MOBILE MAPPING TO SUPPORT AN INTEGRATED TRANSPORT-TERRITORY MODELLING APPROACH

F. Alberti[1], A. Alessandrini[2], D. Bubboloni[3], C. Catalano[3], M. Fanfani[4], M. Loda[5],
A. Marino[6], A. Masiero[2], M. Meocci[2], P. Nesi[4], A. Paliotto[2]

[1] DiDA – Dipartimento di Architettura – francesco.alberti@unifi.it
[2] DICeA – Dipartimento di Ingegneria Civile e Ambientale –
(adriano.alessandrini, andrea.masiero, monica.meocci, andrea.paliotto)@unifi.it
[3] DIMAI - Dipartimento di Matematica e Informatica 'Ulisse Dini' – (daniela.bubboloni, costanza.catalano)@unifi.it
[4] DISIT Lab, DINFO – Dipartimento di Ingegneria dell'Informazione – (marco.fanfani, paolo.nesi)@unifi.it
[5] SAGAS - Dipartimento di Storia, Archeologia, Geografia, Arte e Spettacolo – mirella.loda@unifi.it
[6] DISIA - Dipartimento di Statistica, Informatica, Applicazioni 'Giuseppe Parenti' – andrea.marino@unifi.it

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ABSTRACT:

Transport planning and mobility management is nowadays of paramount importance, particularly in the urban context where innovative, sustainable, smart, and green mobility solutions are required to satisfy the citizen's needs. Such ambitious objective requires a multidisciplinary research approach to address the problem from different perspectives from urban and geographical analysis to social studies including 3D mapping and urban infrastructure analysis. To collect and manage huge amount of data acquired and produced, big data and IOT/IOE technologies are exploited together with 3D city digital twin representations of the urban scenario to simulate, plan and evaluate urban policies and guide the urban development of the future. In this paper, the activities that will be carried out by an interdisciplinary group of researchers of the University of Florence, within the sustainable mobility centre (MOST), are presented and discussed.

1. INTRODUCTION

Traditional transport planning investigates trips which are generated and attracted in different zones of the city and distributed to create Origin-Destination matrixes, which are then split on the different transport modes and assigned to estimate traffic. Consequently, infrastructural and transport needs are estimated with the risk of creating an unsustainable vicious circle (Filippi, 2022) of predicting demand and providing corresponding supply which can only grow over time. However, many factors can influence each individual choice and whether going out (generating a trip), where to go (attracting and distributing that trip), how to go there and which itinerary to use depend on many intertwined choices which depend in turn on geographical, social, urbanistic, infrastructural, economic, and cultural factors. The sustainable urban development will satisfy all the citizens' need while discouraging unsustainable choices. In order to evaluate transport and urban planning policies and measures and their effects in time on all aspects of human choices and transport related factors a different modelling approach is needed.

