Tutorial for creating a plot-space: a 3D-printable model of the spatial shifts in a text

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A plot-space is an object consisting of three adjoining faces of a cube. The first face has text inscribed on its inward-facing surface, while the second face has a curve representing the plotting of some aspect of the text as it changes over time, and this curve extends out from the second face in a 'wave' to connect with the third face, giving the curve of the plot three-dimensionality. I originally used the form to represent scalar and spatial shifts, as this seemed most fitting to the medium, and that is the example used below, but other elements could be plotted such as sentiment or the passage of time.

This tutorial requires the use of software that is either freely available (Google Sheets, Inkscape) or for which student or staff licenses are available (Autodesk Fusion 360). It results in an STL file which can then be sliced in slicing software and 3D printed.

Choose your text and assign values to each line

1. Start by choosing a text that is short enough to be 3D-printed on a square which, depending on your printer, might be as small as 10cm or as large as 30cm. For the purposes of this tutorial, I will use this poem by Emily Dickinson:

> In lands I never saw, they say,
> Immortal Alps look down,
> Whose bonnets touch the firmament,
> Whose sandals touch the town, —
>
> Meek at whose everlasting feet
> A myriad daisies play.
> Which, sir, are you, and which am I,
> Upon an August day?

2. Decide what aspect of the text you want to plot, and assign each line of your text a value accordingly, so you have a sequence of numbers. Here, I have given a number which denotes size on a log scale (where 1 represents the height of a human, measured in metres, 2 represents something measured in 10s of metres, 3 represents something measured in kilometres, such as 'the town'; while going into minus digits corresponds to scales smaller than a meter, so 0 represents something measured in increments of 10cm, -1 to 1cm and so forth). Devise your own scale and your own conventions for measurement. 'Quantifying' a text in this way is highly subjective: the values you end up assigning are obviously artefacts of your own interpretation.

Line number	Line	Core (measurable) concept in the line	Rough size	Value
1	In lands I never saw, they say,	European countries near the Alps	1 x 10^6m	6
2	Immortal Alps look down,	the territory covered by a mountain range	1 x 10^5m	5
3	Whose bonnets touch the firmament,	'firmament' = the sky	1 x 10^8m	8
4	Whose sandals touch the town, —	towns at the foothills of mountains	1 x 10^3m	3
5	Meek at whose everlasting feet	the reader is still in the foothills	1 x 10^3m	3
6	A myriad daisies play.	daisies, around 5-20cm	1 x 10^{-1}m	-1
7	Which, sir, are you, and which am I,	humans (though possibly other beings?)	1 x 10^0 = 1m	0
8	Upon an August day?	no size easily chosen, so retain previous value	1 x 10^0 = 1m	0

Plot values against line numbers

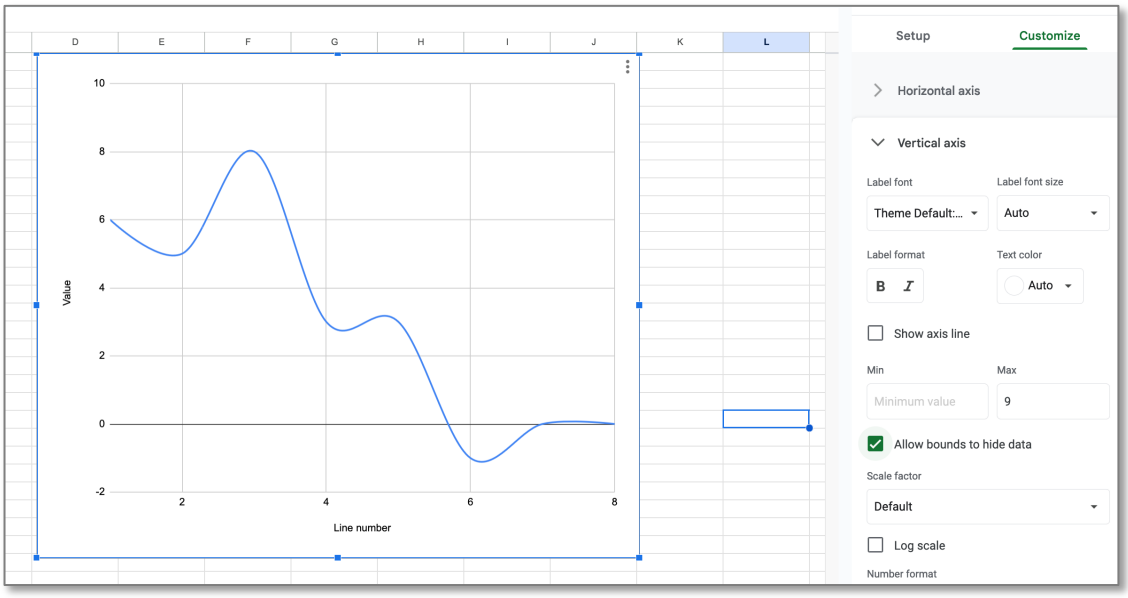
3. Create a line graph which plots line numbers (on the horizontal axis) against the values you just worked out (on the vertical axis). You may have a preferred way of doing this already, eg. in Excel, R or Python, in which case create the plot and save it as a PDF.

If you don't want to use Excel, R or Python, create a new Sheet in Google docs. Paste the line numbers into one column and their corresponding value in the next column.

	A	B	C
1	Line number	Value	
2	1	6	
3	2	5	
4	3	8	
5	4	3	
6	5	3	
7	6	-1	
8	7	0	
9	8	0	
10			

Select all the cells you have just created then **Insert** > **Chart**. In the right hand pane, under **Chart** type, select **Smooth line chart**.

