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The Special Issue collects six papers that use mobile phone data and spatial analysis techniques to study new urban critical features and social phenomena that arose with the Covid-19 pandemic. The applications of mobile phone data in the three study contexts investigated the potentialities of mobile phone data, as well as their limits. Compared to traditional methods of urban survey mobile phone data provide real-time maps of daily practices.

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Special Issue 2.2022

Mobile phone data for exploring spatio-temporal transformations in contemporary territories

print ISSN 1970-9889 e-ISSN 1970-9870
University of Naples Federico II

TeMA Journal of
Land Use, Mobility and Environment

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Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

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Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | online ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

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TeMA Journal of Land Use, Mobility and Environment

Special Issue 2.2022

MOBILE PHONE DATA FOR EXPLORING SPATIO-TEMPORAL TRANSFORMATIONS IN CONTEMPORARY

Contents

TeMA Journal of Land Use, Mobility and Environment

TeMA Special Issue 2 (2022) 9-23
print ISSN 1970-9889, e-ISSN 1970-9870
DOI: 10.6092/1970-9870/8892
Received 10th January 2022, Accepted 11th November 2022, Available online 30th November 2022

www.tema.unina.it

Mobile phone traffic data for territorial research

Opportunities and challenges for urban sensing and territorial fragilities analysis

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Abstract
Mobile phone tracking data collected by telecommunication companies allow recording and reconstructing the practices of mobilities and the presence of users with significant spatial-temporal detail. If properly managed, analysed, and possibly combined with other sources of information, mobile phone data can represent an interesting opportunity for urban research and mobility studies as they shed light on complex socio-territorial dynamics difficult to infer from conventional data analysis. At the same time, reports of numerous experiments using these sources reveal some of the challenges that researchers face in accurately capturing the behaviours of individuals through digital data and translating them into useful research knowledge. Referring both to the direct experience of managing and analysing mobile phone data within the Department of Architecture and Urban Studies of the Politecnico di Milano and to the relevant literature, the paper proposes an overview of the potentialities and limitations of telephone data for urban research and their usability in different territorial contexts characterised by varying socio-spatial and demographic conditions. Besides positioning themselves within and enriching an already lively debate, the issues discussed here will be useful in reading the contributions of the special section that this paper introduces.

Keywords
Mobile phone data; Urban studies; Territorial research; Territorial fragilities.

How to cite item in APA format
Manfredini, F., Lanza, G. & Curci, F. (2023). Mobile phone traffic data for territorial research. *Tema. Journal of Land Use, Mobility and Environment*, 9-23. http://dx.doi.org/10.6092/1970-9870/8892

1. Introduction

For some years, scientific research has been experimenting with digitally generated data, so-called *big data*, to analyze complex phenomena difficult to detect using more conventional "small" data-based methodologies. These experiments have been particularly significant in the disciplinary fields of urban and territorial studies, mainly due to the versatility of these data and the information they carry about the temporal and spatial evolution of citizens' behaviors and ways of interacting with urban spaces and services. The sensing opportunities offered by the collection and analysis of these data have been exploited both for research purposes and in daily urban management, giving way to the concept of *smart city*, i.e., a city in which the big data produced by information and communication technologies (ICT), in conjunction with social capital and broader policies, contribute to leverage a potentially more sustainable growth and urban development (Caragliu et al. 2009; Papa et al., 2013; Kitchin, 2014a; Papa et al., 2016).

Remaining in the field of urban studies, one of the most promising sources to explore the dynamic mobility practices, human presence, and uses of a territory, its spaces, and its activities, is represented by mobile phone location data collected by telecommunication companies. If properly managed and analysed, mobile phone data can shed light on complex socio-territorial phenomena challenging to infer solely by relying on traditional methodologies typically used in urban and mobility research, such as census data analysis and travel and activity surveys, which suffer from structural limits linked to their low frequency of updating. To this limit is added the fact that census and travel patterns data, at least in the Italian case, describe behaviours, socio-economic, and demographic conditions that concern specific populations (e.g., students and workers in the case of travel surveys) or consider only the inhabitants officially registered in the administrative areas of data collection. Thus, they may overlook phenomena such as multiresidentiality, leisure-related use of the territory, and emerging forms of remote working/learning that are becoming increasingly relevant for research and local policies, especially following the outbreak of the Covid-19 pandemic. Digital data, particularly when sourced from mobile phones, open up new opportunities for the enrichment of more traditional methodologies for territorial analysis thanks to the breadth of collection samples, penetration of the technologies from which they are sourced, and the ability to describe different phenomena without many of the sampling biases of official statistics.

