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Mario Boffi et Matteo Colleoni

# Human behaviour and GIS

## Methodologies for analysing urban mobility in a GIS environment



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# *NOTE DE RECHERCHE*

## HUMAN BEHAVIOUR AND GIS: METHODOLOGIES FOR ANALYSING URBAN MOBILITY IN A GIS ENVIRONMENT

**BOFFI MARIO[1], COLLEONI MATTEO[2]**

***Résumé*** *– Jusqu'à aujourd'hui la mobilité urbaine était principalement mesurée à partir de méthodes classiques d'entretiens et de questionnaires auto-administrés. La complexité des déplacements intra-urbains n'a cessé d'augmenter et leur dimension stochastique est alimentée par une nouvelle conceptualisation de la mobilité qui émerge de plus en plus dans la littérature. Ces nouvelles approches nécessitent des données plus riches et permettant de prendre en compte le référentiel spatiale de l'environnement. Cette contribution propose d'explorer les méthodes et les outils les plus récents pour la collecte de données au sujet de la mobilité piétonne intra-urbaine en alliant géolocalisation et informations relatives aux activités. Ces données sont analysées dans un SIG (Système d'Information Géographique) pour identifier les patrons d'activités et construire des indicateurs spatiotemporels. La cartographie thématique et les modèles de densité seront proposés comme des méthodes pertinentes pour visualiser les comportements spatiaux des individus dans l'espace urbain. Les analyses s'appuient sur les données d'une enquête réalisée sur le campus de l'Université de Milan-Bicocca et stockées au SAMIT, le nouveau centre de recherche sur les données environnementales et spatiales.*

***Mots-clés –*** *mobilité intra-urbaine, GPS, SIG, comportement de déplacement, densité*

***Abstract*** *– Up to now urban mobility has been mainly measured by conventional methods and techniques, largely based on interview and self-administered survey questionnaires. The rising complexity of urban movements and their increasingly stochastic quality, compounded by new conceptualisations of mobility itself, powerfully emerging in the theoretical sociological literature, requires richer and more analytical data, and a more consistent analytical environment capable of*

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*managing the spatial dimension. The paper explores cutting-edge issues concerning methods and tools for data collection on pedestrian mobility by GPS, integrated with activity data, for the transformation of track-points into relevant time-space indicators as well as analysis of-mobility pattern inside a GIS (Geographical Information System) environment. Thematic mapping and density models will be proposed as relevant methods for visualising human behaviour in the urban space. Methodological issues will be supported by experimental data coming from a survey held in the University Campus of Milano-Bicocca and stored in SAMIT, the new research centre on spatial and environmental data.*

***Key words*** *- urban mobility, GPS, GIS, human behavior, density*

## INTRODUCTION: MICRO-MOBILITY AND URBAN MORPHOLOGY

One of the most relevant issue of the contemporary world is mobility. As the 2003 Mo.Ve document states "post-fordisation of territory, namely the inextricable link between changes in the workplace, home site developments and the type of mobility being developed in this new urban structure" makes mobility the force at the core of the urban dynamics (Martinotti 2003). In large metropolitan areas all that resulted in the growth of a-systematic, fragmented or "Brownian" mobility (Martinotti and Boffi 2002), particularly in periurban areas (Colleoni 2011). While the traditional 9-to-5 commuting was to a degree predictable, linking the home to a fairly identifiable number of large attractors or to production areas defined by "central-place" theories, the post-fordist mobility is not only greater, but also more random.

In particular micro-mobility continue to have a fundamental role in the contemporary metropolis. New information technology is indeed not able to substitute face-to-face communication and mobility is not, to any extent, replaced by communication: on the contrary, as for instance Wachs (2002) argues, "mobility of the new century will be strongly integrated with telecommunications and with informational flux, and mobility models are changing in this direction".

