SUPPLEMENTARY MATERIALS – S2

INSTRUCTION FOR THE PYTHON SCRIPT FOR ARCGIS® "CaveArtAccessibility" **page 2**

INSTRUCTION FOR THE PYTHON SCRIPT FOR ARCGIS® "CaveArtAccessibility"

First, we need to create a folder named as "CaveArtAccessibility" in the folder "C://" of our computer, to put the python script named as "yjasc_105271_CaveArtAccessibility_mmc6.py" inside. You must not change the name of the folder, because if do, the script is not going to work (Figs. 1 and 2).

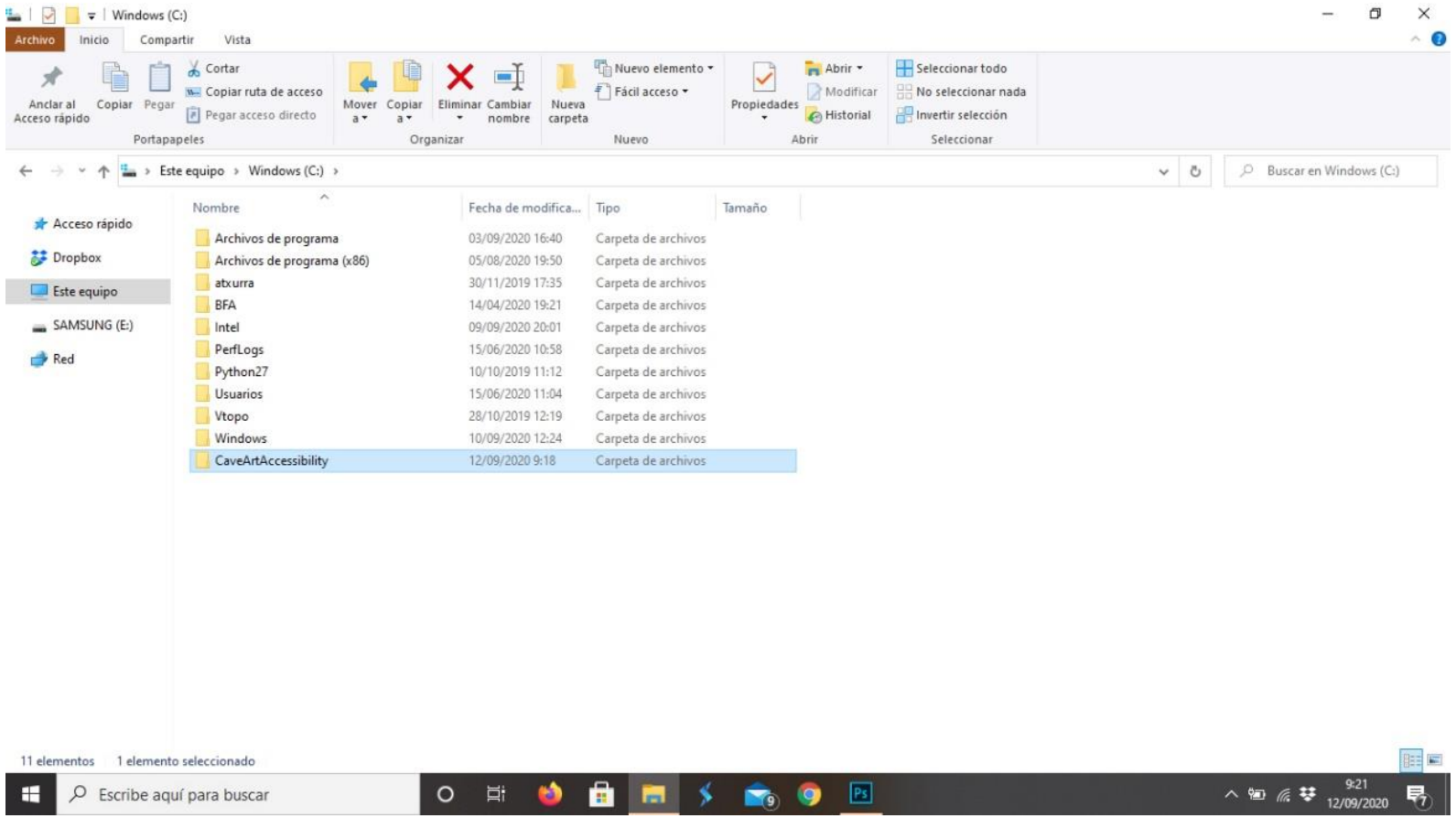


Fig. 2: putting the folder "CaveArtAccessibility" in the folder "C:" of our computer. The direction of this folder must be "C:\CaveArtAccessibility".

Prior to this, you must consider an **important thing**. The python script has the “ETRS 89 UTM TM30” datum as the default coordinates projection system. If your study cave is located in another region, you need to change this in the python script directly. You can make this changing the script with the nemo pad (Fig. 3).

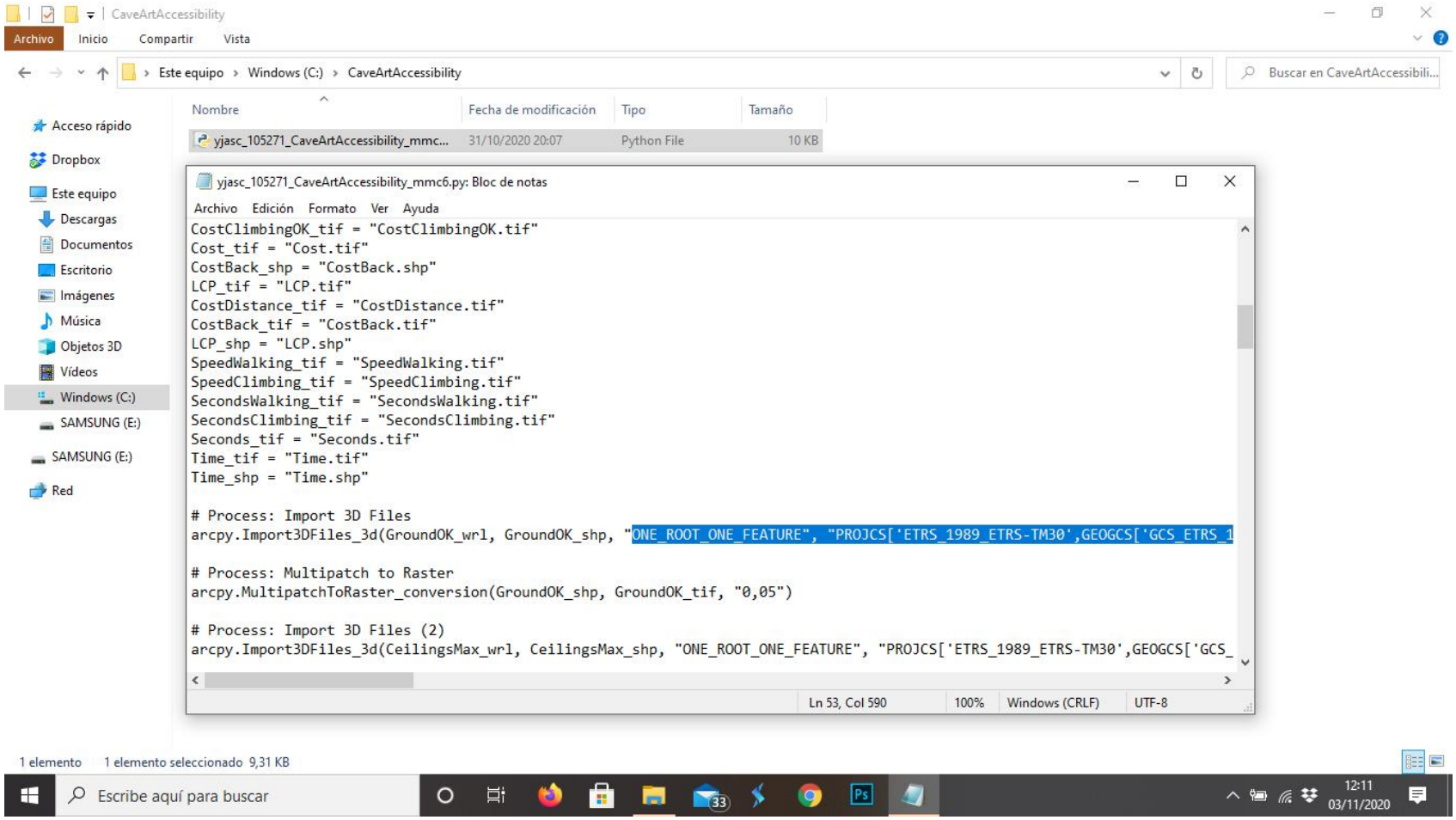


Fig. 3: if you must to put another datum, you need to change this directly in the script, in the lines 53, 59, 66, 73, 145 and 207 of the script with the nemo pad.

Later, we need to prepare the 3D files to work with them in ArcGIS®.

We need three files:

- A first file for ceilings named as “CeilingsMax.wrl”. For this, we can put the entire 3D model of the cave (Fig. 4). GIS are going to take these Z which are located in the up (because it is going to have an orthogonal view of the horizontally displayed cave).
- A second file named as “CeilingsMin.wrl” for those Z values which, when located in an intermediate situation, have not been taken into account. These intermediate Z affect in the caving acting as ceilings for the ones who transit below them (Fig. 5). If you do not have this types of ceilings, enter again the entire 3D model of the cave, but naming this second file as "CeilingsMin.wrl".
- A third file named as “GroundOK.wrl” for those Z values which are located in the floor level (or act like paths to access the rock art panels in the cave, like the cornices, the climbing zones, or similar) (Fig. 6).

All files must be wrl type files.

It is important to put the names of each file correctly, because if not, the script is not going to work well.

To create each file, we recommend firstly extract a 3D model from the scanned point cloud of the cave (we can use a free software like CloudCompare® for this). For this we need to mesh the original point cloud (after cleaning it to erase the noise and the bugs).

After this we need to modify them to extract the different files (for the grounds or for the intermediate Zs, for example). For this, we recommend the use of Meshlab® or Blender®. To obtain accurate results, is essential to work with files as close as possible to the original state of the cave when it was frequented in the prehistory. For this, it is necessary to carry out previous geomorphological studies, to know the evolution of the endokarst and to identify these changes posterior to the frequentation of the Upper Palaeolithic societies (to erase them, and to create accurate files to work with them).

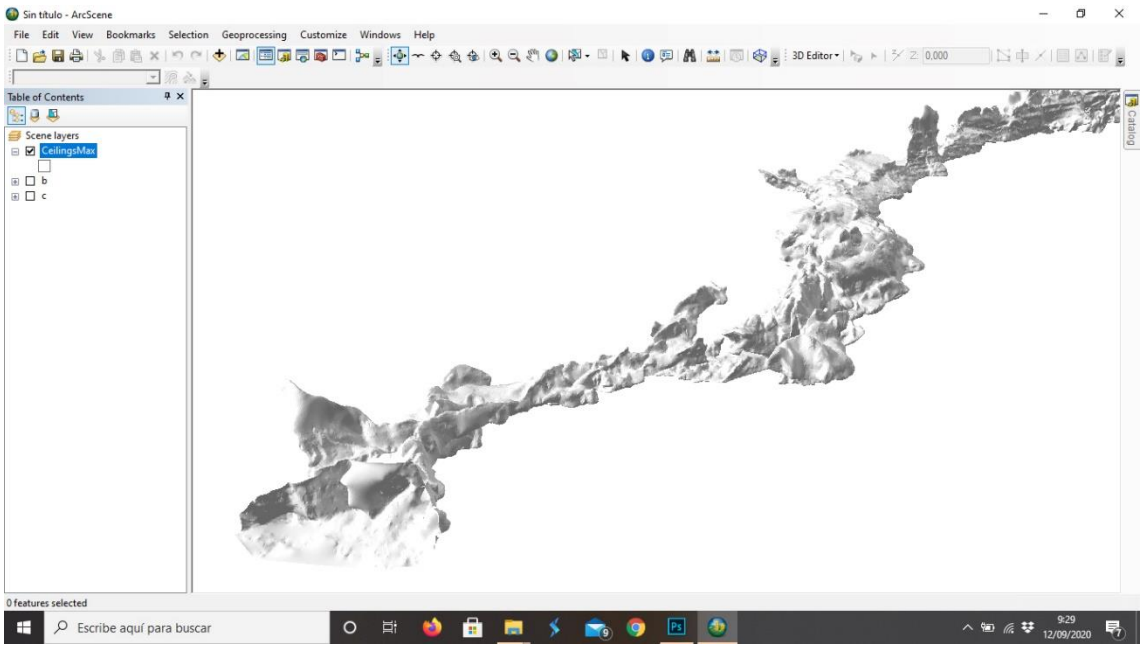


Fig. 4: the entire 3D model of the cave can be used to obtain the Z values for ceilings.