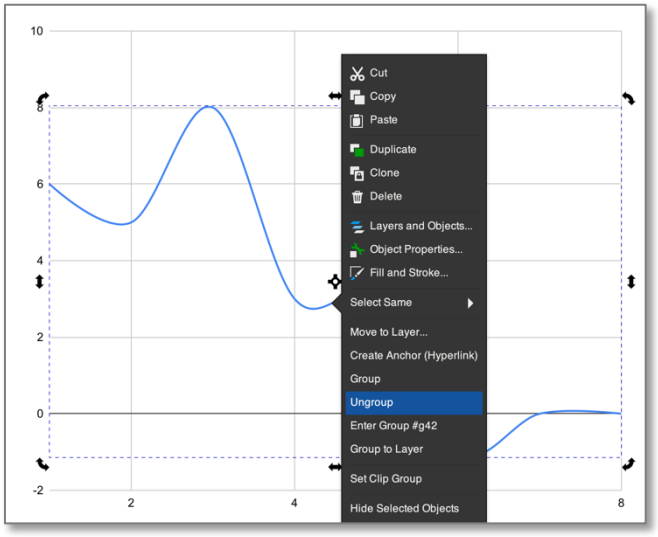
If you find the top (or bottom) of the line is cut off at the top (or bottom), go to **Customize** in the right hand pane, and under **Vertical Axis** change the **Max** value to a value that is one higher than the value that has been cut off. This should bring the top of the line back into view, but if it flattens the shape of the graph too much, drag the bounding lines around the plot to make it into more of a square shape.



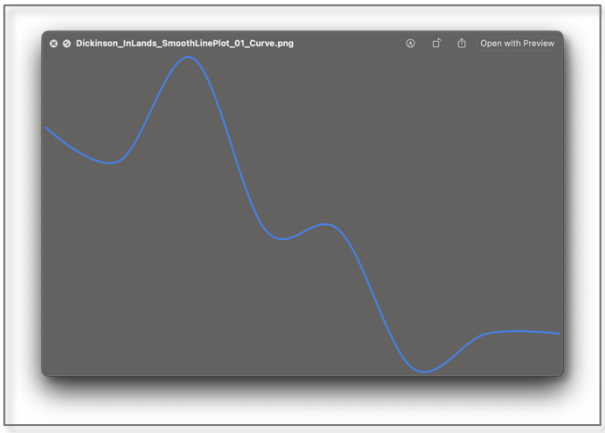
4. Once you are happy with the appearance of the chart, click the three vertical dots in the top right of the plot bounding box and download the chart as a PDF. Give it a sensible filename (eg. Dickinson_InLands_SmoothLinePlot_01.pdf) that will help you keep track of which text you have plotted and distinguish it from different versions you may create later.

Extract the curved line from the rest of the plot

5. You now need to grab the curve from this plot without any of the other things in the images such as gridlines. To do this, open the PDF file you just created in Inkscape. Select the wavy blue line (if it is connected to other parts of the image you may need to right-click and select Ungroup).



6. Once you have selected the line on its own, copy it and paste into a new document in Inkscape. Then go to **File** > **Document properties**, and expand **Resize page to content** and click the **Resize page to drawing or selection** button (on some versions of Inkscape you simply click the button next to **Resize to content**). Close the **Document properties** dialog and then **File > Export** and export as a PNG image with a filename corresponding to the PDF from which it was derived (eg. Dickinson_InLands_SmoothLinePlot_01_Curve.png).



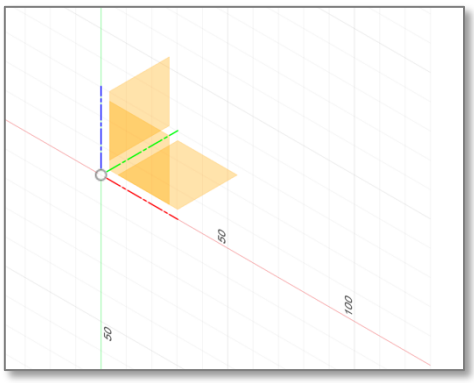
(A quicker way to do this is to select the line in Inkscape and go straight to **Export as a PNG image**, ensuring you have **Selection** selected in the window that swings out to the right. But pasting into a new document is a way to ensure you've got only the line you need and nothing more.)

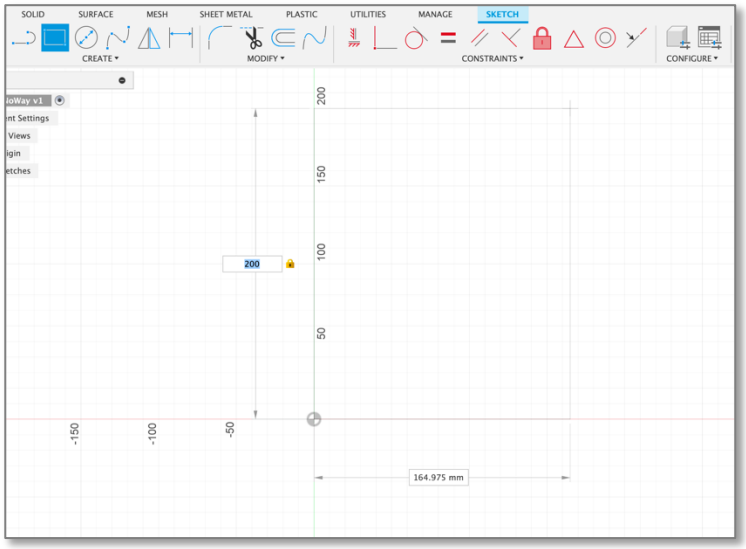
Once saved, find the image in your files and open it to double check it looks like what you expect.

Move to CAD software and create the first wall of the plot-space

7. Now you have extracted the curve of the graph, you can move into CAD software. In this tutorial we will use Autodesk Fusion360.

