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Mapping the changing city trough mobile phone data

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Moving from recent research on the analysis of mobile phone network data for urban studies in the Milan urban region, the paper will focus on how it is possible to map and visualize the changing city by means of this new source of information, characterized by a high temporal and spatial resolution.
The paper will compare several representations of urban dynamics in Milan Urban Region, obtained through both conventional data sources and mobile phone data, for discussing about the potential of this approach in providing a new insight on spatial and temporal patterns of the city. These spatial-temporal patterns are difficult to intercept through traditional data, used in urban studies. In particular, the scale of the observed phenomena, the time-dependent variation in urban spaces usages, the capability of describing and mapping recent changes, the need of new form of representations of the city are some of the topics that will be addressed in the discussion.

Keywords: mobile phone data, representation of the city, spatial patterns

Introduction

In recent years, several research projects are focused on the potentiality of mobile phone traffic data as promising sources for the analysis, visualization and interpretation of people's presence

and movements in urban spaces, by a high temporal and spatial resolution.
Interdisciplinary studies in the fields of urban geography, social studies, computing and interaction design, recognize anonymous and passive monitoring telephone traffic as a valuable alternative to traditional methods, because it can simultaneously overcome the limitations of the detection latency time typical of traditional data sources and take advantage of the pervasiveness of the detection area due to the ubiquity of mobile phones networks. The technology for determining the geographic location of cell phones and other hand-held devices, becoming increasingly available, has opened the way to a wide range of applications, collectively referred to as Location Based Services (LBS), that are primarily aimed at individual users. Among the three main types[1] of survey methodologies, the researches focused on the analysis of aggregated mobile phone data are characterized by two different profiles and purposes: mapping mobile phone activity in urban contexts (Ratti, C., Pulselli, R. M., Williams, S. and Frenchman, D., 2006; Sevtsuk, A. and Ratti, C., 2010), and visualizing urban metabolism (Wolman, A., 1965; Acebillo, J., Martinelli A., 2012; Brunner, P. H., 2007).

The first approach, named Mobile landscape approach, focuses on the relationships between mobile phone measures and people's daily activities in cities (Ratti, C., Pulselli, R. M., Williams, S. and Frenchman, D., 2006; Sevtsuk, A. and Ratti, C., 2010). The aim is to understand patterns of daily life in the city, using a variety of sensing systems (mobile phone traffic intensity, location-based data as GPS devices, wireless sensor network) and to illustrate and to confirm the significant differences in the distribution of urban activities at different hours, days and weeks. Graphic representations of the intensity of urban activities and their evolution through space and time, based on the geographical mapping of mobile phone usage at different times of the day (Ratti, C., Pulselli, R. M., Williams, S. and Frenchman, D., 2006) are the main output of the Mobile Landscape approach.

The approach based on handsets' movements studies the relationships between location coordinates of mobile phones and the social identification of the people carrying them (as Social Positioning Method and its possible applications in the organization and planning of public life proposed by Rein Ahas and Ülar Mark) (Ahas, R., Mark, Ü., 2005). In this direction an interesting issue regards the classification of urban spaces according to their users' practices and behaviors in the use of cell phones (Soto and Frias-Martinez, 2011). In *Robust land use characterization of urban landscapes using cell data* (Soto and Frias-Martinez, 2011b), the authors outline the fact that city areas are generally not characterized by just one specific use, and for this reason they introduce the use of c-means, a fuzzy unsupervised clustering technique for land use classification, which returns for each area a certain grade of membership to each class.

Even if, from a technical point of view[2], both the aforementioned approaches are based on the analysis of aggregated data and traffic volume detected on towers network, the loss of the traces of the origins and destinations of individual movements does not appear relevant for estimate the distribution patterns of the population in different time slots considered for the survey.

Using mobile phones for monitoring urban practices, both approaches show that phone calls are closely related to population density in urban areas (Ratti, C., Pulselli, R. M., Williams, S. and

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[1] The three main types of survey methodology are:

- Individual traces detected with tracking technologies (such as GPS);
- Anonymized Individual trajectories collected by mobile phone carriers;
- Georeferenced and aggregated cell phone activity data.

[2] Among the methods proposed in literature, we mention the social positioning method (SPM) of Positium LBS (Ahas and Mark, 2005; Ahas et al., 2010) based on active and passive positioning systems, and mobile census (MIT Senseable City Lab) which is instead a totally passive tracking system.

