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Methodological framework for evaluating liveability of urban spaces through a human centred approach

Daniele Santucci[1,2], Umberto Fugiglando[1], Xiaojiang Li[1], Thomas Auer[2] and Carlo Ratti[1]

[1] MIT Senseable City Lab, Cambridge MA, USA {danieles, umbertof, xiaojian, ratti}@mit.edu
[2] Technische Universität München, Chair for Building Technology and Climate responsive Design, Munich Germany {daniele.santucci, thomas.auer}@tum.de

Abstract: The quality of urban spaces is fundamental to the liveability of cities. In past decades, many studies at different scales have developed methodologies to evaluate comfort conditions in public spaces, as this aspect is essential for making cities more *walkable*. In this context, the present study develops a methodology for evaluating quality of cities through a dataset that collects millions of anonymous pedestrian trajectories through smartphone applications. This data, which includes about 1 million trips in the Boston area of over 60,000 anonymous users from May 2014 - May 2015, estimates human walking activities. Presence is used as an indicator for walkability by relating it to additional layers to provide an accurate model of the urban morphology. The aim of this paper is to present a case study on how human walking activities can be sensed, quantified and applied to determine the impact of the urban morphology and its effects on climate at a micro-scale. This study also reveals how people flows react to highly fluctuating microclimatic conditions and how pedestrians respond to the variability of the urban environment. Together, these approaches will affect multiple aspects of human life including health and wellness, infrastructure and quality of life in cities to create liveable and healthier cities.

Keywords: liveable urban spaces, data mining, environmental quality, outdoor thermal comfort.

1. Introduction

Keeping citizens in a healthy state is a goal every society should achieve. For achieving this challenging target, walking can be considered as one of the fundamental activities as it is a significant indicator of a healthy population (Ewing and Handy, 2009; Yin et al., 2016). Moreover, walking is possible if conditions are comfortable and safe, if the environment is attractive and if relevant places and activities are reachable.

Therefore, understanding the relationship between the urban built environment and physical activity is a high priority for design and planning (Christian et al., 2011).

Besides this aspect, shared public spaces make urban life distinctive and differentiated.

For administrators, policy makers, designers and planners, it is crucial to determine effective performance indicators to predict and evaluate environmental quality and implement the gathered information into design and planning decisions. This aspect is fundamental since the usage of public realm is the most relevant measure to evaluate its performance and for guaranteeing continuity through time.

Summarizing, walking can be used as an indicator for the quality and attractiveness of the urban environment, using humans as sensors.

This paper, part of a wider research project, attempts to quantify a relation between people’s presence and the urban morphology with a human centred approach.

Through data mining individuals can become the main experimental subjects: using data of individuals allows developing a personal comfort model that predicts individual responses also on a large sample. Personal comfort models are usually based on a small number of individual surveys. In this study, we are using a Big Data approach using signals collected from a sensed environment.

Following this premise, this study uses human response for predicting the quality of comfort conditions in public spaces, and not with a simulation-based method.

For reaching this aim, we use walking data collected over a period of one year – from May 2014 to May 2015 – in the Greater Boston area. The dataset, which consists of 250.000 anonymous pedestrian trajectories collected through smartphone applications, records human walking activity.

1.1. Methodology

The data reveal patterns of how people use public spaces for walking in a high spatiotemporal resolution. Presence is used as an indicator for walkability and, more in general, to estimate the quality and the characteristics of the urban environment. In order to relate walking behaviour to form and its effects, we use the Sky View Factor (SVF) as an indicator of the urban morphology. The SVF is an index that allows determining a variety of parameters such as density, typological variety, and the exposure to the environmental conditions (Carrasco-Hernandez et al., 2015).

Several studies have demonstrated the relevance of the SVF in characterizing both microclimatic conditions, as peak temperature difference can be assessed in terms of height-to-width ratios or sky view factors (Oke, 1987), and comfort, as environmental stimulation is an issue of primary importance in external spaces (Nikoloupoulou et al., 2003)

The novelty of this study is to evaluate the dependency between walking activity and climatic conditions at a micro-level using the SVF as a fundamental indicator to identify spatial patterns of environmental diversity at the urban scale depending on seasonal climatic variations. SVF variability corresponds to the diversity of the built environment and therefore to diverse microclimatic conditions: variant urban environments generate varying comfort conditions in space at the street level. Since complex urban morphology generates environmental diversity, this correlates with freedom of choice and an overall expression of comfort (Steemers and Ramos, 2010).

