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APLICACIÓN DEL MÉTODO WUDAPT EN LA CIUDAD DE MENDOZA-ARGENTINA
PARA DEFINIR ZONAS CLIMÁTICAS LOCALES
MARÍA FLORENCIA COLLI, ÉRICA NORMA CORREA, CLAUDIA FERNANDA MARTINEZ
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APPLICATION OF THE WUDAPT METHOD IN THE CITY OF MENDOZA-ARGENTINA TO DEFINE LOCAL CLIMATE ZONES[1]

APLICACIÓN DEL MÉTODO WUDAPT EN LA CIUDAD DE MENDOZA-ARGENTINA PARA DEFINIR ZONAS CLIMÁTICAS LOCALES

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El trabajo aplica el modelo de Zonas Climáticas Locales en el Área Metropolitana de Mendoza -AMM- utilizando el método WUDAPT y realiza un análisis crítico de su factibilidad de implementación en función de las características de la ciudad. Como hipótesis, contar con una zonificación de las estructuras urbanas homologadas de acuerdo a su condición microclimática es el primer paso para efectivizar la implementación de distintas estrategias de mitigación de la isla de calor a escala ciudad. Las limitaciones del método WUDAPT (World Urban Database and Access Portal Tools) en el área de estudio se vinculan a dos factores: la definición de clases para la zonificación y la condición de homogeneidad necesaria para determinar las áreas de entrenamiento. Los resultados muestran, que la clasificación WUDAPT se estructura en clases puras, con imposibilidad de generar subclases. Las clases puras están definidas de acuerdo a la combinación de un conjunto de parámetros que no describen de manera acabada la condición de los perfiles urbanos del AMM en verano, donde el arbolado en alineación actúa como elemento morfológico estructurante. Esto implica la necesidad de generar subclases, afectando la relación entre Factor de Visión de Cielo, relación alto/ancho de canal vial, Factor de Ocupación de Suelo, superficie impermeable y altura promedio. Otra limitación, es el tamaño de las zonas de entrenamiento, que exige áreas homogéneas de 1 Km2, condición difícil de cumplir en el AMM. En este trabajo la herramienta con clases estándar ha sido adaptada para la apropiada caracterización de las zonas climáticas en ciudades con abundante forestación urbana, cuya tipología es creciente en América Latina. Se concluye que, superadas las limitaciones de la herramienta, las zonas climáticas identificadas dentro del área de análisis muestran correlación con el paisaje de los distintos sectores de la ciudad y homogeneidad térmica intraclase.

Palabras clave: clima urbano, zonificación, LCZ, morfología urbana, Área Metropolitana de Mendoza

The work applies the Local Climate Zones model in the Mendoza Metropolitan Area (AMM in Spanish), using the WUDAPT method and makes a critical analysis of its implementation feasibility based on the characteristics of the city. As a hypothesis, having a zoning of homologated urban structures according to their microclimatic condition is the first step to make the implementation of different urban heat island mitigation strategies effective on a city scale. The limitations of the WUDAPT method (World Urban Database Access Portal Tools) in the study area are linked to two factors: the definition of classes for zoning and the necessary homogeneity condition to determine training areas. The results show that the WUDAPT classification is structured in pure classes, with the impossibility of generating subclasses. The pure classes are defined according to the combination of a set of parameters that do not fully describe the condition of the urban profiles of the AMM in summer. In this season, the trees in rows act as a morphological structuring element. This implies the need to generate subclasses, affecting the relationship between Sky View Factor, road channel height/width ratio, Land Occupancy Factor, impermeable surface and average height. Another limitation is the size of the training areas, which require homogeneous areas of 1 km2, a difficult condition to fulfill in the AMM. In this work, the tool with standard classes has been adapted for the appropriate characterization of climatic zones in cities with abundant urban forestation, whose typology is growing in Latin America. It is concluded that once limitations of the tool are overcome, the climatic zones identified within the analysis area show correlation with the landscape in different sectors of the city and intra-class thermal homogeneity.

Keywords: urban climate, zoning, LCZ, urban morphology, Mendoza Metropolitan Area

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I. INTRODUCTION

Cities drive environmental changes at a global level and are also exceptionally vulnerable to the consequences of said change (Grimmond et al., 2010). Urban planning is fundamental to inform, coordinate and implement measures that improve the environmental quality of cities to face climate change. However, at a local level, there does not seem to be a sensitization, with few initiatives to increase urban resilience to face climate change (Arellano Ramos & Roca Cladera, 2015).

In the metropolis, the morphological characteristics of the spaces, the optical and thermal properties of the materials used in their envelopes, the vegetation index and the elevated contribution of anthropogenic heat, among others, modify the thermal balance, increasing urban temperatures, generating the effects known as "urban heat island" and "urban warming" – UHI and UW. The energy penalization for the cooling induced by the urban heat island is around 0.8 kWH per surface unit of the city and by degree in temperature increase, or 68 kWh per person and degree (Santamouris, Cartalis, Synnefa & Kolokotsa, 2015). The higher urban temperatures have an impact on the quality of life of the urban inhabitant, on the energy consumption to cool buildings, comfort in the open air, contamination, health and the local economy (Akbari & Konopacki, 2004; Sarrat, Lemonsu, Masson & Guedalia, 2006; Taha, 2008; Luber & McGeehin, 2008; Pantavou, Theoharatos, Mavrakis & Santamouris, 2011; Sakka, Santamouris, Livada, Nicols & Wilson, 2012; Hirano & Fujita, 2012). For this reason, creating fresher communities has become a priority for governments; driven mainly by the new goals to reduce carbon emissions in response to global climate change.