At the same time, reports of numerous experiments using these sources available in the literature reveal some of the challenges that researchers face in accurately capturing the behaviors of individuals through digital data and translating them into helpful research knowledge.

To meet these challenges and test the research opportunities related to the use of mobile phone data, the Department of Architecture and Urban Studies (DAStU) at Politecnico di Milano has conducted several experiments within the framework of the research project on "territorial fragilities" (DAStU-TF project)[1], aimed at investigating specific territorial phenomena overlooked by official statistics and their emergence and evolution since the outbreak of the Covid-19 pandemic. The research works that have developed from this interest, inspired by different research questions and resorting to multiple methodologies of analysis, are the subject of the special issues to which this article acts as an introduction. The paper aims to provide an overview of the DAStU-TF project and the case studies analyzed, framing this experience within the broader research on mobile phone data for urban research and their usability in different territorial contexts.

Thus, the paper opens with a review of the literature (section 2) to define a theoretical framework of reference focusing on the challenges and opportunities of mobile phone data for socio-spatial analysis and planning.

[1] Over the five-year period spanning 2018-2022, the Department of Architecture and Urban Studies has been funded by the Italian Ministry of University and Research ("Departments of Excellence" initiative) to explore the many and complex processes of fragilization in the space-society relationship in terms of exposure to different risk factors: environmental, social, economic, political and institutional.

This review offers some critical insights that explain why focusing on this type of data is relevant to the research on urban phenomena and territorial fragilities conducted within the DAStU-TF project. At the same time, the review pointed out some challenges that, in many cases, precede the definition of specific research questions to be answered through data-driven approaches. In fact, the process of acquiring and managing big digital data is by itself significantly complex and has represented, in the case of the DAStU experimentation, a major challenge answered by building negotiation channels with data providers and adapting research questions to the specific characteristics of the available data. The description of this process, presented in section 3, sheds light on the phases of data acquisition and preparation propaedeutic for the subsequent case study analysis, which research questions and objectives are introduced in section 4. Conclusive remarks close the paper.

As a consequence, each of the mobile phone data-based research experiences conducted in the framework of the DAStU-TF project, introduced in this article and subsequently deepened by the individual papers composing the special issue, moves from an awareness of the opportunities and limitations of mobile phone data to respond to specific research questions in a plurality of territorial contexts characterized by different social and spatial dynamics. In this way, the research provides an original framework for the analysis of urban phenomena that are often hidden or difficult to read, besides positioning itself within and enriching an already lively debate on the role of digital data for research and urban planning purposes.

2. Opportunities and challenges of mobile phone traffic data for territorial research

Thanks to the development and the widespread diffusion of information and communication technologies (ICT), contemporary cities produce an increasing amount of digital "big" data, which unprecedented availability allows researchers and planners to unveil previously hidden dynamics and phenomena. Digitally produced massive, dynamic, varied, detailed, inter-related, low-cost datasets can be exploited to discover and analyse the behaviours, choices, needs, and desires of large samples of individuals on extended time frames (Kitchin, 2014 a,b; Rabari et al. 2015; Hilbert, 2016) and, through correlation, to hypothesize the cause-effect relationships binding them. Moreover, the collection and analysis of this information, which can be aggregated at different temporal and spatial scales, let researchers recognize complex patterns of social interaction and their continuous evolution (Bibri, 2018; Birkin, 2019) in a way that can deeply innovate both the methodologies of urban research and the design, implementation, and evaluation of public policies (Concilio & Pucci, 2021).

Since the early 2000s, many experiments have been conducted to test big-data-based analysis' potential and identify limitations and obstacles to their use in research and policymaking, aspects closely related to the source from which the data are obtained and the algorithms that are used to make it operable. Widely used in such experimentations are the so-called *sensor-generated data* (Thakuriah et al., 2017), passively and automatically collected from personal devices, as in the case of mobile phone data and GPS tracking, or through other monitoring systems often used by public administrations for the management of public services, such as traffic sensors, cameras, or smart cards for public transport. Sensor-generated and other types of big digital data are often subject to hybridization and fusion with data obtained from different sources at different times and for different purposes to produce new information that may not be found by analysing a single data type. As a result, the ability to manage different datasets at the same time by combining those produced by new technologies (*big data*) with others obtained from consolidated techniques such as census and surveys (defined, not by chance, *small data* by Kitchin 2014b), allows obtaining a potential completer and more dynamic picture of what happens in cities and territories.

