Urban Network Analysis Tutorial in ArcGIS

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ArcGIS version used: ArcGIS 10.6

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1) Introduction

This tutorial provides a step-by-step guide to applying urban network analysis within GIS. By working through this tutorial you will learn how to create a GIS map consisting of building shapefiles, a street network, and perform a variety of different analyses using the UNA toolbox. A dataset including building and street shapefiles from the Roman city of Ostia accompanies this tutorial to enable you to work through all of the steps and successfully apply different urban network analysis metrics.

2) Assumed Knowledge & Setup Tips

This tutorial assumes that you have a basic working knowledge of ArcGIS.

Make sure your windows operating systems is set to English as problems might arise in being able to successfully execute the analysis.

This tutorial refers to urban network analysis which integrates two regularly used methods of analysis, network analysis and its subset, space syntax.

For different ways of using urban network analysis see, http://cityform.mit.edu/papers. This contains a full list of publications arising from the creators of the UNA Toolbox.

For an example of the Toolbox's application to an archaeological context, see: https://link.springer.com/chapter/10.1007%2F978-3-030-04576-0_15

For introductory resources about network science more generally, see: https://archaeologicalnetworks.wordpress.com/network-science-bibliography/#introductory

For a brief introduction into space syntax, see Bafna 2003: http://www.ihc.ucsb.edu/wp-content/uploads/2015/09/Environment-and-Behavior-2003-Bafna-17-29.pdf

3) Download and add the UNA toolbox to ArcGIS

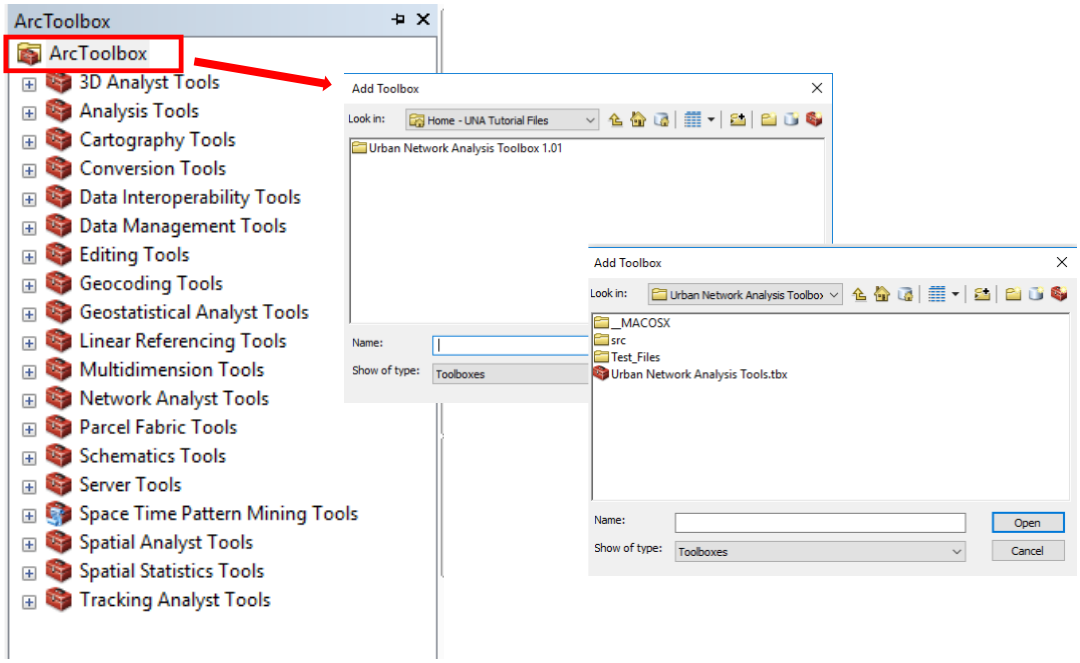
The UNA toolbox is open source and can be downloaded free of charge for Windows

Go to http://cityform.mit.edu/projects/urban-network-analysis.html

Download the toolbox, extract all files, and save files to a known location.

To add the UNA Toolbox to the general toolbox within ArcGIS do the following:

- Open a new map in ArcMap and open ArcToolbox
- *Right click ArcToolbox -> Add Toolbox -> select file download location*



The UNA Toolbox should now appear at the bottom of ArcToolbox, below the 'Tracking Analyst Tools'

4) UNA Toolbox Resources

The UNA Toolbox has a user manual detailing its setup, installation, and use:
http://media.voog.com/0000/0036/2451/files/20160120_UNA_help_v1_1.pdf

5) Download GIS Dataset

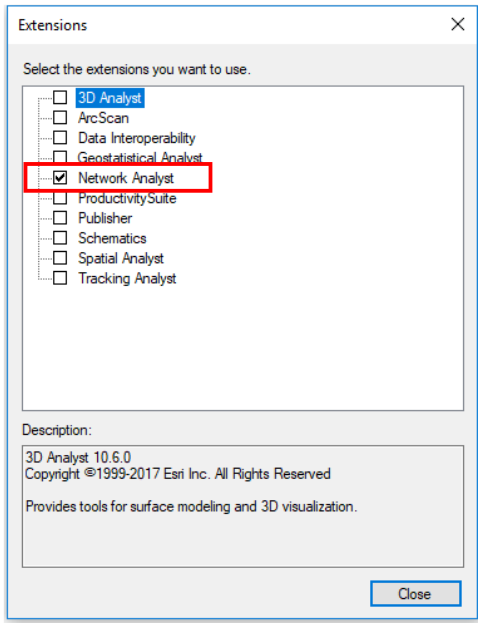
Download and save the sample tutorial dataset. The data represents a portion of the built environment of Ostia during late 2nd century CE. Included are shapefiles of both the building polygons and the street network.

6) Activate the Network Extension

Before you can use the UNA toolbox you first have to active the Network Analyst extension which is used by the toolbox to undertake its calculation.

To activate the extension do the following in ArcMap:

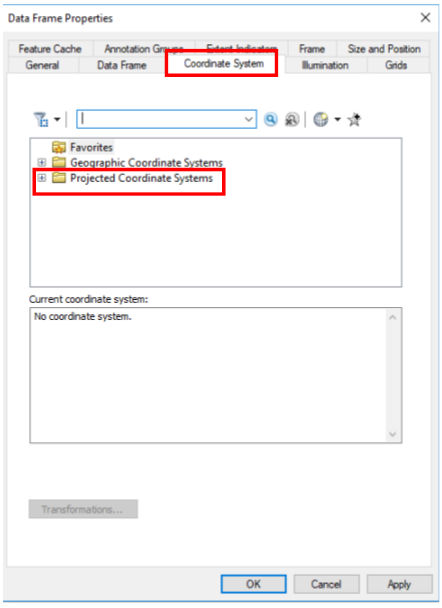
- Navigate to the main menu and select *customize -> Extensions*
- Once the Extensions box is open, select "Network Analyst" and then close the box



7) Create a New GIS Map

Before importing the different building and street files, you will first need to set the coordinate system projection of the project in ArcMap. The dataset that you will be working with comes from Ostia, which uses the projected coordinate system (Roma 1940 Gauss Boaga Est*)*.