Mendoza is the fourth city in demographic and economic importance in Argentina, located in the central western part of the country with a high aridity index, it integrates the Argentinean arid diagonal. It has limited water availability, abundant solar resources throughout the year and an elevated percentage of clear days. The Metropolitan Area of Mendoza (AMM in Spanish) is the most important urban nucleus of west Argentina. The territory is formed by 7 municipalities, it has a surface area of 313.7 km^2, 979,397 inhabitants, a population density of 32 inhabit/km^2 and at an urban scale, 9,950 blocks are identified. It has an open type urban model whose thermal inhabitability, energy and environmental sustainability depend strictly on the presence of urban tree cover (Ruiz, Sosa, Correa & Cantón, 2015). At a microclimate scale, its characteristics of aridity, elevated helophania, and lack of wind and rainfall intensity and frequency, plus a positive thermal anomaly in altitude and the frequent temperature inversions, are optimal conditions for the formation of the heat island. In the city, this phenomenon reaches maximums of 10°C and average values of 6°C, in winter and summer. This produces an increase of approximately 20% in cooling needs of the metropolitan area, with a base of 24°C (Correa. 2006) and impairs comfort conditions in the city's open spaces. Up to 82% of the people feel some degree of discomfort due to heat in the summer period (Ruiz, 2013). At a global scale, the different climate simulations estimated from the general circulation models (GCMs) of the atmosphere, mark a relevant heating for the West Argentina region. The temperatures will increase during the 21st century with greater increases in the summer than in the winter. The regional simulations for the territories of the provinces of San Juan and Mendoza indicate increases of around 3°C in summer months by the end of the 21st century. As a result, the climate change effects forecast for the region imply higher day and nighttime temperatures and less availability of water resources (Villalba et al. 2016). Climate vulnerabilities at a global scale will intensify heatwaves and droughts in the region and will affect the magnitude of the urban heat island.

In Mendoza, the INAHE-Conicet, has been working since 2004 in the characterization and quantification of the spatial and temporal development of the urban heat island within the AMM, determining its causes and effects (Correa, 2006). It has also been working since 2007 in the evaluation of the different mitigation strategies: Efficient tree cover layouts in line with the suitability of the shape of the urban structure and its building density (Ruiz et al., 2015, Sosa, 2018); Increase of the solar reflectivity and the use of cold materials on envelopes, and the use of new green technologies – green walls and covers – associated to different urban contexts (Alchapar & Correa, 2016; Alchapar Correa & Cantón, 2018; Flores Asin, 2019; Martínez, Cantón & Roig, 2014); Design and materiality of the traditional green spaces – parks and squares – (Stocco, 2016). The results show that in sectors with low building density, that currently represent 87% of the AMM, the suitable application of mitigation strategies leads to a reduction of 5 to 6°C in the maximum temperature in 67% of the evaluated scenarios, of 2 to 3°C in the minimum temperature in 58% of the cases and around 3 to 4°C in the average temperature in 75% of the cases (Sosa, Correa & Cantón, 2018), which represents a potential energy consumption saving for cooling that ranges between 24% and 33%, depending on the characteristics of the urban structure where the dwelling is located. In the high building density, the optimal combination of albedo on roofs, facades and paving can reduce urban temperatures by up to 3.5°C and the indoor temperatures in social housing by 2 to 4°C, depending on their typology and orientation (Alchapar & Correa, 2016).

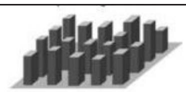
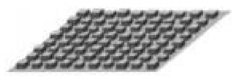
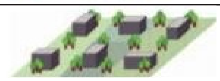
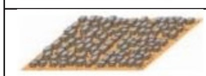
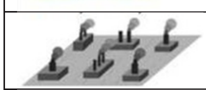
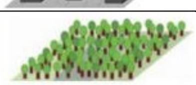
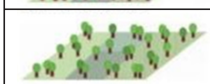
	1-COMPACTO EN ALTURA Edificación densa de edificios de más de 10 pisos. Pocos árboles. Pavimento. Materiales de construcción: concreto hierro, roca y vidrio.
	2-COMPACTO DE BAJA ALTURA Edificación densa de mediana altura (3 a 9 pisos). Pocos arboles. Pavimento.Materiales de construcción: concreto, ladrillos, roca y cerámica.
	3-COMPACTO DE BAJA ALTURA Edificación densa de baja altura (1 a 3 pisos). Pocos árboles. Pavimento. Materiales de construcción: concreto, ladrillos, roca y cerámica.
	4-ABIERTO EN ALTURA Edificios de más de 10 pisos separados. Abundancia de cobertura previas (plantas bajas y algunos árboles). Materiales de costrucción: concreto, hierro, roca y vidrio.
	5-ABIERTO DE MEDIA ALTURA Edificios de mediana altura (3 a 9 pisos) separados. Abundancia de cobertura previas(plantas bajas y algunos árboles). Materiales de construcción: concreto, hierro, roca y vidrio.
	6-ABIERTO DE BAJA ALTURA Edificios de baja altura(1 a 3 pisos) separados. Abundancia de cobertura previa(plantas bajas y algunos árboles). Mteriales de cosntrucción: madera, concreto, ladrillos, roca y cerámica.
	7- CONSTRUCCIONES BAJAS Densa edificación de un piso. Pocos árboles, tierra compactada. Materiales de construcción livianos: madera, metal corrugado y paja.
	8- Grandes construcciones bajas Grandes edificios bajos (1 a 3 pisos) separados. Pocos árboles. Pavimento. Materiales de contrucción: hierro, concreto, metal y roca.
	9- CONSTRUCCIONES DISPERSAS Construcciones pequeñas o medianas dispersas en áreas naturales. Abuendancia de coberturas previas (plantas bajasárboles dispersos)
	10-ÁREAS INDUSTRIALES Edificios industriales de baja y media altura(chimeneas y tanques). Pocos árboles. Pavimento o tierra compactada. Materiales de cosntruccion
	A-BOSQUE/ ARBOLADO DENSO Densamente arbolado por especies perennes o caducifolias. Coberturas previas en su mayoría (plantas bajas). Zonas de bosques, actividad forestal o parques urbanos.
	B-ÁRBOLES DISPERSOS Arbolado disperso de especies caducifolias o perennes. Coberturas previas en su mayoría (plantas bajas). Zonas de bosques, actividad forestal o parques urbanos.
	C-ARBUSTOS Arbustos, matas y árboles leñosos bajos dispersos. Coberuras previas en su mayoría (plantas bajas). Zonas de bosque, actividad forestal o parques urbanas.
	D- PLANTAS BAJAS Paisaje dominados por cultivos, plantas bajas y/o césped. Pocos árboles. Zonas de parques urbanos o de actividad agrícola.
	E- ROCAS O PAVIMENTOS Paisaje de rocas o zonas pavimentadas. Pocos árboles. Zonas rocosas o playas de estacionamiento.
	F- SUELO DESCUBIERTO O ARENA Áreas de cobertura con arena o suelo descubierto. Poca cobertura vegeal. Zonas de desiertos o de agricultura (luego de la cosecha).
	G-AGUA Grandes cuerpos de agua libres como lagos, mares, ríos, reservorios o lagunas.

