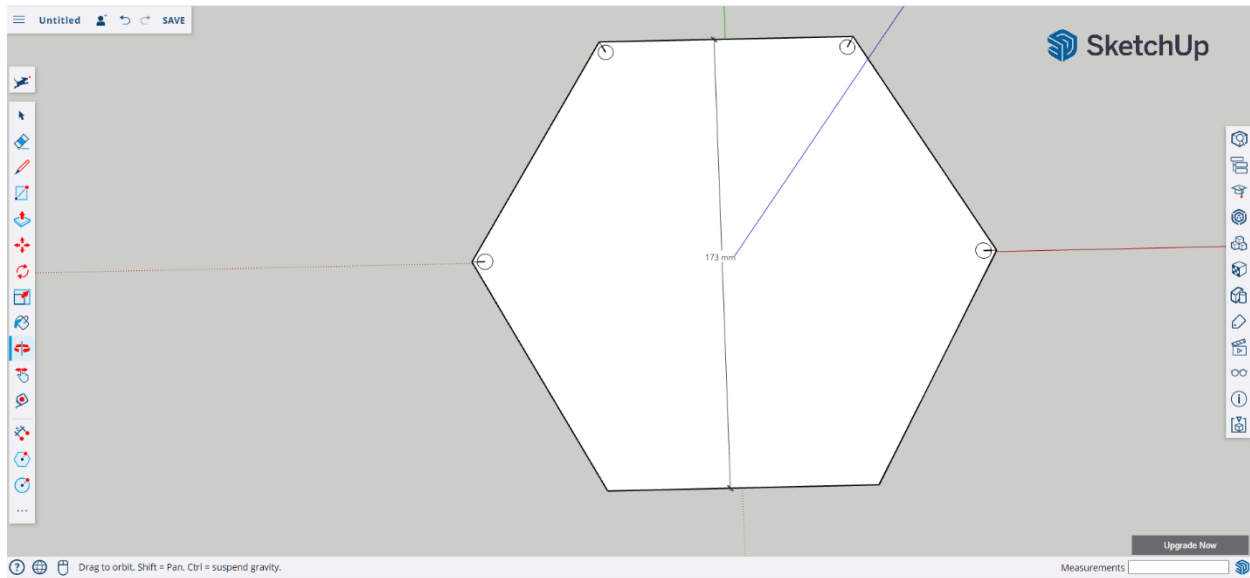
2. Repeat the process to mark the other 3 angles.



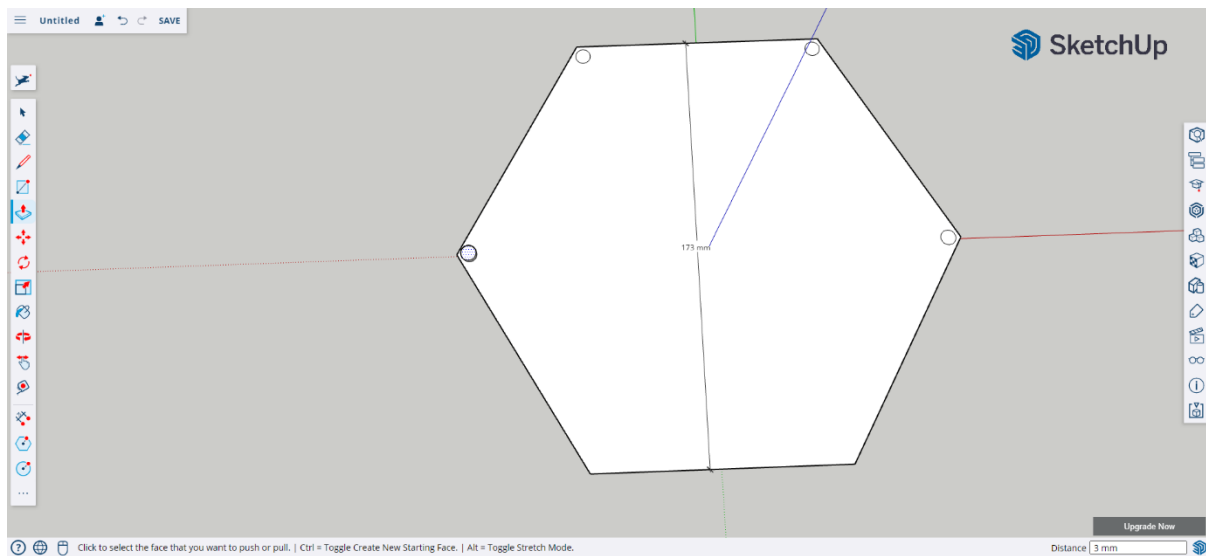
Step 4: Use the circle tool by placing it at the end of each markup that we created. Set the circle's radius to 3mm.

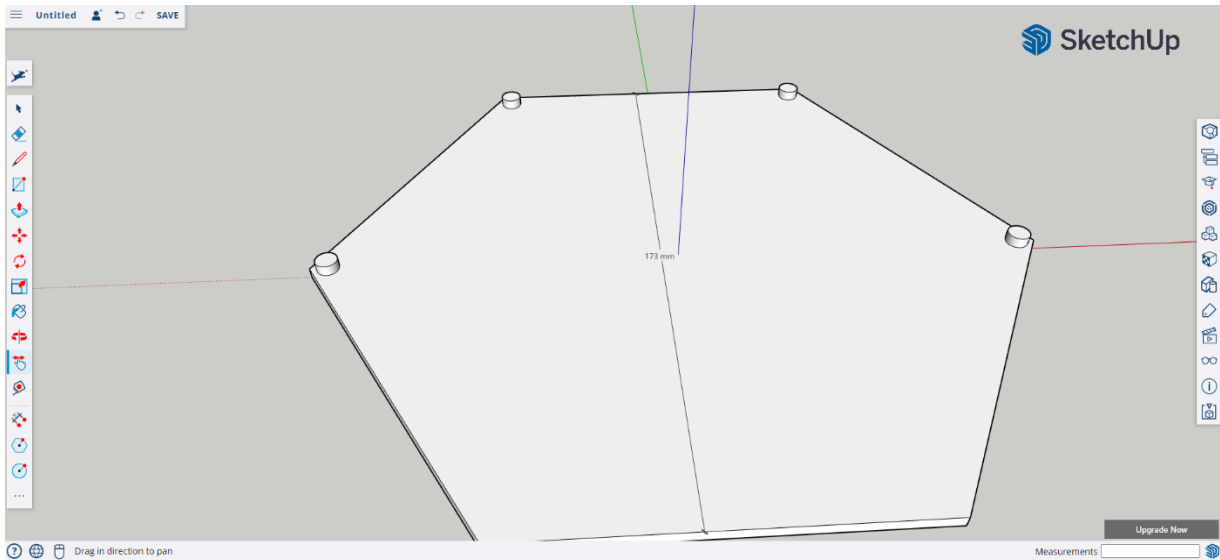


Step 5: Select the markup lines and delete them.

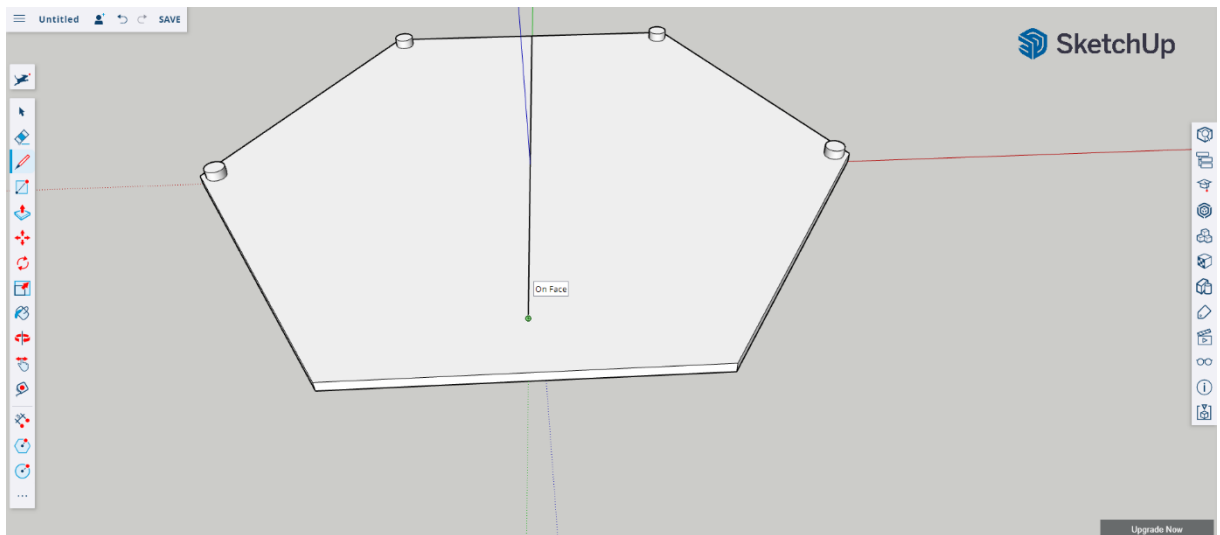


Step 6: Use the push/pull tool to raise the circles to 3mm.

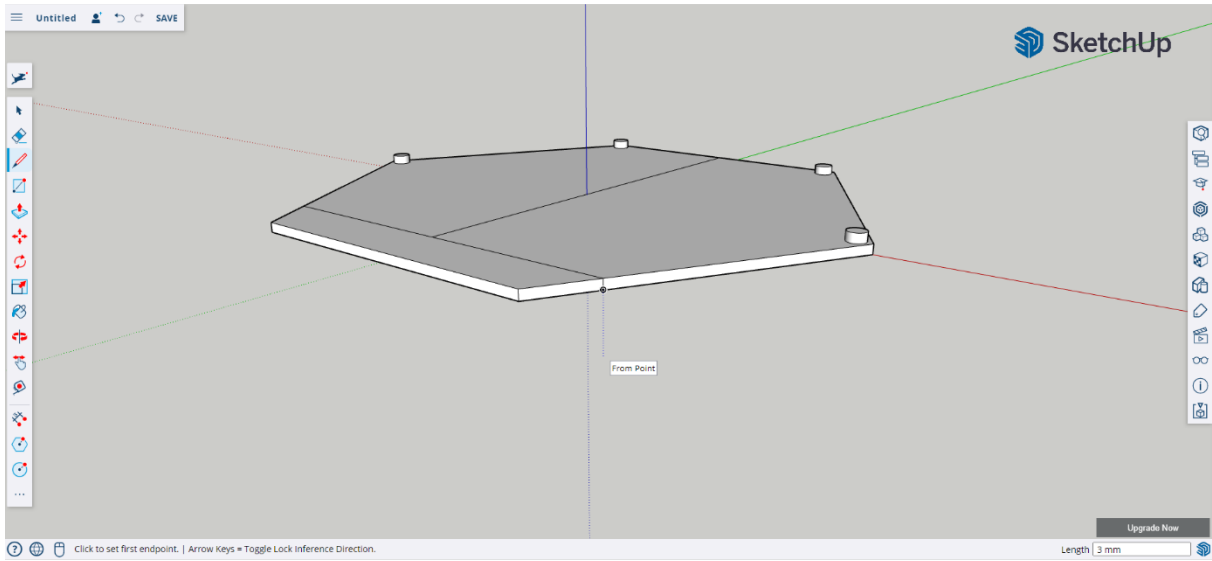




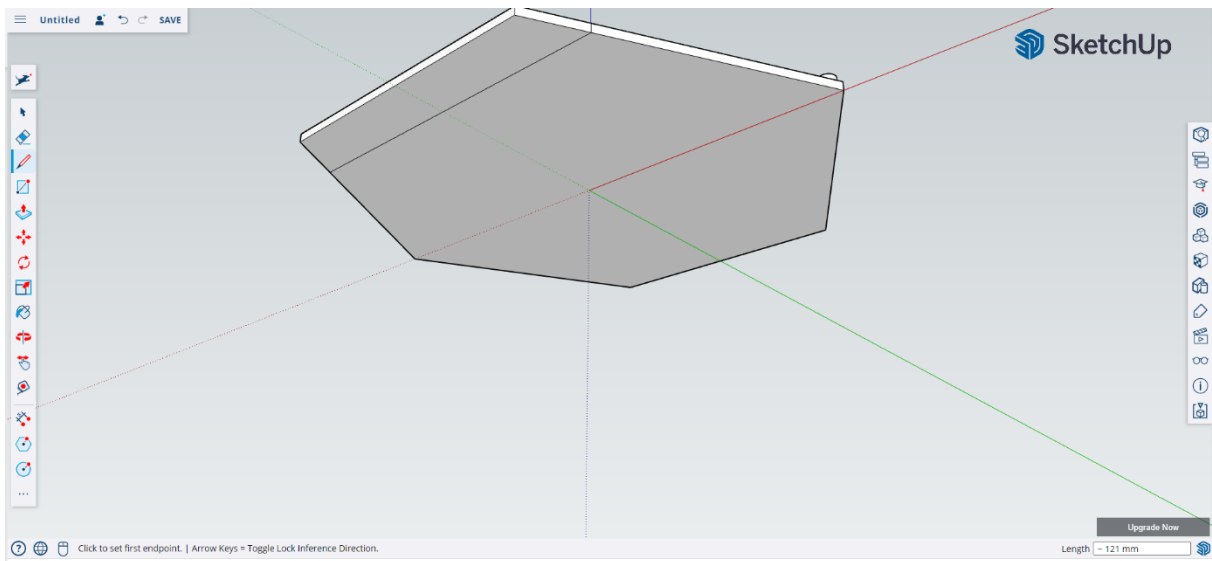
Step 7: Once you raise all circles, use the line tool to find the midpoint of the hexagon's top side and make a line with distance 160mm.