Boden and Molotch (1994) argue that face-to-face interaction, or co-presence, as they named it, is still important in modern life, and it is become maybe more vital than before; they claim also that the main reason for people to locate their activity in the same neighbourhood of the city and for urban re-concentration is the need for co-present interaction. Sassen (1991), dealing with the connections between local dimension and global context, underlines the importance of face-to-face interaction in exchanging information: the more global links are crucial for the life itself of a company, the more it needs informal, not-standardised information; and these kinds of information are available only through face-to-face interaction. On the other hand, Urry (2002) underlines the importance of mobility for proximity and co-presence and in general he emphasizes the significance mobility has in contemporary daily life. As he underlines "societies are build up of different socialites that necessitate often extensive form of mobility", therefore corporeal travel is essential for constituting social and economic life and is not an optional add-on. 'Meetingness', and thus

different forms and modes of travel, are central to much social life, a life involving strange combinations of increasing distance and intermittent co-presence (Urry 2003).

The micro-mobility, unless very important as a generator of proximity and thus of contacts, is often disregarded in the traditional analysis on mobility, and often it is neglected also in the literature about mobility. Most surveys point out that urban mobility is becoming increasingly complex and fragmented, compared to the traditional fordist household mobility. For instance the Nationwide Personal Transportation Survey showed (TRB 2013) that the chaining trips are increasing and they are becoming a key feature of the contemporary mobility; the chaining trips are trips constituted by small consequent segments of movements, aimed at different tasks; working hours are becoming flexible: public offices, shops, schools have opening and closing times more adaptable to people hours. Moreover, mobile communication is shaping new style of living and moving. As Gillespie (2003) has noted, "Digital ways of living then are inherently highly mobile, [as] virtual communications are merging with physical communications to create cyber-enhanced mobility; increasingly fluid and flexible, thanks to the complex forms of feed-back within the decentralised networks of individuals enabled by mobile technologies."

Fragmented mobility and the new forms of metropolitan mobility as driving forces that are reshaping the cities need to be studied in a much detailed way, requiring rich analytical data, not available through the traditional survey methods.

The paper will be divided in two parts: the first one dealing with methods for data collecting and building a relevant dataset of time–space indicators of micro-mobility in un urban context; the second one focusing on methods for transforming mobility data into time-space data, accounting for urban features, such as public spaces, calendar use of the urban space by different populations and location of the activity spaces. The methodologies proposed are envisaged as tools for mapping some of the new dimensions emerging from the contemporary urban form.

## 1. CAPTURING THE FRAGMENTED MOBILITY

Traditionally mobility has been studied using interviews, time-budget diaries and self-completion questionnaires. Although those tools are of great importance and they can be very useful for understanding the macro aspects of mobility, flows and general behaviours, they are poor instruments for capturing the micro and individual aspects of the mobility.

Several methods has been experimented to collect travel micro-data. The most common are personal interview, face-to-face or telephone interview, the self-completion questionnaire or diaries. Time-budget technique has been widely used for traditional survey on travel. National surveys on travel behaviour are conducted in several countries at regular rate (Marconi et al. 2004). For instance, the 2012 National Travel Survey (NTS) is the latest in a series of household surveys designed to provide a databank of personal travel information for Great Britain; The National Household Travel Survey (NHTS) is the nation's inventory of daily and long-distance travel in the U.S.A. The cited surveys include demographic characteristics of households, people,

vehicles, and detailed information on daily and longer-distance travel for all purposes by all modes. The negative outcomes of both surveys are the lack of spatial georeferencing or at least a poor geocoding, and secondly a limited data accuracy of time and scheduled activities.

The use of geocoding in travel surveys represents a major step which improves the quality of the captured data (Taylor et al. 1998) and it has been used since mid of the 1990s in several experimental surveys (Schönfelder 2003; Yang and Hillier 2007). Up to now, the major application of Global Positioning System (GPS) to the travel survey is the Lexington Study (Battelle 1997). The plan focused on an automated data collection device that incorporated self-reported information and GPS information for the collection of personal travel data. In addition, the respondents participated in a post-usage interview that mimicked the recall interview of the National Personal Transportation Survey (NPTS) and explored their attitudes about learning and using the automatic data collection device. The results indicate that the Lexington respondents took more trips of shorter distances than past national estimates would have suggested and the GPS data revealed more complex route choice decisions.