Figure 1. Classification of the Local Climate Zones. Source: Adapted from Stewart et al. (2012, p.7)

From the foregoing, it can be said that there is enough knowledge about the characteristics of the local heat island and the effect of different mitigation strategies on different analysis scenarios. However, to make their implementation effective on a city scale, it is necessary to establish which strategies have a higher cost/benefit viability considering the characteristics of the different urban areas the AMM comprises. It is for this reason, that it is imperative to develop zoning that ties in the characteristics of the different urban areas of the city of Mendoza with their microclimatic response.

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Although there are several models that try to classify the sectors of the city considering the characteristics of the urban areas and their microclimate (Castro, Conrado, Fernández, Álvarez & López, 2014; Fernández García & Martilli, 2016; Palme, Inostroza, Villacreses, Lobato-Cordero & Carrasco, 2017; Salvati, Palme & De la Barrera, 2018) the one that is applied most internationally is that of Local Climate Zones (LCZ), developed by Stewart & Oke (2012).

The goal of this work is applying the Local Climate Zone model in the AMM, using the WUDAPT method and making a critical analysis of its implementation feasibility considering the characteristics of the city, which differ substantially from the urban model of cities in Europe, Asia and North America, where the model was conceived, developed and used. The hypothesis considers that on having a zoning of the urban structures in the AMM, standardized in accordance with the microclimatic condition, is the first step to make possible an in-depth analysis of the feasibility of implementing the different heat island and urban warming mitigation strategies, on a city scale.

II. THEORETICAL FRAMEWORK

The local climate model, LCZ, is a landscape classification system. It comprises the categorization of zones that are "uniform regions in land coverage, structure, materials and human activities whose extension is between several hundred meters up to several kilometers on the horizontal scale" (Stewart & Oke, 2012, p. 1884). The categorization is made in 17 LCZ, 15 of these defined by the morphology of the land surface and coverage, and 2 defined by the land use and the predominant construction materials in each one. The standard set is sectorized into two typologies: a) built – LCZ 1 to 10 and b) land coverage – LCZ A to G (Figure 1).

Each Local Climate Zone is the result of a set of parameters (Table N°1) that configure and characterize the morphological properties, of surface coverage, radiative properties and metabolic properties. Each "zone" is named individually, distinguishing the set of surface properties that characterize them.

Bearing in mind that each class describes a built typology or a type of natural coverage, the parameters are defined only for the standard LCZ, but considering that the characteristics of a city do not fit the proposed types, Stewart & Oke (2012) propose as an alternative, the possibility of making a subclassification, combining typologies. The subclasses are justified when the secondary characteristics of the site affect the local climate or may be related with the particular goals of a climate research project.

The LCZ model has been applied in different cases at an international, regional and local level. Globally, Stewart et al. (2014) make an evaluation of the operation of the LCZ layout, using temperature observations in the cities of Nagano, Vancouver and Uppsala. Wang et al. (2018) make an evaluation of the LCZ in arid cities of the United States, applying LCZ for Phoenix and Las Vegas following the WUDAPT method. In Latin America, Monteiro (2018) and Pezzuto & Silva (2013) analyze the relationship of LCZ with the urban morphology, using as a case study the city of Campinas, Sao Paulo, Brazil.

In Argentina, Piccone (2014) studies the urban climate of the city of Tandil, Buenos Aires; he makes a classification of the city from physical variables, construction features, land coverage and population concentration. Roca, Puliafito, Allende, Ruggieri & Pascual (2016) apply the model to the city of San Juan, for the analysis and formulation of an urban comfort model.

In Mendoza, Puliafito, Bochaca, Allende & Fernández (2013) make an analysis of the green areas and the urban thermal comfort. In the zoning which they propose, they assign 12 LCZ to the AMM. However, the work does not specify what the geospatial interpolation method has been to define the limits of the climate zones and their level of fit was. Although the work refers to air temperature data, it does not verify the thermal comparison between zones. The work refers to temperature data of 2003 and 2005, while the results obtained from the morphological and technological characterization correspond to 2013. In this sense, the LCZ methodology establishes that the measurements are simultaneous and temporally coinciding with the morphological characterization of the points taken as reference. It is for this reason that it is important to avoid temporal disassociation between the meteorology data taken and the characterization of the urban structure to generate a correct zoning. It is worth mentioning that the AMM reports in the last 10 years, a transformation process where the peri-urban or transition zones are dynamic and the microclimate variables have also seen modifications (Sosa, 2018). All of this makes clear the need to properly define the LCZ for the AMM.