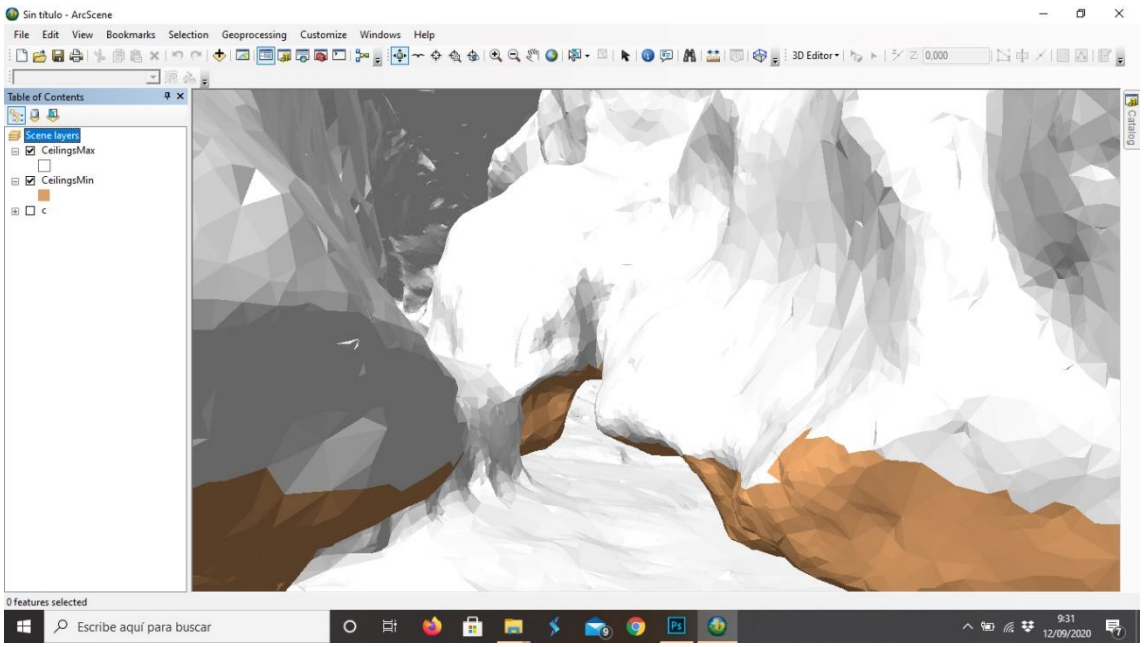


Fig. 5: the 3D model (in brown) of those Z values which, when located in an intermediate situation, have not been taken into account and act as ceilings for who which transit below them.

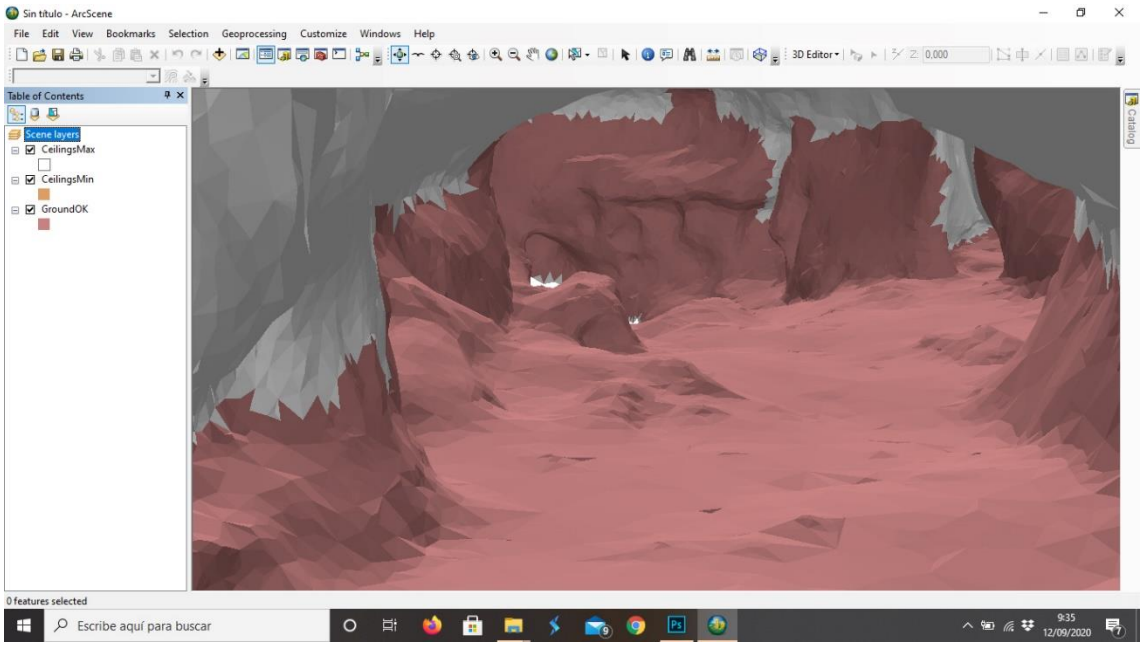


Fig. 6: the 3D model (in purple) for those Z values which act as grounds for who which transit above them.

Once created these files, we need to copy and paste them in the folder "C:\CaveArtAccessibility". The same where the python script is located (Fig. 7).

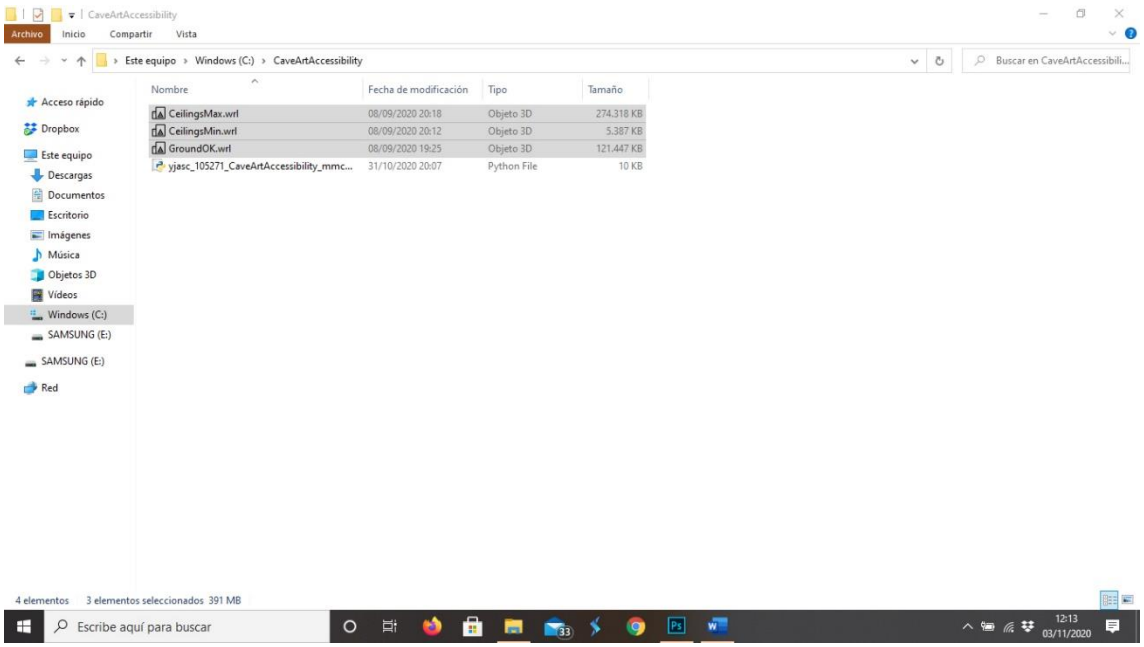
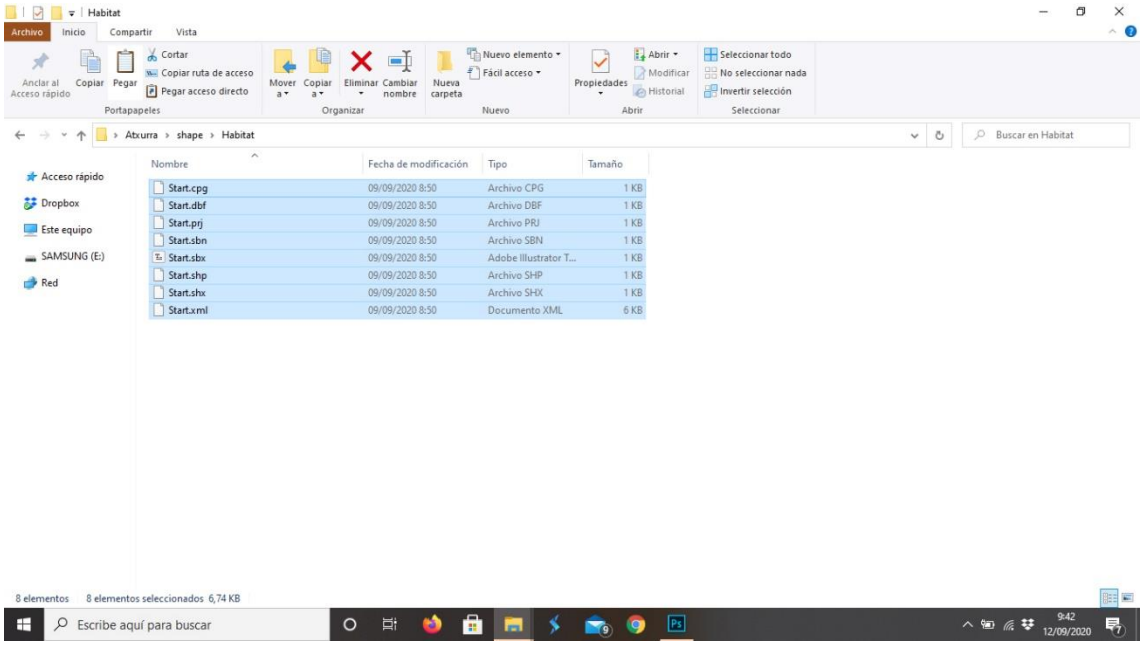


Fig. 7: we need to copy the 3D models in the folder "C:\CaveArtAccessibility".

We also need to create a shapefile for a starting point (e.g. the habitat site in the entrance hall of the cave), and a destination point (e.g. the floor under the last figure of a decorated sector). The former must be named as "Start.shp" (Figs. 8 and 9), and the next one as "Destination.shp" (Figs. 10 and 11). It is important to maintain these names, because if not, the script is not going to work well.

After this, we need to copy and paste them in the folder "C:\CaveArtAccessibility" (The same folder where the script is located).



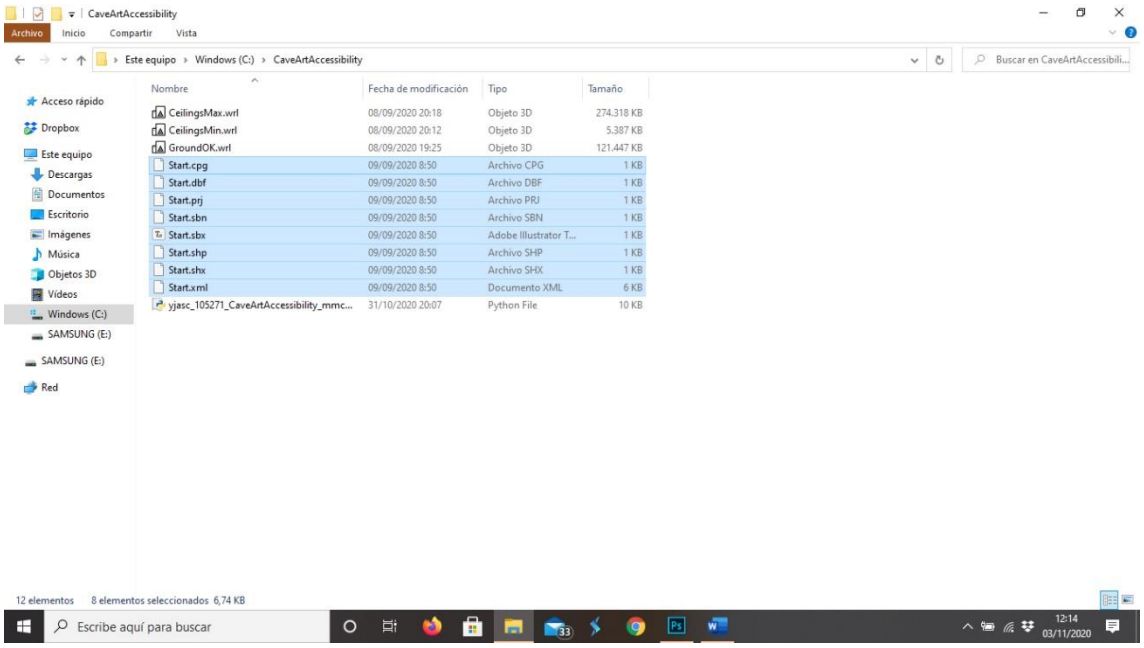


Fig. 8 and 9: the shapefile (they are different files, .shp, .cpg, .shx, etc.) for the start point, named as "Start.shp". In our case, it contains the coordinates of the centroid located in the habitat site of the cave, in the entrance hall. We need to copy them in the folder "C:\CaveArtAccessibility" (the same where the script is located and where we have placed the files for the 3D models).