Frenchman, D., 2006; Sevtsuk, A. and Ratti, C., 2010; Ahas, R., Mark, Ü., 2005; Reades, J., Calabrese, F., Sevtsuk, A. and Ratti, C., 2007), even if additional evidence is needed to show how mobile network signals can be used to characterize and map different urban domains and their occupants and how this tool could support urban planning and urban policies.

In this general framework, our research is focused on how it is possible to map and visualize the changing city by means of this new source of information, characterized by a high temporal and spatial resolution. Our aim is to compare several representations of urban dynamics in Milan Urban Region, obtained through conventional data sources and mobile phone data, in order to discuss the potential of this approach in providing a new insight on spatial and temporal patterns of the city.

The aim is to question the heuristic potential of the maps arising from mobile phone data to represent spatial-temporal patterns of contemporary cities, that are difficult to intercept through traditional data.

An example of a representation of urban dynamics in the Milan Urban Region obtained through conventional data source[3] is presented in figure 1.

updateable to the present days nor extendable to other areas, because it is based on the 2002 survey data, available only for Lombardy and which have never been updated. Other sources, eventually available, are characterized by coarser spatial and temporal granularity and, above all, they are inadequate to describe new forms of mobility.

The map represents the density of all unsystematic movements, other than study and work, which occur in the Milan urban region on a typical 2002 working day. These unsystematic flows are related to individual habits and are the effects of diversified and complex uses of the Milan urban region.

Despite the fact that information on density of movements has been derived from data at the municipality scale, its representation varies in a continuous way across the urbanized territory. This representation is typically used for visualizing environmental and meteorological phenomena.

The result is a new representation of the Milan urban region, a fluid image where the administrative boundaries disappear but where the territorial structure is clearly visible. In the map the high density of unsystematic movements is visible, along the Milan ring roads and in the Central Brianza (Northern Milan urban region), which is an area where many shopping centers are located; the same process can be observed along the Sempione Road and in commercial and business polarities in the South. The map highlights the mobility for personal reasons, for shopping and leisure, that is more and more relevant in daily mobility practices. Unfortunately it is not updateable to the present days nor extendable to other areas, because it is based on the 2002 survey data, available only for Lombardy and which have never been updated. Other sources, eventually available, are characterized by coarser spatial and temporal granularity and, above all, they are inadequate to describe new forms of mobility.

Table 1 compares the available sources on mobility in Lombardy. We can briefly outline some elements explaining their principal pros and cons: mobile phone data have, at least in urban areas, superior spatial resolution than conventional surveys, permitting to obtain finer visualization of mobility practices and to generate customized regions of analysis;

[3] In 2002, the Lombardy Region realized a survey (Indagine OD Regione Lombardia) on mobility based on more than 750.000 interviews. This survey provides data on all mobility flows for the whole Lombardy region during 24 h of a typical working day.

- The temporal resolution of mobile phone data is very high; it allows to monitor in time different practices at an hourly, daily or seasonal basis;
- Mobile phone data lack of information regarding the means of transport used. It is therefore possible to derive only indirect indications about the traffic on main roads, by means of interpretation of derived maps;
- Conventional surveys are expensive and it is possible to guess that, when informations derived by mobile phone data will be available on the market, their cost will be relatively low, being them already collected by providers both for accounting and for network monitoring.

Figure 1: *Density of unsystematic mobility: number of trips per square km in 2002. Source: DiAP elaboration on the OD Regione Lombardia 2002 data.*

Other informations regarding mobility in the region are available (see e.g. fig. 2) but they regard more specifically vehicular traffic along main roads. These data have fine grained temporal resolution but they are not able to represent individual mobility. Moreover they pertain only to main roads. The opacity of traditional data sources (available in aggregated form and not inscribed in a topological space) for reading the transformations of users' practices and mobility patterns is a problem if we have to know the practical use of the city and the different forms of mobility (in terms of quantity and quality) in their articulation in time and in space. This information represents a necessary condition to manage and govern urban transformations, and transport supply too.