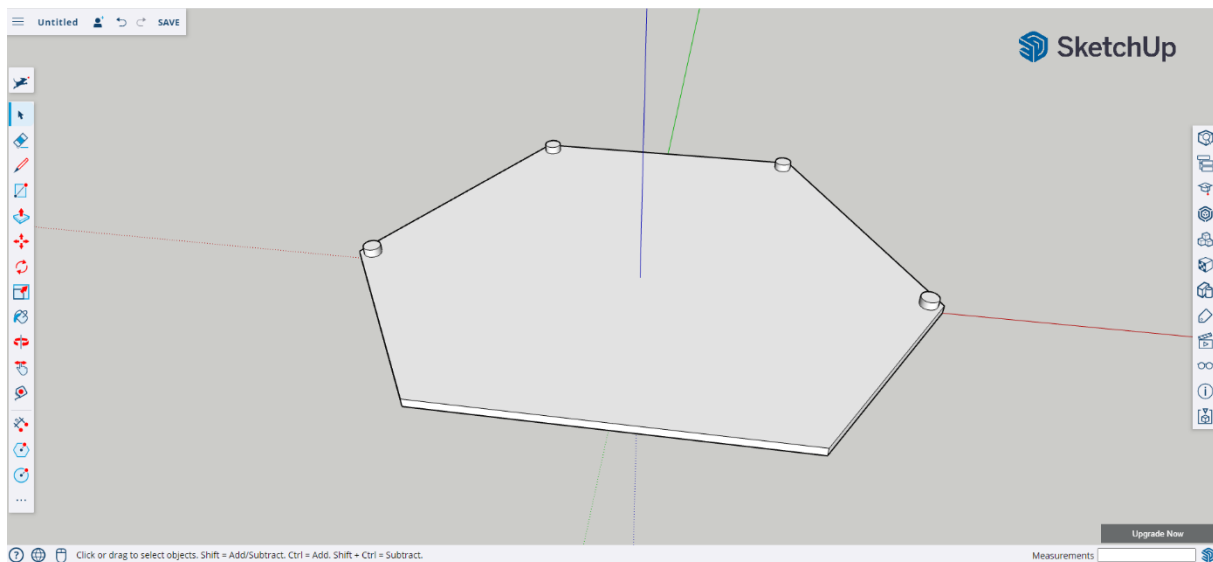
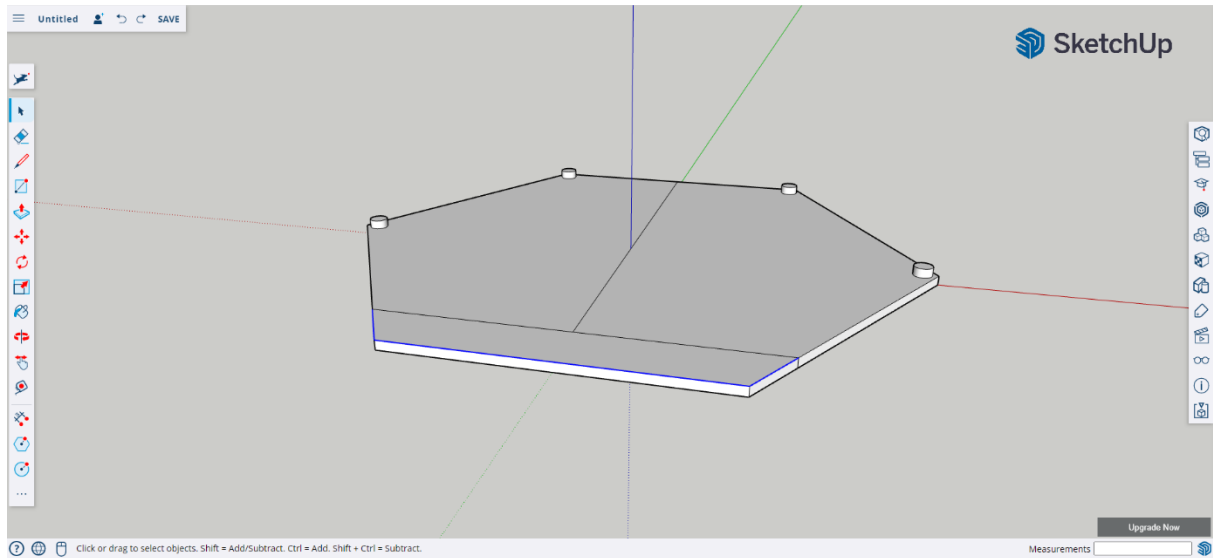
Step 8: Once you mark it, make a line that goes across the polygon from all sides.



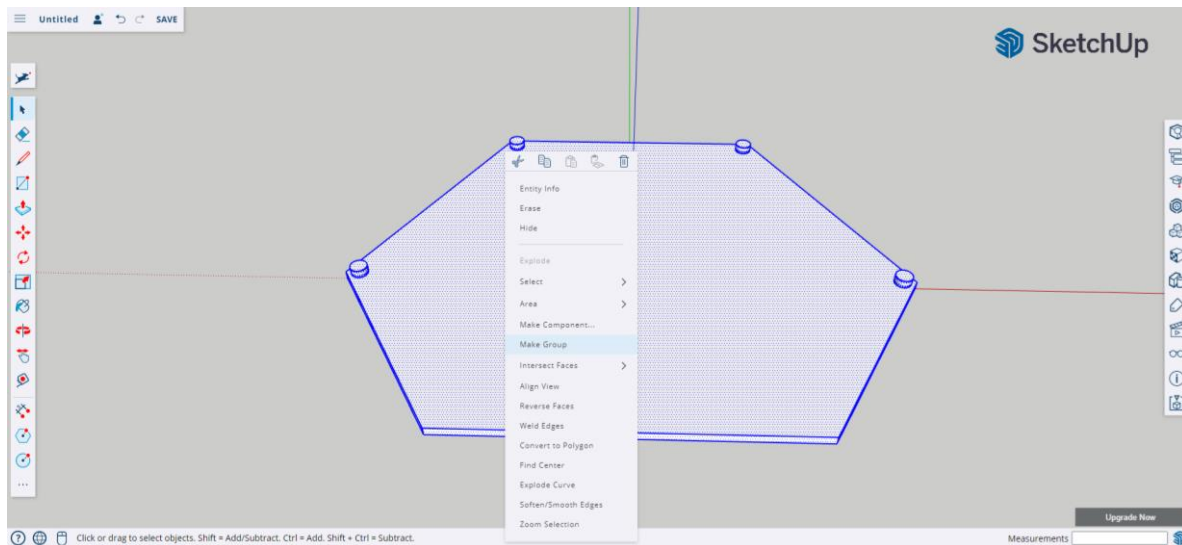
*** Don't forget the back side of the polygon**



Step 10: Select and delete each markup line that you have created.



Step 11: Click the object 3 times to select the whole thing and click-right and select make group option.



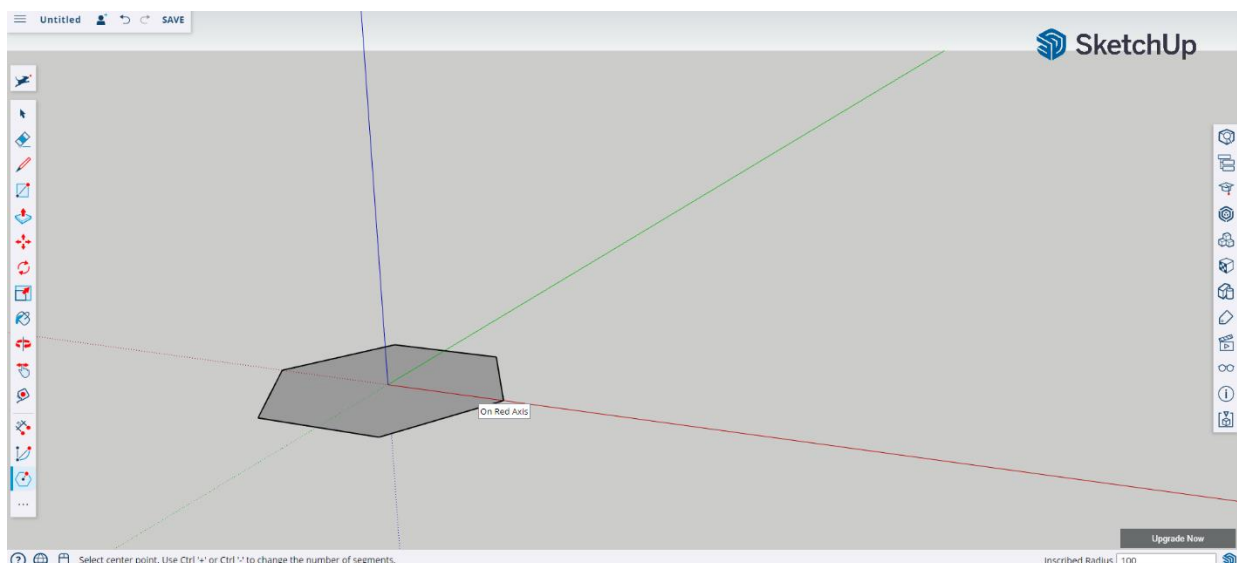
*** Don't forget to save the file on your device or on Trimble connect.**

The top part of the coin box is ready. We had to make it shorter in length to fit the size of the coins to be shown when shaking the box.

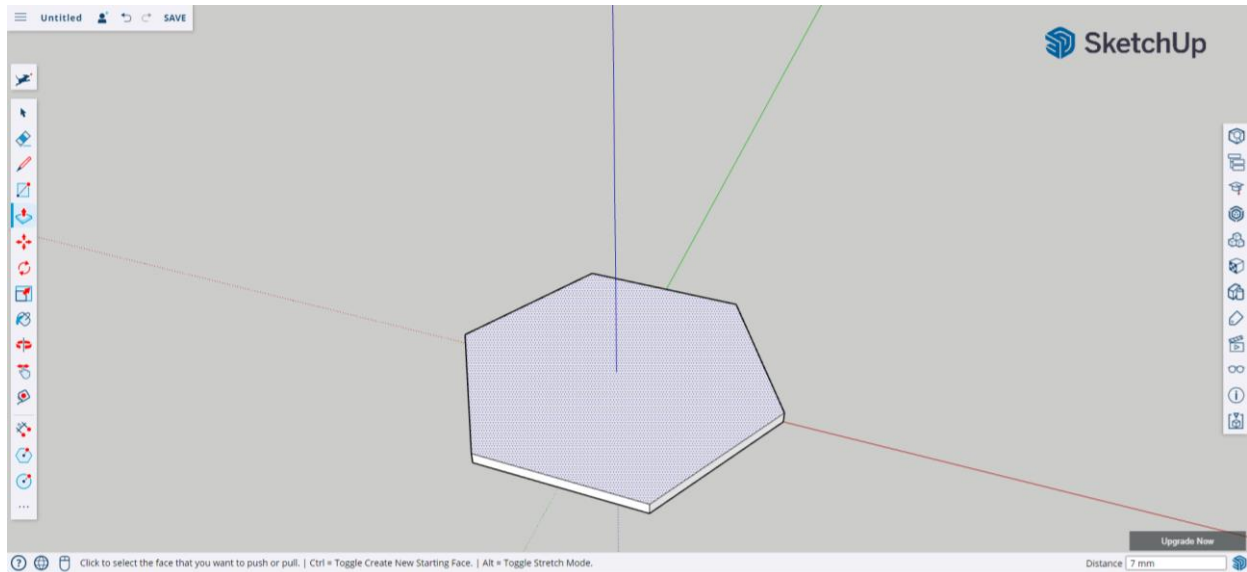
Now we are going to open a new file to create the bottom.

Bottom part of box

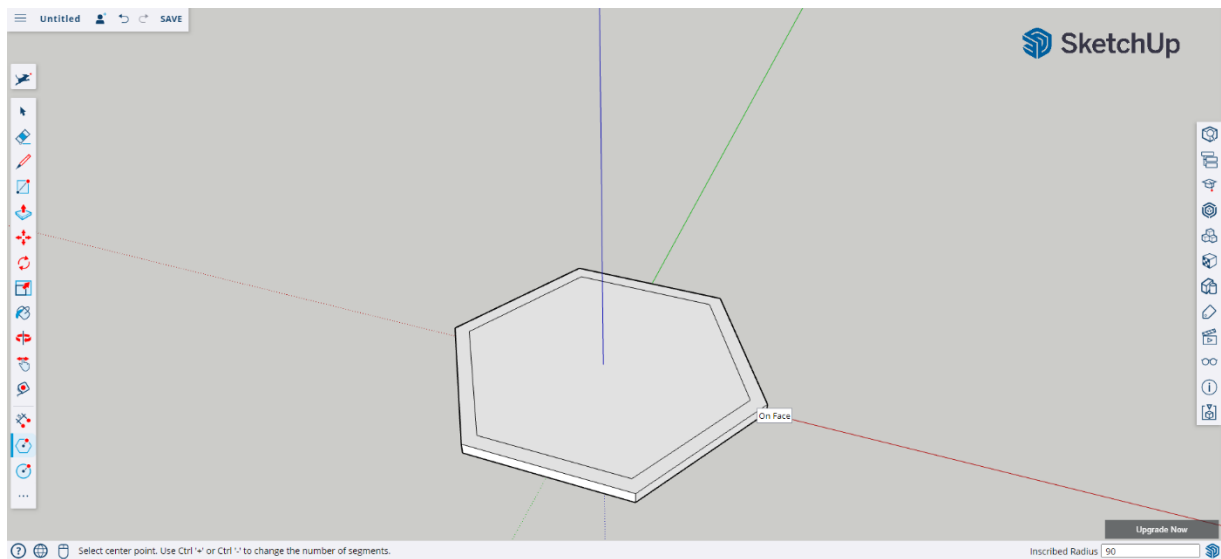
Step 1: Similar to the top part, use the polygon tool to draw a hexagon with an inscribed radius of 100mm. Use the axes to help you center the hexagon.



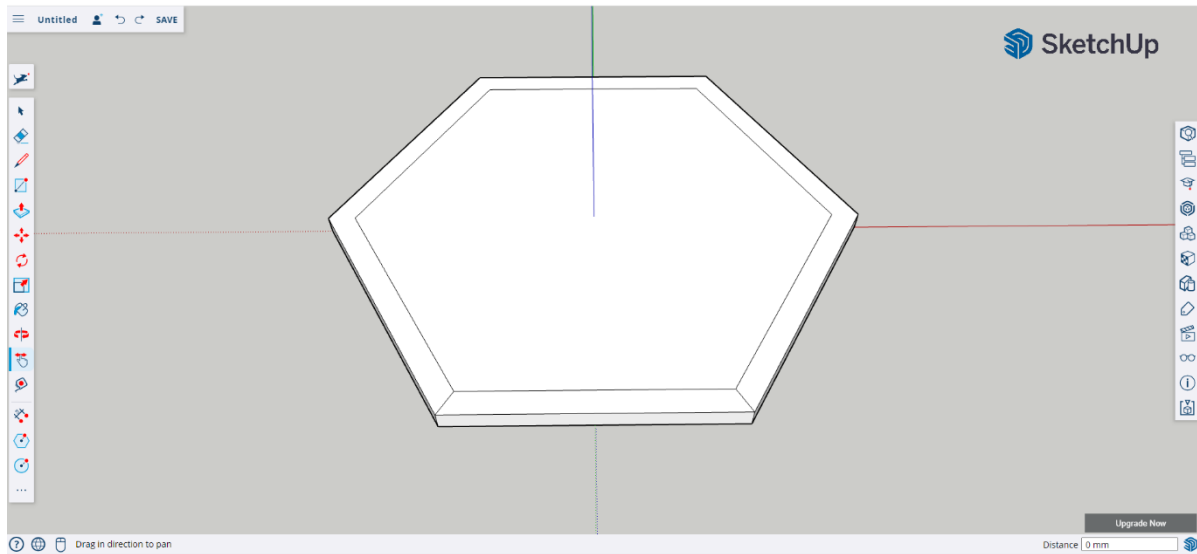
Step 2: Use the push/pull tool to raise the polygon to 7mm.