A key aspect of the analysis of micro-mobility concerns, thus, the collection of geocoded micro-data integrated with qualitative and relevant aspects, such as the purpose of the trip or the social relations connected. The above quoted surveys show that GPS is an essential tool for precise recording of geocoding data and for morphological description of mobility. On the other hand, the matching between the accurate collection of qualitative data and the tracking data is a weak point of the traditional surveys methods, based on CAPI mobility diaries.

The proposed methodology, experimented in other small urban context (Boffi 2008), includes the capability of integrating the space-time morphology of the individual moves, the geographical context, the socio-demographic profile of the people moving and the functional and social activities connected with and supporting the mobility.

## 2. THE MOBILITY INTERVIEW

In order to test the feasibility and the value of micro-data capturing by GPS integrated with qualitative observation and interviews, an experimental survey was performed in 2012, in the urban University campus of Milano-Bicocca, located at the northern border of the municipality of Milano, at the very core of the metropolitan area. The place is the result of a metropolitan urban renewal that took place quite recently, at the end of the 90s. The former industrial area has been transformed into a knowledge city: the University Campus of Milano-Bicocca, a national theatre, a mall, private housing and research centres, i.e. the National Research Council, headquarters of financial and high-tech companies such as Siemens Company, Deutsche Bank, Pirelli. The scientific, cultural and research nature of the area generates an incoming flow of about 30.000 people while the residential population is about 2.000 people. The place is linked with the metropolitan area and the central city by regional railroad

lines and by several transit lines. The area is a site suitable for such an experimental survey principally because of the spatial compactness and the lattice-like urban structure, together with the social mix of the city-users (students, blue and white collars, professors, shoppers and so forth). The research was held as part of the educational activities within the Faculty of Sociology, as part of the Program of Urban Space and Environment, and the interviewers were recruited among students.

### 2.1 The research design

The research was held in the year 2012, in the area of the Bicocca Campus, by 'shadowing' a sample of people on move, recording the trip with GPS and collecting several qualitative information - personal and travel related - by an application program working in conjunction with the GPS receiver on a tablet PC.
On what concerns the calendar of the interviewing, the research took place in four different days during three time ranges, each two hours long, in the morning, in the afternoon and in the evening, making it possible to observe the changes of mobility during three key periods of the day.

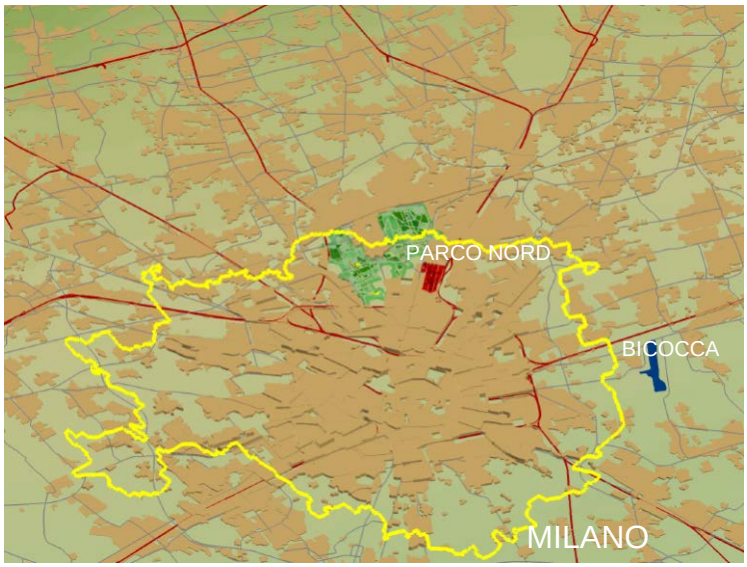


***Figure 1:*** *Overview of the Northern Milan Area – perspective view of the Parco Nord and the Bicocca area*

The respondents were chosen randomly among the pedestrian city-users inside the area of Bicocca, at four main places - the train station, the bus stop, the university entry, the main square. The mobility interviewing came to an end when the respondent had reached the final destination or the borders of the area. The total number of mobility interviews summed up to one hundred.