Most of the experimentations of urban analysis through sensor-generated data available in the literature and implemented by research institutions and public administrations in collaboration with specific data owners, such as transport authorities or telecommunication providers, focus on mobile phone data collection and

analysis. Globally widespread with an extremely high penetration rate, both in developed and developing countries, mobile phones are personal devices that accompany the user throughout the day. For this reason, they are particularly promising in tracking individuals' spatial and temporal activities. When connected to antennas that support the cellular network, mobile phones produce MPR (mobile phone record), timestamped data on users' location, which telephone companies actively or passively collect for billing purposes (Ahas et al., 2010a; Urbanek, 2019). In addition to MPRs, which have been extensively applied in mobility-related research, other kinds of data are produced by the interaction between users and mobile devices, as in the case of positioning data based on GNSS (Global Navigation Satellite System) collected by web-based applications installed on smartphones to offer personalized services to users (Paffumi et al., 2018). Besides, data generated by mobile phones may include data collected through Bluetooth or wi-fi sniffing operations in urban environments (Hasan et al., 2014, Gorrini et al., 2021) and data extracted from the analysis of social media networks (Gadzinski et al., 2018). However, most of the experiences found in the literature use MPRs or, in more recent research, web-based apps.

MPRs are widely experimented with both for research purposes and possible applications in the design of urban policies, particularly in the field of mobility and transport. Indeed, MPRs are structured as chains of location anchor points in which the positioning of a single user is referred to the nearest telephone antenna and collected at even very short time intervals (Ahas et al., 2010b). Measurements are based on large samples of mobile users over geographical areas of flexible extent: being produced following the interaction with the antennas of the mobile network, the data produced can describe patterns of static presence around the single antenna (local scale) and record the mobility behavior of users on larger spatial scales based on subsequent interactions with multiple antennas of the network. This tracking process can also be related to specific spatial areas of interest through resampling algorithms (e.g., administrative boundaries, census tracts). A good density of antennas at the spatial level is thus an essential requirement for reliable tracking (Williams et al., 2015) of everyday life patterns at the individual level – although raw data are generally aggregated for privacy concerns – based on mobility practices and the variation of human presences in different temporalities (Calabrese et al., 2013; Blondel et al., 2015; Jiang et al., 2016), including associating such patterns with the distribution of spatial activities and characteristics of land use (Tu et al., 2017; Ni et al., 2018), transportation systems (Chen et al., 2016), and socio-demographic conditions of users and their interactions with space and other people (Ahas et al., 2010a, 2010b ; Picornell et al., 2015).

Many examples can be found in the literature concerning experiences of the practical application of the opportunities of mobile phone data, especially in recording people's travel patterns and the activities in which they participate by performing the tracked displacements. In the first case, reference is made to the so-defined *trip-based analysis* (Jiang et al., 2016), which involves the application of techniques based on timestamped locations of users to construct origin/destinations (O/D) matrices based on trajectories between positions where users were registered in specific time intervals inferring modal choices and travel times (Chen et al., 2016). More advanced and complex applications concern *activity-based analyses* (ibid.), aimed at recording at different scales and with different levels of aggregation (from the individual to larger populations) the daily area of movement and the activities performed in the anchor locations of measurement (Jarv et al., 2014a, 2014b; Jiang et al., 2016; Bassolas et al., 2019). Different methods can be applied to derive activities. They can be based on time and frequency, thus relying on user presence in prevalent locations at specific time intervals (Alexander et al., 2015), for instance, by considering residential locations as the anchor points in which a person is usually registered during nighttime and working locations as the places visited during the day. Other methods are based on the application of specific models that link the characteristics of the land use surrounding the measurement location using predefined empirical rules (Chen et al., 2016), such as the attractiveness of local points of interest, hourly availability, length of stay, and accessibility to the activity from different origins (Garcia Albertos et al., 2019). The activity-based approach, even if complex to be

implemented, can be helpful in revealing travel behaviors and their relationship with land use characteristics and defining possible correlations with socio-economic conditions when information on user profiling is collected by the telecommunication provider and associated with the data.

The mentioned experiences show how mobile phone data constitute a particularly useful source of information for measuring mobility behaviors, but also the dynamic modes and temporalities of use of a territory and its activities by mobile phone users. The latter group represents a substantial part of the population with a decreasing bias of socio-demographic representativeness thanks to the increasing penetration of ICT technologies in all socio-economic and demographic groups (Deloitte, 2019) and to the development of algorithms allowing extending the tracked sample to larger population based on the market shares of telecommunication providers. For this reason, MPRs are potentially relevant not only in the field of mobility-related planning, policy and research but also promising in a multi-sectoral perspective straddling transportation studies and policy, urban planning, and regional economics by revealing diversified and often unobservable human behaviors in space.