Local Climate Zone (LCZ)	Ratio of average height aspect of building / width of urban cannon H/W	Sky View Factor SVF	Proportion of land surface with the building coverage	Proportion of land surface with impermeable coverage (rock, paving) (%)	Average construction / height of the tree ZH	Anthropogenic Heat
1.Compact high-rise	>2	0.2-0.4	40-60	40-60	>25	50-300
2.Compact mid-rise	0.75-1.5	0.3-0.6-	40-70	30-50	8-20	<75
3.Compact low-rise	0.75-1.5	0.2-0.6	40-70	20-40	3-8	<75
4.Open high-rise	0.75-1.25	0.5-0.7	20-40	30-40	>25	<50
5.Open mid-rise	0.3-0.75	0.5-0.8	20-40	30-50	8-20	<25
6.Open low-rise	0.3-0.75	0.6-0.9	20-40	20-40	3-8	<25
7.Lightweight low-rise	1-2	0.2-0.5	60-90	<10	2-4	<35
8.Large low-rise	0.1-0.3	>0.7	30-50	40-50	3-10	>50
9.Sparsely built	0.1-0.25	>0.8	10-20	<20	3-8	<10
10.Heavy industry	0.2-0.05	0.6-0.9	30-30	20-40	5-15	<300
A. Forest / Dense Trees	>1	<0.4	<10	<10	<3-30	0
B. Scattered trees	0.25-0.75	0.5-0.8	<10	<10	3-15	0
C. Bush, scrub	0.25-1.0	<0.9	<10	<10	<2	0
D. Low plants	<0.1	<0.9	<10	<10	<1	0
E. Bare rock or paved	<0.1	<0.9	<10	<90	<0.25	0
F. Bare soil or sand	<0.1	<0.9	<10	<10	<0.25	0
G. Water	<0.1	<0.9	<10	<10	-	0

Table 1. Surface parameters for each LCZ. Source: Adapted from Stewart, Oke & Krayenhoff (2014, p. 1064).

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III. METHODOLOGY

Application of the WUDAPT method in Mendoza

For the classification of the LCZ, the WUDAPT tool was used, which is a free access tool that allows loading local data and comparing them with other cities. As was discussed previously, the city analyzed has an open urban model of wide streets and relatively low constructions, where the intense forestation that marks off the urban blocks forms true green tunnels. The urban mass is intensely tree-lined with species planted in lines alongside an artificial watering system. 68% of the tree species are concentrated in three types: Morus alba ('mulberry', 39%), Fraxinus ssp. ('European ash' and 'American ash', 20%) and Platanus hispanica ('London plane', 9%) (Martínez et al., 2014). The urban setup added to the intense forestation of its streets changes the radiation conditions and the wind flow of the road channels, exceeding the effects of the built structure in many consolidated areas of the metropolis.

These particularities of the AMM generate that the parameters defined by Stewart & Oke (2012) to determine the standard classes, cannot be directly extrapolated for the local classification. Because the urban tree line is a structuring and determining element of the LCZ for its capacity to modify the SVF, for this reason it is important to compare the operation of the methodology under maximum and minimum vegetative expression conditions of the forest canopy. According to this, the methodology has initially been run in the vegetative break winter season, where the influence of this parameter is lower due to the deciduous condition of the tree species.

LCZ determination with WUDAPT

The zone definition process with WUDAPT is done following the steps set out by the methodology (Betchel et al., 2015) which is detailed on the website. In this study, work was done using Landsat 8 satellite images, available on USGS's Earth Explorer catalog. To avoid the influence of the forest canopy, which does not allow visualization by remote detection of the area that is under it, images corresponding to winter in the southern hemisphere are chosen, from July 24th 2018 at 02.43:13 UTC.

Once the images are chosen, the LCZ classification is generated in two stages. For the processing and analysis of the satellite images, the QGis software was used. The images were projected in Posgar 07 Argentina Strip 2. The calibration and the atmospheric correction of all the strips is done automatically using the DOS1 method and the digital levels are converted to reflectance values (Piccone, 2014). A virtual raster is formed, all the strips merged and a cut of the area of interest is made. In the second stage, to generate the LCZ with the WUDAPT method, a Supervised Classification is used. For this, representative samples of each land coverage class defined must be chosen, in this case, each LCZ defined by Stewart and Oke (2012). Then, the software uses these "training sites" and with the pixel attributes of a known identity, the unknown identity pixels are classified (Linares & Tisnés, 2011). During this stage, it is fundamental to correctly mark the training areas, the field survey, the aerial photographs, the cartography and the use of Google Earth, bearing in mind that the areas must be representative and homogeneous of the class that it aims to define. Once the selection of the areas is finalized, the classification algorithm is run, the result or output file is a raster file, where each pixel value corresponds to a previously defined category.

Then, a first thermal contrast approach is made of the zones, starting from the surface temperature values acquired from satellite data, specifically the thermal infrared of the previously processed and calibrated images of Landsat 8. Although in later stages it is planned to progress and go in greater depth in the thermal comparison of the zones with measurements on the ground, this first approach looks to validate the morphologically identified zones with the thermal responses of each one.

IV. RESULTS

Having applied the WUDAPT method, it is seen that the study area has a total of 69,724.09 ha, of which only 16,814 ha belong to the AMM, and the rest corresponds to the foothills located to the west of Mendoza with crops towards the east (Figure 2).

The output file of the WUDAPT application is a map where the LCZ of the AMM and its surroundings are represented (Figure N°3). The percentage distribution of the LCZ identified following the construction typology is presented in Table 2. In the map, it is possible to see the urban and peri-urban zones of the AMM, where the predominate Local Climate Zone is LCZ-6 "Open low-rise", reaching a percentage of 27.55%, mainly located in the central area of the urban sprawl. This zone is characterized on having separated low-rise buildings (1 to 3 floors), with concrete and bricks dominating the construction materials. LCZ-8 "Large low-rise" follows with a percentage of 22.71%. This zone has a landscape dominated by large low-rise buildings in an open