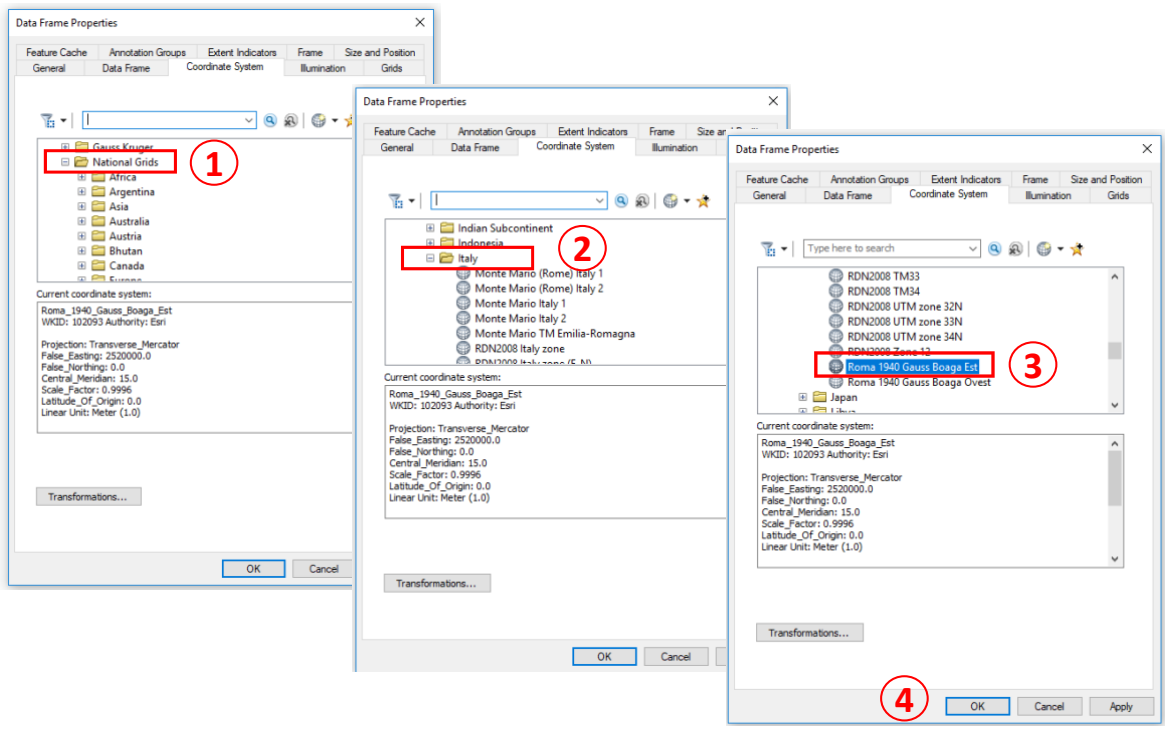
In order to add the appropriate coordinate system, right click the blank map and select *dataframe -> projected coordinate system*



You can either search for the coordinate system, or you can navigate to it manually.

To manually find the correct projection do the following:

- Select *Projected Coordinate System -> National Grids -> Italy ->Roma 1940 Gauss Boaga Est.*
- Select the appropriate projected coordinate system and star it. This will make it easier when importing or digitizing new shapefiles to associate them with the correct coordinate projection system.

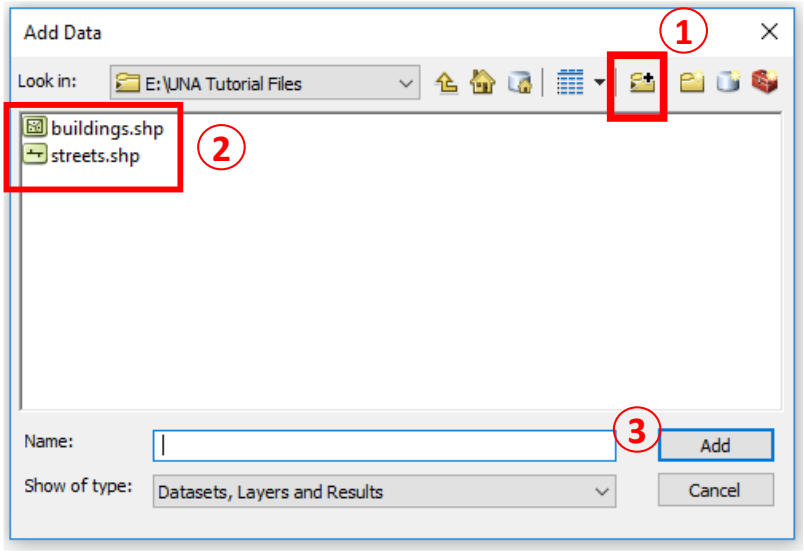


Save your new GIS project with a unique identifiable name eg: “UNA_Ostia.mxd”

8) Import GIS Shapefiles

Import the relevant shapefiles that you previously downloaded which relate to Ostia’s building and streets.

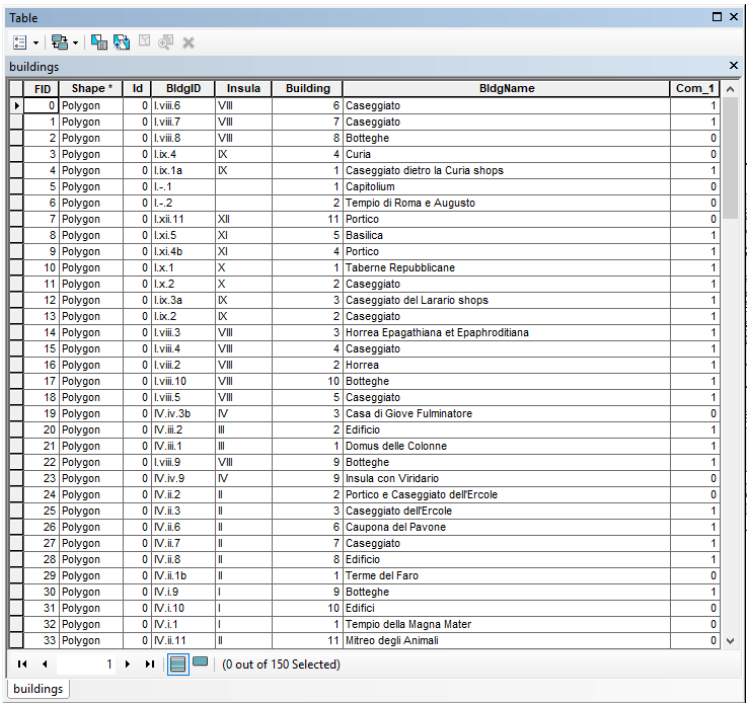
In order to import the data you will need to navigate to *Add data -> connect to relevant folder -> select & highlight all relevant shapefiles -> select Add*



Make sure that the shapefiles are **not** imported into a geodatabase. The UNA toolbox will not work if building shapefiles are situated within one.

9) Check Shapefile Data

Once the two shapefiles are successfully added to you map, check the data that is included. Open the attribute table of the "buildings" shapefile. You will see that each buildings has a set of information. BldgID refers to the unique ID given to each building at Ostia. The associated building name is shown in column "BldgName". The last column labeled "Com_1" represents buildings that likely had a commercial function. Any building provided a value of 1 is identified as having a commercial function. The buildings labeled with a value of 0 have an alternative function. This column will be used later in this tutorial to demonstrate how centrality calculations can be run using weighted variables.