Activity Based Transport Demand models have tried to reconstruct people behaviour and choices as a function of the opportunities and services available but due, mostly, to lack of data and calculus complexity they have never evolved toward a more holistic approach. Indeed, there are several research studies that evaluate the effect of each single variable on modal choice. However, these studies assessed only one parameter per time, or a limited number of variables; for example, Ibrahim et al. (2023) evaluated the effect of the road safety in active travel choice at city level. Other authors proposed to consider in the travel choice different road-related parameters (i.e., road safety, vulnerable road users path, sidewalks presence and their dimensions and conditions) (Aziz at al, 2018) or spatial planning, land use rather than psychological factors (Tyrinopoulos & Antoniou, 2013). To understand the phenomenon, instead, an overall assessment should be conducted, which analyzes how, simultaneously, the different factors can affect modal choice. Additionally, mobile mapping and effective geospatial data processing algorithms are needed in order to acquire an accurate description of the considered area and to extract the required information (Ma et al., 2018, Błaszczak-Bąk et al., 2020), e.g. to automatically determine both the characteristics and conditions of the infrastructures for all users; to be able to measure cyclability, walkability and safety of each path; and to define the buildings characteristics to correlate them with the commercial activities and the residential characteristics of the census data. To accomplish such a task, interdisciplinary competences are required. Therefore, on the one hand, multidisciplinary studies and research to acquire higher volumes of information are required in order to define and assess innovative transport models. On the other hand, to efficiently handle huge amount of data (i.e., Big Data) innovative techniques to store and analyse information are needed. The Internet of Things (IoT)/Internet of Everything (IoE) paradigm (Kumari, 2019) is exploited to ingest, store, process, and manipulate Big Data. In the context of urban mobility for Smart Cities, a huge amount of information is collected, including static data, such as the road graph, 3D infrastructure representations, transport offers of public and sharing services, census data, and dynamic data, as for example information about traffic, weather conditions, presence counting etc. Such information can be directly produced by people or "things", as for example IoT sensors, Open Data, readings from personal devices, social media, etc., or obtained indirectly from 3D mapping activities, or social, geographical, and urbanistic studies. To efficiently ingest and exploit such information, specialized software infrastructures are required. These solutions must support heterogeneous data sources and formats, provide data indexing and storage capabilities, offer APIs to retrieve the data with specialized query on user demand, realize dashboard and visualization for an immediate assessing. Collected data is then exploited to develop and test innovative transport models and evaluate them using Key Performance Indicators (KPIs).

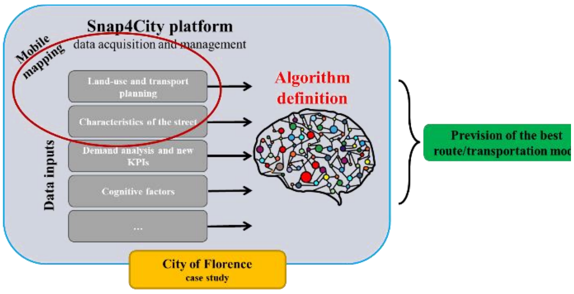

Figure 1. MOST approach

In this paper the holistic approach proposed by the research groups of the University of Florence in the context of the Sustainable Mobility Centre (MOST) is presented. MOST is a research centre funded under the national initiatives of the Next Generation EU recovery instrument. The main objective of this program is to build a competent Italian leadership capable of supporting future development towards inclusive and sustainable mobility. The program is articulated in 14 Spokes. Activities related to Spoke 9 – devoted to urban mobility, with the mission of demonstrating how advances in modelling and technologies can address real-life problems through greener smarter and safer mobility – are presented. The main objective of such activities is to develop an integrated tool to simulate, plan and evaluate in the medium and long terms urban policies and measures, including new technologies, to guide the urban development of the future and make it sustainable. The MOST approach proposes the integrated methodology described in Figure 1. The methodology combines the best technology to collect data such as studies that consider for example the cognitive aspects of the modal choice, the land use, or the street characteristics and conditions to define a new model for modal choice in urban context. The approach will use the Snap4City platform for data management.

The paper is organized as follows: Section 2 describes the case of study of Florence (Italy). In Section 3, the Snap4City platform for data ingestion, management, and visual representation is presented. Then, in Section 4 urban planning activities are discussed, while in Section 5 studies focusing on street analysis are presented. Section 6 shows how social studies can help the understanding of mobility demand. Finally, some conclusions are drawn in Section 7.

2. CASE OF STUDY: THE METROPOLITAN CITY OF FLORENCE

The study area chosen by the research group to test the proposed multidisciplinary approach is the Metropolitan City (MC) of Florence, already the subject over time of numerous studies developed by its members from different disciplinary perspectives, whose data can therefore be usefully transferred into the platform and processed in a synergistic manner. The choice of the study area is also related to the fact that Florence is among the 9 Italian cities selected to participate in the EU Mission for "100 climate-neutral and smart cities by 2030", in the framework of the European Green Deal, and among the 10 Metropolitan City capitals selected by the Italian government for the "Mobility as a Service for Italy" project, in the framework of the national strategy "Digital Italy 2026."