1.2. Previous work

The past work the has been dedicated to the relation between microclimate and people's presence, basing the observation on outdoor comfort mapping using the Universal Thermal Climate Index (UTCI) and relating it to people's presence with different techniques (Chokhachian et al., 2017a). These studies associate field measurements and simulations reaching a high mapping resolution modelled on small samples. Mapping outdoor thermal comfort, which is a complex, subjective human sensation, can be combined with a different perspective, in particular to increase the scale to the urban dimension.

Furthermore, the most used indices to map outdoor comfort such as Physiological Equivalent Temperature (PET), Perceived Temperature (PT) and Universal Thermal Climate Index (UTCI) are expressed as an equivalent temperature that describes how a human would physiologically react to a given set of environmental conditions (Reinhart et al., 2017). UTCI is based on a 187 node model (Fiala et al., 2012. Kampmann et al., 2011) and has been shown to be able to detect potential human discomfort under larger sets of microclimatic conditions than other biometeorological indices (Blazejczyk et al., 2012). In recent years, computational models of environmental processes have been developed in order to use UTCI predictions to design more comfortable outdoor spaces (Matzarakis et al., 2010).

The remaining question is to which extent those indices are able to predict occupancy patterns in public outdoor spaces, due to the resolution that they are able to depict (Reinhart et al., 2017). In fact, these studies show some limitations in terms of scale since the increase of scale corresponds to a decrease in terms of accuracy: either the granularity is very high – up to 1 m – and the model scale is limited to a few blocks, or, to enlarge the observation scale, the resolution drastically decreases.

Furthermore, only few studies have explored the physiology of human comfort in outdoor environments: the physiological response can only partially explain comfort perception in the urban environment (Steemers and Ramos, 2010).

2. Analysis

Using a large dataset of around 250.000 individuals' walking trajectories allows providing a data driven methodology that combines a high accuracy in terms of spatiotemporal distribution in relation to a wider observation scale that more globally illustrates the dependency between walking activity and microclimatic conditions for an entire city area. To accomplish this objective, we analysed the distribution of walking activity and its variations in relation to strongly different climatic conditions, for providing a useful design tool for any urban intervention that aims at improving outside comfort conditions with larger effects on the population.

2.1. Study area

As the largest city in Massachusetts, the city of Boston was chosen as the study area. Boston has land area of 106.7 km^2 and total population of 670,000 in 2016.

Fig. 1: Study area with highlighted trajectories

Due to its compact structure, Boston is one of the most *walkable* cities in the United States (Vanky et al., 2017).

2.2 Dataset

The datasets used in this study include anonymous human trace data, Google Street View (GSV) and Open Street Map (OSM) data.

The anonymous human trace data was collected from activity-oriented mobile phone application. The data, which include about 1 million trips of over 60,000 anonymous users from May 2014 – May 2015, record GPS locations and walking behaviour of anonymous individuals in the Boston metropolitan area.

The available data differ from month to month, with no evident reason: 33,114 trajectories were recorded in September 2014, while in February 2015 only 19,302. This difference is not only related to weather conditions, since hot months such as May, June, July and August have less records than February.

