IndiFrag v2.1: An Object-based Fragmentation Analysis Software Tool

Geo-Environmental Cartography and Remote Sensing Group

http://cgat.webs.upv.es/software/

Universitat Politècnica de València

The following sections describe different analyses done using IndiFrag v2.1 tool, in order to show how to apply the tool and interpret the results. A study sample is used, composed of LULC data from a few districts of the city of Valencia, Spain. The data were obtained from The European Urban Atlas database (http://land.copernicus.eu/local).

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Tutorial 1: Fragmentation Analysis with Super-Objects

In this tutorial, almost the whole set of fragmentation metrics is computed. Firstly, the input data are three layers: the classified objects, the super-objects and the urban centre point (Figure 1).

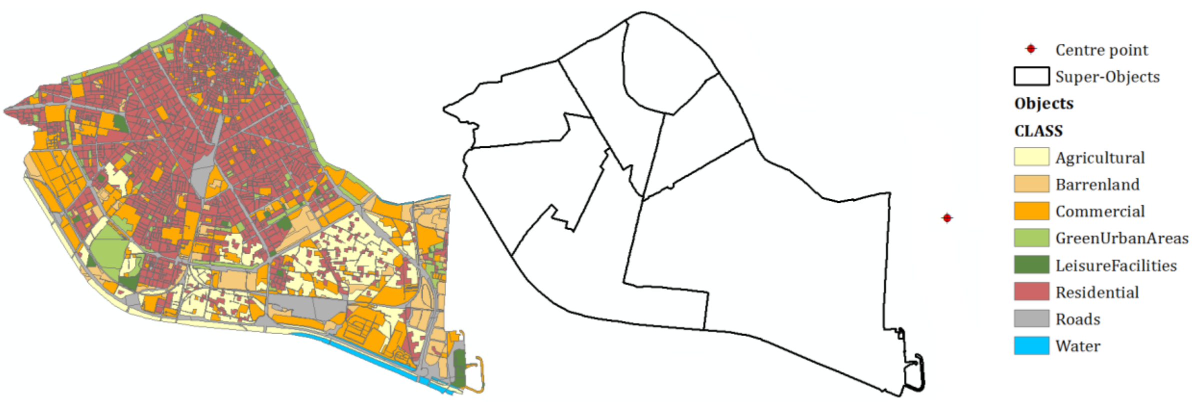

Figure 1. Input data for the fragmentation analysis. Shapefile with the objects (left); shapefile with the super-objects (middle); and centre point (right), with their associated legend

It is desirable that the input data do not have too many fields to facilitate the interpretation, as the tool computes several geoprocessing operations that duplicate the information. The only field needed is the class (LULC field), and optionally the type (urban or not-urban field) and the name of the super-object fields. Once the data are prepared, open the Tool IndiFrag from ArcGis, then the "*Fragmentation Analysis*" module and, finally, open the "*Calculate FI*" window. In the first tutorial the input data are:

- » Input Feature with Objects: Objects.shp
- » Land Use Field Name: CLASS
- » Urban Field Name: TIPO
- » Urban Value: URBAN
- » Input Feature with Super-Objects: SuperObjects.shp
- » Super-Object Field Name: Nome
- » Output Text File: Results_FI (*do not write any extension*)
- » Is there any Road class? Roads
- » Select/Unselect all: all except IFUP
- » Input Feature with a Centre Point: Centre_point.shp
- » Ring Equidistance (metres): 500
- » Densify Distance (meters): 10

When the check box "Select/Unselect all" is selected, all the indices will be activated and additional data have to be introduced. In this tutorial, the IFUP index is not checked because it is more suitable for forest fragmentation analyses.

When entering the data is recommended to open the "Show Help" button, thus the tool will guide the user in the introduction of the expected input and output data, as well as describing briefly the indices.

When the process ends, the results are located in "*C:/IndiFragTemp_FI*". During the calculation process, temporal data are located in a geodatabase also in this path, and upon finishing the process these files are deleted. When dimB and dimR indices are calculated, two graphs per class are created and also stored in this path. If the RCB index is computed, intermediate layers with the "expanded" objects (after removing roads) are saved in *"C:\IndiFragTemp_FI\ContrastTemp\gdb_noroad.gdb"*. If the result is not good enough the densify distance should be changed.

On the other hand, in the same path as the input data a new shapefile with the results stored in the attribute table is created, called "*NameoftheShape*INT.shp", this is the result of intersecting the object and super-object input shapefiles, and object and class level results will be stored here. While super-object level results are stored in "*SuperObjects*.shp". A text file with the results is also created in the given path.

In order to interpret the results, those indices calculated at different levels are indicated with a sub-index: object (O), class (Cl) and super-object (SO) levels (Figure 2 and Figure 3).

ObjectsINT

FID	CLASS	TIPO	AreaO	PerimO	SO	AreaCI	PerimCI	NobCI	DC	LPF	TMCI	DBCI	DimB	RPA	RMPACI
1565	Barrenland	URBAN	3075,24	222,03	QuatreCarreres	1,47	40,5882	53	0,135796	0,105337	27735,8	0,003749	1,10874	0,072199	0,345768
1682	GreenUrba	URBAN	3075,16	395,224	LOlivereta	0,137181	5,76046	12	0,068718	0,450935	11431,8	0,002886	0,962393	0,128521	1,50901
609	Residential	URBAN	3072,78	229,396	CiutatVella	0,90239	70,2802	281	0,524364	0	3211,35	0,040839	0,998704	0,074654	0,093043
578	Residential	URBAN	3068,93	219,243	Eixample	1,13488	51,7388	132	0,653715	0,000777	8597,58	0,029803	0,998704	0,07144	0,410567
26	Residential	URBAN	3056,9	260,741	Jesus	1,07424	58,0613	158	0,270737	0,016322	6799,01	0,014633	0,998704	0,085296	0,106874
986	Residential	URBAN	3049,46	243,833	Jesus	1,07424	58,0613	158	0,270737	0,016322	6799,01	0,014633	0,998704	0,079959	0,106874
580	Residential	URBAN	3048,21	257,618	LOlivereta	0,961024	49,0183	127	0,481401	0	7567,12	0,024555	0,998704	0,084515	0,299457
1616	Barrenland	URBAN	3045,5	232,326	CiutatVella	0,005819	0,451708	2	0,003381	1	2909,48	0,000262	1,10874	0,076285	0,077693
1144	Residential	URBAN	3038,31	302,42	QuatreCarreres	1,93209	104,762	278	0,178484	0,043751	6949,97	0,009678	0,998704	0,099536	0,132165
131	Residential	URBAN	3035,72	237,41	Jesus	1,07424	58,0613	158	0,270737	0,016322	6799,01	0,014633	0,998704	0,078205	0,106874