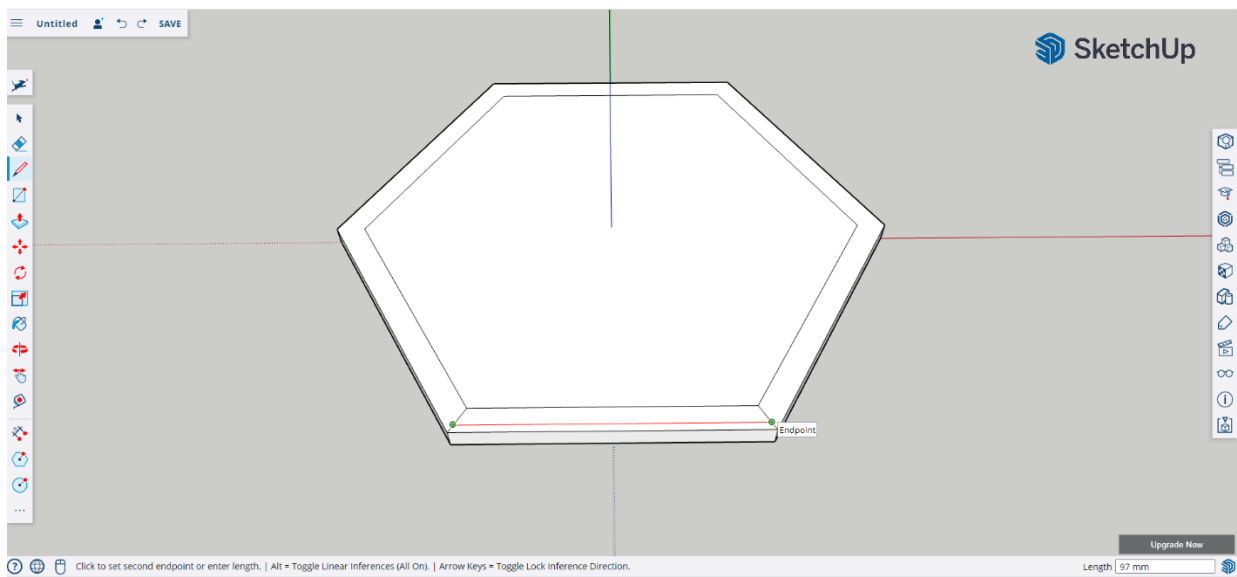
Step 3: Use the polygon tool to create another polygon within the existing one. Set its radius to 90mm. Use the center to help you align it.



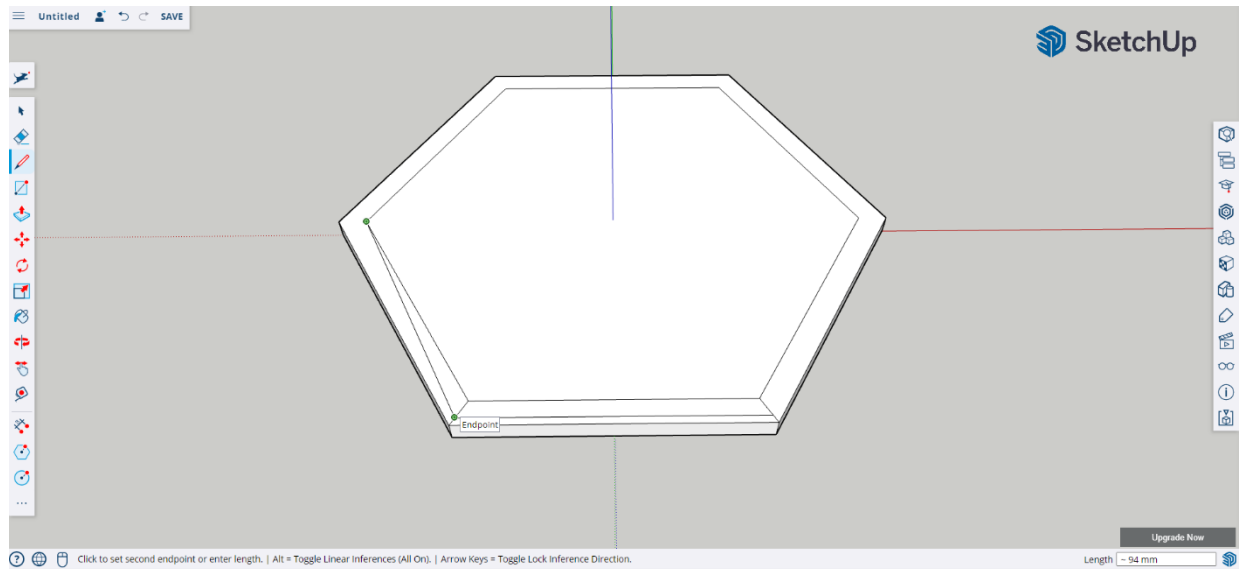
Step 4: Use the line tool to create the shape of the bottom part of the polygon.



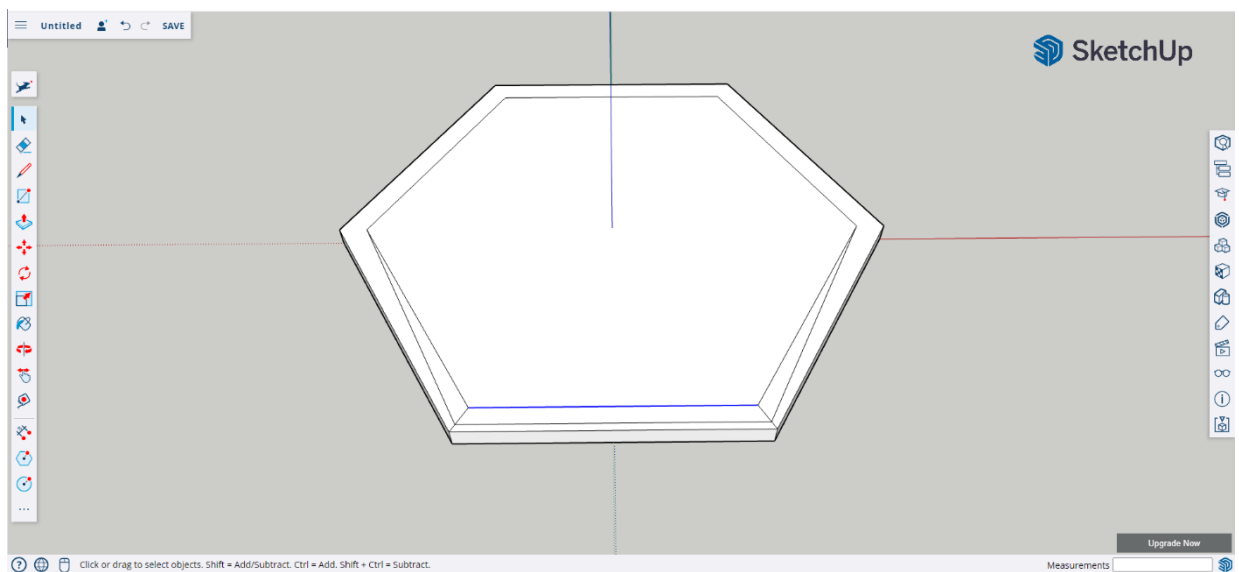
Step 5: Measure 3mm with the line tool on the side of each to draw a straight line.

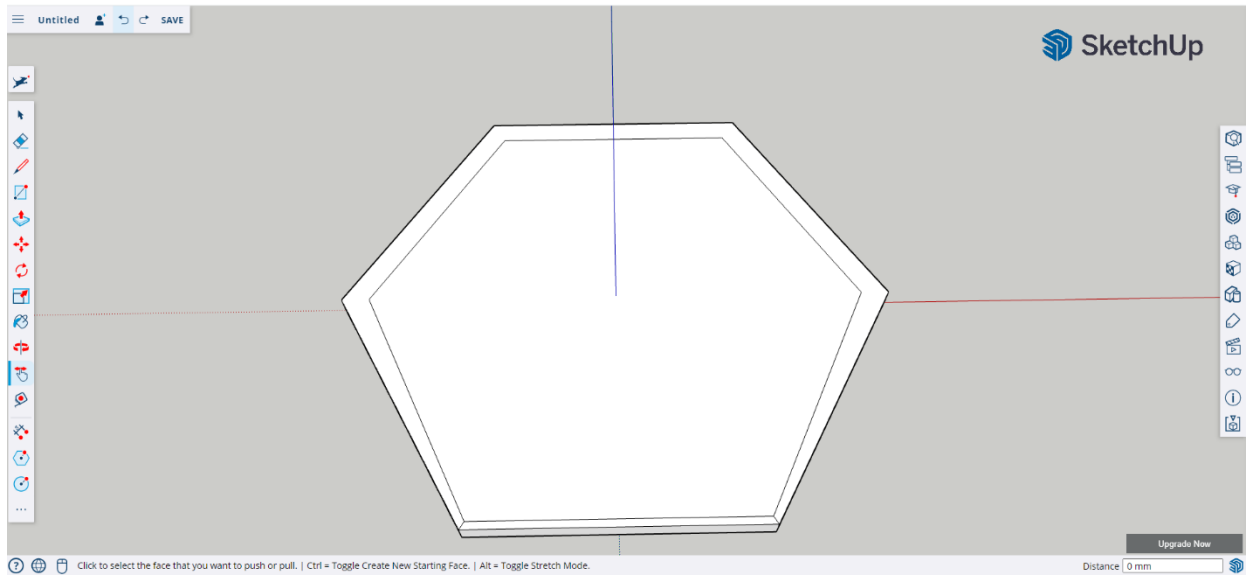


Step 6: Make diagonal lines on the sides as indicated in the screenshot below.

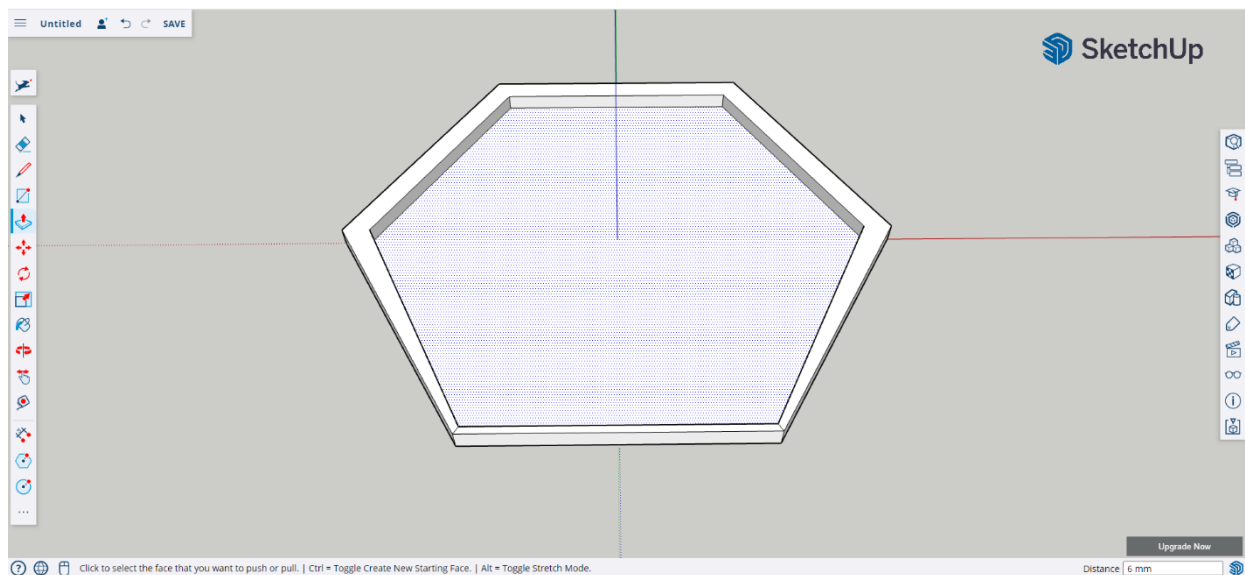


Step 7: Select and delete the extra lines to make a slide on the sides of the polygon.

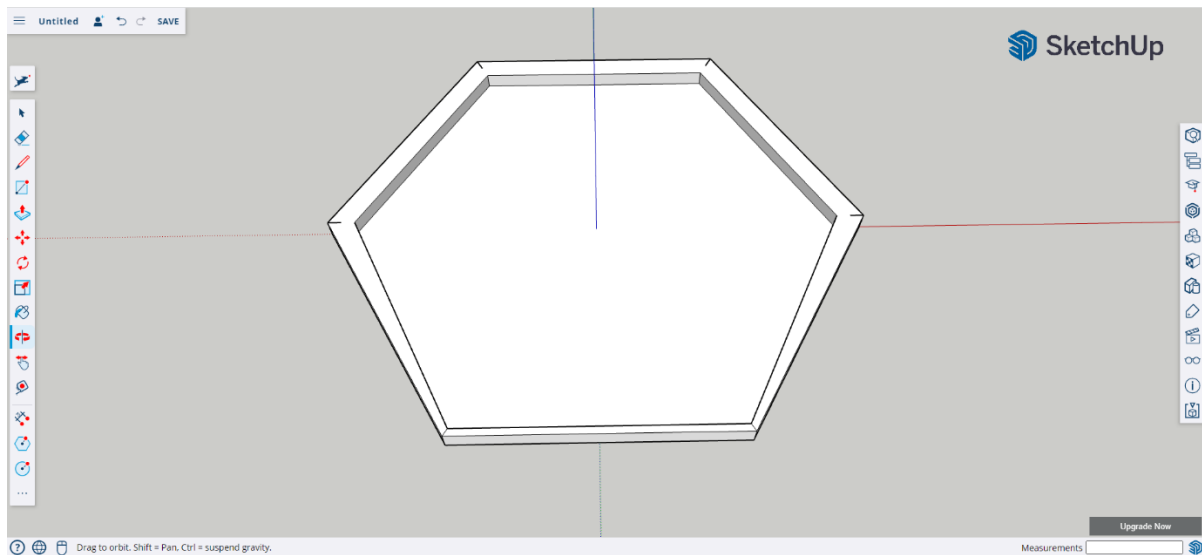
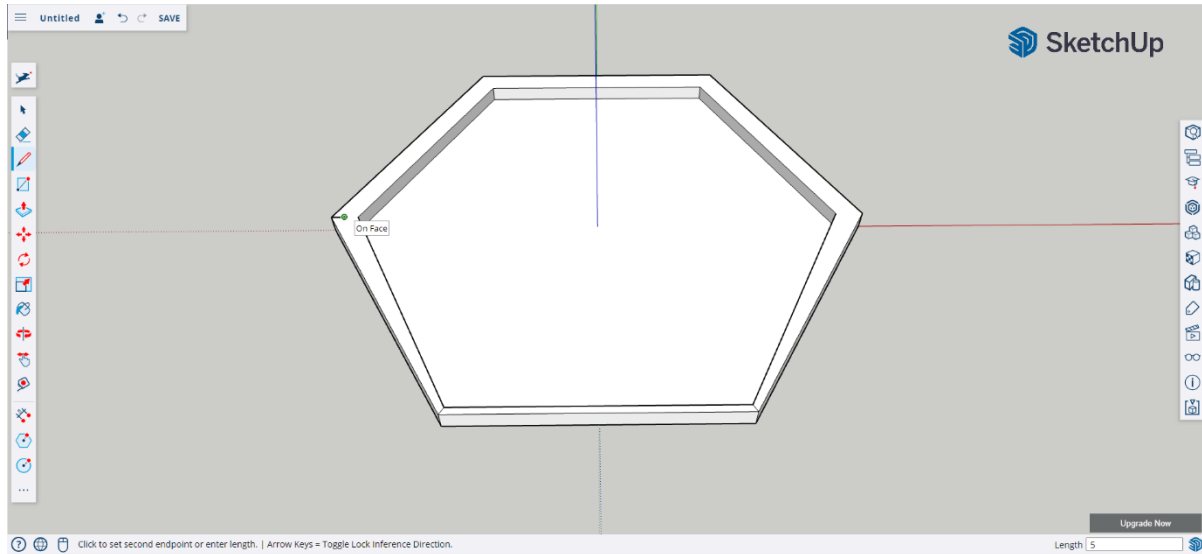




