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Building Local Climate Zones by using socio-economic and topographic vectorial databases

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1. Introduction

(Stewart and Oke, 2009) have acknowledged the need for a more accurate knowledge of ground description at micro-scale levels in order to improve consistency and accuracy in urban climate reporting. To address this, they propose to use Local Climate Zone (LCZ) as geographical objects allowing a finest description of landscape, whatever its nature, urban or rural. We agree that this could hence enhance a lot the understanding of Urban Heat Islands phenomenon, but we are also convinced that LCZ should include somehow the knowledge about citizens behavior in their in-doors: do they open windows during winter? Do they use intensively air conditioners? In fact, previous projects on adaptation of cities to climate (Masson *et al.*, 2014) change have shown that human behavior is a very potent level to address energy consumption reduction, much more than urban forms or architectural technologies.

This approach has been funded by the French National Agency for Research, in a project named MAPuCE. The primary objective of this project is to obtain climate and energy quantitative data from numerical simulations, focusing on urban microclimate and building energy consumption in the residential and service sectors, which represents in France 41% of the final energy consumption. Both aspects are coupled as building energy consumption is highly meteorologically dependent (e.g. domestic heating, air-conditioning) and heat waste impacts the Urban Heat Island. For instance, the use of air cooling can increase up to 1 or 2°C the outdoor air temperatures (Munck *et al.*, 2013 – Ohashi *et al.*, 2007 – Kikegawa *et al.*, 2003). One part of this project consists to automate the computing of urban morphological indicators as well as estimate households' behavior at the micro-scale levels, in order to incorporate those quantitative data in urban micro-meteorological simulations. The project specifies that data sources should be available everywhere in France, for free, which is compatible with the goal of contributing to World Urban Databases.

Using French databases available for free to research and academic domain, a generic and automated method for generating Local Climate Zones (LCZ) has been developed for all cities in France, including the urban morphological geographical and sociological parameters necessary for energy and microclimate simulations. The code is released under GPL v3 license. This paper describes our methodology to automatically build LCZ knowledge from vectorial topographic databases. The originality of this approach is to introduce a zonal object that implements the LCZ specification: the urban islet. This zonal object groups a set of buildings separated from each other's by roads, streets or rivers, delimitating a set of contiguous cadastral parcels, and the set of these zonal objects compose a full partition of urban area.

We explain in this contribution how this task can be achieved, using programs we have developed under open-source license, designed for reuse in various contexts. We show that it allows for the automatic computing of an accurate topographic and socio-economic classification fitting the LCZ's one. A comparison with LCZ specifications is made in order to check whether an islet answers fully the needs raised by LCZ (Stewart I. D. and Oke, T. R. 2012).

2. Building a zoning to catch LCZ's indicators (and more) on urban areas

The aim of the new zoning we would like to design is to catch at the best urban morphological parameters as well human behavior: it is needed a zoning at a micro scale as close as possible to the real urban forms. We are saying that being to a micro scale is a necessary but not sufficient condition. For instance, regular zonings such as grids of 200 m, 500 m or 1 km of width can arbitrary split in many parts homogeneous urban blocks, and/or mix together heterogeneous urban blocks (Long *et al.*, 2008). The homogeneity we are speaking about concerns both the morphological forms of the buildings (what can be seen from the outside) but also the socio-economic indicators from which human behavior could be derived (who is living inside). Our main hypothesis is that contiguous urban plots (or parcels) which can also be called the "*urban islet*", may group together humans

having a very similar way of living, in similar housing (Conzen, 1960). Using those urban islets, we can go toward a full LCZ zoning by proceeding to a classification grouping together neighboring cells having similar characteristic, not only for human behavior or architectural characteristics but also for more classical but necessary indicators like canyons aspect ratio, building surface fraction, impervious/pervious surface fraction and such on, developing thus a methodology that was previously applied on gridded data (Bonhomme *et al.*, 2012). Using a composition of parcels has another advantage: there is a direct link with cadastral land databases, which allows for a finest knowledge of usages and renovations of buildings, at a scale that is used by urban planning agencies.

The observation of LCZ's maps made handy by experts supports our hypothesis. It seems that they recognize at first the shape of contiguous urban plots, surrounded by streets, roads or waterways. This is exactly the case of the expert LCZ's map available on <http://carto.iau-idf.fr/webapps/imu/> made for the Institute of Urban Planning and Layouts for Ile-de-France region: cells of this zoning are made of contiguous urban blocks (Fig. 1).

