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Multicriteria Methodology for Open Space Analysis:

Understanding Environmental Performance and Diversity

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ABSTRACT

This paper describes an urban analysis method for the evaluation of the diversity of open spaces. Diversity is understood as the variety of options that a public space offers to the users, giving them the opportunity to choose the area which best suits their needs, activities, and personal preferences. The method facilitates an environmental quality assessment and comparative evaluation between spaces. Decision support tools based on data analysis are developed to facilitate technical urban design decisions. The methodology is based on a multi-criteria analysis of a public square in Madrid, Spain. Field measurements of climatic data and thermal properties of materials, the activities carried out by people and their location, as well as factors related to urban design are collated in the analysis. Data are complimented with bioclimatic and simulation tools. The analysis identifies differentiated thermal profiles, as well as patterns of use of the space. This enables the identification of specific locations currently favored by citizens and the microclimatic and spatial variety of the square.

KEYWORDS

Digitalization, Environmental Performance, Liveable Cities, Microclimate, Space Diversity, Square, Urban Design, Urban Life

INTRODUCTION AND BACKGROUND

After decades of decay and relegation to secondary importance behind the demands on space made by wheeled transport and parking (Brandis 1978), making open spaces more livable, hospitable and attractive and ensuring that they are fully enjoyed, has once again become one of the objectives of urban design and planning (Carr et al., 1993; Marcus and Francis 1998; Gehl and Gemzoe 2004; Maruani and Amit-Cohen 2007). The condition of public space is an indicator of the civic and democratic health of a society.

Urban design determines the quality and habitability of open spaces. The quality of a space determines the leisure, social and economic activities that occur within it, and the use of public

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spaces entails many social, physical, environmental and economic benefits (Jacobs 1961, Whyte 1988, Hass-Klau 1993, Hakim et al., 1998).

On the one hand, urban microclimate conditions the use of the public space (Gehl 1971). The use of public space can be intensified, and its hours of effective usage can be extended if environmental variables are taken into account for the creation of microclimates adapted to the local climate across different seasons (Culjat and Erskine, 1988). Although numerous studies have been carried out, the general framework for evaluating people's behavior in public spaces and the effects of microclimates on this behavior is still under discussion (Chen and Ng 2012). The first of the investigations to use quantitative and qualitative data to address microclimatic conditions, thermal comfort and the use of space were authored by Nikolopoulou et al. (1999). This study places an emphasis on people's adaptive capacity and the importance of the psychological factors in creating a sensation of comfort. Zacharias, Stathopoulos, and Wu (2001) evaluated by means of regressions and analysis of variance the relationship between microclimates and the level of use of space in plazas in Montreal. They determined that 12% of variations in use could be attributed to microclimate. They concluded that temperature is the main parameter that conditions the sensation of comfort, but that transitory exposure and preconceived expectations are also very important in subjective evaluations of thermal comfort. Katzschner (2006) also studied the relationship between microclimates and the use of space, establishing neutral temperatures by means of the index PET-Physiological Equivalent Temperature (Höppe, 1999) and by observing people. His study reached the conclusion that expectations were important in the use of space. Eliasson et al. (2007), in contrast with many other investigations, did not find a close relationship between microclimatic conditions and the use of space but instead suggested that use was culturally conditioned. They highlighted the importance of considering existing uses of public space and the importance of climate sensitive planning.

In addition to climactic comfort factors, the use of public space is also affected by social and cultural factors, as well as the uses given to the space and by design factors. For that reason, Chen and Ng, (2012) indicate that studies of thermal comfort in open spaces should combine "climatic knowledge" with physiological and physical factors and psychological factors as "human knowledge", with interviews and observation of people using the space.

In the 1960s, Kevin Lynch (1960) carried out studies on how people perceived their cities. Jan Gehl (1971) and William H. Whyte (1980) authored numerous studies on the relation between physical aspects of urban design and the level of activity and use that the citizens made of public space. Other investigations such as those by Newman (1996) and Katz (1994) are centered on the importance of public spaces as meeting points between people. They argue that a well-defined space can increase the sense of belonging and strengthen relationships between neighbors. This author also indicates the importance of the mixed usage in public spaces as a way of fomenting the relationships between individuals, a point also made by Jacobs (1961).

Quality urban design foments social activities, and being in public space is the starting point for those relations. Other factors, such as the legibility of the space, accessibility, the existence of benches and seats, urban greenery and street furniture among others, have been demonstrated to foment the use of space (Gehl, 1971; Whyte, 1980). This use attracts other types of activities (Jacobs, 1961).

On many occasions, urban designers place more emphasis on the urban form than on the activities that are carried out in public space (Lozano 1990). Our understanding of how to create spaces for people that encourage social activities is still formative. Investigations such as those by Carmona and Magalhães (2009, 2018) and Gehl and Svarre (2013) establish quantifiable design principles and tools to evaluate the environmental quality public space and urban life.

For this study, a plaza in the historical center of Madrid was selected with the purpose of studying some of its environmental conditions to determine the uses people gave to the space.

The main goal of this research work is to define a method of analysis applicable to real public spaces for the determination of the diversity of an open public space. Measuring diversity is related to the quality of the space., because it defines the potential of an area to host social activities in conditions of comfort throughout the year.