A second part of the experimental design concerned also a few people – i.e. a student, a baby sitter, a dog-sitter, an elder person, a sportsman and a biker – as

samples of the users of the large urban park – Parco Nord - located at North-West of Bicocca area and connected by a biking lane to the University Campus.

Mobility micro-data were collected using an application of Esri-ArcPad, working on a Tablet PC, which was managing, by a GPS receiver, the automatic collection of mobility track point in real time, at regular time interval of 30 second for the interviews in the area of Bicocca and of 1 second in the Parco Nord area. An extension of the main application was adapted for the surveying of purposes and activities occurring during the movement, automatically matching the tracking points. The spatial analysis were performed using Esri-ArcView v.9.2.

### 2.2 The mobility interview

A first set of personal data was collected at the very starting of the interview, in order to fill the socio-demographic profile of the people interviewed: gender, age, condition, place of residence, mode of transportation, reasons of the presence, place of final destination, weekly average travel to the Bicocca area.

Afterward the proper mobility interview had started, automatically registering time-space track points, and for each section of mobility, defined according to the declaration of the respondent and identified by a given purpose, a number of variables were set. The first ones, regarding the purpose of the trip, were directly questioned and geo-time-referenced, while the other ones resulted from a direct observation by the interviewer, collected 'just in time' by the GPS.

### 2.3 The micro-mobility dataset

The following table shows an abstract of the dataset containing the tracks and a selection of the attributes: each GIS object is located in the space according to the spatial coordinate system and the time; special events, such as an 'inadvertent meeting' are marking some points, while some other points are defining the purpose movement.

| OBJ ID | SHAPE | ID Track | LAT | LON | ALT | UTC(**) DATE | UTC(**) TIME | SOG (*) | Inadv. Meeting | Purpose |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Point ZM | B02 | 45.5184 | 9.2105 | 216 | 10/12/2012 | 093029 | 0.0 | | |
| 20 | Point ZM | B02 | 45.5185 | 9.2104 | 217 | 10/12/2012 | 093100 | 0.0 | | |
| 21 | Point ZM | B02 | 45.5185 | 9.2102 | 218 | 10/12/2012 | 093131 | 0.7 | | |
| 22 | Point ZM | B02 | 45.5186 | 9.2101 | 218 | 10/12/2012 | 093202 | 3.1 | | |
| 23 | Point ZM | B02 | 45.5179 | 9.2093 | 217 | 10/12/2012 | 093233 | 4.2 | | |
| 24 | Point ZM | B02 | 45.5180 | 9.2089 | 217 | 10/12/2012 | 093304 | 4.0 | .. | |
| 25 | Point ZM | B02 | 45.5181 | 9.2088 | 217 | 10/12/2012 | 093335 | 0.0 | .. | Work University |
| | | | | | | | | | | |
| 60 | Point ZM | B04 | 45.514 | 9.2112 | 243 | 10/12/2012 | 120653 | 4.9 | | |
| 61 | Point ZM | B04 | 45.5134 | 9.2115 | 232 | 10/12/2012 | 120724 | 0.0 | | . |
| 62 | Point ZM | B04 | 45.5134 | 9.2116 | 242 | 10/12/2012 | 120755 | 0.7 | meeting | Work University |
| | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 64 | Point ZM | B05 | 45.5181 | 9.2140 | 243 | 10/12/2012 | 121743 | 0.0 | | |
| 65 | Point ZM | B05 | 45.5178 | 9.2141 | 235 | 10/12/2012 | 121814 | 4.9 | | |
| 66 | Point ZM | B05 | 45.5174 | 9.2142 | 228 | 10/12/2012 | 121845 | 4.3 | | |
| 67 | Point ZM | B05 | 45.5172 | 9.2142 | 228 | 10/12/2012 | 121916 | 4.2 | | |