	Survey on mobility (OD) Lombardia Region 2002	Census (on commuting) ISTAT 2001	Mobile phone data
Sample	750K interviews	All residents	Mobile phone users ~1.5M per day
Type of movement	All	Study and work	All
Reference Period	"Typical" working day of 2002 (one Wednesday)	One working day of October 2001	Every day
Updates	No	Census 2011 (results not yet available)	Continuous
Information on vehicle	Yes	Yes	No
Spatial resolution	Municipalities, aggregation of minor municipal districts, subdivision of major municipalities	Municipalities	Variable aggregation of cells
Temporal resolution	24 hrs	7am-10 am	Hourly or subhourly
Cost	Expensive	Very expensive	Not known

Table 1: *Comparing available sources on mobility in Lombardy*

Figure 2: *Real time traffic map on Italian highways (www.autostrade.it) (left) and real time traffic map on major roads in Milan (maps.google.it) (right).*

New maps for the Milan Urban Region through mobile phone data

In this framework, an interesting contribution aimed at describing the different densities and times of use of the city that traditional sources of analysis are unable to return with continuity, may come from mobile phone network data. Starting from the results of a research carried out in Lombardy Region, using mobile phone data provided by Telecom Italia [10], we intend to explore how new maps, based on unconventional data sources and better tailored to the dynamic

processes in place, can represent spatialized urban practices and can give new insights for improving the effectiveness of urban policies.
In order to analyze the complex temporal and spatial patterns emerging from mobile phone data we used two different types of data. The first data type concerns the mobile phone traffic registered by the network over the whole Milan urban region (Northern Italy).
Data are expressed in Erlang, namely the average number of concurrent contacts in a time unit, and they are spatially distributed over a grid with squared cells of 250 meters for every 15-minute time interval. We performed time series analysis on this data along a period of 14 days in September 2009, in order to evaluate specific characteristics of population behaviors at an hourly and daily base. We then applied a novel geo-statistical unsupervised learning technique aimed at identifying useful information on hidden patterns of mobile phone use. We will show that these hidden patterns regard different usages of the city in time and in space and that they are related to the mobility of individuals. The results return new maps of the region, each describing the intensity of one of the identified mobility pattern on the territory. This highlights, in our opinion, the potentials of this data for urban planning and transport research studies.
The second typology of data consists in localized and aggregated tracks of anonymized mobile phone users. The data set was collected in different working days (five Wednesday in July, August, September, October and November 2012). In this case the available information was based on the geolocation of users' mobile phone activity in time and in space. With mobile phone activity we intend each interaction of the device with the mobile phone network (i.e. calls received or made, SMSs sent or received, internet connections, etc..). This information was available at the level of the antenna which handled the activity. The distribution of antennas in the space depends on the amounts of mobile phone traffic that needs to be managed. In dense urban areas we therefore observe a high density of antennas while in the suburbs the density of antenna may be very low. From this capillar information (which is not directly accessible for privacy policy constraints) the extracted data, available to us, consisted in hourly time series of Origin Destination matrices returning the number of users flowed at each hour of a day from an origin to a destination zone. The zones of origin destination were determined as tiles of different tessellations. We defined and considered for this study a tessellation related to the density of antennas, consisting of 526 zones.
With localized and aggregated tracks of anonymized mobile phone users we put in evidence the main hourly distribution of origin – destination movements of a huge sample of people (more than one million per day). Our goal was to display prevalent fluxes of mobility at different hour of a typical working day through a visualization of the sum vector moving from each zone. The sum vector is the single vector resulting from the sum of all the single connections between each zone and the others and is characterized by two dimensions: the magnitude, which is function of the magnitudes of the original vectors and the angle which expresses the direction of the flux. The sum vectors have been finally applied to each zone of the fine-grained tessellation.
A set of maps of the sum vector moving from each zone at different hours has been produced in order to highlight the main patterns of mobility during a typical working day (interactive map available at www.ladec.polimi.it/maps/od/fluxes.html).
The morning map (9pm; fig 3) confirm a polarization of movements towards the main centers offering job opportunities and highlights also the most commonly used infrastructures. On the other hand, the aggregated flows of mobile phone users in the afternoon allow to recognize significant places for shopping and leisure, that are attended after work.
Cell phone data have potential to produce maps, with temporal continuity throughout the day, describing the movements carried out for both work and personal reasons. Informations derived

from the continuous mapping of flows represent an important basis to build policies for the provisioning of more effective public transport services. In this sense we can consider the map in fig. 4 (left): it represents the areas for which the flows towards Milan are more regular, varying the days. This provides considerable indications with respect to the effective catchment area of Milan, to which regulation measures and appropriate rates of the public transport service should correspond. If we compare the left and right maps in fig. 4, we can easily notice the disconnection between fixed jurisdictions and mobile factors (**Estebe, P.,** 2008).
The comparison of fig. 4 (left) with fig. 5, which maps only the work travels with traditional data sources (Istat 2001), clearly shows the inconsistency of the boundaries, especially in the North, due not only to the temporal distance of the reference data (2012 vs 2001), but also to the information available with the data sources (daily mobility vs work-travel).
In the Milan Urban Region "only" the 56% are one-way job or study-related travels; while the mobility for personal reasons, for shopping and leisure, increases.