Diversity is understood as the possibilities for use that a place offers in diverse climatic conditions, giving citizens the ability to choose the location in that space best adapted to their needs. Diversity facilitates adaptation to the environment and encourages comfort and a sensation of well-being.

Secondary objectives of analysis are the following:

- To determine by means of measurements *in situ* the microclimatic behavior of the space under investigation and to compare these results with models drawn from bioclimatic theory;
- To analyze physical design parameters and uses of the space identified in human scale design theory as being important for the promotion of urban life;
- To observe the use that people made of the space and the degree of correlation between observations and theories of thermal comfort and urban design.

This analysis was carried out in order to develop a Decision Support Tool to facilitate the making of technical urban design decisions. It is based on the creation of a multivariable matrix that compiles and evaluates those physical, climatic and use conditioning factors of urban design that have the capacity to enhance urban life and quality of life. It aims to contribute to an ongoing movement towards more appropriate, human scaled, climate change adapted and healthier environments. Urban design is seen as a framework for creating meaningful, livable and healthy urban public spaces.

CASE STUDY

Many of the public works projects carried in urban spaces in Madrid since the 1990's have been based mainly on aesthetic and economic criteria. This has often resulted in empty spaces, environmentally and functionally unsuitable for citizens. Urban furniture, including benches and drinking fountains, is disappearing and a notable privatization of open spaces is underway. This includes the establishment of private terraces and temporary shops. Many of these spaces are thermally uncomfortable.

A daily use urban space in Madrid (Spain) has been selected: The 2 de Mayo square. It is in the city center. It has a local character, is not a tourist attraction, and it is easily accessible, being surrounded by walkable streets and public transport. It is a space that fulfills the basic standards of environmental quality, being safe, clean and strong space (Carmona, 2009).

Madrid is located in Southern Europe, in the interior of the Spanish mainland. It is an area where the effects of climate change are pronounced (EEA, 2012). Since 2000, the number of extremely hot days has increased (Fernandez et al., 2001). The city is especially vulnerable to heatwaves (Smid et al., 2019) and it has a clearly defined urban climate with a large number of days experiencing intense Urban Heat Island (UHI) effects (Fernández et al., 2016). 2 de Mayo square is located within the UHI's greatest intensity area.

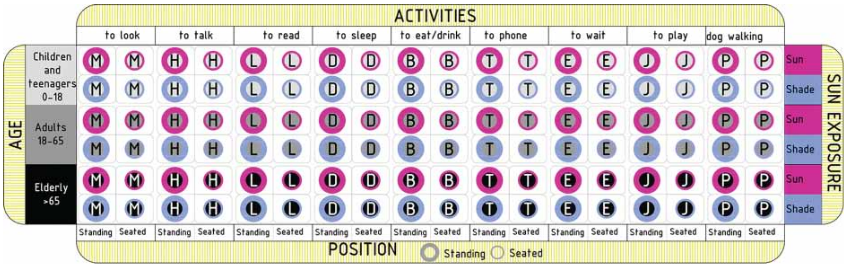
According to the Köppen Hagen classification, Madrid has a Csa climate: warm with hot dry summers. There are high temperature contrasts between winter and summer (up to 30ºC) and day-night differences (up to 17ºC in summer). At periods of peak usage (from 8am to 10pm), the relative humidity in open spaces is below 40% for most of the year and below 20% in summer.

METHODOLOGY

This investigation carried out a multicriteria analysis of environmental conditions and the use that people make of the square. It contrasts results anticipated in theoretical analyses with data collected *in-situ*. Finally, a procedure for the definition of the diversity in a given space is developed:

1. Establishment of the theorical framework. Studied subjects:
    a. Environmental sustainability international and national certifications.
    b. Institutional guides and documents on sustainable urbanism.
    c. Bioclimatic urbanism, urban microclimate and climate sensitive urban design.
    d. Outdoor thermal comfort and people activities in public space.
    e. Urban design and the use of public space.
    f. Papers and institutional guides for urban open spaces' quality assessment.
2. Data gathering and preparatory works. Preparatory investigation included both field work and the use of archival material:
    a. Physical description and systematization of usage: The shape, size, distribution, height-width ratio, urban furniture, landmarks, slopes, levels, private-public transitions, maintenance, security, accessibility and finishing materials used as well as the housing density of the surrounding area were taken into account.
    b. Uses and urban utilities study: The uses of surrounding buildings (houses, schools, churches, social services), uses of the space (roads, parking, pedestrian areas, places for staying, playgrounds, area for the elderly, green areas, private terraces), urban furniture (benches, fountains), private facilities (shops, restaurants, parking access), urban landmarks and points of reference (monuments, the Maravillas convent) and the activities in the urban space (spontaneous or guided) were reviewed, making use of Madrid City Hall's GIS data analysis.
    c. Measurement of local climatic conditions: Measurement of air temperature, relative humidity, surface contact temperatures of different materials in the square and wind speed, during the mornings, afternoons and nights of three days in April, May and June. A Testo 400 data logger with three sensors supported by a FLIR Systems thermal camera was used. The points with highest and lowest solar gain on paving materials and in recreational areas were selected as the points of data collection. These points were identified by solar radiation simulation during the days that the field measurements were to be done.
    d. Climate and microclimate study: Olgyay (1963) and Adapted Wellbeing CBA (Neila, 2004) climograms were drawn up to determine strategies to achieve minimum levels of comfort during the months of April, May and June. Three different activities were categorized at different metabolic levels: a person walking or child playing (2,95met), a person standing (1,65met) and a seated person (1.15met). Clothing was also thermally rated, at 1clo for the months of April and May, and reduced to 0,7clo in June. Complimentary to this data, an analysis of lighting, shade and solar radiation was carried out using Autodesk Ecotect 3D simulation software from April to September.
    e. Documentation of Usage: 867 photographs were taken for the non-intrusive documentation of the distribution of people and the activity they were engaged in. This observation was carried out simultaneously to the gathering of environmental data in order to establish possible relationships between environmental conditions and the use that the citizens made of the space. The following criteria were used (Figure 1):
        i. Only people making specific use of the plaza for at least ten minutes were included in the analysis.
        ii. Only people making use of public space were considered, excluding those present in the terraces of the bars and restaurants, where the use of the urban space is primarily conditioned by the infrastructure rather than the climactic or design features of the square.
        iii. Activities were categorized into three metabolic categories: sitting, standing and dynamic activities including walking and playing.
        iv. Users' approximate ages were also recorded.
        v. People's location in sun or shade was recorded, with no differentiation made between shade cast by buildings, architectural elements and greenery.