Table

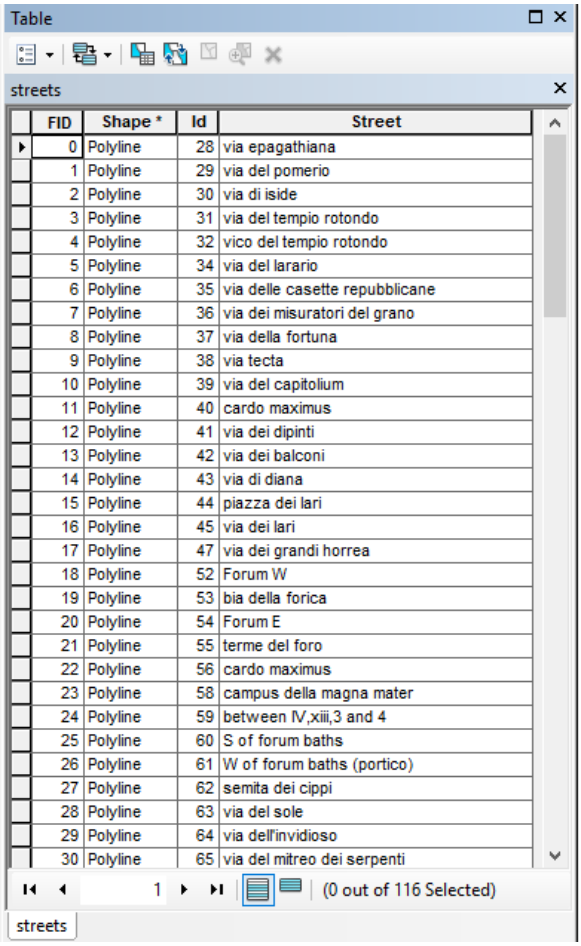
buildings

FID	Shape *	Id	BldgID	Insula	Building	BldgName	Com_1
0	Polygon	0	I.viii.6	VIII	6	Caseggiato	1
1	Polygon	0	I.viii.7	VIII	7	Caseggiato	1
2	Polygon	0	I.viii.8	VIII	8	Botteghe	0
3	Polygon	0	I.ix.4	IX	4	Curia	0
4	Polygon	0	I.ix.1a	IX	1	Caseggiato dietro la Curia shops	1
5	Polygon	0	I.-.1		1	Capitolium	0
6	Polygon	0	I.-.2		2	Tempio di Roma e Augusto	0
7	Polygon	0	I.xii.11	XII	11	Portico	0
8	Polygon	0	I.xi.5	XI	5	Basilica	1
9	Polygon	0	I.xi.4b	XI	4	Portico	1
10	Polygon	0	I.x.1	X	1	Taberne Repubblicane	1
11	Polygon	0	I.x.2	X	2	Caseggiato	1
12	Polygon	0	I.ix.3a	IX	3	Caseggiato del Larario shops	1
13	Polygon	0	I.ix.2	IX	2	Caseggiato	1
14	Polygon	0	I.viii.3	VIII	3	Horrea Epagathiana et Epaphroditiana	1
15	Polygon	0	I.viii.4	VIII	4	Caseggiato	1
16	Polygon	0	I.viii.2	VIII	2	Horrea	1
17	Polygon	0	I.viii.10	VIII	10	Botteghe	1
18	Polygon	0	I.viii.5	VIII	5	Caseggiato	1
19	Polygon	0	IV.iv.3b	IV	3	Casa di Giove Fulminatore	0
20	Polygon	0	IV.iii.2	III	2	Edificio	1
21	Polygon	0	IV.iii.1	III	1	Domus delle Colonne	1
22	Polygon	0	I.viii.9	VIII	9	Botteghe	1
23	Polygon	0	IV.iv.9	IV	9	Insula con Viridario	0
24	Polygon	0	IV.ii.2	II	2	Portico e Caseggiato dell'Ercole	0
25	Polygon	0	IV.ii.3	II	3	Caseggiato dell'Ercole	1
26	Polygon	0	IV.ii.6	II	6	Caupona del Pavone	1
27	Polygon	0	IV.ii.7	II	7	Caseggiato	1
28	Polygon	0	IV.ii.8	II	8	Edificio	1
29	Polygon	0	IV.ii.1b	II	1	Terme del Faro	0
30	Polygon	0	IV.i.9	I	9	Botteghe	1
31	Polygon	0	IV.i.10	I	10	Edifici	0
32	Polygon	0	IV.i.1	I	1	Tempio della Magna Mater	0
33	Polygon	0	IV.ii.11	II	11	Mitreo degli Animali	0

1 (0 out of 150 Selected)

buildings

Open the “streets” shapefile. You will see that each street has an id number, this just serves as a counter of the number of streets. Since the street network used for this tutorial is just a portion of Ostia’s total cityscape, there are likely missing street “id” numbers. Each street with a given name following excavations of the city are recorded in the column labeled “Street”. Some streets have no associated name, in these instances, this field is left blank.



FID	Shape *	Id	Street
0	Polyline	28	via epagathiana
1	Polyline	29	via del pomerio
2	Polyline	30	via di iside
3	Polyline	31	via del tempio rotondo
4	Polyline	32	vico del tempio rotondo
5	Polyline	34	via del larario
6	Polyline	35	via delle casette repubblicane
7	Polyline	36	via dei misuratori del grano
8	Polyline	37	via della fortuna
9	Polyline	38	via tecta
10	Polyline	39	via del capitolium
11	Polyline	40	cardo maximus
12	Polyline	41	via dei dipinti
13	Polyline	42	via dei balconi
14	Polyline	43	via di diana
15	Polyline	44	piazza dei lari
16	Polyline	45	via dei lari
17	Polyline	47	via dei grandi horrea
18	Polyline	52	Forum W
19	Polyline	53	bia della forica
20	Polyline	54	Forum E
21	Polyline	55	terme del foro
22	Polyline	56	cardo maximus
23	Polyline	58	campus della magna mater
24	Polyline	59	between IV,xiii,3 and 4
25	Polyline	60	S of forum baths
26	Polyline	61	W of forum baths (portico)
27	Polyline	62	semita dei cippi
28	Polyline	63	via del sole
29	Polyline	64	via dell'invidioso
30	Polyline	65	via del mitreo dei serpenti

10) Create Network Dataset

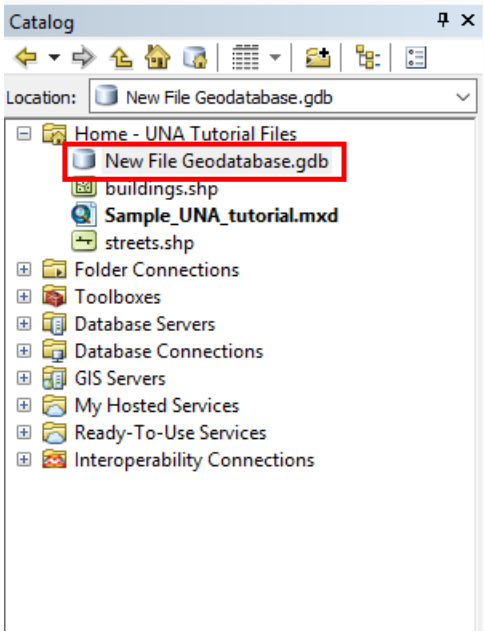
Ensure the network analyst extension is engaged.

In order to create a network dataset using the ArcGIS extension, you will need to create a new geodatabase.gdb. This is done by right clicking the folder you would like the save the geodatabse within, you can saved it within the home UNA tutorial files folder.

To create a new geodatabase do the following:

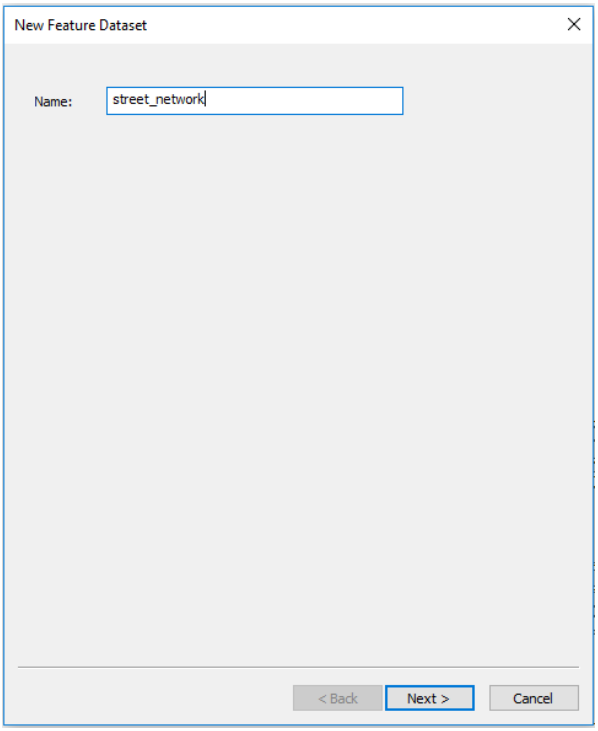
- *Right click home – UNA Tutorial Files -> New -> File Geodatabase*

A new file geodatabase should now be visible within ArcCatalogue. Rename it with a specific identifiable name.