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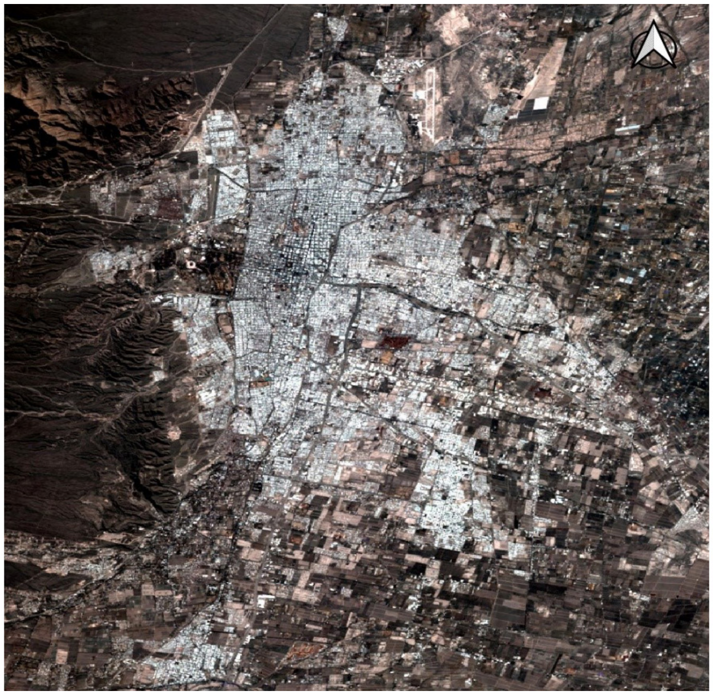

Figure 2. Case study. Metropolitan Area of Mendoza-Argentina. Source: Preparation by the Authors

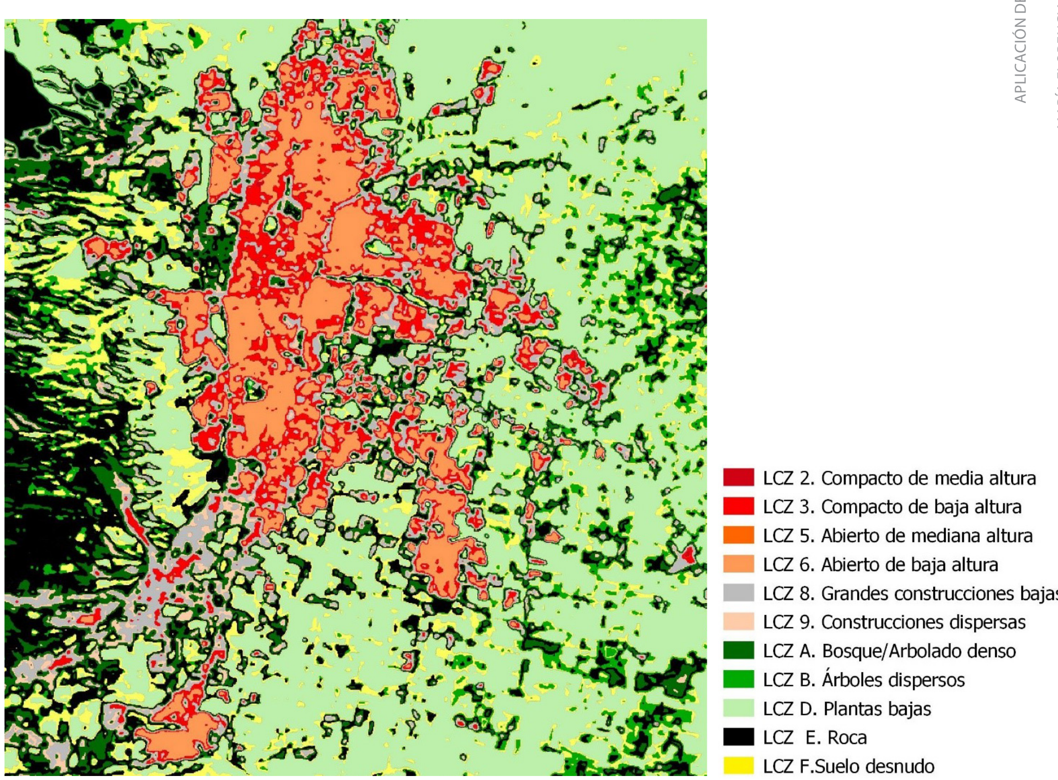

Figure 3. Local Climate Zones. Metropolitan Area of Mendoza. Source: Preparation by the authors.

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LCZ – Building Type	Surf in hectares	Percentage
LCZ 2. Compact mid-rise	770.32	4.58
LCZ 3. Compact low-rise	3601.53	21.42
LCZ 5. Open mid-rise	1491.08	8.87
LCZ 6. Open low-rise	4632.21	27.55
LCZ 8. Large low-rise	3819.09	22.71
LCZ 9. Sparsely built	2500.31	14.87
TOTAL	16814.53	100.00

Table 2. Percentage distribution of Local Climate Areas in AMM – Building Type. Source: Preparation of the authors.

Local Climate Zones	Surf in hectares	Percentage
LCZ 2. Compact mid-rise	770.32	1.10
LCZ 3. Compact low-rise	3601.53	5.17
LCZ 5. Open mid-rise	1491.08	2.14
LCZ 6. Open low-rise	4632.21	6.64
LCZ 8. Large low-rise	3819.09	5.48
LCZ 9. Sparsely built	2500.31	3.59
LCZ A. Forest/Dense forest	5144.11	7.38
LCZ B. Scattered trees	4656.76	6.68
LCZ D. Low plants	27376.1	39.26
LCZ E. Rock	8700.38	12.48
LCZ F. Bare soil	7032.21	10.09
TOTAL	16814.53	100.00

Table 3. Percentage distribution of Local Climate Zones in the AMM and Foothills. Type of building and coverage Source: Preparation by the authors