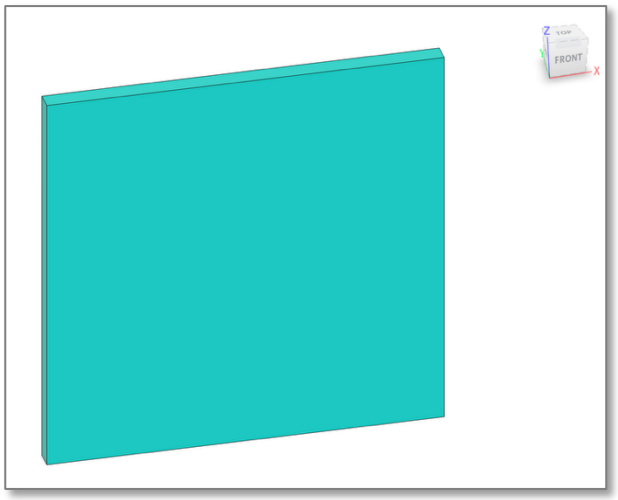
8. Open Autodesk Fusion 360 and start a new design. We'll start by creating the face on which the curve will appear. In the **Solid** tab, click **Create** then **Create Sketch.** Click the vertical plane (the one that appears as a darker yellow in the screenshot): this tells the program which plane you want to work in.





9. The interface should reorient so that the yellow planes disappear and you see the origin (the small circle with 2 grey quadrants and 2 white quadrants). Go to **Create > Create Rectangle > 2-point rectangle**. Click at the origin and drag your mouse to create a rectangle but, before clicking again, type in the height measurement (I've chosen 200mm in the screenshot) then hit tab and type the breadth measurement (which should be equal to whatever you chose for the height, as we are creating a square).

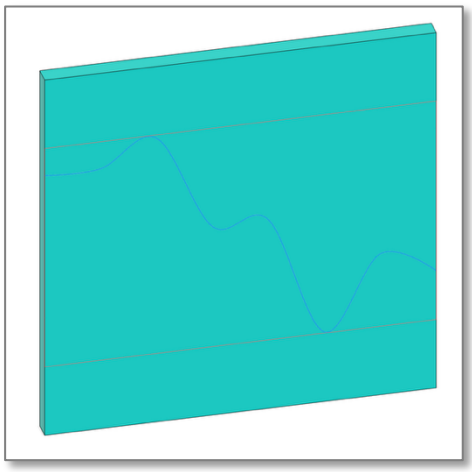
Hit return and press the **Finish Sketch** button to create your sketch of a square. Save the document.

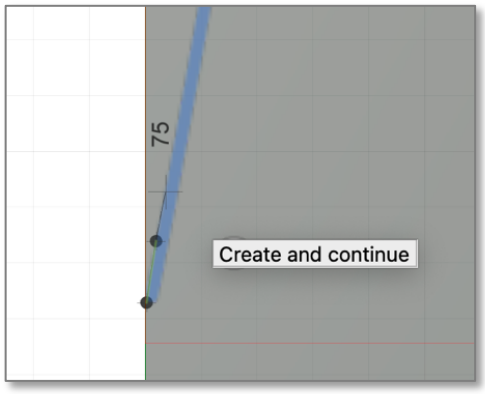


10. Now we'll give this 2-dimensional square a third dimension to make the first wall of the plot-space. Go to **Solid > Create > Extrude** (or, as shortcut, select your rectangle and press e). In the Extrude box that comes up, type a figure into the **Distance** box for how thick you want your walls to be. (I find 10mm produces sturdy walls; if you want something more bendy, go lower). Under **Operation** select **New Body** and press **OK**. To check the extrusion has worked as expected, rotate your new wall using the X / Y / Z cube at top right of the screen.

Add the curved line to the new wall

11. Now we'll add the curve you exported as a PNG earlier. Go to **Solid > Create > Create Sketch** and click the wall you just created. Then **Insert > Canvas** and find your PNG file in the dialog (you will need to click **Insert from my computer**). Click the face of the wall where you want the image to appear, and move it up or down if you wish, then press **OK**. (Note that you want the face nearest to you; if you accidentally choose the wrong face, press **Escape** and start again from **Insert > Canvas**). You should see your plot line appear, scaled so it fits across the width of the wall. Don't worry about the red lines which indicate the edges of the image file.



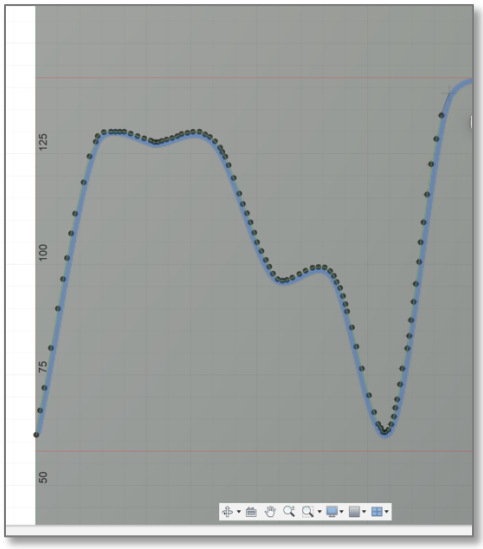


12. You now need to manually trace the line. This is the most time-consuming part of the work in the CAD software, but it is finicky rather than difficult.

Go to **Solid > Create > Create sketch** and select the wall with the curve on it (take care to select the wall rather than the smaller yellow rectangle showing the face). Then **Create > Spline > Fit Point Spline.**

You now need to trace over the blue line, matching it as closely as you can, so zoom in as necessary. Click the first point and continue clicking points so the thin black line you create matches the blue line of the plot. In the screenshot below I have placed my points on the outside of the blue line but you could choose the middle or the underside.

If you place a point wrongly, ctrl-Z your way back to a point you're happy with.