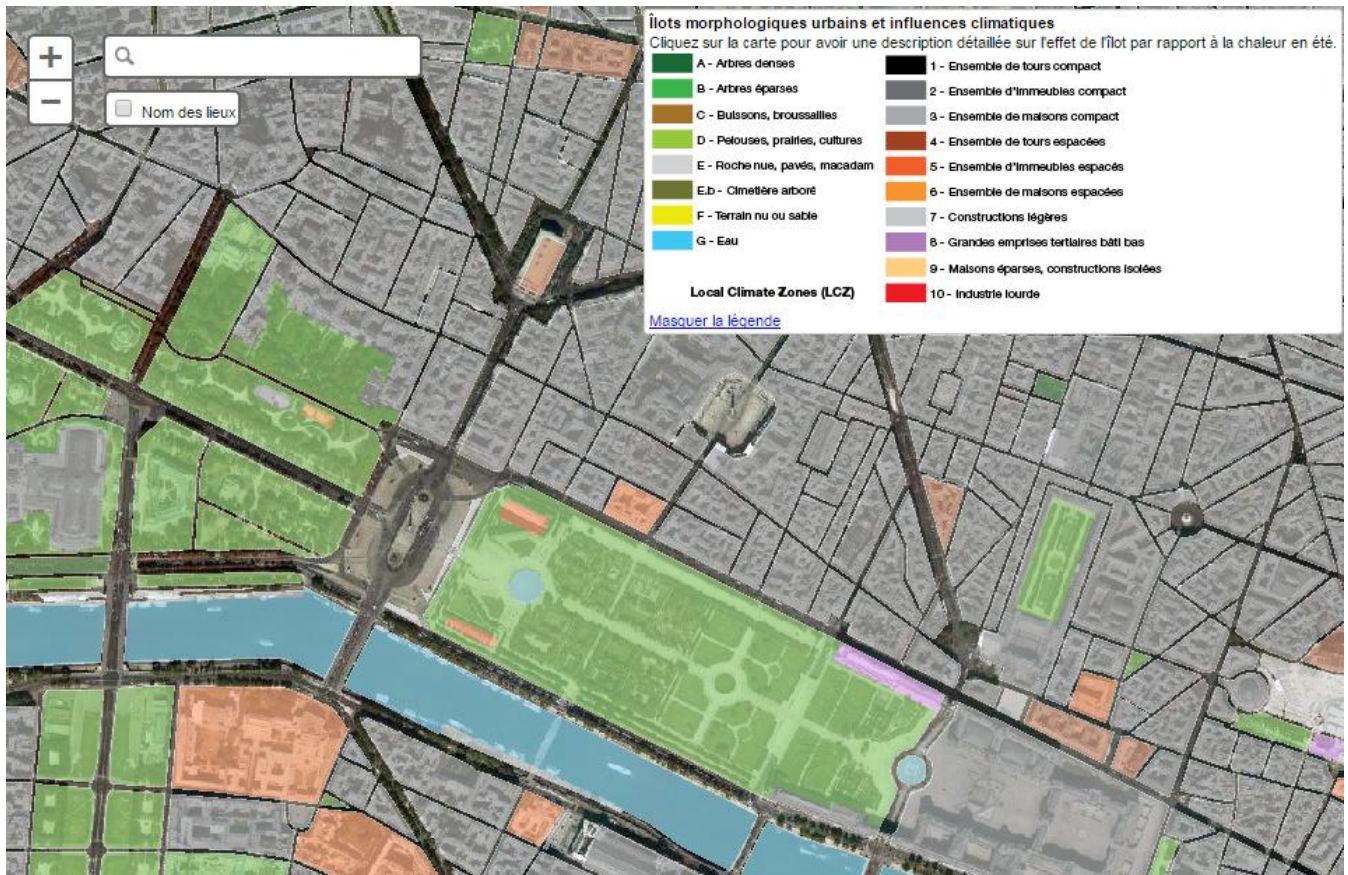


Fig. 1 Local Climate Zone map produce by IAU, accessed at <http://carto.iau-idf.fr/webapps/imu/> on 2015-06-22.

However, this approach raises a problem because the produced zoning is not a continuous one: the set of cells do not build a full partition of the urban space. Thus, impervious surfaces like roads or parking are not included within the limits of the cells of this zoning. It is required to build a full partition of the space, grouping contiguous parcels together. Looking at vectorial features extracted from databases, on Fig. 2, with the street-blocks paint in purple, and industrial buildings in orange, residential ones in grey, and other functions in green or red, it gives the impression that each street-block groups a set of building having the same function. The space in between is filled with blank, and it is required to compute a limit that could make its path in between each street-block.