To this extent, at least three aspects make MPRs a source worth relying on for urban and territorial planning and research that distinguish these sources of information from traditionally employed small data in the same fields.

The first aspect concerns the possibility allowed by mobile phone data (and, in general, by other types of big data) of *observing phenomena not recorded by official statistics* (La Rocca, 2014). Compared to conventional census data and travel surveys available in the Italian case, which are generally concerned with recording the characteristics and behaviors of the residents registered in the specific administrative areas of collection, mobile phone data track the activities of users who interact with the telephone network. Consequently, MPRs allow analyzing both the presence of residents, domiciled populations, and territory users not officially counted at the statistical level, unveiling the magnitude of phenomena such as multiresidentiality and temporary presence in specific locations for work, study, or leisure-related reasons or during specific events. This information can be promising in inferring human presence and uses of a territory and its activities that is more adherent to reality, overcoming the limitations of an administrative bias in the collection of socio-demographic information.

The second concerns the opportunities for *user profiling*. In addition to users' location, telecommunication companies collect limited information on the socio-demographic and economic characteristics of all the users interacting with the network (Calabrese et al., 2010), thus allowing the investigation of certain characteristics of resident and non-resident populations by associating behaviors and choices in space and time with specific socio-economic and demographic profiles. In the case of mobility and travel analysis, this means that a limitation inherent in the census-based travel survey (especially in the Italian case) is overcome by broadening the responding sample – not just limiting it to the systematic commuting-related displacements performed by students or workers – and by increasing the possibility of correlation with other conditions recorded by the same digital data.

The third aspect concerns the *temporal granularity and frequency* of updating of mobile phone databases. Unlike census data, which are updated infrequently (e.g., annually, or even every ten years, as in the case of the Italian mobility surveys up to 2011), mobile phone data are collected continuously and at short intervals. Consequently, they can, firstly, record the evolution of specific trends on an hourly or semi-hourly basis. Secondly, they are sensitive to sudden or temporary changes with a level of detail that is unreachable by conventional small data. In this sense, MPRs can be usefully employed to record the effect of specific events circumscribed in time and space (e.g., public events), as well as unexpected sudden changes (e.g., related to the outbreak of the Covid-19 pandemic). This type of information is very relevant not only for urban research but also for the management of public events and states of emergency.

However, it is worth noting that relying on MPR-collected data for research purposes raises important epistemological and operational issues.

From the first point of view, many authors have discussed how big data collected through mobile phones and other sources, whose objectivity may be challenged by the fact that their use requires processing through algorithms that mediate between the observed reality and possible interpretations by the researcher (Kwan, 2016), could subvert the very foundations of the scientific research process. This perspective founds on the idea that big data could support a new paradigm based on data-intensive research and exploration, establishing empiricism based on the observation of datasets and their possible correlations in the search for new problems otherwise unobservable, without therefore needing to base the research on theory. Kitchin (2014a), however, argues that the development of a data-driven science is more likely, in which digital data will support research and analysis of known problems. According to this perspective, the theory will remain a substantial element in the process since not all phenomena can be measured through data analysis (McNeely et al., 2014), and the found cause-effect correlations still need to be verified (Rabari et al., 2015). Therefore, it is interesting to consider what has been argued by Kitchin (2014c), according to which digital data will have different impacts depending on the field of research in which they are employed and will express their value if used in combination with already consolidated research techniques. According to Lazer et al. (2014), and as demonstrated by the approach followed by the research developed under the DAStU-TF project, more than a big data revolution, we are facing an *all data* revolution in which, despite the limitations and challenges described in this paragraph, the availability of digital data will create new opportunities to know the world through a more in-depth and precise analysis of its phenomena.

From an operational perspective, mobile phone data is subject to some critical aspects related to digital innovation, such as data ownership, privacy, and dependence on data and technology providers (Calzada, 2018; Kazmi et al., 2018) which can make accessing this data complex and expensive for research. In addition, mobile phone data have analytical limitations related primarily to the degree of accuracy of the measurements that depends on the potentially uneven spatial density and distribution of the antennas in different study contexts and the fact that raw data must be processed through complex algorithms to translate the recorded tracks in punctual locations (Chen et al., 2014; Alexander et al., 2015; Semanjski et al., 2016). Moreover, the reliability of the information may be influenced by the unequal penetration of technologies, which can lead to biased survey samples (Calabrese et al., 2013) and may produce inaccurate insights (Hasan et al., 2014). Also, if used to infer users' modal choices and activity patterns, the statistical error at the individual level is likely to be particularly significant (Chen et al., 2014). Other known issues are the scarce information they provide on users' socio-demographic characteristics and the limited potential to infer non-commuting activities (for instance, after-work or leisure activities) that travellers participate in (Jestico et al., 2016). As a consequence, and to overcome these limitations, numerous experiments put in place specific strategies of hybridisation between different types of data aimed at better interpreting users' behaviour and relating them to land use, transport-related and socio-economic characteristics of the context of analysis, for example, by combining data from MPRs with traditional small data from census and identify potential relationships between user activity spaces and the socio-economic status of the places they usually frequent (Calabrese et al., 2013; Jarv et al., 2014a).