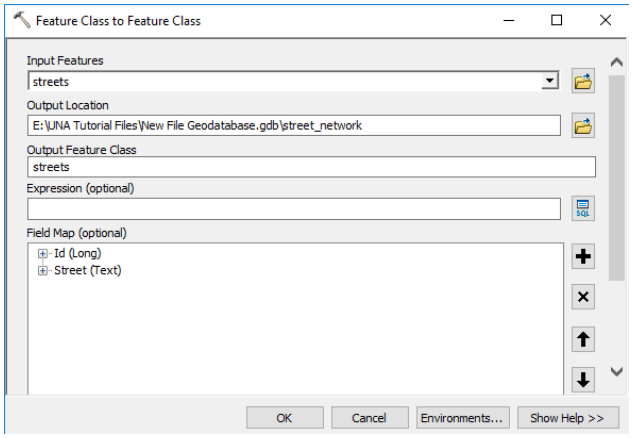
Next you will need to create a new feature dataset. This is the location where we will be able to create the street network. To accomplish this do the following:

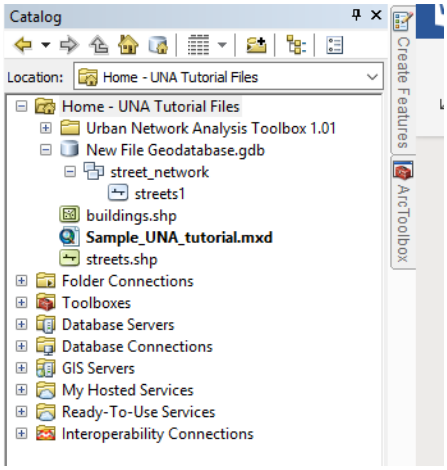
- *Right click File Geodatabase -> New -> Feature Dataset -> save as street_network*



Next you will need to import your "street" shapefile into your new feature dataset. To accomplish this do the following:

- *Right click street_network feature dataset -> import -> feature class (single)*
- Select streets and change the Output Feature Class name to "streets1" so that it is differentiated from the original streets shapefile.





Now you are ready to create a new network dataset

To create a network dataset do the following:

- *Right click street_network (feature dataset) -> New -> Network Dataset*
- When the box opens up, enter a clearly identifiable name for the network dataset "Street_Network_ND" and click next

- Choose the latest version for your network dataset "10.1" and click next

- Choose the feature class that will participate in network, which is "streets1" and click next

- When ask "Do you want to model turns in this network" answer "no" and click next

- The window will display a connectivity settings message, it is not necessary to adjust anything, click next

- You will be asked how would you like to model the elevation of your network features. Since the present files deal with a uniform elevation, select "none" and click next

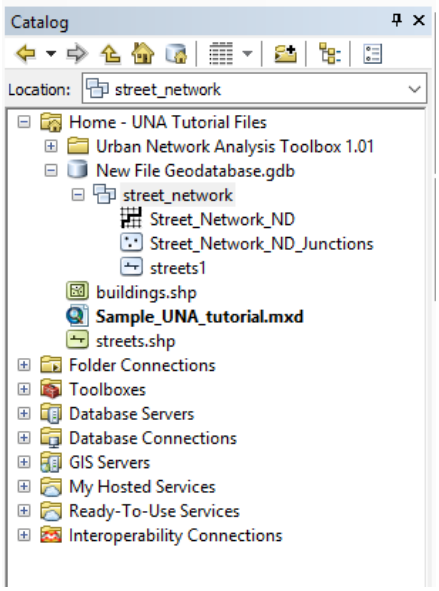
- This window allows you to specify the different attributes of your dataset depending upon your research questions. For now we will leave this as the standard Length, click next

- When asked about travel mode nothing needs to be added at this time, click next

- You will be asked if you want to establish driving direction settings for this network dataset, select "no" and click next

- The final window will ask if you would like to build service area index, select "yes" and click next to finish

Your new network dataset should have been created. When asked "Would you like to build it now" respond "yes"

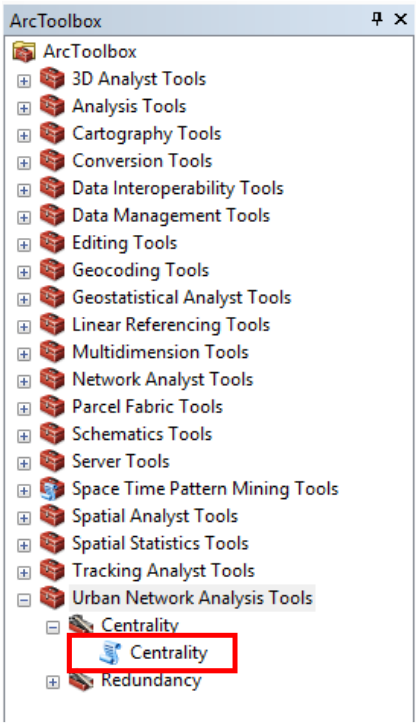


If you check the street network that is generated by the Network Dataset, you will see the below image. The street network has been reduced to individual street segments and nodes which correspond to the connections between two or more streets. You will notice in the figure below that there are several nodes that do not have visible street connections. Since this represents just a portion of Ostia, those nodes in reality connect to other streets. If creating your own street network, ensure that prior to generating a Network Dataset that you have a clean street typology, with a street broken up into segments whenever it connects to another street. Alternatively, try removing nodes that do not have additional street connections and see how the later centrality results change.

11) Calculate Reach

You will be computing "Reach" which measures how many surrounding buildings are within a certain radius of all other buildings.

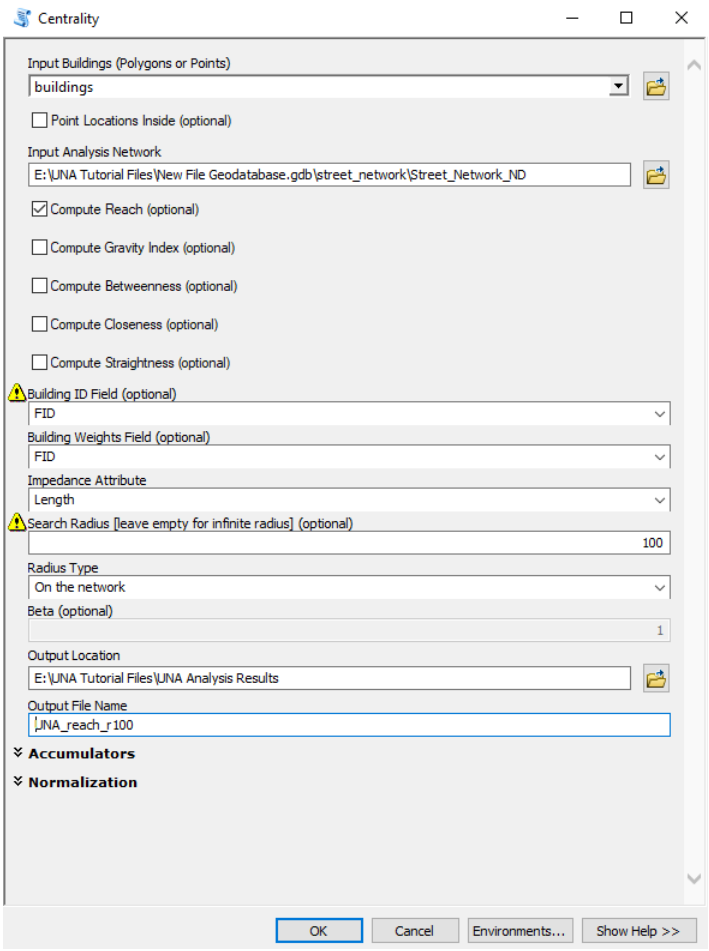
Now that you have successfully prepared your GIS data for analysis, open the Urban Network Analysis Toolbox for Centrality



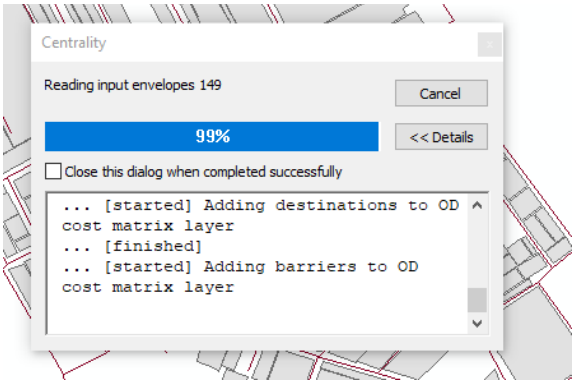
You will see a box that requires a range of different inputs.