Using a mask of road network coupled by hydrological network could be an idea, but when looking at the result it would produce (linears in red-orange-yellow on Fig 2), some problems occurs: many artefacts are produced by roundabouts or roads in two separate ways for instance.

That's why our solution is based on the union of contiguous cadastral parcels, without using the road network *a priori*: the frontiers of islets are built so as to share in two parts the space existing between each street-block. For that, we proposed to use the properties of Voronoï tessellation which allows for building a balanced zoning between a set of points (Fig 3). In fact, by placing points on the borders of each polygon (in grey on Fig. 3), the corresponding Voronoï tessellation will define borders (in red on Fig. 3) at equal distance from each points, and thus define the frontiers of the new cells.

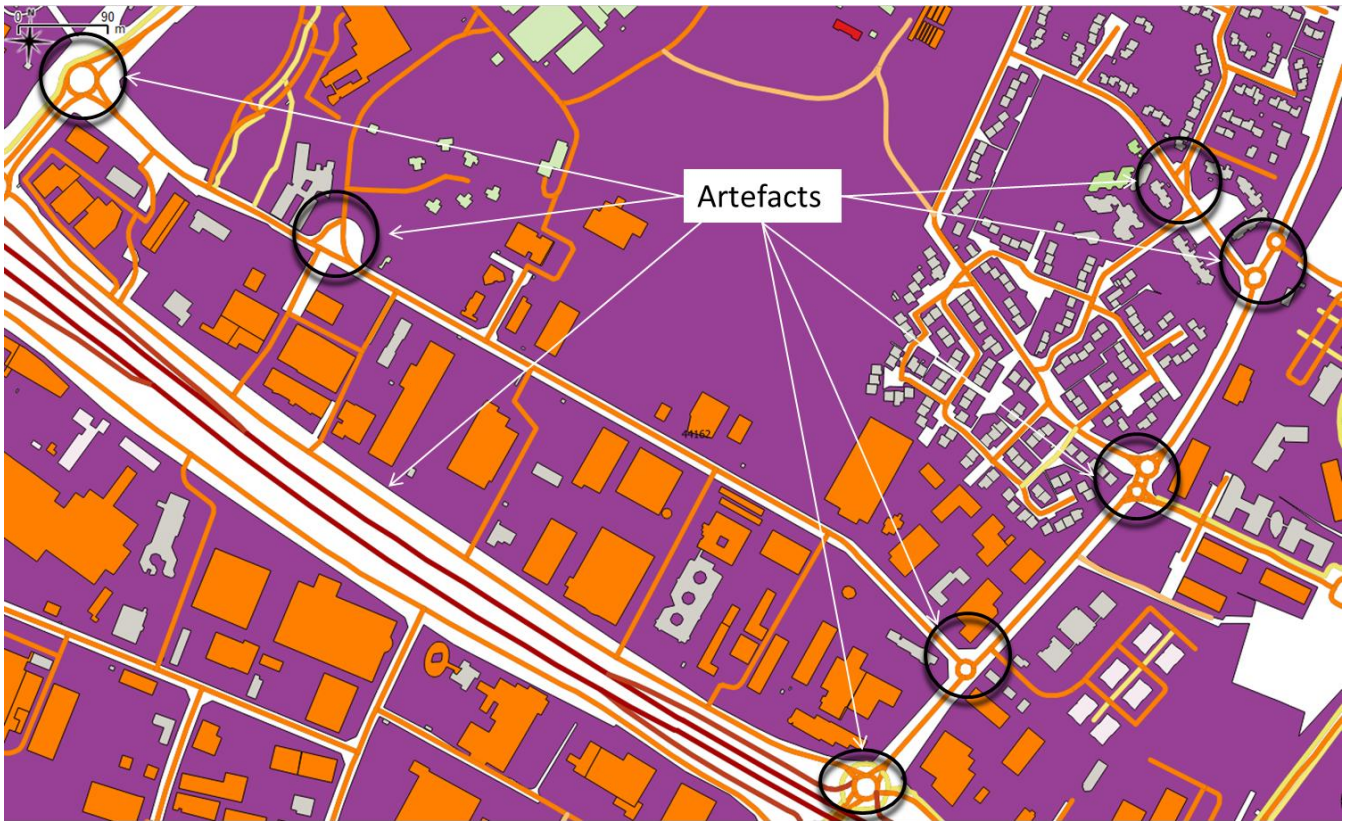


Fig.2 Tessellation built using a road mask: artefacts that may appear.