IFO	IFCI	DFO	DFCI	DFP	DOCI	DEPCI	DEM	TEMCI	GCCI	ISCI	COHECI	CCI	DDCI	DimR	RCBO	RCBCI
1,00095	1,32882	1,00024	1,02175	1,06253	4,89606	1533,44	48,7154	7615,64	0,000704	1421,42	99,5656	0,11365	0,64735	4,05787	0,253969	0,621885
1,78176	1,31567	1,14384	0,92591	1,05013	6,0111	565,833	81,7669	1448,79	0,000726	1377,92	99,2751	0,227927	0,142745	3,28022	0,610483	0,724814
1,03457	1,1487	1,00846	1,03251	1,03692	163,284	494,806	5,27579	2635,57	0,001531	652,96	98,4418	0,047915	1	1,08379	0,209943	0,288007
0,989401	1,28005	0,997346	0,63133	1,0217	76,0347	509,604	6,25971	7622,9	0,004391	227,741	99,0644	0,07299	1	1,08379	0,356319	0,157527
1,17899	1,20231	1,04103	1,04019	1,03647	39,8201	750,497	13,5914	2903,5	0,000732	1366,57	98,9334	0,063281	1	1,08379	0	0,377291
1,10388	1,20231	1,02464	1,04019	1,03647	39,8201	750,497	13,5914	2903,5	0,000732	1366,57	98,9334	0,063281	1	1,08379	0,198252	0,377291
1,16652	1,337	1,0384	1,09125	1,04182	63,6174	633,004	5,46132	7350,22	0,003682	271,598	99,0447	0,070895	1	1,08379	0,030846	0,338011
1,05247	1,04695	1,01275	1,01149	1,01155	1,16217	0	891,275	9,85935	0,000006	174547	98,2312	0,598646	0,006448	4,05787	1	1
1,37162	1,22311	1,07881	1,04746	1,04603	25,6812	1225,34	12,1394	2193,61	0,000203	4934,8	98,9692	0,047034	0,850845	1,08379	0,828346	0,569046
1,07723	1,20231	1,01856	1,04019	1,03647	39,8201	750,497	13,5914	2903,5	0,000732	1366,57	98,9334	0,063281	1	1,08379	0	0,377291

Figure 2. Attribute table of ObjectsINT.shp with the results. Green field are calculated always even if no indices are indicated, red fields are object level indices and orange class level

SuperObjects

FID	NAME	AreaSO	PerimSO	RCBSO	PerimT	NCI	NobSO	DU	TMSO	DBSO	RMPASO	IFSO	DFSO
0	CiutatVella	1,72092	5,0562	0,278524	91,3808	5	341	0,999546	3970,03	0,051424	0,088688	1,14103	1,0305
1	Eixample	1,73605	6,03858	0,148424	63,3763	4	148	0,99954	9457,14	0,033954	0,371443	1,2664	0,673937
2	Extramurs	1,97718	7,41787	0,124288	67,4344	5	156	0,999555	9116,07	0,031167	0,451026	1,25759	1,09398
3	LOlivereta	1,99631	6,83564	0,310836	70,9582	5	173	0,999571	9462,2	0,033752	0,336128	1,29544	1,06707
4	Patraix	2,92495	8,50321	0,340964	94,011	6	212	0,926543	11259,3	0,030454	0,143651	1,28503	1,05754
5	Jesus	3,96785	11,5817	0,375966	124,223	6	251	0,756382	12941,8	0,029565	0,100165	1,27702	1,0505
6	QuatreCarreres	10,825	17,8606	0,527553	283,054	7	568	0,781969	15172,6	0,025499	0,198753	1,33518	1,05318

DOSO	DEPSO	TEMSO	GCSO	ISSO	COHESO	CU	DSHAN	USHAN	IFFR	IFFA	DDSO	SIMP
198,149	543,623	7101,99	0,004127	242,316	98,7082	0,918731	0,980636	0,609303	0,333333	0,055274	1,50022	0,511787
85,251	592,094	13628,4	0,00785	127,385	99,1834	0,775647	0,650742	0,469411	0,5	0,09922	1,23331	0,326308
78,9004	664,358	11153,2	0,005641	177,274	99,1597	0,672672	0,556696	0,345895	0,333333	0,117037	1,16832	0,258183
86,66	609,133	20544,1	0,010291	97,1719	99,2231	0,731507	1,06282	0,660364	0,333333	0,096282	1,70335	0,569657
72,4799	745,313	25673,5	0,008777	113,929	99,3233	0,539119	1,30501	0,728342	0,166667	0,090231	2,46961	0,672073
63,2585	965,824	42810,1	0,010789	92,6848	99,4345	0,166614	1,52232	0,849623	0,166667	0,090569	3,02389	0,752728
52,471	1437,41	46515,1	0,004297	232,721	99,5351	0,120823	1,66741	0,856877	0	0,054926	3,79516	0,789186

Figure 3. Attribute table of SuperObject.shp with the results. Green field are calculated always even if no indices are indicated and blue fields are super-object level indices

Regarding the text file, some information related to the input data is stored to easily identify the analysis where it comes from. Results are organised by levels, and this file is easily opened with Excel or any text editor (Figure 4).

Results_T1.txt: Bloc de notas

Archivo Edición Formato Ver Ayuda

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**************
   IndiFrag
**************

IndiFrag is a processing tool used for the extraction of a set of indices and variables that
describe quantitatively the level of fragmentation and spatial distribution of land uses in
response to morphological, spatial and typological properties of cartographic objects.

Created in:              September 25th, 2014

Developed by:            Marta Sapena Moll

                         Luis Ángel Ruiz Fernández

                         Grupo de Cartografía, GeoAmbiental y Teledetección

                         Universitat Politècnica de València

                         http://cgat.webs.upv.es/software/

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INDIFRAG METRICS
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Input path of the Object's shapefile: E:\IndiFrag_1_2017\IndiFrag_v2.1\Tutorial_Shapes
\Tutorial1_With_SuperObjects\Objects.shp

Input path of the Super-Object's shapefile: E:\IndiFrag_1_2017\IndiFrag_v2.1\Tutorial_Shapes
\Tutorial1_With_SuperObjects\SuperObjects.shp

Numer of Super-Objects in the study area: 7

Number of Classes in the study area: 8

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OBJECT LEVEL INDICES
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FID     SO      CLASS   TIPO    AreaO   PerimO  RPA     IFO     DFO     RCBO