***Table 1:*** *Sample table of track-point collected by travel interview*
*(*) Speed Over Ground km/h*
*(**) Coordinated Universal Time*

A joining between the previous table and the table containing the personal attributes of the 'mobile respondents' (not shown in the table), gave a personal identity to each track point. Moreover, the track points were aggregated and transformed into polylines, according to the common belonging to each 'short trip'.
The dataset transformed in such a way is offering relevant data on the mobility behaviour: individual mobility, precisely located in time-space, purposes of the mobility itself, personal profile of the people moving, way and mode of the mobility – i.e. pace, by foot or by a vehicle – and spatial context embedding the mobile activities.
Some examples of exploratory analysis based on the dataset are shown in figures 2-3-4.

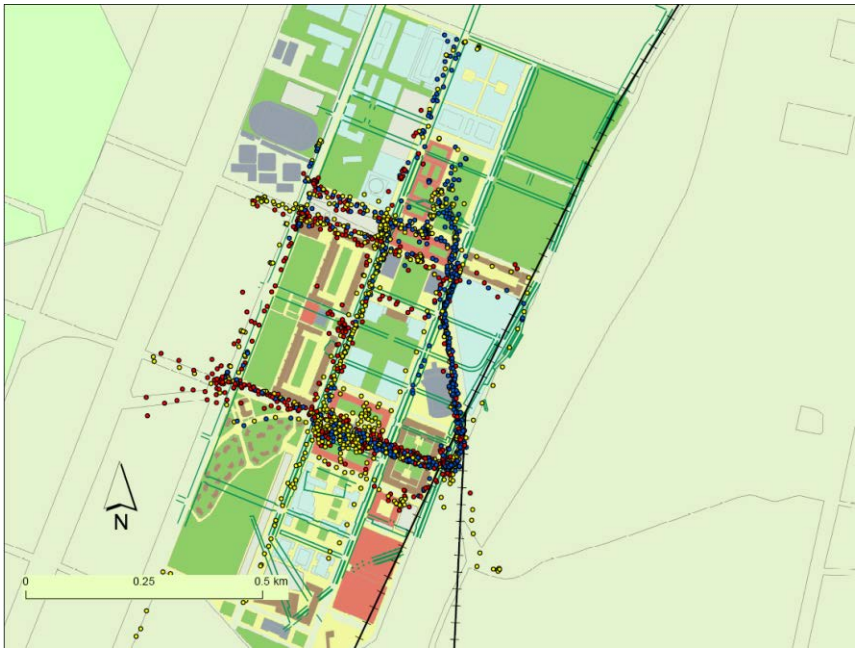


***Figure 2:*** *Track-points of the general mobility in the Bicocca area.*
*The figure gives an intuitive view of the mobility in the area.*
*Red points are tracks in the morning time; Yellow around lunchtime; blue in the evening.*
*The blocks in Red are University Buildings.*