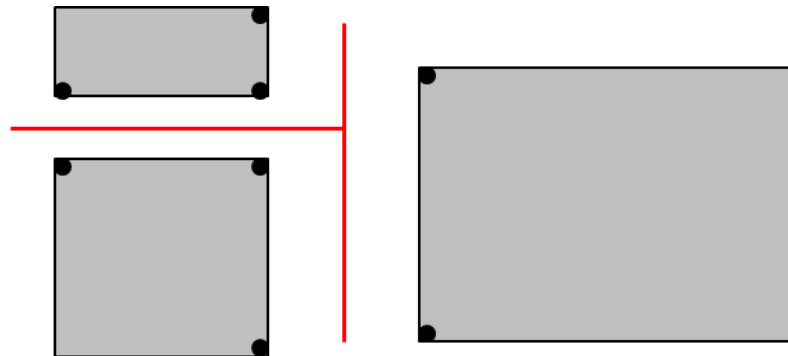


Fig.3 Using Voronoi tessellation to compute mid path (in red) between street blocks (in grey).

2.1 Automating a workflow using available data sources

The data sources have to cover the national French territory and be available for free for researchers: topographic data are provided by the French National Agency, (IGN) and socio-economic datasets are downloaded from the French National Institute for Statistical and Economic Studies (INSEE).

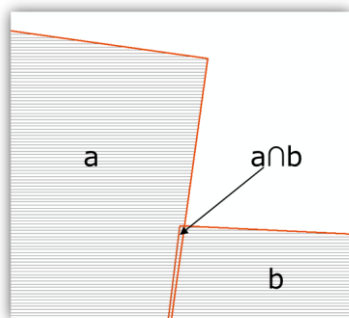
Concerning topographic data, IGN proposes various vectorial datasets amongst which two of them retain our attention:

- The BD Topo ® which provides buildings with their height for a part of them, classified in 3 categories: “unclassified”, “industrial” (industrial and commercial) and “remarquable”. It contains also roads network, hydrographic network, shapes of vegetation patches, and some interesting punctual features named “Point Of Interest” that may help for a classification of various buildings or areas functions (they describe some administrative, cultural, educational or sportive functions).
- The BD Parcellaire ® that provides harmonized limits of cadastral parcels on French territory, and a most updated and complete layer of buildings than BDTopo, but without any functional description nor morphological description (not any height). Using the parcels and their attributes, there is a direct link with other cadastral databases that are not public but can be accessed for free under conditions, and provide more accurate information about land use or housing (date of building renovation for instance).

Concerning socio-economic data, INSEE provides at the finest scale two types of datasets : a regular grid for

population density on cells of 200m x 200m (having an area of 4 ha), associated to a set of variables such as the number of proprietary households, the surface of their housings, and the number of households living in collective housings¹. Income ranges of households are also provided with some cautions about privacy. However, many interesting features are lacking, such as the kind of heating system, the main energy source (gas, fuel, and electricity), the education level or size of the residents' household. This kind of detailed information are available only at IRIS scale which is a statistical zoning grouping at least 2000 households, and whose median cell area is about 740 ha, and maximal cell size is of 36700 ha. The main database linked to IRIS zoning is a survey called "RP logement"², that is fully released by INSEE every 5 years (2006, 2011, next is 2016). Downscaling this information at a micro scale level requires computing some proxies (also called *predictors*) such as inhabitants, household number per building, and share of households living in individual residence, to realize a modified areal weighting regression using control zones (Goodchild *et al.*, 1993; Plumejeaud *et al.*, 2010). Thus we prior the automatic computing of those proxies at the finest scale we can get (the grid) and forecast to use those variables like proxies to downscale the various variables available at IRIS scale.

Using these data, the proposed workflow mixes various sources, in order to build an enriched and qualified dataset on a specific study area whose extent is specified by the user. However this task is difficult because of the various inconsistencies (buildings may overlap, intersect, or appear twice) in the sources as show on Fig. 4.



Intersection of building footprints.



On the left side, the aerial view of roofs, and the right side the vectorial shapes in colored areas. Three artifacts overlap the building shapes in red.

Fig.4 Few examples of inconsistencies that must be fixed in topographic data sources.

Thus the workflow is composed of 5 steps for a given study area:

1. Import and clean the datasets
2. Build a continuous zoning of urban islets
3. Associate buildings to urban islets
4. Enrich topographic description of islets (share of water surfaces, roads surfaces, vegetation surfaces, etc.) and buildings (functions)
5. Prepare a downscaling by transferring some proxies from INSEE's grid to urban islets and building scale.