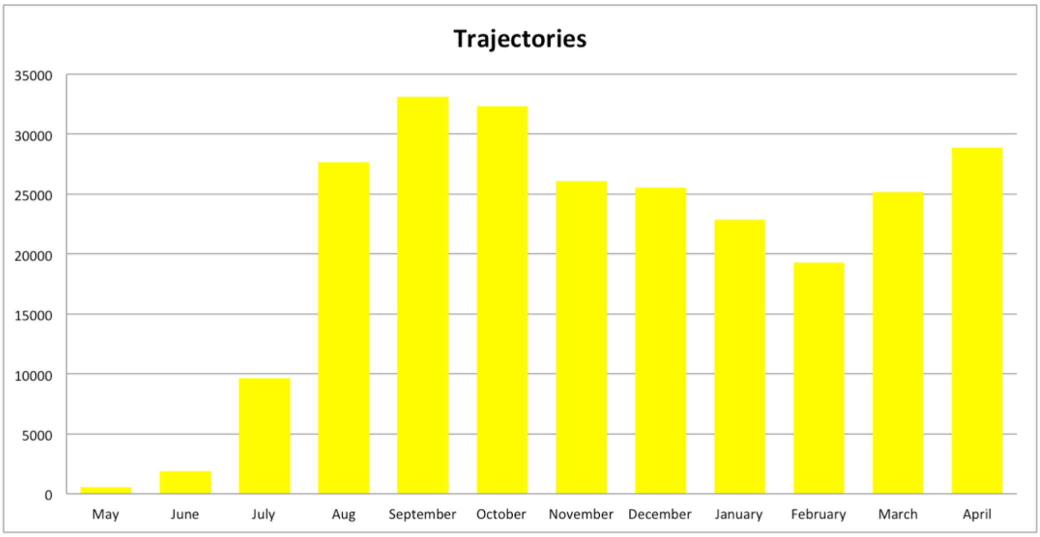

Fig. 2: Monthly distribution of the trajectories

Due to the noise of the original GPS locations, the data were normalized using a map-matching algorithm based on the Open Street Map to rectify those mistaken trajectories. In this study, we used the Hidden Markov Map Matching algorithm (HMM) to match the measured longitudes/latitudes in human trace records to roads (Newson and Krumm, 2009). The HMM algorithm accounts for the GPS noise and the layout of the road network, and matches the GPS locations to corresponding streets with very good accuracy.

The GSV data were used to measure and estimate the geometries of street canyons and the amount of street greenery. Since GSV panoramas are distributed discretely along streets, we first created samples every 100m along the streets in the study area. Based on those created samples, we further downloaded the GSV images based on the Google Street View API (Google, 2016; Li et al., 2018).

The GSV images and the walking trajectories matched with the OSM street segments have a complete correspondence in space since they are both located at the street centreline. The datasets allow generating a georeferenced occupancy study in relation to the sky view factor (SVF) that quantifies the degree of sky visibility and therefore the proportions of street canyons. Previous studies have shown that the enclosure of street canyons is related to human perception of the environment (Asgarzadeh et al., 2014; Li et al., 2015) and the walkability of the streets (Yin and Wang, 2016).

2.3 Climate analysis

Additionally, we analysed weather data for the same time period May 2014 until May 2015 using Weather Underground hourly data records retrieved from the KBOS station (Boston Logan Airport) to classify daily conditions and cluster them into typical days categories, as in Table 1.

After selecting the most representative days for each season in terms of Air Temperature, Relative Humidity, Wind speed and Wind direction that are considered typical in relation to the season's averages, we identified the highest concentration of hot days, including the hottest day of the year 2014 (September 2nd) in September, whereas February 2015 was the coldest month (including the coldest days, February 15th and 16th).

This classification was used as a fundamental clustering of mesoclimatic conditions throughout the year corresponding to the available human trace data.

Table 1: Climate data classification

Hot	Average	Cold
Hot and humid	Average humid	Cold and humid
Hot and dry	Average dry	Cold and dry
Hot peak		Cold peak

3. Results

3.1. Trajectories' distribution

In a first phase, we carried out a quantitative analysis of the trajectories in terms of length and street segments. As outlined in §2.2, GPS positions recoded by the phone app were matched to street segments in the OSM database: specifically, each trajectory can be considered as a list of street segments, which are identified by unique codes called OSM IDs.

In Fig. 3, trajectories are grouped according to their length in meters (considering stepping intervals of 200m) and their normalized frequencies (counts) are plotted. Trajectories were also divided between weekdays and weekends in order to highlight potential specific patterns assuming different behaviours during working and leisure routines. The resulting graphs show very similar patterns: the subdivision in weekdays and weekends does not show substantial differences. Similar are also the distributions of the cold and hot period.

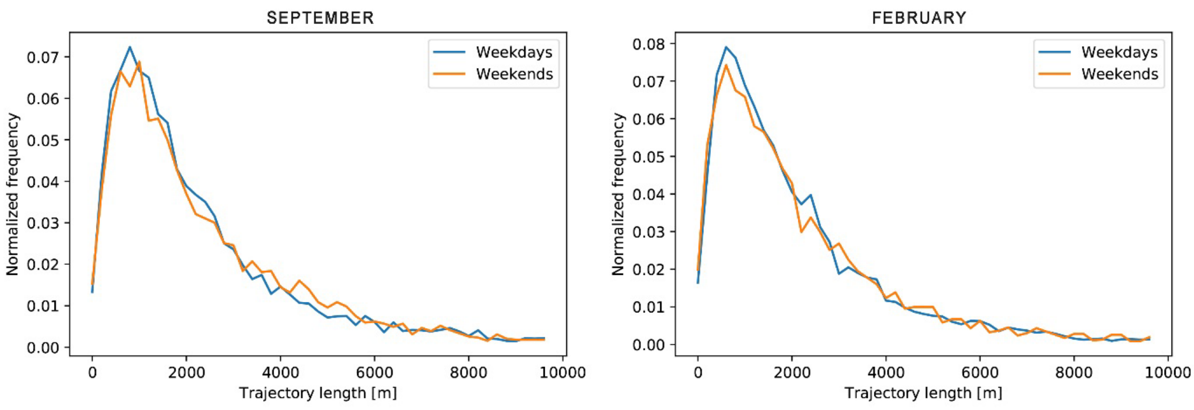

Fig. 3: Frequency of trajectory lengths.

