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Preliminary Local Climate Zones (LCZ) Classification

Deliverable D3.2

URBANFLUXES

URBAN ANTHRPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

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1 INTRODUCTION

1.1 Purpose of the document

The Deliverable D3.2 aims at documenting the database containing the preliminary Local Climate Zone (LCZ) maps for the URBANFLUXES project. The document is an intermediate result of WP3 task 3 of the project.

After a general introduction of the URBANFLUXES project, the document describes the concept of the LCZ, its use in URBANFLUXES and the current approach for mapping LCZ. By defining LCZs, more or less standardized urban landscapes are theoretically created according to their thermal properties. LCZs can then be used for simplified analysis of urban heat aspects. In the evaluation and outlook the approach and its results are discussed and subsequent steps are described. A final section focusses on the organization of the LCZ data base within the project.

1.2 Definitions and acronyms

Acronyms

CoP	Community of Practice
DEM	Digital Elevation Model
DSM	Digital Surface Model
DSS	Decision Support System
EO	Earth Observation
LCZ	Local Climate Zones
NDVI	Normalized Difference Vegetation Index
SVF	Sky View Factor
TIFF	Tag Image File Format
UEB	Urban Energy Budget
UHI	Urban Heat Island
UMEP	Urban Multi-scale Environmental Predictor
URBANFLUXES	URBan ANthropogenic heat FLUX from Earth observation Satellites
UTM	Universe Transverse Mercator
VHR	Very High Resolution
WP	Work Package

1.3 Document references

[R1] URBANFLUXES Deliverable D3.1, Urban surface morphology land cover-use and characteristics.

2 PROJECT OVERVIEW

The anthropogenic heat flux (Q_F) is the heat flux resulting from vehicular emissions, space heating and cooling of buildings, industrial processing and the metabolic heat release by people. Both urban planning and Earth system science communities need spatially disaggregated Q_F data, at local (neighbourhood, or areas larger than the order of 100 m x 100 m) and city scales. Such information is practically impossible to derive by point *in-situ* fluxes measurements, while satellite remote sensing is a valuable tool for estimating Urban Energy Budget (UEB) parameters exploiting Earth Observation (EO) data. While the estimation of Q_F spatial patterns by current EO systems is a scientific challenge, the major challenge lies on the innovative exploitation of the Copernicus Sentinels synergistic observations to estimate the spatiotemporal patterns of Q_F and all other UEB fluxes.

The main goal of URBANFLUXES is to investigate the potential of EO to retrieve Q_F, supported by simple meteorological measurements. The main research question addresses whether EO is able to provide reliable estimates of Q_F for the time of the satellite acquisition. URBANFLUXES answers this question by investigating the potential of EO to retrieve Q_F spatial patterns, by developing a method capable of deriving Q_F from current and future EO systems. URBANFLUXES aims to develop an EO-based methodology easily transferable to any urban area and capable of providing Q_F benchmark data for different applications. URBANFLUXES is expected to increase the value of EO data for scientific analyses and future emerging applications (such as urban planning and local/regional level climate change mitigation/adaptation), by exploiting the improved data quality, coverage and revisit times of the Copernicus Sentinels data. To this end, the specific objectives of the project are:

- to improve the accuracy of the radiation balance spatial distribution calculation;
- to develop EO-based methods to estimate the flux of heat storage in the urban fabric, as well as the turbulent sensible and latent heat fluxes at local scale;
- to employ energy budget closure to estimate the anthropogenic heat flux patterns;
- to specify and analyse the uncertainties associated with the derived products;
- to evaluate the products by comparisons with Q_F estimations by independent methods;
- to improve the understanding of the impact of Q_F on urban climate; and to communicate this understanding to the urban planning community, which will in turn lead to a better understanding of what new knowledge is needed on the ground;
- to exploit Sentinels 2 and 3 synergistic observations to retrieve UEB fluxes at the local scale, with the frequency of the Sentinel 3 series acquisitions.
- to standardise the resulting products, and by organizing an effective dissemination mechanism, to enhance their use by urban planners and decision makers in cities, as well as by EO scientists, Earth system modellers and urban climatologists.