To begin computing centrality, do the following:

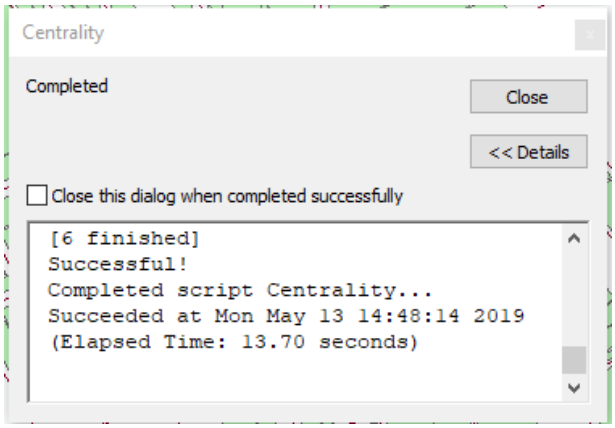
- Click “Centrality” to open the window.
- Select input building shapefile “buildings”.
- Select the street network previously computed using the network analysist, this should be titles “Street_Network_ND”.
- Check the box to “compute reach”.
- Build ID: select unique identifier “FID”.
- Search Radius: input 100 (meters). If an infinite radius is used, due to the small size of the dataset all buildings will return identical results within the Reach calculation. This is not the case for the other analyses available through this toolbox.
- Radius Types: Select ‘on the network’ if you want results computed relating to movement along the city streets.
- Output Location: Create a new identifiable folder to save your centrality results “UNA_Analysis_Results”. Select this folder to save calculation.
- Output File Name: give our calculation a clearly identifiable name “UNA_reach_r100”.
- Select OK to run the calculation.



The reach centrality calculations will now be computed.

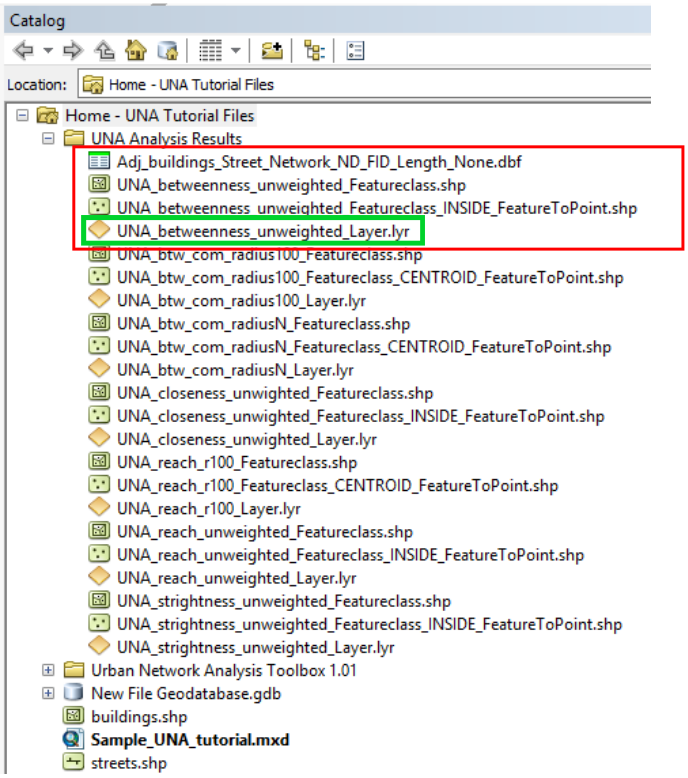


Once the results are finished, you will get a message stating the run has been successful.

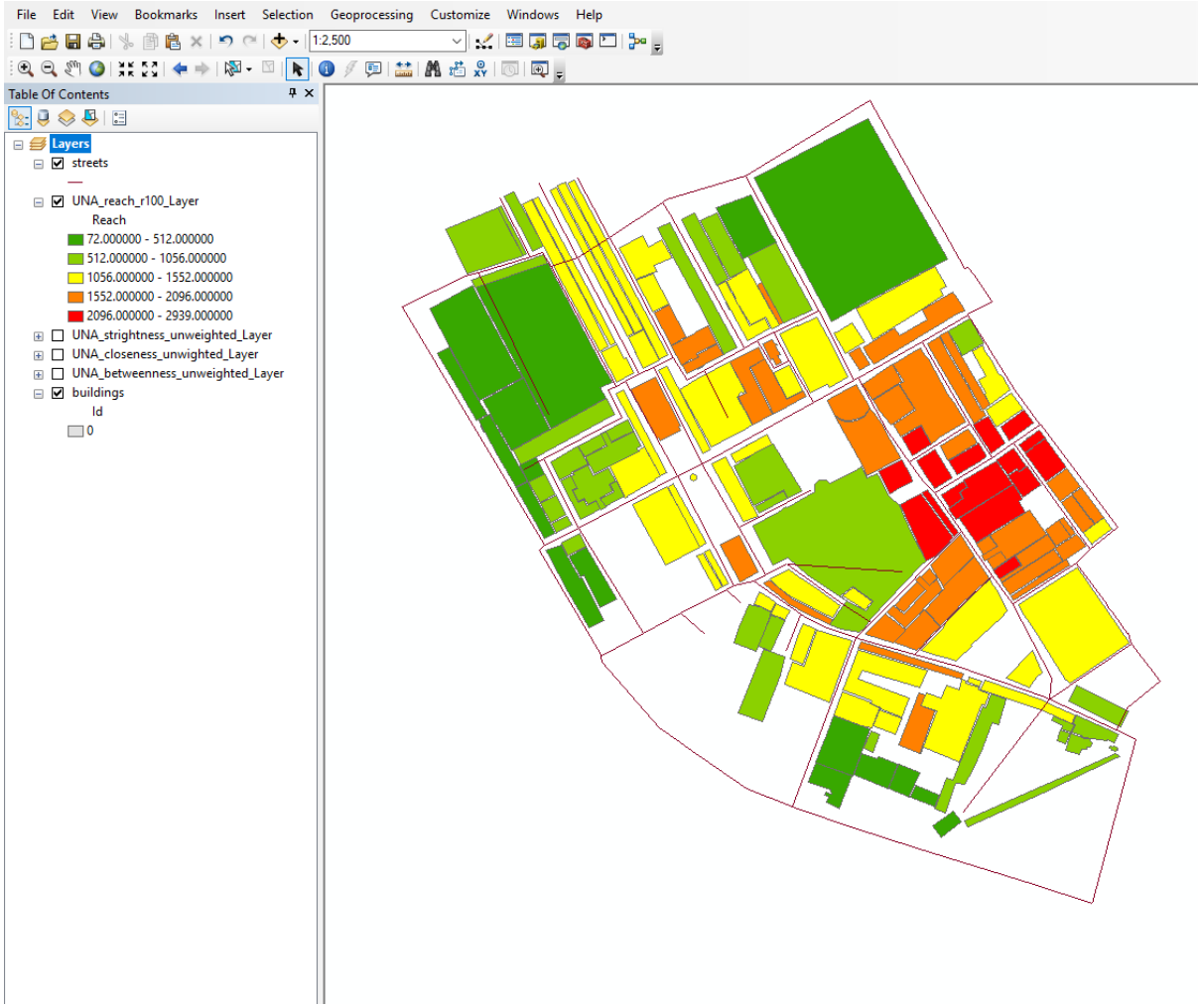


If you are running the Urban Network Analysis Toolbox within ArcMap, then the result files will automatically appear within your map. Alternatively, if you run the calculation within ArcCatalogue, then you will have to select the relevant result shapefile and add it to your map. In the following image, you will see there are four files associated with a single calculation, outlined in red.

- The first file, "Adj_buildings_Street_Netowork_ND_FID_Length_None.dbf" is calculated only once for files saved within the same folder. It computes all of the metrics related to the street network as well as each building's location in relation to the street. After its initial computation, all subsequent analyses undertaken within this folder location will run significantly quicker.
- The next two files, "UNA_betweenness_unweighted_Featureclass.shp" and "UNA_ betweenness_unweighted_INSIDE_FeatureToPoint.shp" are specific to the buildings and street network specifically.
- The last file, which is inside the green box is the layer which will display the betweenness centrality results "UNA_betweenness_unweighted_Layer.lyr". Add this layer to ArcMap in order to visualize the results of computing Reach.