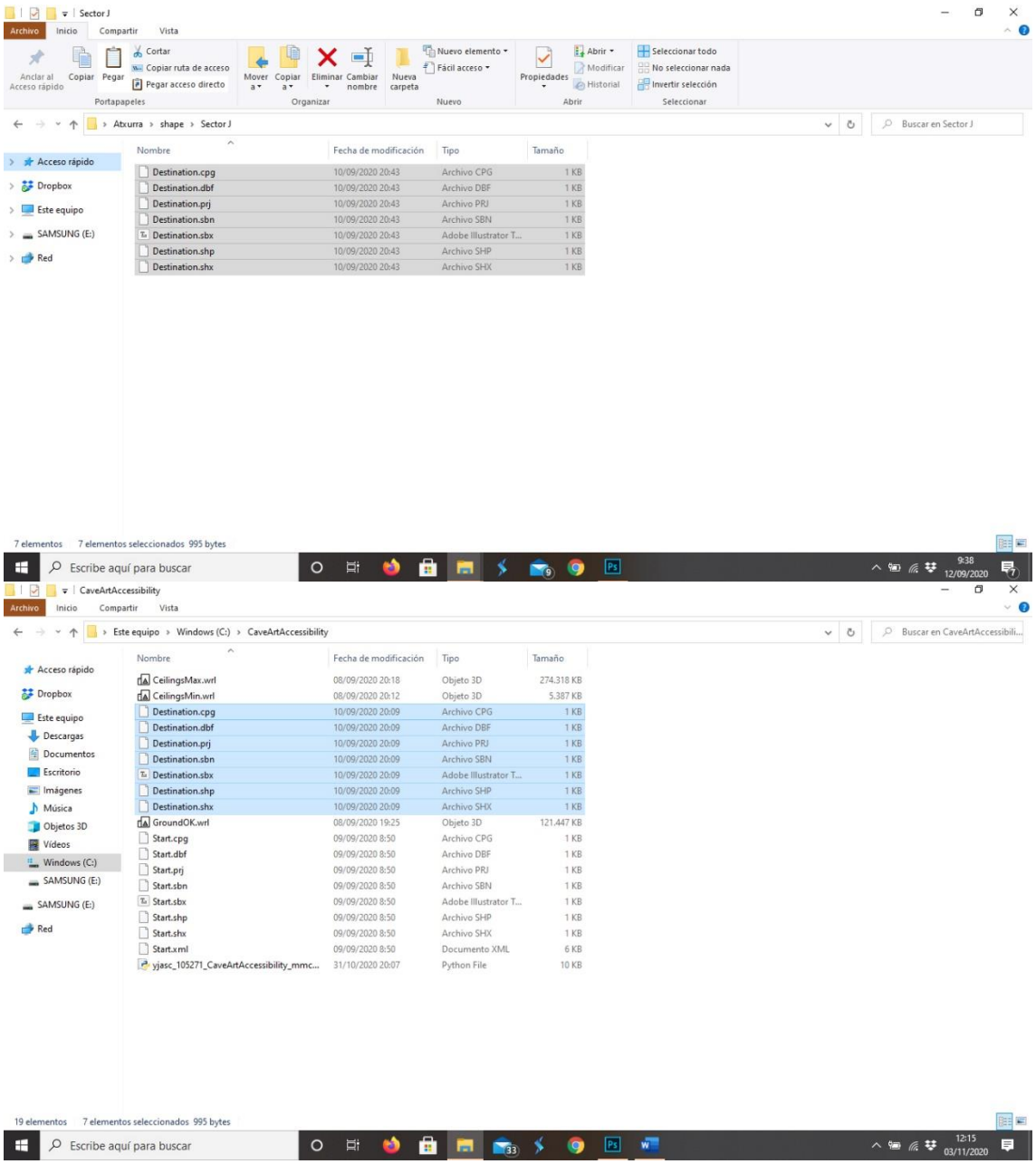


Fig. 10 and 11: the shapefile (they are different files, .shp, .cpg, .shx, etc.) for the destination point, named as "Destination.shp". In our case, it contains the coordinates of the point of the floor located under the last GU of the sector J, in the inner part of the cave. We need to copy them in the folder "C:\CaveArtAccessibility" (the same where the script is located and where we have placed the files for the 3D models).

Once prepared all files, we need to open ArcGIS® in our computer. We can open ArcMap™, ArcScene™, whatever we want.

We need to open the "catalog" window (Fig. 12), and to create the script in the "Toolbox.tbx" folder (Fig. 13) (it is located in the user's "documents" folder, inside the ArcGIS folder). After this we need to give a name (e.g. CaveArtAccessibility), and introduce the script located in the folder where we have placed all files. The direction must be "C:\CaveArtAccessibility\yjasc_105271_CaveArtAccessibility_mmc6.py" (Figs 14, 15 and 16).

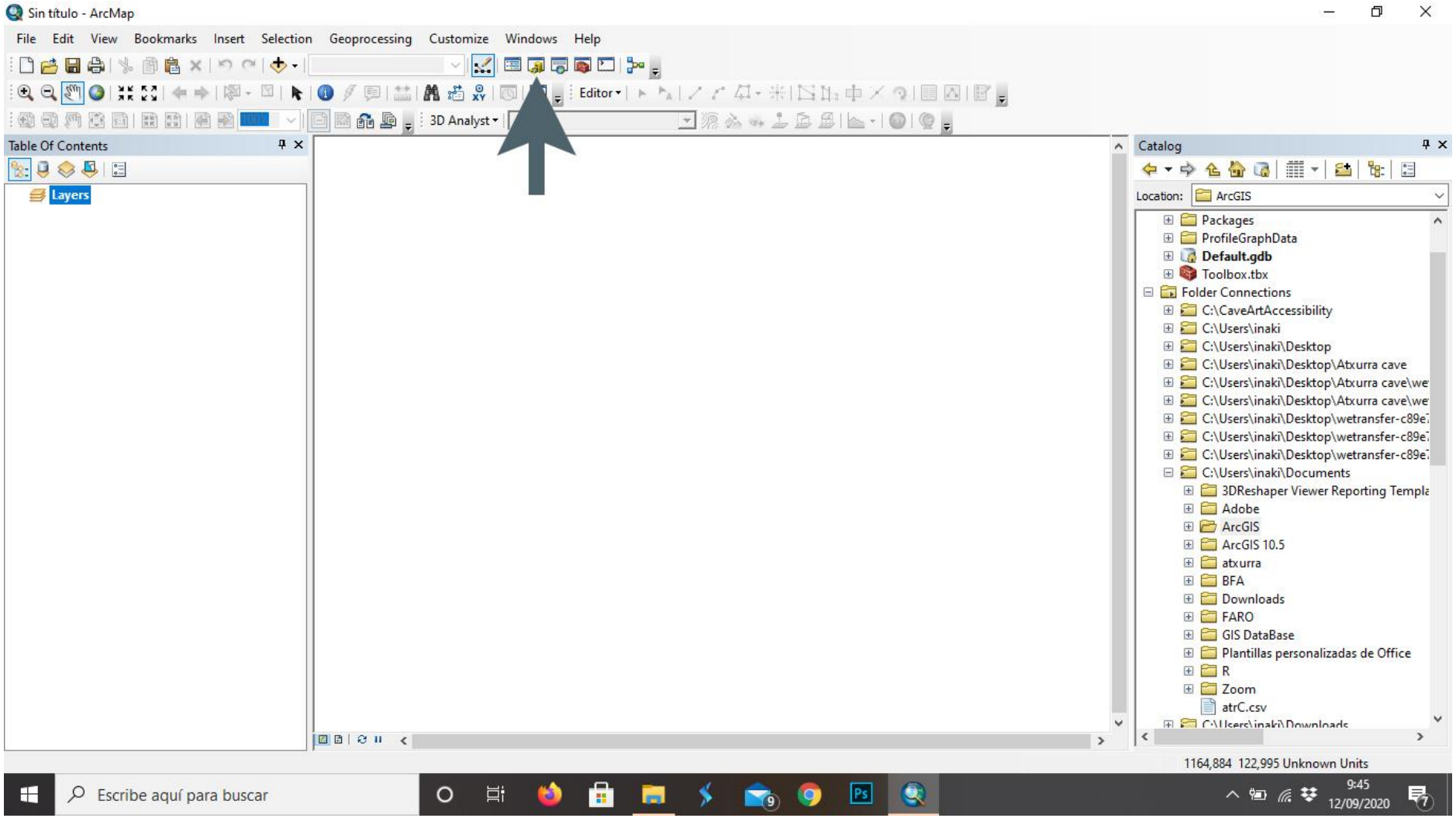


Fig. 12: location of "catalog" window in ArcMap™.

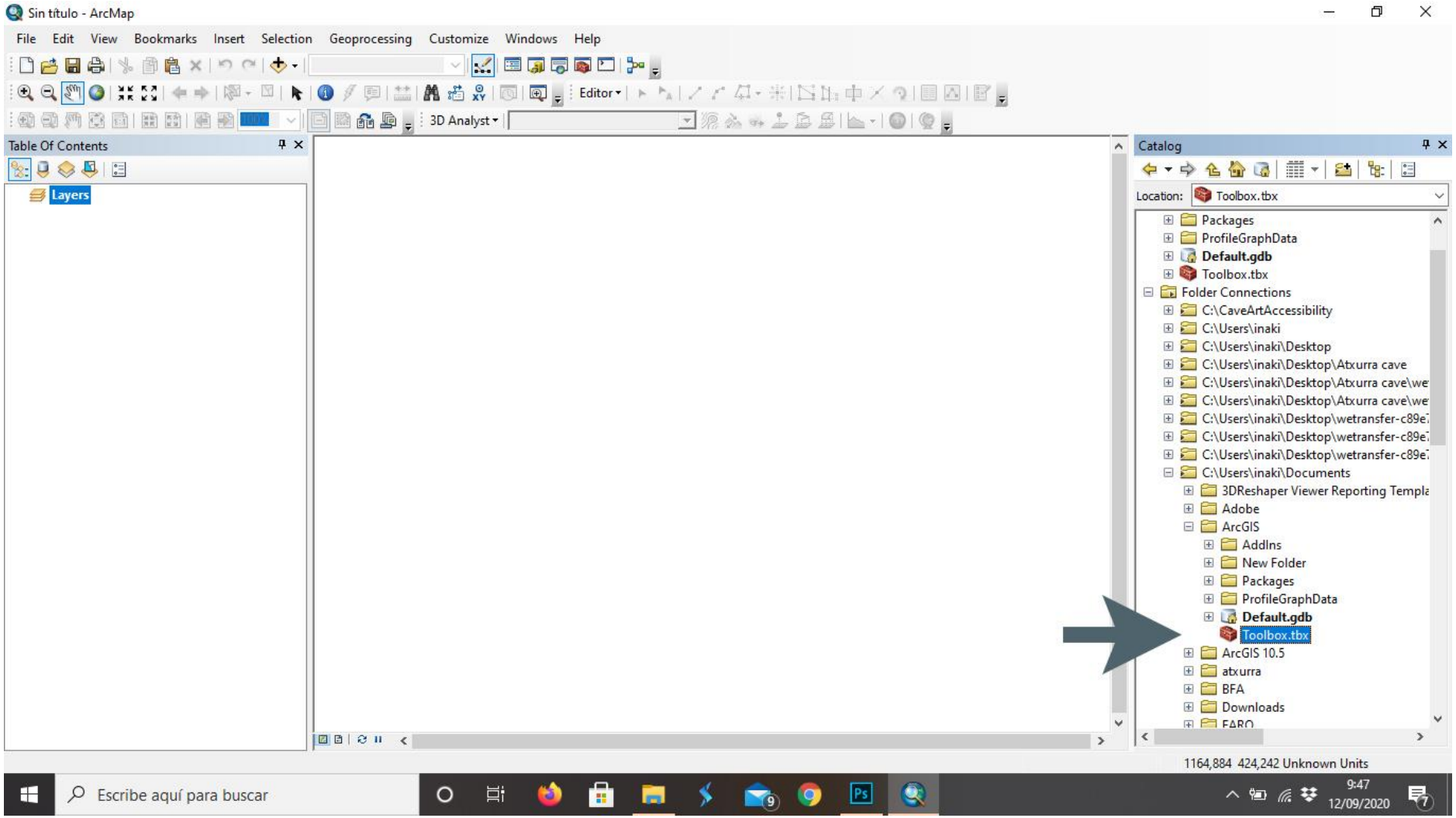


Fig. 13: location of "Toolbox.tbx" folder in ArcMap™.