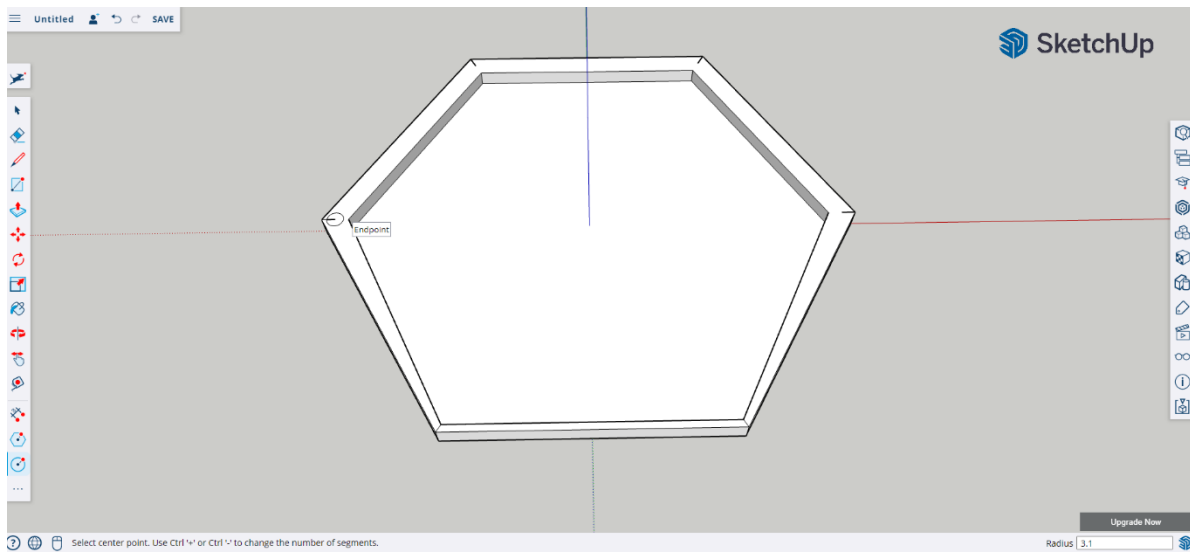
Step 8: Use the push/pull tool to lower the inside part of the polygon to 6mm.



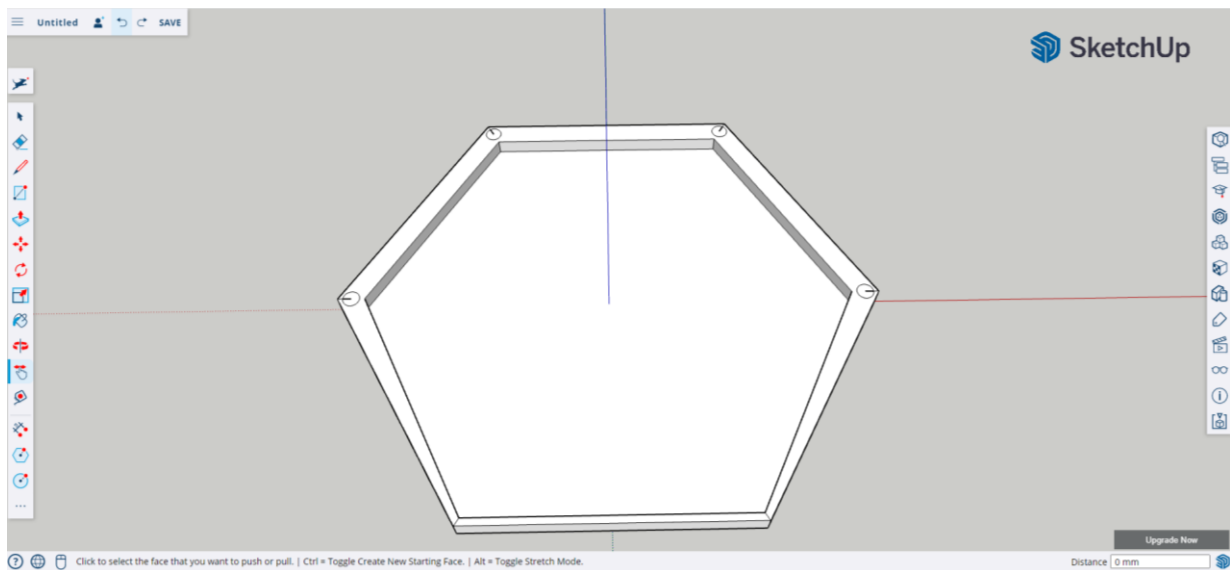
Step 9: Use the line tool to create markup lines for the assembly parts with length 5mm.



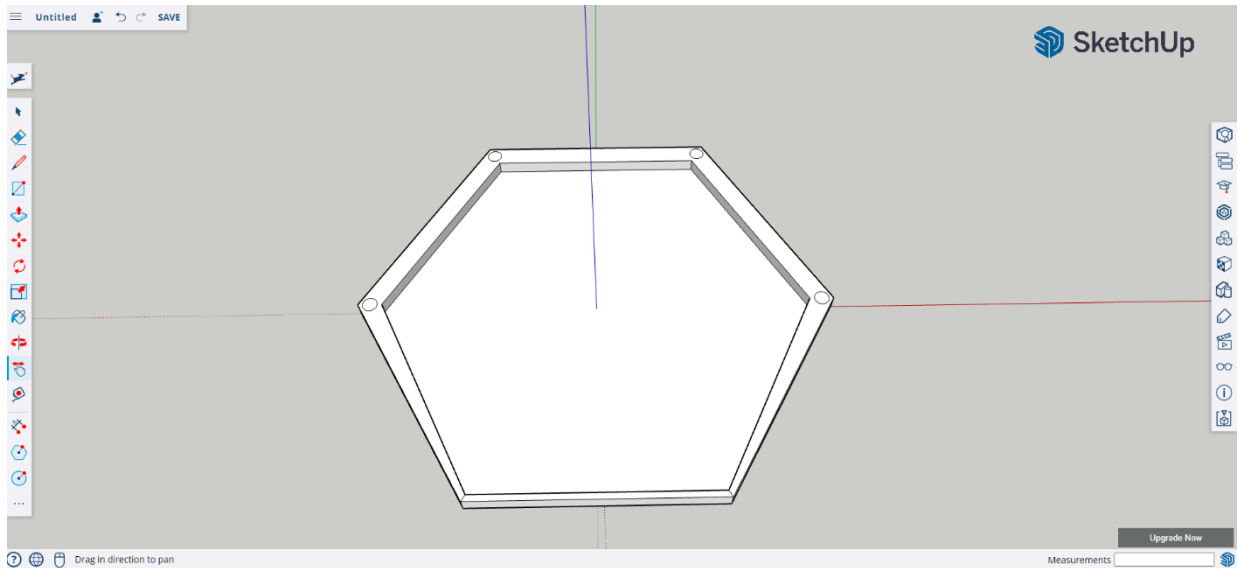
Step 10: Use the circle tool to create the assembly circles that match the top part of the box. Set the radius to 3.1mm.



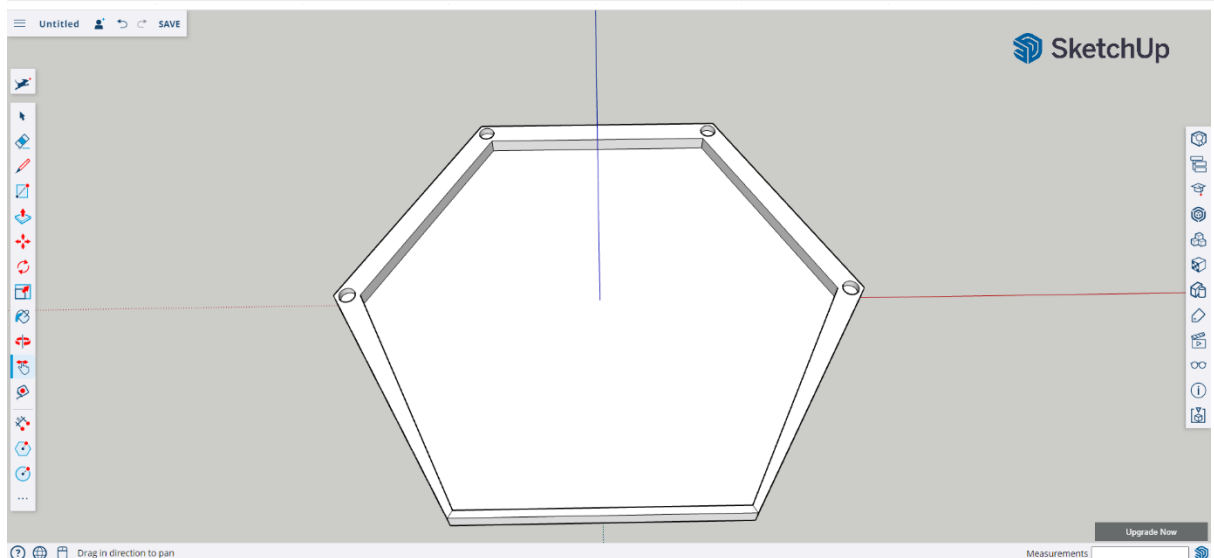
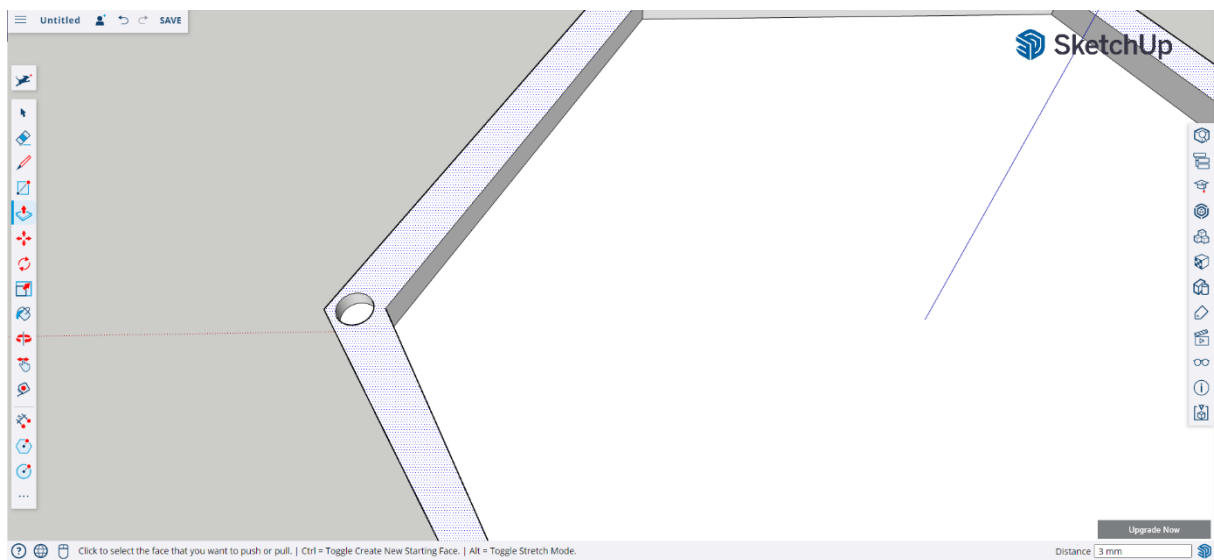
* The assembly parts need to have 0.2 to 0.4 mm difference to be able to fit into one another.



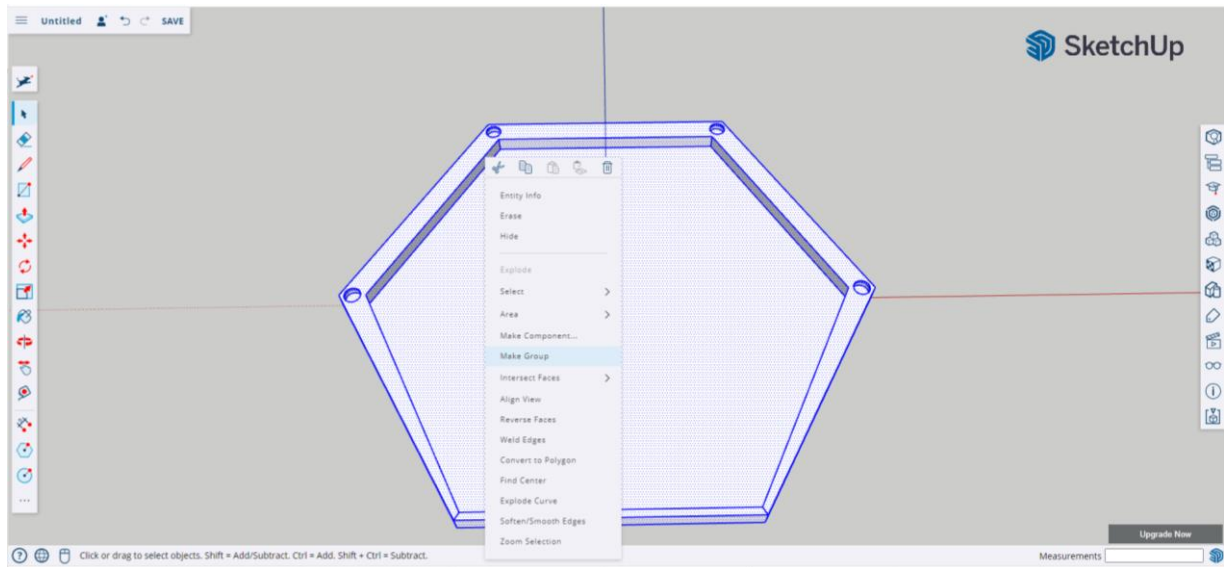
Step 7: Select and delete the markup lines inside and around the circles.



Step 8: Use the push/pull tool to push the circles down by 3mm.



Step 10: Select the whole model by clicking 3 times continuously and make it into a group.