The MC of Florence comprises 41 municipalities over a territory of 3,514 square kilometres, with a total population of about one million. Of these, a little over a third live in Florence, which is also the capital of the Tuscany Region; about a quarter in the 9 belt municipalities, which form, together with Florence and the municipalities in the plain west of the MC belonging to the nearby provinces of Prato and Pistoia, the densest, most populous and productive metropolitan area in Tuscany; and the rest, finally, in the other 31 municipalities, spread over three-quarters of its total surface area in mostly rural and mountain territories.
In 2017, the MC adopted a Strategic Plan, developed with the scientific advice of the University of Florence, which identified multimodal mobility as one of the main strategies to be pursued, with the aim of overcoming the current mobility model mainly relying on the use of the individual car[1]. This was followed in 2019 by the Sustainable Urban Mobility Plan (Piano Urbano della Mobilità Sostenibile, PUMS), which provides an operational follow-up to the main transport measures included in the Strategic Plan. Namely: (i) the use of the many existing regional railways converging on Florence for a high-frequency service on the model of the German S-Bahn, to be activated in stages until the ongoing work on the new high-speed train tunnel and station is completed and most of the surface tracks freed from national train transit; (ii) the completion of the tramway system, being implemented since the early 2000s, by new urban lines and connections between Florence and the adjacent municipalities which are not covered by rail; (iii) the creation of intermodal hubs with different service levels according to traffic flows, to be located at the main stops of public rail transport and junctions of the highway and regional road networks; (iv) the creation of a metropolitan bicycle network, including fast inter-municipal bicycle routes[2].

3. DATA ACQUISITION, MANAGEMENT AND VISUALIZATION

Data acquisition and management will be a core activity required to enable the development and validation of models and analytics. In this project the Snap4City platform (Bellini, 2021) (www.snap4city.org) will be used. Snap4City is an open-source IoT platform developed at DISIT Lab of the University of Florence, able to manage heterogeneous data sources, such as IoT devices, Open Data, external services, etc. Collected static and real-time data are semantically indexed in a graph-based RDF Knowledge Base (KM4City), while dedicated APIs can be used to retrieve the data with spatial, temporal, and relational queries. The platform allows to store and use two kinds of data: static data, which describe the city, its infrastructures and the socio-economic attributes, and dynamic data which describe people and socio-economic activities and their behaviours. More in details, several kinds of mobility related data are included into the Snap4City knowledge base. Census data, obtained from open data made available by government institutions like national statistic institutes or regional and local public organizations, can give insight on the geographical distribution of people, helping to identify possible travel origins. Information regarding the house prices is also included and can be exploited to find correlations between the resident's wealth and the preferred transport modalities. Conversely, locations of Points of Interest (POIs) – such as schools, hospital, shopping centres, etc. – acquired from open data and urban analysis (see Sect. 4), can give insight about possible points of attraction, i.e., probable destinations for urban travels. A fundamental information required to study mobility problems is the road graph. Such data can be acquired from free services like Open Streat Map (OSM)