0       QuatreCarreres  Residential     URBAN   1897.85 177.65  0.0936  1.0195  1.0051  0.7438
1       QuatreCarreres  Residential     URBAN   2455.94 201.59  0.0821  1.0169  1.0043  0.7820
2       QuatreCarreres  Residential     URBAN   9.45    54.02   5.7153  4.3925  2.3177  0.2353
3       QuatreCarreres  Residential     URBAN   3765.59 263.89  0.0701  1.0751  1.0176  0.6138
4       Jesus   Residential     URBAN   4669.73 275.22  0.0589  1.0069  1.0016  0.7608
```

Figure 4. Example of the output text file

Working with vector data and storing results in the attribute table has many advantages, e.g. the user may easily represent the results in a GIS software, such as using choropleth maps to graphically represent the indicators. Next, we show a few examples about the representation of results, mapping them by level.

- **Object level**

The Boundary Contrast Ratio (RCB), for instance, measures the interspersion among land uses. The contrast is higher when the boundary of an object is adjacent to objects with different land use or class. When studied at object level, RCBO gives a value between zero and one, showing the contrast of each object. It is a relative measure of the amount of contrast along the object perimeter (Figure 5).

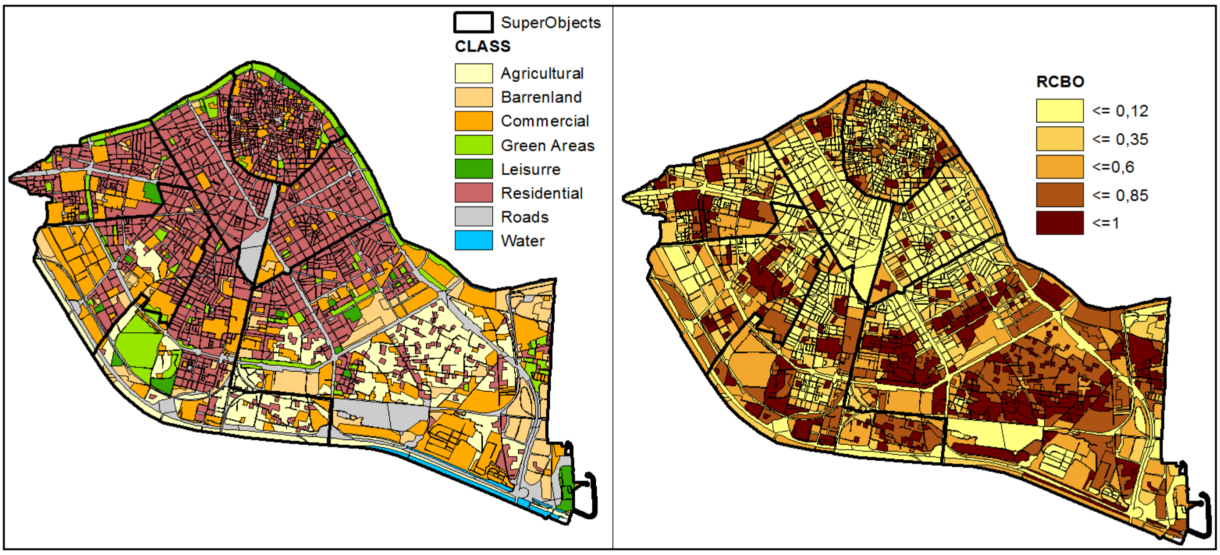


Figure 5. Boundary Contrast Ratio at Object level (RCBO), where objects with high contrast equals to one, while high contrast objects have near to zero or low contrast

In this case, the road class is not taken into account and thus road objects have null values. The contrast is computed removing the influence of the objects from the road class.

- **Class level**

When this index is analysed at class level, a value per class and super-object is obtained. In this case, the contrast is quantified comparing the boundary of all the objects from the same class with respect to the rest of the classes in a super-object. It provides a global idea of the interspersion among classes. The value of RCBCl, in the attribute table, will be the same for all the objects in the same class and super-object (Figure 6).

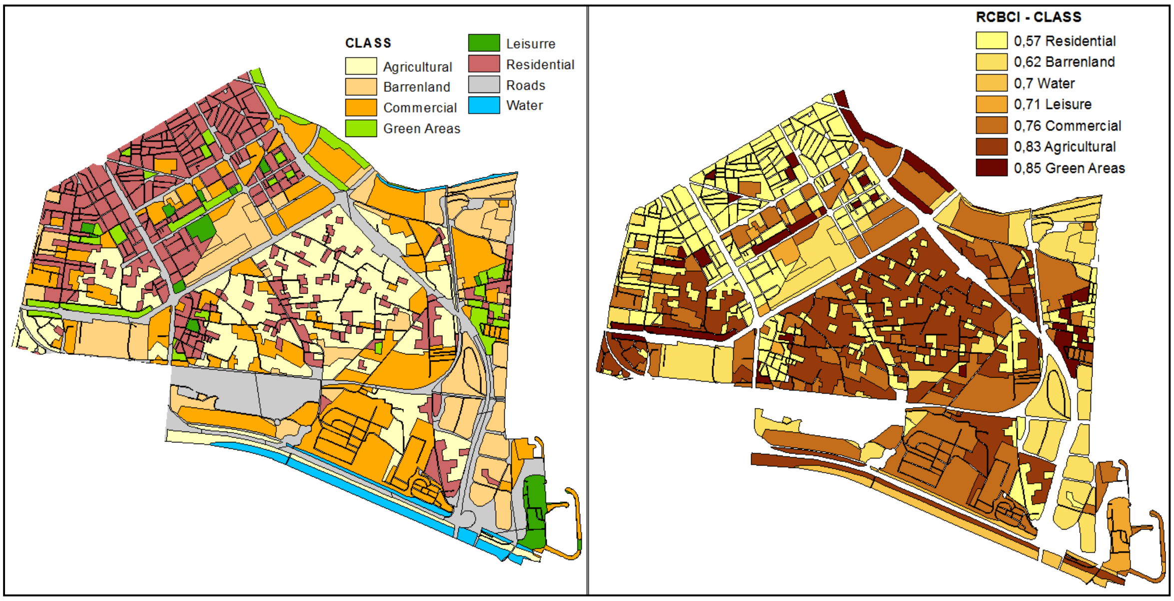


Figure 6. Boundary Contrast Ratio at Class level (RCBCl). This example shows only one super-object, where all objects from the same class have the same value

- **Super-object level**

Finally, the same index at super-object level (RCBSO) allows comparing the contrast among super-objects. The higher is the mix of classes within the super-object, the higher are the values of RCBSO (Figure 7). For example, in Figure 7 the super-object with RCBSO = 0.125 corresponds to a residential district, where mainly residential, green and commercial classes are present. In this case residential objects are compact and contiguous, therefore a low contrast is found. However, RCBSO=0.53 shows an heterogeneous super-object with mixed classes, in this case residential class is disaggregated, increasing the contrast between objects, e.g. between agricultural and residential classes.

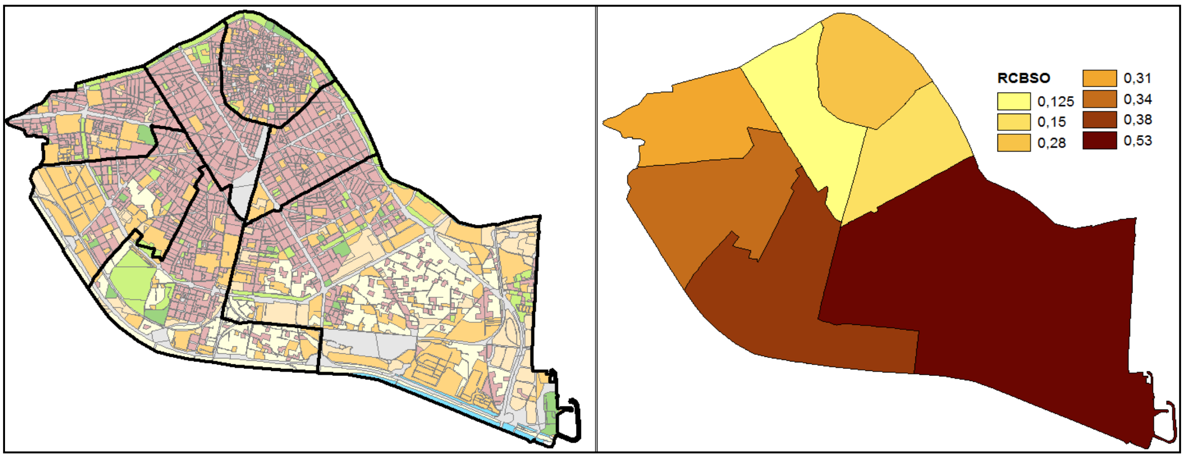


Figure 7. Boundary Contrast Ratio at super-object level (RCBSO). Contrast near one means high contrast and near to zero low contrast.