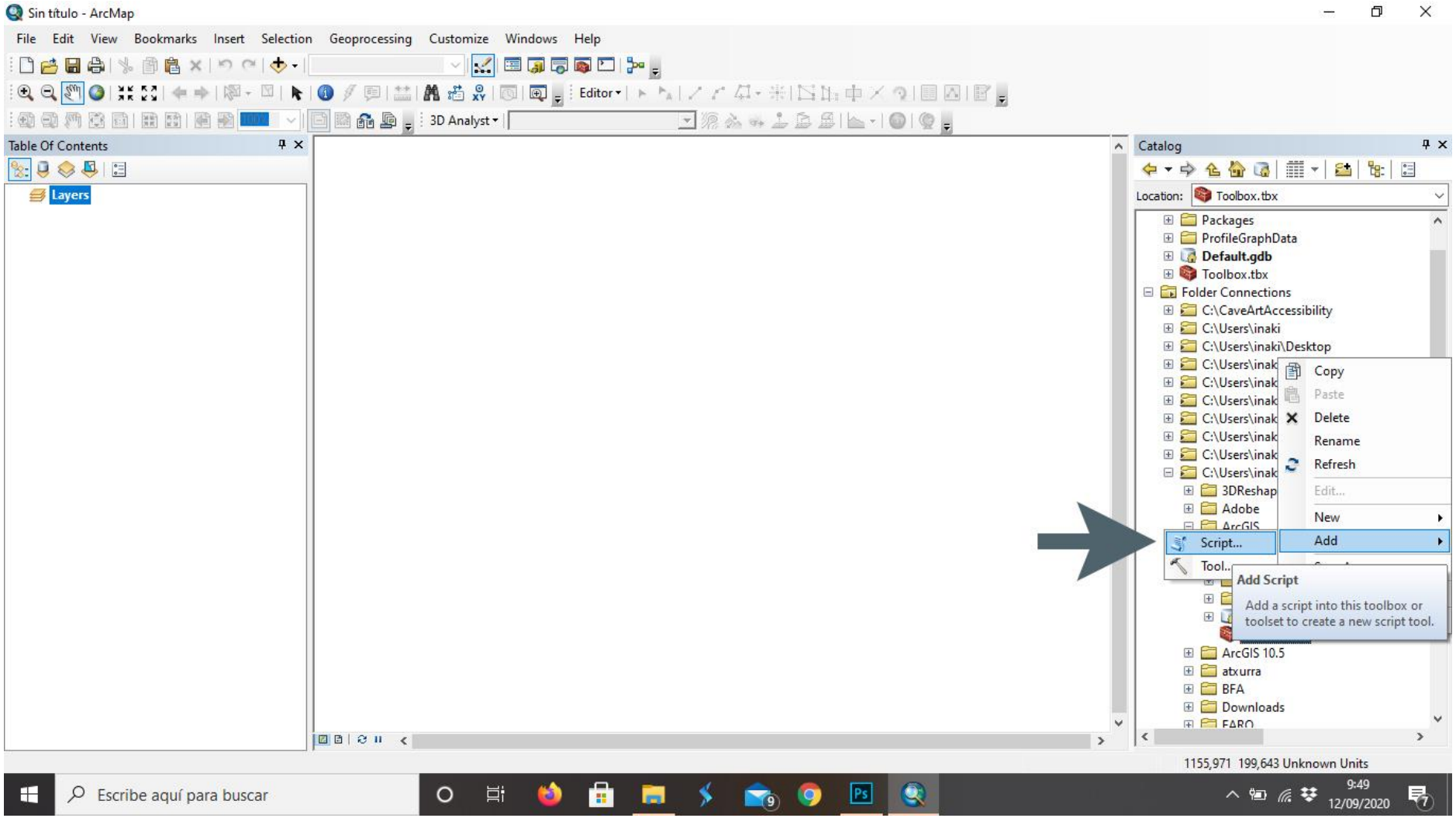


Fig. 14: Creating the script.

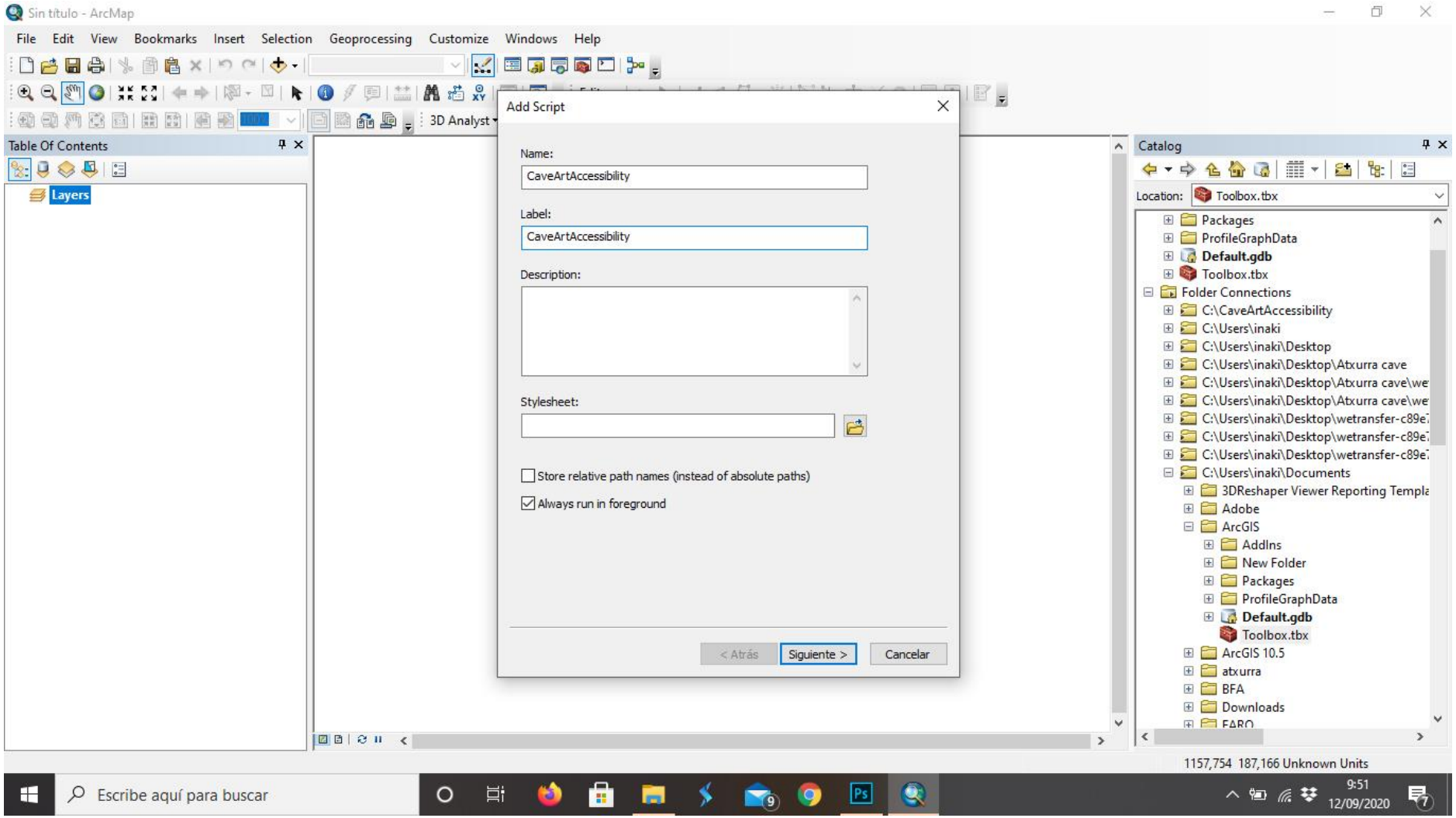


Fig. 15: naming the script.

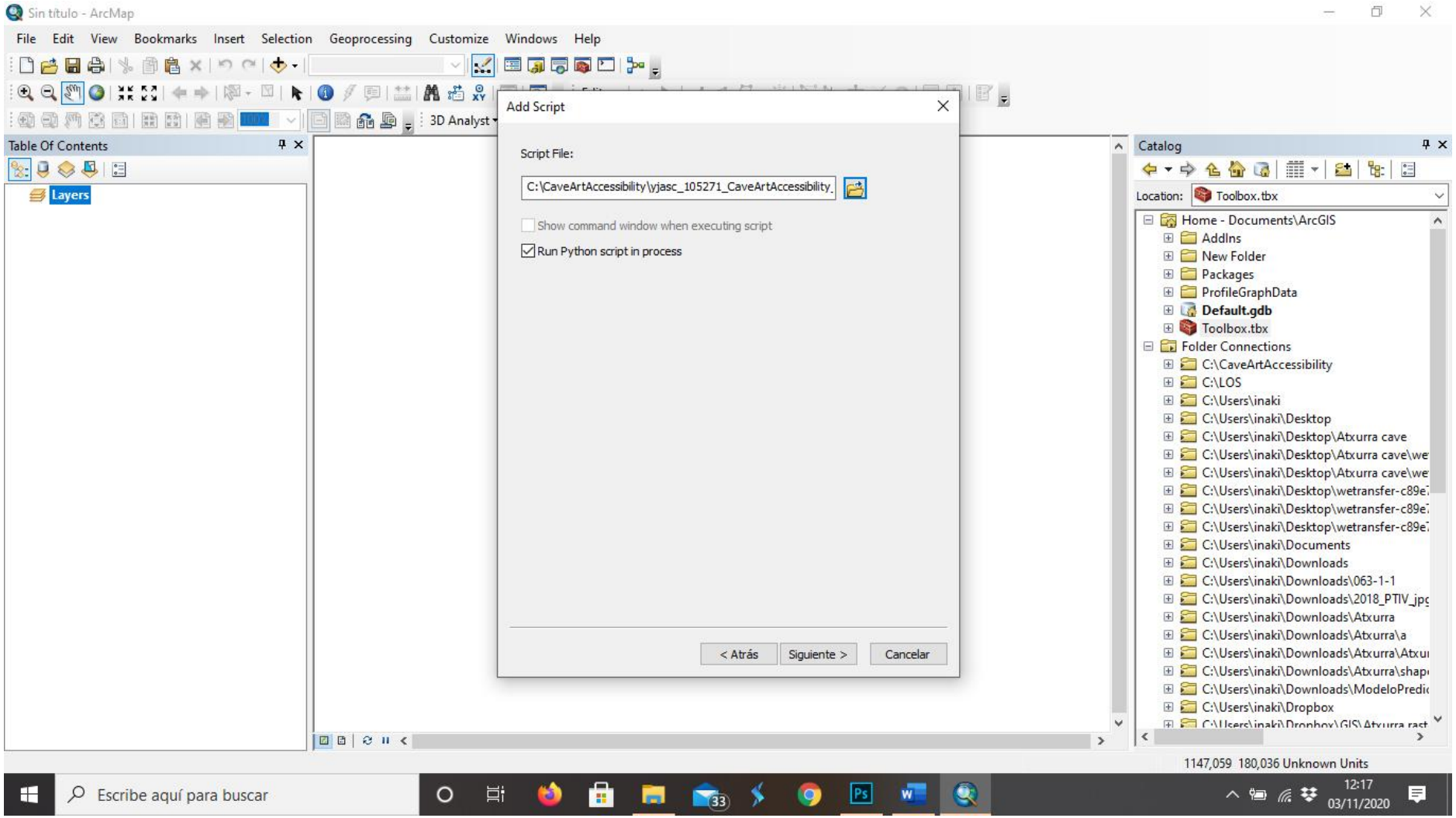


Fig. 16: introducing the script's direction "C:\CaveArtAccessibility\yjasc_105271_CaveArtAccessibility_mmc6.py".

Once made this, we only need to finish this (Fig. 17), and activate the script to run the accessibility analysis (Fig. 18).

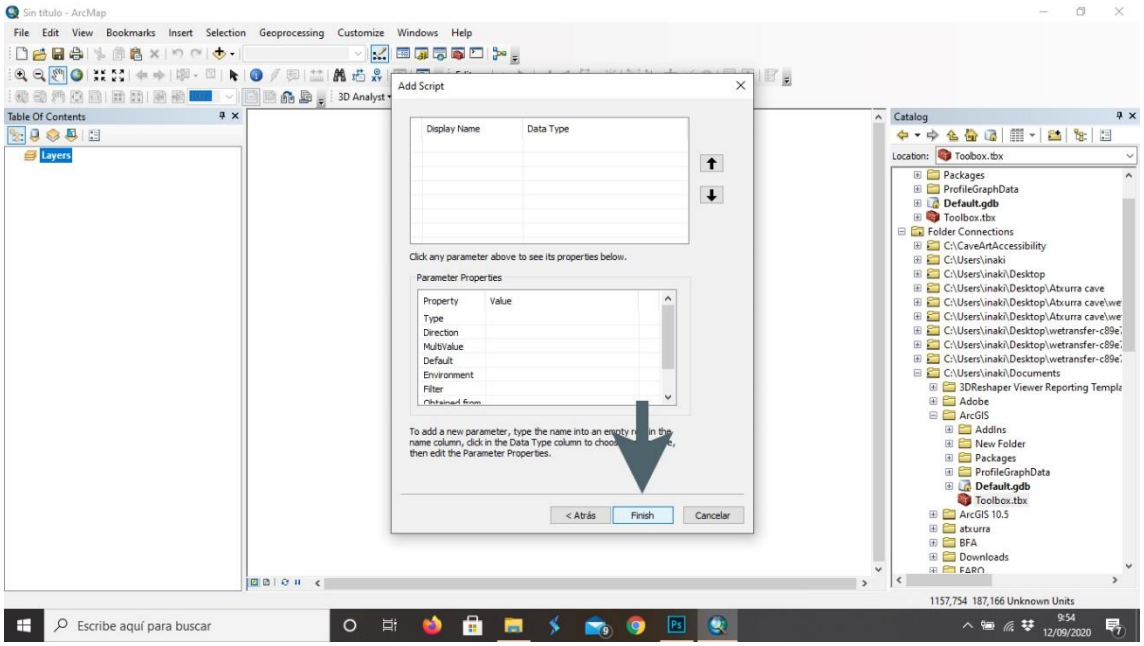


Fig. 17: finishing the creation of the script in ArcMap™.