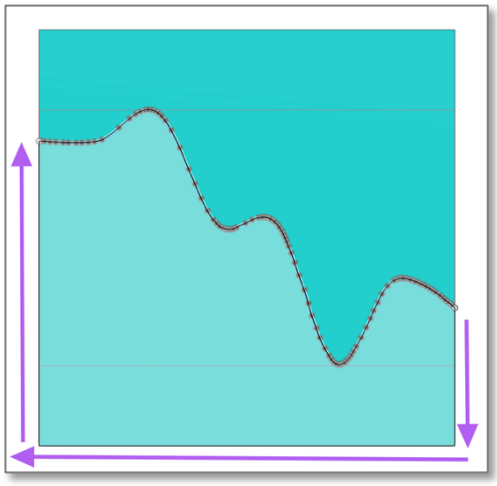
As shown in the screenshot, where the curves are tight you will need to use more markers and keep them closer together, than straighter sections.

Resist the temptation to put markers only at the start and end of the straight parts of any lines: too few markers and your arc will swell out in random directions once done.

Be careful that your first and last points are exactly on the outer horizontal lines of the wall. If they aren't, this will cause problems later (you can come back and fix them by right-clicking which provides access to editing options.)

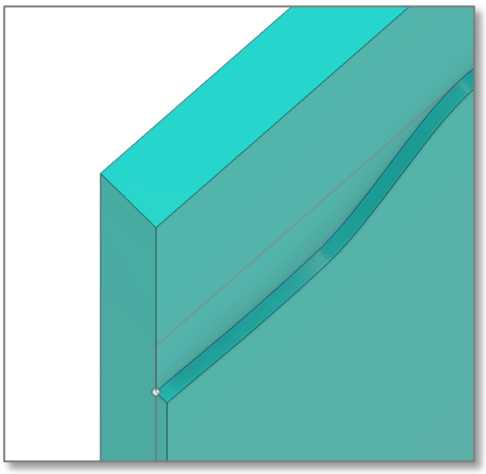
When you have placed your final marker at the other end of the line, click the tickbox in a circle, then click the **Finish Sketch** button and save your work.

13. The final step for this section is to create a closed loop, which you need to do as part of the same sketch as the spline curve you just created. Right-click the line you just created and select **Edit Sketch** then press **L** to create a line. Start by clicking the very final point where you ended the curve (zoom in if necessary to ensure you click exactly the right spot; the cursor will turn into a square), then go down to the bottom of the wall and click the bottom right corner, then move across to left corner and click that, then up to the start of the curve and click on exactly the spot where you initially started the curve in the previous step (again, make sure the cursor turns into a square). The arrows in the screenshot in a U-shape indicate where to go. As in the previous step, once you have completed the three lines click the tickbox in a circle, then **Finish Sketch**.



When you click the area inside the space you just created, it should all become one colour to indicate it is now a separate shape. Save your work again.

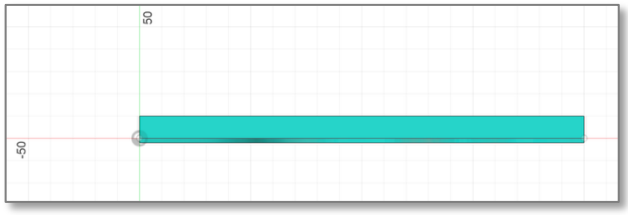
Make the area under the curve three-dimensional

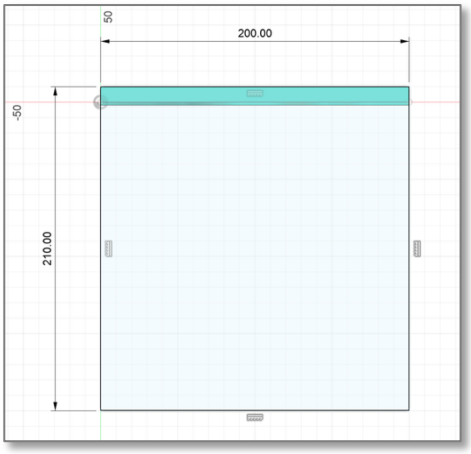


14. Now we will extrude this new shape so it sits out from the wall by a few mms. Click inside the shape you just made, then press **E** to extrude. Next to Profiles, you should see **1 selected**; if not, click **Select** and then click the face just below the curve. Type in the number of millimetres you want the curve to come out from the wall (2mm is good). Set the **Operation** to **New Body**, keep the other defaults as they are and press **OK**. As before, you can check the extrusion has worked by rotating the model to see whether the line and the area under it is now jutting out a little from the upper part of the wall (as shown in the close up in the screenshot).

Create the floor of the plot-space

15. To create a new plane to serve as the 'floor' of the plot space, go to **Create > Sketch**, select the plane that corresponds to the floor (you may need to zoom out to see the three yellow squares designating the three planes). You will get a top-down view of your new wall.

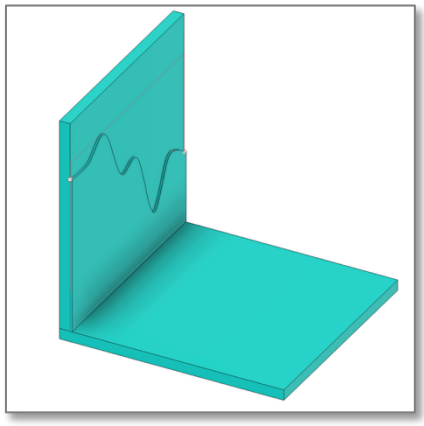




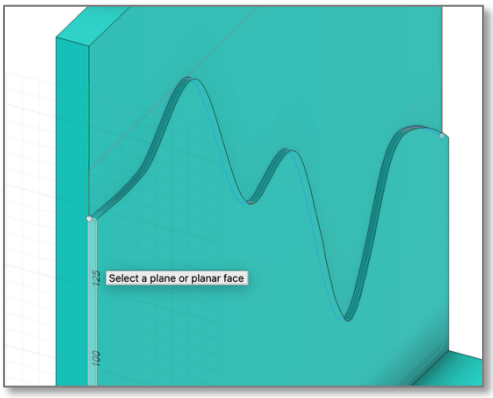
16. Go to **Create > Rectangle > 2-Point Rectangle**. in the tool bar. Click once at the top left corner of the existing wall (note that this is not the origin). Then, as you did in step 9, type the numbers you used for the dimensions of the first wall, except this time ensure you add extra to account for the section of floor that will be directly under the wall you initially created. In the screenshot, for instance, I've put in 200 and 210.