The duration of URBANFLUXES is three years and it is divided into two main phases: during the 1st Phase an analysis method is being developed to estimate Q_F spatial patterns using currently available satellite data; during the 2nd Phase the developed method will be adapted to Sentinels synergy to derive Q_F spatiotemporal patterns. Three different urban areas are selected in URBANFLUXES as case studies: a highly urbanized mega city (London); a typical central European medium size city, that requires a substantial amount of energy for heating (Basel); and a smaller, low latitude Mediterranean city that requires a substantial amount of energy for cooling (Heraklion). The project uses a Community of Practice (CoP) approach, which means that in the case studies, local stakeholders and scientists meet on a regular basis to learn from each other and to make clear what aspects are important for the future users of the URBANFLUXES products.

URBANFLUXES is expected to generate a novel analysis method for estimation of UEB components from Copernicus data, enabling its integration into applications and operational services; for example to: develop rules of thumb for density and green space ratio, distinguish between insulated and non-insulated buildings and evaluate the implementation of climate change mitigation technologies, such as solar-screening and green-belting.

Despite its local importance, Q_F is omitted from climate models simulations. Observations of global temperature evolution indicate a pronounced warming over the last 150 years, with an increase in the occurrence of heat waves. The added value and benefit expected to emerge from URBANFLUXES is therefore related to quality of life, because it is expected to improve our understanding of the contribution of Q_F to heat wave intensity and thus to allow insight into strategies for mitigation. Q_F estimates are needed for all cities to be able to document the magnitude of the fluxes effects on urban climate so that the impact of Q_F can be included in climate modelling. URBANFLUXES is therefore expected to advance the current knowledge of the impacts of Q_F on urban heat island and hence on urban climate, and consequently on energy consumption in cities. This will lead to the development of tools and strategies to mitigate these effects, improving thermal comfort (social benefit) and energy efficiency (economic benefit). The long term operation of the Sentinels series guarantees the future supply of satellite observations, providing the means for the development and realization of the URBANFLUXES methodology.

URBANFLUXES is expected to support sustainable planning strategies relevant to climate change mitigation and adaptation in cities, because knowledge of Q_F spatio-temporal patterns is important for urban planning (e.g. to reduce or prevent Q_F hot spots), health (e.g. to estimate the impact on thermal comfort) and future proofing (e.g. to plan and implement interventions towards Q_F reduction in these areas). Planning tools, such as Urban Climatic Maps and Climatope Maps, should be enriched with information on Q_F patterns. Mapping provides visualization of assessments of these phenomena to help planners, developers and policy makers make better decisions on mitigation and adaptation.

3 LOCAL CLIMATE ZONES

3.1.1 Concept and Definition

Recently, Stewart and Oke (2012) introduced a systematic classification scheme of Local Climate Zones (LCZ) based on various urban typologies, which explicitly defines urban landscapes according to their thermal properties. The scheme aims to be objective (incorporating measurable and testable features relevant to surface thermal climate), inclusive (sufficiently generic in its representation of local landscapes to not inherit regional or cultural biases) and standardized. The individual classes aim to have relatively homogenous air temperature within the canopy layer. They are defined by fact sheets with both qualitative and quantitative properties, including several features that can be derived from EO data. This concept will be used in URBANFLUXES in two ways. First, the properties of a certain LCZ type can be used as an approximation or generalisation for the modelling of anthropogenic heat. For example, certain material properties can be assumed for each LCZ type. Second, LCZ types can represent areas with similar anthropogenic heat characteristics. This is especially interesting for a quick assessment of new study areas when not all data or time is available to do extensive modelling. To both uses of LCZ it is assumed that the properties that define the LCZ can be derived from EO data, preferably satellite based data sets such as from the upcoming Sentinel missions.

With the preliminary mapping step of the LCZ described in this deliverable, it is tested how the LCZ maps can be used as required for URBANFLUXES.

3.1.2 Preliminary mapping

The preliminary mapping of the LCZ followed closely the approach described by Stewart and Oke (2012). They defined 17 LCZ types by thresholding 10 geometric and surface cover properties. The definitions are listed in Table 1. For the classification of LCZ in URBANFLUXES, the following parameters are derived from EO data: impervious surface cover, pervious surface cover, surface albedo, sky view factor, canyon aspect ratio, mean building/tree height and building density. The overview in Figure 1 shows how and from which EO data they are derived and what processing steps are applied to derive the LCZ map from the LCZ parameters. This is described in more detail below.

Table 1: Values for geometric and surface cover properties for local climate zones after Stewart and Oke (2012).