Further analysis focused on the correlation between the intensity of telephone calls at certain times of the day with the spatial configuration of residents and workers in the Milan urban region. The outcomes showed that telephone traffic data could effectively help to represent and to describe, dynamically over time, the intensity of activities and the presence of temporary populations at the urban scale.
A statistical processing (spatial clustering) of the Erlang data, aimed at extrapolate the recursive trends over the period considered (**Manfredini, F.; Pucci, P.; Secchi, P.; Tagliolato, P.; Vantini, S.; Vitelli, V.,** 2012), has allowed us to build maps on the spatial distribution of the intensity of mobile phone traffic and the amenities of the area (presence of infrastructures, services and different activities). The results return new time-varying maps of the Milan Urban Region. At the same time, they allow to place in space some different "communities of practices" that use, with different temporality and purposes, the urban spaces.
Describing the trends of use of the urban spaces, the maps of mobile phone data give important information for mobility policies: the lack of coincidence between the mobility practices in the peak hours in the morning and in the afternoon when the chains of displacements are very articulate and complex, allows to recognize not only the variability in mobility practices, but also the places where these practices are occurring.
The commuters between 8 am and 9 am, become city users between 5 pm and 7 pm. This phenomenon strictly affects land use and can pose new questions and indications for transport policy. The variability in the space-time of use of urban spaces resulting by mobile phone data is also revealed by:

- the spaces of daily mobility during working days (morning and evening rush hour, fig. 6, left, right resp.);
- the spaces of night leisure that define a geography of places densely crowded at Saturday night (fig. 7, left), that is quite different from the territories of night work during the week (Monday to Friday night) (fig. 7, right);
- the shopping and leisure spaces during the weekend (between 10 am and 8 pm) show the inner city center of Milan and the western part of the city, but not the commercial malls along the ring roads that they won't seem to have a very remarkable weight in the Saturday practices (fig. 8).

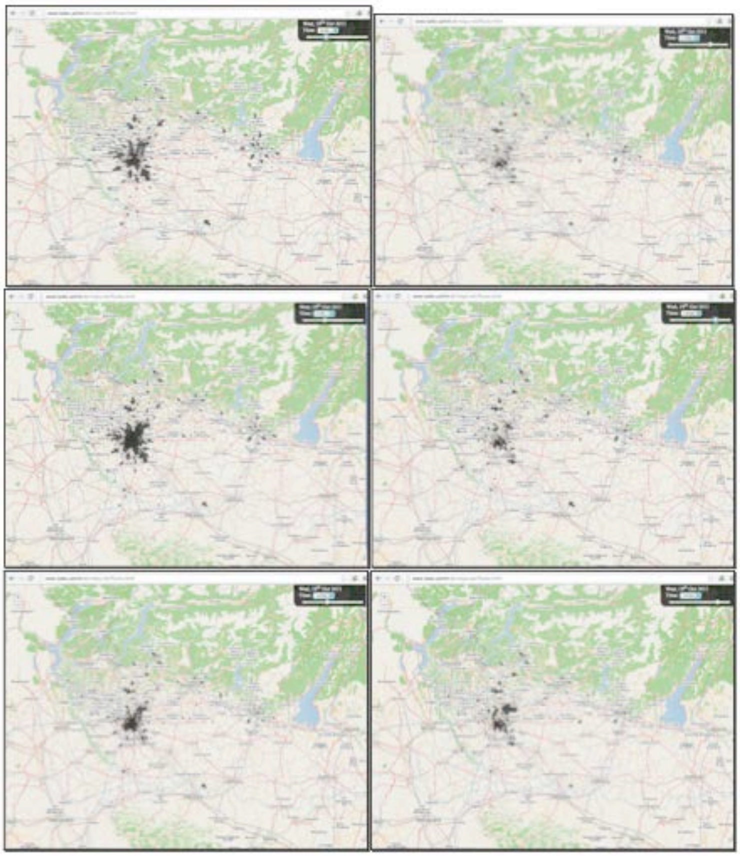

Figure 3: *Aggregated flows of mobile phone users: 2011-10-19 – 9:00-11:00 am (left, from top to bottom), 5:00-7:00pm (right, from top to bottom)*