When you have put the right numbers in, press return and **Finish Sketch**. Rotate the view around a little to check that the floor is really a floor.

17. Press E (shortcut for Extrude), select the rectangle you just created, then make it the same thickness as the initial wall (10mm if you are following my defaults; type -10 into the **Distance** box to make it go down below the existing wall rather than coming up into it). Next to **Operation** select **New Body**. Press and your new floor should be created.



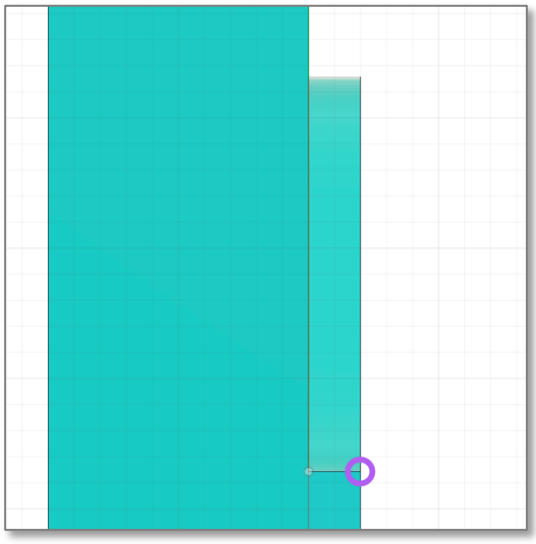
Add rails to guide the shape of the three-dimensional curve



18. To bring the curve of the line out in three dimensions from the wall and create 'waves' down towards the floor, we will need to create rails – guide lines that indicate how we want the curves to be shaped.

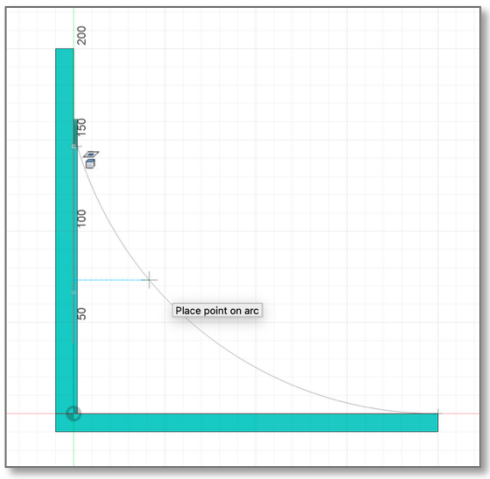
Go to **Solid > Create Sketch** and choose as your face the long thin rectangle that is highlighted in white in the screenshot.

When the model swings around automatically, look for the point circled in purple on the screenshot. This is where you are aiming to start your first point in the arc you are about to draw.



Go to **Create > Arc > 3-Point Arc** and put your cursor exactly on this point (make sure the cursor turns into a box when it is on the line, so the two lines will be joined).

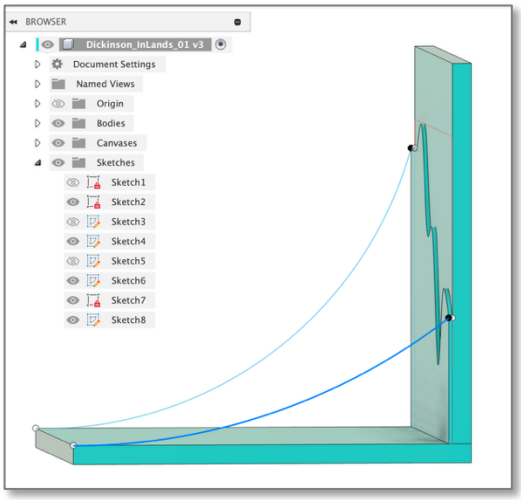
Place the second point on the front corner edge of the floor (again, make sure the cursor turns into a box).



You then need to do a third click to place the point that governs the shape of the arc, so choose a place which makes for a visually appealing curve.

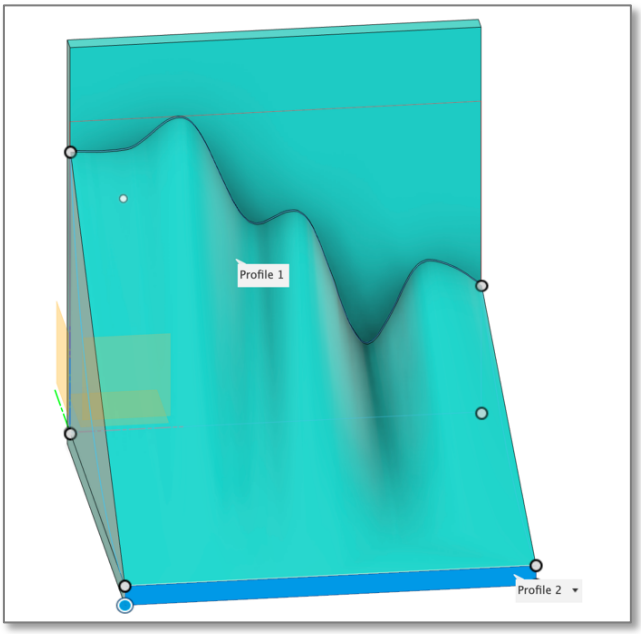
Once the curve is in place, click **Finish Sketch**. On the left side of the screen you will see a list of headings under **Browser**. Expand **Sketches**, right click on the new curve, and you should see one of the Sketches become highlighted (click onto other elements and back again to see how the highlighting changes in the Browser. Make a note of the name of the sketch (eg. Sketch6). Save your work.