Local climate zone (LCZ)		Sky view factor[a]	Aspect ratio[b]	Building surface fraction[c]	Impervious surface fraction[d]	Pervious surface fraction[e]	Height of roughness elements[f]	Terrain roughness class[g]	Surface Admittance [h]	Surface albedo[i]	Anthropogenic heat output[j]
Compact high-rise	LCZ 1	0.2–0.4	> 2	40–60	40–60	< 10	> 25	8	1500-1800	0.1-0.2	50-300
Compact midrise	LCZ 2	0.3–0.6	0.75–2	40–70	30–50	< 20	10–25	6–7	1500-2200	0.1-0.2	<75
Compact low-rise	LCZ 3	0.2–0.6	0.75–1.5	40–70	20–50	< 30	3–10	6	1200-1800	0.1-0.2	<75
Open high-rise	LCZ 4	0.5–0.7	0.75–1.25	20–40	30–40	30–40	>25	7–8	1400-1800	0.12-0.25	<50
Open midrise	LCZ 5	0.5–0.8	0.3–0.75	20–40	30–50	20–40	10–25	5–6	1400-2000	0.12-0.25	<25
Open low-rise	LCZ 6	0.6–0.9	0.3–0.75	20–40	20–50	30–60	3–10	5–6	1200-1800	0.12-0.25	<25
Lightweight low-rise	LCZ 7	0.2–0.5	1–2	60–90	< 20	<30	2–4	4–5	800-1500	0.15-0.35	<35
Large low-rise	LCZ 8	>0.7	0.1–0.3	30–50	40–50	<20	3–10	5	1200-1800	0.15-0.25	<50
Sparsely built	LCZ 9	> 0.8	0.1–0.25	10–20	< 20	60–80	3–10	5–6	1000-1800	0.12-0.25	<10
Heavy industry	LCZ 10	0.6–0.9	0.2–0.5	20–30	20–40	40–50	5–15	5–6	1000-2500	0.12-0.20	>300
Dense trees	LCZ A	<0.4	>1	<10	<10	>90	3–30	8	unknown	0.1-0.2	0
Scattered trees	LCZ B	0.5–0.8	0.25–0.75	<10	<10	>90	3–15	5–6	1000-1800	0.15-0.25	0
Bush, scrub	LCZ C	0.7–0.9	0.25–1.0	<10	<10	>90	<2	4–5	700-1500	0.15-0.3	0
Low plants	LCZ D	>0.9	<0.1	<10	<10	>90	<1	3–4	1200-1600	0.15-0.25	0
Bare rock or paved	LCZ E	>0.9	<0.1	<10	>90	<10	<0.25	1–2	1200-2500	0.15-0.3	0
Bare soil or sand	LCZ F	>0.9	<0.1	<10	<10	>90	< 0.25	1–2	600-1400	0.2-0.35	0
Water	LCZ G	>0.9	<0.1	<10	<10	>90	–	1	1500	0.02-0.1	0

a Ratio of the amount of sky hemisphere visible from ground level to that of an unobstructed hemisphere
b Mean height-to-width ratio of street canyons (LCZs 1–7), building spacing (LCZs 8–10), and tree spacing (LCZs A–G)
c Ratio of building plan area to total plan area (%)
d Ratio of impervious plan area (paved, rock) to total plan area (%)
e Ratio of pervious plan area (bare soil, vegetation, water) to total plan area (%)
f Geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F) (m)
g Davenport et al.'s (2000) classification of effective terrain roughness (z) for city and country landscapes.
h Ability of surface to accept or release heat (J m–2 s–1/2 K–1).
i Ratio of the amount of solar radiation reflected by a surface to the amount received by it.
j Mean annual heat flux density (W m–2) from fuel combustion and human activity.