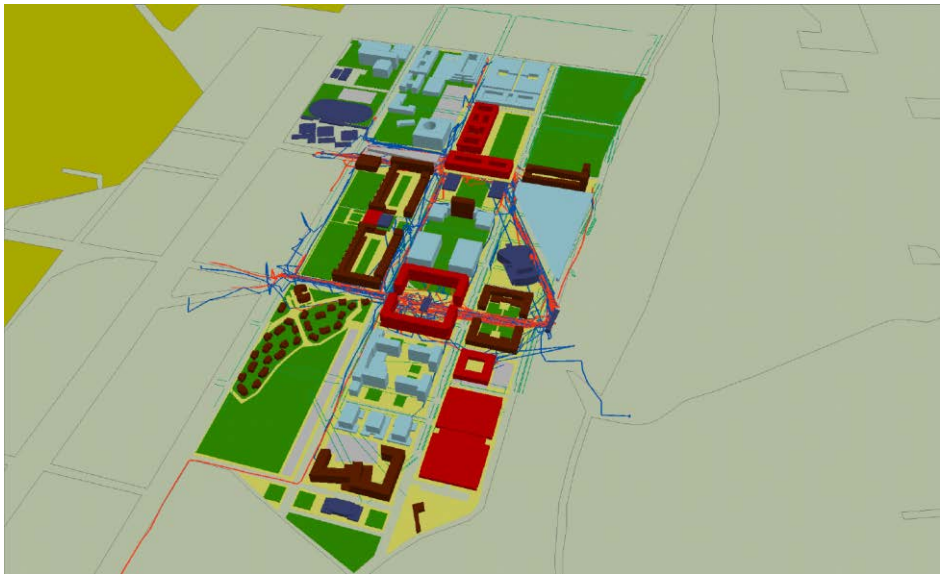

***Figure 3:*** *Track-lines in the Bicocca area according to the sociological profiles of moving people – in Red color the Students, in Blue other people.*

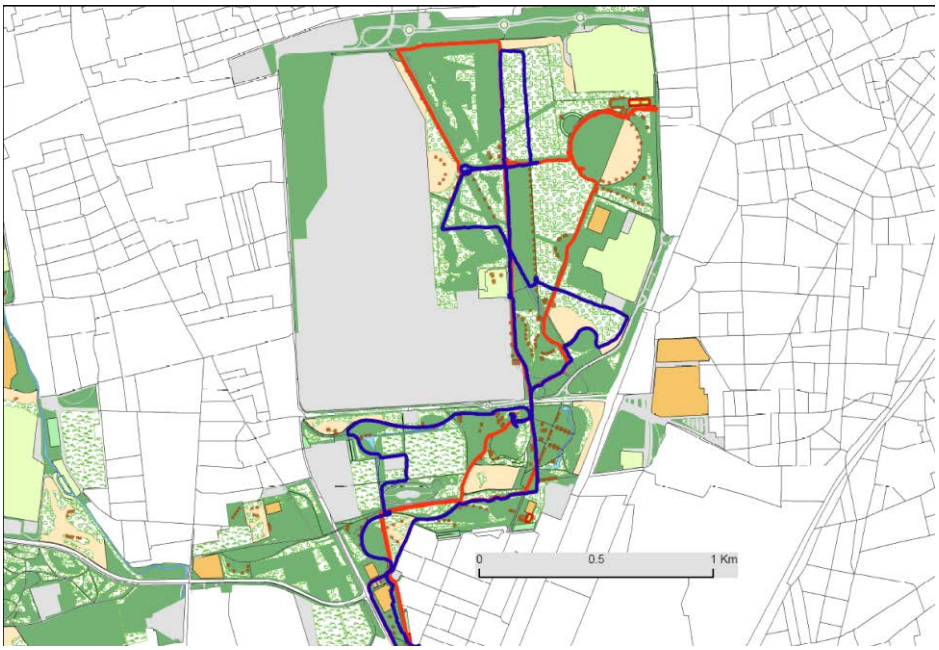


***Figure 4:*** *Track-lines of selected users of the Parco Nord, embedded in the spatial infrastructure for the leisure. In Red a Biker, in Blue a Sportsman.*

## 3 THE SPATIAL ANALYSIS

The spatial analysis tools offer a wide range of transformation over the micro-mobility dataset in order to focus on several relevant urban issues. In particular, density surface models can make visible public spaces, emerging as 'hot spots'3 produced by high density in time and space of mobility tracks (figure 5).

The map was based on an indicator of space consuming, i.e. the number of track points, aggregated according to the statistical model known as KDE (Kernel Density Estimation) (Boffi 2004, de Smith *et al.* 2006; Boffi, Colleoni and Lipari 2012). The model provide an informative tool for hot spot identification analysis by rendering the density of Gaussian circular spaces drawn over the track points; the resulting grid can be interpreted as a map of different level of the social space consuming, where the highest density zones indicate public space.