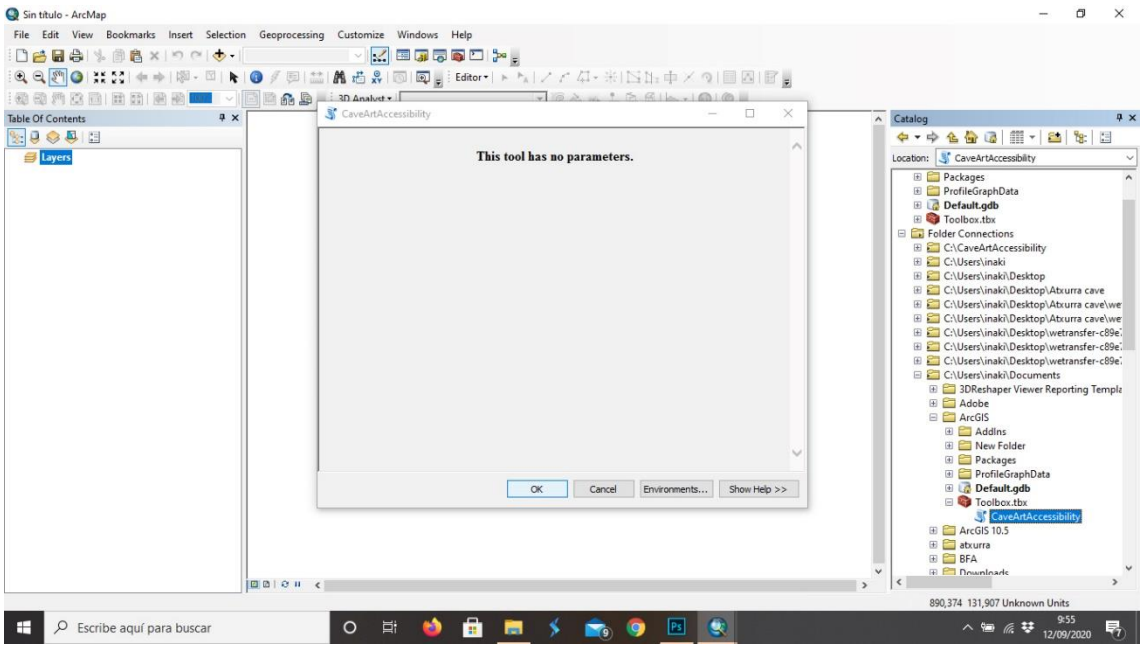


Fig. 18: activating the script in ArcMap™, we need to click "OK" to run the tool.

When the tool is running, it is going to use the 3D models to create raster files for Ceilings and Ground levels. After this, it is going to use them to obtain the galleries size in each cell of the raster (with a dimension of 5 cm^2), measured by the height of the passage, and the slope between cells. For this last thing, software is going to use the ArcGIS® default algorithm[1] for calculating slopes. The script is also going to use this last algorithm to, using trigonometry, obtain the elevation gained between cells, using the next formula:

[1] For more information: https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-slope-works.htm

Slope / 57.296 = Raster1 *Because the tangent is calculated in radians, not in degrees. 57.296 = 180/π*

Tan(Raster1) = Raster for elevations (if we want to obtain the value in meters for each cell, we ned to multiply this by 0.05)

Once calculated these three-dimensional features of the cave (the height of the passages, the slope and the elevation gained), the previously created regression are going to be used to calculate costs.

For this, the script is going to classify the raster obtained for the paleo floors of the cave, depending on the slope. If it is lower than 45º, Walking or Crawling movements are going to be estimated for them. If it is higher than 45º, a Climbing or traversing movement is going to be supposed.

Also, those values of the height of the passage lower than 0.24 are going to be removed, and those values higher than 1.86, are going to be reconverted in 1.86.

The script is also going to use the shapefiles, to calculate the cumulated cost between them as well as the Least Cost Path to reach this sector of the cave (Figs. 19 and 20).

The cost's algorithm and the length of the LCP, can be used to estimate the needed time to reach the sectors of the cave during the Upper Palaeolithic. However, we must to remember that the script has obtained the value counting by cells of 5cm2, so if we want to relate the travel rates and the length (in meters), we need to divide 1 by the cost values (both to walking/crawling and climbing/traversing movements) (to obtain the travel rates in meters by second), and 0.05 by the this travel rates. Prior to this, we need to discard values bigger than 1.23 (because the estimated average maximum value of speed in the experimentation was this), and lower than 0.02 (because the lowest values were given by those volunteers who were not able to overcome the vertical obstacles in 5 minutes). In addition, we need to multiply by gained elevation between cells in those cells with vertical slopes. With this we are going to obtain values of time in seconds to cross each cell.

All files are going to be created in the same folder (C:\CaveArtAccessibility) (Fig. 21).

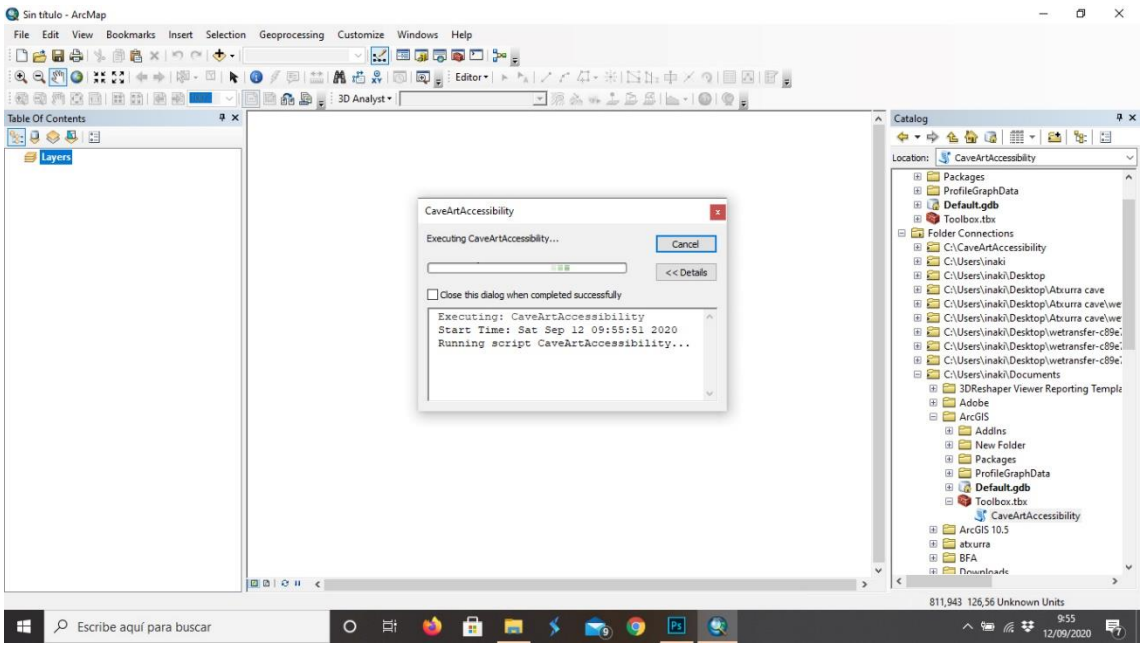


Fig. 19: the script "CaveArtAccessibility" starts to run.

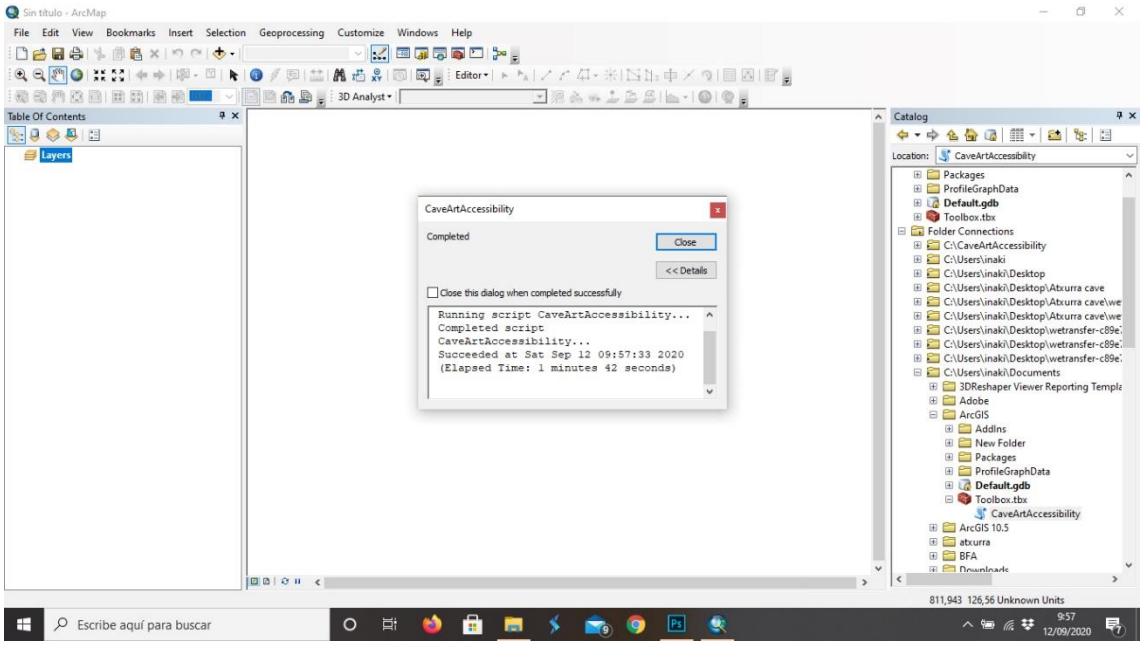


Fig. 20: the script "CaveArtAccessibility" has completed the processes.

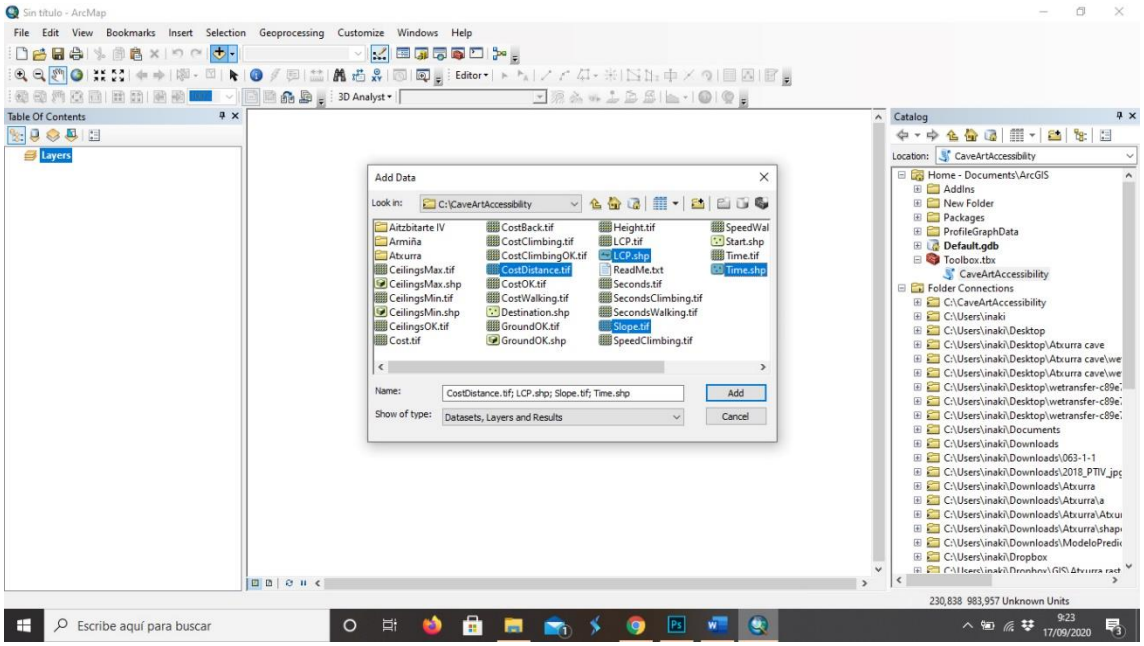


Fig. 21: the files are going to be created in the folder "C:\CaveArtAccessibility". We can open the file "LCP.shp" (by using "Add Data") to see the cost of the accessibility to the analyzed sector of the cave.