As shown above, once the indicators are computed their representation through maps is straightforward, facilitating their interpretation and comparison. If applied to different dates, the evolution and change of the fragmentation metrics can be compared.

Tutorial 2: Fragmentation Analysis without Super-Objects

This second case is similar to the previous one, but without subdividing the analysis into different super-objects. The input data are two layers, the shapefile with the objects and the centre point (Figure 8)

Figure 8. Input data for the fragmentation analysis without super-objects. Shapefile with the objects (left); and centre point (right), with their associated legend

The input data are:

» Input Feature with Objects: Objects.shp
» Land Use Field Name: CLASS
» Urban Field Name: TIPO
» Urban Value: URBAN
» Input Feature with Super-Objects: *None*
» Super-Object Field Name: *None*
» Output Text File: *None*
» Is there any Road class? Roads
» Select/Unselect all: all except IFUP
» Input Feature with a Centre Point: Centre_point.shp
» Ring Equidistance (metres): 250
» Densify Distance (meters): 10

When the process ends, a new shapefile is created in the temporal geodatabase "*C:\IndiFragTemp_FI\gdb_temp.gdb*" called "SupObject". This shapefile is the result of dissolving all the objects from the input shapefile. Thus there is only one super-object (that corresponds to the total study area) to store the results (there is only one row in the attribute table) and also for mapping them.

The output shapefile "*NameoftheShape*INT.shp" that contains object and class level indices has not been subdivided since the super-object is the total study area.

In this case the object level indices are the same as in the first tutorial, as they do not depend on the super-object. However, class level indices are not equal, as now there is one value for each class for the total study area. For instance, the Euclidean nearest neighbour mean distance (DEM) that depends on the distance between nearest objects in a class has one value per class (Figure 9).

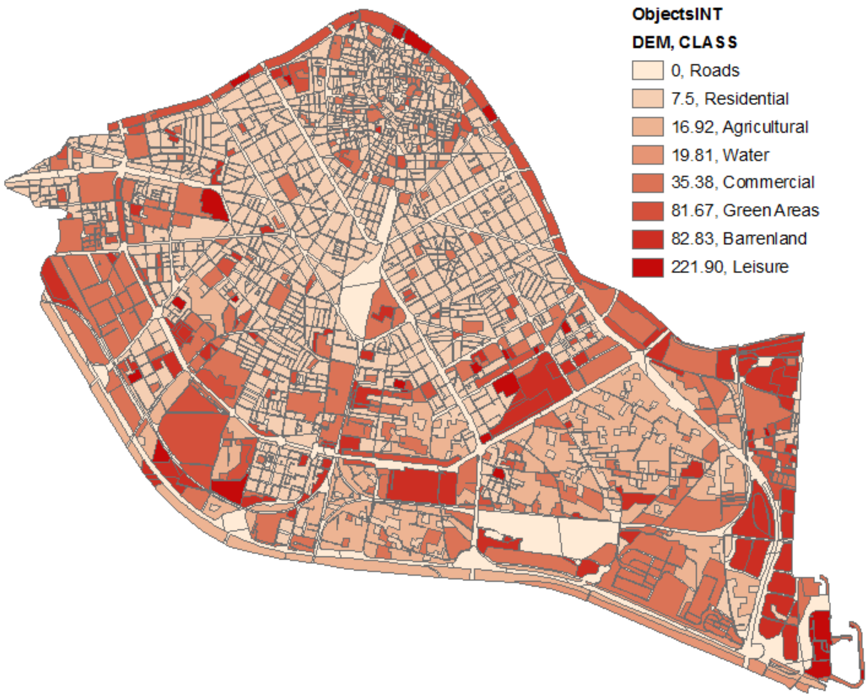
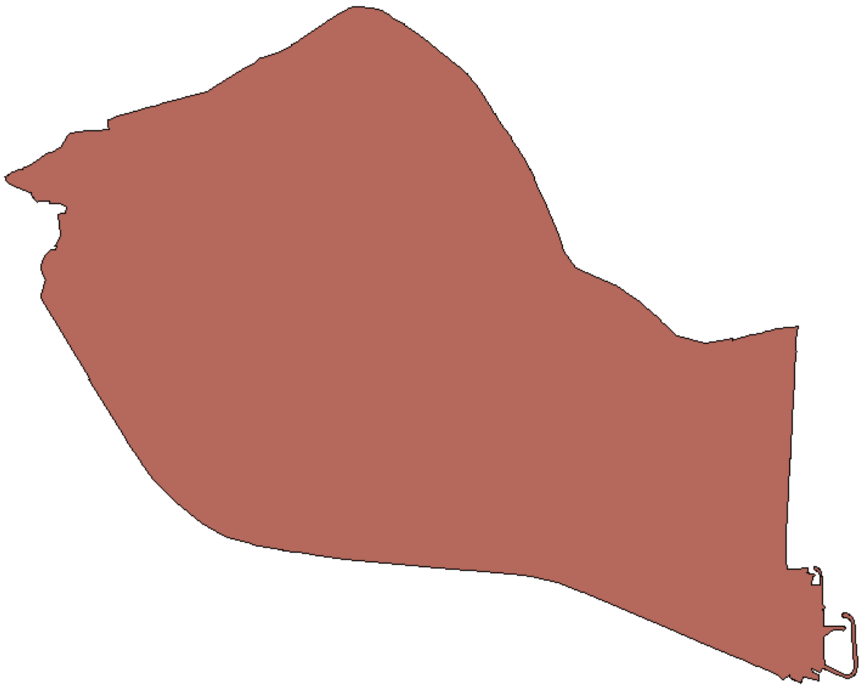


Figure 9. Euclidean nearest neighbour mean distance at class level (DEM). This example shows the total study area, where all objects from the same class have the same value

At super-object level, all the indices are stored in the same row of the attribute table, and the results have to be mapped one by one, or shown in a table (Figure 10)



NAME	SuperObject1
AreaSO	25.125
PerimSO	25.884
RCBSO	0.423
PerimT	756.652
NCl	7.000
NobSO	1810.000
DU	0.860
TMSO	11086.124
DBSO	0.030
RMPASO	0.122
IFSO	1.223
DFSO	1.039
DOSO	72.039
DEPSO	2270.088
TEMSO	33891.484
GCSO	0.001
ISSO	741.346
COHESO	99.360
CU	0.136
DSHAN	1.546
USHAN	0.795
IFFR	0.000
IFFA	0.031
DDSO	2.451
SIMP	0.739

Figure 10. The "SupObject" layer created, it corresponds to the total study area with the results and its associated table

Tutorial 3: Multi-temporal Analysis