[1] http://pianostrategico.cittametropolitana.fi.it

[2] https://www.cittametropolitana.fi.it/pums/

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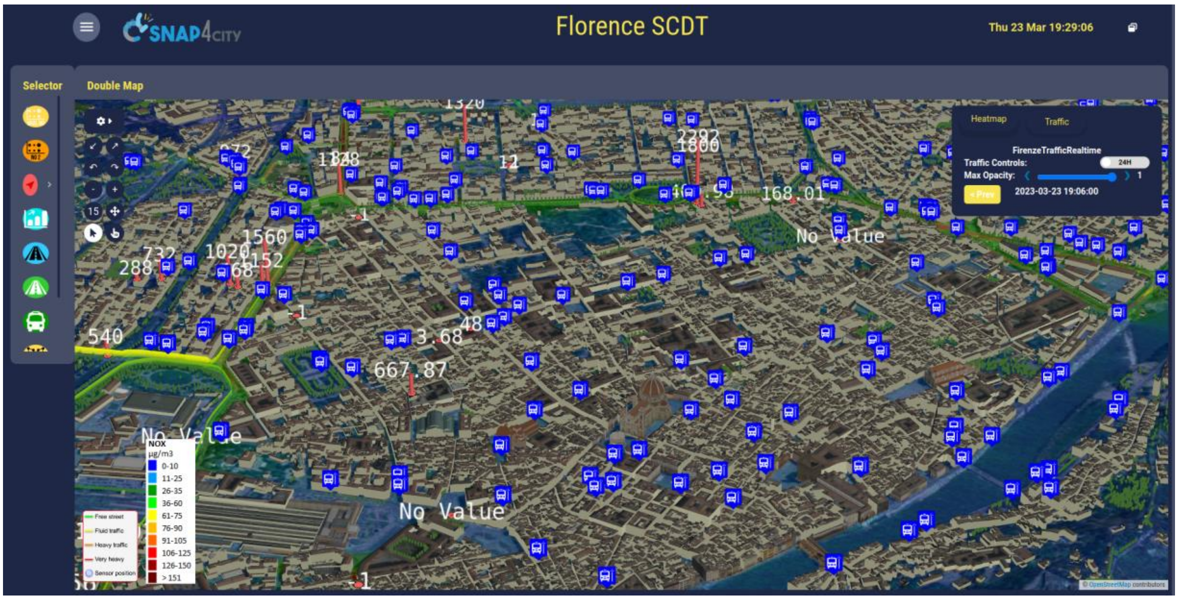

Figure 2. Snap4City dashboard showing the Smart City Digital Twin of Florence. The dashboard is presented with 3D buildings and trees, PINs indicating the position of IoT devices and POIs, 3D Crests for traffic flow representation, heatmaps, 3D Cylinders representing sensor measurements. To try our SCDT of Florence the reader is invited to visit the following link *https://www.snap4city.org/dashboardSmartCity/view/Gea-Night.php?iddasboard=MzQ5OA==*

and local public agencies and collected into the knowledge base. Snap4City includes and can provide information about road intersections, road lengths, number of lanes, speed limits, and a classification of road according to their relevance (e.g., motorways, primary roads, etc.). Obstacles like rivers, highways, fences are included, together with information about specific transport modalities as for example cycle paths or pedestrian routes. Public transportation services are considered, by exploiting General Transit Feed Specification (GTFS) data reporting busses lines and stops – that are classified in beginning, transfer, and final stops – as well as their time scheduling in order to model the public transport offer (Arman, 2022). Similarly, railways and train stations are modelled into the knowledge base. Indeed, in Snap4City additional public or private transport operators can easily been included when available to better represent the complete urban transport offer.
Real-time data are also managed by the platform. Traffic data acquired by several sensors scattered over the urban area give information about the vehicle flow, together with the vehicle average speed and density. Obviously, traffic sensor readings can give information only in a limited number of locations on the road graph. For this reason, macroscopic traffic flow reconstruction algorithms (Bilotta, 2021) have been exploited to obtain a dense representation of the traffic flow in real-time. Additionally, real-time information is also available for parking slots and bike racks occupations.
Environmental data are also acquired. Even if not directly related to the mobility problem, knowledge of the weather conditions or the level of pollutant (in real-time or predicted) can allow the definition of more complete models that better align with the real scenario. Finally, in Snap4City are present additional data acquired only for a limited time interval. For example, tracking of presences using Wi-Fi sniffing, cameras or mobile apps, occupancy levels of public services, origin-destination matrices.
To handle data ingestion, Snap4City offer the possibility to build IoT Apps, that are Node-RED[3] flows augmented with specifically developed libraries able to perform data transcoding and insertion into the knowledge base passing through an internal IoT broker. Ingested data can then be retrieved using specific APIs based on secure HTTP REST calls to execute geographic queries towards the so called ServiceMap (Badii, 2017), a 2D GIS representation of the data managed by the platform.
Several analytic services are included to perform analysis and predictions exploiting the stored data computing for example reconstruction of traffic flows in real-time, assessment of the 15-Minutes Index, What-If analysis (Bellini, 2022).
Acquired data and results of analytics can be shown though dashboards and visualized on 2D and 3D maps. As can be seen in Figure 2, an interactive web interface is provided to show a 3D Digital Twin representation of the city (Adreani, 2022) that can be exploited to include three-dimensional representations of urban scenarios.