The file of the Least Cost Path (LCP.shp), contains an attribute in his own with the value of cumulated cost to reach this sector (Figs. 22 and 23). We can also add a new attribute to calculate the length of this LCP (Figs. 24 and 25).

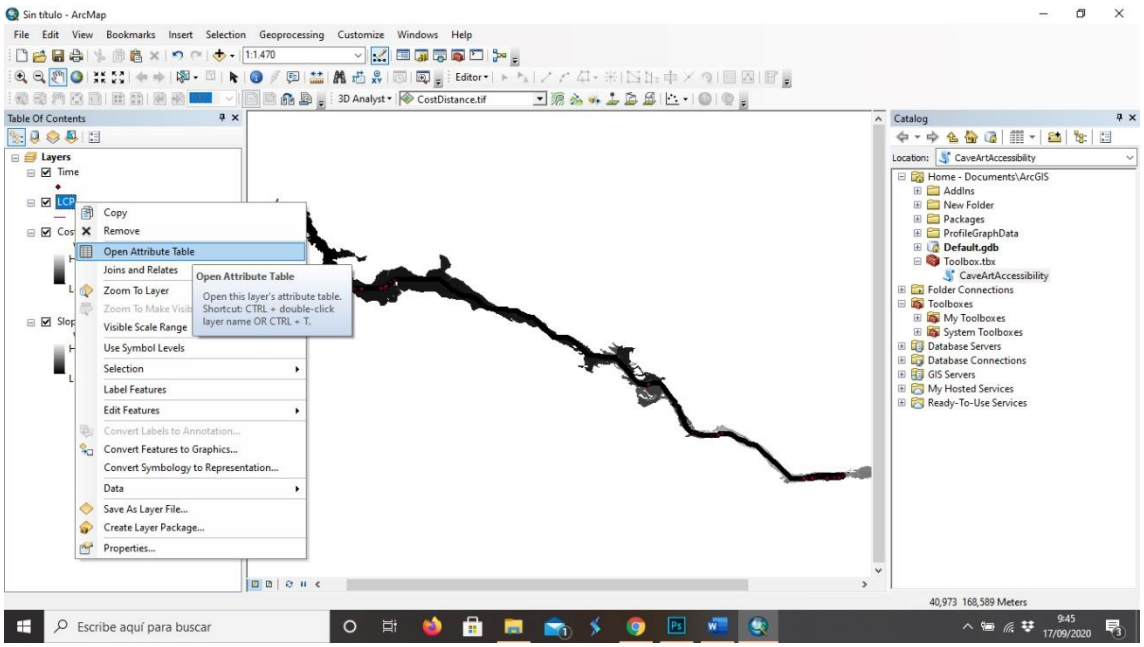


Fig. 22: opening the attribute table to see the cost of the path.

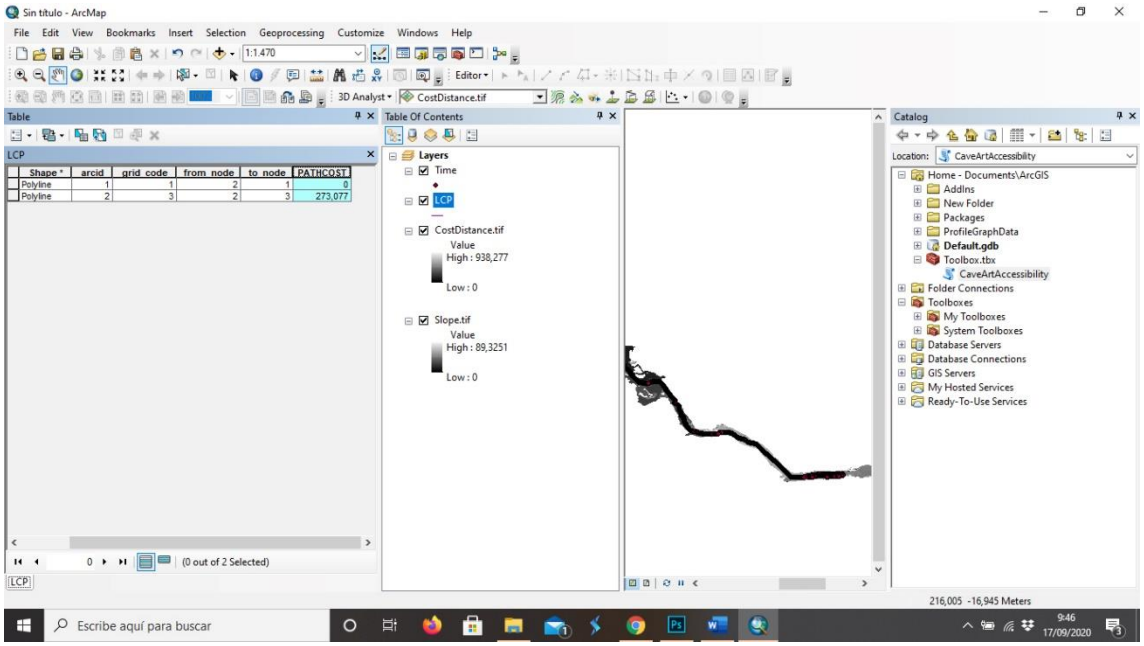


Fig. 23: the cumulated cost value to reach the analyzed sector, calculated in using our travel rates (1 divided by meters per second) for each cell and then using the own algorithm of the software (ArcGIS®) for Cost Distance[2].

[2] For more information: https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-the-cost-distance-tools-work.htm

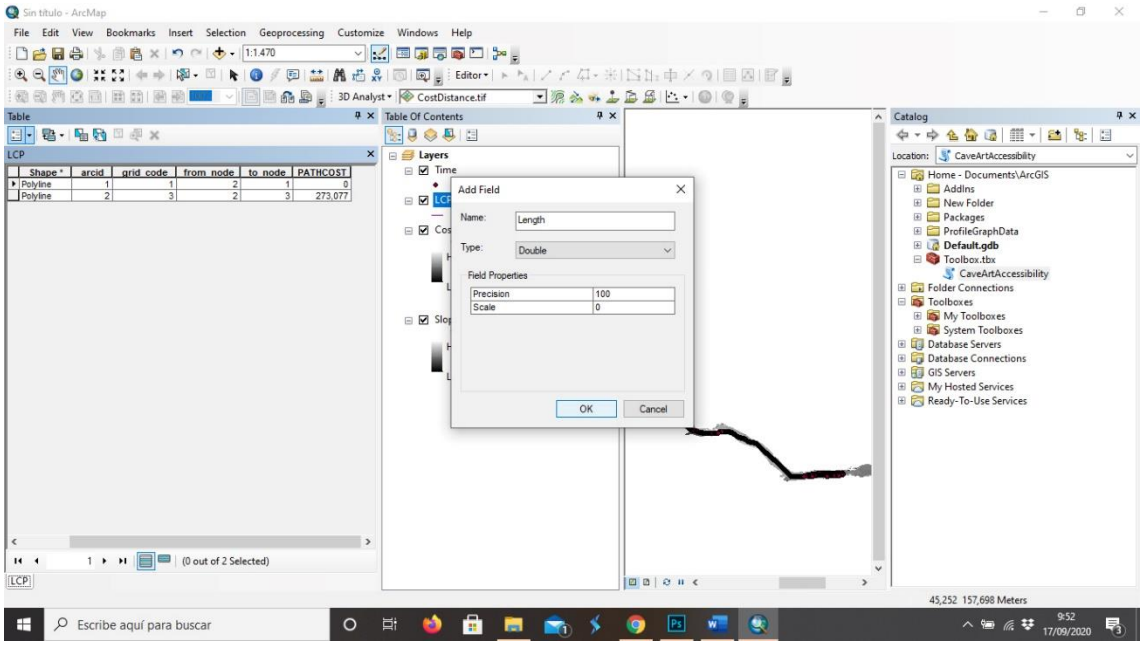


Fig. 24: adding a new attribute to obtain the Length of the path.

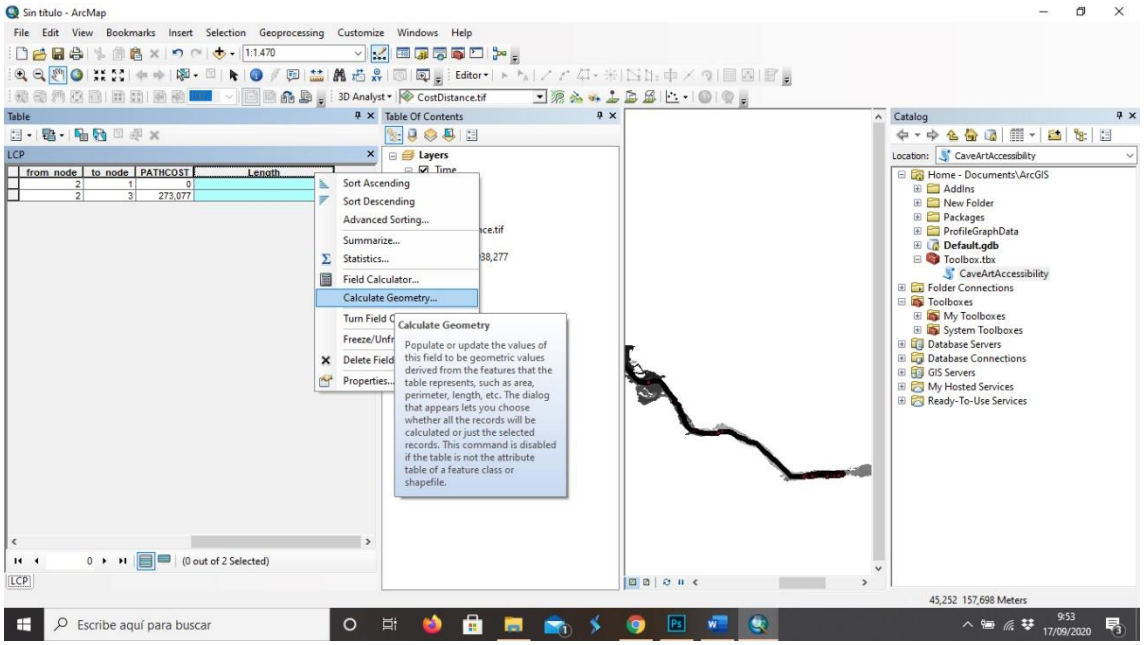


Fig. 25: calculating the geometry of the new attribute.

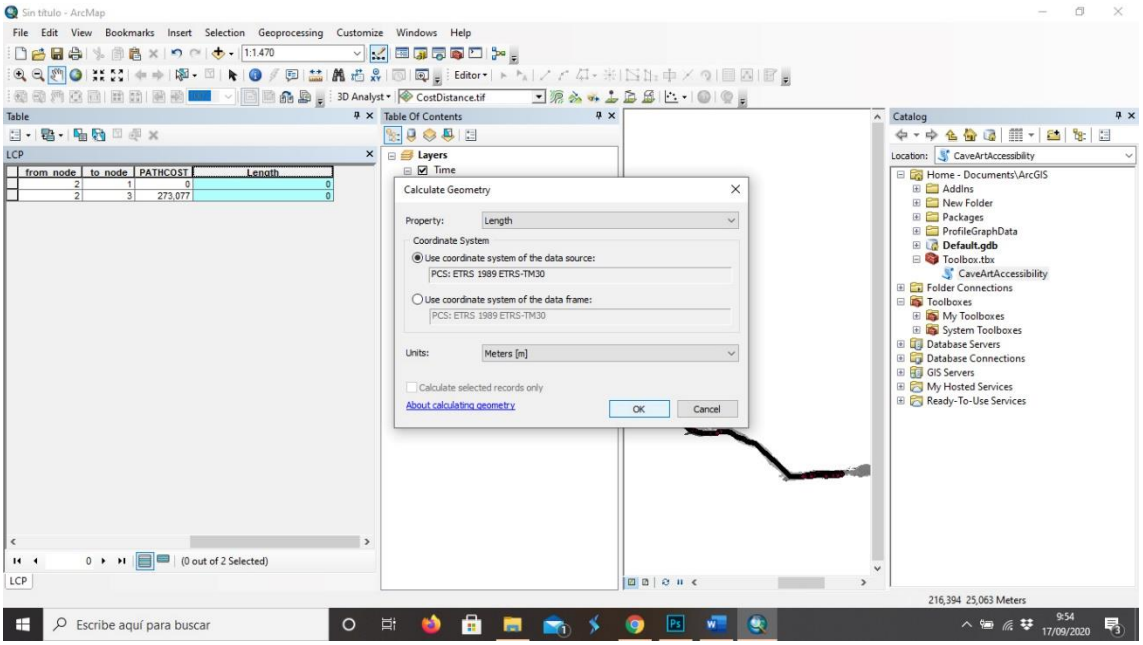


Fig. 26: obtaining the length of the path.