Therefore, it seems necessary for researchers to develop the proper ability to understand what information mobile phone data can provide compared to or in combination with other data and what are the inherent limitations to its use; build negotiation processes with private data providers and owners to acquire high-quality, reliable data; manage and analyse data establishing interdisciplinary research teams that can address the complex challenge of extracting value and insights. As described in the next section of the article, these challenges were addressed by the DAStU-TF project in the preliminary management of data provider relationships and subsequent data preparation operations. These steps are essential to carry out big data-

driven research because the choice of the type of data and its preparation affect the definition of research questions and objectives, orienting them according to the potential and limitations of the data itself.

3. Mobile phone data as a component of the DAStU project on "Fragile Territories"

Within this general context, the DAStU developed a complex and ambitious research program aimed at testing the potential of mobile phone data for urban research in the field of *territorial fragilities*, which is the research theme that DAStU embodies within the "Departments of Excellence" initiative (2018-2022) launched and funded by the Ministry of University and Research (MIUR). This ministerial action rewards departments with high-quality research and funds their development projects on specific themes. In this perspective, the DAStU aims to become an essential node of an international network of researchers and institutions that work on the various declinations of socio-spatial fragility. The ultimate goal is to set up a transdisciplinary competence center on "fragile territories" that can become a permanent point of reference both for the academic and non-academic realm and among all the institutional, professional, and social actors involved in "anti-fragile" policies and projects. The issue of *fragility* has led many researchers of the DAStU to explore different territories, from the most urban to the most rural, to interpret their variegated weaknesses and, in particular, all the forms of risk and uncertainty that characterize their present condition. The concept of fragility is linked to radical uncertainty (Chiffi & Curci, 2021), and the Covid-19 pandemic has increased the general interest in this issue.
The resources mobilized by the project have been an opportunity to start a discussion within the Department on the ongoing research and on the possibility of acquiring innovative data to enrich the empirical analysis of the Italian territories. Through the skills of the Mapping and Urban Data Lab (MAUD)[2] of the DAStU, which has long been engaged in research on mobile phone data, the scientific direction of the project has oriented the choice towards mobile phone tracking data to extend their use also to research groups that had not yet tested their potential.
As explained in section 2, mobile phone data were chosen due to the specific analytical opportunities compared to conventional data sources. What was particularly relevant for the purposes of the DAStU-TF project was having access to mobile phone data characterized by high spatial resolution and available for different Italian contexts. In addition, a high temporal resolution was required to ensure the availability of information for a continuous period from 2019 to 2020 on a sub-hourly basis to detect from yearly to daily trends.
Therefore, a preliminary step concerned the identification of a provider capable of delivering adequate mobile phone data for different Italian contexts characterized by specific conditions of territorial fragility. The issue required engaging with private data owners among Italian telecommunication companies to select the most suitable provider according to the mentioned criteria. This first phase ended with the selection of the TIM company[3].
The negotiation process between the DAStU research team and TIM had two major challenges. Firstly, the definition of suitable research questions according to the availability and features of the data (XXXX in this special issue). Secondly, the implementation of procedures for managing, cleaning, and tailoring the data for the research teams. This time-consuming process was necessary to uncover the main issues related to the collaboration between academia and a private company characterized by specific economic, technological, and data accessibility constraints. For example, the initial interest of the research teams in analyzing the data even

[2] The Mapping and Urban Data Lab – MAUD is an experimental laboratory that focuses scientific, technical and methodological skills on the analysis, on the mapping and on the visualization for urban and regional studies.

[3] TIM is an Italian telecommunications company. Founded as a mobile telephony company in 1995, since 2015 it has become a brand that provides mobile, fixed telephony, and Internet services. TIM customers in Italy were 30.5 million (September 2021).

at a very high level of spatial detail was redefined during the process due to the available data resolution only at the municipal level for most territorial case studies.