4. LAND-USE AND TRANSPORT PLANNING

A key aspect, to facilitate the ecological transition of settlements using sustainable mobility as a lever, is the integration of land-use and transportation planning (see, *inter alia*: Gaffron, 2005; Newman, 2009). In the development of the first Territorial Plan of the MC, this issue was addressed in two researches carried out by a team of the Department of Architecture of the University of Florence, with the aim of providing the cognitive background and guidelines for planning, both at the scale of the MC and at the local scale of its municipalities.
The first research focused on the 59 railway stations and stops in the Metropolitan City (two of them planned) to assess their current and potential role as intermodal hubs and 'central places' in the settlement system, in relation to their location with respect to metropolitan flows, existing transportation infrastructure and services, and the characteristics and development opportunities of the surrounding urban areas, according to the Transit Oriented Development model (Calthorpe, 1993). Each station's performances were analysed by using 4 KPI - rail service level, intermodality, accessibility, and the 'urban weight' of the

[3] https://nodered.org/

surrounding areas; moreover, the related 'catchment areas' were identified, based on time distances (or 'network distances'), in the form of isochrones on the road graph, calculated considering standard speeds for walking, cycling, and motor vehicle travel (O'Sullivan, 2000).

- concentrated cores, characterized by the co-existence, within a radius of 200 m (corresponding to a walking distance of about 5 minutes), of services and activities, even of different types, of a supra-local rank, which individually do not represent attraction poles but together contribute to attracting flows from outside equal to (or greater than) the normalized threshold value of a monofunctional pole; the Kernel Density Estimation method (Brunsdon, 1995; Loret, 2012) was used to identify the cores;
- multifunctional clusters, i.e., relatively large urban areas characterized as a spatial continuum of poles, multi-poles, and concentrated cores, that draw substantial flows from outside (employees, students, tourists, etc.)