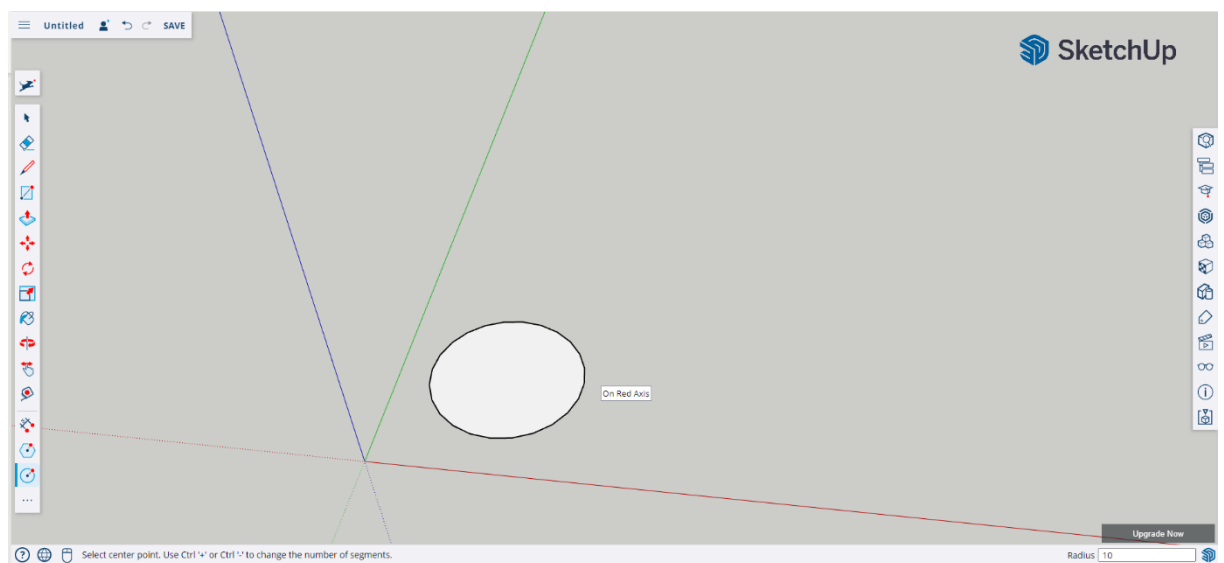


Now, you can save the file on your device or on Trimble connect. Both the top and bottom parts of the coin box are now ready. Let's open a new file to create the coins.

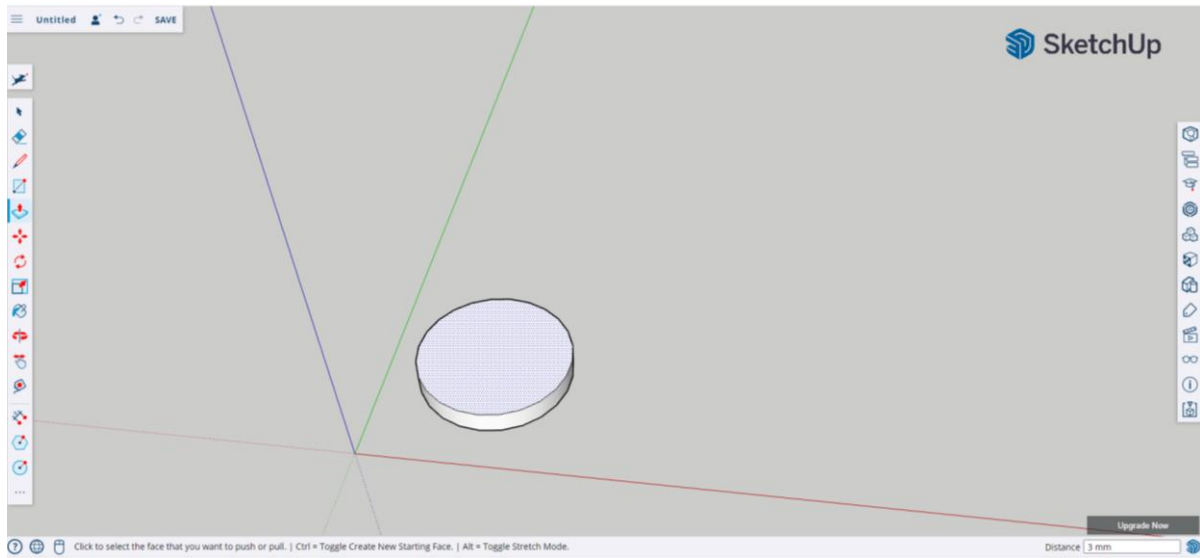
Coins

We need to make two different coins depicting 1 euro and 2 euros in a simpler form.

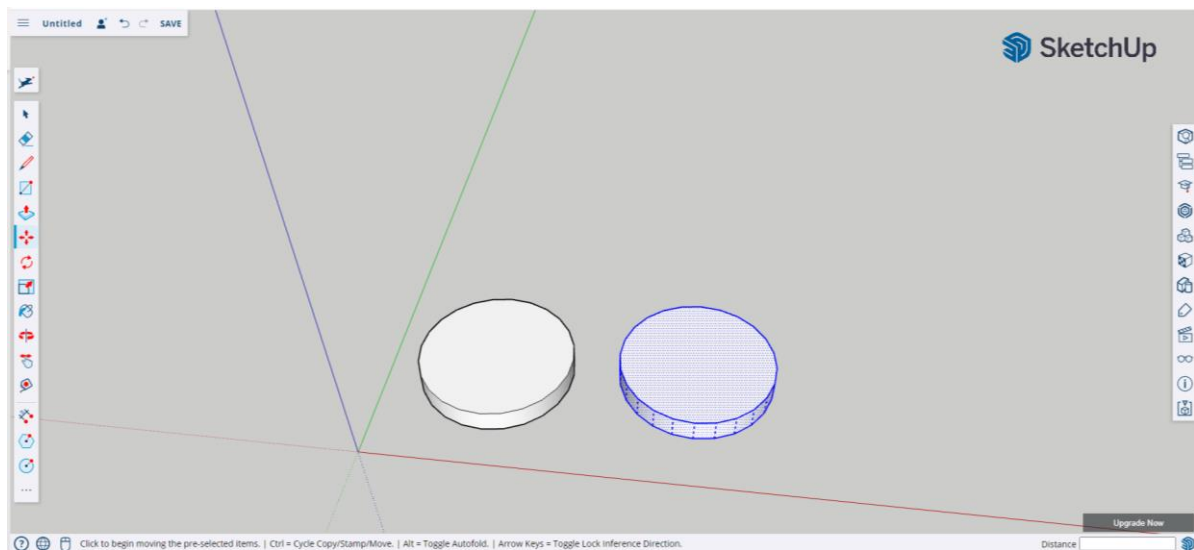
Step 1: Once you open a new file, use the circle tool to create the coin with a radius of 10mm.



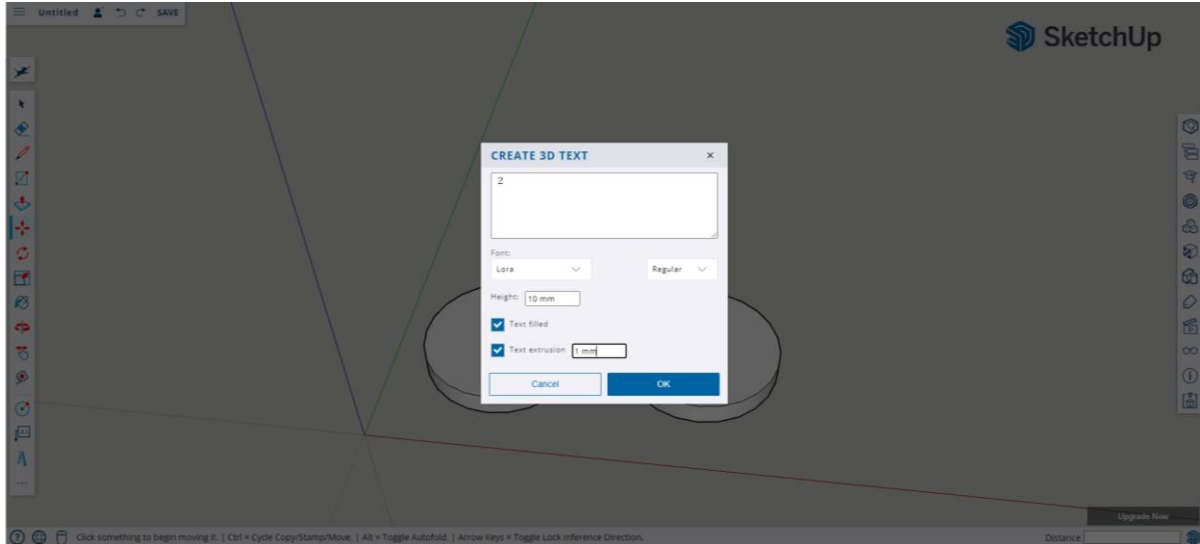
Step 2: Use the push/pull tool and set the distance to 3mm.



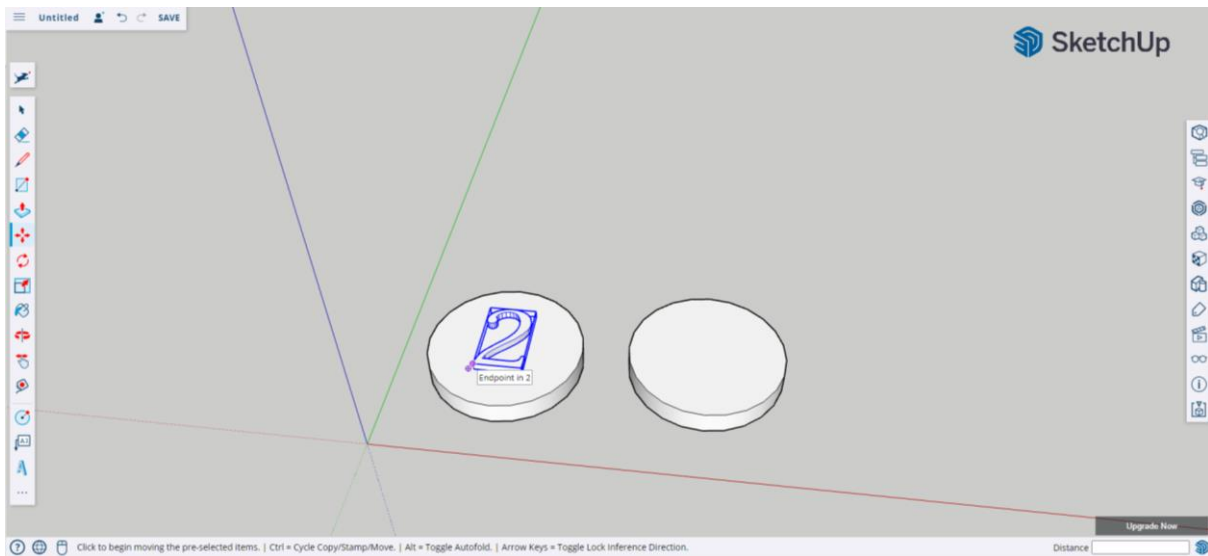
Step 3: Select the existing coin (by clicking 3 times on it), copy (Ctrl+C) and paste (Ctrl+V) it and add the new one next to it.



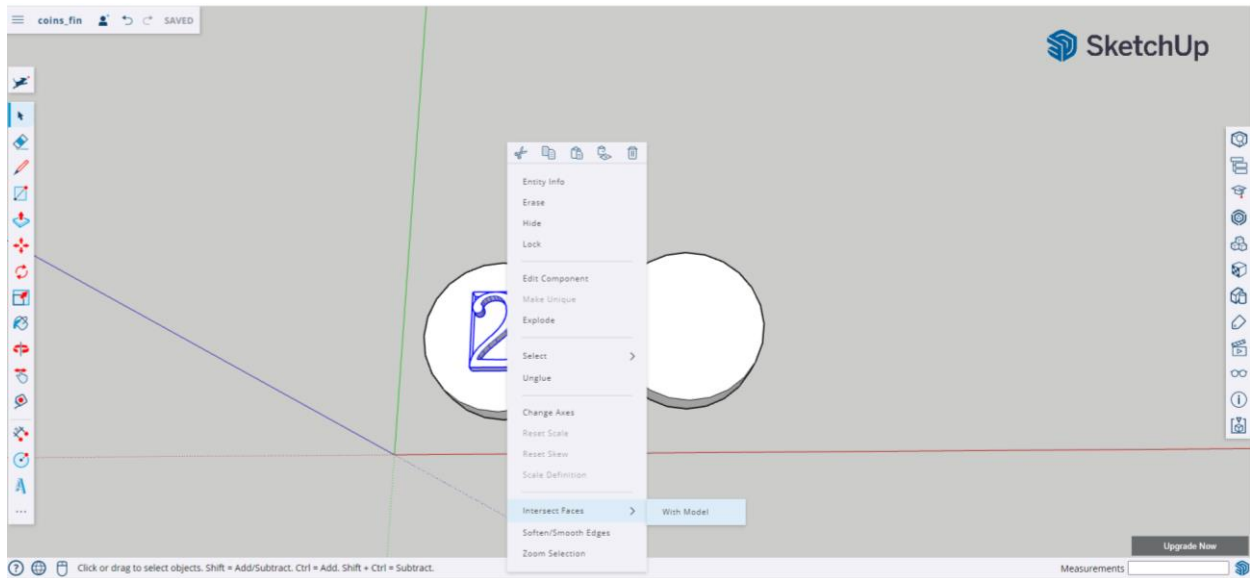
Step 4: Select the 3D Text tool and write the number 2 to be added as text. Use of font of your choice and set the font style to regular. Set the height to 10mm, set the text extrusion to 1mm and select ok.



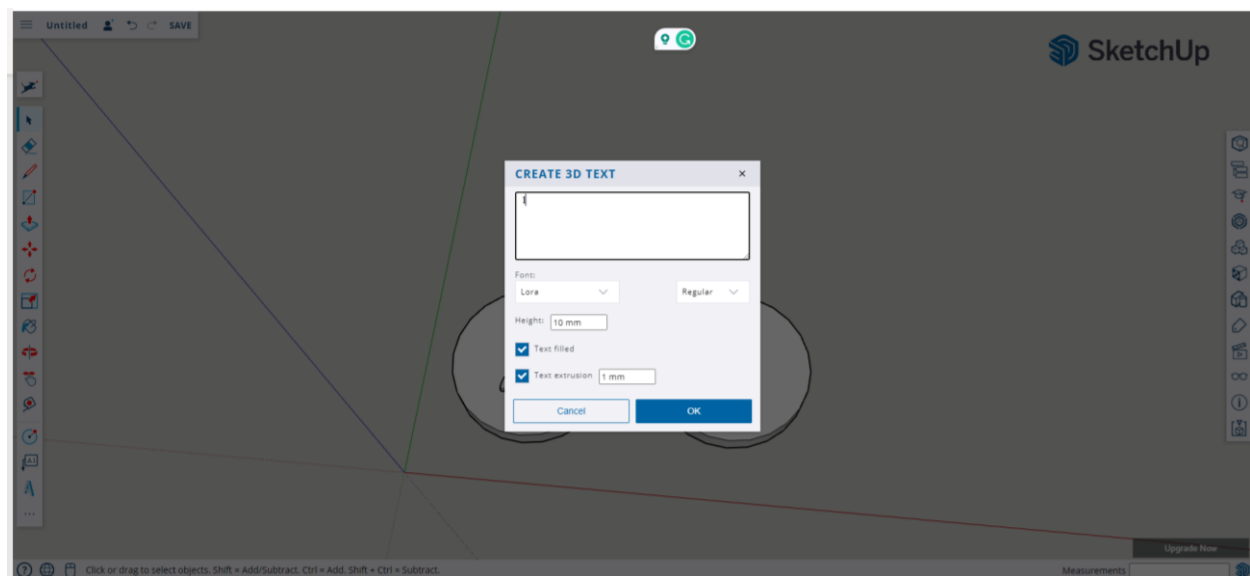
Now, you can place it on the coin.