In this tutorial, multi-temporal metrics are computed. Firstly, the input data are four layers: the classified objects for two dates (Figure 11, A and B), the super-objects, optionally, (Figure 11, C), and the urban centre (Figure 11, D). It is recommended that the shapefiles with the objects cover the same area or at least have an overlapping area, otherwise the analysis would make no sense. If a super-object shapefile is included only its extension will be evaluated.

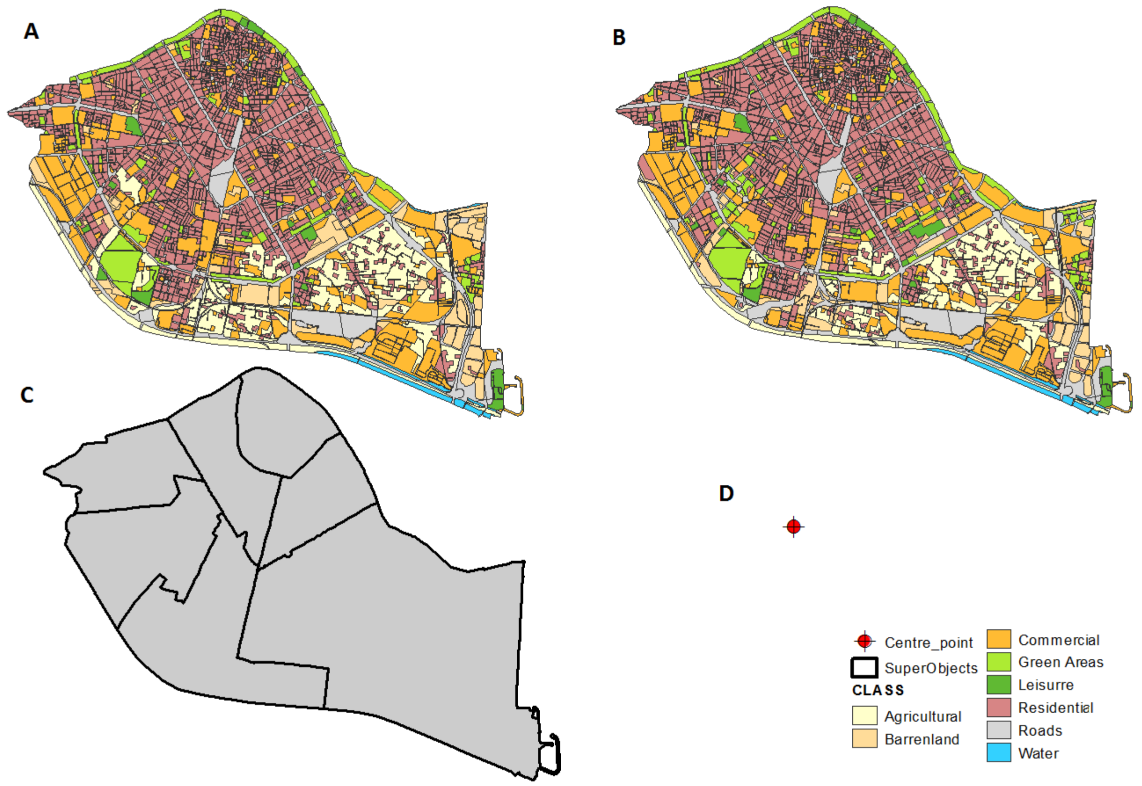


Figure 11. Input data for the multi-temporal analysis. Shapefile with the objects for first date (A); for second date (B), super-objects (C), and centre point (D), with their associated legend.

In this module, the analysis can be made using the classification in classes (LULC values) or typologies (Urban/non-Urban), both cases are shown:

- **Urban Level**

Urban level analysis is conducted when the user is only interested in the urban/non-urban classes and how they change in the study area analysed per super-objects.

Once the data are prepared, open the Tool IndiFrag from ArcGis, then the "*Multi-temporal Analysis*" module, and finally open "*Calculate MI*" window.

- Input Feature with Objects (T1): ObjectsT1.shp
- Land Use Field Name (T1): TIPO
- Input Feature with Objects (T2): ObjectsT2.shp
- Land Use Field Name (T2): TIPO
- Input Feature with Super-Objects: SuperObjects.shp
- Super-Object Field Name: Nome
- Number of years between T1 and T2: 6

- Output Text File: Results_MI_Urban
- Input Feature with a Centre Point: Centre_point.shp
- Ring Equidistance (metres): 250
- Exploitation degrees: None (there are not in the urban level)

When the process ends, results are located in "*C:\IndiFragTemp_MI*". This folder should have the following files for the urban class (also non-urban class results are provided, but in this tutorial are not analysed and were removed):

⇒ **Growth_Distance_URBAN.png**: this graph shows the result of the concentric circle analysis with an equidistance of 250 metres that quantifies the urban area variation (km²) with respect to the centre point (Figure 12).

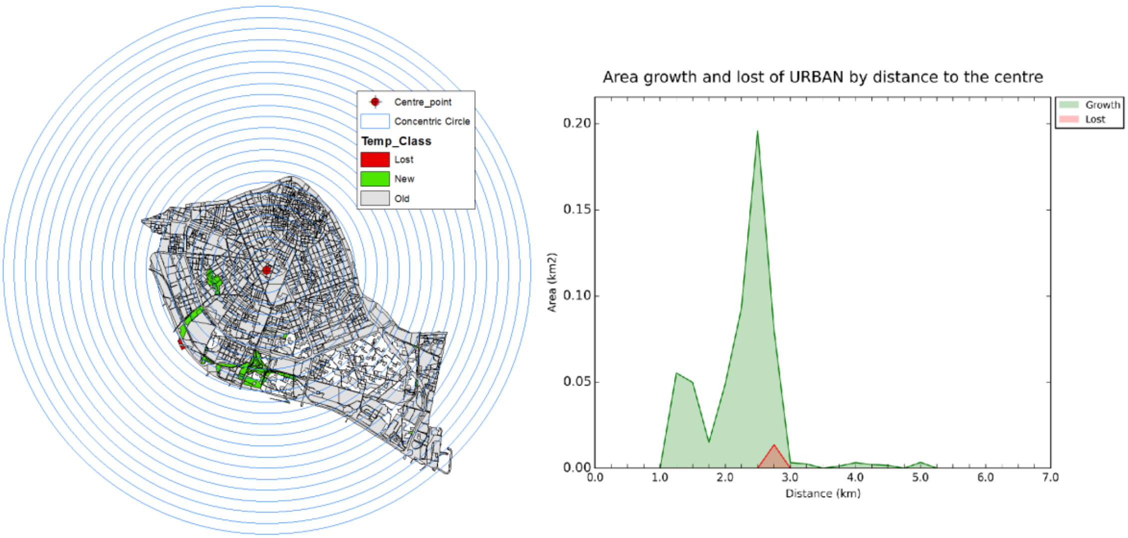


Figure 12. Urban growth (green) and lost (red) with the concentric circles overlapped in blue (left) and Growth_Distance_URBAN.png associated graph (right)

⇒ **Growth_Sector_URBAN.png**: this graph shows the result of the sector analysis with 16 divided sectors (with an angle of 22.5°) from the centre point provided, that quantifies the variation of the urban area (km²) per orientation (Figure 13).

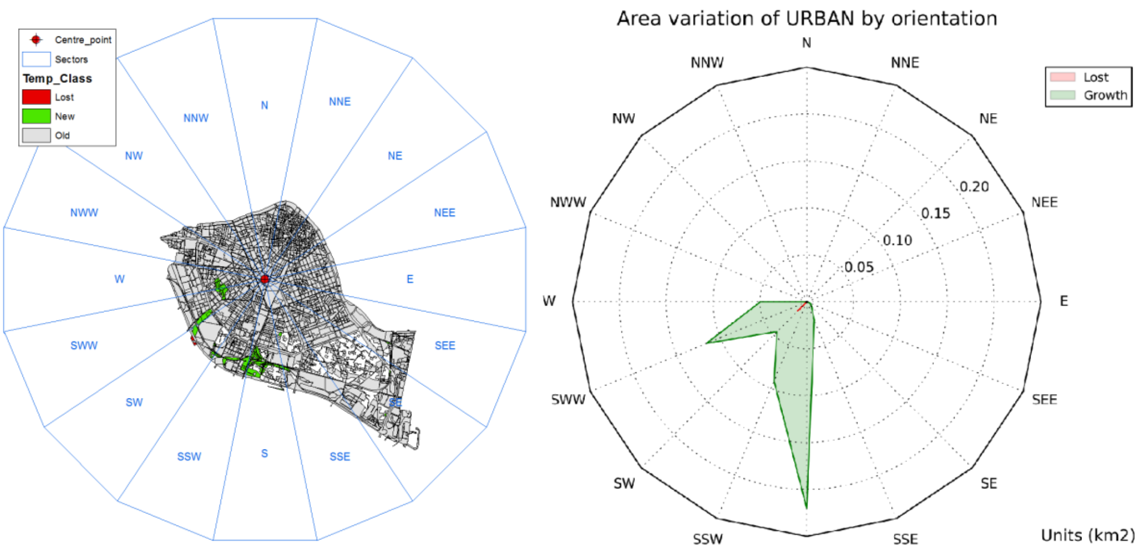


Figure 13. Urban growth (green) and lost (red) with the sectors overlapped in blue (left) and Growth_Sector_URBAN.png associated graph (right)

⇒ **Growth_Types.png**: this graph shows the change types for urban areas in the whole study area without taking into account the super-objects (this information per super-object is stored in the attribute table of the shapefile, but this is not represented in this graph). It represents the amount of change (km^2) according to its type considering three types: infilling, edge-expansive and outlying, calculated based on the LEI index (Figure 14).

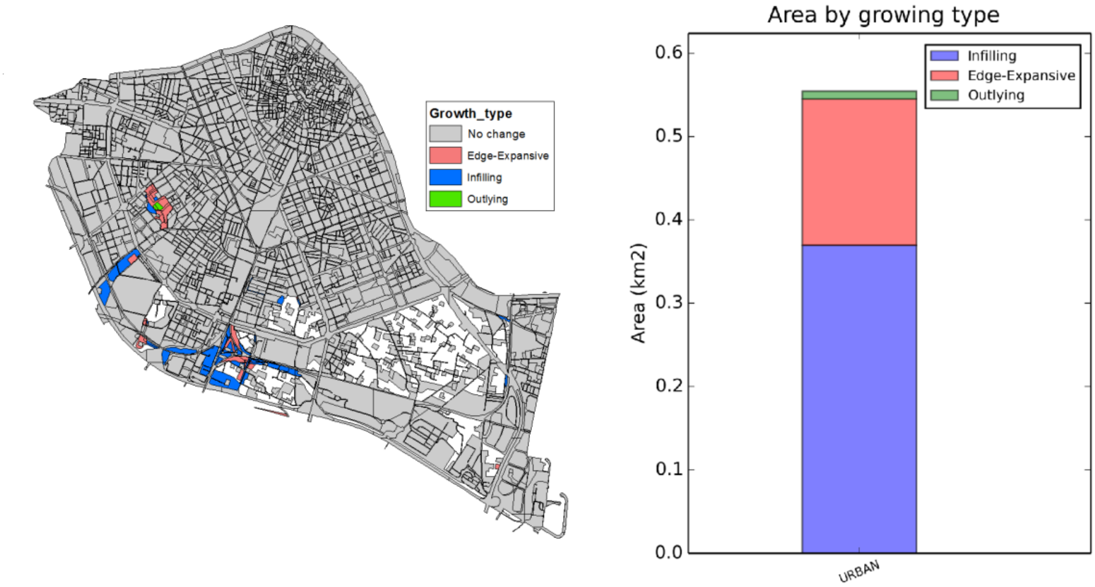


Figure 14. Urban growth by type: Infilling, edge-expansive and outlying (left), and graph with the accumulated growth by type (right)