Figure 1. Legend of user registry: Location, activity, age and posture



3. Data Analysis:
   a. Comparison of field measurements of environmental variables with the meteorological station closes to the square.
   b. Relationships between the climate data collected and the use given by users to the square: a comparison between theoretical models and observed behaviors.
   c. Determination of the quality of the design: Comparison of field data gathered on microclimates, physical characteristics and the use of the space with established models in bioclimatic urbanism (Olgyay 1963; Givoni, 1998; Erell el al., 2010) and human orientated design (Whyte, 1980; Gehl, 1971; Carmona 2009).
4. Definition of a methodology for the characterization of the diversity of space in relation to the options of location and use under various climatic conditions. The diversity of the space is established as a key parameter in the physical design of open spaces (Zacharias, 2004; Mehta, 2014). The viable uses that can be made of the square in diverse environmental conditions are determined by cross referencing microclimatic and urban design parameters, such as:
   a. The ability to create varied microclimates combining sun, shade, green elements and finishing materials.
   b. The uses of the open space: playgrounds, sport areas, …
   c. The seats, benches, lying and staying areas.

These are parameters used by urban designers. Those qualities of the space that cannot be modified in an urban consolidated area (enclosure and general dimensions, façades, ground floor private uses' permeability…) are studied to understand people behavior, but they are not included in spatial diversity classification procedure.

RESULTS

Results of the Physical-Space Study of the Square

The 2 de Mayo square acquired its current dimensions (69m x 77m) in 1869. It has been renovated several times. The surrounding buildings are from 2 to 7-stories high, though primarily 5 stories, so the square's height–width ration is between 1/4.8 and 1/4.3. The height of the buildings does not imply the total solar obstruction of the space, but creates both sunny and shaded areas. The height of the surrounding buildings protects the square form the wind (Kofoed and Gaardsted, 2004).

The buildings are aligned to the street, generally without recesses nor irregularities and they lack eaves or zones of protection against rain or sun for pedestrians.

30,3% of the square is permeable paving, natural soil where mature trees grow. Road paving represents only 8% of the squares surface area, while 61.7% of square is paved in granite. There are 15 wooden and 8 granite benches.

The slopes within the square are gentle and differences in ground level are resolved with stairs and ramps. Curbs are present between roads for wheeled transport and pedestrian zones. At crossing points, the curbs are lowered and road – pedestrian area differentiation is achieved through the use of different pavements. All the points of the square are accessible to all users and road crossings are correctly signposted.

The legibility of the space is good and routes within the square are open. Users can choose a route through the square that is more comfortable, safer, faster or interesting. In addition, lines of vision are unobstructed and it is possible to see what is happening in the square and its surroundings (Figure 2).

Results of the Study of Functions and Uses of the Square

A mixture of different uses is given to the square. Social, religious, educational, commercial and hospitality infrastructure is represented. This allows neighbors to carry out everyday activities, including shopping. In general, this infrastructure is located in the ground floor shopfronts of the buildings surrounding the square, which are easily accessible. In most cases, there is a visual permeability between private spaces and the square itself.

In some cases, the private use of space extends into the square. Three bars maintain terraces in the square that extend from their shopfront locations. However, these terraces are not permanent installations.

Zones within the square are differentiated, including areas dedicated to children, older people, parking, roads and gardens. Roads delineate the perimeter of the square, which contains a number of gardens and large trees.

It has a sufficient number of benches, in excess of the ratio suggested by William H. Whyte of 1 foot of bench for each 30 feet of square (1980). The number is not excessive as virtually all of the benches are in use on certain afternoons. The benches are distributed throughout the space, giving people the choice of which area of the square they would like to sit in. Some benches are placed in a

Figure 2. 3D model and photograph of 2 de Mayo square

way that complicates social relationships, for example back to back, facing low walls or away from the open space of the square. There are also secondary benches (Gehl, 2001) that result from the design of the square itself. For example, people were observed to be seated on flowerpots, stairs, fences, low walls and other projecting architectural features.