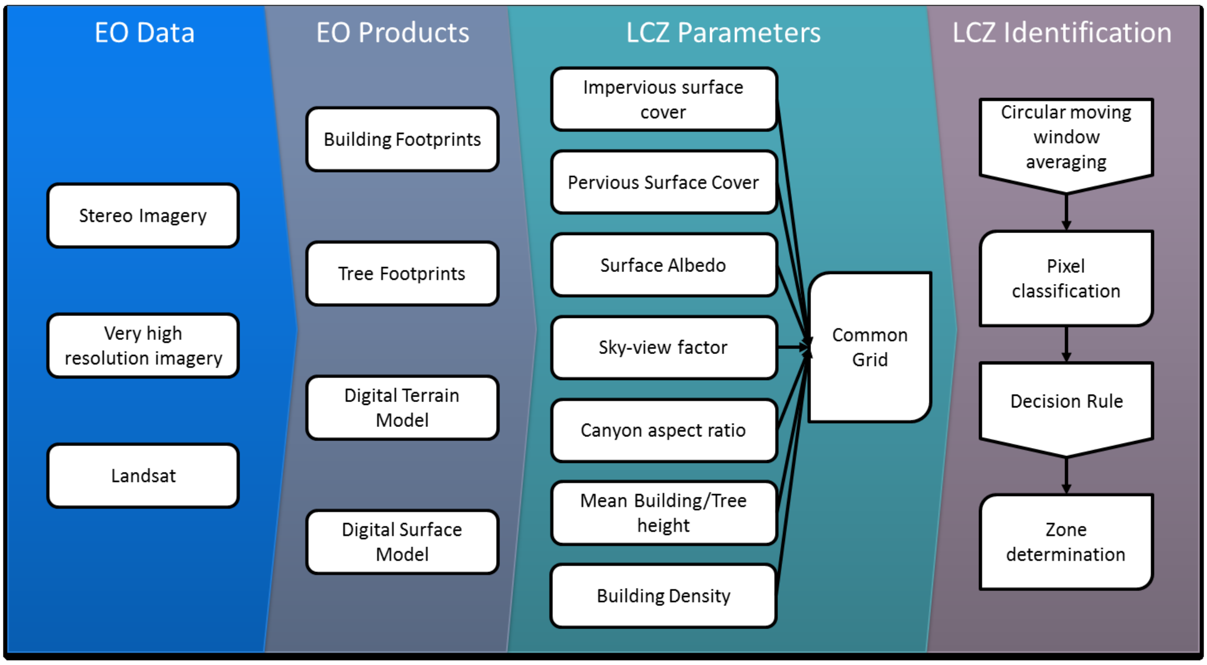

Figure 1: Overview of the LCZ mapping method

3.1.2.1 Impervious surface cover

Impervious surfaces are all surfaces that are impermeable to water, thus the area covered by buildings and paved roads. The impervious surface cover is derived from the land cover classification by the sum of the fractional covers of urban and industrial land cover. Details are provided in D3.1.

3.1.2.2 Pervious surface cover

Pervious surfaces are all surface that are permeable to water, being the opposite of the impervious surfaces. The pervious surfaces include vegetation, bare soil and water. The pervious surface cover can be derived from the fractional land cover maps by summing the abundances of all vegetation land covers, agriculture, bare soil and water. Details to the land cover classification are provided in D3.1.

3.1.2.3 Building density

Building density represents the proportion of ground surface with building cover. The surface percentages resulting from the land cover classification (abundance maps) provide this information. Details to the land cover classification are provided in D3.1.

3.1.2.4 Surface albedo

Surface albedo represents the surface ability to reflect the incoming direct and diffused irradiance at all wavelengths and towards all possible angles. Albedo is calculated as the bi-hemispherical reflectance of a surface and varies between 0 and 1 (unitless). Given the Bidirectional Reflectance Distribution Function (BRDF) of specific surface, its albedo can be estimated from EO data as the ratio of the total reflected energy of the surface to the total incident energy on the surface (Lucht et al., 2000). For URBANFLUXES the surface albedo is either calculated using the methods implemented in ATCOR2 or by applying the approach described by Liang (2001). In future, the DART model is expected to provide most accurate albedo estimates, at least for small areas. Details are provided in D3.1.

3.1.2.5 Sky view factor

The sky-view factor describes the ratio between the potential visible sky and the actual visible sky from a certain location, it depends on the height to width ratio of the street canyon and its values range between 0–1. For URBANFLUXES the sky view factor is calculated based on the high resolution DSM using the approach implemented in UMEP. Details are provided in D3.1.

3.1.2.6 Canyon aspect ratio

The canyon aspect ratio or height/width ratio is calculated based on the high resolution DSM. The H/W ratio is calculated based on the plan area index and the fraction of wall area related to the total horizontal area. Details are provided in D3.1.

3.1.2.7 Mean building/tree height

The mean height of buildings and/or trees is calculated based on the high resolution DEM using a zonal statistics or aggregation approach. Details are provided in D3.1.