⇒ **gdb_temp.gdb**: This geodatabase contains the results in different feature layers:

- <u>Res_URBAN</u>: This layer is created combining the urban areas of the two dates. It has several fields of interest:
  - *<u>Temp_Class</u>*: This field classifies objects in three types: "Old" for objects in both dates, "New" for non-urban objects changed to urban, and "Lost" for objects that are no longer urban.
  - *<u>Growth_type</u>:* New objects are subclassified in three types of growth: infilling, edge-expansive and outlying. Infilling refers to the gap inside old urban objects that have been partially or totally filled with a newly grown urban object. Edge-expansion occurs when a new urban object appears on the contour of an existing urban object. The outlying growth occurs when new urban objects are isolated.
  - *<u>Nome</u>*: Name of the super-object to which the object belongs.
  - *<u>Area and Perim</u>:* Area and perimeter of the object (in metres).
  - *<u>LEI</u>*: Landscape Expansion Index for each object. This is used to assign the growth type: $100 \geq LEI > 50$ for infilling, $50 \geq LEI > 0$ for edge-expansive, and $LEI=0$ for outlying.
- <u>Res_SO_CL</u>: This layer has the results of multi-temporal metrics for each super-object at urban level. It allows comparing urban growth in different super-objects.
  - *<u>Area and Perim</u>:* Area and perimeter of the super-objects (km^2).
  - *<u>At1_URBAN</u>:* Urban area for the first date (km^2).
  - *<u>At2_URBAN</u>:* Urban area for the second date (km^2).

- *ANew_URBAN:* Area of new urban objects (km^2). Differs from Ac because this does not have into account lost urban objects. It is the accumulative area of objects classified as "new" in "Temp_class".
- *AInf_URBAN:* Area of new urban objects with infilling growth type (km^2).
- *AEdg_URBAN:* Area of new urban objects with edge-expansive growth type (km^2).
- *AOut_URBAN:* Area of new urban objects with outlying growth type (km^2).
- *MEI_URBAN:* Mean Expansion Index for urban type in the super-object.
- *AWM_URBAN:* Area-Weighted Mean Expansion Index for urban type in the super-object.
- *CP_URBAN:* Change Proportion of urban area for the super-object (%).
- *RC_URBAN:* Ratio of Change of urban area for the super-object (%).
- *Ac_URBAN:* Area of urban change for the super-object (km^2).
- *Ar_URBAN:* Ratio of urban change per year for the super-object ($km^2/year$)

The results can be interpreted using the numeric results from the attribute table, but also mapping them. For instance, it is possible to combine their results to give more information as seen in Figure 15. Not only quantifies its growth, but also qualifies its process.

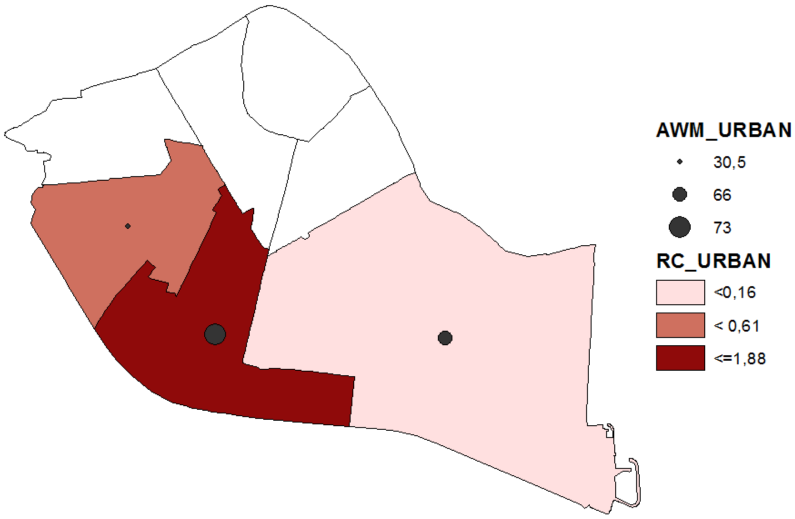


Figure 15. Example of multi-temporal metrics. Graduate dots represent the compactness of the growing process (AWM), while the colour shows the ratio of change (RC), absence of dot and colour means no change.

⇒ **Results_MI_Urban.txt:** this text file stores additional results of urban change. Global growth rates, geometric centres for both dates, distance between centres and orientation to reflect changes of the urban footprint (Figure 16).