Results: Climatic Field Measurements

Air temperature (Ta), relative humidity (RH), wind speed and direction and contact temperature (TC) of pavements, façades and urban furniture were measured from April to June in the pedestrian zones of the squares. The data was collected in both in sunny and shaded locations on clear days, at three different times during the day: morning, afternoon and night (10 to 10.30 am, 6 to 6.30 pm and 10.30 to 11 pm, local time). The measurements were taken 1.5m to 2m above ground level (Caballero, 2004).

Summer in Madrid is extremely warm: the maximum registered temperature was 33.6ºC one an afternoon in June. Ta is considerably lower in shaded spaces than in sunny ones. Humidity is low (RH<30%) during the day. Recorded Ta values are above the summer physiological equivalent temperature PET that people prefer in Madrid, which range from 22 to 27ºC, and this can lead to thermal dissatisfaction and heat stress (Fernández et al., 2012).

Ta reduction (3.2ºC less in April and 1ºC less in June) and RH increase (up to 12% in April and 4% in June) in shaded spaces is noticeable, although the higher the outside temperature, the less effect shade has.

Wind direction and intensity varied across both months and days. It varied from calm to maximum speed of 4 m/s, with no prevailing direction.

Pavement materials are natural soil, light grey and dark grey granite. Façades were both whitewashed and light grey granite. Benches are made of wood and light grey granite1.

The TC of the materials vary based on their location and their thermal, hydric and optical properties. They influence the energy balance with the environment, creating different microclimate conditions (Hernández et al. 2013; Santamouris, 2001). According to measurements in sunny locations, the highest recorded TCs occur on dark granite and the lowest on light granite. There are differences of 7.5ºC in April and 10.2ºC in June between the most and least warm materials in the middle of the day.

Materials' TCs evolves similarly throughout the day both sun and shade, recording considerably lower TCs in the shade. TC differences in the same materials in the sun and in the shade are bigger in the afternoons and in June, reaching 19ºC for dark granite. Shading is a very effective strategy to improve comfort during the warmest hours of the day.

Even though the TC of wooden benches is higher during the early hours of the day, at hours of peak intensity, their temperature is lower than that of granite benches (4º to 7ºC less). Maximum TC for wooden benches is 43.1ºC for wooden benches and 50.5ºC for granite benches. While granite benches preserve part of the day´s stored energy at night, energy loss is faster for wooden seats, so, during the night, wooden benches remain practically at Ta.

Natural soil and similar vegetation TC is very to Ta, being just slightly to higher (3ºC maximum). At midday, the TC of materials in the sun, except natural soil and vegetation, can rise between 8ºC and 17ºC above Ta, which has a considerable effect on comfort in open spaces. TC measurements have confirmed that permeable and natural pavements remain practically at Ta.

In the measurements taken at locations surrounded by trees and with natural soil, a 4% RH increase was registered, although this parameter depends on the weather conditions (Kurbán et al. 2011).

Differences in the materials' thermal behavior is linked to their albedo, thermal inertia and density and exposure to direct sunlight. Albedo in particular is a decisive property. While vegetation remains practically at air temperature (Ta), construction materials absorb, store, reflect and emit radiant energy influencing near-surface air temperatures. During the daylight hours, when people use the most open spaces, finishing materials have a high TC. These spaces became even warmer place due to the radiant exchange that takes place, increasing near-surface Ta. In May, pavements and facades become heat sources for square users. UHI is closely related to construction materials (Hui, 2015).

Results: Climatic and Microclimatic Conditions

Through the study of temperature and humidity at one-hour intervals, taking into consideration the comfort parameters established by the climogramas, needs and strategies to be adopted were determined for diverse activities and types of clothing.

During the month of April, assuming clothing with a 1clo value, independently of the activity being engaged in (walking, standing or sitting), additional thermal input was needed to achieve thermal comfort.

In May, warmth from sunshine was necessary up until 4:00 p.m. for a seated person, until 3:00 p.m. for a standing person and until 1:00 p.m. for a person in movement. Comfortable conditions were present in the early hours of the afternoon, three or four hours for a standing or sitting person, and two 2-hours blocks for a person working in the early and late afternoon. The availability of shaded areas becomes necessary for the comfort of people playing or walking for the majority of the afternoon.

During the month of June, shade is required from midday and throughout the entire afternoon, even taking into account a shift to clothing with a lower thermal value of 0,7clo. At certain moments in the midafternoon, a breeze is also required for the thermal comfort of people playing or walking. In June, from early morning until midday if one is seated or standing up, or until 10:00 a.m. if one is walking, sunshine is required for thermal comfort. The time of widest comfort (20% of people unsatisfied) is between 12:00 and 1:00 p.m. for stationary people and between 10:00. and 11:00 a.m. for walkers.

In the period analyzed, in the 2 May square there were more shaded spaces (62% of the pedestrian zone), than spaces without access to shade (38%). There is a great variety of spaces with diverse intensities of both shade and sunshine.