Moreover, an analysis of the most frequent street segments (OSM IDs) has been carried out throughout all the trajectories in the database. Fig. 4 shows the total counts of the first 100 most frequent street segments, ordered by their rank. The different ordinate's axis scale is due to the fact that the total number of trajectories in February is approximately double of the one for the trajectories in September.

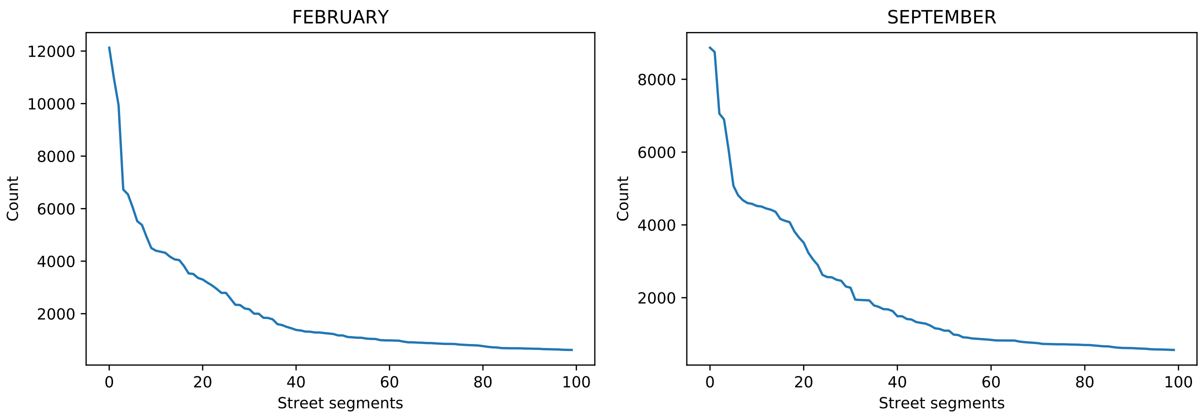

Fig. 4: Total counts of the first 100 most frequent street segments.

The similar distribution can be referred to a certain continuity in patters of urban occupancy: besides varying seasonal climatic conditions, specific routes maintain their qualities besides meteorological variations: people rather adopt different clothing insulation than drastically changing their walking habits.

3.2. Sky view factor variability

To further investigate people's response to microclimatic conditions and for finding correlations between varying weather conditions and trajectories' length and location, a streetscape variable was selected – street enclosure by buildings – to identify a parameter that corresponds to diverse outdoor comfort conditions.

Numerous studies have already demonstrated that the sky view factor (SVF) can be a representative indicator for urban building density and layout. SVF is the ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment and it affects urban radiation exchange and urban microclimate (Watson and Johnson, 1987). Several others have related the effects of SVF to thermal comfort in the urban environment (Mayer et al., 1987; Lin et al., 2008/2011; Bröde et al., 2012).

Under this premise, the SVF is considered to be a fundamental parameter in order to evaluate microclimate in urban space as it has been demonstrated that the correlation between SVF and outdoor thermal comfort (mean radiant temperature) is particularly strong, in particular for dense urban environments (Wang et al., 2014).

In this section, we analyse the variability of microclimatic conditions through the variability of the SVF. As explained in §2.2, SVF sampling points on the streets (obtained combining different GSV pictures) are uniformly distributed every 100m in the urban environment. We therefore compute for each street segment the standard deviation of the corresponding SVFs, assigning a value equal to zero to the segments that contain only one SVF sample. The SVF variability (in terms of standard deviation) is then compared to the total frequency of the street segments (as calculated in Fig.4). In Fig. 5, each plotted point represents a street segment, along with its frequency count and the standard deviation of its SVFs.

In order to investigate a possible relation between the street segment frequency and the SVF's variability, a linear regression model has been fitted to the data. The regression line is plotted in Fig. 5, and a positive linear dependency has been found between the SVF standard deviation and the street segment frequency. In fact, the null hypothesis on the regression line's coefficient equal to zero can be rejected through a t-test with a significance level of 1.6% and 3.8% for respectively February and September.