```
Results_MI_Urban: Bloc de notas
Archivo  Edición  Formato  Ver  Ayuda
---------------------
MULTITEMPORAL MODULE
---------------------

Input path of the object's shapefile (Time 1): path..\ObjectsT1.shp

Input path of the object's shapefile (Time 2): path..\ObjectsT2.shp

Input path of the Super-Object's shapefile: path..\SuperObjects.shp

Period of time (years): 6

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CLASS LEVEL
-----------

 Whole study area, LAND USE: URBAN

- Area (t1): 21.6033 km2
- Area (t2): 22.1441 km2

- Growth rate (t1 - t2): 0.5545 km2 (6 years)

- Anual Growth rate  (t1 - t2): 0.0924 km2/year

- Growth area infilling (t1 - t2): 0.3694 km2.(66.63 %)
- Anual Growth rate infilling: 0.0616 km2/year

- Growth area edge-expansive (t1 - t2): 0.1757 km2.(31.68 %)
- Anual Growth rate edge-expansive: 0.0293 km2/year

- Growth area outlying (t1 - t2): 0.0094 km2.(1.69 %)
- Anual Growth rate outlying: 0.0016 km2/year

- Coordinates of the Urban Area Geometric centre (T1):  X1 = 3425784.2544 , Y1 = 1879834.1347 metres

- Coordinates of the Urban Area Geometric centre (T2):  X2 = 3425761.4022 , Y2 = 1879797.1521 metres