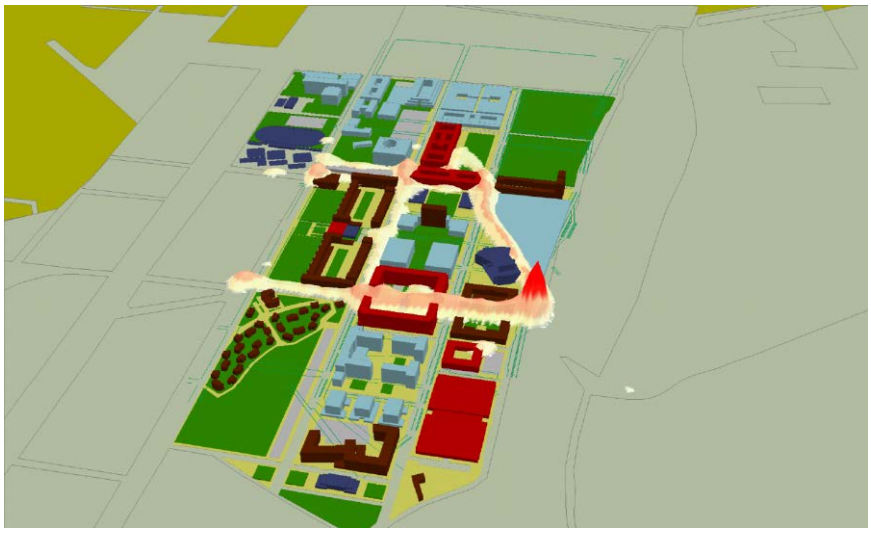

***Figure 5:*** *The public spaces. In dark Red the railway Station; the two hot spots in the western area are located in a dense area of services – drinking and eating places, bookstore.*

A second example of analysis on the mobility dataset concerns the calendar of the urban spaces. In the Figure 6a and 6b are shown the contouring of the hot spots of mobility during the day, in the morning and in the evening, providing a twofold map of the public spaces in the Bicocca area, according to the mobility profile in two different day periods. The map was built selecting, at a time, track points belonging respectively to morning and evening trips; with a similar method it could easily be built a comparative map of public spaces generated by different populations, e.g. students and inhabitants.

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[3] The term was introduced in the scientific literature in the course of the CrimeStat project, supported by the National Institute of Justice of the U.S.A. (Eck et al. 2005)