19. Flip the model around and repeat step 18 to create another rail on the other side. Again, take note of the name of the sketch once completed, and save your work. The screenshot shows the model with both lofting rails, and the list of sketches and their names on the left of the screen.



Use the Loft function to bring three-dimensionality to the are under the curve

20. Now the rails are in place, we are ready to use the Loft function.

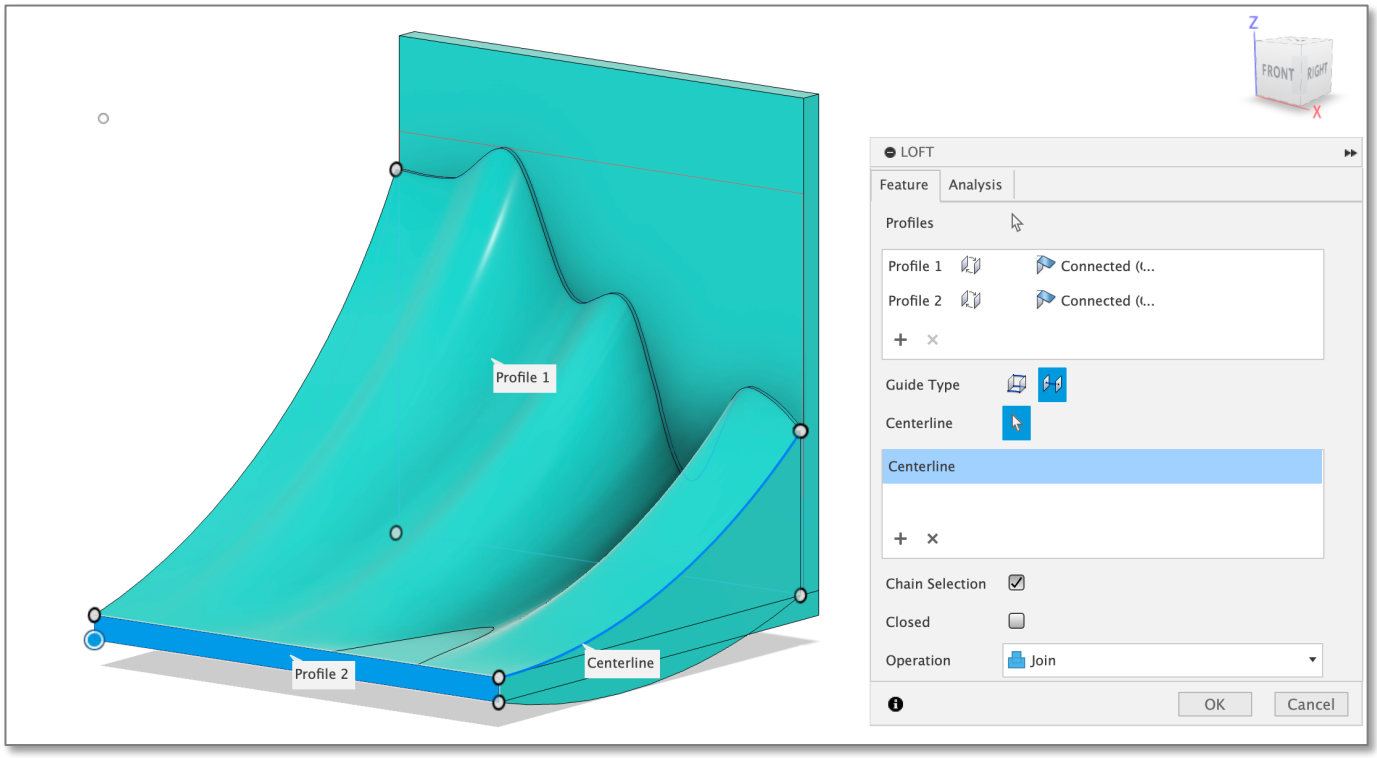


Swing the model around so the area under the curve is facing you. Go to **Solid > Create > Loft** and click the face under the curve: you should see it appears in the Loft dialogue under **Profiles** as **Profile 1**.

Then click the long thin face closest to you (highlighted in blue in the screenshot) so that it becomes **Profile 2** in the **Profiles** box.

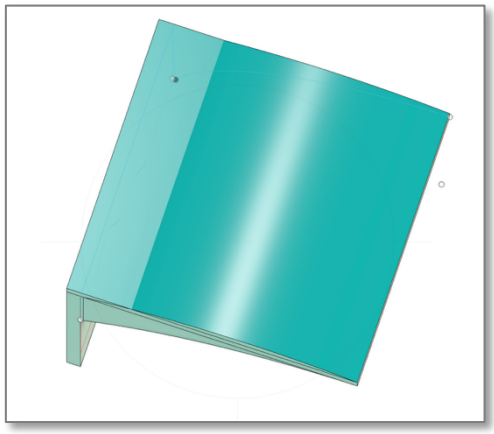
The two planes are now joined. Under **Rails**, click the plus sign and then select one of the rails you just drew (remembering its name from earlier). The straight lines will become curves. Experiment with changing the Guide type and the types of connections for the profiles, and swapping between rails until you have the effect you want.