3.1.2.8 LCZ identification

The multiple sources of information used for estimating the different parameters resulted in products of different scales. Thus, there was a need to set a common scale of calculations to further proceed with the identification of possible LCZ. A 30 m grid matching the Landsat data (source of most of the parameters) was selected and all parameters were aggregated to that grid.

Because of the nature of the parameters, a single aggregation method was not sufficient for all parameters. Thus, different aggregation methods were used. For the case of impervious and pervious surface cover and the building density a simple mean over each the grid cell is sufficient to estimate the total percentage of the parameter. The same can be used for the sky-view factor, since it can be considered the percentage of sky visible from the ground level. The albedo and the canyon aspect ratio were directly estimated in the 30 m resolution. For the mean building/tree height, the geometric mean $(\prod_{i=1}^{N} x_i)^{\frac{1}{N}}$ was estimated per grid cell.

Based on that grid, all parameters were then averaged using circular moving windows of various diameters. This implicitly includes information on the surroundings in each grid cell. Following, an individual cell is assigned a score, depending on how many times it is found to belong to a zone type, according to the definitions of Stewart and Oke (2012) presented in Table 1. A grid cell is finally assigned to a LCZ type if its score reaches a certain threshold.

An application with a graphical user interface was created to facilitate the identification of LCZ, provided the calculated parameters. Two exemplary results, for Basel and Heraklion, are shown below (Figure 2 and Figure 3).