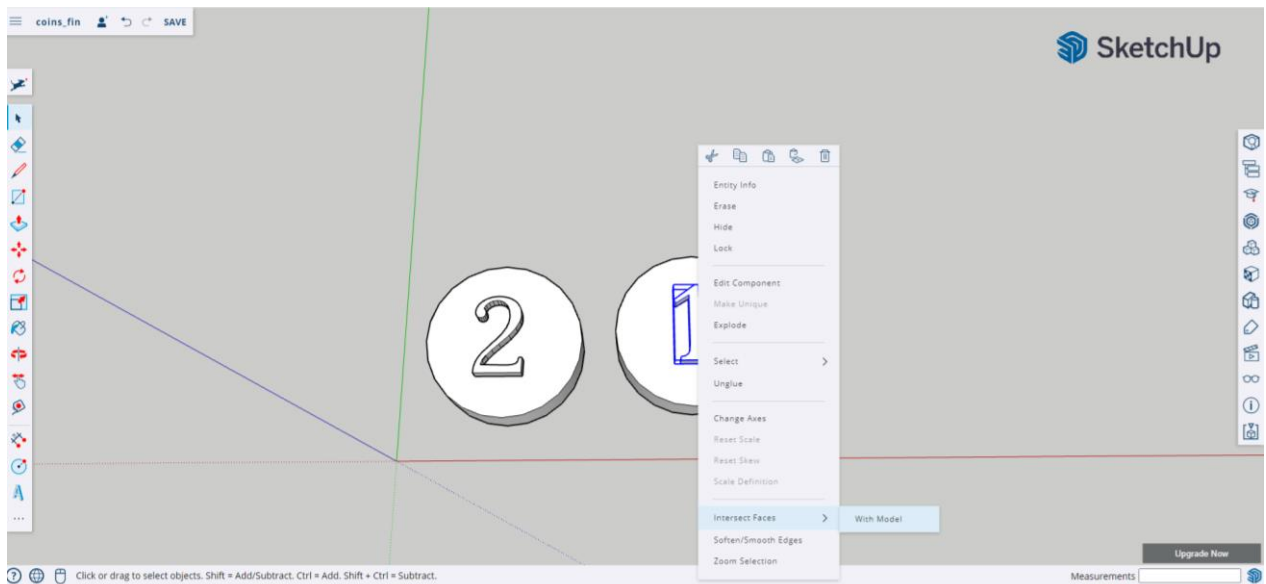
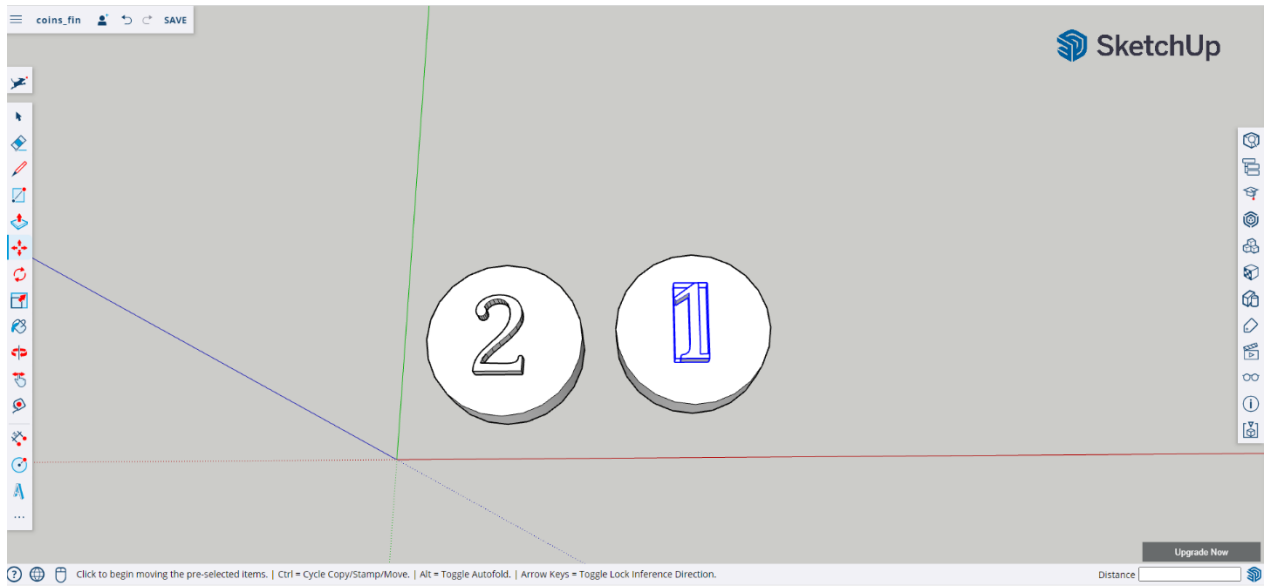


Step 5: Select the number, right-click and select Intersect face with model.



Step 6: Repeat the process for the other coin.



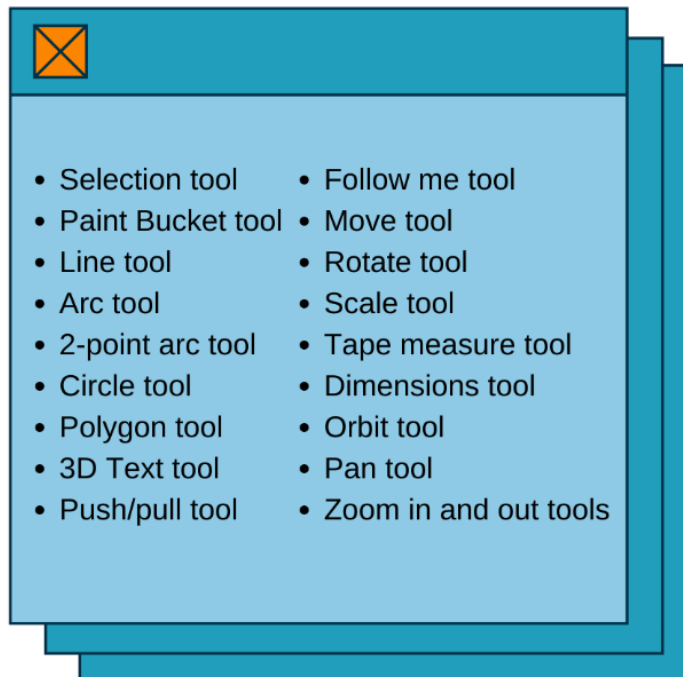


That's it, you are done.

*** Remember to save your file and you can download it in .STL format.**

Summary

So far, we have experimented with SketchUp by creating a cup and three mathematical exhibits from the Numeric[All] project. These exhibits and two more will be available on the DIY Creation Kit with detailed steps on how to be constructed using 3D modelling and printing. Through these projects, we were able to practice the following tools in SketchUp:



4. Slicing software: Cura

So far, we have learnt how to create 3D models from scratch in SketchUp. In this chapter, we will see how you can prepare the 3D model you have created to be 3D printed. In order to go from 3D modelling to 3D printing, you need to use 3D printing slicer software.

4.1. What is a 3D slicing software?

In simple words, a 3D slicing software takes the 3D model and translates it into a language that the 3D printer can understand and print. As shown in Figure 22, it takes the visual image of the model, slices it into thin layers for the printer to understand how to print each layer, and then it's ready to be printed.



Figure 23. The process of 3D printing

A slicing software is essentially the middleman between 3D modelling and 3D printing. The slicing software prepares the model for the 3D printer to know how to print the item by allowing you to adjust its settings in order to print the model according to your needs and printer. The 3D slicing software translates the STL format file (3D model) into G-code so the printer can understand what to do.

This where Cura enters the picture. Cura was developed by Ultimaker and is one of the most popular software used to make 3D printing easy and efficient. The printing settings are optimised for Ultimaker 3D printers, but it can also slice 3D models for any other 3D printer. Cura is a free and open-source desktop software that can be

downloaded from the [Ultimaker website](#) and is available for Windows, Mac and Linux users.

Once downloaded, you simply follow the instructions to install the software, and you are ready to start using it.

4.2. How to use Cura

Cura recognises a variety of file formats from 3D file formats (.STL, .OBJ, .3MF, .X3D) to 2D imported images (.BMP, .GIF, .JPG and .PNG) that can be converted to 3D models.

Now, let's see how we can use Cura. Figure 23 indicates the main functions of Cura's interface.

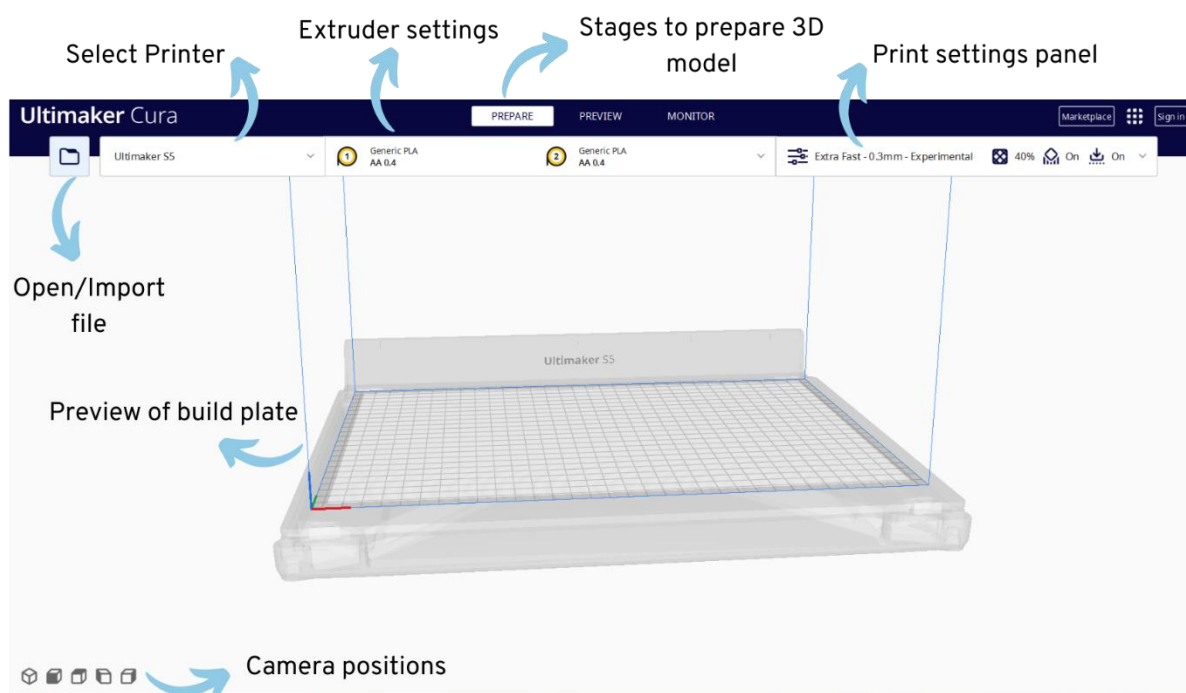


Figure 24. Ultimaker Cura Interface

Let's start by importing an .STL format file of the 2x2x2 cube that we have created in the previous chapter.

Step 1: Go to the folder icon and click it to import the .STL file.

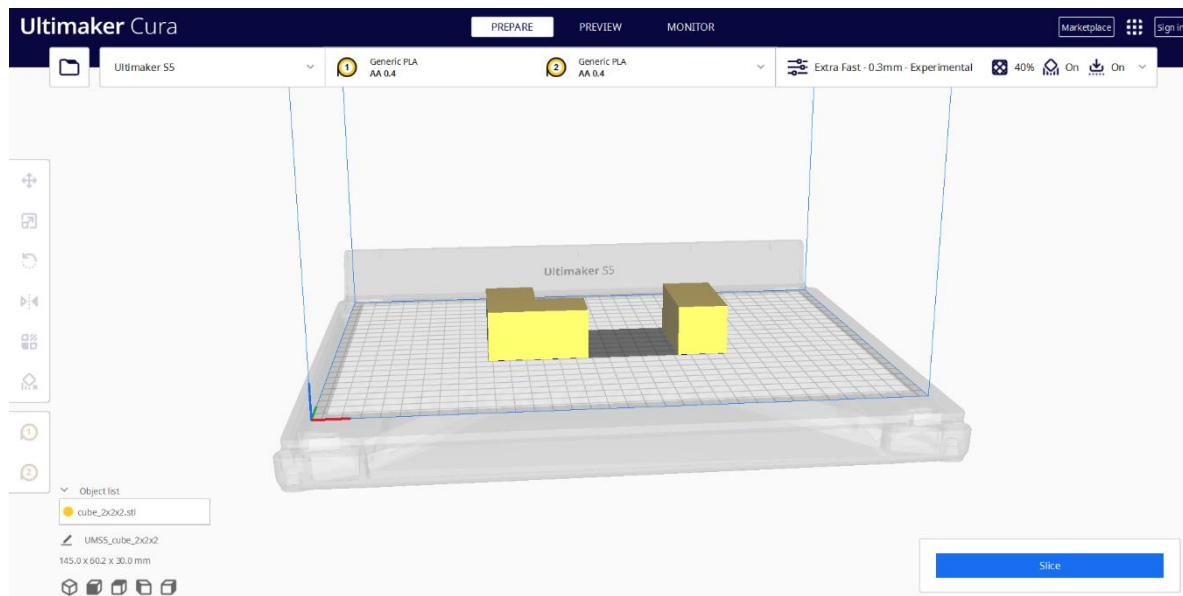


Figure 25. Importing file into Cura

Step 2: Once you import your 3D model, you will see a set of tools appear. These allow you to make changes to how your 3D model is going to be printed. If you do not wish to make any changes, you can skip this step.

Move tool: You can change your model's position on the build plate by either moving it with your mouse or by entering precise coordinates on the x, y, z axis.