The design of the workflow is generic: for instance, the extent of the study area can be specified like a shape containing polygonal objects provided in parameter of the function that prepare a *data_zone* space inside the database. The only constraint we set is to put raw data sources in a schema named '*raw_data*' in tables named according this pattern '*src_source_XXXX_theme*' where *source* can be BDTOPO, BDParcellaire, OSM, or what else, whereas XXXX gives the year on 4 digits of the produced data, and *theme* is a free text describing of the content of the data.

The code is developed using PL/SQL languages, on top of PostgreSQL DBMS (version ≥ 9.2) with postgis (version ≥ 2.1) for spatial and topological operations handling, working in hand with R *tripack* package allowing for Voronoï tessellation computation (Bivan and Gebhardt, 2000). The *genilot* extension comes as a set of PL/SQL functions that may be called independently of the proposed workflow in order to clean datasets, or build a continuous tessellation of space from a set of polygonal shapes, or enrich a zoning or a set of buildings with vegetation layers, road network layers or water network layer. The workflow is driven by python programs, and uses open-source ogr2ogr utility³ that helps to feed the database with the 200 Go of data coming from sources having heterogeneous formats (SHP, MIF-MID, ASCII, DBF, CSV). Thus the global architecture is modular, based only on open-source softwares, and can be continuously enhanced.

¹ Only population is inside tiles, other variables are proposed in set of tiles forming rectangles, grouping at least 11 households, http://www.insee.fr/fr/themes/detail.asp?reg_id=0&ref_id=donnees-carroyees&page=donnees-detaillees/donnees-carroyees/donnees-carroyees-200m.htm

² http://www.insee.fr/fr/themes/detail.asp?reg_id=99&ref_id=fd-rp2011&page=fichiers_detail/RP2011/telechargement.htm

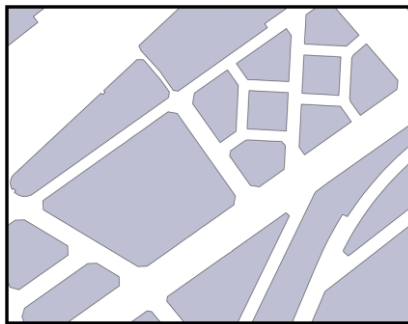
³ <http://www.gdal.org/ogr2ogr.html>

2.2 Focus on the step 2: zoning calculation

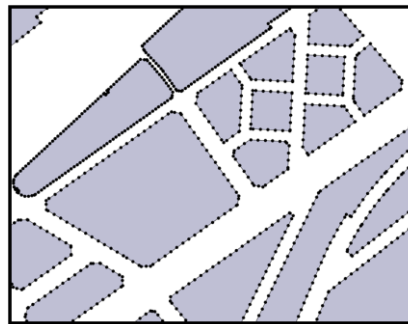
Here we give the focus to the method developed in order to obtain a continuous tessellation of space from a set of parcels. The main idea is to fusion contiguous parcels in order to obtain a set of street-blocks, and then, to extend block's borders so as they touch (without overlapping) each other's and form a set of cells called "continuous urban islets" covering entirely the study area.

We use data that have been cleaned at the previous step, namely the parcels, which should always represent a private area. Roads and rivers usually fall in public domain and are not included inside the set of parcels. However, some parcels may not have already fall in the public domain, for specific reasons (it is a recent modification of the cadastre for instance) and the workflow proposes to identify and filter those parcels. For that, an elongation index (Miller, 1953) is computed, as well as the intersection with any road or river. Whenever a parcel is not built and is elongated, or when the share of road/river intersecting it exceeds a certain threshold (a parameter of the function), then it is filtered to reverse it to the public domain.

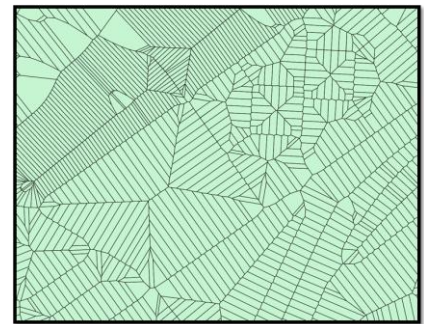
The next task is the computation of street blocks by fusing the contiguous parcels, which is quickly done (step 1 on fig. 4). Then the workflow has to prepare the computing of Voronoï diagrams, by preparing a set of points following the borders of the street-blocks (step 2 on fig. 4). In fact, calculation of Voronoï diagrams is based on an algorithm whose complexity is in $O(n \log(n))$, where n is the number of points generated on each vertex of the polygon. The dot density along the polygon edges depends on the proximity of the block with another: this allows for a balance between accuracy and consumption of computational resources. The more the blocks are close, the more the points are densely put along the frontiers of both blocks (1 m for blocks separated of 0.5 m).