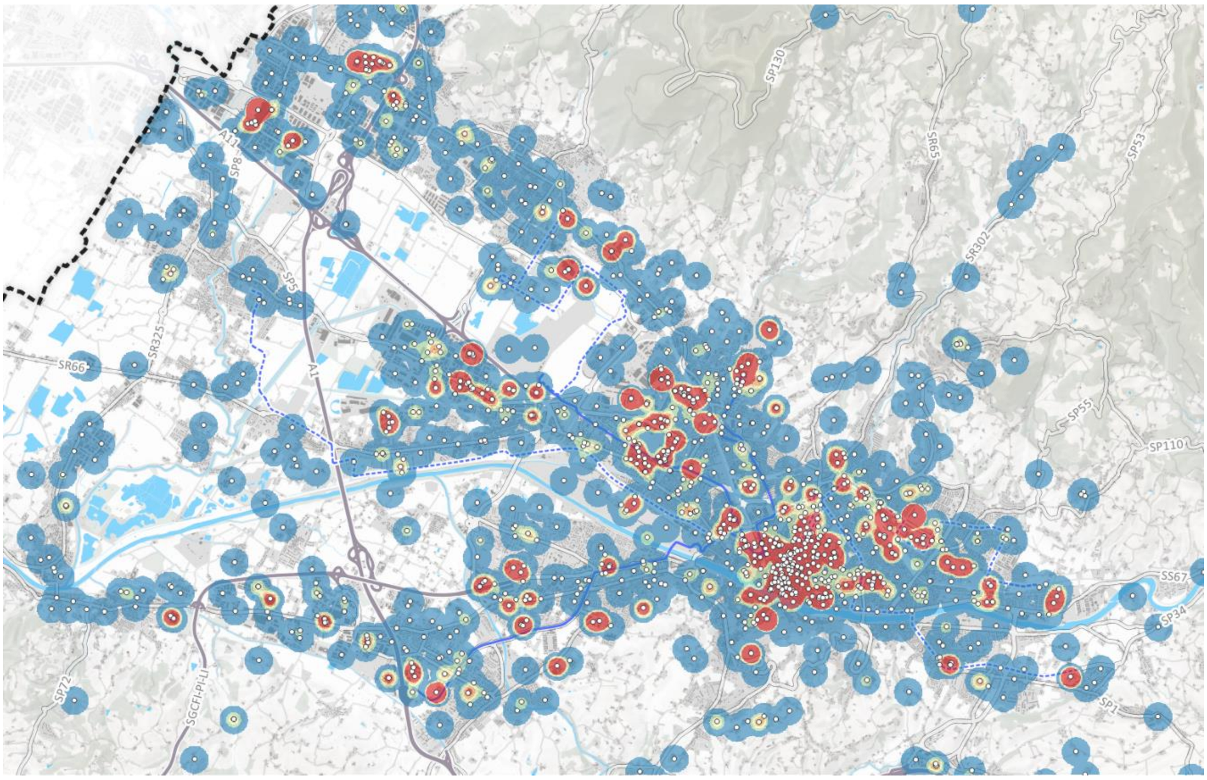

Figure 3. Detail of the map "Concentration of urban functions of metropolitan significance" released by a team of the Department of Architecture of the University of Florence as part of the cognitive framework of the Territorial Plan of the Metropolitan City of Florence.

More specifically, the same network distances were considered in all metropolitan areas for foot and bicycle trips (equal to 12 minutes), while different network distances, depending on the spatial context, were considered for car trips (from 6 to 18 minutes), assuming that in the less densely urbanized areas longer travel times to reach a transit stop are acceptable.
The data collected for each macro-indicator were then used to analyse the transportation and urban performance and potential of all railway stations and stops, adapting the Place/Node method (Bertolini, 1998; Bertolini, 1999; Reusser, 2008; Zemp, 2011) to the heterogeneous territory of the Metropolitan City. Similar analysis will be carried out exploiting the Snap4City platform to perform What-If analysis. Indeed, novel scenarios based on the conclusions of urban planning research will be defined and impact on the city mobility will be evaluated exploiting the 3D Digital Twin representation of Florence, to directly observe the effects of the proposed changes.

The second research concerned the identification, classification, and mapping of metropolitan attractors, i.e., POIs, understood as public facilities or economic activities which generate travel at a supra-local scale, above a threshold value relevant to the type of service or activity concerned. Specifically, four classes of attractors were identified:
- single monofunctional poles;
- multi-poles, consisting of two or more contiguous poles of the same type;

The following urban functions were considered to identify the metropolitan attractors: health services, high schools, universities, museums, sports facilities, public administration headquarters, transportation hubs, medium and large commercial facilities, big outdoor markets, and industrial activities. Based on available data sources, significant indicators and thresholds were defined for each urban function, and normalization coefficients were also set to compare different indicators.
The identified attractors, which also allow the Metropolitan City municipalities to be ranked according to the overall attractiveness of the supra-local services/activities found there, were then evaluated in terms of their potential to be reached by car, public road transport, rail transport, and bicycle, according to their network distance, respectively, from major road infrastructure, public transport stops, and metropolitan bicycle routes.
The data collected in the above-mentioned research describe and measure some salient features of the urban system that affect mobility demand, both in terms of volume and modal choice. When entered into the Snap4City platform, they can help outline