Results of the Analysis of the Use of the Square

On the 2 de Mayo a total of 1002 people were recorded in the square (0.188personas/m ^{2}), of whom 244 (24,3%) were children, 705 (70,4%) adults and 52 (5,3%) elderly. The afternoons are the moment of the day in which the square is most frequented.

The most common activity documented was conversation. Almost half of all users, 447 people, were engaged in this activity. Play was the second most common activity, enjoyed by 269 people. Most of these were children, but some adults also accompanied this activity. The third most common activity was people watching, in which 154 people participated. Dog walking, eating and drinking, reading, using a mobile phone and sleeping were amongst the other activities documented.

Adults and elderly people were predominantly seated as they used the square to speak or observe. Children, by contrast, were more often upright, walking or running as they played.

The sunnier areas without shade were those least used over the months analyzed, as were the areas without urban furniture or designed to facilitate transiting the square. People tended to group together around benches and urban furniture as points of reference. Users preferred to occupy the space around the edges of the plaza, and when this zone was fully occupied more central areas were also used. The children were the only users who made use of the entire square.

There are also specific meeting points within the square which are used frequently. These meeting points tend to be located at corners offering good visibility over the square, and they tend to be standing areas. They are also zones where people remain standing while speaking, while waiting or due to casual meetings. During months analyzed, people mainly waited in the shade.

Generally, the public-private border is where most activities occur (Gehl, 2001), but in the 2 de Mayo square this border was not used extensively. The absence of benches in these those zones, their narrowness which establishes them as transit areas and the existence of design features separating these areas from the central area of the square could be amongst the reasons for the reduced usage of these areas (Figure 3).

Figure 3. Use of the space. Pedestrian areas where people did not stay are highlighted.

DATA ANALYSIS: DISCUSSION ON MICROCLIMATIC CONDITIONS, PHYSICAL DESIGN AND THE USE OF THE SPACE

On-Site Measurements and Climate Databases

A divergence exists between the climatic databases and local measurements. In bioclimatic studies one works with climatic data drawn from an average of between 10 and 30 years of recorded data. At an international level the .epw archives of Energy Plus2 are used, and at a national level, the Spanish State Meteorology Agency-AEMET climate databases and those of the Technical Construction Code3 are available. A difference between the temperatures recorded in situ and historical average temperatures was observed. Those recorded between afternoon and dawn were notably higher. Digital archival data more closely approximate the observed local climatic reality, although in all cases temperatures recorded in the field were higher than averages drawn from the archives. Recent studies have verified these differences between predicted and actual temperatures. Recent studies have shown that these differences in information between the climatic bases and the local data are the most important fact when determining the differences between simulated data and real data. (Cuerda et al., 2009). New investigations into energy efficiency and thermal comfort incorporate the effects of the UHI in energy simulation (Santamouris, 2014; Bouyer et al., 2011). In public spaces, when it comes to defining strategies to improve the thermal comfort, it must be taken into account that the primary hours of use are mainly in daylight and within a few hours of sunset.

According to the updated UHI map (Núñez, 2017), there is a 2ºC to 3ºC Ta difference between the location of the nearest weather station in Parque del Retiro, an urban park, and the square. Field data confirms the UHI: Ta is 0.5ºC to 5.2ºC to higher in comparison with the weather station Ta data during the day and 2.3ºC to 5.2ºC to higher at night. The relative humidity is also noticeably lower in the square as compared to weather station readings.

Urban Microclimate and the Use of Space

A relation between the climate and the use of the space is observed: in the month of June, in which the highest daytime temperatures occurred, even children changed their use of the space. While they normally ignored thermal conditions, using the entire area of the square, in June they shifted their use to shaded areas. The square received least use at this time.

Nevertheless, it was observed that people have a greater climactic tolerance in outdoors than that anticipated by means of bioclimatic modeling. They remain in the sun even at times where the temperature exceeds theoretical comfort levels. Numerous investigations have demonstrated that indexes of quantitative comfort lack universal character (Auliciems, 1981; Humphreys and Nicol, 1998; Busch, 1995; Of Dear and Brager 1998; Haghighat and Donnini, 1998; Bravo and González, 2003). More recent investigations emphasize adaptive capacity, including physiological, physical and psychological adaptation. This adaptability results in the range of comfort in outside spaces expanding noticeably. (Nikolopoulou, 1999, 2003, 2007¸ Oliveira and Andrade, 2007; Lenzholzer, 2010).

Urban Design and the Use of Space

Urban design conditions the use of the space by adults and the elderly, however, children do not act in accordance with theories of the use of space (Gehl, 2001; Whyte 1980; Carmona, 2009). Whereas the adults occupy the space from the edges inwards, concentrate in areas with clear lines of vision or remain seated in on benches, children make use of the entire space, seek out hidden corners and use the urban furniture in alternative ways, although they also use designated play areas. Thus, as far as urban design, the presence of seats, benches and other urban infrastructure was the principle determiner around which people carried out their activities.

PROCEDURE FOR DETERMINING SPACE DIVERSITY

Characterization of Spatial Diversity

A methodology is proposed for the characterization of the diversity of the space in relation to variety of options for location and use of the space under various microclimatic conditions. The graphical representation of this spatial diversity facilitates a rapid assessment of some of the basic conditions of environmental quality, those that allow peoples' adaptation.