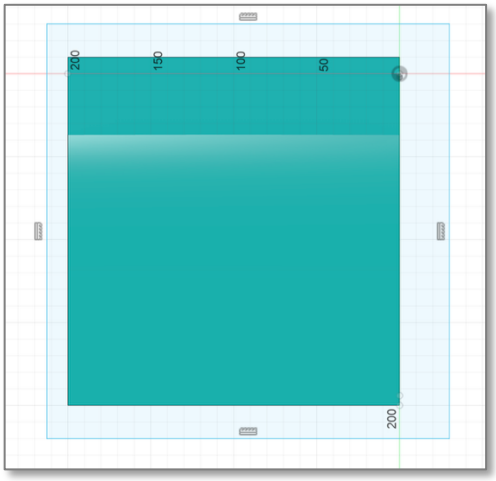
The screenshot below shows the parameters I chose to achieve the effect I did (though change **Join** to **New Body** when you are ready to press OK; I have selected Join for this screenshot because otherwise the profile face is highlighted and makes viewing the loft slightly more difficult). Press **OK** when you are done and save your work.



21. You will see there is a lump underneath the model which is an artefact of the lofting. You might want to leave this on if you want the model to rock back and forth, but if you want to slice it off so your model will sit flat, here are the steps to follow.

22. Rotate the model so you are looking at it from underneath. Go to **Solid** > **Create sketch** then click the flat part of the underneath of the model (the rectangle in a lighter colour in the screenshot).





23. Then **Create Rectangle** and draw a rectangle that is slightly bigger than the whole base of the model. Finish the sketch, press **E** for extrude and select the rectangle you just drew. Under **Operation** select **Cut** and a distance that is big enough to enclose the bulge (40 mm worked for me). Leave the other defaults as they are, press **OK** to slice the bulge off, and rotate around to check it has worked.

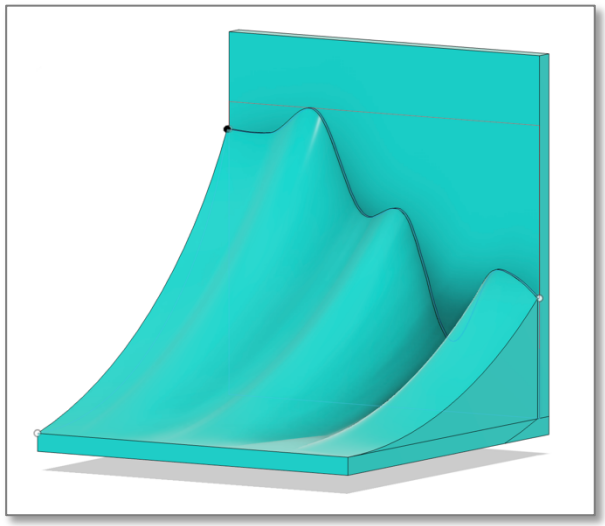
If this doesn't work, and you get an error message saying there's no body to cut or intersect, you may need to do an additional step where you join the bulge to the floor of the model.

In the **Solid** tab, go to **Modify > Combine** and a dialog box will come up. For **Target Body**, select the body you want the bulge to be part of. For **Tool Bodies**, select the bulge. Set the **Operation** to **Join**, then click **OK** to merge the bulge with the surrounding body. You can then retry steps 22 and 23.

Save your work before going to the next step.

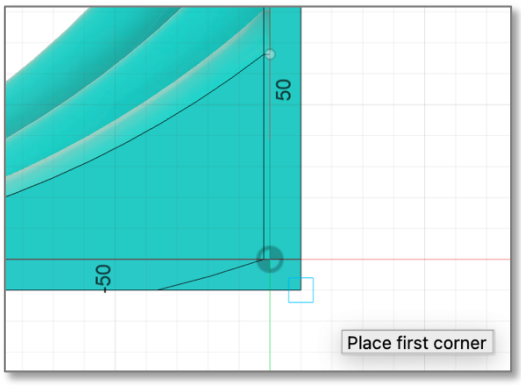
Create the final wall of the plot-space

24. We turn now to creating the third wall on which the text will be inscribed. This face is added last because fonts can have complex geometry, and rendering them over and over to display them on the screen can slow CAD software down.

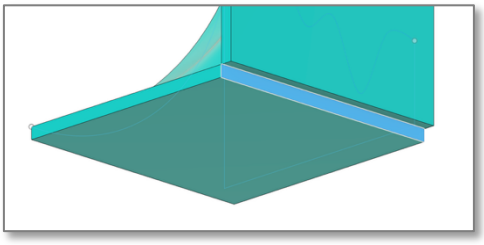


25. Decide whether you want the wall with the text to go to the left or right of the lofted curve, and turn the model so you can click on the face that will be hidden by the new wall. If you want the text on the right of the plot-space's two vertical walls, turn it as shown in the screenshot.

26. Go to **Solid > Create > Create sketch** and click one of the sides of the L shape which will shortly be hidden by the new face (this is easier than selecting the triangular shape, now that there are many surfaces to the model). Go to **Create** > **Rectangle** > **2-point rectangle** and draw a square extending from the bottom-most right point (as shown in the screenshot), to the upper left point. As before, type in the distances rather than trying to drag the mouse (if you used the same numbers I did earlier on, they will be 210 x 210 mm).



Press return then **Finish sketch** and you will see the outline of a square appear. Extrude this square to the same depth as the earlier walls (10 mm if you used that earlier) and make the operation a Join. Press **OK** and you should see your new third wall appear.