more reliable scenarios than those derived from traditional transportation planning methods.
Additional contributions from urban planning studies can come from the assessment of accessibility parameters of basic urban functions (see Fig. 3), both to identify, through configurational analysis, local improvements to transportation networks, with special regard to the most sustainable modes, and to assess the propensity of different urban areas to work as 15-Minute Neighbourhoods (Moreno, 2021).

We believe that the efficient computation of the analysis mentioned above, including urban and performance network indicators, can benefit from algorithmic temporal graph theory, which provides for instance tools to quickly compute reachability towards POIs in transportation networks also considering the time dimension. Indeed, using the temporal graph formalism, centrality analysis to identify hubs, clustering, reachability, and distance analysis can be augmented to take into account the fact that connections can be available according to a time schedule or can take different time depending on the hour in which they are performed (Michail, 2016). These tools can translate in an analysis of a transportation network more adherent to the reality, which can in turn be compared with the transportation demand in a more trustworthy way. They can play a fundamental role for urban planning and network design, as they can help to better understand the effects of local improvements to transportation networks.

5. CHARACTERISTICS OF THE STREET

At the lowest and most detailed level of analysis the physical composition of infrastructures must also been considered. Infrastructural elements such as the presence of sidewalks, their type and their maintenance, the presence of trees, the street type and conditions (e.g., high traffic street or low traffic street), the longitudinal grade of the street, the geometry of the street and the possibility of a fast track, are all parameters that are accounted by pedestrians and bicyclists when choosing the best path to reach their destination. Many examples in literature are present. (Ti et al., 2023) demonstrated that the geometry of a path is relevant for the path choice from the moment you look at the map. (Neeraj et al., 2020) investigates pedestrian choices of shorter and more direct paths despite they are forbidden. Other authors tried to investigate the pedestrians and cyclists route choices both through visual analysis and surveys considering different users attributes and scopes (López-Lambas et al., 2021) (Jin et al., 2022) and their attitude towards "green paths" (Lin et al., 2022). Different types of users (different age, gender, scope of the journey, choice of the travel mode) are all influenced and influence in turn, the path choice. For this reason, MOST will also include a detailed analysis of the streets' elements and characteristics acquired by routinely surveys based on Mobile Mapping System able to collect accurate 3D data of the road and its features (e.g., sidewalk dimension and distresses) or signals. This allows us to create a large database integrated and managed by the Snap4City platform and represented into the 3D Smart City Digital Twin, and which will be part of the algorithm used to generate the best path prevision.
Moreover, the project aims at investigating the elements which are most considered by pedestrians during their walk by using eye-tracker device. The in-filed experiment will be conducted using Pupil Invisible, a portable eye-tracker glass able to capture driver's eye movement and gaze. Pupil Invisible eye-tracker consists of glasses with three video cameras that are fixed on the glasses. One camera records the environment in front of the pedestrian, following the movement of their head. Two cameras allow the detection of the eye-pupils and their movements. Those movements are recorded with a frame frequency of 200 Hz and projected on the video recorded by the first camera. The glasses are connected to a smartphone equipped with Pupil Invisible App from which registration can be managed and real time observed. Such analysis will increase the knowledge of the elements that are the most influencing and/or attractive in the pedestrian route choice (considering the path within the same street, e.g., were to cross, which side of the road to walk, and so on.).