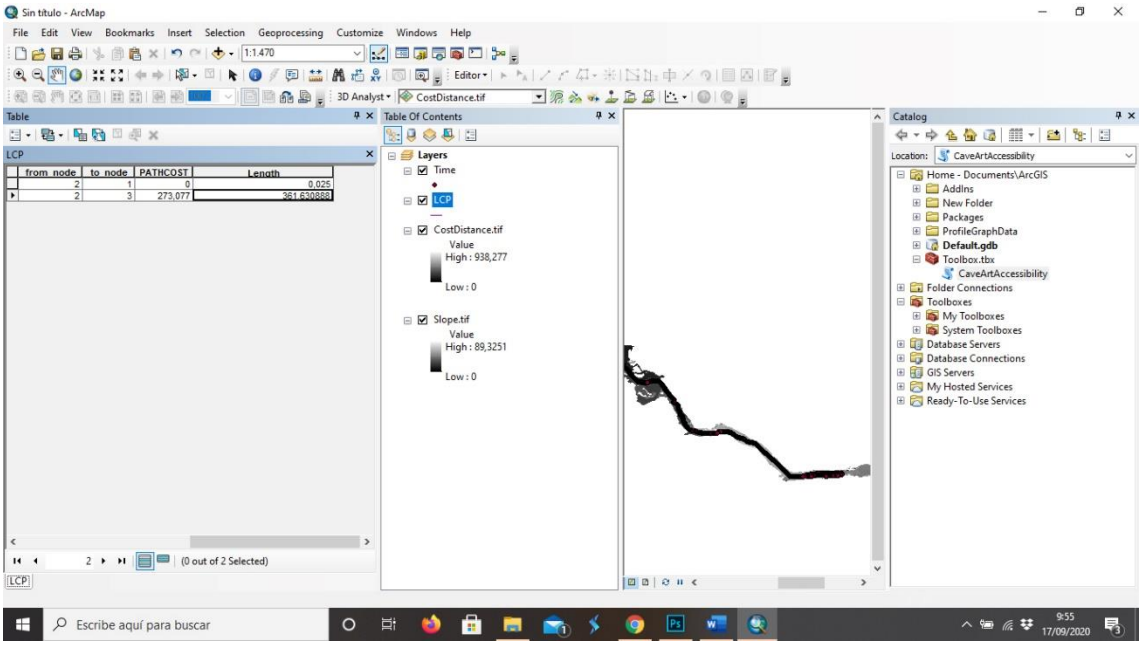


Fig. 27: the length of the LCP (in meters).

The file "CostDistance.tif" can be used to symbolize the cumulated cost over a plan. If we change the colors, we are going to illustrate it better (Fig. 28). We also can use the archive of slopes "Slope.tif" (Fig. 29), to see the unevenness of the floor level, or open these files in ArcScene™, to obtain 3D views of the cave (CeilingsMax.shp) and the LCP (Fig. 30).

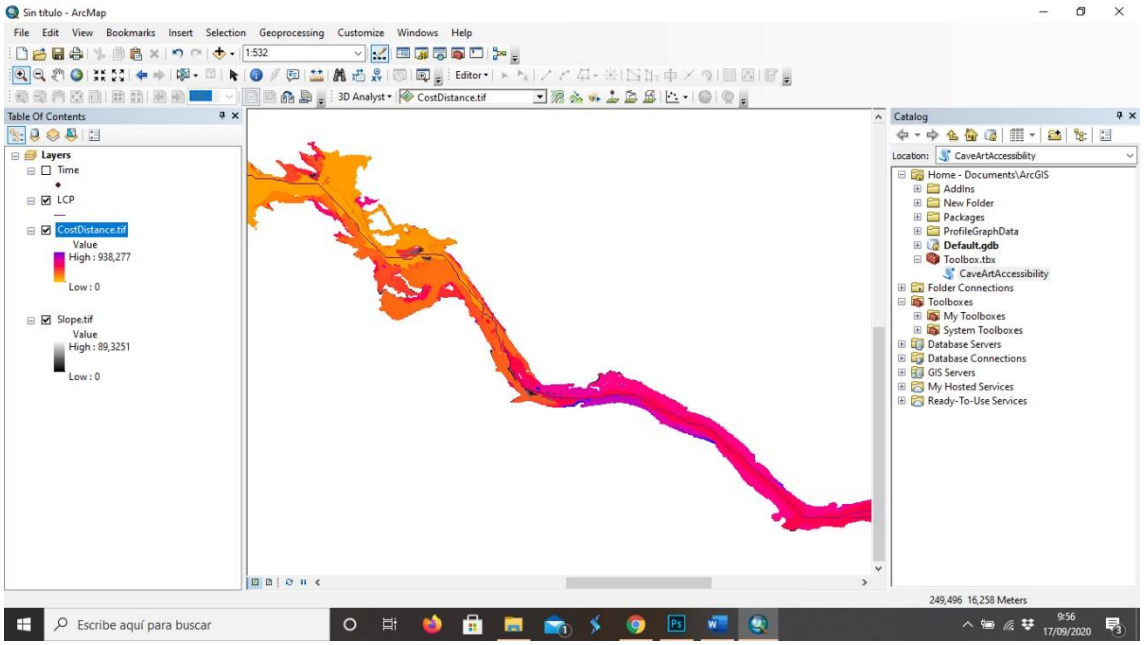


Fig. 28: CostDistance.tif file.

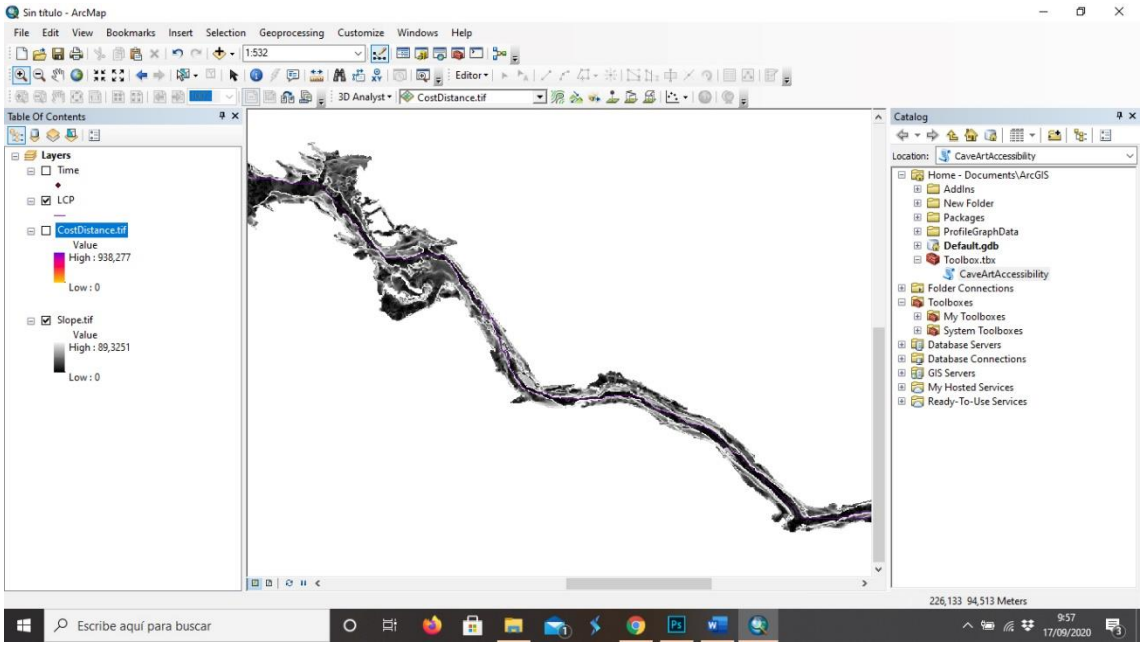


Fig. 29: Slope.tif file.

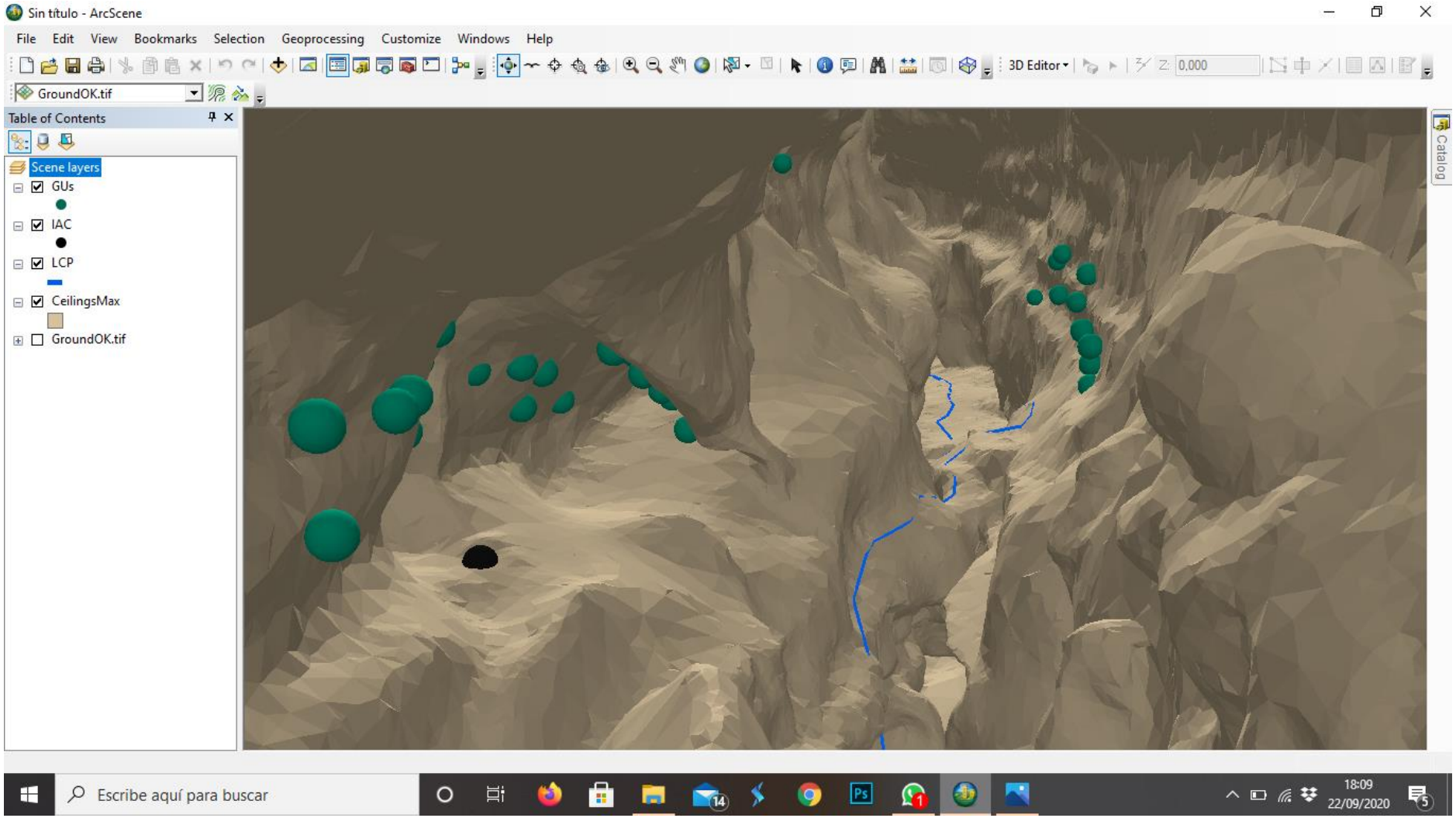


Fig. 30: the 3D model of the cave, opened in ArcScene™ (CeilingsMax.shp), seeing the LCP inside of him, as well as the GUs and the IAC remains.