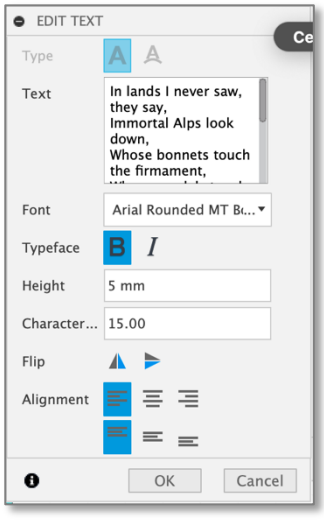
27. One final extrusion is needed to fill the gap between the new wall and the floor. Rotate the model so you can see underneath, click the face shown in blue in the screenshot, press E and extrude so the face you are creating lines up with the wall (10 mm if you used that earlier). Under **Operation** select **Join** and press **OK**: the two faces should now be joined without a gap. Save your work.

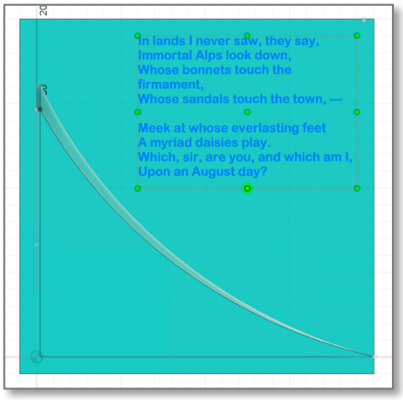
Place the text on the new wall

28. To add text to the wall you just created, position your model so you can easily see the inside face of that wall. Go to **Create > Create Sketch**, select the new wall then **Create > Text**. You'll then need to create a frame on the wall by drawing a rectangle: do this by clicking two points on the face. If you make a mistake, press **Escape** and start again from **Create > Create sketch**. Note that you can draw a rectangle that is partially obscured by the lofted curves, as you can change the lineation of your text manually.

29. Once you have placed the frame for the text to go into, a dialog will come up into which you can paste your chosen text and make formatting choice. Adjust the font, alignment etc to your liking, and experiment with the height. Non-serif fonts such as Arial are likely to come out much better than serif fonts. Press **OK** when you are happy then **Finish Sketch**.

    Note that if you want some text in plain text and some in italics (eg. the author's name beneath the text), you'll need to create a separate sketch with a separate text box for the italicised text, as it's all or nothing for text formatting in each text box.



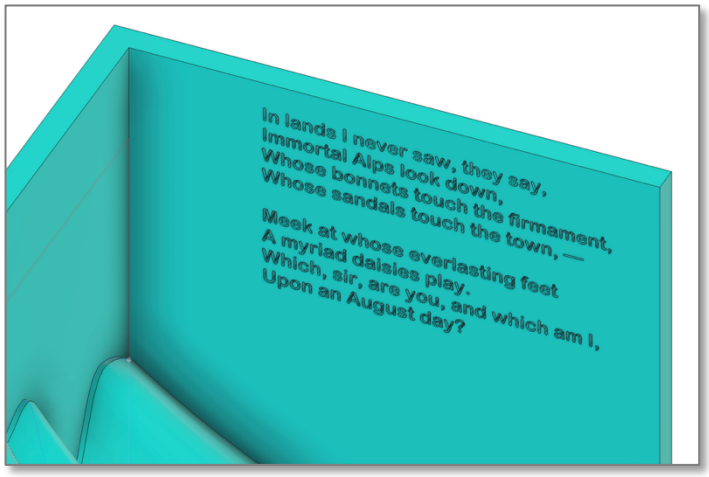


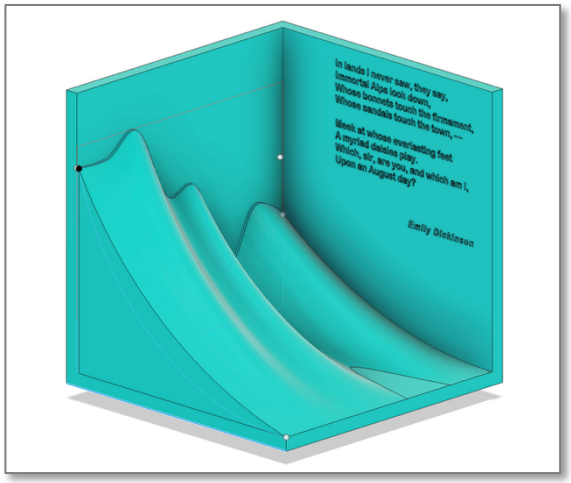
The screenshot shows how the text box sits clear of the lofted curve. If you are intending to use an additive process such as 3D printing to make the plot-space, you can extend the text so that it is closer to the curves; just make sure that the text does not go into the area under the lofted curve (if it does, the 3D printer will still print it, but you will not be able to see that part of the text). If you are using a subtractive process such as milling, you will need to leave enough space between the lofted curve and the text for the bit to fit.

Extrude the text from or into the wall

30. The last step of the process in Autodesk Fusion 360 is to engrave the text into the plane, or to extrude it out from the wall. Again, consider the materials you are using, and whether you are using additive or subtractive manufacture. If 3D printing, it is difficult to inscribe letters into plastic and still have them come out as legible unless the letters are quite large, so extruding the letters out from the plane will usually give a better effect. If working with wood or metal on a milling machine, however, engraving the text into the plane is likely to work better.

Select the text and press **E** to extrude. In the **Extrude** pane, check that next to **Profiles** it says **1 selected** and the text of the model has turned a darker blue; if not, **Select** next to **Profiles** and click the text. To cut into the wall, set **Distance** to a number less than zero (eg. -2 .00 mm) and **Operation** to **Cut**. To extrude from the wall, set **Distance** to a number greater than zero (eg. 5.00 mm). Press **OK** and you should see the text take on three-dimensional form. Save your work.





Your plot-space is now complete! After saving your work, export it to your own machine in STL format or whatever file format you want. From there it can be imported into slicing software and then printed.

Tip: If you are 3D printing, it works best to orient the model in the slicer so that the plane with text is facing upward, as that will produce the best results when the text is extruded or engraved.