6. DEMAND ANALYSIS AND NEW KPIS

To better understand the effects of mobility policies and planning, analysis of transport demand is of paramount importance. Indeed, transport demand can drive decision-makers and can be exploited to help the extrapolation of origin-destination matrices from general mobility data. Moreover, this kind of analysis can give useful insights to define new KPIs. KPI computational models are described by official documents released by public organizations. For example, the Italian Ministry of Transports and Infrastructures proposed the PUMS (the urban sustainable mobility plan). Similarly, the Sustainable Urban Mobility Indicators (SUMI) project, funded by the European Commission, defined 18 indicators starting from the indications of the World Business Council for Sustainable Development (WBCSD) community. However, more specific KPIs can be defined using social studies to deepen our knowledge and identify key factors and people motivations to travel, therefore to better assess policies and urban planning activities.

This analysis is based on the assumption that in a complex and interconnected social context such as the present one, mobility demand — as an indication of individual needs — will also showcase significant interconnectedness, and can thus be broken down into distinct segments which focus on different social groups (with differences in needs connected to age, gender, work, income, cultural affiliation, area of residence and so on). However, knowledge in this area is still limited and with virtually no modelling attempts having been made to date. Therefore, research directions are needed — focusing on different social groups and considering as indicative of such groups those individuals belonging to them — which will highlight the specific characteristics of mobility demand, as well as their determining factors, with the aim of formalising the results within a mobility plan.
Two research directions stem from this approach. First, emphasis is laid on the university's student population, as it seems to be connected to specific mobility demand. The deduction of formalizable characteristics from the analysis of this specific segment appears particularly significant for urban contexts in which university students constitute a quantitatively significant part of the overall population. This is the case in Florence, where university students (not considering those enrolled at foreign universities) account for just under 1/5 of the municipality's officially registered resident population. For this social group, insights with regards to trip frequency, distribution, modal split, as well as additional variables to those usually considered, appear useful including the change in physical attendance rates, due to the possibility of attending online. From a sustainability point of view — and as a policymaking indicator — it is interesting to examine the relationship between student value orientation (individualism as opposed to solidarity, traditional instead of open-to-change attitudes, higher or lower environmental sensitivity and so on) and modal choices. While solidarity and environmental sensitivity do not automatically translate into corresponding mobility choices, such orientations are associated with certain tendencies that can materialise into consistent behaviour, in the presence of favourable contextual conditions.

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One could therefore measure the gap between value orientation and modal choice, as well as the flexibility margin, which policies, aimed at increasing active mobility, could affect. Looking into students' mobility choices in connection with their leisure trips proves just as relevant, as these seem to become more frequent during evening and night-time hours and tend to tilt in the direction of confined areas. Thus, an attempt will be made to provide useful information that will help theoretically quantify mobility demand by time slot, and the extent to which it is reflected in the use of public and/or collective transport.
The second research direction focuses on points connected to gender and/or cultural background. The objective in this case is to identify factors that determine mobility behaviours of women who may or may not belong in the same cultural context — provided they are part of the same social group in terms of income, area of residence, and so on — and that might generate mechanisms of exclusion. Again, the aim is to produce results that can be formalised within a more general mobility model. From a methodological point of view, the research makes use of traditional empirical survey techniques, both quantitative (through standardised questionnaires targeting representative samples) and qualitative. With respect to the latter, traditional semi-structured interviews, and the use of walk-along interviews, are used alongside GPS tracking of mobility routes, participative mapping, participative video and other visual methodologies. Such data will be included into the Snap4City platform, expanding the knowledge base already present, in order to validate the more relevant aspect of the project analysis outcomes and identify the best actions able to maximize KPIs addressing people needs.

7. CONCLUSIONS

In this paper, a short summary of the activities of the research groups of the University of Florence working in the framework of the Sustainable Mobility Centre (MOST) has been presented. Exploiting a multidisciplinary approach, different aspects related to the urban mobility problem are addressed in order to develop innovative, inclusive, and sustainable solutions. Exploiting the Snap4City platform it is possible to acquire and manage different kind of data produced by geographical, infrastructural, and social studies, sided with 3D mapping activities. This project will provide fundamental instruments for decision-makers to plan and evaluate urban policies and the development of smart cities.

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