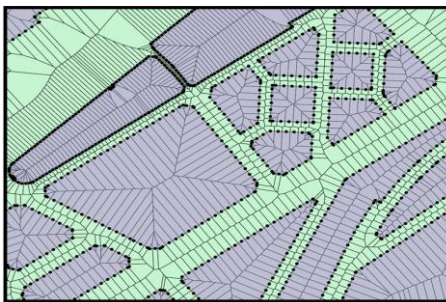
Step1. Union the contiguous parcels to get the street blocks.



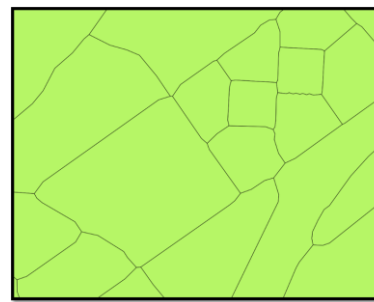
Step 2. Prepare the points seeding for Voronoï tessellation.



Step 3. The set of Voronoï polygons are computed.



Step 4. The set of urban islets are computed by fusing Voronoï diagrams.



Step 5. The frontiers of each urban islets are smoothed.

Fig.5 Computing a continuous tessellation of urban space using cadastral parcels.

Time for computation is exponential due to the algorithm complexity: it depends on the surface to compute. Globally, it requires one hour on a virtual machine running a dual core CPU with 8 Go of RAM in order to process a study area having an average size (1861 ha) for a French municipality. However the processing could be easily parallelized since the computing internally splits the study area in little regular pieces of grid, before reassembling them in memory.

2.3 Enrich data for building LCZ's indicators

Figure 6 shows the complete data model at the output: blue attributes are derived from topographic sources, whereas pink ones are derived from INSEE gridded data. *Continuous_urban_islets* is the urban islet enriched with attributes such as length of roads, area of vegetation, roads and hydrographic objects, count of population, households, etc. *Buildings_BDtopo* represents each building of BDTopo (fully qualified and fixed) that references the islet it belongs to. Each building is classified for its function in *poi_nature* through a "Point Of Interest" feature intersecting its parcel, or with its industrial/commercial nature, in order to avoid "unclassified" buildings that may have a non residential function. From given *height*, a new attribute *fixed_height* is derived in order to compensate for null or 0 values, which are numerous in BDTopo database (13 % of the total). Using *fixed_height*, *nb_levels* is an estimation of the number of levels in each building, which is a key data to compute the total built area of each

islet. The model exports also fixed *parcels* and *street_blocks* that have been used to build the urban islets zoning. Attributes *inhabitants* (per building, per islet), *households* (per islets), etc., are the proxies that should help to reallocate into each urban islet the census figures we can get at IRIS scale. Their values are computed by summing the share of each grid cells proportionally to the share of built area (which is restricted to “unclassified” buildings) intersecting both cells and urban islets