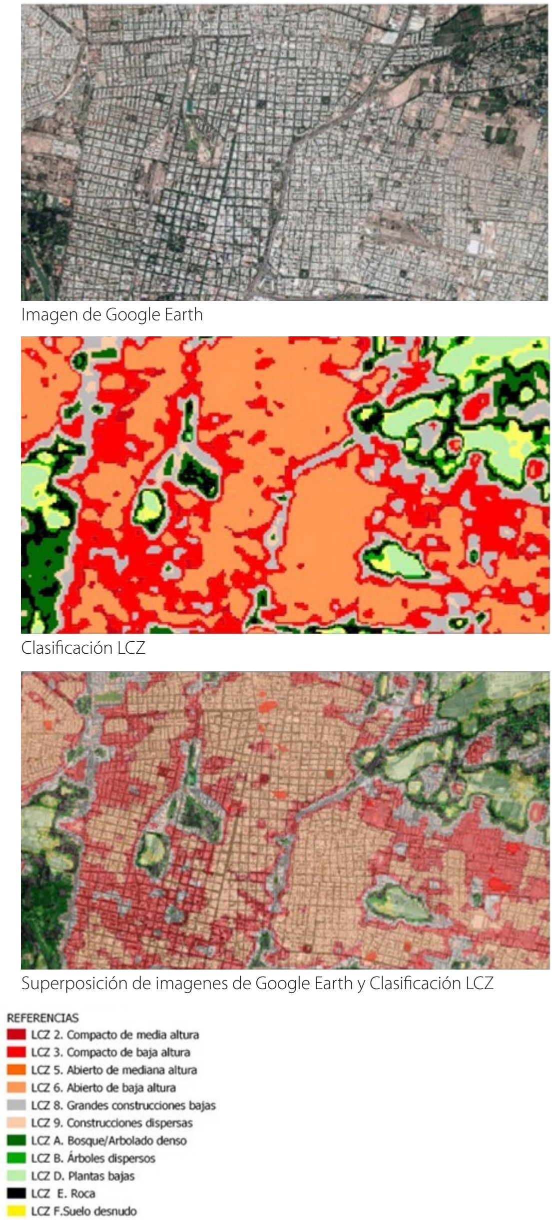
arrangement. It is found to the south of the urban sprawl, where private neighborhoods have grown, in detriment of the agricultural surface. Towards the east, this zone has a heterogeneity of uses, industrial and storage, scattered with gated-neighborhoods whose expansion has grown in the last decade.

In third place, in decreasing order (21.42%) is the category, LCZ-3 "Compact low-rise", located in the central areas of the city of Mendoza, characterized on being the administrative, financial and commercial center of the province, with dense low-rise buildings (1 to 3 floors). This class is also in regional capitals and their immediate surroundings.

Next are LCZ-9 "Sparsely built" (14.87%), LCZ-5 "Open mid-rise" (8.87%) and LCZ-2 "Compact mid-rise" (4.58%). In the AMM, LCZ-1, 4 and 7 are not present. To the west of the city, an important sector with classes A "Dense forests" and B "scattered trees" are seen, which represents the General San Martin Park (374 ha).

The percentage distribution of LCZ in the AMM and the foothills is seen in table N°3, following the type of buildings and coverage. The foothill's sector is categorized with the classes, E "Bare Rock" and F, "Bare soil", finding scattered sprawls of native vegetation. To the north and mainly towards the east of the urban sprawl, zone D "low plants" predominates, which in fact corresponds to the production belt of the northern oasis of Mendoza, represented by a landscape where fruit and vegetable crops prevail.

If sectors of the AMM are taken and a superimposition of the image of Google Earth (100% opacity base) and the LCZ classification (40% opacity) is made, convergence is seen between the urban morphology and the climate zones defined



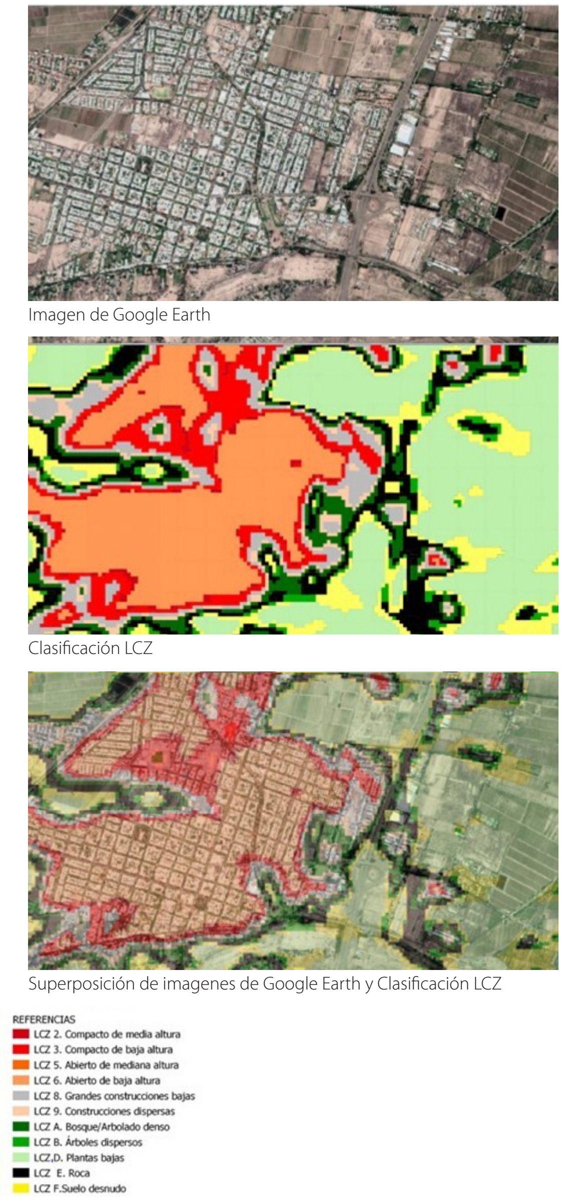


Figure 4. Cartographic superimposition. Mendoza city hub – LCZ. Source: Preparation by the authors
Figure 5. Cartographic superimposition – City of Luján de Cuyo – LCZ. Source: Preparation by the authors.

using WUDAPT. As an example, figures 4 and 5 show the results of this process in the central hub of the city of Mendoza and in the city of Luján de Cuyo with their respective surroundings. It is seen that the morphological patterns and land use, represent different climate zones. Such is the case of the regional capital of Mendoza, where the sectors of greater building density are superimposed with LCZ 2 and 3, and the surroundings where larger opening spaces are perceived, LCZ-6. The same occurs with General San Martin Park and the urban squares, which are identified as LCZ A and B.