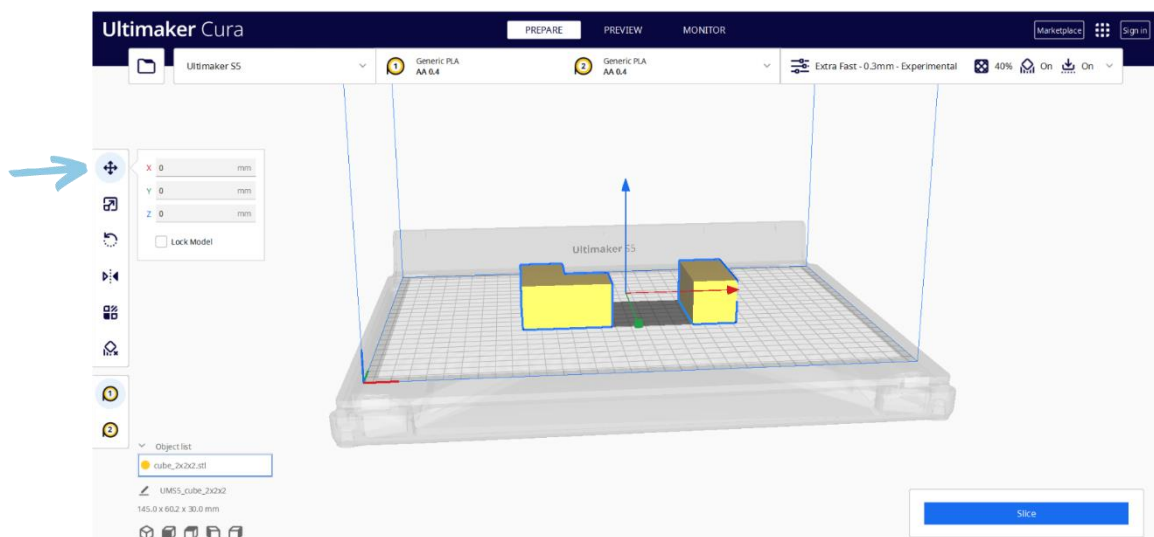


Figure 26. Move tool in Cura (Shortcut key: T)

Scale tool: You can decrease or increase your model's size by 1) dragging the axis appearing on the build plate, 2) entering specific percentages on each axis or by 2)

adjusting the numbers.

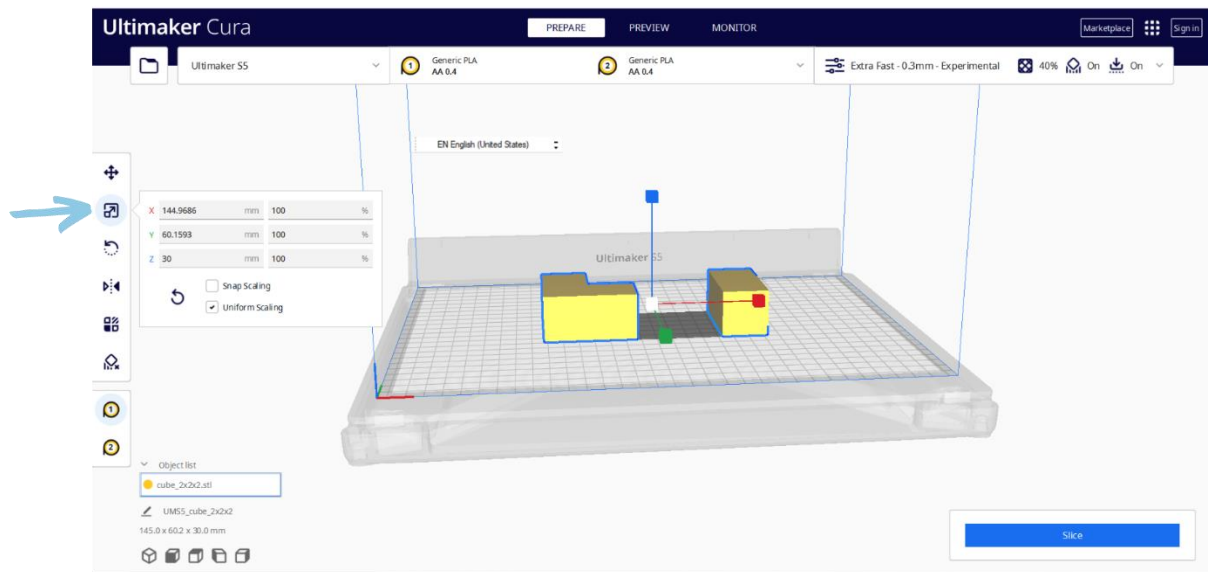


Figure 27. Scale tool in Cura (Shortcut key: S)

Rotate tool: You can change your model's orientation by using the arrows on the build plate or by selecting one of the ready tools available. The first button resets the model to its original orientation. The second button lays flat your model on the build plate. The final button allows you to select the side that you want your model's face to align on the build plate.

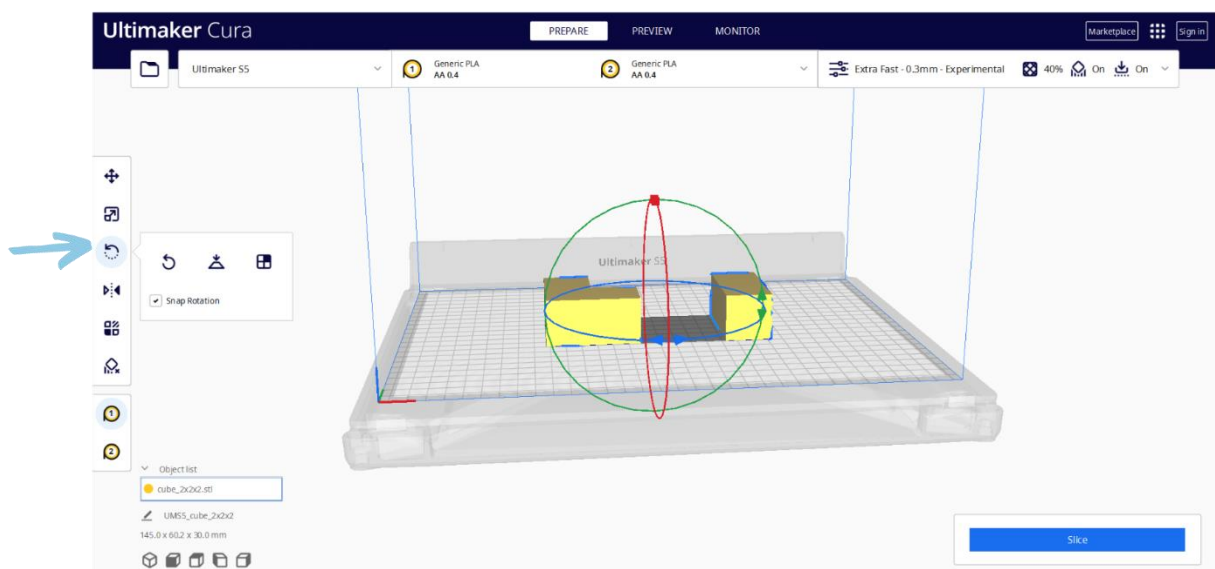


Figure 28. Rotate tool in Cura (Shortcut key: R)

Mirror tool: You can use the mirror tool to rotate your model on 180 degrees in any direction shown on the arrows of the build plate.

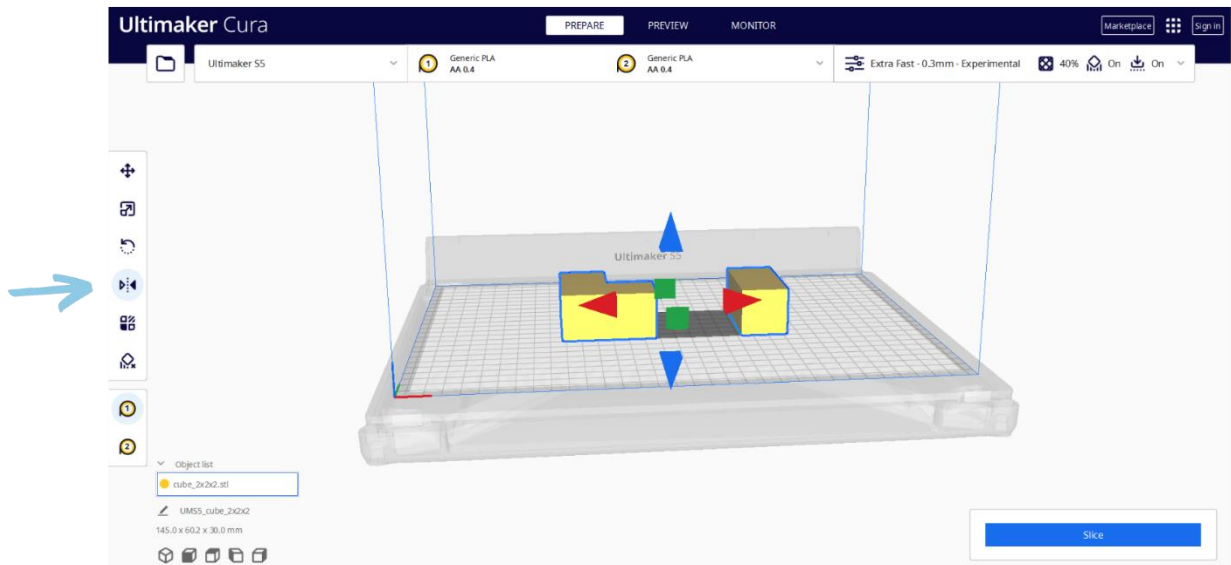


Figure 29. Mirror tool in Cura (Shortcut key: M)

Step 3: After making changes to the model, you can adjust the printer and printing settings from the nozzle size to the support to correspond to your needs.

Printer settings: The 3D printer settings refer to choosing your networked or non-networked printer so that Cura can adjust the printer settings such as the nozzle size.

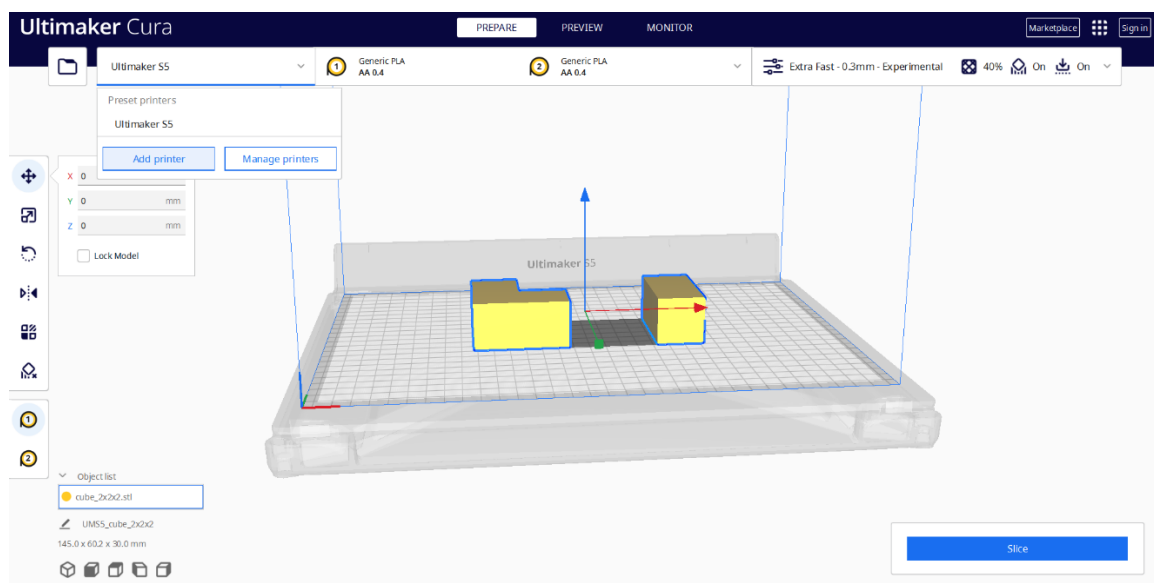


Figure 30. Selecting 3D printer in Cura

If your printer is a non-networked printer, there is a long list of printers available for you to find your 3D printer model.

Once you select your 3D printer, the nozzle size and the type of printing material are usually adjusted to correspond your printer settings. However, you can also customize these settings by clicking the tab shown in Figure 28.

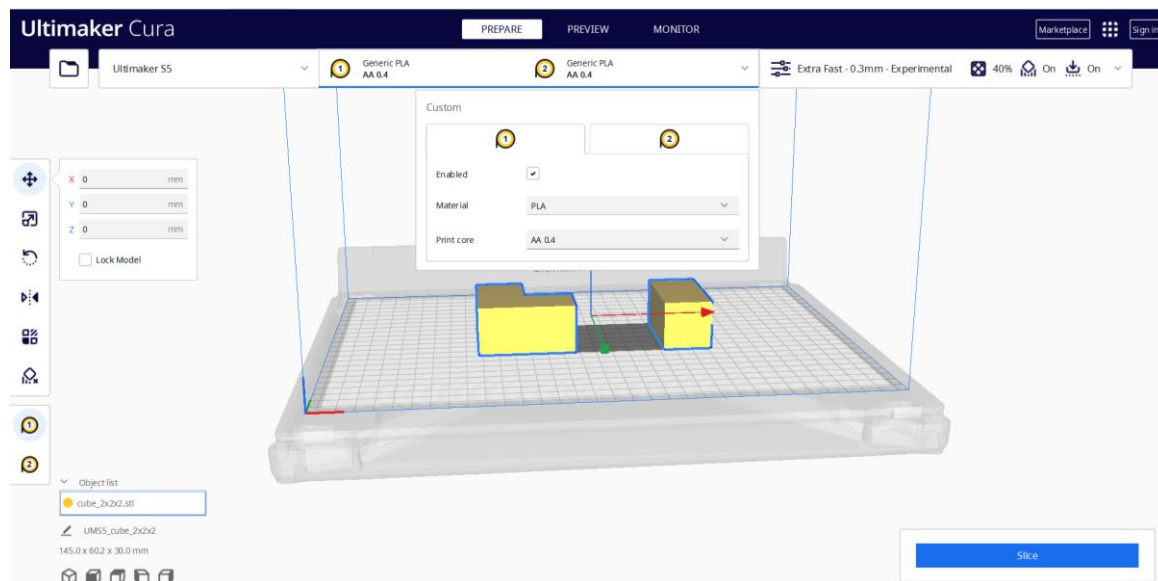


Figure 31. 3D Printer Settings in Cura

Depending on your printer, you can also enable or disable the number of nozzles available.

Print settings: These settings essentially refer to how you want to print your model such as its resolution, print speed and supporting material.

There are two modes available: Recommended and Custom. The recommended options available are set based on recommended profiles depending on the common needs. However, you can also customise your print settings, which includes a greater variety of options. For more information on [customised settings](#).

In Figure 29 below, you can see the recommended options available:

- Resolution (Layer Height): determines the quality of your 3D item and is largely based on the nozzle size. The smaller the distance between layers, the

longer the printing period, but with higher quality. There is an associated trade-off between quality and print speed.

- Infill: refers to the density of your 3D print from hollow to completely solid. 10-40% is considered as a light infill and is usually recommended. For more information on infill settings, [click here](#).
 - Gradual infill option increases the density as the printing progresses to the top of the model. It is usually good practice to leave the box unticked since having a good base of an item is important, although it depends on what you are printing.
 - Infill pattern is found in the customised options and allow you to change the pattern of the infill structure to make the 3D object sturdier. The zig-zag option is preferred for more complex shapes.
- Support: is used to produce supportive material to protect your model from sagging if it has overhand parts.
- Adhesion: works to increase the surface area of the first layer of your 3D print in order to avoid material shrinkage. You need to consider the type of material used to print your 3D model. PLA filament doesn't usually need adhesion.