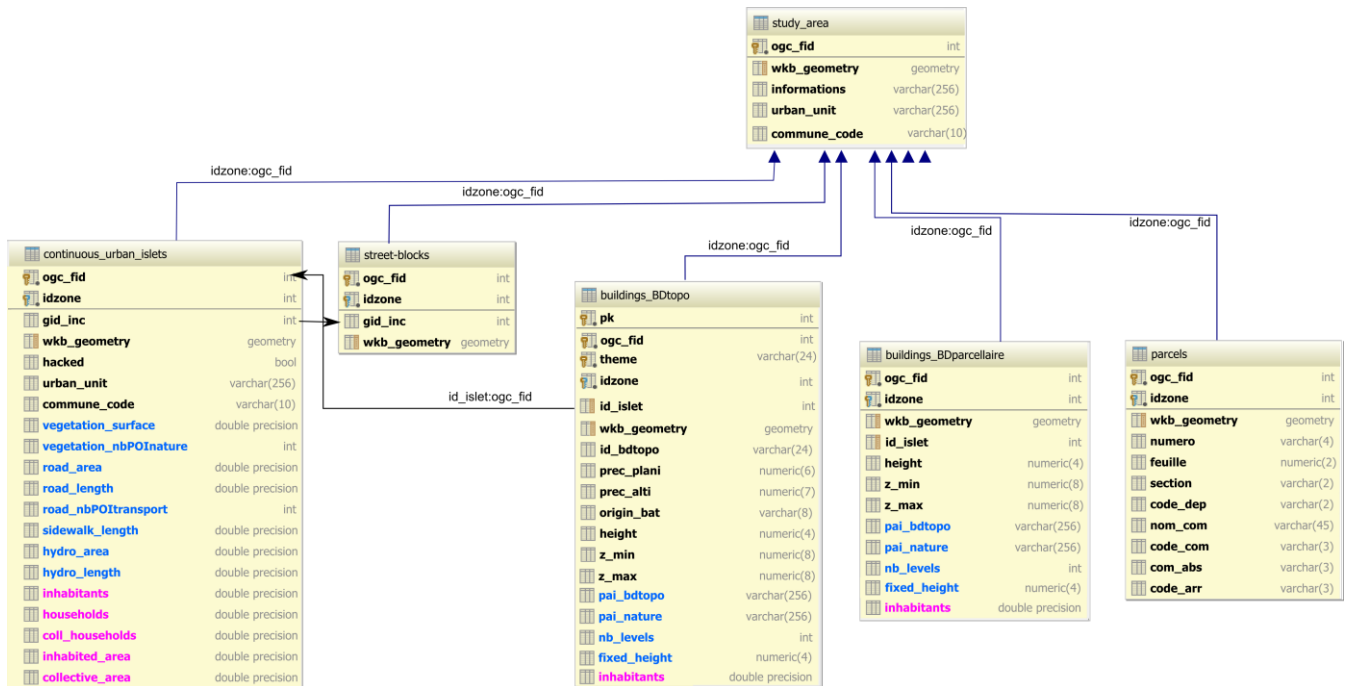


Fig.6 Model of the enriched dataset.

At this step, still little information is missing for a complete LCZ's characterization. Indeed, those indicators must be computed:

- sky view factor
- canyon aspect ratio
- surface admittance
- surface albedo
- terrain roughness

Indicators (a) and (b) can be obtained using the buildings' class since the model described the height of buildings, gives their footprint and area can be deduced. Indicator (e) may require further investigation in rural area, where high vegetation must be distinguished from low vegetation. Concerning the (c) and (d) indicators, further knowledge is required about materials used in the study area (white stone like in La Rochelle area, or red brick as used in Toulouse may not have the same albedo), but this knowledge can be downscaled to the urban islets or building scale, using proxies we have computed: share of industrial/commercial or residential buildings, share of individual or collective housings, as already done in (Masson, 2014).

3. Analysis and comparison with LCZ specification

In order to provide some clues about the pertinence of this zoning, the quality of this zoning is discussed according to the homogeneity hypothesis we have made. First we provide some statistical description of the islets. Then an assessment of the quality of the proposed zoning based on criteria of homogeneity for building's occupation, height, and land use (share of impervious/pervious surfaces, and water surfaces) is proposed.

Table 1 gives a complete statistical summary for islets concerning their number and shapes, computed for 170 461 computed islets on 1 114 852 ha, on various urban units, from Marseille-Aix-en-Provence (50 communes) to middle areas such as Saint-Quentin (grouping 5 communes). This demonstrates a great variety of shapes and surfaces, with high dispersion coefficients, in particular concerning the area of islets (4.14), which means that a mean area of 6 ha (that would be equivalent to a cell of about 250 m by 250 m in a grid) do not well represent the heterogeneity of the urban shapes. However they tend to be convex in their shape, the solidity index having a mean of 0.89 with a low dispersion (0.15).

One of the main quality criteria should be that cells of the zoning should maximize the inter-class variance and minimize within-group variance for the various indicators we associate to them. It is possible to realize this analysis by considering the internal composition of each islet for various kind of surfaces (thus qualifying their physical properties for climate modeling) and kind of housings and usages (describing thus their properties for energy balance properties linked to human behaviors).

Table 1 Statistical summary describing shapes of islets.

	Area_ha	Perimeter	Miller index	Solidity index	Compacity index	Side (meters)
Minimum	0.00	4.40	0.00	0.01	1.01	1
1st Quartile	0.44	307.10	0.49	0.86	1.17	66
Median	1.16	506.00	0.63	0.93	1.26	107
Mean	6.04	821.40	0.58	0.89	1.50	246
3rd Quartile	3.75	932.70	0.73	0.97	1.43	194
Maximum	2 387.73	56 764.50	0.98	1.00	20.63	4 886
Standard deviation	25.02	1 031.15	0.19	0.14	0.95	500
Dispersion	4.14	1.26	0.33	0.15	0.63	2

Let's introduce the Shannon's diversity index H (Shannon and Weaver, 1962) as a measurement of the redundancy in data of each islet, for a variable y that can be decomposed in n sub-categories, computed according to Eq. 1.

$$H = -\frac{1}{\ln(n)} \sum_{i=1}^n \frac{y_i}{y} \ln \frac{y_i}{y}, \quad E \in [0,1] \quad \text{Eq. 1.}$$

When the specialization of each islet is maximal, which means each islet constitutes a class of similar things (one of the categories of y is predominant), H tends to 0. H as a derived measure of entropy is a multiscalar measure allowing also the measurement of the global diversity of a study area. When there is an equidistribution of each sub-categories in the study area, H tends toward 1. The Table 2 presents figures computed for Toulouse urban unit, which groups 100 communes, having a whole area of 105106 ha and for which 12358 islets have been computed.