In the city of Luján de Cuyo, it is seen that the sector which greatest building density is categorized with LCZ-6, and in the surroundings, where the agricultural sectors predominate, is categorized as LCZ D; the same occurs for the areas with greater forestation which are represented through LCZ A and B. At a Street level, morphological correlation of the landscape is seen with the defined LCZ. This can be seen in Figure N°6, where the street level image is distinctive of the building typology defined using the WUDAPT method,

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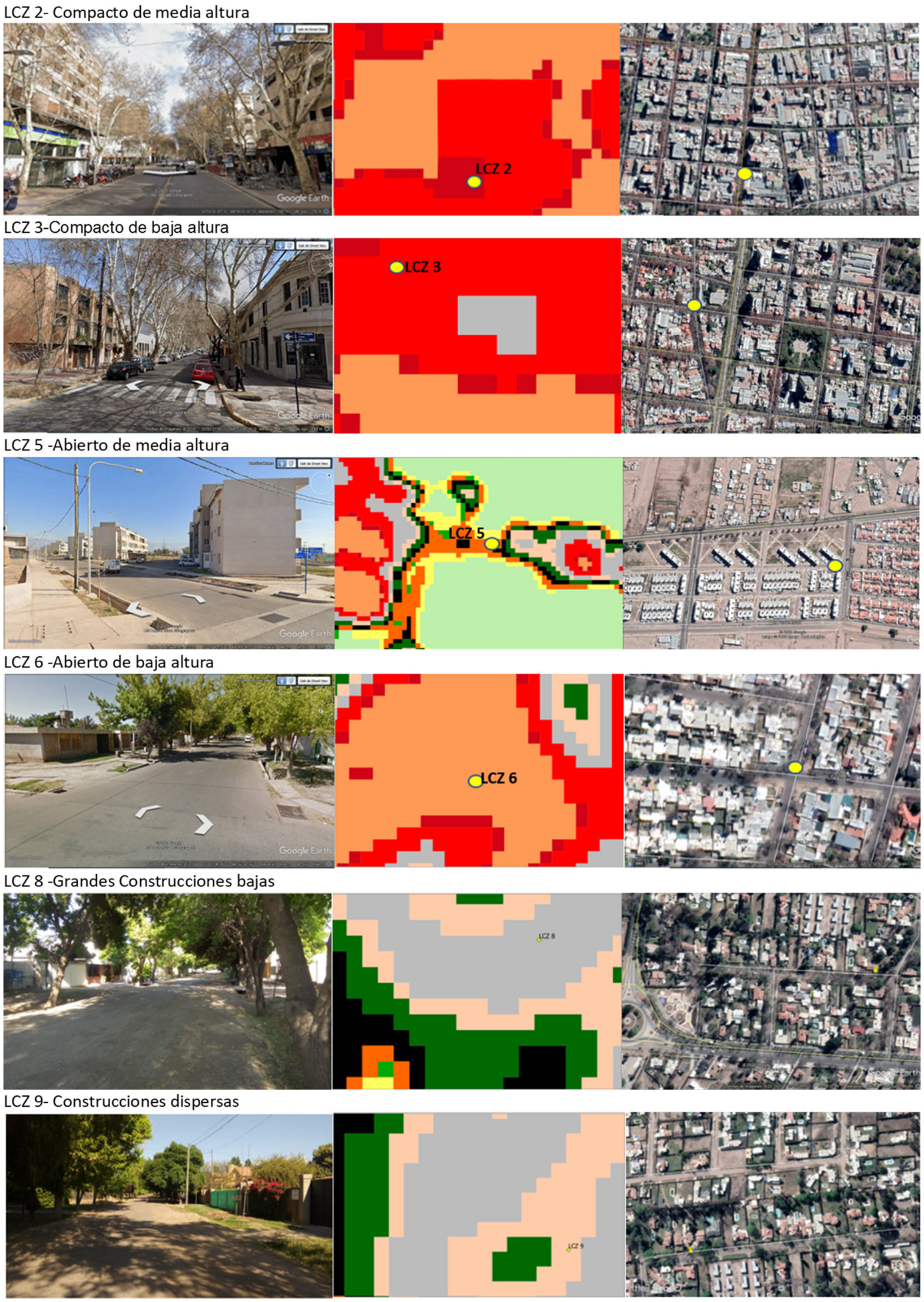

Figure 6. Street level image correlation, LCZ classification and Google Street View image. Source: Preparation by the authors.

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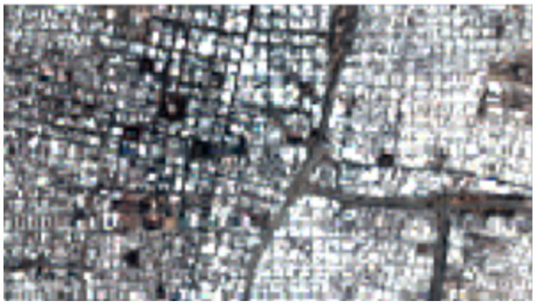
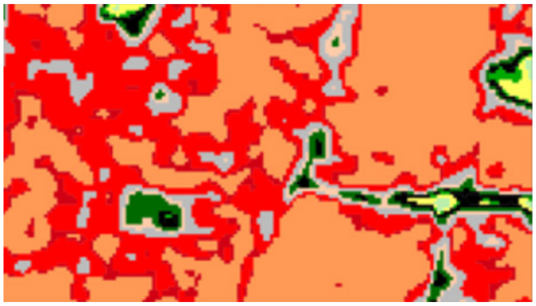


Ciudad de Mendoza. Color natural, RGB (4,3,2)



Zonas Climáticas Locales. Ciudad de Mendoza

Temperatura superficial. Ciudad de Mendoza

Figure 7. Thermal comparison. LCZ classification – Surface temperature. Source: Preparation of the authors.