The proposal is based on the theory that well-being in urban open spaces is founded, in addition to physiological parameters, on human factors (Nikolopoulou et al., 2001) and on inhabitants' ability to choose the urban microclimate best adapted to them and their activities. The definition of thermal comfort has evolved from a purely quantitative determination towards a qualitative approach (Shooshtarian et al., 2018). In adaptive models, comfort is based on the interaction between people and the environmental thermal conditions. Citizens react based on their physiological and psychological conditions. Thus, people with more options with respect to adapting to their environment will generally feel more comfortable (Fountain et al., 1996; Brager et al., 2004). Creating options improves livability, increases the number of users and the amount of outdoor activities undertaken. Zacharias et al. (2001), who identify key ideas for climate sensitive urban planning, emphasized the creation of diverse microclimates as a way of enhancing peoples' physical and psychological adaptive capacity.

The principal variables for thermal regulation (solar gain, heat storage and radiation) in dry climates with cold winters and very hot summers like that of Madrid can be drawn from a base of bioclimactic studies, simulations and local measurements:

- **Shading:** The most important consideration to avoid energy gains and Ta increase.
- **Paving Materials:** Energy storage and radiation capacity.
- **Existence of Trees:** shading element, non-energy radiating element and HR increase.

The importance of these variables has been analyzed extensively in numerous investigations (Chatzidimitrioua el al., 2016; Salata el al 2015; Tsitoura el al., 2016; Sangkertadi el al., 2016).

Thus, a preliminary map of microclimatic diversity over the period studied was created in which 5 zones with different microclimatic conditions are differentiated:

Microclimate 1: Very warm without shade or greenery, paved in energy accumulating materials.
Microclimate 2: Warm without shade nor greenery, paved in light or permeable materials.
Microclimate 3: Slightly cool space with shade, paved in energy accumulating materials.
Microclimate 4: Cool space with shade and greenery, paved in light or permeable materials.
Microclimate 5: Coolest space with shade and greenery, paved in light or permeable materials.

In addition to the thermal diversity of the square basic urban design parameters that condition the use of the space have been included: the availability of benches and secondary seating and specific use areas such as children playgrounds or exercising areas. The cross referencing of thermal and design variables leads to the identification of 15 types of space in addition to roads and non-pedestrian spaces. For example, a T1 type space would be a very warm area in the square without shade or greenery, with heat absorbent paving, seating area and other urban equipment (Table 1).

The variety of spaces in the 2 de Mayo Square would be defined by the number of types of space present in the square and their percentage. The larger the number of different spaces available, the better the square is adapted to diverse climatic conditions, different users and their needs and long duration stays and activities (Figure 4).

In order to visualize their distribution, spaces identified have been represented graphically in a 5x5m grid for geometric simplicity, and overlaid on the square map (Figure 5).

The classification of 15 spatial types is applicable throughout the year based on the selected variables. Most variables are constant throughout the year: urban furniture location, space uses, finishing materials, trees and vegetation.

Table 1. Space types' characterization

Microclimate	Sitting Place	Utilities	Space Type	Type's Percentage
Microclimate 1	YES	YES	T1	0.09%
	OR	OR	T2	0.9%
	NO	NO	T3	16.36%
Microclimate 2	YES	YES	T4	3.63%
	OR	OR	T5	0.18%
	NO	NO	T6	0%
Microclimate 3	YES	YES	T7	0%
	OR	OR	T8	0.09%
	NO	NO	T9	15.45%
Microclimate 4	YES	YES	T10	3.63%
	OR	OR	T11	4.54%
	NO	NO	T12	10%
Microclimate 5	YES	YES	T13	10%
	OR	OR	T14	7.27%
	NO	NO	T15	0%