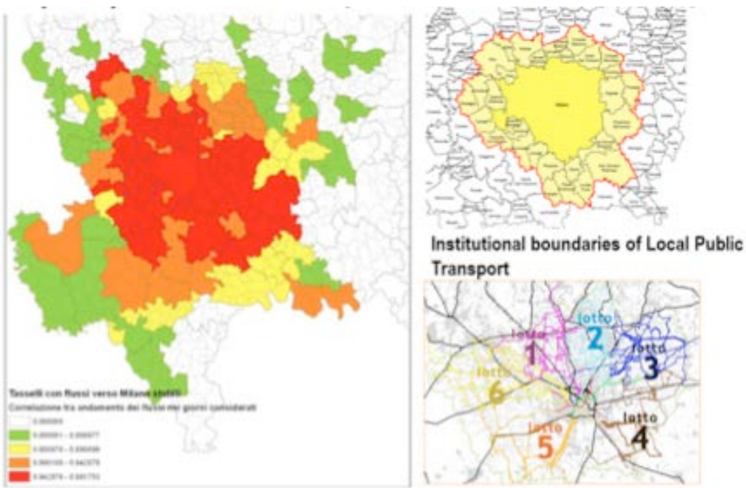

Figure 4: *Daily mobility Milan sphere of influence obtained by mobile phone data (left) and institutional boundaries for the management of Local public transport (right)*

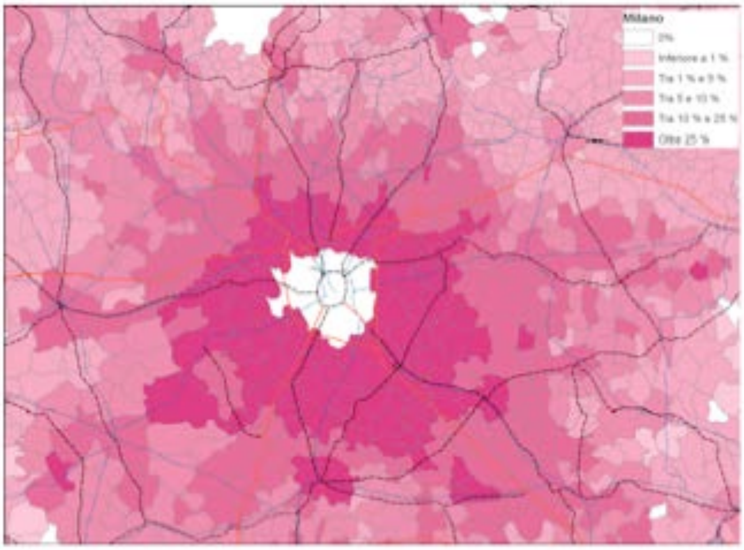

Figure 5: *Daily work travels Milan sphere of influence obtained by Istat data (2001)*

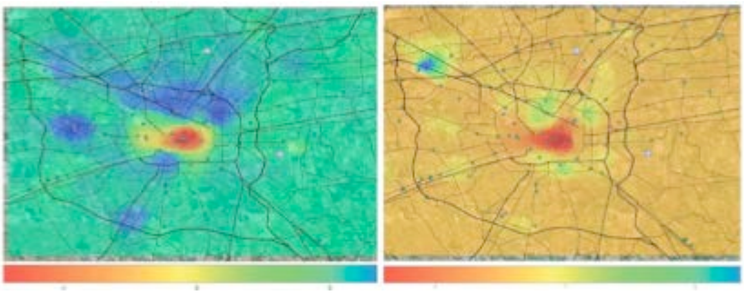

Figure 6: Daily mobility spaces :morning map (left), evening map (right). Source: MOX/DiAP on Telecom Italia data