Regarding the thermal comparison of the zones, it is seen that the surface temperature has a spatial correlation with the classes defined using the WUDAPT method, that is to say, that the zones have a similar thermal response (Figure 7). Nevertheless, as the satellite image corresponds to 11:27am (local time), it cannot be corroborated that this pattern is complied with at other times.

V. DISCUSSION

The LCZ system provides a simple and comprehensive discretization of the urban landscape. It looks to achieve a balance between precision and applicability. The fundamental limitation of the model is that it does not allow capturing the particular aspects of each site analyzed, mainly in cities of a heterogeneous geometry and with abundant urban vegetation, as is the case of the AMM, as this is a reductionist system.

Analysis of the international bibliography shows that these limitations have been overcome through the generation of subclasses. There is a clear difference between the works done in European, North American or Asian cities compared with the Latin American cities. In the former, all the classes used or a high percentage of them, are pure; in the case of the cities of Phoenix and Las Vegas, 14 LCZ were defined, all standard classes (Wang et al., 2018). Stewart et al. (2014) identified 8 classes in Vancouver, of which just one is a subclass. A different panorama is seen in the Latin American cities, where most of the zones or all are subclasses. Monteiro (2018) in Campinas, Brazil, works with 17 zones, all subclasses. Roca et al. (2016) in San Juan, Argentina, define 8 zones, 7 subclasses. This difference in the methodological approach shows that the method has been conceived in cities that have homogeneous landscapes of a greater horizontal surface, with narrow road channels and low or no presence of urban tree lines.

Given that the pure classes defined in the method do not represent the typical characteristics of Latin American cities, the need arises of creating a large number of subclasses, which undermines the main goal of the methodology, namely standardizing and systematizing the study of urban climate. As a result, the classifications of Latin American cities cannot be standardized and contrasted at an international level, which is why in spite of the application of the tool, the studies of each researcher are hard to compare or extrapolate to other cities.

In the particular case, the abundant urban forestation in the AMM represents a structuring element when it comes to defining the LCZ, as this particular aspect determines SVF values that do not match the properties established for the built typologies of the WUDAPT method. At a local level, bearing in mind just the urban morphology, the sectors of the administrative center of the AMM should be classified in LCZ 2, where the SVF values defined are between 0.3-0.6; however, the SVF measurements made on site have values of 0.13 (Sosa et al., 2016). According to what has been discussed and in order to manage these differences, most of the classes defined for the AMM should be subclasses, repeating the issue identified in the rest of the Latin American cities. Facing this, this work proposes defining, at a local scale, a classification with no or few subclasses. For this, a modification is made to the procedure of the LCZ and WUDAPT through the elimination of one of the variables. At an international level, Salvati et al. (2018) also propose a modification to the LCZ system aiming at improving the classification and attaining a better thermal fit, correlating three morphological parameters with the UHI value in summer and winter.

This work suggests first developing a morphological base, which allows the suitable characterization of the urban spaces in winter, minimizing the effect of the forestation, defining the LCZ based on the urban geometry, comparing the thermal response in winter, to adjust the definition of the zones. This generates a first LCZ definition, which will be analyzed and adjusted later in summer, to extract from the parameters that define the pure zones in the WUDAPT methodology, those that have a higher statistical weight in its thermal response. This will allow representing particular aspects without moving away from the reductionist goal of the system, or compromising its possibilities of standardization. In addition, this first fundamentally morphological based zoning, is a tool to move forward in the systematic analysis of the cost/benefit feasibility of the widespread implementation of different urban warming and heat island mitigation strategies, analyzed at a local level, whose benefits have been shown to be strongly dependent on the morphology (Alchapar & Correa, 2016; Sosa ***et al***., 2018).

VI. CONCLUSIONS

With the LCZ classification made for the AMM, Argentina with the WUDAPT method, 11 classes were defined, 6 of building typologies and 5 of coverage. Of the built typology, the zone that predominates is "LCZ-6 Open low-rise" with great development in the central zone of the urban sprawl. LCZ-8 "Large low-rise" which is essentially to the south of the urban sprawl and to the east, where there is a heterogeneity of uses, industrial and storage, with some gated-neighborhoods. In third, in decreasing order is the category, LCZ-3 "Compact low-rise", located in the central zone of Mendoza, characterized on being the administrative, financial and commercial hub of the province. This class is also found in regional capitals and their immediate surroundings. LCZ-9 "Sparsely built", LCZ-5 "Open mid-rise" and LCZ-2 "Compact mid-rise" come next.

Making a correlation of the satellite images, images at street level and the zoning developed, it is seen that the morphological and land use patterns are distinctive from the zones defined through the WUDAPT method. The LCZ defined would seem to fit the thermal response, a priori, it is seen that the surface temperature corresponds spatially with the defined classes, that is to say that intra zone they have a similar thermal response. However, it is planned to continue with the thermal validation, comparing on site measurements and satellite thermal infrared images and to go into greater depth with the analysis of the behavior of the microclimatic variables.

Analyzing the WUDAPT method, it is identified that although this is a process with numerous steps and multiple variables to bear in mind, it is run in a simple and economic way, as on having data and knowledge of the study area, it can be done completely using remote detection. It is a very useful tool for a first approach to the classification. It is concluded that the application of the LCZ Methodology with the WUDAPT method in the AMM has been useful to generate a morphological base, where the urban landscapes with different geometries are distinguished. Although WUDAPT does not allow the creation of subclasses, it is considered that it can be adapted to the local reality, through the selection process of satellite images, opting for winter images to avoid the interference of the canopy. This methodological proposal can be extrapolated to other Latin American cities that have similar characteristics in order to keep the reductionist goal of the classification system proposed by LCZ.

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