- Distance between the geometric centres (T1 and T2):  D = 43.4734 metros

- Direction of the displacement between the geometric centres (T1 and T2):  D = South-West (SW)
```

Figure 16. Text file with additional urban growth results

- ### Class Level

In this level changes between classes are shown in the study area. In this case, the super-object shapefile is not included, in order to analyse change patterns for each class, without comparing among super-objects.

Once the data are prepared, open the Tool IndiFrag from ArcGis, then the "*Multi-temporal Analysis*" module, and finally, open "*Calculate MI*" window.

- » Input Feature with Objects (T1): ObjectsT1.shp
- » Land Use Field Name (T1): CLASS
- » Input Feature with Objects (T2): ObjectsT2.shp
- » Land Use Field Name (T2): CLASS
- » Input Feature with Super-Objects: -
- » Super-Object Field Name: -
- » Number of years between T1 and T2: 6
- » Output Text File: Results_MI_Class
- » Input Feature with a Centre Point: Centre_point.shp
- » Ring Equidistance (metres): 250
- » Exploitation degrees:
  - Low: BarrenLand
  - Medium: GreenUrbanAreas;Water
  - Medium-high: Agricultural
  - High: Residential;Roads;Comercial;LeisureFacilities

When the process ends, results are located in "*C:\IndiFragTemp_MI*". During the calculation process, temporal data are located in a geodatabase in this path, but when the process finishes correctly, these files are deleted. At the end, this folder should have the following files:

⇒ **Growth_Types.png**: this graph shows change types for every class in all the study area, even if included it does not take into account the super-objects. It represents the amount of change (km^2) according to its type: infilling, edge-expansive or outlying for each class calculated based on the LEI index (Figure 17).

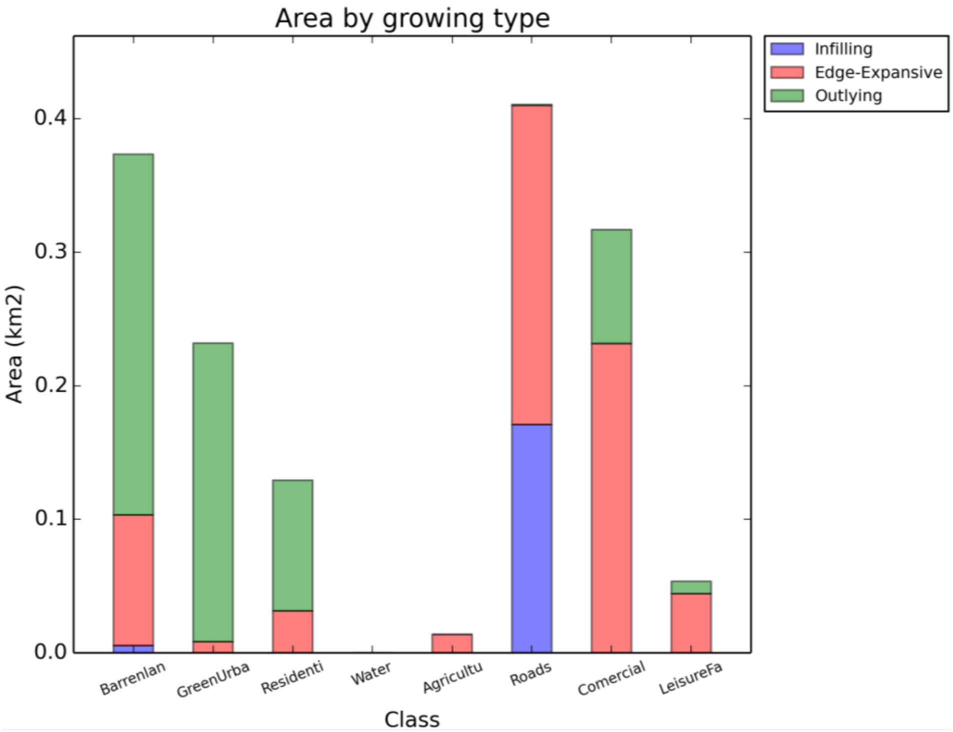

Figure 17. Growth types graph for each class for the study area

⇒ **Growth_Distance_"*Class*".png**: this graph shows the result of the concentric circle analysis with an equidistance of 250 metres that quantifies the area variation (km^2) for each class with respect to the provided centre point, as shown in urban level.

⇒ **Growth_Sector_"*Class*".png**: this graph shows the result of the sector analysis with 16 divided sectors (with an angle of 22.5°) from the provided centre point, that quantifies the area variation (km^2) for each class per orientation, as shown in urban level.

⇒ **gdb_temp.gdb**: This geodatabase contains the results in different feature layers:

- Res_"*Class*": These layers are created combining the area of the same class for both dates; there are as much layers as classes. They have the same fields as those explained in the urban level (Res_URBAN).
- Res_SO_CL: This layer has the results of multi-temporal metrics for each super-object at class level, in this case there is only one super-object, and the results of the classes are stored in different columns. When the Exploitation degree is included three fields are added to those seen in the urban level.
  - *LUD_t1*: Land Use Degree for the first date.
  - *LUD_t2*: Land Use Degree for the second date.
  - *LUC*: Land Use changes between dates having into account all included classes.

- Chng_Cl_SO: This layer shows for each super-object the change between classes, those objects with the same class in the first date and the same in the second are dissolved. It has the following fields:
    - Class_t1: all the objects from the same class for the first date.
    - Class_t2: all the objects from the same class for the second date.
    - Descrip: if there is or not change between Class_t1 and Class_t2.
    - SUM_COUNT_OBJECTID: number of objects in the same situation.
    - PORCENT: percentage of change/no change area respect to the area in the first date.
- Chng_Cl_all: This layer shows for all the study area the change between classes, when there is only one super-object or none this layer is the same as "Chng_Cl_SO".
- Chng_Ob_SO: This layer is similar to "Chng_Cl_SO" but without dissolving the objects. Each object has its previous and current class, and can be analysed separately, it allows making different analysis.
- Res_SO_Ob: Shows the amount of kept and lost areas for each class in percentages. There are two fields for each class "Ch_*Class*" for changed objects, and "NCh_*Class*" for objects that did not change.

These layers are useful for analysing change patterns in a study area, and also quantify its amount, as shown in Figure 18 and Table 1.

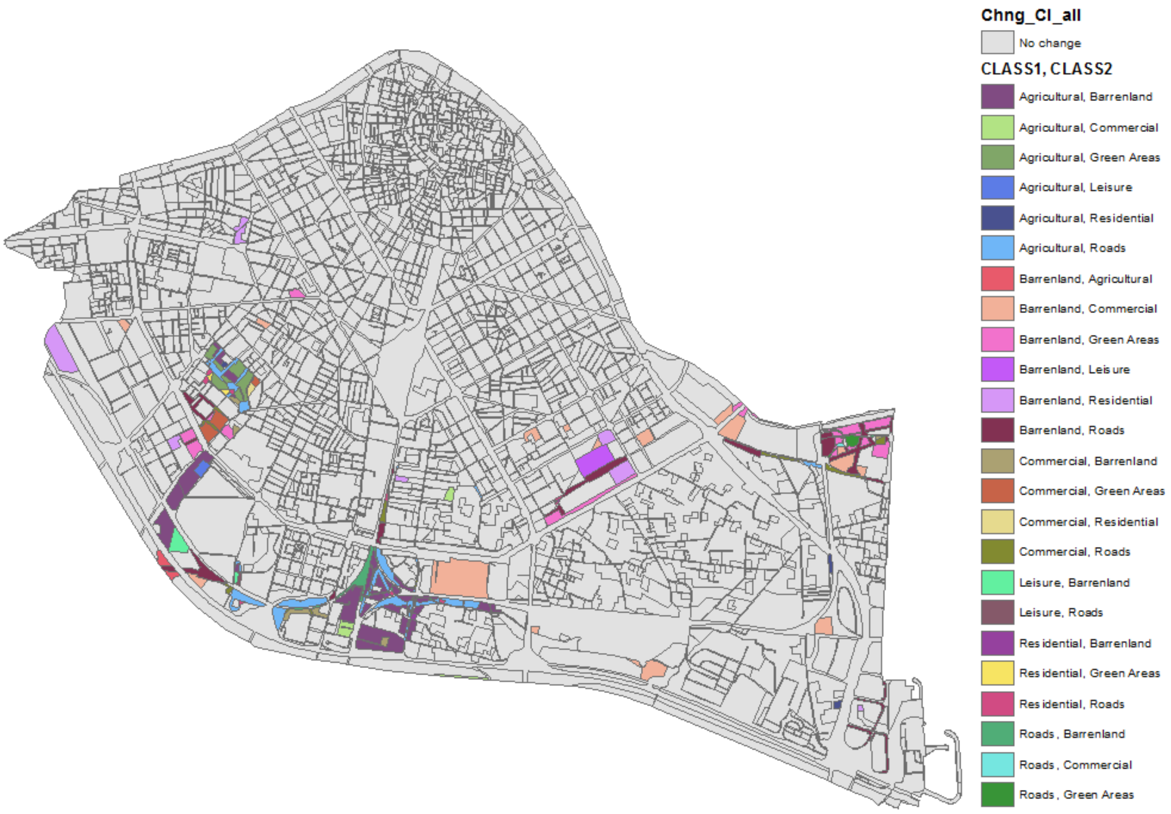

Figure 18. Change between classes for the study area (grey objects mean no change).

Table 1. Change between classes in km². In the diagonal of the table are no changed values. Data extracted from "Chng_Cl_all"

t1 \ t2	Agricultural	Barrenland	Commercial	Green	Leisure	Residential	Roads	Water	Total Area t1
Agricultural	**2.706**	0.286	0.025	0.053	0.009	0.009	0.173	-	3.261
Barrenland	0.014	**1.084**	0.290	0.132	0.044	0.116	0.187	-	1.867
Commercial	-	0.025	**4.531**	0.030	-	0.004	0.036	-	4.627
Green	-	-	-	**1.450**	-	-	-	-	1.450
Leisure	-	0.023	-	-	**0.386**	-	0.002	-	0.411
Residential	-	0.004	-	0.005	-	**8.166**	0.013	-	8.188
Roads	-	0.035	0.002	0.012	-	-	**5.010**	-	5.059
Water	-	-	-	-	-	-	-	**0.261**	0.261
Total Area t2	2.720	1.458	4.848	1.682	0.439	8.295	5.421	0.261	