Figure 4. Diagram of the variety of space types of 2 de Mayo square

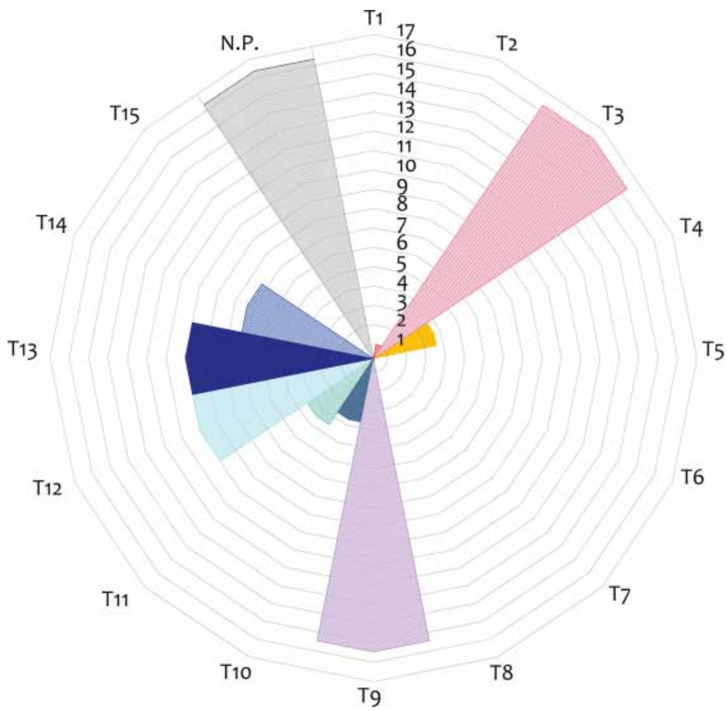
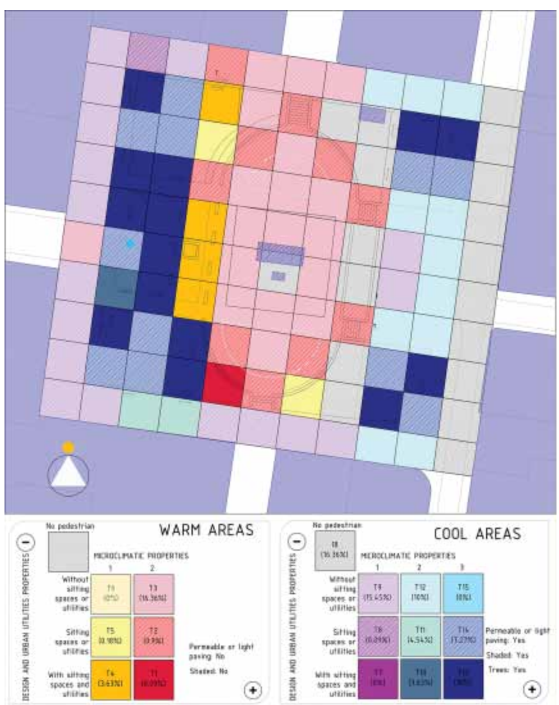


Figure 5. Spatial distribution of square's diversity represented by space types (valid fron April to September)



The variable that changes over time is shading. On the basis of microclimatic studies, two distinct periods should be identified, and thus at least two different maps of the climate diversity of a space should be produced: one for the period in which there is generally need for additional heat and one for the period in which heat reduction is a priority.

It was observed that the 2 of May Square offered its users a large choice of different recreational and usage areas, both sunny and shaded with diverse microclimates. This made the square comfortable, comfort understood precisely as the availability of diverse microclimatic areas enabling users to choose which best facilitated their enjoyment of the space.

Spatial Diversity and People's Behavior

During the daytime data (morning and afternoon), which is the main period of influence of sunshine and accumulation of energy in pavements, people are located both in the sun and in the shade. There is a correlation with the strategies defined in the bioclimatic study in the warmest moments of the day. It is when most people, including children, remain in the coolest spatial types. Anyway, even when air temperature is over 30ºC some people remain in warm spatial types.

People is using the most the warmest, T1, T2 AND T3, or the coolest spaces, T13 and T14. Space types T1, T2 and T3 are used by 30.65% of the total registered people in the morning and 34.8% in the afternoon. Moreover, 51.8% of the people in the morning and 42.85% in the afternoon are located in T13 and T14 spatial types (Figure 6).

These 5 types, the warmest and the coolest, make up 58.25% of the surface of the square, but welcome 82.48% of the people in the morning and 77.65% in the afternoon. Less use is made of spatial types with intermediate microclimates (Figure 7).

The cool space types are the most used ones on study days, as they correspond to the period when shading is required to reach thermal comfort levels according to the bioclimatic study. Among them, types T10, T13 and T14 are widely used. They are the coolest but also have urban furniture and services.

With increasing temperatures, the warm and very warm types T1, T2, T3, T4 and T5 are hardly used by people in June. In types T1, T2, T4 and T5, people are mainly talking and looking around as they have numerous benches and sitting areas. Type T3 corresponds mainly to the centre of the

Figure 6. People's space types utilization (people/m2)