Other technical requirements concerned the possibility of accessing the data through an online service and the opportunity to customize the spatial units of analysis to acquire patterns of mobile phone activity in different spatial contexts. An agreement was made with TIM, which already had a specific program named "City Forecast" available for public administrations: through a web platform, TIM allows visualizing and downloading raw data on human presence and mobility practices (at the municipal or sub-municipal scale, the latter being available also for major cities) at a very high temporal resolution (15 minutes). To have access to this already implemented infrastructure for research purpose, a specific arrangement has been made with TIM for the provision of several datasets accessible through the proprietary web platform named Data Visual Insight (DVI), falling in the following geographical categories:

a) The municipality of Milan, chosen considering the observatory role played by DAStU as a research actor in the geographical area of belonging;
b) Other single Italian municipalities with around 100.000 inhabitants;
c) Multiple contiguous Italian municipalities which aggregate around 100.000 inhabitants.

The selection of the research areas required a phase of internal presentation and discussion inside the Department about the characteristics of mobile phone data available, also to prompt interest about the possibility to experiment with the use of mobile phone data among those who were already researching territorial fragilities. An internal call open to different research groups was launched which led to the selection of several research ideas based on their relevance to the DAStU-TF project, the type of application proposed, and the ability of the groups to conduct research with a significant level of complexity due to the amount of data to be managed and analysed. Eight different research groups participated in the call of interest and proposed a research activity based on the analysis of TIM mobile phone data. Some of the proposals were developed in the framework of the territorial fragility project. Others were directly related to the ongoing research activities of Ph.D. students or research fellows. The variety of proposals made by the groups that participated in the call demonstrates, as described in section 2, how mobile phone data can offer multiple insights for urban and spatial research. Among the proposed topics it is worth mentioning the following research themes that were suggested: community behaviours in the Milan city parks before and during the pandemic; mobility in Milan and its relationship with the heat islands affecting the city; human presence and activity participation in marginal territories; seasonality of human presences in Apulian informal coastal settlements; mobility practices in a low-density mountain area in Emilia-Romagna; mobility of younger students around selected high schools within the metropolitan area of Milan; mobility of older people in some selected municipalities in northern Italy regions.

The MAUD Lab managed the call and the dialogue with the research groups to evaluate the feasibility of the proposal concerning the available data, their scale, reliability, and the actual capability of the different groups to carry out data-driven research, which is characterized by the need for strong analytical and methodological skills. At the end of the selection process, in addition to the case study of Milan on which several proposals have converged, two other territorial cases study have been selected, covering different research issues and experimenting with different possibilities offered by the data as will be described in the following paragraph and deeply depicted in the papers of the special issue.

Following this preliminary phase for the selection of a data provider and the territorial contexts of analysis, an uninterrupted dialogue has been opened with TIM to define the requisites of the data needed for the research (time interval, spatial resolution), the testing of the spatial platform and finally the opening of the access to the data itself through the DVI platform.

Date	Activity
September 2018	First contact with TIM
July 2019	TIM Commercial proposal
July 2019	Acceptance of proposal and start of administrative procedures
April 2020	Presentation to DAStU of the data available and of the DVI platform
June 2020	DAStU call for project proposals
July 2020	Opening of the DVI platform and data access
September 2020	DAStU research teams constitution and starting of the research activities
March 2021	Seminar at DAStU on research progress
October 2021	Closing of DVI platform
October 2022	Tema Journal Special Issue

Tab.1 Timeline of the project

4. Research questions and their applications to three specific Italian contexts

The data acquisition process lasted over two years when the world faced the first phase of the Covid-19 emergency, a condition that was not foreseeable when the decision was made to acquire these data, but it turned out to be an opportunity to compare urban phenomena occurring in the absence of restrictions with other months in which a series of measures have severely limited the mobility of people for work, study or leisure (lockdown, closure of schools, massive use of remote working to cite some). The analysis and comparison of people's behaviors and their relationship with land use make it possible to determine the response of territories to the pandemic concerning daily, weekly, or seasonal mobility practices.

The works of research presented in the following chapters are aimed to test whether and to what extent the mobile phone traffic data allow detailed interpretations of complex urban phenomena related to the different dimensions of territorial fragilities otherwise challenging to study with conventional data sources. Among these, we can also mention the spatial effects of the pandemic on urban behaviors influencing changes in the timing of the cities' use, the rhythms of daily commuting, the impact of remote working and learning, and the multi-residentiality practices. The pandemic has therefore reoriented the research proposals, which, however, already intended to evaluate the specificities of the territories concerning a series of relevant urban phenomena. In particular, the possibility to use and process mobile phone data in three selected Italian contexts proposed by DAStU researchers and characterized by different socio-territorial conditions, settlement density, and mobility practices (Milan, the Piacenza Apennines, Lecce and its coast) allowed us to test their potentialities as well their limitations, investigating the following issues:

- The changes in the attractiveness of Milan's neighbourhoods during the Covid-19 pandemic;
- The analysis of remote working and remote learning practices on sparsely populated, marginal, and low-connected territories (Piacenza Apennines) and near-home tourism before and during the pandemic;
- The seasonality of use in the coastal areas in the municipality of the city of Lecce, characterized by the presence of second homes, mainly unauthorized.