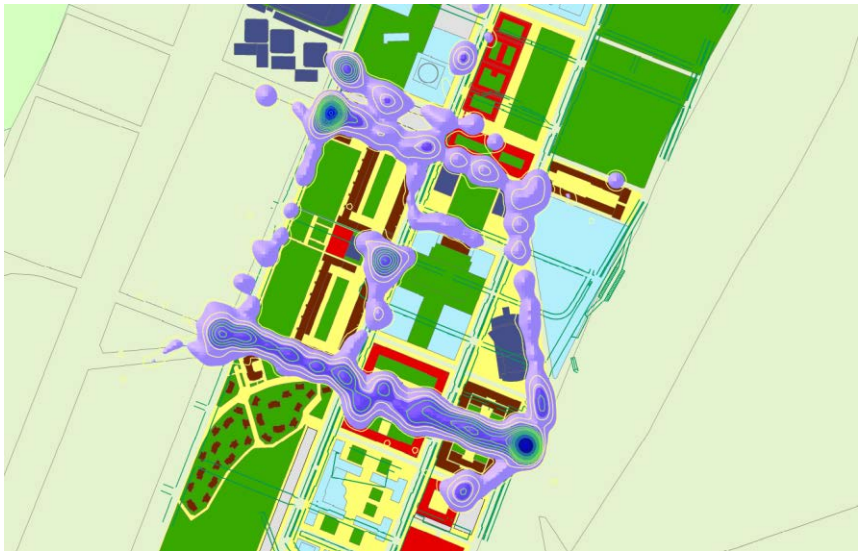

***Figure 6a:*** *The calendar of public spaces in the Bicocca area – The morning mobility*

***Figure 6b:*** *The calendar of public spaces in the Bicocca area – The evening mobility*

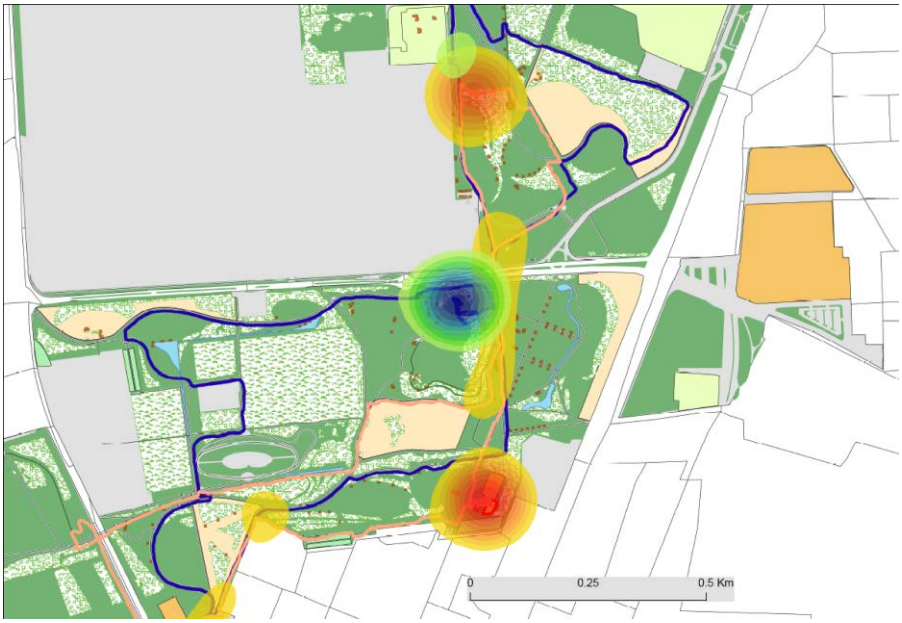


***Figure 7:*** *Space activities and the infrastructural context in the Parco Nord*

The Figure 7 is profiling individual lists of activities by a Sportsman – in Blue and Green- and a Baby-sitter – in Pink and Red - being evaluated on the background of the leisure infrastructure of the park. The Blue areas, i.e. the density clusters of track points of the Sportsman, resulted located in the specialized sporting areas, whereas the Red areas, - the Baby- sitter space clusters, are partly located out of the reserved baby areas. The map illustrate both the confirmation process by the Sportsman of the official use of the sporting areas, while the Baby-sitter is redefining the social use of the space, conflicting with the official rationale; in a very simplified way, the map may mark a general process either of reconfirmation or of redefinition of the space use by the urban populations.

## CONCLUSIONS

The previous examples of spatial analysis focused on the public spaces could give an idea of the rich empirical observations that can be derived from an analytical dataset of individual micro-mobility. In fact the dataset make it possible to evaluate the mobility behaviour embedded into the urban context, to build an urban map as result of social activities, and to analyze the impact of the urban environment on the people mobility. The methodology is grounded on new technologies of mobile localization, such as GPS, on a developing set of management tools of spatial data, such as the geo-database, and a set of statistical methods for the spatial analysis.

What it seems to be needed yet is a set of protocols for designing general surveys and generating relevant dataset of micro-mobility, and the capacity to develop,

by using the rich analytical tools mainly produced in the physical environmental sciences, a new line of empirical studies on the urban issues. According to that perspective, the newly created Research Center for the Spatial Analysis and Environmental Data (SAMIT) at the University of Milano-Bicocca, is holding as main activity a program for experimenting survey methods and developing a GIS-GPS archive oriented to the analysis of the urban mobility.

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