Catalog
Location: Home - UNA Tutorial Files
Home - UNA Tutorial Files
UNA Analysis Results
Adj_buildings_Street_Network_ND_FID_Length_None.dbf
UNA_betweenness_unweighted_Featureclass.shp
UNA_betweenness_unweighted_Featureclass_INSIDE_FeatureToPoint.shp
UNA_betweenness_unweighted_Layer.lyr
UNA_btw_com_radius100_Featureclass.shp
UNA_btw_com_radius100_Featureclass_CENTROID_FeatureToPoint.shp
UNA_btw_com_radius100_Layer.lyr
UNA_btw_com_radiusN_Featureclass.shp
UNA_btw_com_radiusN_Featureclass_CENTROID_FeatureToPoint.shp
UNA_btw_com_radiusN_Layer.lyr
UNA_closeness_unwighted_Featureclass.shp
UNA_closeness_unwighted_Featureclass_INSIDE_FeatureToPoint.shp
UNA_closeness_unwighted_Layer.lyr
UNA_reach_r100_Featureclass.shp
UNA_reach_r100_Featureclass_CENTROID_FeatureToPoint.shp
UNA_reach_r100_Layer.lyr
UNA_reach_unweighted_Featureclass.shp
UNA_reach_unweighted_Featureclass_INSIDE_FeatureToPoint.shp
UNA_reach_unweighted_Layer.lyr
UNA_strightness_unweighted_Featureclass.shp
UNA_strightness_unweighted_Featureclass_INSIDE_FeatureToPoint.shp
UNA_strightness_unweighted_Layer.lyr
Urban Network Analysis Toolbox 1.01
New File Geodatabase.gdb
buildings.shp
Sample_UNA_tutorial.mxd
streets.shp

The Reach Centrality results will automatically display on a color scale of Green to Red. Try adjusting the colours and see how that changes your interpretation of the results.

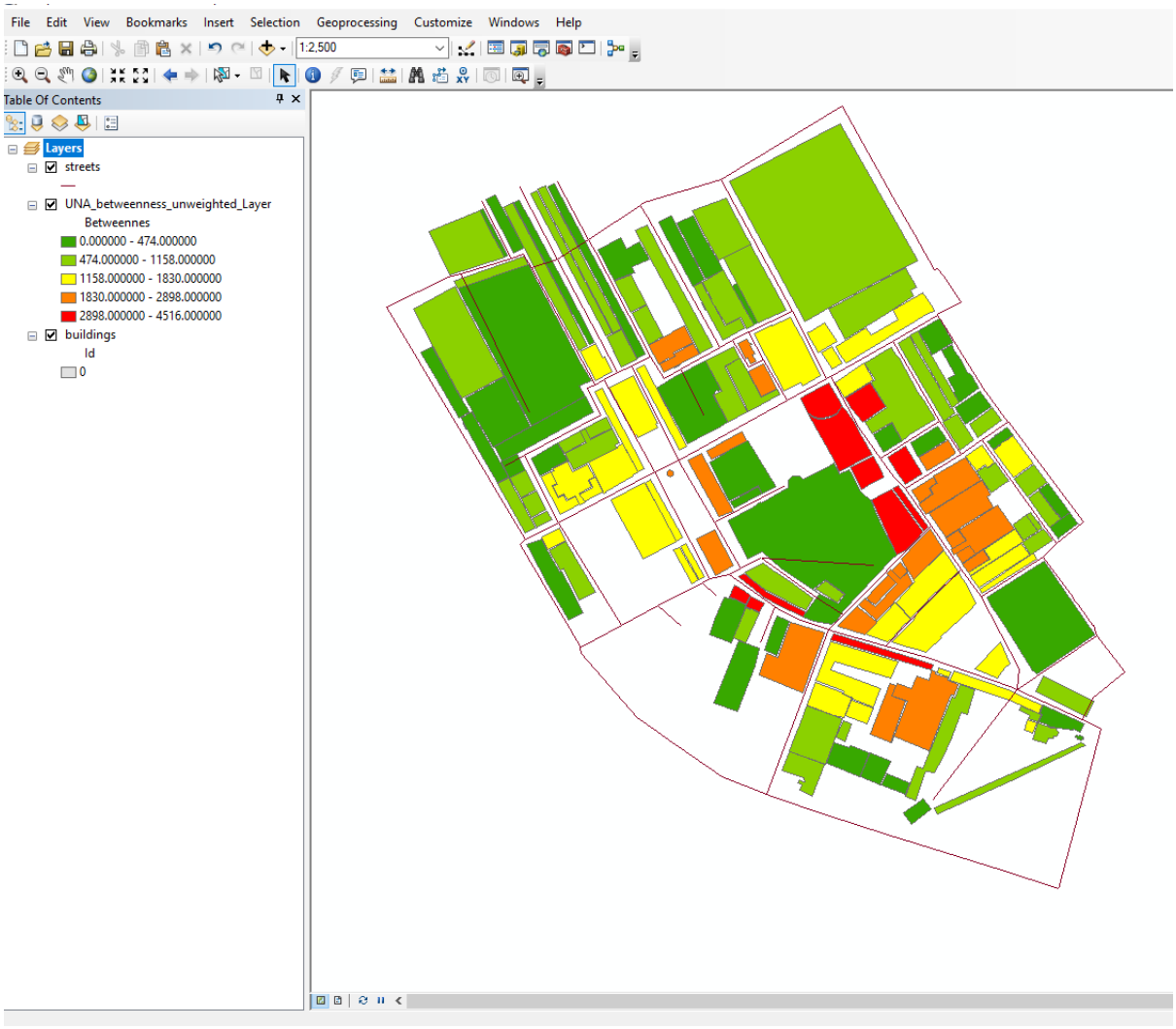


12) Calculate Unweighted Betweenness Centrality

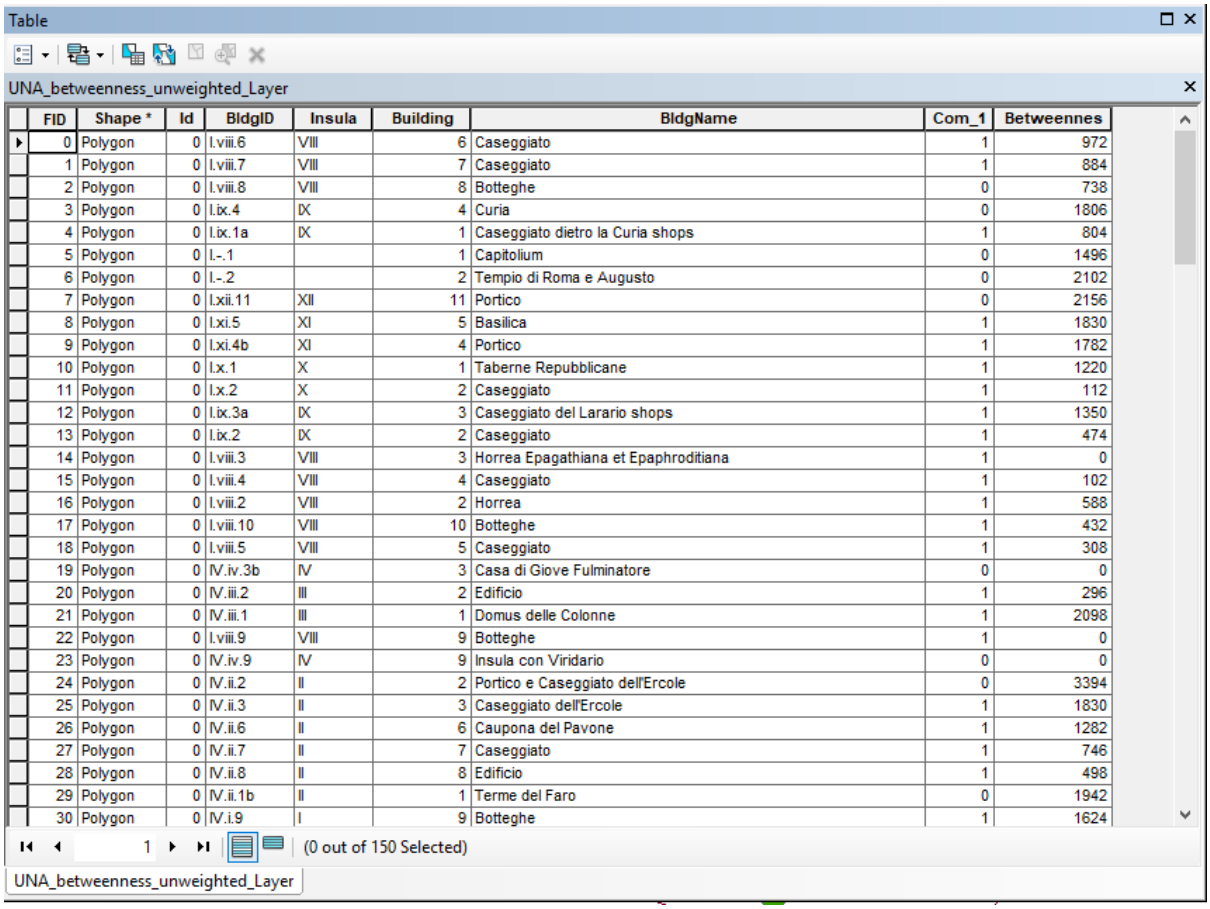
Next you will practice computing betweenness centrality using unweighted and weighted values. Betweenness computes the shortest route between two points regardless of ones origin or destination. At the urban scale it is often used to identify areas that would see the greatest flow of traffic.