Also, if we sum all obtained values in each cell in the "Time.shp" file, we can obtain the estimated needed time in the Upper Paleolithic to reach each sector (Figs. 31, 32 and 33)

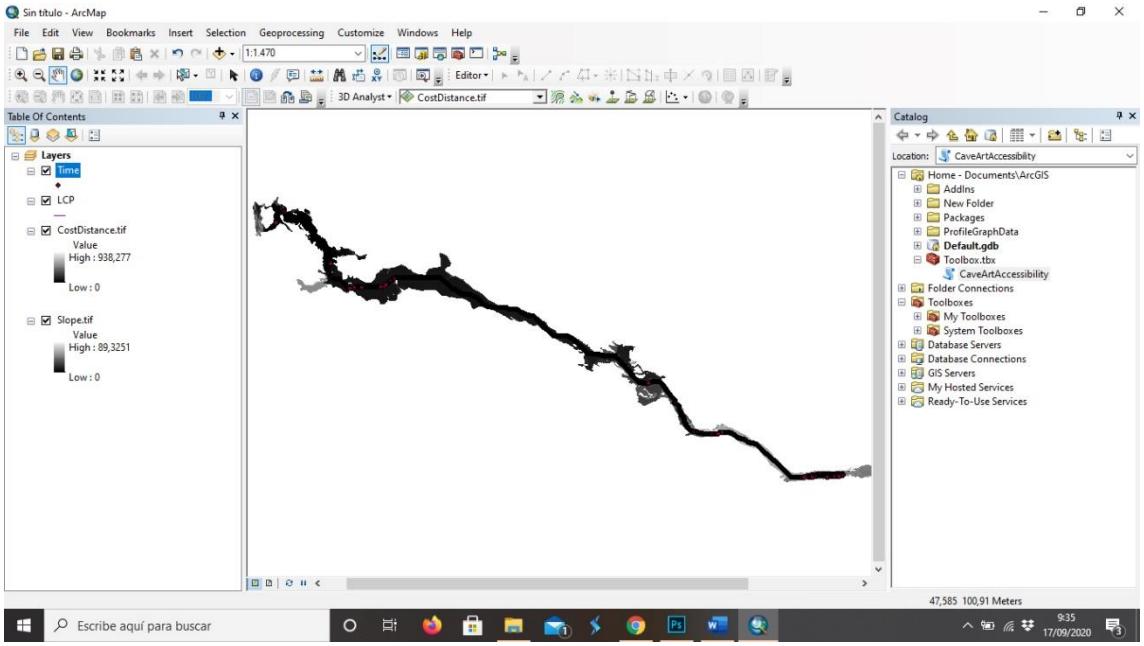


Fig. 31: the "Time.shp" file, can be used to estimate the needed time to reach a sector.

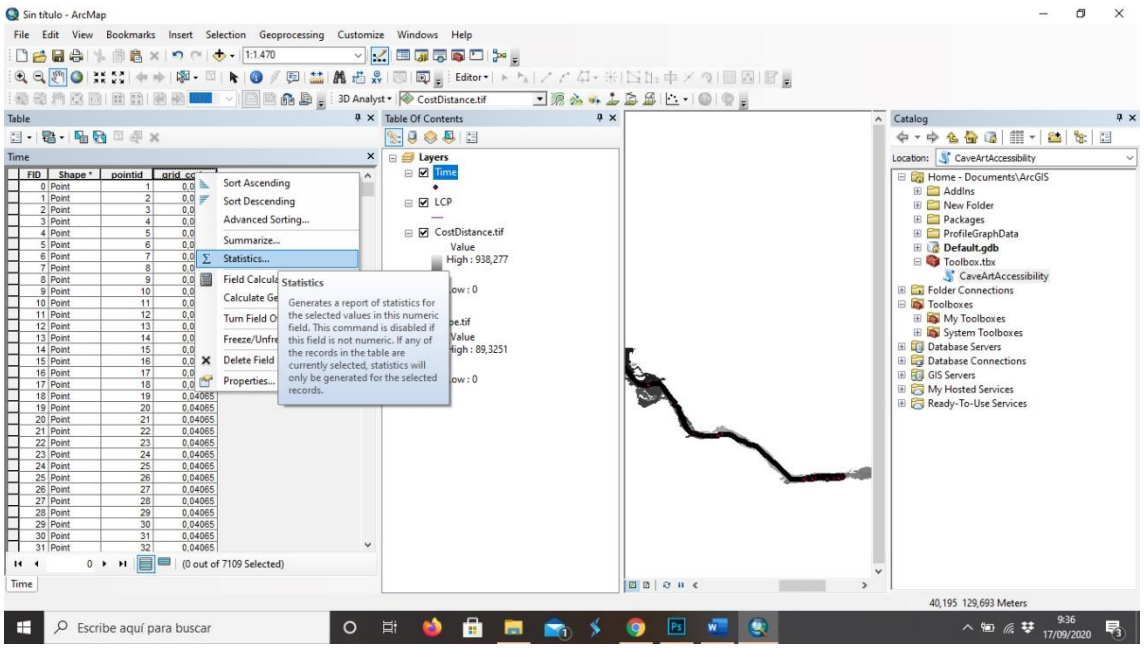
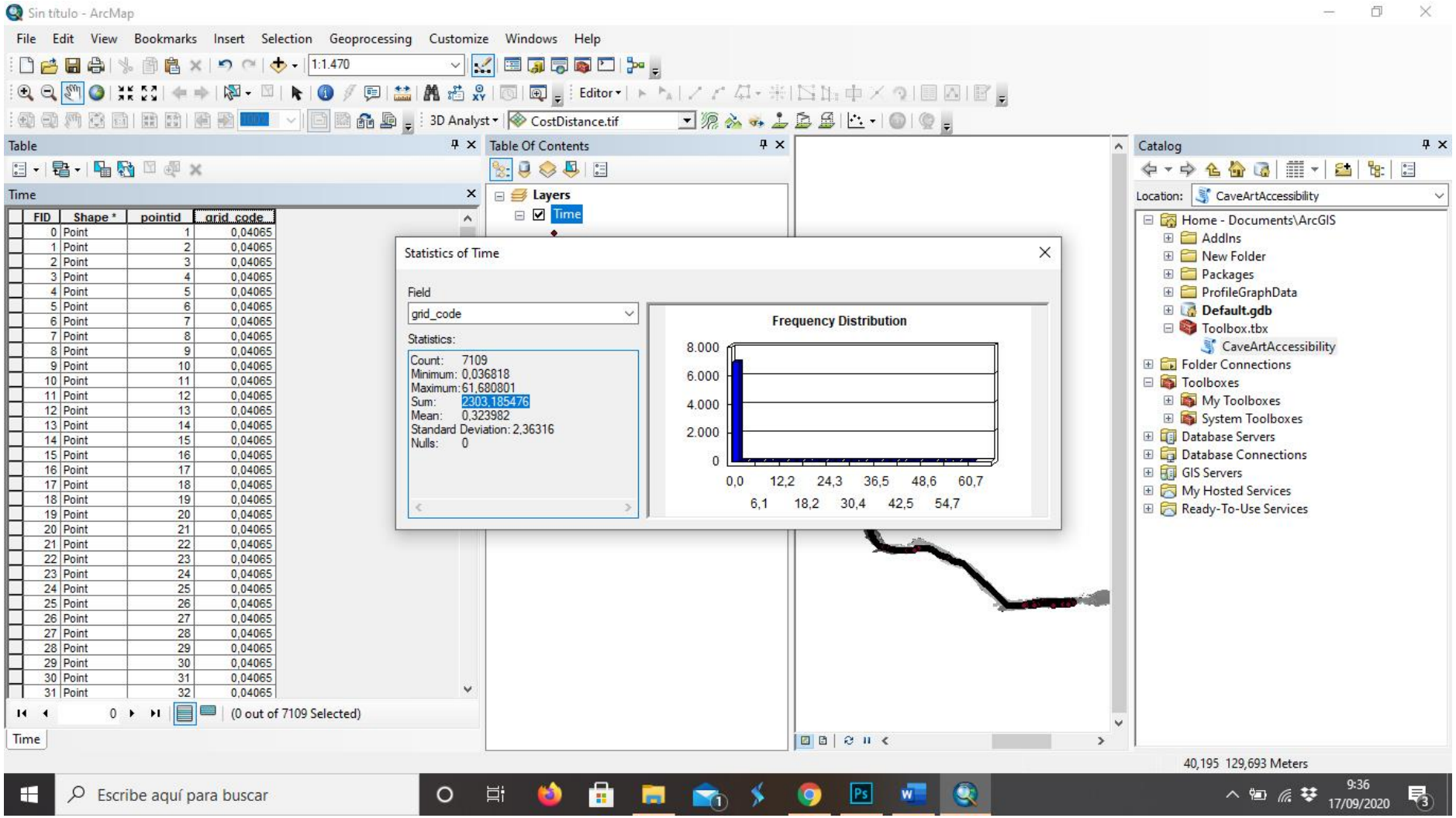


Fig. 32: for this, we need to use the Statistics in the last attribute (which contains the estimated needed time to cross each cell in seconds).



FID	Shape *	pointid	grid_code
0	Point	1	0,04065
1	Point	2	0,04065
2	Point	3	0,04065
3	Point	4	0,04065
4	Point	5	0,04065
5	Point	6	0,04065
6	Point	7	0,04065
7	Point	8	0,04065
8	Point	9	0,04065
9	Point	10	0,04065
10	Point	11	0,04065
11	Point	12	0,04065
12	Point	13	0,04065
13	Point	14	0,04065
14	Point	15	0,04065
15	Point	16	0,04065
16	Point	17	0,04065
17	Point	18	0,04065
18	Point	19	0,04065
19	Point	20	0,04065
20	Point	21	0,04065
21	Point	22	0,04065
22	Point	23	0,04065
23	Point	24	0,04065
24	Point	25	0,04065
25	Point	26	0,04065
26	Point	27	0,04065
27	Point	28	0,04065
28	Point	29	0,04065
29	Point	30	0,04065
30	Point	31	0,04065
31	Point	32	0,04065

Fig. 33: if we divide the sum of the values by 60, we are going to obtain the estimated needed time (in minutes) to reach a sector during the Upper Paleolithic.

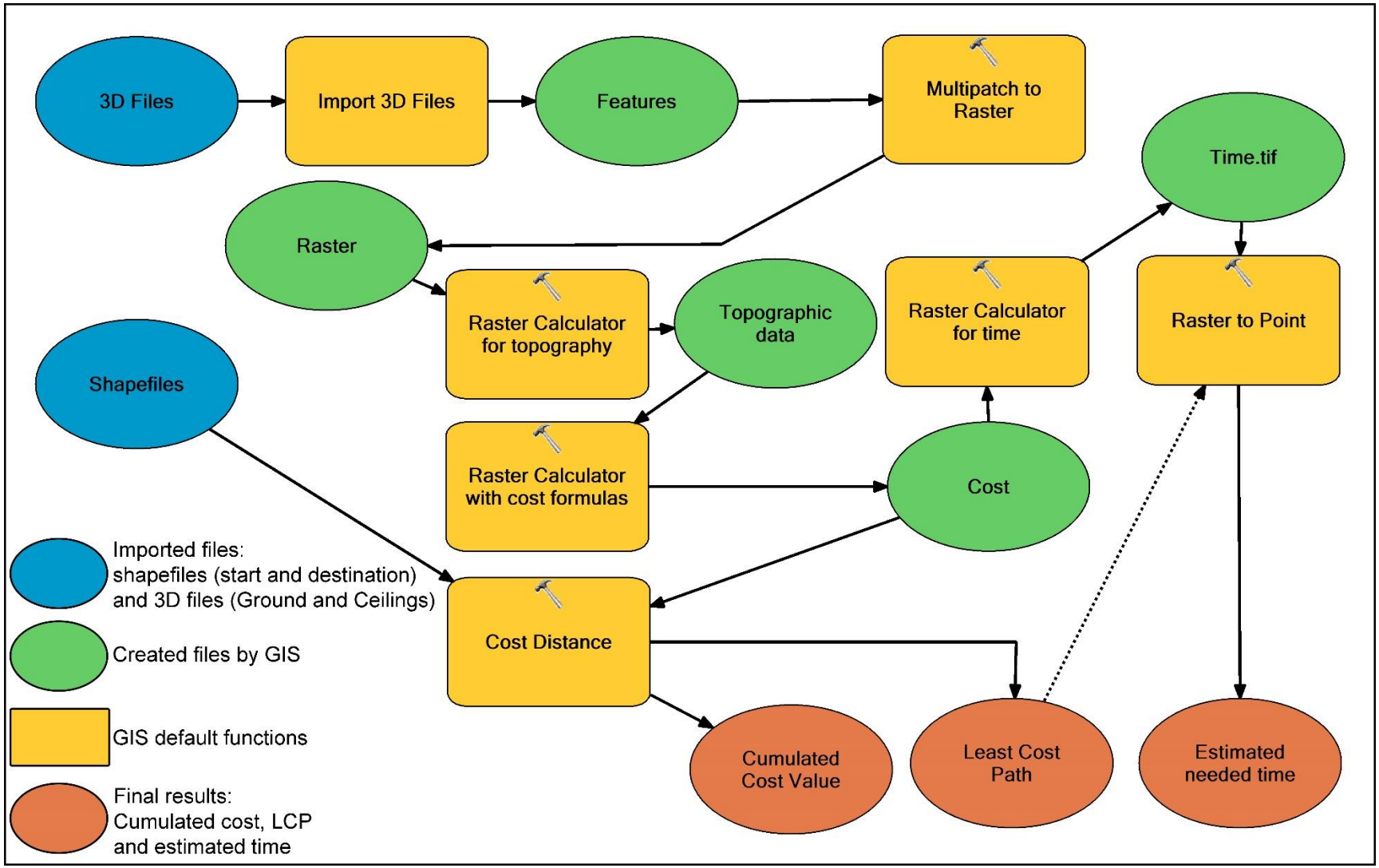


Fig. 34: the python script for ArcGIS® "yjasc_105271_CaveArtAccessibility_mmc6.py" summarized in a conceptual map made with Model Builder™.