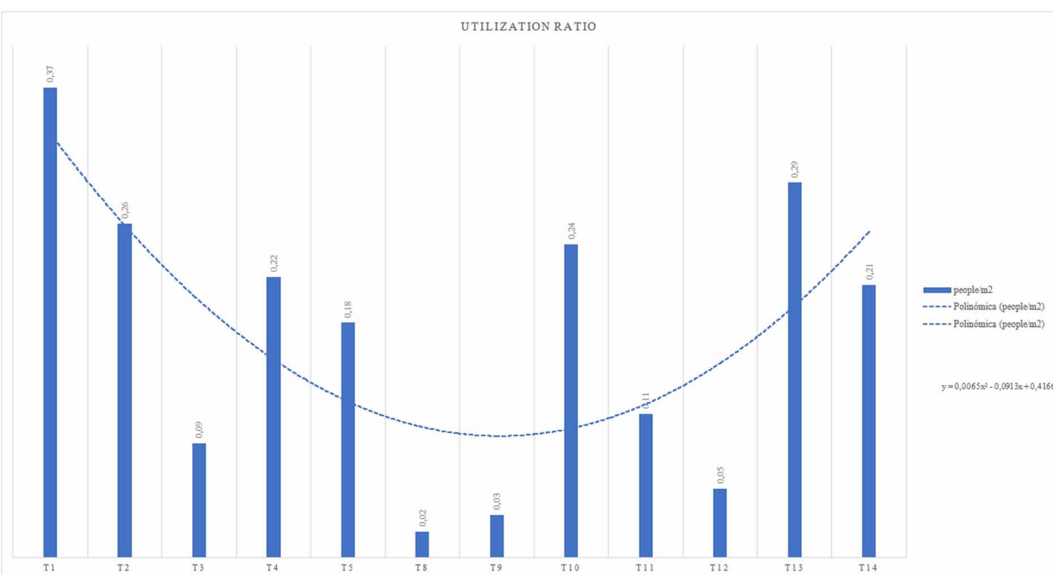
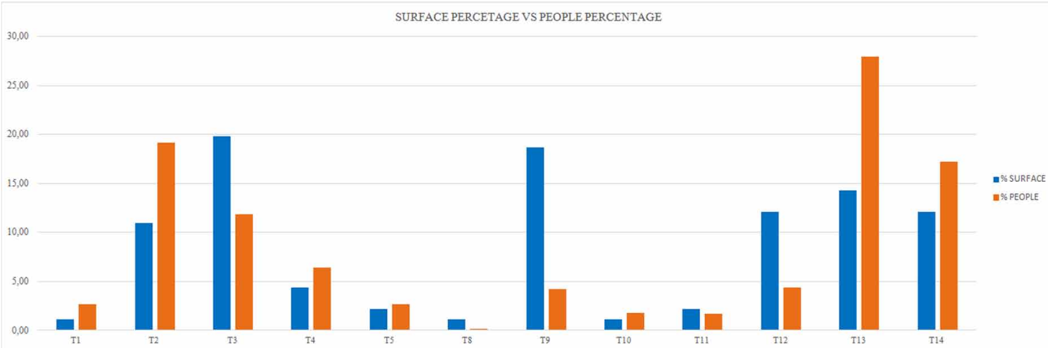


Figure 7. Comparison between the percentage of surface area of each spatial type and the percentage of people using them



square, where almost all registered people were children playing. T1 type is located in an area with benches, next to one of the entrances to the square and close to a playground, so it is very used even if its surface is very scarce.

However, types T3, T9 and T12, without uses nor furniture, are scarcely used by people. Children playing or adults waiting for someone use them. Type T3 corresponds mainly to the center of the square, where almost all registered people were children playing. T9 and T12 types occupy a large area of the square, but the people rarely choose these places, because they are established as transit areas.

The selected parameters for microclimate control are not relevant at night in terms of space use. Thus, at night people move to the central area of the square, a place very exposed to the weather conditions during the day. During the night, the users are practically all adults talking, drinking and dog walking. The activities change significantly from those of the day. The main variable for people's location in public space are benches, sitting places and urban references.

CONCLUSION

This paper describes a climatic, microclimatic, physical and usage analysis of a public square in Madrid. It establishes a methodology for the characterization of the microclimatic and functional diversity that an urban space can offer.

The observations and measurements obtained have illustrated the importance of the variable of climate and activities within the square. People stayed in the 5 microclimatic areas throughout the analysis period, but areas with no references, urban uses, equipment or furniture were scarcely used. Basic elements of design around which people meet were identified, confirming the existing theories on this matter. It is worth emphasizing that the behavior of children and adolescents does not correspond to adults' theoretical models and specific researches are required.

The investigation was centered on physical and climatic aspects related to urban design and its conclusions can be useful for decision making with respect to physical interventions urban spaces. Specifically, is suggests methodology for the analysis of a space that can be applied prior to an intervention for the detection of deficiencies and identification of elements that are effective.

This mapping methodology enables a determination of the extent to which a space offers a diversity of microclimatic zones with different usages, and so, gives users options to choose the area which best suits their needs, activities and personal preferences. It also facilitates an environmental quality assessment and comparative evaluation between urban spaces.

The spatial diversity classification methodology assists the urban designer:

- To understand the environmental performance of an urban space. To know if it is possible to use the space in thermal comfort conditions in the current state, and to propose reforms to mitigate possible existing shortcomings;
- To get to know the urban microclimate of a space;
- To create diverse urban microclimates by combining finishing materials, vegetation, sunshine and shade;
- To select finishing materials;
- To locate in the space selected materials;
- To locate space's uses (playgrounds, sport areas…) based on their climate requirements;
- To locate places to stay (primary and secondary benches) based on climate requirements.

This analysis method is complimentary to processes of citizen participation and socio-economic studies.

Just as a dynamic, livable and democratic city is based on a diverse mixture of people and activities, urban spaces offering citizens diverse choices to fulfill their specific needs are also important. Thus, from this small-scale case study, we have sought to demonstrate the importance of the creation and recovery of a city offering diverse choices for its use, in order to create inclusive and humane urban spaces.

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ENDNOTES

1. Materials' reflectance, density, water vapour diffusion coefficient, specific heat, absorptivity and thermal conductivity data source: Spanish Construction Code. URL: https://itec.cat/cec/ (2018-07_01).
2. Energy Plus Weather Data. URL: https://energyplus.net/weather
3. Climate .MET archives of Spanish Construction Code. URL: https://www.codigotecnico.org/index.php/menu-documentoscte/133-ct-documentos-cte/ahorro-de-energia.html

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