First compute betweenness using unweighted values, follow the same steps from the previous section. The only changes you will need to make is to unselect Reach and select Betweenness. Also leave Search Radius as infinite.

Once completed, you should achieve the following image. The unweighted results assume that all buildings are equally important within this portion of Ostia's street network.



Now open the betweenness layer attribute table. You will see that each building has a unique betweenness centrality value.



FID	Shape *	Id	BldgID	Insula	Building	BldgName	Com_1	Betweennes
0	Polygon	0	I.viii.6	VIII	6	Caseggiato	1	972
1	Polygon	0	I.viii.7	VIII	7	Caseggiato	1	884
2	Polygon	0	I.viii.8	VIII	8	Botteghe	0	738
3	Polygon	0	I.ix.4	IX	4	Curia	0	1806
4	Polygon	0	I.ix.1a	IX	1	Caseggiato dietro la Curia shops	1	804
5	Polygon	0	I.-.1		1	Capitolium	0	1496
6	Polygon	0	I.-.2		2	Tempio di Roma e Augusto	0	2102
7	Polygon	0	I.xii.11	XII	11	Portico	0	2156
8	Polygon	0	I.xi.5	XI	5	Basilica	1	1830
9	Polygon	0	I.xi.4b	XI	4	Portico	1	1782
10	Polygon	0	I.x.1	X	1	Taberne Repubblicane	1	1220
11	Polygon	0	I.x.2	X	2	Caseggiato	1	112
12	Polygon	0	I.ix.3a	IX	3	Caseggiato del Larario shops	1	1350
13	Polygon	0	I.ix.2	IX	2	Caseggiato	1	474
14	Polygon	0	I.viii.3	VIII	3	Horrea Epagathiana et Epaphroditiana	1	0
15	Polygon	0	I.viii.4	VIII	4	Caseggiato	1	102
16	Polygon	0	I.viii.2	VIII	2	Horrea	1	588
17	Polygon	0	I.viii.10	VIII	10	Botteghe	1	432
18	Polygon	0	I.viii.5	VIII	5	Caseggiato	1	308
19	Polygon	0	IV.iv.3b	IV	3	Casa di Giove Fulminatore	0	0
20	Polygon	0	IV.iii.2	III	2	Edificio	1	296
21	Polygon	0	IV.iii.1	III	1	Domus delle Colonne	1	2098
22	Polygon	0	I.viii.9	VIII	9	Botteghe	1	0
23	Polygon	0	IV.iv.9	IV	9	Insula con Viridario	0	0
24	Polygon	0	IV.ii.2	II	2	Portico e Caseggiato dell'Ercole	0	3394
25	Polygon	0	IV.ii.3	II	3	Caseggiato dell'Ercole	1	1830
26	Polygon	0	IV.ii.6	II	6	Caupona del Pavone	1	1282
27	Polygon	0	IV.ii.7	II	7	Caseggiato	1	746
28	Polygon	0	IV.ii.8	II	8	Edificio	1	498
29	Polygon	0	IV.ii.1b	II	1	Terme del Faro	0	1942
30	Polygon	0	IV.i.9	I	9	Botteghe	1	1624

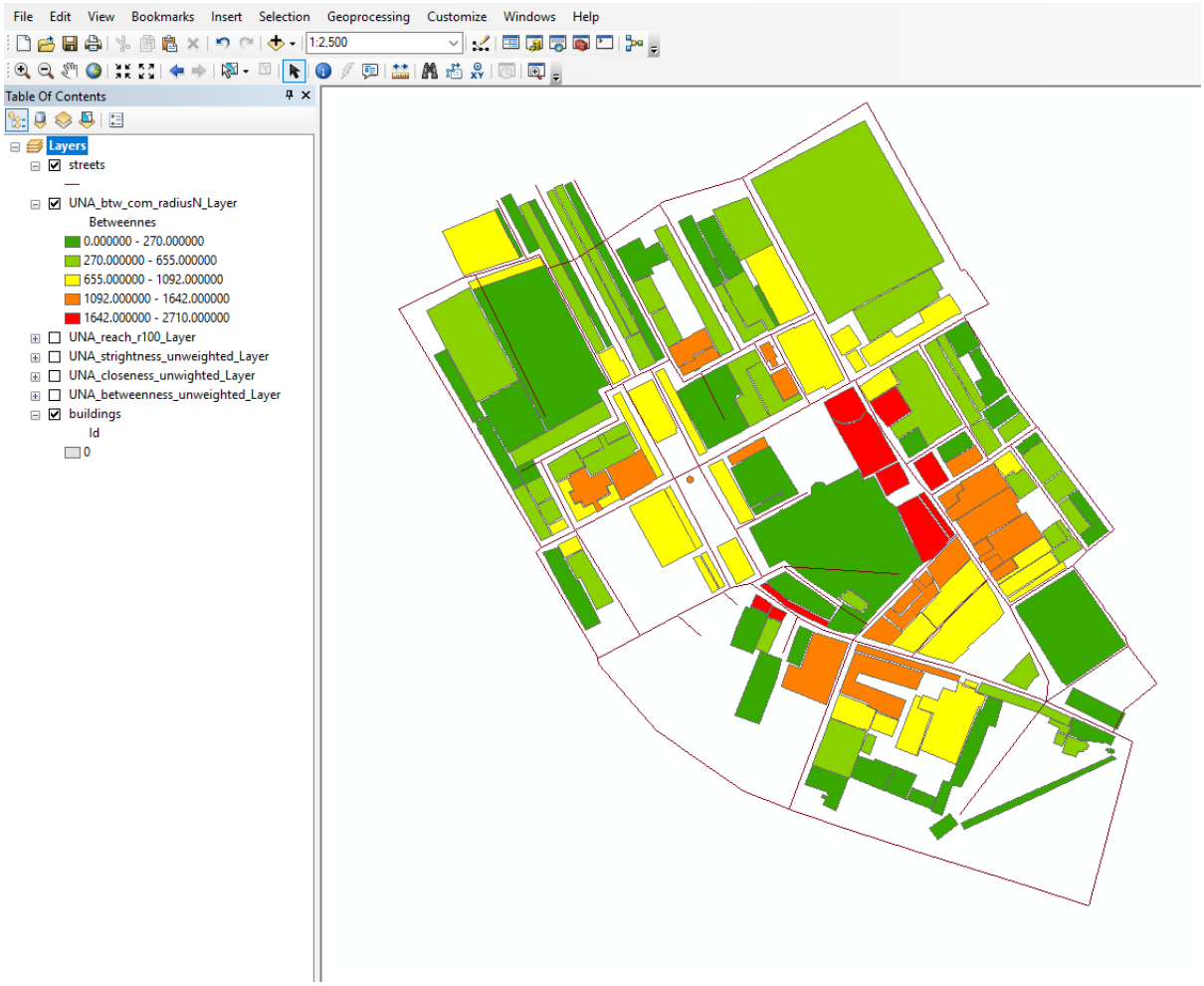
13) Calculate Weighted Betweenness Centrality

Now you will compute betweenness centrality using weighted buildings values. Follow the same steps of inputting information into the centrality window as in the last two sections.