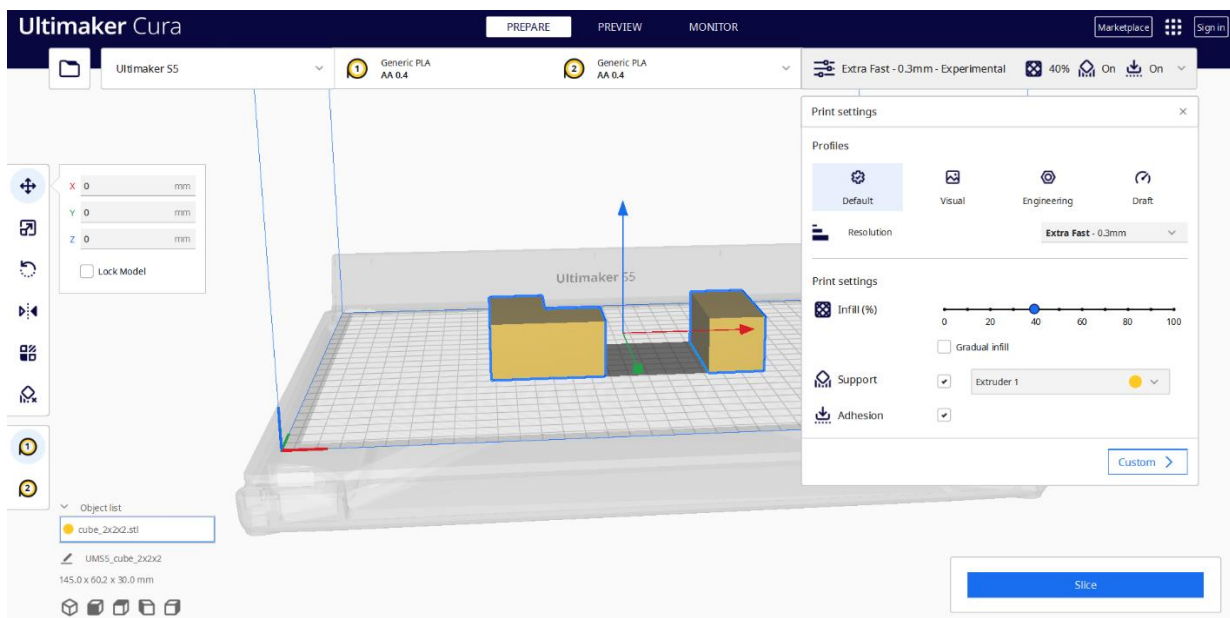


Figure 32. Print settings in Cura

Step 4: Once you have made all the changes that you would like, you can click the Slice button to slice your model.



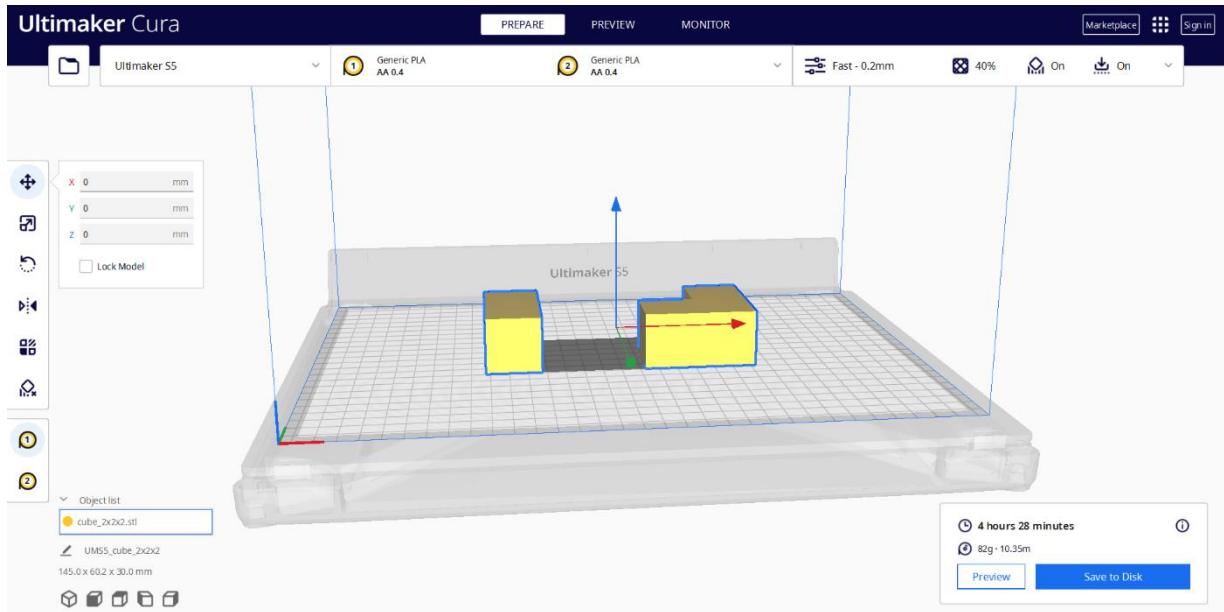


Figure 33. 3D Printing Estimation

In Figure 30, you can see the estimated amount of time that it will take to print the pieces for the 2x2x2 cube according to the setting we have set.

Step 5: Before saving your model, it is a good idea to preview the printing process to spot any issues. Preview demonstrates the printing process in two views: Layer and X-ray.

Layer view displays with different colours the elements of the 3D item such as material, line type, speed, layer thickness, etc. This is especially useful to spot any potential issues and see how the item is going to be printed.

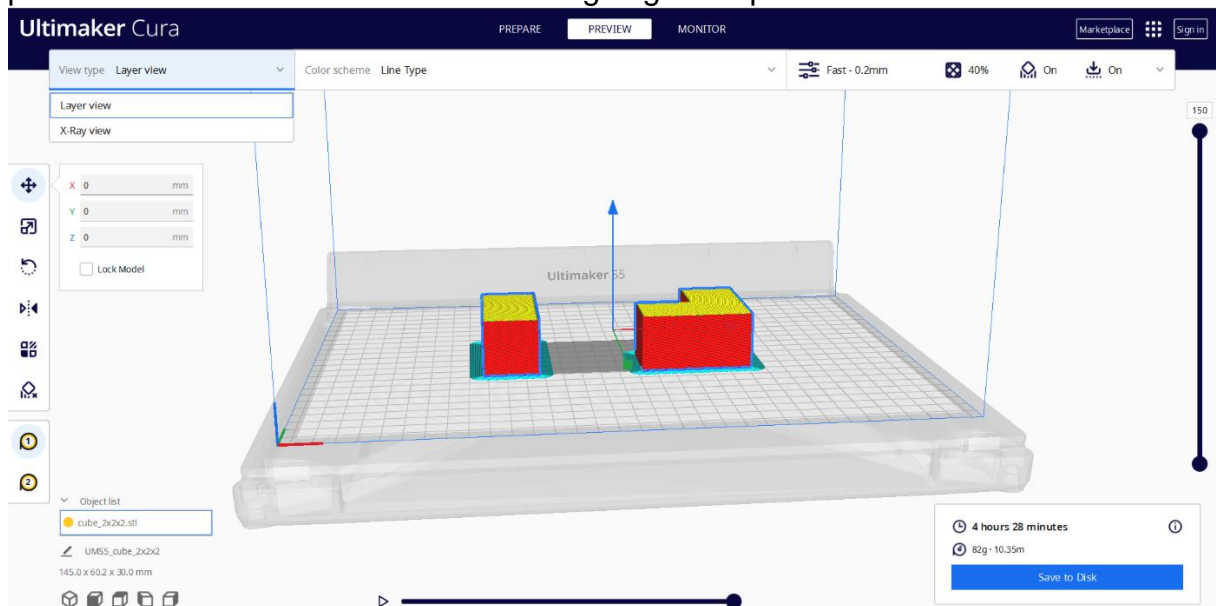


Figure 34. Layer view in Cura (Preview)

X-ray view displays the internal structure of your 3D model in order to spot any issues with intersecting edges and make changes before printing.

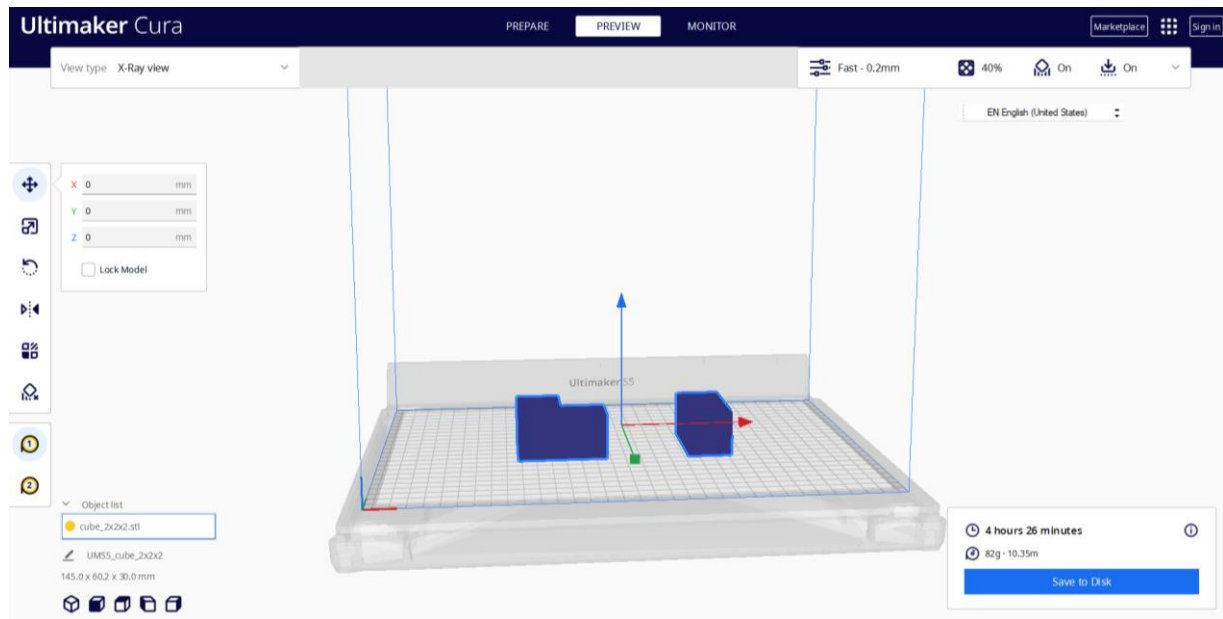


Figure 35. X-ray view in Cura (Preview)

Step 6: Once you have made sure that everything is in order, you can save the G-code directly to disk (i.e., SD card, hard drive of your computer or laptop) and send it to the 3D printer to begin the printing process.

There are a few ways that you can send the G-code file to the 3D printer, that is via:

- a Micro SD Card,
- a USB cable, and/or
- Wi-Fi connection.

Depending on your 3D printer, you can choose one of the above options to start the printing process.

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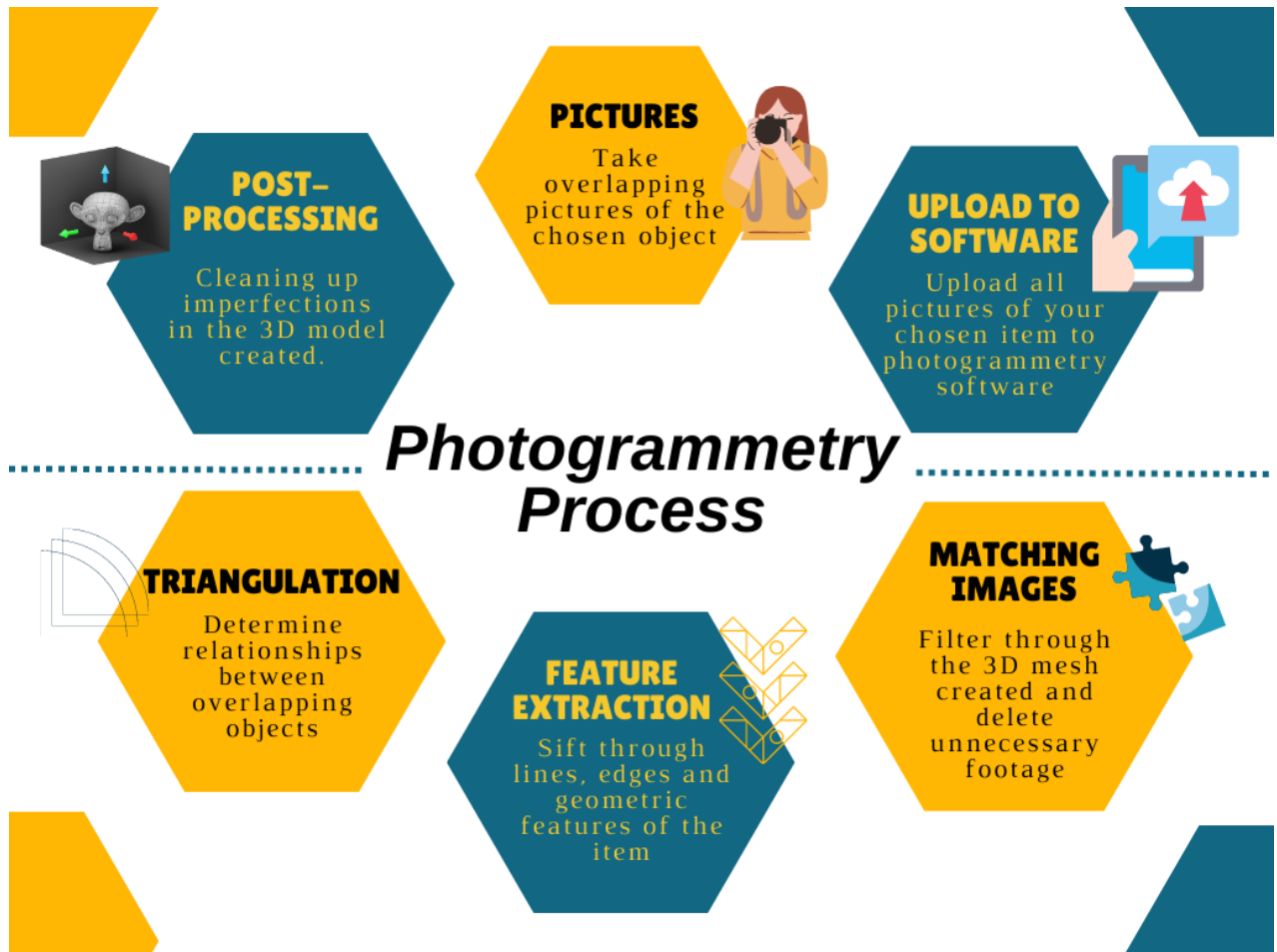
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Annex

Annex 1

A summarised graph of the Photogrammetry process:



Resources for beginners in Photogrammetry:

- FormLabs: <https://formlabs.com/eu/blog/photogrammetry-guide-and-software-comparison/>
- ModTechLabs: <https://modtechlabs.com/beginners-guide-photogrammetry/>
- Poux, F. (2022): <https://towardsdatascience.com/the-ultimate-guide-to-3d-reconstruction-with-photogrammetry-56155516ddc4>



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