Table 2 Shannon measures for Toulouse study area.

Variable	Categories	Shannon on study area	Shannon per islet	Shannon per grid
Y1	Buildings levels ≤ 2	0.44	Mean: 0.20	Mean: 0.23
	Buildings levels >2		Q1 - Q3: [0.00 - 0.39]	Q1 - Q3: [0.00 - 0.45]
Y2	Built area	0.85	Mean: 0.85	
	Roads surface		Q1 - Q3: [0.72 - 0.92]	
	Vegetation surface			
	Water surface			
Y3	Residential buildings	0.40	Mean: 0.13	Mean: 0.22
	Industrial buildings		Q1 - Q3: [0.00 - 0.00]	Q1 - Q3: [0.00 - 0.43]
Y4	collective housing	0.99	Mean: 0.44	
	individual housing		Q1 - Q3: [0.04 - 0.81]	

The Shannon index distribution computed on islets (Table 2) show that islets group buildings having a very similar number of levels (the index is low with a mean of 0.20 per islet), whereas there is much more diversity on the study area (0.44 is merely a balance level of Shannon index). Similarly the classification of residential/industrial buildings per islets demonstrates a high specialization of islets for this kind of buildings (Shannon index mean is 0.13, and more that 75% of islets are totally specialized with only one category built on). Concerning the specialization into collective or individual buildings, which is not present on the whole study area (with a Shannon index of 0.99), most of the islets group together same kinds of housing, lowering the Shannon index down to 0.44 in average. This means that the aim of this zoning is reached: it groups together similar contiguous things, even when there is some diversity on the whole study area.

This result is not reached for the land cover of the urban unit, which is much diversified concerning the land cover knowledge derived from vectorial databases (0.85 for Shannon index). The diversity for islets is also quite important (0.85 in average for Shannon index, with more than 50% of islets close to this index value). However, this is concordant with definition of an islet, that is to say, it should be surrounded by roads or waterways, and be described by the share of those linears crossing it.

Further investigations led by comparing the islets zoning with similar properties computed on a regular grid of 250 by 250 meters drawn upon the agglomeration of Toulouse, show that Shannon indexes are enhanced when using islets. For instance, buildings levels are less concentrated in a cell of a regular grid, (75% of the cells demonstrate a Shannon index of 0.45 against 0.39 for islets), despite the fact that we count twice (or more) the numerous buildings belonging to many cells (28% of the 256 019 buildings), which barely happens on islets. This is well underlined by the analysis of residential versus industrial buildings distribution: 25% percent of cells are above 0.43 Shannon index, a level much higher than for islets. This indicates a higher diversity of buildings in regular cells concerning their usage (housing or economic activities) than in urban islets.

4. Conclusion and perspectives

This contribution exposes a new methodology to build a continuous tessellation of urban space that fits to urban blocks forms, but can also answer to the LCZ's specifications. This methodology is reproducible everywhere, as long as one disposes from topographic databases specifying parcels' limits and a minimum building's feature such as their footprint and height. The computation of a complete partition of urban space based on cadastral parcels shapes gives new insights to urban planning, because this zoning achieve the qualification of street-blocks with surrounding land-use characteristics in a balanced manner. It takes advantage of the internal homogeneity of these street-blocks concerning the housing, households and buildings characteristics. The first destination of this zoning enriched with topographic and socio-economic data is to feed TEB (Town Energy Balance), (Masson, 2000) in order to run urban micro-meteorological simulations, in 80 urban units in France, chosen for their diversity for various parameters such as for size, climate zone, physical geography, plans. Results will be used to produce heat maps for a better integration of the Urban Heat Island phenomenon into urban planning schemas.

Thanks to the link existing between urban islets and cadastral land databases, it is also planned to realize a quality check in depth about the accuracy of the produced indicators on three urban units used as study cases: La Rochelle, Aix-en-Provence, and Toulouse. One of the perspectives of this work is also to enhance Energy-Climate assessment, by estimating energy consumption of households at this micro-scale level, and publishing this information for urban planning. The proxies that are computed for the downscaling of micro-survey from IRIS to urban blocks levels should be very useful.

Acknowledgment

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