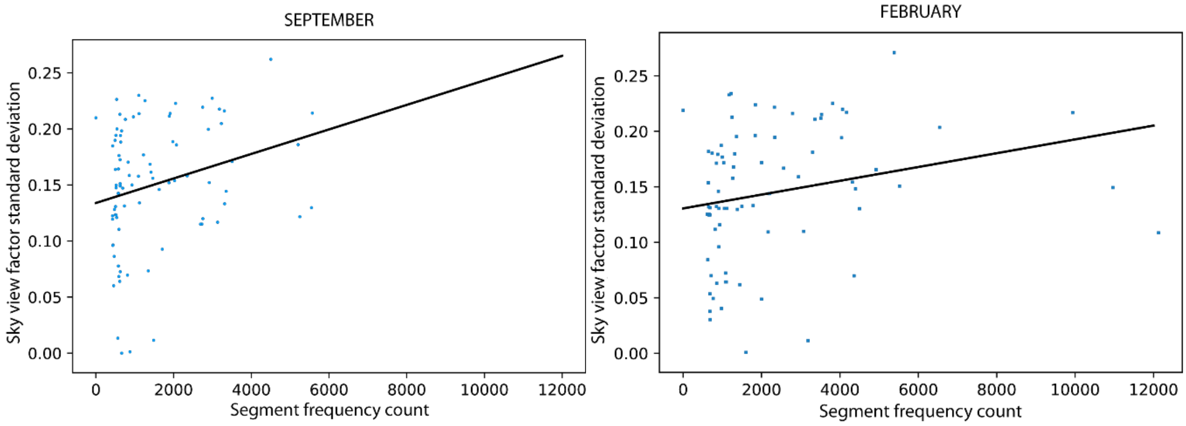

Fig. 5: SVF Standard deviation and street segment frequency

4. Conclusions

4.1. Outlook

The present study provides a global mapping that illustrates to which extent pedestrians respond to the variability of the urban environment. The correlation between the SVF and the frequency of pedestrian activity along a street segment shows strong relations between the variability of urban spaces and their attractiveness for pedestrian use.

This result can be associated to the concept of diversity of cities that Jane Jacobs (Jacobs, 1961) considered one of the most important indicators for urban vitality.

Furthermore, a higher variance of the SVF corresponds to a higher variability of the microclimatic conditions, producing frequent differences and variations in terms of outdoor comfort conditions: people preferably walk where the urban morphology determines variant microclimatic conditions. From a physiological point of view, sudden changes do not immediately provoke skin temperature shifts (Chokhachian et al., 2017b; Parkinson et al. 2012).

This tendency is valid under highly different climatic conditions, both for cold periods as well as for hot ones. The large number of trajectories and the urban scale allow considering this relation as an effective indicator for planners and policy makers with potentially extensive design implications.

For extensively representing the variance of the urban morphology, multiple additional layers, such as sidewalk area, population and building density, will be integrated to the model to support the assumption that variability in urban morphology generates more liveable urban environments.

4.2. Limitations

The first limitation of the study is given by the dataset characteristics, which might not represent a large population. Compared to similar studies that have been developed in the last decades, the sample includes a larger number of subjects: interview-based studies have usually been transversal with the number of subjects varying from 91 to 2700, some longitudinal studies were conducted with in between 8 and 36 subjects (Reinhart et al., 2017).

Besides this, the amount of trajectories varies every month, without any demonstrable reason. The data, that was made anonymous, do not allow discerning between fluctuating individual walking activity and irregular use of the activity-oriented mobile phone application. The different amount of trajectories could be related both to less application users as well as to less walking activity. Due to this reason, in the presented study trajectories frequencies were normalized.

Finally, the availability of the data from GSV images for gathering the SVF was not fully covering the entire area. The SVF information is available for a percentage between 74 and 85 of the analysed OSM street segments depending on the observed month.

However, this study focuses on the variability of microclimatic conditions and does not map the equivalent temperature for each time-stamp and location, as this process would be too time and resources intense.

4.3. Future work

To obtain more solid results, the missing months will be analysed following the outlined methodology.

In an upcoming phase, the results will be validated through different methods; in space, the outdoor comfort conditions will be mapped using the UTCI model. The most frequented segments will be included in a microclimatic model to verify the relevance of the SVF in terms of exposure to environmental factors, in particular how strong it influences the mean radiant temperature and its effects on the equivalent temperature. In time, the trajectories will be framed with a more detailed temporal distribution.

Scaling down to a higher resolution will allow evaluating each individual trajectory, and not limiting it to the most frequented street segments. This process will take also into account the thermal history of people and the path finding theories to more accurately describe sequences and the impact of variance.

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