Therefore, the three research works seek to answer complex questions for which no conventional data exists, being them scarcely updated or unavailable. Thus, mobile phone data have been tested to evaluate their potential in covering emergent issues in urban studies related to the time variation patterns of presence during the pandemic in a major Italian city (Milan), the variability in the use of coastal areas during summer months, and the mobility practices in low-density marginal mountain areas. These three study cases cover situations that represent territorial trends occurring in Italy, both in cities and in "inner" peripheral contexts. At the same

time, their relevance is expressed by the possibility of extending the methodology of analysis and the main outcomes to other contexts.
Mobile phone data were then specifically exploited to highlight their potential for urban studies and to contribute to a discussion on the value of a data-driven approach for a new research agenda while dealing with significant challenges related to the role of big data in urban research and their integration with conventional data, the ability of these data to bring out temporal and spatial behaviours difficult to intercept through conventional data, the relevance of these data for urban and mobility policies even in fragile territories. Within this general framework, the three research works that are deepened in the papers composing this special issue are relevant in that they attempt to answer these challenges.

4.1 Human presence and mobility patterns in urban contexts

In highly urbanized contexts, mobile phone data have been widely used to analyze and map large events, highlighting the overall attractivity of cities for visitors and tourists. In the current research, the focus was on exploring the potential of these data in describing human mobility patterns and evaluating the different temporal behaviors connected to the presence of urban populations in Milan.
These data also make it possible to characterize the amount of presence in space and in time based on specific categories of TIM users (gender, class age, type of contract) and based on their personal behaviors (commuters, inhabitants, visitors, and tourists) as will be explained in the next paper.
The idea was to use these data for the analysis of the variation of human presences within the different neighborhoods of Milan during a long period (16 months), including four months in 2019, the total lockdown period during the first phase of Covid -19 pandemic and two more months of partial activity reopening in 2020. The availability of data covering the whole lockdown period guaranteed the possibility of building general figures about the overall number of displacements and human presence per hour at the city level and in the different neighborhoods, both in a period where most of the activities were closed and in the pre-lockdown period when Milan's attractiveness was at its best. The spatial and temporal differences in mobile phone activity and, therefore, human presences highlighted specific behaviors in the neighborhoods and their responses to the lockdown measures that differently impacted the areas with a high concentration of activities such as service companies, universities, and shops compared to most residential areas.
Within this general context, the change in the city users' presence in the Milan neighborhoods in 2019-2020 is analyzed using TIM mobile phone data. This analysis allows investigating which neighborhoods lost city users during the day, and which have gained them, thus providing an overview of the social and spatial impacts of Covid-19 lockdown pandemic in Milan that put in discussion the competitivity of the city (Deponte et al., 2020) and, as a reaction, pushed the local administration to propose ambitious strategies to reorient mobility patterns and reconsider the role and qualities of public spaces with a longer term perspective extended beyond the pandemic emergency (Pucci et al., 2021; Ravagnan et al., 2022).
A specific paper in this issue (Mariotti et al., 2022) investigates the change in the attractiveness of the Milan neighborhoods during the Covid-19 pandemic (2020) compared to the year before it (2019) with a specific focus on the issue of remote working and near working. The paper has twofold aim: (i) measure the presence of remote workers at the neighborhood level, and (ii) explore which neighborhoods meet the requirements of the "15 minutes city" paradigm, with specific attention to near working.

4.2 New home/work and tourism-related mobility practices in low-density mountain areas during the Covid-19 pandemic

If Mobile phone data represent a promising resource for the analysis of mobility and presence that has been extensively experimented in densely urbanized areas, the contribution they can offer in low-density, rural, and mountain territories is less explored. As introduced in section 2, in these geographical contexts digital data

could reveal dynamics and rhythms that cannot always be deduced from the analysis of traditional sources of information. Moreover, the information inferable from sensor-generated data concerns not only the registered residents of a specific geographical context of study but also other types of territory-users who, for various reasons, frequent it, use its services, and contribute to increasing its liveliness and well-being.