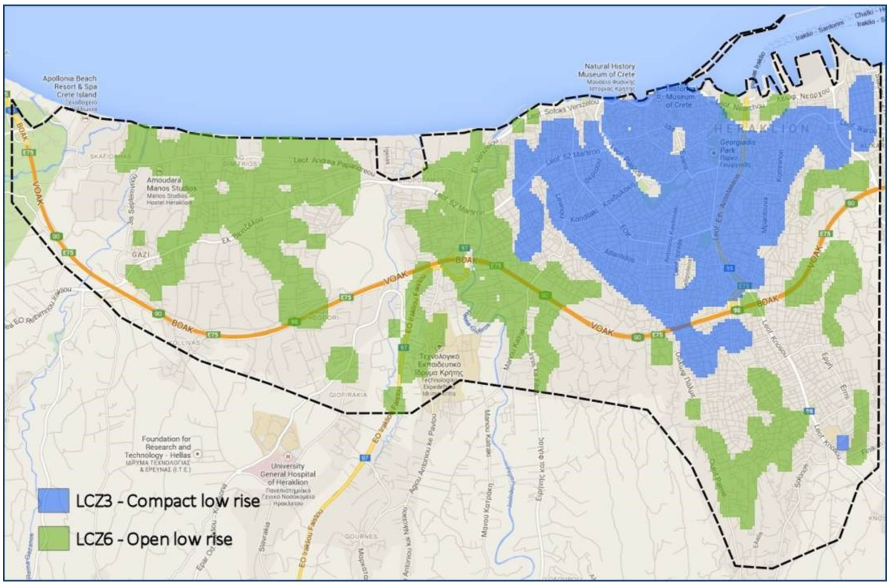

Figure 2: Preliminary LCZ map of Heraklion

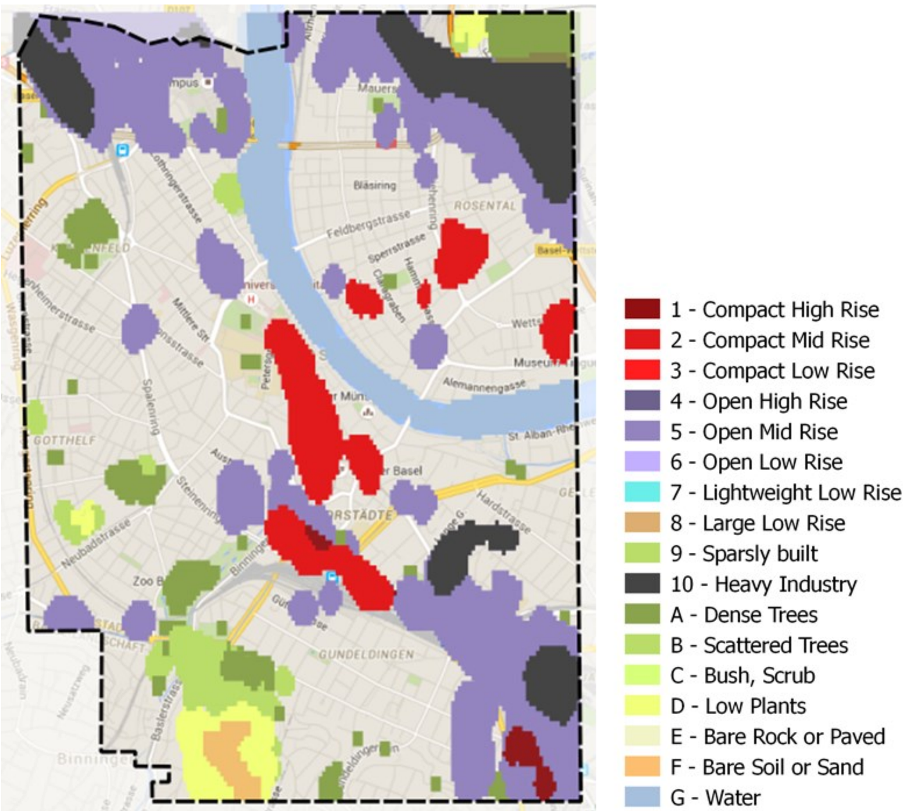

Figure 3: Preliminary LCZ map of Basel

3.1.3 Evaluation and Outlook

When looking at the preliminary LCZ maps, it becomes clear that not all pixels could be assigned to an LCZ type. This means that additional LCZ types need to be defined for specific case studies and the definitions of Stewart and Oke (2012) have to be enriched to match the requirements of the URBANFLUXES project. If necessary, additional parameters which are especially relevant for the estimation of anthropogenic heat could be included. The selection of the parameters and final definitions will be done through extensive exchange between the other WPs that will make use of the LCZ maps.

The preliminary analysis showed that the spatial scale is very important for the success of mapping the LCZ. The patchy results of the preliminary LCZ maps indicate that a grid of 30 m is too detailed for the mapping of LZC, resulting in many inhomogeneous pixels that cannot be connected to homogeneous zones. Spatial aggregation of the parameters and subsequent classification will therefore be done for the 100 m grid that is also used for the modelling. Additionally, it will be tested if the LCZ classification becomes more reliable if grid cells of 500-1000 m are used (the suggested area for LCZ according to Steward and Oke). Also the use of polygons of building blocks or similar units could be considered as spatial unit for LCZ.

Currently the LCZ can only be calculated for areas where a high resolution DSM is available. This is problematic because the DSM often doesn't cover the whole urban area of interest, especially not the urban fringes. It would be important to extrapolate the available data to these areas in order to enlarge the coverage of the LCZ maps. This is also addressed in D3.1.

Summarizing, in order to evolve the preliminary LCZ maps to the final maps to be used with URBANFLUXES, the following steps will be taken:

- Improvement of the definition of LCZ types specifically for URBANFLUXES, or test alternative schemes, such as the Urban Zones for Energy partitioning (UZE) developed by Loridan et al. (2013)
- Perform tests with lower spatial resolutions
- Expanding the LCZ mapping to areas outside the coverage of the high resolution DEM
- Implementation of updated EO maps
- Further adjustment to feedback from other WPs
- Accuracy assessment (e.g. error propagation from the input products)

4 Organization of the Data Base

4.1 Data Description

The LCZ maps generated within the project will be uploaded in the URBANFLUXES website and made publicly accessible to external users. Every file will have an xml metadata file (with the same name) describing the data, so that external users will be able to search for it through the website. The whole structure and the XML files will be based on the INSPIRE guidelines.

4.2 Meta Data Description

The meta data follows the INSPIRE guidelines and is described in detail in D3.1

4.3 Meta Data Directories

Figure 4 represents the tree of the directories containing the LCZ maps for the public data of the URBANFLUXES project.

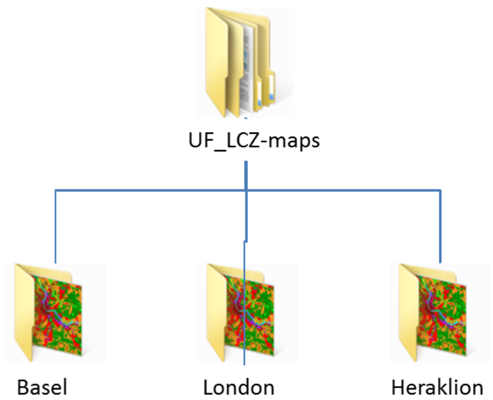

Figure 4: Directory tree for public LCZ maps.

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