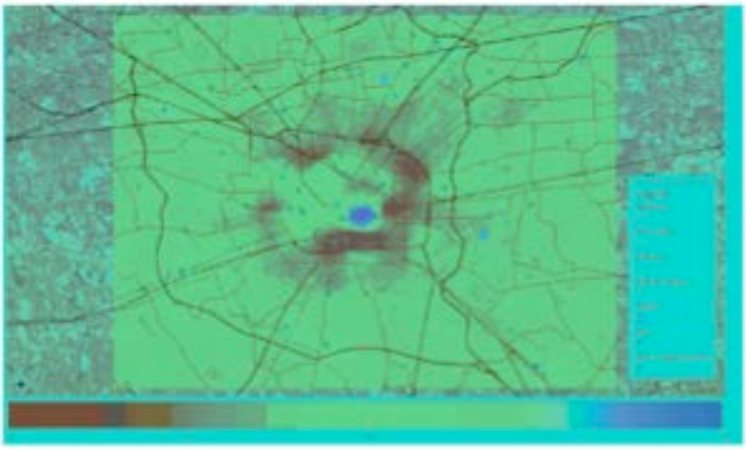

Figure 7: Night life spaces (left) and night work spaces (right). Source: MOX/DiAP on Telecom Italia Data

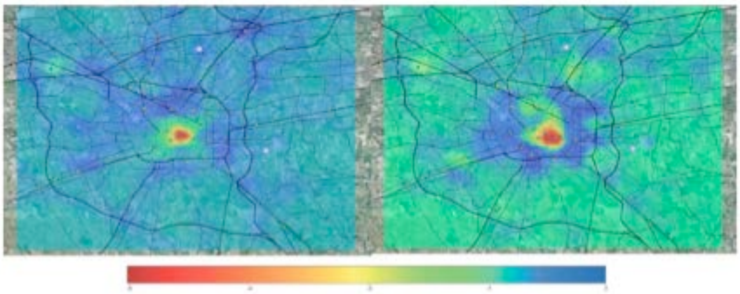

Figure 8: *Shopping and leisure spaces (Saturday, 10 am – 8 pm). Source: MOX/DiAP on Telecom Italia data*

Final remarks

The production of maps through mobile data and other digital sources, in many cases exceeds the real capacity of them to provide information useful for the urban policies. Often, the maps seem to have a value in itself, rather than representing a tool for reading and interpreting processes.
The ease in the production of the maps by mobile phone data, but more generally by digital sources, offers a lot of views and animations whose communicative potential is clear, much less are the uses of these maps to describe and represent urban practices.
Our research allowed us to test the potential of mobile phone data in explaining relevant urban usage and mobility patterns at the Milan urban region scale and in understanding the dynamic of temporary populations, two important topics that can be hardly intercepted through traditional data sources.
The presented data and methodology let the recognition of effective mobile populations in the urban environment. This knowledge can be exploited by decision makers for the definition of specific policies directed to temporary populations, which are more and more important in contemporary cities, otherwise ignored.
The same data help us to question some interpretations in the literature on the erratic behaviors of metropolitan populations, on the nomadism that characterizes the contemporary practices, that surveys on mobile phone data have already undertaken (**Gonzalez, M. C., Hidalgo, C. A. and Barabási, A.-L.,** 2008). Some research about a significant sample of mobile phone data have, in fact, contested interpretations of nomadism of contemporary populations.
If they confirm the high density of commuting, they also show the strong recursion of the paths. In other words we move more during the day, but according to the known and usual paths. Far from an analytical determinism that allows to photograph the reality of the practices in the urban spaces with mobile phone sources, our preliminary reflections want to explore the potentialities of these new data source, beyond the production of suggestive maps. More specifically, we have tried to understand the possible applications of these data in explaining the spatial dimension of varying practices that have great impacts on the densities of use of the city and its services.
This implies to consider the phone traffic data as the effect of behaviors and individual habits that become an indirect information on the characteristics of the territory and, somehow, an intrinsic feature of it, that changes in time. This study therefore suggests that mobile phone-network data have the potential to drastically change the way we view and understand the urban environment. Secondly, it explores whether mobile network data can reveal the significant time- dependent variation, which is missing from traditional analysis and can thus describe cities dynamically over time.
A further conclusion is that urban planning competences, with specific knowledge on urban dynamics, are needed to correctly interpret mobile phone data and to characterize and map urban contexts and their occupants, as emerged from interviews with different stakeholders, belonging to private and public sectors, with

which also future applications have been discussed (event management, civil protection, mobility monitoring, urban rhythms analysis and mapping).

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