In this perspective, mobile phone data have been analyzed in a paper proposed in this issue (Lanza et al., 2022) to deepen the knowledge of the living rhythms of a low-density mountain area between Piacenza and Parma provinces. This territorial context is characterized by some conditions typically associated with forms of marginality and territorial fragility found in the Italian Apennines and alpine regions, such as progressive depopulation, aging, and poor availability and accessibility to essential services and networks. However, at the same time, it represents a context of environmental and landscape value strategically located between the metropolitan area of Milan and the axis of the Via Emilia. Because of its geographical position and intrinsic qualities, this territory can potentially attract near-home tourist flows and be a place to experiment with new forms of remote living and working, made increasingly flexible and possible by the development of information and communication technologies. This theme has become particularly relevant and discussed, in the field of urban planning, following the outbreak of the Pandemic Covid-19, an event that has prompted questions about the role and livability of large urban centers considering the restrictions and the need for social distancing and has simultaneously shift the attention to smaller settlements and the possibilities of re-inhabiting them as quality places (Cotella & Vitale Brovarone, 2019). Provided that specific assets and infrastructure are available (i.e., high-speed internet connection), a similar perception can generate significant opportunities to make inner areas attractive and generate new forms of economic development and repopulation (De Luca et al., 2020). The availability of mobile phone data recorded between July 2019 and September 2020 made it possible to observe the presence variations before the pandemic outbreak and during the different phases of the total lockdown and explore if and how these changes could be explained according to the spatial and functional peculiarities of the different parts of the territory. Thanks to an analytical approach that exploits the updated and temporally exhaustive information inferable from the analysis of mobile phone data and the evaluation of the results obtained, the research questions the extent of the repopulation processes induced by the Covid-19 pandemic and how the presence of new territory users can create unprecedented development opportunities, enrich the territory, and contribute to reversing the dynamics of abandonment and fragility.

4.3 Multiresidentiality in coastal areas marked by second homes and unauthorized construction

Mobile phone traffic data allows for the integration of official statistics and registry data, especially in those contexts which by their nature escape systematic analyses on an administrative and census basis. In this sense, second homes settlements and informally urbanized coasts represent fields of particular interest for mobile phone data utilization: they provide spatially and temporally detailed information on residential and recreational mobility (inter-weekly and inter-seasonal comparisons, between high and low bathing season, between weekdays and holidays); their spatial detail, free from administrative constraints and limits, enables the analysis of the effective use of the coastal space in all its components: beaches, backdunal spaces, wetlands, coastal roads, protected areas, state-owned soils. A more specific aspect is related to the phenomenon of unauthorized construction since mobile phone data can help establish orders of priority in demolishing non-condonable illegal buildings. Accordingly, analysis based on mobile phone data can offer helpful information for the public administrations in preparing urban plans and the programming and maintenance of public facilities.

In a paper proposed in this issue (Curci et al., 2022), the first results of an analysis conducted on the coast of the Municipality of Lecce are reported. The dedicated article primarily aims at understanding the relationship between permanent and temporary human presence, questioning: the differences between adjacent coastal

settlements in terms of seasonal/recreational and residential/permanent presences; the effectiveness of the 2011 Census in detecting the resident population; the correlation between the seasonal-recreative vocation of the settlements and the existence of environmental risks.
The analysis confirms substantial seasonality and permanence differences between adjacent and similar coastal settlements. Moreover, it reveals that Census data may be effective in some areas and less effective in others. Concerning the specific geographical context, the elaborated maps show that the area most exposed to environmental risks is also the most seasonal and intermitting.
Regarding the pandemic period, the analysis conducted between September 2019 and September 2020 seems to confirm the impression of wider and more prolonged use of second homes even after the end of the summer with a general increase in the human presence (temporary and permanent).

5. Conclusion

This article serves as an introduction to the entire special issue and has the main objective of discussing the meaning and importance of acquiring and elaborating mobile phone data in the context of the DAStU research project on "territorial fragilities" within a broader discussion on the role of big digital data for urban studies.
In the first two paragraphs, we introduced the topic and examined in depth what are the main characteristics of mobile phone data compared to traditional ones and how they are gaining ground in socio-territorial research. We explained that, however, mobile phone data often need to be associated with other types of data to express their maximum potential, and this represents one of the main methodological challenges. We further explained that this type of data requires a great deal of negotiation with private data providers and owners to acquire high-quality reliable data.
In paragraph 3, we retraced the entire process that led the DAStU to acquire TIM data to use them in different research scopes and on different territories, but with the theme of territorial fragilities as a common denominator.
Finally, in paragraph 4, we went into more detail about the specific research questions that have been built around the three thematic case studies that are dealt with in the other articles composing this special issue. In this way, the article laid the foundation for framing the goals, methodologies and experimental purposes of the works conducted under the DAStU-FT project into the broader data-driven urban research that are presented in this special issue.

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