To add weighted values, do the following:

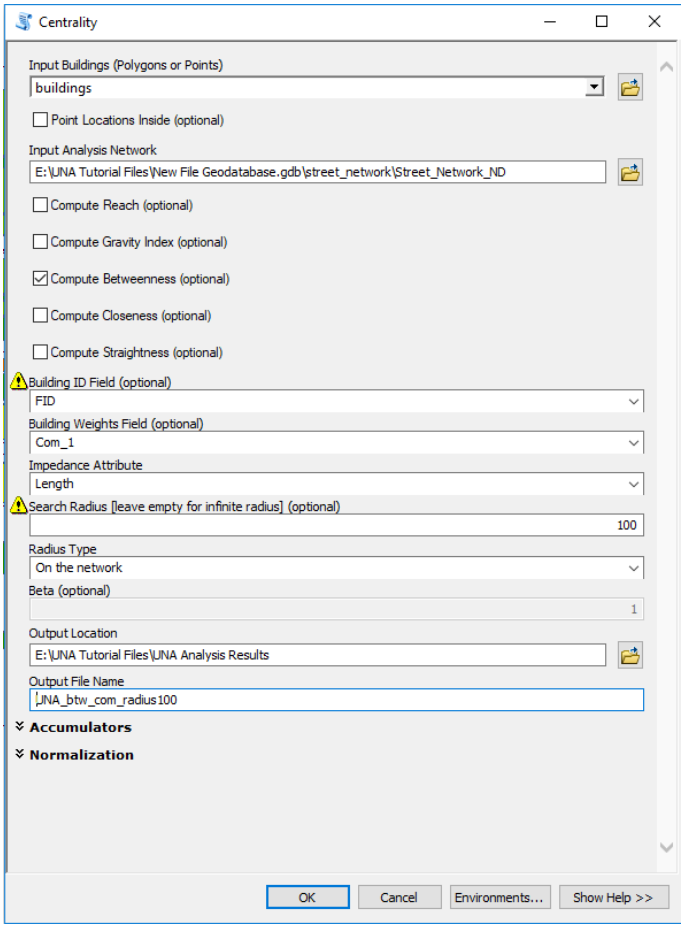
- Under the “Building Weights Field (optional)”, select the option named “Com_1”. This will weight the calculation by buildings identified as having a commercial function. Buildings that have an alternative function retain a value of 0, but they are still accounted for within the calculation.
- Leave the search radius empty
- Select OK

You should have received the following result which shows the betweenness centrality value of buildings identified as having a commercial function. Compare it to the previous calculation, what observations can you make? Do you have a clear understanding of which buildings had a commercial function? Are the results as you expected?

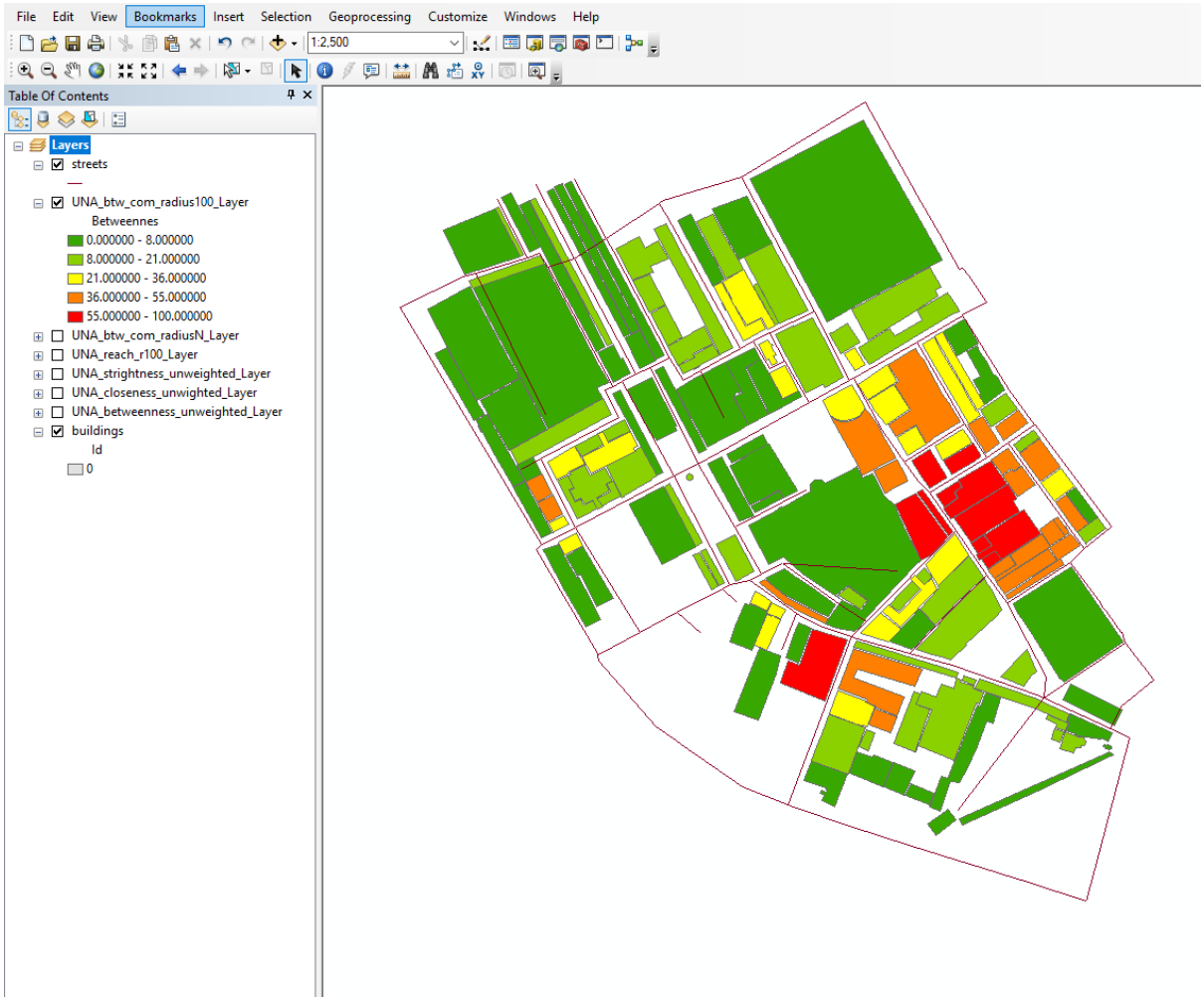


14) Calculate Weighted Betweenness Centrality with radius100

Following the same steps as in the previous section, select the "Building Weight Field" with "Com_1" to weight the calculation by commercial structures. In the Search Radius box, input the value 100. This tells the toolbox to calculate the betweenness values on a 100m radius. This means that betweenness will be calculated from every building to every other building located within a 100 m radius, along a network radius.



You should have achieved the following results. Compare this to the previous section, what noticeable differences and similarities do you see?



Now try adjusting the calculation by using different radii values and see how the results change.

15) Additional Exercises

Try adjusting the weighted building values in the "buildings" shapefile. What happens if you increase the weighted value from 1 to another value? Alternatively, how do the results change if you add more than one weighted category (eg. weighted values of 0; 5; 10; 15 in one attribute table column)? Try adding a new weight that is based upon the total area of each building, how do the results change? Try running centrality calculations using the other values, such as closeness or straightness. What do the different calculations tell us about the this built area of Ostia?